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A SIMULATION MODEL OF FIELD DRYING ALFALFA WITHIN THE SOIL-SWATH-ATMOSPHERE CONTINUUM

By

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in

Agricultural Engineering

Department of Agricultural Engineering

1987

ABSTRACT

A SIMULATION MODEL OF FIELD DRYING ALFALFA
WITHIN THE SOIL-SWATH-ATMOSPHERE CONTINUUM

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Field drying is a primary step in alfalfa hay production. A model was developed to closely simulate the drying procedure in order to better understand the process.

The model was based upon the physical and physiological principles governing heat and moisture transfer in the soil-swath-atmosphere continuum. Short-wave and long-wave radiation, wind speed, soil temperature, exchanges between leaf surfaces and surrounding air, between air spaces, and between the soil surface, the swath and the ambient air were modeled and integrated via energy and moisture conservation. The Monteith-Penman equation was adapted to characterize exchanges at leaf surfaces with consideration of the equilibrium relative humidity of leaves under severe water stress. Leaf internal resistance to moisture removal (r_l) was modeled through an exponential function of the leaf moisture content (M):

$$r_l = 10^{a-bM/M_o}$$

Parameters a and b were statistically determined with the use of field-collected data for nine cutting dates, two locations and the entire data set.

Field experiments were conducted over a wide range of swath

densities (0.262 to 2.548 kg dry matter/m^2), initial moisture contents (2.645 to 4.495 kg water/kg dry matter), maturity levels (0 to 100% bloom) and meteorological conditions for East Lansing, Michigan (1984) and Fresno, California (1985).

The overall adjusted coefficient of determination of the average swath moisture content was 0.936 (by nine cutting dates), 0.914 (by two locations) and 0.906 (by the entire experiment). For a particular location, one set of the parameters a and b under normal production conditions would be sufficient to make reasonable predictions.

The model was most sensitive to changes in parameter a. Other important parameters included parameter b, leaf area index, swath density, leaf moisture content at full hydration and a conditioning factor. Further investigation of leaf resistance to moisture loss is essential for improving the model.

The model was written in standard FORTRAN-77 and used on CDC-750, PRIME-750, HP-9000, VAX-8600/750, SUN-3/180 and IBM-PC compatible computers. Weather data, i.e. air temperature and humidity, wind speed, precipitation and sky cloud fraction, were required to drive the model. These can be measured at a location or obtained from a local weather service.

APPROVED BY _____
Major Professor

APPROVED BY _____
Department Chairman

To my family

ACKNOWLEDGMENTS

The author wishes to express deepest appreciation to Dr. C. Alan Rotz (United States Dairy Forage Research Center, Agricultural Engineer and Adjunct Associate Professor, Department of Agricultural Engineering) for his encouragement, guidance and support as the major professor and chairman of the doctoral program committee.

Special gratitude is toward Dr. Merle L. Esmay (Professor Emeritus, Department of Agricultural Engineering) for his continual advice and help during the author's graduate study at Michigan State University.

The author is very grateful for having Dr. James V. Beck (Professor, Department of Mechanical Engineering), Dr. J. William Thomas (Professor Emeritus, Department of Animal Science) and Dr. J. Roy Black (Professor, Department of Agricultural Economics) on the doctoral advisory committee, and Dr. Fred W. Bakker-Arkema (Professor of Agricultural Engineering) as the outside examiner.

Many thanks are due to Mr. Randall Davis, Mr. Dennis Buckmaster and other persons working in the forage research project for their assistance in field experiments. The author is indebted to the faculty, staff and students in the Department of Agricultural Engineering, other Departments, M. S. U. Computer Laboratory and Albert H. Case Computer Center of the College of Engineering for their help during the author's study on the Spartan campus.

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CHAPTER 1

INTRODUCTION

1.1 Background

Forages play a very important role in the agricultural economy of the United States. Maintaining a productive agriculture in the United States depends in part on the utilization of forage crops in overall farming operations (Miller, 1984). Forage crops provide 80% of the feed consumed by ruminant animals (cattle and sheep) which produce 1/3 of the American food supply. Therefore, in an American diet, 18% of the energy and 36% of the protein originate indirectly from forages. Recently, the importance of pastures and forages has increased due to the larger number of horses in the United States. A year-round forage program including pasture, hay, haylage, and silage can reduce the feed cost for gestating sows by as much as 50% (Miller, 1984).

Many farmers have recently been interested in growing forage as a cash crop. Due to the energy crisis, the cost of nitrogen fertilizer has increased, so the production of forage crops for nitrogen fixation has become more important for American farmers.

Alfalfa is the only forage known to be cultivated before the era of recorded history, 7000-4000 B.C. (Hanson, 1972). Alfalfa is the most productive perennial legume grown in the United States, and it has the highest feeding value among all forage crops. It contains superior

protein and energy; it is high in vitamin and mineral contents. One thousand kilograms of alfalfa (dry matter) contains 180 kg of protein, which is equivalent to 810 kg of corn grain or 180 kg of soybeans, and 710 kg of Total Digestible Nutrients (TDN), which equals 350 kg of corn grain or 520 kg of corn silage (Miller, 1984). Alfalfa is also a good crop for nitrogen fixation. Alfalfa-grass combinations are excellent in reducing soil erosion and water run-off for soil conservation.

Hay is the major form of harvested alfalfa. In 1985, the total production of alfalfa hay in the United States was 86 million tons on 11 million hectares (Petritz, 1986). Although techniques of artificially drying hay have been developed since 1920, most alfalfa hay is still naturally dried in fields rather than in barn dryers or dehydrators. The greatest challenge in hay-making is to dry alfalfa as quickly as possible in order to minimize losses and preserve forage quality. As high as 4% of the dry matter yield can be lost each day when cut alfalfa remains in the field (Wilkinson, 1981). Discoloring and nutrient changes also occur during field curing due to excessive sunshine, rain and microbial activity.

During field drying, cut alfalfa remains in a soil-plant-atmosphere continuum. In the field environment, drying is a complicated process governed by physical and physiological principles. The major mechanisms are heat and moisture transfer. Many plant and environment factors influence field drying, such as solar radiation, sky cloud cover, atmospheric temperature and humidity, wind speed, rainfall, dew, alfalfa variety, leaf area, leaf orientation, plant growth stage, plant resistance to moisture removal, swath density, soil temperature and soil moisture level.

Mathematical models based upon the physical and physiological principles of the soil-plant-atmosphere continuum provide useful tools to study field drying and to comprehensively understand the natural drying process. Through modeling, the relative importance and interrelationship among various factors can be quantified. Altering important and controllable factors can speed field drying and, thus, improve hay quality. For instance, mechanical conditioning and chemical treatments can reduce the plant's resistance to moisture removal. Tedding can manipulate the swath structure and expose undried alfalfa to direct sun light.

Differing from artificial drying in a controlled environment, field drying takes place in a natural environment. The number of controllable factors is limited. For example, weather and soil conditions are rarely controllable. However, when statistical data of those uncontrollable factors are available, mathematical models can be employed to predict the rate of field drying under certain environmental conditions. This may enable selection of suitable dates for field curing operations.

Computer technology provides a powerful tool for rapid calculation and modeling of complicated phenomena. This extends the human capability of problem-solving. By use of computers, the dynamic behavior of a real process, which may take place for hours, days, months, or years, can be simulated in seconds, minutes, or hours. Therefore, extensive studies and predictions become possible. Computer simulation is a numerical technique for conducting hypothetical experiments on mathematical models which describe the quantitative behavior of dynamic systems. This methodology is very suitable for studying field drying of alfalfa.

1.2 Objectives

The overall goal of this study was to develop a simulation model of the soil-plant-atmosphere continuum for field drying alfalfa. Emphasis was on the dynamic behavior of the heat and moisture status within the soil-plant-atmosphere continuum, and the application of engineering principles to biological systems. The model was to be general enough to represent field drying of alfalfa under various conditions. Specific objectives were:

(1) to formulate a computer model to simulate the processes of heat and moisture transfer in the system of the soil-plant-atmosphere continuum when cut alfalfa is dried in the field;

(2) to validate the model by comparing simulated results with measured data of field drying alfalfa; and

(3) to quantify the importance among parameters and variables of the model by a sensitivity analysis.

CHAPTER 2

LITERATURE REVIEW

This chapter presents a brief review of the literature on previous experimental and modeling work dealing with field drying of alfalfa. Some literature will be discussed more extensively in later chapters.

Alfalfa was the first domesticated forage crop. History indicates that alfalfa was used as a forage in Turkey over 3300 years ago (Miller, 1984). Alfalfa was introduced from South America into the United States during the California gold rush. In the United States, there were a few hectares of alfalfa cut for hay in 1854; since then alfalfa production reached a peak of 12.1 million hectares in 1958 (Hanson, 1972).

The earliest study on improvement of field drying of hay was reported in the 1930's. Jones and his associates (1932, 1933, 1934, 1936, 1939 and 1941) conducted a series of research studies on the influence of plant physiological reactions on field curing of hay. In their early work, the goal was to investigate the behavior of stomata, leaves and stems regarding their effects on field drying. Since then, many investigators have focused on related topics. Harris and Tullberg (1980) presented an extensive review of the literature in this area. They reported that leaves where stomata were abundant played an important role in plant moisture loss rather than stems where few stomata were present. Leaves drew moisture from stems continuously until leaves were dried. The loss of plant

moisture was attributed to the opening of stomata. About 2 hours after cutting, stomata completely closed to prevent further moisture loss; thereafter, the plant internal resistance to moisture removal increased substantially. The plant moisture content at which stomata were closed was about 70-80% of the initial moisture level at cutting. However, precise and detailed data on the plant resistance to moisture loss as affected by light intensity, temperature and plant moisture content, especially under severe water stress, is not available.

Due to the complex nature of field drying, modeling of field curing hay was not attempted until some drying theories of agricultural products were developed and widely applied to artificial drying of grain and hay. Researchers have attempted to model field drying of hay with the theory of thin-layer drying. According to the theory, drying biological materials during the falling-rate period can be expressed as an exponentially decaying function (Henderson and Perry, 1966):

$$MR = (M-M_e)/(M_i-M_e) = Ae^{-kt} \quad [1]$$

where MR = moisture ratio, decimal,

t = time,

M = moisture content at time t, kg water/kg dry matter,

M_e = equilibrium moisture content, kg water/kg dry matter,

M_i = initial moisture content, kg water/kg dry matter,

k = drying constant, reciprocal time,

and A = coefficient of the material shape, decimal.

The differential form of Equation [1] is:

$$\partial M/\partial t = -k(M-M_e) \quad [2]$$

where $\partial M/\partial t$ = drying rate, kg water/kg dry matter per unit time.

Models of field drying hay have normally been modifications of these basic equations. The drying constant k has been modeled as a function of various plant and environment factors.

Kemp et al. (1972) proposed a regression model in which the drying constant k was a nonlinear function of time and 'latent evaporation'. Latent evaporation was a meteorological parameter representing the evaporation rate of water into the atmosphere measured with a special instrument called an atmometer. A limited number of laboratory trials were used to test the model. However, no validation with field drying data was reported.

Hayhoe and Jackson (1974) suggested a replacement of the exponent term, kt, in Equation [2] with a sum of daily drying indices. The daily drying index was defined as a linear regression function of the daily potential evaporation and the daily precipitation. For drying and harvesting operations, predictions made on hourly bases would be more desirable than those on daily bases. In the model, the equilibrium moisture content M_e was not included.

Hill et al. (1977) presented a model in which the drying constant k was a nonlinear function of time and vapor pressure deficit. Their model was derived from laboratory experiments. They expected that major errors may occur if the vapor pressure deficit is calculated from ambient air conditions, since surface temperature of swaths is substantially elevated under sunshine. They suggested study of the effects of solar radiation intensity and soil moisture on field drying.

Savoie et al. (1982) proposed an empirical model of the form of Equation [2]. The drying constant k was a linear combination of solar radiation, air temperature, wind speed, windrow area density and indices

for raking, conditioning, rain-dew and day. The coefficient of determination (r^2) of the model was only 0.36, which was not adequate to apply the model to various drying practices.

Rotz and Chen (1985) improved Savoies' model by using a nonlinear regression technique. In their empirical model, the drying constant k was an algebraic fraction of solar radiation, vapor pressure deficit, swath area density, application rate of a chemical conditioner, soil moisture and a day index. The equilibrium moisture content M_e was removed from the expression of moisture ratio MR (see Equation [2]), because they found that M_e was very small under field drying conditions. The coefficient of determination (r^2) was increased to 0.64.

Pitt (1984) related the term, kt, in Equation [2] to pan evaporation through a mathematical analysis. Pan evaporation is a climatic parameter which measures the integrated effects of sunlight, air temperature and humidity over time. Parameters of the model, including k, were assumed to be constant. However, results showed that the values of those parameters varied from one experiment to another, which implied that application of the model was limited. He also found that the model was not sensitive to the choice of the equilibrium moisture content M_e, and a zero value of M_e was assumed.

These aforementioned models have used one equation to depict a complicated system during field drying of alfalfa. Therefore, these models can not expose the systems structure, or the behavior of individual components and their interactions. The parameters of these models were derived by use of statistical techniques, which can limit applications of these models to other sets of data not used in model development. Rewetting due to dew or precipitation were excluded from

these models, except the one by Hayhoe and Jackson (1974).

More complicated models in which the field drying process was integrated step-by-step over a drying period have been developed (Dyer and Brown, 1977; and Dale et al., 1978). For each time step, the drying rate of alfalfa was calculated as a function of various environment and plant factors.

Dyer and Brown (1977) proposed a model (FHAYD). In the model, the daily drying index by Hayhoe and Jackson (1974) was adopted to calculate a daily drying rate, and empirical relations were used to determine a daily rewetting rate due to rain and/or dew. The length of the time step was one day, and thus, the model could not simulate the progress of drying within a day period.

Dale et al. (1978) developed a drying model in which an hourly drying rate was the result of evaporation, rain and/or dew. The evaporation rate was obtained from an empirical expression including effects of solar energy, equilibrium moisture content, wind speed, vapor pressure deficit, windrow surface area and hay species.

None of these models above was developed based on the principal mechanism - heat and moisture transfer - in the field drying process. These models did not simulate the actual transfer process in the system of field drying of alfalfa. The relations of various environment and plant factors to field drying in these above models were descriptive rather than functional.

Bruck and van Elderen (1969) reported a two-layer model in which the drying rate of hay was calculated based upon the moisture and energy balance between the atmosphere and the upper portion of a hay swath. The thickness of the upper layer increased or decreased as drying or

rewetting advanced. The lower portion of the swath was assumed to be not directly affected by environmental conditions. During field drying, interactions exist between plants, soil and the air; however, their model neglected transfer processes within the swath and between the swath and soil. Validation of the model was limited to only one field drying case. Nevertheless, their work was an early modeling attempt of relating field drying to heat and moisture transfer processes in hay swaths.

Plant science has made great advances since the introduction of the concept of the soil-plant-atmosphere continuum. The systems approach has been applied to living vegetation only. Many researchers have studied the soil-plant-atmosphere continuum systems of growing plants. Monteith (1973 and 1975), Milthope and Moorby (1974), Campbell (1977), Lange et al. (1982) and Rosenberg et al. (1983) discussed various topics regarding the energy and water relations of the microclimatic environment - above, within and below plant canopies - in soil-plant-atmosphere continuum systems. An equation known as the Monteith-Penman equation has been widely applied in modeling the evapotranspiration loss of plant moisture in various environments (see Chapter 4 for detail).

In recent decades, the tendency of research in vegetation science has shifted from descriptive to analytical and functional development. Ross (1981) presented a thoroughly theoretical analysis of the radiation regime and the architecture of plant stands. His work was a major contribution to applied plant sciences, since solar energy is the fundamental source driving various physical and biological processes on the earth.

Simulation models have been developed to study plant physiology. DeWit and Keulen (1972), and Hillel (1977) reported their simulation models of heat transfer and water movement in soil. Goudriaan (1977) and deVries et al. (1981) proposed simulation models for plant growth and crop production. These models provided useful background information for this study. However, the models could not be directly applied to field drying alfalfa.

Cut alfalfa in the field has different characteristics from living plant stands. Several major changes take place. First of all, alfalfa plants lay on the ground, and form thin swaths. The wind speed at the top of a swath is much less than at the top of standing alfalfa, since the wind speed decreases as the height above the ground decreases. Within a swath, there is little air movement, and thus, convective transfer of heat and moisture is reduced. For a living alfalfa canopy, most leaves are located in the upper portion, so the leaf distribution is height-dependent. However, in a swath, leaves are distributed more evenly along the swath height. This affects both light penetration and air movement inside the swath. Secondly, plant growth stops after cutting and living activities gradually cease. Thirdly, the water supply from the soil through roots to stems and leaves is broken. Water stress causes stomata closure which increases the internal resistance to moisture and gas transfer. Heat and moisture actively transfer between the soil surface and the plants at the swath bottom. These affect field drying significantly. Simulation models of the soil-plant-atmosphere continuum for field drying plants should reflect these factors.

Thompson (1981) proposed a bulk model and a multi-layer model for

field drying of hay. Average swath moisture contents (dry basis) estimated by the bulk model were overestimated compared to those obtained by the multi-layer model. This may lead to erroneous decisions if the bulk model is applied for management purposes. Thompson (1981) indicated that a bulk model could not provide a completely adequate treatment of the drying process. The multi-layer model treated heat and moisture transfer based upon the differences of temperature and specific humidity between leaves of each layer and the ambient air above the top. This was similar to that of the bulk model. Transfer properties of heat and moisture within the swath should be determined by local conditions immediately around transfer surfaces, e.g. leaf surfaces and interfaces between adjacent 'layers'. Although the swath was modeled in eight-layer detail, the modeling of radiation, wind speed within the swath and leaf resistance seemed to be oversimplified. Validation of the two models was also limited.

Smith (1985) proposed another bulk-swath drying model in which the effect of horizontal advection was taken into account. He presented some analytic discussions with no experimental verification. The disadvantage of the bulk model was pointed out by Thompson (1981).

Therefore, it was necessary to develop a functional multi-layer model to closely simulate the physical and physiological processes, especially heat, momentum and moisture transfer, during field drying of alfalfa within the soil-plant-atmosphere continuum.

CHAPTER 3

SYSTEM DEFINITION

A system is an integration of interacting parts which can be distinguished from its surrounding environment by either physical or conceptual boundaries, and which functions as a whole to reach certain goals. A system interacts with its environment through certain exchanges, e.g. energy and matter for biological systems. The boundaries of a system are arbitrary and dependent on the subject to be studied. To avoid complicating a problem, boundaries of a system are often chosen so that the interactions between the system and the surrounding environment can be neglected. This type of system is called a closed system. The parts of a system interact with each other, and thus, link together to form the system. Some parts of a system can be defined as subsystems (first-level, second-level, etc.). The lowest-level subsystems comprise individual components. The scope of subsystems and components is also arbitrary and dependent upon the desired detail of an analysis.

3.1 System Boundaries

The soil-plant-atmosphere continuum system studied consisted of three parts: the soil, an alfalfa swath and the atmosphere. The soil and the atmosphere are infinitely large, but the swath is not. The

determination of the system boundaries should therefore focus on the swath. It was preferred to chose the spatial boundaries of the system such that the system had little influence on its surrounding environment, i.e. to be approximately a closed system.

The swath has a long, wide and thin configuration. Its length might be hundreds of meters depending on the field size, its width is about 2 m determined by the setting of the mower, and its thickness is about 0.1-0.2 m subject to the alfalfa yield and the machine width setting. Since the length and width of the swath are much larger than the thickness, the swath might be abstracted as a thin but infinitely large substance laying on the ground.

In the central portion of the swath, the temperature and moisture status could be considered to be uniform in the horizontal direction, so horizontal transfer of heat and moisture was negligible compared with that in the vertical direction. At the swath edges, lateral heat and moisture transfer (advection) might be substantial. The abstraction of an infinitely large 'swath' leads to avoiding edge effects, and thus, simplifies the swath to be horizontally homogeneous. Based upon this assumption, the horizontal boundaries of the system studied were set to be the borders of a section (1 m by 1 m) taken from the center of the infinite soil-plant-atmosphere continuum.

The assumption of horizontal homogeneity could also be applied to the soil underneath the swath, and the atmosphere above the swath. The horizontal dimension (1 m) of the system was so small compared to the infinite dimensions of the soil and the atmosphere, differences in temperature and moisture in the horizontal direction in the soil and the atmosphere are meaningless, or normally not

detectable in such a small scale.

Past research (Monteith, 1973, Monteith et al. 1975; Campbell, 1977; Goudriaan, 1977; Rosenberg et al. , 1983) indicated that transfer phenomena in the vertical direction are the major concern in biological environmental sciences. Rosenberg et al. (1983) showed that at a given depth below the soil surface there is a heat wave with a daily period. The amplitude of the daily heat wave in soil decreases as the depth increases. At about 0.5 m below the surface, the amplitude is close to zero, i.e. the soil temperature at that depth is nearly constant. This implies that heat transfer to and from deeper soil layers is negligible. The lower boundary of the soil-plant-atmosphere continuum was, hence, set at a depth of 0.5m below the soil surface.

The upper boundary of the system might be chosen at the highest elevation of the atmosphere where exchanges between the atmosphere and the extraterritorial space could be ignored. However, this would be impractical, because measurements of weather data up to that upper boundary are extremely difficult, even impossible, and that boundary is too far away from the region of interest in this study. Rosenberg et al. (1983) pointed out that in the region of the first few meters over the ground, very large quantities of energy, momentum and moisture are exchanged. The rates of these exchanges with respect to time and elevation are much greater than those at higher elevations. Therefore, the upper boundary of the system was set at an elevation near the ground where the changes in temperature, wind speed and moisture can be easily monitored. This elevation is called the reference height in the literature. The standard reference height for meteorological observations is 2 m for weather stations. Fields where alfalfa drying

takes place are usually not near a local weather station; and climatic measurements should be made at the actual field. When the reference height is close to the top of the swath (or a plant canopy), the influence from adjacent swaths (or canopies) is slight, hence, the influence can be ignored (Goudriaan, 1977). In this study, the reference height was 0.64 m, a level at which a portable microweather station was placed (see Chapter 5 for detail).

At the reference height, transfer of heat, momentum and mass between the system and its surrounding environment cannot be ignored. The strengths of these transfer processes depend upon the state of temperature, wind speed and humidity at the interface. Therefore, these quantities at the reference height were used as force functions for the system studied.

In addition, solar radiation and sky diffuse radiation travel through the atmosphere and then are intercepted, scattered and absorbed by alfalfa leaves. These radiation energy quantities are major force functions in field drying. The atmosphere is normally assumed to be transparent, and hence, the interception, reflection, transmission and absorption take place from the top of the swath down to the ground, i.e. in the region where leaves exist.

The soil-plant-atmosphere continuum of field drying alfalfa was therefore defined as a semi-closed system with one-dimensional transfer in the vertical direction. The system studied will be referred to as the soil-swath-atmosphere continuum from now on. Figure 1 shows the system boundaries of the soil-swath-atmosphere continuum.

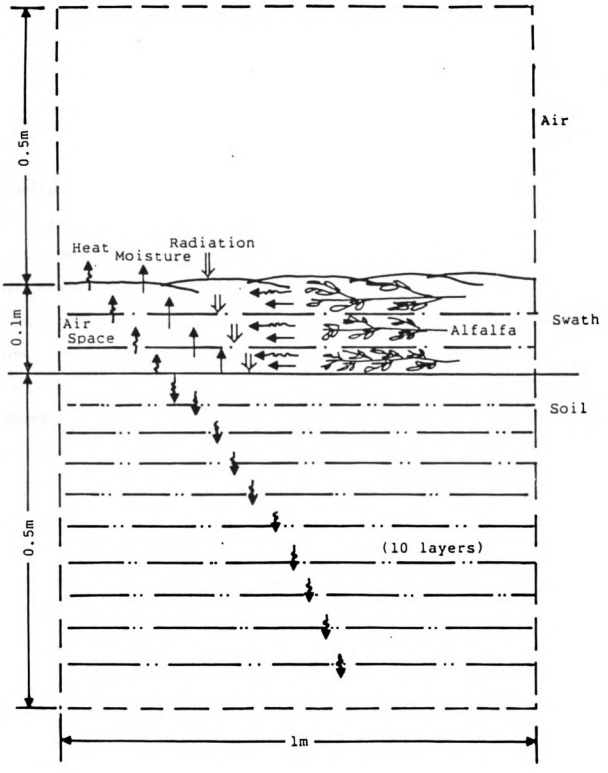

Figure 1. System boundaries for the Soil-Swath-Atmosphere Continuum.

3.2 Subsystems and Components

Since the transfer rates of heat, momentum and moisture with respect to elevation were great in the system, it became mandatory to further define subsystems so that the model could represent the real system more accurately. Each part (the soil, the swath or the atmosphere) of the soil-swath-atmosphere continuum was considered as a subsystem, which was conceptually formed by dividing it into several thin layers along the vertical direction. The soil subsystem of 0.5 m in depth was divided into 10 layers of 0.05 m thickness. In each layer, soil temperature was assumed to be uniform; and heat transfer occurred between adjacent soil layers. Generally speaking, the thinner the layer, the more accurate the simulated profile of soil temperature, but more computer time is required for the simulation. In addition, temperature data measured under field conditions are not so precise as that in laboratories. According to Goudriaan's experience (1977), choosing 10 soil layers was reasonable for numerical stability.

The atmosphere subsystems comprised 4 layers of even thickness. In each layer, temperature, wind speed and humidity were assumed to be uniform. This choice of the number of layers in the atmosphere was due to the employment of a procedure by Goudriaan (1977) to determine the wind speed profile above the swath when the atmosphere was unstable (see Section 4.3 for detail).

The swath subsystem consisted of 3 layers of uniform thickness. Field observations showed that there were significant differences in temperature, air humidity and alfalfa moisture content from the top to the bottom of swaths. Hence, distinction of swath layers was preferred.

Since the swath thickness was relatively small (0.1-0.2 m), dividing it into too many layers was unnecessary.

A swath is a porous structure which contains alfalfa plants and surrounding air spaces. Heat, momemtum and moisture transfer between the alfalfa and the air spaces. Moisture loss from alfalfa actually take place through the air spaces. Hence, each swath layer was further classified as a second-level subsystem which was made up of a layer of alfalfa plants, and an air space surrounding the plants.

The alfalfa plants may also be defined as a lower-level subsystem consisting of leaves and stems. However, as indicated in the literature, alfalfa leaves are the most important in the drying process; plant moisture is removed mainly through leaves rather than stems. Thus, it was assumed that leaves represented the alfalfa plant in field drying. This simplification was also necessary as the study of water transport from stems to leaves was beyond the scope of this study.

3.3 System Linkage and State Variables

The transfer of energy and moisture were the major linkage within the soil-swath-atmosphere continuum. There were sensible heat transfer and moisture transfer between adjacent layers in the atmosphere, between adjacent layers in the soil, between the leaves and the surrounding air space in each layer of the swath, between the top layer of the swath and the atmosphere, and between the bottom layer of the swath and the soil. There also exists momentum transfer between adjacent layers of the air within and above the swath. The wind profiles within and above the swath were determined by the characteristics of momentum transfer.

The air is the major medium of these transfer processes. Leaves and stems are surrounded by the air. Heat and moisture transfer between plants in adjacent swath layers, between plants and the soil was assumed to be carried through the air spaces only. Any direct contact between the leaves in adjacent layers of the swath, or between the leaves and the soil surface was ignored in this study. Transport of solar radiation and diffuse radiation is also through the air.

This study focused on the transfer of heat and moisture in the soil-swath-atmosphere continuum, so temperature and moisture level (water vapor density in the air and in the soil, and moisture content of alfalfa) at various locations within the system were defined as state variables of the system. Since these transfer processes through the air are subject to the air movement, wind speed was also defined as a state variable in the air spaces and in the atmosphere.

In summary, the soil-plant-atmosphere continuum system studied was defined as a semi-closed system with one-dimensional transfer in the vertical direction. The system had negligible interactions with the surrounding environment at the lateral and lower boundaries, but significant exchanges of energy, momentum and moisture at the upper boundary. Solar radiation, sky diffuse radiation intercepted at the swath top, and temperature, wind speed and humidity at the upper boundary of the system were driving force functions of the system. Transfer of heat, momentum and moisture through the air were the linkage throughout the system. Temperature, wind speed, water vapor density in the air and in the soil, and alfalfa moisture contents were state variables of the system.

CHAPTER 4

MODEL DEVELOPMENT

This chapter presents the construction of the mathematical model which simulated the essential features and behavior of the soil-swath-atmosphere continuum. Numerical methods were employed in the model for computer analysis. The model (ALFDRY) was made up of several submodels. These submodels and corresponding subprogram names (in capital letters) are listed below:

(1) the short-wave radiation profile inside the swath (SWRAD),

(2) the long-wave radiation profile inside the swath (LWRAD),

(3) the wind profile and aerodynamic resistances to heat and moisture transfer above the swath (ABOVE),

(4) the wind profile and aerodynamic resistance to heat and moisture transfer inside the swath (INSIDE),

(5) energy and moisture balance on leaf surfaces (DBLEAF),

(6) rewetting and redrying of alfalfa (DBMCL),

(7) energy and moisture balance in air spaces of the swath (MATRIX),

(8) energy balance on the soil surface (GROUND), and the temperature profile in the soil (DBSOIL).

These submodels are discussed in corresponding sections, and at the end of this chapter, the overall model structure and choices of integration time steps are presented.

Many assumptions were implemented to simplify the model based upon

the discussion in the preceding chapter. The assumptions were:

(1) the alfalfa plant was represented by the leaves;

(2) properties of both sides of the leaves were identical;

(3) the leaf area density was independent of the elevation inside the swath;

(4) the leaf orientation distribution was uniform;

(5) radiation energy was intercepted, reflected, transmitted and absorbed by the leaves only;

(6) photosynthesis in leaves was neglected during field drying;

(7) the air spaces inside the swath were the media for transfer of heat and moisture, except radiation energy; and

(8) physical properties of the leaves, the air spaces and the soil were uniform within each layer of the swath and the soil, respectively.

4.1 Short-Wave Radiation Profile inside the Swath

Short-wave radiation originating from the sun is the most important energy source for daytime drying. Short-wave radiation (wavelength 280-4000 nm) can be roughly divided into three wave bands (wavelength 400-760 nm), and near-infrared (wavelength 760-4000 nm) (Rosenberg et al., 1983). The ultraviolet portion contributes only about 1% of the total solar radiation energy; and the rest is nearly equally contributed by visible and near-infrared radiation. Since this study neglected photosynthesis, no special provision was made to separate visible and near-infrared radiation.

Short-wave radiation emitted directly from the sun is called direct solar radiation, or beam radiation, which concentrates in a fixed

direction characterized by the solar elevation angle. When direct solar radiation travels through the atmosphere, it is attenuated by clouds and dust due to scattering and absorption. The scattered solar radiation is called diffuse sky radiation, which goes in all directions. Incoming solar radiation for a swath is a combination of both direct solar radiation and diffuse sky radiation.

Short-wave radiation inside a swath depends upon incoming solar radiation at the top of the swath, and optical properties of the swath which are affected by the leaf area, leaf orientation, leaf density distribution, and leaf optical properties.

4.1.1 Solar Irradiance at the Swath Top

Solar irradiance (radiation energy per unit area) on a horizontal plane is an integration of direct solar radiation and diffuse sky radiation at the elevation of the plane. The solar irradiance is defined and often measured perpendicularly to the horizontal plane.

Both the strength and the composition of the solar irradiance at the top of a swath are a function of the solar elevation angle and the sky cover fraction. When the sky is overcast, only diffuse sky radiation reaches the swath, so the fraction of diffuse sky radiation in the solar irradiance is unity. When the sky is clear, the fraction of diffuse sky radiation in the solar irradiance is a function of the solar elevation angle β (Table 1). Near sunrise or sunset, the solar irradiance is solely diffuse sky radiation, while at noon time the primary radiation is direct solar radiation. Goudriaan (1977) mentioned that the solar irradiance of an overcast sky is only 17% of a clear sky.

Table 1 The fraction of the diffuse sky radiation in the solar irradiance as a function of the solar elevation angle†

Sun Elevation Angle β (degrees)	(radians)	Diffuse/Total f_r (decimal)
0	0.0	1.00
5	0.0873	1.00
15	0.2618	0.32
25	0.4363	0.22
35	0.6109	0.18
45	0.7854	0.16
90	1.5708	0.13

† From Goudriaan (1977)

For a partly cloudy sky, the solar irradiance was assumed to be the sum of a component under a clear sky, and another component under an overcast sky.

$$S_l = S_{lc} + S_{lo}$$
$$= (1-C_v)S_{cs} + 0.17C_vS_{cs}$$
$$= (1-0.83C_v)S_{cs} \quad [3]$$

where S_l = solar irradiance at the top of a swath, W/m^2,

S_{lc} = component of S_l under a clear sky, W/m^2,

S_{lo} = component of S_l under an overcast sky, W/m^2,

S_{cs} = clear sky irradiance, W/m^2,

and C_v = sky cover fraction, decimal.

The solar irradiance S_l at the top of a swath was also expressed as:

$$S_l = S_{dir} + S_{dif} \quad [4]$$

where S_{dir} = direct solar irradiance, W/m^2,

and S_{dif} = diffuse sky irradiance, W/m^2.

$$S_{dir} = (1-f_r)S_{lc} \quad [5]$$

$$S_{dif} = f_rS_{lc} + S_{lo} \quad [6]$$

where f_r = fraction of diffuse radiation in S_l, decimal.

Data of C_v was obtained from the local weather service. With these four equations, the direct solar irradiance S_{dir} and the diffuse sky irradiance S_{dif} could be determined from measured S_l. In subroutine SOLAR, variables SLO, SLDIRO, SLSKYO, FR and CV stood for S_l, S_{dir}, S_{dif}, f_r and C_v, respectively. S_{dir} and S_{dif} were calculated as:

$$S_{dir} = (1-f_r)(1-C_v)S_l/(1-0.83C_v) \quad [7]$$

$$S_{dif} = S_l - S_{dir} \quad [8]$$

4.1.1.1 Estimation of the Solar Irradiance

When measured S_l was not available, it was estimated from the beam irradiance. Under a clear sky (C_v=0),

$$S_{b0} = (1-f_r)S_{cs} = (1-f_r)S_l/(1-0.83C_v)$$

where S_{b0} = beam irradiance, W/m^2.

In subroutine SOLAR, S_l was calculated as:

$$S_l = (1-0.83C_v)S_{b0}/(1-f_r) \quad [9]$$

Function subprogram BEAMCL calculated the beam irradiance S_{b0} for a standard clear sky with a procedure by Duffie and Beckman (1980).

$$S_{b0} = \tau S_c \sin\beta(1-0.033\cos(2\pi n/365)) \quad [10]$$

where τ = atmosphere transmittance, decimal,

S_c = solar constant, 1375 W/m^2,

β = solar elevation angle,

and n = day of the year, 1 to 365 or 366.

Subroutine YRDATE was used to convert calendar dates to days of the year.

The atmosphere transmittance τ was estimated as:

$$\tau = a_0 + a_1 e^{-k/\sin\beta} \quad [11]$$

where

$$a_0 = r_0(0.4237-0.00821(6.0-A_{lt})^2)$$

$$a_1 = r_1(0.5055+0.00595(6.5-A_{lt})^2)$$

$$k = r_k(0.2711+0.01858(2.5-A_{lt})^2)$$

Where A_{lt} is the altitude of the location in km. Correction factors r_0, r_1 and r_k equaled 0.97, 0.99 and 1.02, respectively, for mid-latitude regions in summer seasons.

4.1.1.2 Solar Elevation Angle

The solar elevation angle β was the angle between the ray of beam radiation and its projection on a horizontal plane at a given time between sunrise and sunset. From sunset to next sunrise, β was zero. In the model, β was calculated in subprogram BETA according to:

$$\sin\beta = \sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega \quad [12]$$

where ϕ = local latitude,

δ = solar declination angle,

and ω = hour angle.

The solar declination angle δ was the angular position of the sun at solar noon (12:00 solar time) with respect to the equator plane. The angle δ was calculated in degrees as:

$$\delta = 23.45\cos(2\pi(n-172)/365)) \quad [13]$$

where n = day of the year.

The hour angle ω was the angular displacement of the sun east or west of the local meridian due to the rotation of the earth at a speed of 15° per hour.

$$\omega = 15(t_s-12) \quad [14]$$

Where t_s was the solar time, in hours, and ω was in degrees.

The solar time t_s was determined based on the apparent angular motion of the sun across the sky. At solar noon, the sun crosses the meridian of the observation location.

$$t_s = t + \Delta t \qquad [15]$$

where t = local time, hr,

and Δt = time increment, hr.

The time increment Δt was due to the difference between the local longitude and the meridian of the local standard time. It was calculated as:

$$\Delta t = (4(L_{st}-L_{loc})+E)/60 \qquad [16]$$

where L_{st} = meridian of the local standard time, °West,

L_{loc} = local longitude, °West,

and E = equation of time, minutes.

The equation of time E took into account the perturbations of the rate of the earth's rotation (Duffie and Beckman, 1980). It was computed as:

$$E = 9.87\sin 2C - 7.53\cos C - 1.5\sin C \qquad [17]$$

where

$$C = 2\pi(n-81)/365 \qquad [18]$$

where n = day of the year.

The time angles at sunrise and sunset were estimated from Equation [12] by setting $\beta=0$.

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \qquad [19]$$

$$\omega_r = -\omega_s \qquad [20]$$

where ω_s = time angle at sunset,

and ω_r = time angle at sunrise.

Then, the local time of sunrise and sunset was determined from Equations [14] and [15].

In submodel SWRAD, variables HSUN, D, H, HSET, HRISE, TSOLAR, LAT, LST, LON and ALT denoted β, δ, ω, ω_s, ω_r, t_s, ϕ, L_{st}, L_{loc} and A_{lt}, respectively.

4.1.2 Optical Properties of the Swath

When short-wave radiation is intercepted by leaves, it is reflected, transmitted, and absorbed by the leaves. The absorbed portion of the radiation is used to vaporize moisture, to remove water vapor, and to raise plant temperature. The scattered (reflected and transmitted) portion of short-wave radiation may be intercepted by other leaves again, and then, reflected, transmitted and absorbed. This is a multi-scattering phenomenon. Optical properties of leaves play an important role in the scattering process. Furthermore, there are many leaves in the swath, so the optical behavior of the swath is normally not the same as that of a single leaf.

4.1.2.1 Scattering Coefficient of Leaves

Ross (1981) has summarized past research on the optical behavior of leaves and pointed out that:

(1) Part of the radiation is reflected on the leaf surface due to surface roughness and the refractive index of the cuticular wax of the upper epidermis;

(2) Internal scattering is due to the arrangement of tissues, cells and

intercellular air spaces;

(3) Leaf absorption is determined by the composition, amount and distribution of pigments, and by the concentration and distribution of leaf moisture. The absorption decreases with yellowing of leaves; and

(4) Leaf absorptance, reflectance and transmittance are largely determined by the mean optical pathlength of leaves, which is affected by the leaf thickness.

Despite the complex structure of a single leaf, the apparent optical properties of the leaf, as a whole, obey:

$$\alpha_l + \gamma_l + \tau_l = \alpha_l + \omega_l = 1.0 \qquad [21]$$

where α_l = leaf absorptance,

γ_l = leaf reflectance,

τ_l = leaf transmittance,

and ω_l = leaf scattering coefficient.

Ross (1981) has showed that leaf reflectance is wavelength-dependent, but it can be assumed to be approximately a constant for the whole solar spectrum. Idso et al. (1969) found that albedo (short-wave reflectance of canopies) varied with respect to time, but it could be averaged for a whole day. The effect of the moisture content of leaves on the optical properties of plants has been studied by some researchers. Thomas et al. (1966), Woolley (1971) and Carlson et al. (1971) reported that the leaf reflectance of corn, cotton, soybean and sorghum increased as leaf's moisture content decreased. Thomas et al. (1966) mentioned that when cotton leaves became near fully turgid, the leaf reflectance was invariant with respect to the moisture content. Thomas et al. (1966) proposed linear functions

to characterize the relationship between γ_l and the moisture content of cotton leaves. There was a lack of information, however, about leaf reflectance and its relationship to the moisture content of alfalfa.

In function subprogram REFL, the following equation was assumed:

$$\gamma_l = \begin{cases} 0.45-0.0525M & (0.0 \leq M \leq 4.0) \\ 0.24 & (M \geq 4.0) \end{cases} \quad [22]$$

where M = leaf moisture content, kg water/kg dry matter.

Idso et al. (1969) used a value of 0.24 as the albedo of alfalfa stands.

The transmittance of leaves is closely related to the reflectance, due to a similar mechanism of scattering. DeWit (1965) mentioned for a wide variety of leaf species, the transmittance was about the same as the reflectance. Monteith (1973), Goudriaan (1977) and Ross (1981) applied equal reflectance and transmittance in their analyses. In this study, τ_l and γ_l were assumed to be the same, so the scattering coefficient ω_l was equal to $2\tau_l$ or $2\gamma_l$.

4.1.2.2 Scattering Coefficient of a Swath Layer

A layer of the swath consists of many leaves distributed randomly with various orientation angles. When a layer of leaves, as a whole, is studied, its optical behavior should be related to the optical properties of the leaves, and the leaf orientation distribution.

Ross (1981) used a G-function to characterize the leaf orientation distribution. The G-function was defined as the projection of a foliage area in a given direction at a given height inside a canopy. If all leaves in a unit area are horizontal, the value of the G-function equals the sine of the angle between the ray of the direction and the

horizon. This example shows the physical meaning of the G-function.

In a real swath (or canopy), leaves are not oriented in the same direction, but randomly in all directions. The orientation of leaves is a probability distribution function over the whole range of inclination from horizontal to vertical. For instance, if all leaves in a canopy are horizontal, then the probability of horizontal leaves is unity, and of other angles - zero. In the literature, the leaf orientation distribution has often been assumed to be uniform, i.e. the probability for any inclination angle of leaves was equal. This can be visualized as if leaves were evenly located on a hemisphere surface. Hence, uniform orientation distribution is also referred to as spherical distribution.

Ross (1981) derived the G-function for spherically (uniformly) oriented leaves:

$$G = 1/2 \qquad [23]$$

By use of the hemisphere approach, the projection of the hemisphere to any inclination is equal to the area of a circle which passes through the center of the sphere. The area of the circle is exactly one half of the surface area of the hemisphere.

Ross (1981) proposed an approach that a plant stand could be considered as a plate medium. He assumed that there was no mutual shading of leaves in any direction within an elementary thickness of the plate, but there were a sufficient number of leaves in the element so that the optical properties of the plate were homogeneous. He showed that the optical properties of the abstracted plate medium were equal to those of a single leaf, if both sides of leaves had

identical properties, and if the leaf orientation was spherically distributed. This approach was applied to each layer of the swath in this study. The scattering coefficient (ω), reflectance (γ), transmittance (τ), and absorptance (α) of each layer of the swath were equal the corresponding properties of leaves (ω_l, γ_l, τ_l and α_l) in the same layer.

$$\tau = \tau_l, \qquad \gamma = \gamma_l,$$

$$\omega = \omega_l, \qquad \alpha = \alpha_l,$$

and

$$\omega = \tau + \gamma = 2\gamma \qquad [24]$$

4.1.3 Radiation Field due to Beam Radiation

When direct solar radiation at a given solar elevation angle incidents on the top of a swath, a part of the radiation is intercepted (scattered and absorbed) by leaves. Unintercepted direct solar radiation passes through gaps between leaves downwards into the swath. It is still beam radiation; however, its strength is attenuated compared with that at the top of the swath. The scattered radiation is diffuse radiation due to various orientations of the leaves. This portion of the radiation goes in all directions (upwards and downwards). It is again intercepted, scattered and absorbed by other leaves. These complicated processes of interception and passing take place throughout the swath. Therefore, the radiation field from direct solar radiation consists of a portion of attenuated beam radiation and another portion of complementary diffuse radiation.

4.1.3.1 Attenuated Beam Radiation inside the Swath

The attenuated beam radiation in the swath was written as:

$$S_{b,i} = a_{s,i} S_{b0} \qquad [25]$$

where $S_{b,i}$ = attenuated beam irradiance in the ith layer, W/m^2,

S_{b0} = incoming beam irradiance at the top of the swath, W/m^2,

and $a_{s,i}$ = penetration function down to the ith layer, decimal.

For spherically oriented leaves:

$$a_{s,i} = e^{-L_i/2\sin\beta} \qquad [26]$$

where L_i = downward cumulative leaf area index, m^2 leaf/m^2,

and β = solar elevation angle.

In SWRAD, SLDIR(I), SMU2 and SUML denoted $S_{b,i}$, $2\sin\beta$ and L_i, respectively. The downward cumulative leaf area index L_i was:

$$L_i = \sum_{n=1}^{i} \partial L_n \qquad (i=1,\ 2 \text{ and } 3)$$

Where ∂L_n was the leaf area index (LAI) in the nth layer. When the leaf area density was independent of the height in the swath. Thus,

$$\partial L_1 = \partial L_2 = \partial L_3 = L_{ai}/3 = L_3/3 \qquad [27]$$

Where L_{ai} was the leaf area index (LAI) of the whole swath, in m^2 leaf/m^2. Note that ∂L_i was the element LAI in the ith layer, but L_i was the downward cumulative LAI to the ith layer.

4.1.3.2 Estimation of the Leaf Area Index

The leaf area index (LAI) of alfalfa could be estimated from alfalfa yields. Fuess and Tesar (1968) reported field experimental data on the dry matter (DM) yield and LAI of alfalfa (Table 2).

Table 2 Average yield of hay and leaf area index (LAI) of alfalfa harvested three times per season

Cutting	Average Yield† (kg DM/m^2)	Average LAI† (m^2 leaf/m^2)	LAI/Yield (m^2 leaf/kg DM)
1	0.492	3.66	7.40
2	0.383	2.03	5.30
3	0.181	1.20	6.62

† From Fuess and Tesar (1968)

Therefore, the leaf area index (LAI) of the swath was estimated from a known swath area density (dry matter, DM):

$$L_{ai} = L_y d_{sw} \quad [28]$$

where L_y = proportional constant from the last column of Table 2, and d_{sw} = swath area density, kg dry matter/m^2.
In the model, variables LAI and DENS denoted L_{ai} and d_{sw}.

As drying advanced, plant leaves lost turgor and wilted due to severe loss of moisture. This often coincided with stomatal closure at a certain level of the leaf moisture content (Bradford and Hsiao, 1982). During wilting, laminae and petioles of alfalfa (dicot) drooped downwards. This resulted in a decreasing projection area on a horizontal plane, thus, a reduction in the leaf area index, even though the total leaf area may not change. A droopy swath (canopy) layer enhanced penetration of sun light and wind, so alfalfa in deep layers could dry faster. However, the droopy layer intercepted less radiation which led to less evaporespiration.

There was lack of information for modeling the leaf area index as a function of leaf moisture status. In this study, an assumption was made that the leaf area index was an exponentially decaying function with

respect to the leaf moisture content, when the leaf moisture content dropped below 80% of its initial level. It was also assumed that a decreased leaf area index could not be recovered when rewetting occurred, i.e. the wilting phenomenon was irreversible for cut alfalfa.

$$\partial L = \begin{cases} \partial L_0 & (M > 0.8M_0) \\ \partial L_0 e^{-c(1-M/M_0)} & (\text{otherwise}) \end{cases} \quad [29]$$

where ∂L = LAI of a swath layer, m^2 leaf/m^2,

∂L_0 = initial LAI of the layer, m^2 leaf/m^2,

M = moisture content in the layer, kg water/kg dry matter,

M_0 = initial moisture content, kg water/kg dry matter,

and c = coefficient.

A value of 0.12 was assigned to coefficient c which implied that the final leaf area index would be 89% of its initial value when alfalfa was completely dried. The c value was obtained through a preliminary parameter estimation after the model was formed. Further investigation on this topic is needed.

4.1.3.3 Complementary Radiation due to Beam Radiation

Ross (1981) derived a pair of differential equations to describe the gradients of the average complementary irradiances (upward and downward) on a unit horizontal area. In this study, three pairs of differential equations were written for three swath layers:

$$\partial D_{s,i}/\partial L_i = -(1-\tau_i)D_{s,i} + \gamma_i U_{s,i} + 0.5\tau_i S_{b,i} \quad (i=1 \text{ to } 3) \quad [30]$$

$$\partial U_{s,i}/\partial L_i = -\gamma_i D_{s,1} + (1-\tau_i)U_{s,i} - 0.5\gamma_i S_{b,i} \quad [31]$$

where $D_{s,i}$ = downward complementary irradiance, W/m^2,

$U_{s,i}$ = upward complementary irradiance, W/m^2,

∂L_i = element of LAI, m^2 leaf/m^2,

$\partial D_{s,i}$ = increment of $D_{s,i}$ within ∂L, W/m^2,

$\partial U_{s,i}$ = increment of $U_{s,i}$ within ∂L, W/m^2,

τ_i = transmittance of the canopy, decimal,

γ_i = reflectance of the canopy, decimal,

and $S_{b,i}$ = attenuated beam irradiance down to the element, W/m^2.

These equations were valid when the complementary radiation was isotropic, both sides of leaves were identical, and τ was equal to γ. The boundary and continuity conditions for Equations [30] and [31] were:

$D_{s,0} = 0$ at the top of the swath

$D_{s,1} = D_{s,2}$

$U_{s,1} = U_{s,2}$ } at the interface of layers 1 and 2

$D_{s,2} = D_{s,3}$

$U_{s,2} = U_{s,3}$ } at the interface of layers 2 and 3

$U_{s,3} = \gamma_g(D_{s,3} + S_{b,3})$ at the soil surface

Where γ_g was the reflectance of the soil surface, and assumed to be a constant (0.15) in the model. Subscript 0 meant at the swath top.

The analytic solutions of the set of differential equations [30] and [31] were expressed as:

$$D_{s,i} = A_i/H_i + B_iH_i - F_iU_i \qquad (i=1, 2 \text{ and } 3) \qquad [32]$$

$$U_{s,i} = R_iA_i/H_i + B_iH_i/R_i + F_iV_i \qquad [33]$$

where

$H_i = e^{C_i \partial L_i}$

$F_i = 0.25\omega_i\mu_s S_{b0} e^{-L_i/\mu_s}$

$R_i = (1-C_i)/(1+C_i)$

$$U_i = \begin{cases} -(C_i\partial L_i + 0.5R_i)/(1-R_i) & \mu_s C_i = 1 \\ (1+\mu_s)/(1-\mu_s^2 C_i^2) & \text{otherwise} \end{cases}$$

$$V_i = \begin{cases} (C_i R_i \partial L_i + 0.5)/(1-R_i) & \mu_s C_i = 1 \\ (1-\mu_s)/(1-\mu_s^2 C_i^2) & \text{otherwise} \end{cases}$$

with

$$\omega_i = \tau_i + \gamma_i$$

$$\mu_s = 2\sin\beta$$

$$C_i = \sqrt{(1-\omega_i)}$$

Six integration constants (A_i and B_i, i=1, 2 and 3) were obtained by use of a matrix method (subroutine GAUSS) to solve a system of six linear equations according to the boundary and continuity conditions above applied to Equations [32] and [33]. Then, the solutions of Equations [30] and [31] were calculated in subroutine DIRDF. Arrays DFDIRD and DFDIRU stored values of $D_{s,i}$ and $U_{s,i}$, respectively.

4.1.4 Radiation Field due to Diffuse Sky Radiation

Similar to the radiation field of direct solar radiation discussed in Section 4.1.3 above, the radiation field of diffuse sky radiation comprised a portion of attenuated diffuse sky radiation plus a portion of complementary diffuse radiation.

4.1.4.1 Attenuated Diffuse Sky Radiation

The attenuated diffuse sky radiation averaged on a unit horizontal area inside the swath was described as:

$$S_{f,i} = a_{d,i} S_{f0} \qquad [34]$$

where $S_{f,i}$ = attenuated diffuse sky irradiance, W/m^2,

S_{f0} = diffuse sky irradiance at the top of the swath, W/m^2,

and $a_{d,i}$ = penetration function for diffuse sky radiation, decimal.

In the model, values of $S_{f,i}$ were stored in array SLSKY.

Ross (1981) proposed a model that $a_{d,i}$ was an integration of the directional penetration function $a_{s,i}$ (Equation [26]) over a whole hemisphere. He showed that for spherically oriented leaves:

$$a_{d,i} = 2E_3(L_i/2) \qquad [35]$$

where L_i = downward cumulative LAI, m^2 leaf/m^2,

and $E_3(x)$ = third-order exponential integral of $E_n(x)$.

The nth-order exponential integral (Beyer, 1984) is:

$$E_n(x) = \int_1^{\infty} y^{-n}e^{-xy}dy$$

$$= \int_0^{\pi/2} \cos\theta(\sin\theta)^{n-2}e^{-x/\sin\theta}d\theta \qquad [36]$$

This integral cannot be analytically solved. In the model, it was numerically solved in function subprogram E(N,X) by use of the Gaussian Quadrature formula (Beyer, 1984), see function subprogram GAUINT.

4.1.4.2 Complementary Radiation due to Diffuse Sky Radiation

Ross (1981) derived a pair of differential equations for the complementary diffuse irradiance averaged on a horizontal plane due to diffuse sky radiation. In the model, three pairs of differential equations were formulated for the swath:

$$\partial D_{f,i}/\partial L_i = -(1-\tau_i)D_{f,i} + \gamma_i U_{f,i} + \tau_i S_{f0}E_2(L_i/2) \qquad [37]$$

$$\partial U_{f,i}/\partial L_i = -\gamma_i D_{f,i} + (1-\tau_i)U_{f,i} - \gamma_i S_{f0}E_2(L_i/2) \qquad [38]$$

(i = 1, 2 and 3)

where ∂L_i = element of LAI, m^2 leaf/m^2,

$D_{f,i}$ = downward complementary diffuse irradiance, W/m^2,

$U_{f,i}$ = upward complementary diffuse irradiance, W/m^2,

L_i = downward cumulative LAI, m^2 leaf/m^2,

and $E_2(x)$ = second-order exponential integral, see Equation [36].

This set of differential equations could not be solved analytically, because they involved the following indefinite integral:

$$I(y) = \int E_2(x)e^{\pm xy}dx \qquad [39]$$

An approximation was made in order to solve Equations [37] and [38]. Numerical solutions were obtained in subroutine SKYDF with the following structure:

$$D_{f,i} = A_i/H_i + B_iH_i + S_{f0}P_i \qquad [40]$$

$$U_{f,i} = R_iA_i/H_i + B_iH_i/R_i + S_{f0}Q_i \qquad [41]$$

(i=1, 2 and 3)

Where H_i and R_i were the same as those in Equations [32] and [33]. Integration constants A_i and B_i were calculated with the matrix method (subroutine GAUSS) based on the boundary and continuity conditions which were the same as those of Equations [30] and [31]. Functions P and Q were declared from numerical solutions of Equations [37] and [38]. Subroutine PQ carried out the numerical calculation for P and Q. The variable names for $D_{f,i}$ and $U_{f,i}$ in SKYDF were DFSKYD and DFSKYU, respectively.

4.1.5 Total Short-Wave Radiation in the Swath

The total short-wave radiation in each layer of the swath was the sum of six terms: (1) the attenuated beam radiation ($S_{b,i}$), (2) the attenuated diffuse sky radiation ($S_{f,i}$), (3) the complementary diffuse radiation due to direct solar radiation ($D_{s,i}$ and $U_{s,i}$) and (4) the complementary diffuse radiation due to diffuse sky

radiation ($D_{f,i}$ and $U_{f,i}$). If a positive sign is designated to downward radiation, then the total short-wave radiation may also be called net downward short-wave radiation.

In subroutine SWRAD, the net downward short-wave irradiance at various interfaces of the swath was calculated as:

$$S_i = S_{b,i} + S_{f,i} + D_{s,i} + D_{f,i} - U_{s,i} - U_{f,i} \qquad [42]$$

(i=0, 1, 2 and 3)

Where 0 meant at the top of the swath, and 3 - at the interface between the soil and the bottom layer of the swath. In SWRAD, array SL stored values of S_i.

The net absorbed short-wave radiation in a layer of the swath was the difference in the net downward irradiance at two interfaces.

$$R_{ns,i} = S_{i-1} - S_i \qquad (i=1, 2 \text{ and } 3) \qquad [43]$$

This quantity was one source for the energy balance of leaf surfaces.

The net downward short-wave irradiance at the soil surface was:

$$R_{nsg} = S_3 \qquad [44]$$

R_{nsg} was used for the energy balance at the soil surface.

The albedo, i.e. the effective reflectance of the swath, was the ratio of the total upward short-wave irradiance to the incoming solar irradiance at the top of the swath. It was calculated in SWRAD as:

$$\gamma_e = (U_{s,0}+U_{f,0})/S_1 \qquad [45]$$

where γ_e = albedo.

The effective transmittance for the swath was the ratio of the total downward short-wave irradiance at the bottom of the swath to the incoming solar irradiance at the top of the swath. The effective transmittance was obtained as:

$$\tau_e = (S_{b,3}+S_{f,3}+D_{s,3}+D_{f,3}/S_1 \qquad [46]$$

where τ_e = effective transmittance.

In subroutine SWRAD, array RNSW, and variables RNSWG, RE and TE stored values of $R_{sn,i}$, R_{nsg}, γ_e and τ_e, respectively.

Figures 2 and 3 show the simulated net downward short-wave radiation profile, the albedo and the effective transmittance for an alfalfa swath in East Lansing, Michigan on August 14 of 1984.

4.2 Long-Wave Radiation Profile inside the Swath

Long-wave radiation is another important energy term within the soil-swath-atmosphere continuum system. The laws of physics states that any surface emits radiation as long as its temperature is above absolute zero (0°K or -273.16°C). Radiation is governed by:

$$E = \varepsilon\sigma T^4 \qquad [47]$$

where E = irradiance, W/m^2,

ε = emissivity, decimal,

σ = Stefen-Boltzmann constant, 5.57×10^{-8} $W/m^2°K^4$,

and T = absolute temperature of the emitting surface, °K.

Wien's law states that:

$$\lambda_{max} = 2897/T \qquad [48]$$

where λ_{max} = wavelength of the maximum intensity emitted, μm.

The surface temperature of the sun is about 6000°K, so the wavelength of solar radiation is around 480 μm which is within the short-wave spectrum. Within the earth's atmosphere, temperature of natural objects is usually close to the atmospheric temperature, which is seldom above 50°C. So, wavelengths of radiation emitted by natural surfaces are within the long-wave spectrum (4-3000 μm). Long-wave radiation is also

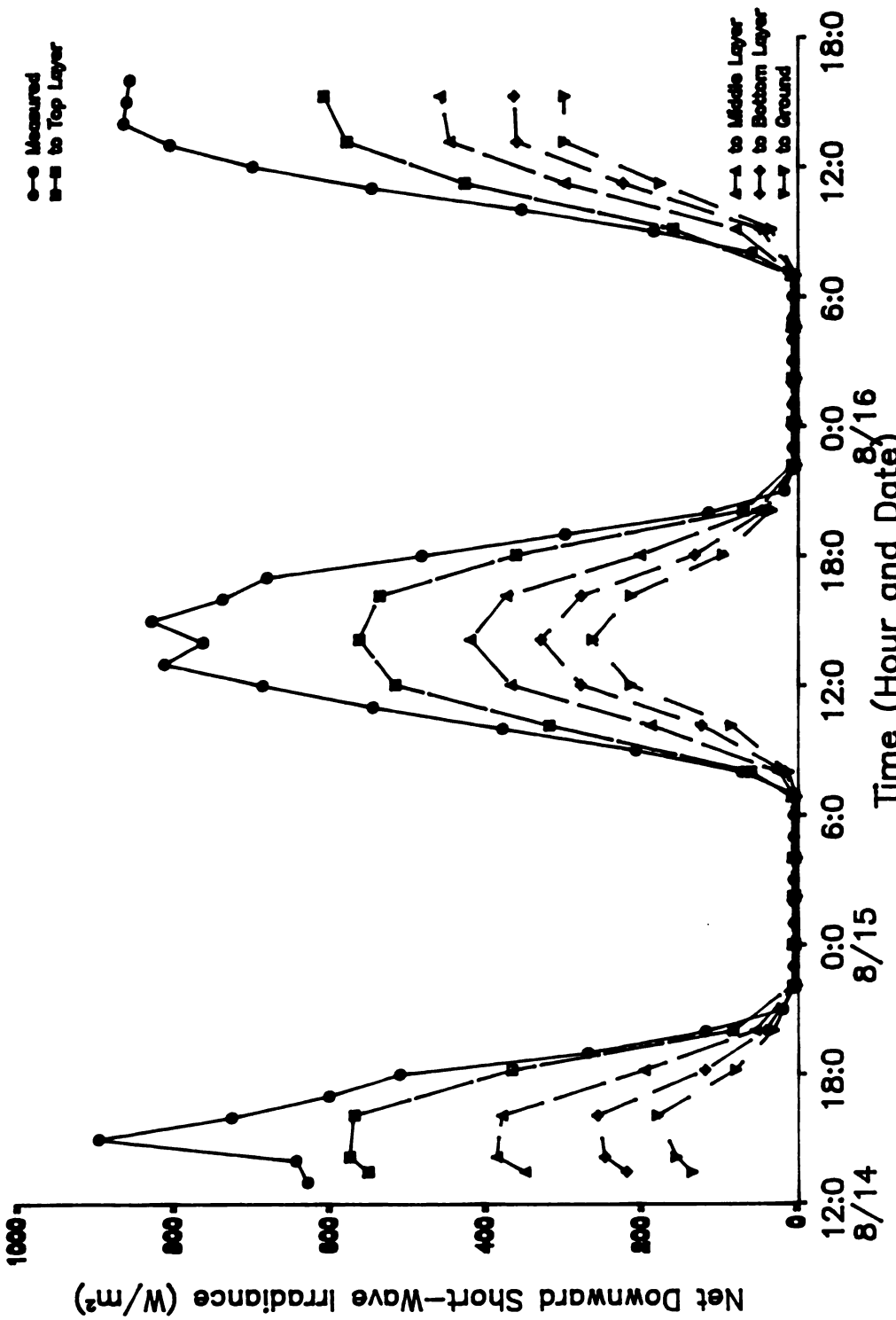

Figure 2. A simulated profile of net downward short-wave radiation of a swath in East Lansing, Michigan on August 14-16, 1984.

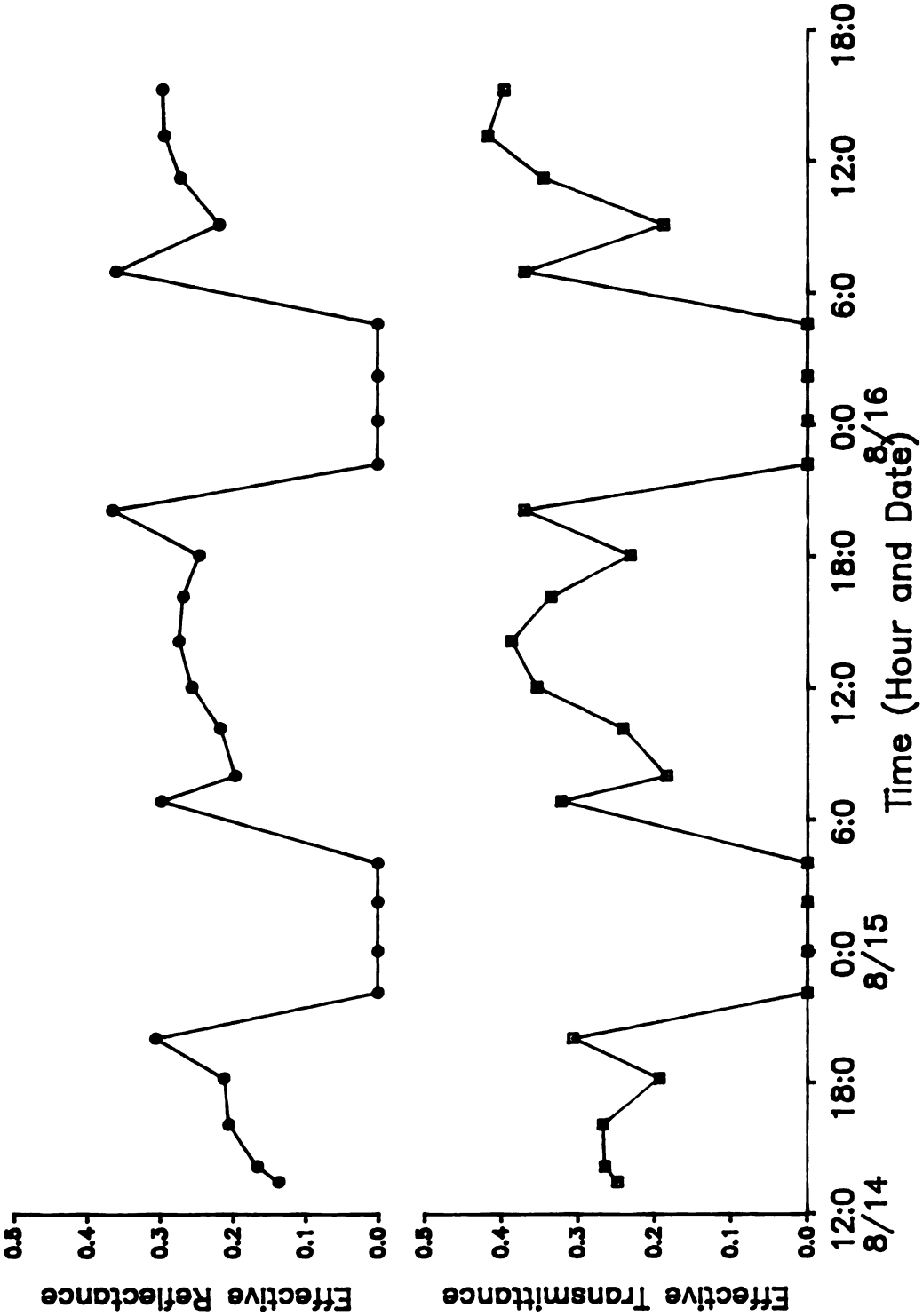

Figure 3. Simulated albedo and the effective transmittance for a swath in East Lansing, Michigan on August 14-16, 1984.

called infrared radiation or thermal radiation; and it is diffuse radiation.

In addition to emission of thermal radiation, the atmosphere, particularly water vapor, clouds and carbon dioxide, absorbs about 90% of the infrared radiation emitted by the earth, and radiates back to the earth (Rosenberg et al., 1983). Therefore, long-wave radiation plays an important role in the energy balance within the microclimate region.

Plants gain thermal radiation energy as well as sensible heat when their temperature is lower than that of the atmosphere or the soil. However, plants lose thermal radiation energy as well as sensible heat when the plants are warmer than the atmosphere or the soil.

Submodel LWRAD with associated subprograms simulated the long-wave radiation profile inside the swath.

4.2.1 Emissivities of the Atmosphere, Alfalfa and Soil

Similar to the optical properties of short-wave radiation, radiative properties of objects also obey the law stated in Equation [21]. For short-wave radiation, the scattering coefficient (reflectance plus transmittance) is dominate, however, for long-wave radiation absorptance is primary. This is because most soils and vegetation behave nearly as blackbody (ε=1.0) emitters (Rosenberg et al., 1983). Kirchoff's law states that:

$$\varepsilon = \alpha = 1.0 - \gamma \qquad [49]$$

where ε = emissivity, decimal,

α = absorptance, decimal,

and γ = scattering coefficient, decimal.

Therefore, the emissivity, absorptance of soils and plants for thermal radiation are close to unity while the scattering coefficient is near zero, and negligible. Monteith (1973) listed long-wave emissivities of 8 species of plants which ranged from 0.938 to 0.995, and he mentioned most soils have thermal emissivity from 0.90 to 0.95. Campbell (1977) mentioned that thermal emissivities of natural surfaces are between 0.90 and 0.97, and he used both 0.95 and 0.97 for plant leaves in sample problems. Ross (1981) used ε=0.95 for both plant leaves and soils in his model. The literature has not yet provided detailed data on the radiative properties of alfalfa and soils. In this study, it was assumed that:

$\varepsilon_l = 0.96$ (each layer of alfalfa)

$\varepsilon_g = 0.95$ (soil surface)

The literature shows that the long-wave emissivity of the atmosphere is mainly affected by the water vapor density in the air and the sky cover fraction (Monteith, 1973; Campbell, 1977; Rosenberg et al., 1983). Monteith (1973) and Campbell (1977) reviewed past research on development of empirical models to estimate the atmospheric thermal emissivity. They indicated that in a clear sky, the atmospheric emissivity is strongly influenced by the air temperature and humidity in the first few hundred meters above the ground. Both of them suggested use of parameters measured at a reference height (1 to 2 m) to estimate the atmospheric emissivity. Air temperature, vapor density and vapor pressure have been used in various empirical equations. In this study, a model by Brutsaert (1975) was applied because of its reasonable theoretical justification.

$$\varepsilon_{a,c} = 1.543(\rho_w e^{0.44z})^{1/7} \quad [50]$$

where $\varepsilon_{a,c}$ = thermal emissivity of clear skies, decimal,

ρ_w = vapor density at the location, kg water/m^3 air,

and z = altitude above the sea level, km.

For an overcast sky, the atmospheric emissivity was very close to unity. Campbell (1977) proposed an equation:

$$\varepsilon_{a,o} = 1 - 4\Delta T/T \quad [51]$$

Where $\varepsilon_{a,o}$ was the atmospheric emissivity of an overcast sky, and ΔT is the difference between air temperature and cloud base temperature, with a typical value of 2°K (Monteith, 1973). For a partly cloudy sky, the atmospheric emissivity was calculated as:

$$\varepsilon_a = (1-C_v)\varepsilon_{a,c} + C_v\varepsilon_{a,o} \quad [52]$$

where ε_a = effective atmospheric emissivity, decimal

and C_v = sky cover fraction, decimal.

Campbell (1977) indicated that Equation [52] was insensitive to errors in C_v and ΔT since the range of ε_a was relatively small. In subroutine LWRAD, variables EML, EMG and EMA stood for ε_l, ε_g and ε_a, respectively.

4.2.2 Long-Wave Radiation Field inside the Swath

Ross (1981) derived a pair of differential equations of projection of directional long-wave intensity on a horizontal plane for isotropic emissivities of the atmosphere, plants and soils and for spherically oriented leaves:

$$(\partial d_t/\partial L)\sin\theta = -0.5d_t + \eta_l \quad [53]$$

$$(\partial u_t/\partial L)\sin\theta = 0.5u_t - \eta_l \quad [54]$$

where ∂L = element of LAI, m^2 leaf/m^2,

d_t = downward directional thermal intensity, W/m^2,

u_t = upward directional thermal intensity, W/m^2,

∂d_t = increment of d_t in ∂L, W/m^2,

∂u_t = increment of u_t in ∂L, W/m^2,

θ = inclination angle in the upper hemisphere,

Θ = inclination angle in the lower hemisphere,

and η_l = emission intensity from one side of leaves, W/m^2.

For spherically oriented and isotropically emitting leaves,

$$\eta_l = 0.5E_l/\pi \qquad [55]$$

where E_l = long-wave irradiance from one side of leaves, W/m^2.

In Equations [53] and [54], no term dealing with either reflection or transmission of thermal radiation was included because it was negligible. Note that leaves emit thermal radiation from both sides, so long-wave radiation from one side of leaves appeared in both Equations [53] and [54].

Ross (1981) solved these transfer equations, integrated the directional intensities over the upper and lower hemispheres, respectively, and obtained the downward and upward thermal irradiance averaged over a unit horizontal area. The solution equations were used in this model:

$$D_{t,i} = \pi a_{d,i} A_i + E_{l,i} \qquad [56]$$

$$U_{t,i} = \pi a'_{d,i} B_i + E_{l,i} \qquad [57]$$

(i=1, 2 and 3)

where $D_{t,i}$ = downward thermal irradiance, W/m^2,

$U_{t,i}$ = upward thermal irradiance, W/m^2,

$a_{d,i}$ = downward penetration function, decimal,

$a'_{d,i}$ = upward penetration function, decimal,

A_i and B_i = integration constants, W/m^2.

The upward penetration function was expressed as:

$$a'_{d,i} = 2E_3(L'_i/2) \qquad [58]$$

where

$$L'_i = L_{ai} - L_i \qquad [59]$$

where L'_i = upward cumulative LAI from the ground, m^2 leaf/m^2,

L_{ai} = total downward cumulative LAI, m^2 leaf/m^2.

and L_i = downward cumulative LAI from the top, m^2 leaf/m^2.

Integration constants A_i and B_i were calculated based upon boundary and continuity conditions.

$D_{t,0} = E_a$ at the top of the swath

$D_{t,1} = D_{t,2}$
$U_{t,1} = U_{t,2}$ } at the interface of layers 1 and 2

$D_{t,2} = D_{t,3}$
$U_{t,2} = U_{t,3}$ } at the interface of layers 2 and 3

$U_{t,3} = E_g + (1-\varepsilon_g)D_{t,3}$ at the soil surface

where E_a = atmospheric thermal irradiance, W/m^2,

E_g = soil thermal irradiance, W/m^2,

and ε_g = thermal emissivity of the soil.

In subroutine LWRAD, variables EMG, EAO and EBO, arrays EL, ED and EU stored values of ε_g, E_a, E_g, $E_{l,i}$, $D_{t,i}$ and $U_{t,i}$, respectively. $D_{t,i}$ and $U_{t,i}$ were calculated in subroutine TRM.

4.2.3 Total Long-Wave Radiation inside the Swath

In LWRAD, the net downward long-wave irradiance at various interfaces was calculated as:

$$E_{t,i} = D_{t,i} - U_{t,i} \qquad (i=0,\ 1,\ 2 \text{ and } 3) \qquad [60]$$

where $E_{t,i}$ = net downward thermal irradiance, W/m^2,

$D_{t,i}$ = downward thermal irradiance, W/m^2,

and $U_{t,i}$ = upward thermal irradiance, W/m^2.

For the top of the swath, i=0; and for the interface between the soil and the bottom of the swath, i=3.

The net absorbed long-wave irradiance in a layer of the swath was:

$$R_{nt,i} = E_{t,i-1} - E_{t,i} \qquad (i=1, 2 \text{ and } 3) \qquad [61]$$

where $R_{nt,i}$ = net absorbed thermal irradiance, W/m^2.

This quantity was used for the energy balance on leaf surfaces.

The net downward long-wave irradiance at the soil surface was:

$$R_{ntg} = R_{nt,3} \qquad [62]$$

R_{ntg} was used as a source for energy balance at the soil surface.

The net absorbed irradiance in a layer of the swath was the sum of absorbed long-wave and short-wave irradiances in the layer. Likewise, the net downward irradiance at the soil surface was the sum of net downward long-wave and short-wave irradiances at the interface.

In LWRAD, arrays ENET and RNLW, and variables RNLWG were used to store data of $E_{t,i}$, $R_{nt,i}$ and R_{ntg}, respectively.

It should be pointed out that the long-wave radiation profile inside the swath depended upon the temperature profile at various locations of the soil-swath-atmosphere continuum, but this temperature profile itself was dependent on the thermal radiation profile. Therefore, an iteration procedure was preferred; however, it required repetition of a whole model simulation which was very time-consuming and costly. Detailed discussion about this is presented in the last section of this chapter.

Figure 4 shows the simulated profile of net downward long-wave radiation within a swath in East Lansing, Michigan on August of 1984.

In the figure, negative values indicate upward thermal radiation.

4.3 Exchanges above the Swath

In the soil-plant-atmosphere continuum, transfer of sensible heat and moisture between the atmosphere and the canopy (swath) is normally convective due to air movement. Horizontal wind speed above the swath governs the characteristics of convective transfer. Vertical air movement also exists due to eddies and rising air parcels caused by a temperature gradient in the vertical direction. From fluid mechanics, changes in flow speed over a surface is due to momentum exchange between different layers in a flow. Therefore, exchange above the swath is simultaneous transfer of momentum, heat and moisture. Knowledge of the wind profile with height above the swath enables determination of wind speed at any height level with measured wind speed at a reference height. This also leads to finding characteristics of sensible heat and moisture transfer.

The literature indicates that there is a surface layer above a natural surface in the downwind direction. The thickness of this surface layer depends on the fetch distance from the edge of the surface. For agricultural crops, Rosenberg et al. (1983) suggested a ratio of thickness to fetch of about 1:100, i.e. the surface layer would be 2 m thick at a distance of 200 m from the edge of a field in the downwind direction. In this study, transfer processes discussed were mainly within the surface layer.

Submodel ABOVE with associated subprograms ABVI, RSHABV, ITER, INVEXC and HCONV simulated the wind profile and aerodynamic resistances

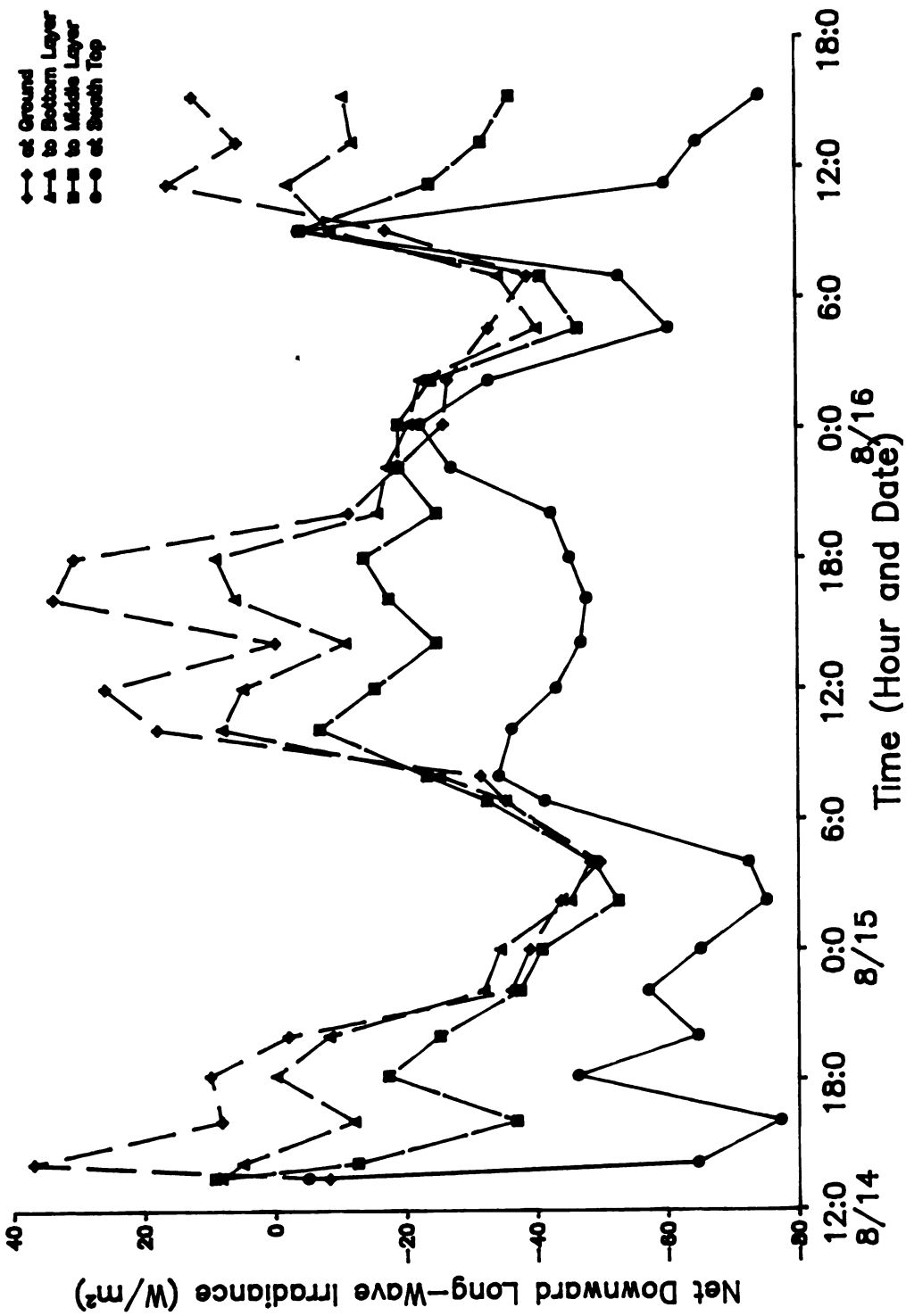

Figure 4. A simulated profile of net downward long-wave radiation for a swath in East Lansing, Michigan on August 14-16, 1984.

to heat and moisture transfer above the swath.

4.3.1 Virtual Temperature

Past research has shown that in the atmosphere near the earth's surface, an air parcel moving upwards is cooled at a rate of about 0.01°K/m due to a decrease in the atmospheric pressure, if the process is adiabatic (Rosenberg et al., 1983). This rate is called the 'dry adiabatic lapse rate'. This pressure decrease leads to an expansion in the air, and thus, a reduction in the air density. In addition, air humidity also affects the air density. Goudriaan (1977) mentioned that an increase in water vapor pressure of 1 Pa was equivalent to a temperature increase of 0.001°K. Taking these two factors into account, Goudriaan (1977) presented an equation to calculate 'virtual temperature' of the air as:

$$T_p = T + 0.001P_v + 0.01z \qquad [63]$$

where z = height, m,

T_p = virtual temperature of the air at z, °K,

T = absolute temperature of the air at z, °K,

and P_v = water vapor pressure of the air at z, Pa.

In function RSHABV, the concept of the virtual temperature was also used to calculate the difference in virtual temperature between the reference height z_r and the swath top z_c:

$$\Delta T_p = \Delta T + 0.001\Delta P_v + 0.01\Delta z_h \qquad [64]$$

where ΔT_v = virtual temperature difference from z_r to z_c, °K,

ΔT = dry-bulb temperature difference from z_r to z_c, °C,

ΔP_v = water vapor pressure difference from z_r to z_c, Pa,

and Δz_h = height difference, $z_r - z_c$, m.

In the model, variables DTP, DDB, DPV and DZH stood for ΔT_p, ΔT, ΔP_v and Δz_h, respectively.

4.3.2 Zero Plane Displacement and Roughness Parameter

A swath (or canopy) is not a solid but a loose structure. Thus, wind speed is generally not zero at the top of a canopy. In microclimatology, a canopy (swath) is abstracted as if there existed a virtual solid plane at a height d with a 'roughness parameter' z_0. At the height of $d+z_0$, the virtual extrapolation of the wind profile above the canopy (swath) reached zero. This abstracted height d is called the 'zero plane displacement', which is lower than the top height of a swath (or canopy). The zero plane displacement d and the roughness parameter z_0 are often estimated with empirical expressions. In this model, d and z_0 were calculated as (Goudriaan, 1977 and Rosenberg et al., 1983):

$$\log_{10} d = 0.979 \log_{10} z_c - 0.154 \quad [65]$$

$$\log_{10} z_0 = 0.997 \log_{10} z_c - 0.883 \quad [66]$$

where z_c = swath (canopy) height, m.

For a 0.1m-thick swath, the estimated d was 0.074 m and z_0 0.013 m. Thus, zero wind speed was assumed at 0.087 m height, which was 0.013 m below the swath top.

In submodel ABOVE, variables ZR, ZC, D and ZO denoted z_r, z_c, d and z_0, respectively. D and ZO were estimated in subroutine ABVI which initialized the atmosphere above the swath.

4.3.3 Rate Equations of Momentum, Heat and Moisture Transfer

Analogous rate equations have been established for momentum, sensible heat and moisture transfer in the layer within the first few meters above vegetation covers.

$$\tau = -\rho K_m \partial u/\partial z \quad [67]$$

$$H = -\rho c_p K_h \partial T_p/\partial z \quad [68]$$

$$E = -K_w \partial \rho_w/\partial z \quad [69]$$

where τ = shear stress, or momentum flux density, N/m^2,

H = sensible heat flux, W/m^2,

E = moisture flux, kg/m^2s,

ρ = air density at constant pressure, kg/m^3,

c_p = air specific heat at constant pressure, $J/kg°K$,

$\partial u/\partial z$ = wind speed gradient, $1/s$,

$\partial T_p/\partial z$ = virtual temperature gradient, $°K/m$,

$\partial \rho_w/\partial z$ = water vapor density gradient, kg water/m^4,

K_m = momentum transfer coefficient, m^2/s,

K_h = sensible heat transfer coefficient, m^2/s,

and K_w = moisture transfer coefficient, m^2/s.

Note that τ is in the horizontal direction, opposite to horizontal wind speed u, while the other two fluxes are vertical. To avoid confusion, the negative sign in Equation [67] will be omitted in the discussion.

The differential forms of rate equations above are often rewritten in difference forms:

$$\tau = \rho \Delta u/r_m \quad [70]$$

$$H = -\rho c_p \Delta T_p/r_h \quad [71]$$

$$E = -\Delta \rho_w/r_w \quad [72]$$

where Δu = wind speed difference, m/s,

ΔT_p = virtual temperature difference, °K,

$\Delta \rho_w$ = water vapor density difference, kg water/m^3,

r_m = resistance to momentum transfer, s/m,

r_h = resistance to sensible heat transfer, s/m,

and r_w = resistance to moisture transfer, s/m.

The resistances r_m, r_h and r_w have been defined as:

$$r_m = \int_{d+z_0}^{z} r \, dz/K_m \qquad [73]$$

$$r_h = \int_{z_c}^{z} r \, dz/K_h \qquad [74]$$

$$r_w = \int_{z_c}^{z} r \, dz/K_w \qquad [75]$$

In the model, variables RSHR and RSVR denoted r_h and r_w respectively.

4.3.4 Mixing Length and Friction Speed

The transfer coefficients K_m, K_h and K_w have been defined as a function of a mixing length l_{mix} and a friction speed u* in literature. Here, l_{mix} and u* are two important parameters which characterize the momentum exchange in the air. The mixing length l_{mix} is related to the free pathlength of air parcels, and the friction speed u* characterizes the strength of momentum transfer. In the literature, l_{mix} and u* are assumed to be:

$$l_{mix} = k(z-d) \qquad [76]$$

$$u^* = \sqrt{\tau/\rho} \qquad [77]$$

where k = von Karman constant, about 0.41, dimensionless,

and z-d = adjusted height from the zero plane displacement, m.

4.3.5 Atmosphere Stability

Due to turbulence, irregular topography or buoyancy, some air parcels are pushed upwards in the atmosphere, as mentioned above. If the virtual temperature of the air is constant with height, there would be no heat exchange between an upward moving air parcel and the surrounding air. Also the density of the air parcel would be the same as its surroundings, so the air parcel would continue to move upwards at its initial vertical velocity. This is called a 'neutral' condition.

There are two other conditions in the surface layer of the atmosphere. First, the virtual temperature of the air increases with height, so a rising air parcel will be cooled by its surroundings, and thus become more dense. The upward velocity of the parcel will be gradually reduced. This is called a 'stable' condition, or 'inversion'. On the other hand, when the virtual temperature of the air decreases, an air parcel will be warmed by its surrounding air, and become lighter. In this case, vertical movement of the air parcel will be accelerated. This is an 'unstable' condition, or 'lapse'.

Unstable conditions of the atmosphere near the ground occur usually from afternoon to early in the morning when the ground (or vegetation) surface is much warmer than the air above. Inversion occurs in the morning when the air is warmed by solar radiation first while the vegetation surface is still cool. Neutral conditions exist only for very short periods during transition.

In microclimatology, the following assumptions have been established by Monin and Obukhov (1954):

$$K_m = l_{mix} u^* / \Phi_m \qquad [78]$$

$$K_h = l_{mix} u^* / \Phi_h \quad [79]$$

$$K_w = l_{mix} u^* / \Phi_w \quad [80]$$

where l_{mix} = mixing length, m,

u^* = friction speed, m/s,

Φ_m = stability factor for momentum transfer, dimensionless,

Φ_h = stability factor for sensible heat transfer, dimensionless,

and Φ_w = stability factor for moisture transfer, dimensionless.

Thom (1975) mentioned that the effective mixing length l_{mix}/Φ_m was smaller than $k(z-d)$, i.e. $\Phi_m > 1$, under stable conditions; and larger than $k(z-d)$, i.e. $\Phi_m < 1$, under unstable conditions.

From Equations [67], [77] and [78], the following was written:

$$\partial u/\partial z = \Phi_m u^*/k(z-d) \quad [81]$$

Integrating this equation with respect to height gives the wind profile above a canopy (or swath). The shape of the wind profile depends upon the form of Φ_m. Likewise,

$$\partial T_p/\partial z = -\Phi_h T_p^*/k(z-d)$$

$$\partial \rho_w/\partial z = -\Phi_w \rho_w^*/k(z-d)$$

where

$$T_p^* = H/\rho c_p u^*$$

$$\rho_w^* = E/u^*$$

Therefore, profiles of wind speed, temperature and water vapor density are analogous in the atmospheric surface layer, as mentioned in the literature. In the surface layer near the ground, H and E are often assumed to be constant. So, the surface layer is also called the 'constant flux layer'. According to this, H and E can be estimated if temperature and water vapor density at two height levels are known, e.g. at the reference height z_r and the swath top z_c.

Integration of Equation [81] from $d+z_0$ to z_r and from z_c to z_r, and Equation [74] from z_c to z_r gave:

$$u^* = ku_r/I_m \quad [82]$$

$$u_c = u_r I_{mc}/I_m \quad [83]$$

$$r_h = I_h/ku^* = I_h I_m/k^2 u_r \quad [84]$$

where

$$I_m = \int_{d+z_0}^{z_r} \Phi_m dz/(z-d) \quad [85]$$

$$I_{mc} = \int_{d+z_0}^{z_c} \Phi_m dz/(z-d) \quad [86]$$

$$I_h = \int_{z_c}^{z_r} \Phi_h dz/(z-d) \quad [87]$$

In function subprogram RSHABV, variables USTAR, UR, UC, INTM, INTH and INTMC denoted u^*, u_r, u_c, I_m, I_h and I_{mc}, respectively.

Stability factors Φ_m, Φ_h and Φ_w are often expressed in terms of a stability parameter ζ or Richardson number Ri:

$$\Phi_{m,h,w} = \Phi_{m,h,w}(\zeta) = \Phi_{m,h,m}(Ri)$$

The stability parameter ζ is defined as:

$$\zeta = (z-d)/L \quad [88]$$

where z-d = adjusted height, m,

and L = Monin-Obukhov stability length, m.

$$L = z_1 - d = -\rho c_p (u^*)^3 T_p/kgH \quad [89]$$

where z_1 = virtual height of distance L above d, m,

d = zero plane displacement, m,

ρc_p = volumetric heat capacity of the air, $J/m^3\,°K$,

u^* = friction speed, m/s,

T_p = mean virtual temperature, °K,

k = von Karman constant, dimensionless,

g = gravity acceleration, m/s^2,

and H = upward sensible heat flux, W/m^2.

The Monin-Obukhov length L is an abstracted distance above the zero plane displacement. A positive L (or ζ) indicates a stable condition z while a negative L (or ζ) represents an unstable condition. When L is infinite, i.e. zero ζ, the air is neutral. On the other end, the surface is extremely stable as $L \to 0$, i.e. $\zeta \to \infty$.

The Richardson number Ri is the ratio of the buoyancy acceleration $gl_{mix}(\partial T_p/\partial z)/T_p$ to the friction deceleration $l_{mix}(\partial u/\partial z)^2$:

$$Ri = g(\partial T_p/\partial z)/T_p(\partial u/\partial z)^2 \qquad [90]$$

A negative, zero or positive Ri represents an unstable, neutral or stable condition of the air, respectively. The relationship between Ri and ζ is:

$$Ri = \zeta\Phi_h/\Phi_m^2 \qquad [91]$$

The difference forms of L and Ri are:

$$L = T_p(u^*)^3 r_h/gk\Delta T_p = T_p I_h(u_r)^2/g\Delta T_p(I_m)^2 \qquad [92]$$

$$Ri = g\Delta z_h\Delta T_p/T_p(u_r-u_c)^2 = \Delta\zeta_h I_h/(I_m-I_{mc})^2 \qquad [93]$$

where

$$\Delta z_h = z_r - z_c$$

$$\Delta\zeta_h = \Delta z_h/L$$

$$T_p = (T_{pr}+T_{pc})/2$$

$$\Delta T_p = T_{pr} - T_{pc}$$

Where, subscripts r and c stood for the reference height and the canopy (swath) top, respectively. In submodel ABOVE, variable RI, L, DZH, DTP, TPR, TPC, TP and KARMAN represented Ri, L, Δz_h, ΔT_p, T_{pr}, T_{pc}, T_p and k, respectively.

4.3.6 Neutral Conditions

A zero ΔT_h, Ri, ζ or an infinite L characterizes neutral conditions of the atmospheric surface layer. The momentum stability factor Φ_m is commonly assumed to be unity (Φ_m=1) under neutral conditions. Thus,

$$K_m = k(z-d)u^*$$

Equation [81] becomes:

$$\partial u = (u^*)\partial z/k(z-d) \qquad [94]$$

Integrating from $d+z_0$ to z gives:

$$u(z) = (u^*/k)\ln[(z-d)/z_0] \qquad [95]$$

This shows the wind profile above a canopy under neutral conditions is logarithmic. When wind speed u_r (at reference height z_r) is known, the friction speed u* and wind speed at any height, especially the wind speed at the swath top u_c, can be found:

$$u^* = ku_r/B_m \qquad [96]$$

$$u_c = u_r B_{mc}/B_m = u_r(1-B_h/B_m) \qquad [97]$$

where

$B_m = \ln[(z_r-d)/z_0]$ i.e. $I_m = B_m$

$B_h = \ln[(z_r-d)/(z_c-d)]$ i.e. $I_h = B_h$

$B_{mc} = \ln[(z_c-d)/z_0]$ i.e. $I_{mc} = B_{mc}$

In the model, a neutral condition was assumed if the absolute value of ΔT_p was less or equal to 0.001. In subroutine ABVI and RSHABV, variables BM, BH and BMC stood for B_m, B_h and B_{mc}, respectively.

In the literature, K_h and K_w have been assumed to be equal to K_m under neutral conditions. However, recent research has shown some deviation from that assumption. Businger et al. (1971) found K_h could

be 1.35 times as large as K_m under field conditions. In this study, it was expressed as:

$$K_h = K_w = K_m/f$$

i.e.

$$\Phi_h = \Phi_w = f\Phi_m$$

where f = 0.74~1.0

From this, r_h and r_w were found as:

$$r_h = fr_m = fB_h/ku^* = fB_hB_m/k^2u_r \qquad [98]$$

4.3.7 Stable Conditions

A positive ΔT_p, Ri, ζ or L characterizes inversion in the atmospheric surface layer. In the literature, most empirical equations of Φ_m and Φ_h under stable conditions have the form:

$$\Phi_m = 1 + b\zeta \qquad \Phi_h = f + b\zeta$$

where b (4.7~5.2) and f (0.47~1.0) are constant. For example,

$\Phi_m = 1 + 4.7$ $\quad$ $\Phi_h = 0.74 + 4.7$ $\quad$ Businger et al. (1971)

$\Phi_m = 1 + 5.0$ $\quad$ $\Phi_h = 1 + 5.0$ $\quad$ Dyer (1973)

It can be shown that under stable conditions:

$$I_m = B_m + b\Delta\zeta$$

$$I_h = fB_h + b\Delta\zeta_h$$

$$I_{mc} = B_{mc} + b\Delta\zeta_c$$

Hence

$$u^* = ku_r/(B_m+b\Delta\zeta) \qquad [99]$$

$$u(z) = (u^*/k)\{\ln[(z-d)/z_0]+b(z-d-z_0)/L\} \qquad [100]$$

$$u_c = u_r[1-(B_h+b\Delta\zeta_h)/(B_m+b\Delta\zeta)] \qquad [101]$$

$$r_h = (fB_h+b\Delta\zeta_h)/ku^* \qquad [102]$$

where

$\Delta\zeta = \Delta z/L$ $\qquad$ $\Delta z = (z_r-d-z_0)$

$\Delta\zeta_c = \Delta z_c/L$ $\qquad$ $\Delta z_c = (z_c-d-z_0)$

$\Delta\zeta_h = \Delta z_h/L$ $\qquad$ $\Delta z_h = (z_r-z_c)/L$

Equation [100] shows that under stable conditions the wind profile with height is not strictly logarithmic. It has been called a 'log-linear' profile. However, Goudriaan (1977) indicated that the deviation of a log-linear profile from logarithmic shape was very small.

To determine u*, L should be found. The difference form of L was rewritten as:

$$L = [T_p(u_r)^2/g\Delta T_p][fB_h+b\Delta\zeta_h]/[B_m+b\Delta\zeta]^2 \qquad [103]$$

This gave a quadratic equation of L:

$$AL^2 + BL + C = 0 \qquad [104]$$

where

$A = (B_m)^2$

$B = 2bB_m\Delta z - fB_hT_p(u_r)^2/g\Delta T_p$

$C = (b\Delta z)^2 - bT_p\Delta z_h(u_r)^2/g\Delta T_p$

The solution of Equation [104] depended upon:

$$B^2-4AC = [T_p(u_r)^2/g\Delta T_p]^2 + [4bB_mT_p(u_r)^2/g\Delta T_p](B_m\Delta z_h-fB_h\Delta z)$$

The following points were drawn from Equation [104].

(1) $B^2-4AC>0$, since $B_m\Delta z_h>B_h\Delta z$ for $z_r>z_c$.

(2) Equation [104] had only one positive solution:

$$L = (-B+\sqrt{B^2-4AC})/2A$$

if and only if $C<0$, i.e.

$$\Delta T_p < \Delta T_{pcr} = T_p(u_r)^2\Delta z_h/bg(\Delta z)^2 \qquad [105]$$

where T_{pcr} = critical virtual temperature difference, °K.

For example, if z_r=0.6 m, z_c=0.1 m, d=0.074 m, z_0=0.013 m, T_p=300°K,

u_r=1.0 m/s and b=5, then ΔT_{pcr}=11.62°K. In real fields, this rarely occurs.

(3) L→0 when C→0, i.e. $\Delta T_p \rightarrow \Delta T_{pcr}$. This meant $\zeta \rightarrow \infty$. Physically, this meant the surface layer was extremely stable, i.e. full inversion was established. Eddy motion was completely inhibited, and convection ceases.

(4) Ri approached a critical value Ri_{cr} as L→0

$$Ri_{cr} = 1/b = 0.19\sim0.21 \qquad [106]$$

This was the direct result of Equations [93], [103] and [105]. Webb(1970), Businger et al. (1971), Obukhov (1971), Thom (1975) and Goudriaan (1977) showed the same critical Ri value from various aspects. The analysis presented by the author was another proof and give a new ΔT_{pcr} which was easier to examine than Ri_{cr}. Obukhov (1971) set K_h=0.0 for $Ri>Ri_{cr}$, which meant $r_h \rightarrow \infty$. Goudriaan (1977) treated such a case as no transfer by setting r_h to be equal to 10^{10} s/m. This model adapted the same procedure.

4.3.8 Unstable Conditions

Unstable conditions in the atmospheric surface layer are represented by a negative ζ, Ri or L. Under unstable conditions, most suggested forms of Φ_m, Φ_h and Φ_w are nonlinear and difficult to analytically integrate:

$$\Phi = p(1-q\zeta)^r$$

where p, q and r are constant. For instance,

$\Phi_m = (1-15\zeta)^{-1/4}$ $\quad$ $\Phi_h = 0.74(1-9\zeta)^{-1/2}$ $\quad$ Businger et al. (1971)

$\Phi_m = (1-16\zeta)^{-1/4}$ $\quad$ $\Phi_h = (1-16\zeta)^{-1/2}$ $\quad$ Dyer (1973)

A procedure by Goudriaan (1977) was applied in the model to get numerical solutions for integration. Stability factors were approximated with a fourth-order Taylor's series:

$$\Phi = C_1 + C_2(z-d) + C_3(z-d)^2 + C_4(z-d)^3 + C_5(z-d)^4 \quad [107]$$

Where C_1~C_5 were coefficients to be determined, and z-d was the adjusted height. If values of Φ at five different height levels were known, then these coefficients could be determined by solving a system of five linear equations. For this purpose, the distance between z_r and z_c was divided into four even increments in the model. Five adjusted heights, i.e. z_c-d, z_r-d and the others from three division points, were formed and used to determine the coefficients of the Taylor series. Under unstable conditions:

$$I_m = C_{m1}B_m + C_{m2}\Delta z + C_{m3}[(z_r-d)^2-z_0^2]/2 + C_{m4}[(z_r-d)^3-z_0^3]/3 + C_{m5}[(z_r-d)^4-z_0^4]/4 \quad [108]$$

$$I_h = C_{h1}B_h + C_{h2}\Delta z_h + C_{h3}[(z_r-d)^2-(z_c-d)^2]/2 + C_{h4}[(z_r-d)^3-(z_c-d)^3]/3 + C_{h5}[(z_r-d)^4-(z_c-d)^4]/4 \quad [109]$$

$$I_{mc} = C_{m1}B_{mc} + C_{m2}\Delta z_c + C_{m3}[(z_c-d)^2-z_0^2]/2 + C_{m4}[(z_c-d)^3-z_0^3]/3 + C_{m5}[(z_c-d)^4-z_0^4]/4 \quad [110]$$

where C_{m1}~C_{m5}, and C_{h1}~C_{h5} were coefficients in the Taylor series for Φ_m and Φ_h, respectively.

Recall that L was related to I_h and I_m which were dependent upon Φ_h and Φ_m, thus, ζ and L.

$$L = T_p(u_r)^2 I_h/g\Delta T_p(I_m)^2 \quad [111]$$

An iteration technique was used in the model. A value of L (-0.001) was first assigned and used to determine two sets of coefficients in the Taylor series of Φ_m and Φ_h. Then, I_m and I_h were calculated. From Equation [111], a new L was found. The process was repeated until the

absolute difference between two L values reached a preset convergence tolerance (0.01). In the model, subroutine ITER and INVEXC carried out the iteration and determination of the coefficients of the Taylor's series, respectively.

When instability was moderate ($-1.0<Ri<-0.001$), r_h was calculated with Equation [84]. Thom (1975) indicated that the wind profile was very close to the log-linear shape when Ri was not less than -0.1. Under heavily unstable conditions ($Ri\leq-1.0$), however, Thom (1975) and Goudriaan (1977) pointed out that buoyancy forces rather than friction forces dominated sensible heat transfer, which became free convection instead of forced convection. In this case, r_h was calculated based on a procedure by Holman (1981), see Section 4.5 and function subprogram HCONV for detail. Table 3 lists some aerodynamic parameters estimated in the model.

The discussion above dealt with nonzero wind speed at z_r. When u_r was zero, forced convection ceases. If $\Delta T_p=0$, the surface layer was neutral with no heat transfer at all. This was represented by a very large r_h in the model as well as a zero ΔT_p. If $\Delta T_p>0$, the surface layer became extremely stable, i.e. heat transfer was suppressed, which was also represented by a very large r_h. If $\Delta T_p<0$, the surface layer was highly unstable since $L\rightarrow0$ and $Ri\rightarrow-\infty$, which led to free convection as $Ri<-1.0$.

4.3.9 Resistance to Moisture Transfer

Resistance to moisture transfer in the atmospheric surface layer depends heavily upon the turbulence status in the layer. The resistance

Table 3 Aerodynamic parameters in the atmospheric surface layer with z_r=0.6 m, z_c=0.1 m, T_p=300°K and u_r=1.0 m/s

Ri	L (m)	t (K)	u* (m/s)	u (m/s)	r (s/m)
-1.	-0.175	-35.23	0.188	0.241	12.48
-0.1	-1.693	-3.784	0.132	0.213	37.52
-0.01	-16.17	-0.399	0.115	0.193	59.47
-0.001	-167.0	-0.040	0.112	0.188	64.94
-0.0001	-1670.	-0.004	0.111	0.188	65.60
0		0	0.111	0.188	65.73
0.0001	1669.	0.004	0.111	0.188	65.74
0.001	166.2	0.040	0.111	0.187	66.72
0.01	15.86	0.410	0.107	0.181	72.16
0.1	0.835	4.799	0.061	0.114	240.8
0.15	0.278	7.900	0.032	0.072	919.5
0.175	0.119	9.671	0.016	0.049	3590.
0.2	0	11.62	0	0	

was commonly assumed to be the same as the resistance to heat transfer. This was appropriate when both ΔT_p and Δp_v had the same sign, i.e. both sensible and moisture fluxes were in the same direction. However, two special cases needed to be further discussed. First, $\Delta T_p>0$ but $\Delta p_v<0$, i,e. a downward sensible heat flux but a upward moisture flux. In this case, the surface layer was thermally stable and forced convection was reduced. Since upward-movement of air parcels was limited, upward moisture transfer was also reduced. Thus, the equality of both r_h and r_w was reasonable in this case. Secondly, $\Delta T_p<0$ but $\Delta p_v>0$, i.e. an upward sensible heat flux with a downward moisture flux. The surface layer was thermally unstable in this case. Forced convection was enhanced due to buoyancy effects of rising air parcels. The resistance to sensible heat transfer became smaller. However, downward moisture transfer in this case should be compensated rather than enhanced because air parcels with

lower water vapor densities inside would pick up some moisture from the surroundings of their upward path. In this case, setting r_{wv} equal to r_h was obviously unreasonable. Since there was a lack of information about realistic treatments on this special case, r_w was assumed to equal a virtual r_h as if there existed $-\Delta T_p$ (>0) in the surface layer. A positive value of $-\Delta T_p$ would induce a relatively large resistance.

To determine the stability of the atmospheric surface layer, temperature at the top of a swath (canopy) should be known in advance. However, the swath top temperature was one of the state variables to be determined in the model. Iteration techniques or other methods should be applied. In this model, the thermal stability and resistance above the swath were estimated from the temperature and water vapor density at each time step and used to determine temperature and water vapor density at the next time step.

4.4 Exchanges inside the Swath

Inside a swath (or canopy), exchanges of momentum, sensible heat and moisture are also affected by wind speed in air spaces. Strengths of these exchanges are smaller than those above the swath (or canopy) due to reduced wind speed. Goudriaan (1977) pointed out that there had not been a well-verified theory for exchanges inside canopies, like the similarity theory above canopies. However, some working hypotheses for exchanges above canopies could be approximately used.

Submodel INSIDE with associated subprograms RSHINS, PHIHM and HCONV simulated the wind profile and calculated corresponding resistances to sensible heat and moisture transfer within the swath.

4.4.1 Neutral Conditions

The hypothesis of K_m being the product of l_{mix} and u^* has been adapted by many researchers, e.g. Thom (1975) and Goudriaan (1977). In this model, the procedure by Goudriaan (1977) was employed with some modification.

Differing from the air above canopies, the travel of the air inside canopies was restricted by leaves and stems. The mixing length l_{mix} inside canopies was related to the mean free space between leaves. Goudriaan (1977) proposed an equation to calculate l_{mix} for narrow and long leaves:

$$l_{mix} = \sqrt{4w/\pi L_d} \qquad [112]$$

where l_{mix} = mixing length, m,

w = mean width of leaves, m,

and L_d = volumetric density of leaf area, m^2 leaf/m^3.

The volumetric density of leaf area for uniformly distributed leaves is:

$$L_d = \Delta L/\Delta z = LAI/z_c \qquad [113]$$

where Δz = element of height, m,

and ΔL = element of the leaf area index in z.

When LAI=3.0, z_c=0.1 m and w=0.005 m, l_{mix}=0.009 m. The mean eddy velocity inside canopies was assumed to be proportional to local wind speed:

$$u^* = i_w u \qquad [114]$$

where i_w = relative turbulence intensity, dimensionless,

and u = local wind speed, m/s.

The relative turbulence intensity i_w ranged from 0.3 at the top to 0.8

at the soil surface for a corn canopy (Goudriaan, 1977). In this model, i_w was assumed as 0.55 in view of a thin swath. Variables WI and XIML denoted i_w and l_{mix} in submodel INSIDE.

Momentum loss inside swaths (canopies) was due to drag forces between leaves and the air flow. Shear stress inside a canopy was often characterized with:

$$\tau = K_m \partial u/\partial z \quad [115]$$

$$\partial \tau/\partial z = \rho C_d L_d u^2 \quad [116]$$

where τ = shear stress, N/m^2,

ρ = air density, kg/m^3,

C_d = drag coefficient, dimensionless,

K_m = transfer coefficient, m^2/s,

and L_d = volumetric density of leaf area, m^2 leaf/m^3.

C_d was a bulk drag coefficient over an element thickness of plants (leaves and stems), which was different from a drag coefficient of an individual leaf (or stem). Thom (1968) found the latter was a function of wind speed. However, C_d was assumed as constant by Cowan (1968) and Goudriaan (1977). Thom's data (1968) showed that when wind speed was below 0.2 m/s the drag coefficient of individual leaves rose rapidly. Similar tendency was found by use of Equation [116] to calculate the bulk drag coefficient of canopies with wind data at the top of canopies. In this model, a value of 0.5 was used. From Equations [115] and [116], a second-order differential equation was formed:

$$u(\partial^2 u/\partial z^2) + (\partial u/\partial z)^2 - 2a^2 u^2 = 0 \quad [117]$$

where a = extinction coefficient, 1/m.

$$a^2 = C_d L_d / 2 i_w l_{mix} \quad [118]$$

The range of az_c has been reported from 2 to 4. For instance, if

LAI=3.0, z_c=0.1 m, C_d=0.5, i_w=0.5, then az_c=4.03.

The solution of Equation [117], wind speed u at height z, was:

$$u = u_2 e^{-a(z_2-z)} \quad [119]$$

where z_2 = height of the top of a layer, m,

and u_2 = wind speed at z_2.

This showed that the wind profile was exponentially decaying inside a canopy (swath). Thom (1975) indicated that realistic canopy wind profiles could be generated on the basis of any reasonable assumption about K_m. For example, an assumption of constant K_m by Thom (1975) led to a wind profile very close to exponential. It should be pointed out that the exponential profile did not lead to zero wind speed at the soil surface as expected. However, estimated wind speed with Equation [119] at the ground level was very small, and the error introduced was immaterial.

4.4.2 Unneutral Conditions

Because of lack of information, many researchers have ignored discussion on the thermal stability inside canopies. Goudriaan (1977) assumed under unneutral conditions K_m and K_h to be as:

$$K_m = l_{mix} i_w u/\Phi_m \quad [120]$$

$$K_h = l_{mix} i_w u/\Phi_h \quad [121]$$

Where Φ_m and Φ_h were the same as those expressions above canopies discussed in the previous section. The differential equation became:

$$(\partial/\partial z)[(u/\Phi_m)\partial u/\partial z] - 2a^2u^2 = 0 \quad [122]$$

The solution would be very complicated because Φ_m was also a function of z. To simplify the solution, Goudriaan (1977) assumed an average

value of Φ_m over a height range, and hence obtained an approximate solution, like Equation [119]. The extinction coefficient became:

$$a^2 = C_d L_d \Phi_{mav} / 2 i_w l_{mix} \quad [123]$$

where Φ_{mav} = average Φ_m.

Goudriaan (1977) also redefined the Richardson number:

$$Ri = [g(\partial T_p / \partial z)/T_p](l_{mix}/u_{av})^2 \quad [124]$$

where u_{av} = mean wind speed over a height range, m/s.

This was based upon the fact that the friction deceleration inside canopies was due to collisions with plant elements rather than viscous efforts. Rearranging Equation [124] in a different form gave:

$$Ri = [g\Delta T_p \Delta z / T_p (u_{av})^2](l_{mix}/\Delta z) \quad [125]$$

Note that the term in the brackets was similar to the difference form of Ri above canopies, see Equation [93]. If this term was comparable with Ri above canopies, the ratio of Ri inside canopies to Ri above canopies would be $(l_{mix}/\Delta z)^2$, which was normally smaller than unity. Since wind speed u_{av} inside a swath was very very small, a small value of ΔT_p would make Ri inside a swath comparable to that above the swath. This implied that inside the swath, thermal stability played an important role on exchanges of sensible heat and moisture. In this model, thermal stability was estimated between each layer of the swath. This was due to the fact that temperature at the center of a swath might be higher or lower than those at the top and bottom of the swath at sometime during the drying process. This kind of vertical temperature profile has been reported in many cases for crop canopies. Thus, different patterns of thermal stability should be distinguished at different levels of a canopy at a given time.

The mean wind speed over a height range from z_1 to z_2 was

calculated as:

$$u_{av} = (u_2/a\Delta z)[1-e^{a\Delta z}] \quad [126]$$

where

$$\Delta z = z_2 - z_1$$

The resistance to sensible heat transfer r_h under moderate unneutral conditions was calculated as:

$$r_h = \Phi_{hav}\Delta z/l_{mix}i_w u_{av} \quad [127]$$

For full inversion or free convection, the criteria used were the same as those above the swath. In this model, Φ_{mav} and Φ_{hav} were estimated in subroutine PHIHM based upon the relationship given in Equation [91].

The resistance to moisture transfer r_w was treated based upon the signs of ΔT_p and Δp_v in the same way as that above the swath aforementioned.

In the model, variables RSH and RSV stored data of r_h and r_w, respectively. Figure 5 shows a simulated wind profile within a swath in East Lansing, Michigan on August of 1984.

4.4.3 Resistance at the Soil Surface

The resistance to sensible heat transfer between the soil surface and the bottom layer of the swath consisted of two components. One resistance component (RGH) was the aerodynamic resistance in the bottom layer which was determined by the thermal stability of the bottom layer. The other component (RBS) was a resistance near the soil surface which was affected by the boundary layer near the surface. In the soil boundary layer, air flow was laminar and the characteristic dimension

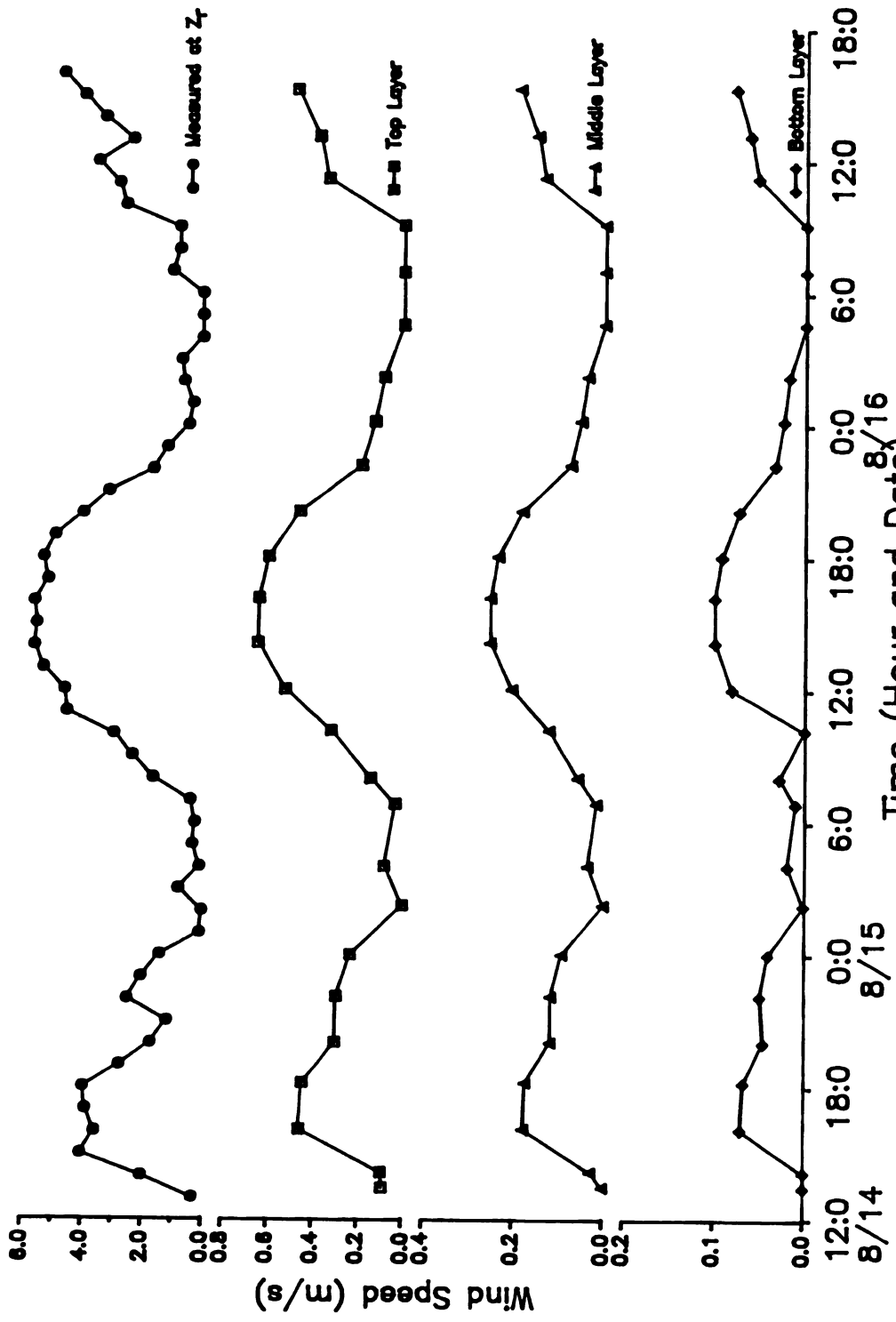

Figure 5. A simulated wind profile within a swath in East Lansing, Michigan on August 14-16, 1984.

was the average soil clod size. A value of 0.05 m was assumed in the model. The resistance to sensible heat transfer near the soil surface was estimated in HCONV, which will be discussed in depth in the next section. The resistance to moisture transfer (RSVG) had three components (RVG, RVS and RSG). Two of which corresponded to the two components of resistance to sensible heat transfer. The third component (RSG) represents the resistance to moisture removal from the soil just below the soil surface. Goudriaan (1977) assumed a zero value for this component if the soil was wet, or 10^7 s/m for dry soil. Thompson (1981) used a value of 100 s/m for wet soil and 1000 s/m for dry soil. In this model, the variable RSG was set to 10 s/m for a typical soil surface in East Lansing, Michigan; and 1000 s/m for the soil in Fresno, California.

The resistances at the soil surface were estimated in function subprogram RESGND, a component of the soil submodel which will be discussed in Section 4.7.

4.5 Exchanges on Leaf Surfaces

Leaf surfaces play a major role in connecting plants to their environment. This is especially important for cut plants because their connection with soil through roots is broken. Exchanges of energy and mass between plants and the surrounding air take place on surfaces of leaves and stems. Exchanges of water vapor and other gases are normally through stomata. Wax and cuticles on plant surfaces prevent unnecessary exchanges of vapor and gases. Most stomata are located on leaf surfaces since leaves have larger surface area and higher stomata density than

stems. Leaves are also less waxy and covered by thinner cuticles. Thus, the amounts of energy and mass exchanged on leaves are the dominant components of total exchanges of a plant. Therefore, the status of temperature and the moisture content of plants can be approximately represented by that of leaves, respectively.

Submodel DBLEAF and associated subprograms RESIST, HCONV, RBVMC and DFMCL simulated the exchanges of sensible heat, latent heat and moisture on leaf surfaces based upon physical laws of transfer and conservation of energy and mass.

4.5.1 Sensible Heat Transfer on Leaf Surfaces

Sensible heat transfer between one side of an individual leaf and its surrounding air has been classically treated as convective heat transfer of a thin flat plate in an air flow.

For convective heat transfer, the heat flux was expressed as:

$$Q = h(T_l - T_l) \qquad [128]$$

where Q = heat flux, W/m^2

T_l = leaf surface temperature, °C,

T_a = air temperature, °C,

and h = convection heat-transfer coefficient, $W/m^2\,°C$.

The resistance to heat transfer was:

$$r_h = \rho c_p / h$$

where r_h = resistance to heat transfer, s/m,

and ρc_p = volumetric heat capacity of the fluid, J/m^3C.

The volumetric heat capacity of the air was about 1240 $J/m^3\,°C$ and varied with temperature and water vapor content of the air.

In the model, DBA, DBL, HLA, RBH and FXHLA denoted T_a, T_l, h, r_h and Q, respectively. The calculation of HLA and RBH were carried out in HCONV and RESIST, respectively; and FXHLA in DBLEAF and RATE.

Convective heat transfer is related to flow characteristics and thermal properties of the fluid. When the air flows over a flat plate, a boundary layer is developed in the flow near the plate surface. In the boundary layer, the influence of viscous forces is significant. The flow in the boundary layer can be laminar or turbulent, determined by the Reynolds number

$$Re = uX/\nu \qquad [129]$$

where u = free-steam velocity, m/s,

X = characteristic dimension of the plate, m,

and ν = kinematic viscosity of the fluid, m^2/s.

When $Re < 5\times10^5$, the flow is laminar; otherwise, turbulent (Holman, 1981).

For canopies, the characteristic dimension X could be the arithmetic mean of the sum of leaf width and length. The mean wind speed in a canopy could be taken as the free-stream velocity. For an alfalfa swath, X=0.0125 m (assumed leaves of 0.005 m width and 0.02 m length), and $\nu=16\times10^{-6}$ m^2/s at 30°C. To reach the critical Re (5×10^5), u should be 640 m/s which was impossible. Thus, in real fields, the air flow in the boundary layer over a single leaf would be laminar. If the wind speed was 0.1 m/s, then Re=78.1.

For laminar boundary layers over plates with constant temperature, the relationship between heat transfer and flow characteristics has been often expressed as:

$$Nu = a(Re)^{1/2}(Pr)^{1/3} \qquad [130]$$

where Nu = average Nusselt number over length X, dimensionless,

Re = Reynolds number, dimensionless,

Pr = Prandtl number, dimensionless,

and a = empirical constant.

Equation [130] has been derived based upon the analogy of fluid friction and heat transfer. The value of a was found to be about 1.1 in field conditions which was 1.65 times as large as that for smooth plates (0.668) of the same dimension (Goudriaan, 1977). This enlargement was due to roughness of real leaves.

The Prandtl number Pr characterizes the relative magnitude of diffusion of momentum and heat, and hence, relates the velocity and temperature fields in the fluid.

$$Pr = \nu/\alpha \qquad [131]$$

where ν = kinematic viscosity, m^2/s,

and α = thermal diffusivity, m^2/s.

The Prandtl number Pr for the air is about 0.7 at 30°C.

The Nusselt number Nu characterizes the convective effect with respect to the conductive effect in the flow. A value of unity for Nu indicates pure conduction.

$$Nu = hX/k \qquad [132]$$

where h = convection heat-transfer coefficient, $W/m^2°C$,

X = characteristic dimension, m,

and k = fluid thermal conductivity, W/m°C.

For Re=78.1, Pr=0.7, X=0.0125 m, $k=26.4\times10^{-3}$ W/m°C and a=1.1, then Nu=8.64 and h=18.3 $W/m^2°C$.

Heat transfer due to viscous forces in a fluid flow is forced convection. On the other hand, natural (or free) convection may also

occur, which is caused by buoyancy forces imposed on the fluid due to density changes in a heat exchange process. For free convection, the following expression has been established:

$$Nu = c(GrPr)^m \quad [133]$$

where Nu = Nusselt number, dimensionless,

Gr = Grashof number, dimensionless,

Pr = Prandtl number, dimensionless,

c and m = empirical constants.

The Grashof number measures the relative importance of the buoyancy forces with respect to the viscous forces.

$$Gr = g\beta X^3 \Delta T/\nu \quad [134]$$

where β = volumetric coefficient of expansion, $1/°K$,

g = acceleration due to gravity, m/s ,

ΔT = temperature difference between the surface and flow, $°K$,

X = characteristic dimension, m,

and ν = kinematic viscosity, m^2/s.

For air, β is the reciprocal of the absolute temperature of the air.

When heated surfaces face up or cold surfaces face down, free convection is enhanced; or it is reduced if heated surfaces face down or cold surfaces face up. If the plate is inclined, free convection is also dependent upon the inclination angle. Values of c and m in Equation [133] reflect these geometric and other fluid conditions. Procedures and typical values of c and m given by Holman (1981) were employed in subprogram HCONV.

For a single leaf, one side could be considered as facing up and the other - facing down. However, the orientation of a leaf in a swath could be any angle from horizontal to vertical.

Holman (1981) indicated that pure conduction was observed when Gr < 1700. For air at 30°C (303°K), β=0.0033 1/°K, g=9.81 m/s^2, ν=16x10^{-6} m^2/s and Pr=0.7. Suppose ΔT=2°K and X=0.0125 m, then Gr=494 which implied pure conduction, i.e. h=k/X=2.11 W/m^2°C. If, ΔT=7°K, then Gr=1729, c=0.54, m=0.25, Re=3.18 and h=6.72 W/m^2°C.

Within the swath, wind speed was small as shown in Section 4.4, so the effect of forced convection might be insignificant. A combination of forced and free convection on each side of a single leaf was likely to occur. In HCONV, two convection heat-transfer coefficients were estimated. One (HCONVF) was for forced convection, and the other (HCONVN) was for natural convection. As an approximation, the combined heat-transfer coefficient (HCONV) was obtained by adding HCONVF and HCONVN. The relative importance between HCONVF and HCONVN was determined based upon their magnitudes. This additive approximation might overestimate the heat transfer coefficient; however, it would not affect results much since the magnitude of the convective heat-transfer coefficient was not very large. For the example given above, the convective heat-transfer coefficient and the resistance to heat transfer for each side of a leaf was about 22 W/m^2°C and 56 s/m, respectively.

As a whole, the resistance to heat transfer of a single leaf was the sum of resistances from two sides in parallel.

$$1/r_{hl} = 1/r_{hu} + 1/r_{hd} \qquad [135]$$

where r_{hl} = leaf resistance, s/m,

r_{hu} = resistance at the upward-facing side, s/m,

and r_{hd} = resistance at the downward-facing side, s/m.

In the example above, r_{hl}=28 s/m and h_l=44 W/m^2° for one leaf.

The overall resistance to heat transfer of a layer of leaves was the combination of resistances in parallel from all leaves of the layer. Equation [135] was also valid for a layer of leaves. As discussed earlier, the distribution of leaf orientation in a layer was assumed to be uniform (spherical). When horizontal wind flows through a layer of leaves, the wind components parallel to each leaf surface were different due to various orientation angles. In the model, a mean inclination angle (45°) and a mean wind component ($2u/\pi$) were used to estimate average values of h and r_h for leaves in a layer.

Note that the discussion above was with respect to a unit leaf area. The overall heat-transfer coefficient h and the resistance r_h could be also expressed with respect to a unit land area:

$$h = h_l \partial L$$

$$r_h = r_{hl}/\partial L$$

Where ∂L was the element leaf area index in a layer (m^2 leaf/m^2). The subscript 1 stood for leaves.

4.5.2 Moisture Transfer on Leaf Surfaces

The rate equation for moisture (water vapor) transfer on a leaf surface due to molecular diffusion was similar to the rate equation for sensible heat transfer:

$$E = P(\rho_{wl}-\rho_{wa}) = (\rho_{wl}-\rho_{wa})/r_w \qquad [136]$$

where E = moisture flux, kg water/m^2s,

ρ_{wl} = water vapor density on the leaf surface, kg water/m^3,

ρ_{wa} = water vapor density of the air, kg water/m^3,

P = permeability coefficient or mass-transfer coefficient, m/s,

and r_w = resistance to moisture transfer, s/m.

Moisture transfer on a leaf surface should overcome two resistances. One was the resistance in the boundary layer over the surface; the other was the resistance of the surface, including a series of resistances due to stomata, sub-stomatal cavities and cell walls in parallel with a resistance of cuticles. The former was an external resistance affected mainly by the air flow characteristics; however, the latter was a resistance determined by internal factors of the plant.

The boundary resistance r_{vb} and the surface resistance r_{vs} were linked in series for each side of a leaf. The resistances of both sides in parallel formed the resistance for the leaf. As to a layer of leaves, the overall resistance to moisture transfer resulted from parallel resistances of all leaves in the layer. In the model, the overall resistance r_v was treated the same as the resistance to heat transfer discussed in the preceding section. Conversion of r_v from unit leaf area to unit land area was also made.

Transfer of water vapor also carried latent heat transfer. The latent heat flux λE (W/m^2) was the latent heat of vaporization λ times the moisture flux E. The latent heat-transfer coefficient h_v was λ times the reciprocal of the resistance r_v. In the model, RBV, HW, FVLA, VLA and FXVLA denoted r_v, λ, E, h_v and λE, respectively.

4.5.2.1 Resistance to Moisture Transfer in the Boundary Layer

According to the theory of convection, there is an analogy between momentum transfer, sensible heat transfer and mass transfer in the boundary layer over flat plates. For solving problems in convective

mass transfer, the following equation has been derived:

$$\rho c_p P/h_{hb} = (Pr/Sc)^{2/3} = (D/\alpha)^{2/3} \quad [137]$$

where ρc_p = volumetric heat capacity of air, $J/m^3\,°C$,

P = mass-transfer coefficient, m/s,

h_{hb} = heat-transfer coefficient, $W/m^2\,°C$,

Pr = Prandtl number,

Sc = Schmidt number,

D = mass diffusivity, m^2/s,

and α = thermal diffusivity, m^2/s.

The Schmidt number Sc, similar to the Prandtl number Pr, relates momentum and mass diffusion of the fluid.

$$Sc = \nu/D$$

Where ν is the kinematic viscosity of the fluid in m^2/s. Based on these equations, the resistance to mass transfer in the boundary layer of a fluid flow is:

$$r_{vb} = (\alpha/D)^{2/3} r_{hb} \quad [138]$$

For diffusion of water vapor in the air at 30°C, $D=25.7\times10^{-6}$ m^2/s, $\alpha=22.8\times10^{-6}$ m^2/s, and thus, $r_{vb}=0.92r_{hb}$.

Note that k, Pr, D, α and ν varied with temperature. In the model, these properties were estimated with an interpolation routine (APL2) from tabulated data provided by Monteith (1973). In this submodel, K, PR, DV, DH and DM denoted k, Pr, D, α and ν, respectively. Resistances r_{vb} and r_{hb} were calculated in subroutine RESIST.

4.5.2.2 Surface Resistance to Moisture Transfer

For living plants, the surface resistance is influenced by light intensity, leaf temperature and leaf water stress. Some information about the individual effect of each of these factors was reported (Milthorpe and Moorby, 1974, and Norman, 1979); but there was a lack of information about the combined effects of these factors.

For cut plants, the surface resistance follows the pattern of that of living plants before stomata are closed. However, after stomata are completely closed, the influence of light intensity would be less, even negligible. This should be reasonable within deep layers of swaths where penetration of sun light is low, especially if leaf area index is large.

It was found that leaf surface resistance was approximately constant over a wide range of leaf temperatures (10° to 40°C) for living plants (Milthorpe and Moorby, 1974, and Norman, 1979). It was assumed that the temperature influence on the surface resistance was negligible for alfalfa swaths if leaf temperature was within the range aforementioned.

Therefore, the dominant factor affecting the surface resistance should be water stress. Milthorpe and Moorby (1974) postulated an exponential function for the surface resistance with respect to relative water content (RWC) of leaves:

$$r_{vs} = 10^{a-bRWC} \qquad [139]$$

where r_{vs} = surface resistance, s/m,

RWC = relative water content, dimensionless,

a and b = empirical constant, dimensionless.

For cotton leaves, a=5.9 and b=4.2 (Milthorpe and Moorby, 1974). In

this model, a and b for alfalfa leaves were parameters to be determined. It was expected that the values of a and b for alfalfa would be smaller than those for cotton. In subprogram RBVMC, A and B denoted a and b, respectively.

The minimum stomatal resistance is less than 50 s/m; the resistance of sub-stomatal cavities or cell walls is about 20 s/m. The cuticular resistance is 2000-8000 s/m for mesophytes, and 5000-8000 s/m for xerophytes (Milthorpe and Moorby, 1974). For many crops, the minimum surface resistance is about 100 s/m (Monteith, 1973, Milthorpe and Moorby, 1974, Goudriaan, 1977, and Thompson, 1981).

The relative water content RWC is the ratio of the actual water content at a given time to the moisture content at full hydration.

$$RWC = M/M_f \qquad [140]$$

where M = moisture content (dry basis), kg water/kg dry matter,

and M_f = M at full hydration, kg water/kg dry matter.

The leaf moisture content varies with plant species, the age of plants, and the history of water stress. Bradford and Hsiao (1982) pointed out that herbaceous crops had the ability of osmotic adjustment to withstand water stress to a certain extent. They also mentioned that the wilting point of RWC, corresponding to pronounced stomata closure, for the vast majority of leaves was in the range of 0.75 to 0.85. Goudriaan (1977) also indicated that when RWC was above 0.9 (maximum 1.0), the surface resistance to moisture losses was near constant.

There was a lack of information of values of the moisture content at full hydration for alfalfa. Van Elderen et al. (1972) used a range of 7.0~9.0 for the maximum moisture content of plants when they studied water uptaking of grass swards. If the range were used as the alfalfa

moisture content at full hydration, a question would arise. Field observations showed that the moisture content of freshly cut alfalfa was about 3.0~4.0 (dry bases) which was much lower than 75% to 85% of the moisture content at full hydration (7.0 to 9.0) as assumed. However, no indication of wilting was found for majority of freshly cut alfalfa. Thus, the moisture content of freshly cut alfalfa should be above 85% to 90% of its M_f value. A reasonable assumption was that living alfalfa might have an adjustable moisture content at full hydration which might depend upon the variety, growth stage and water stress of the plant. Therefore, the actual moisture content of fresh leaves should be close to M_f at that stage of growth under that particular conditions. In this model, the initial moisture content of the alfalfa swath was considered to be equivalent to the moisture content at full hydration. In the model, ENTMC, FMC and RWS denoted M, M_f and r_{vs}, respectively. RWS was estimated in function subprogram RBVMC.

To speed up drying, field conditioning has been widely applied in hay production. Mechanical conditioning breaks cuticles on alfalfa surfaces to increase the exposure area of alfalfa to the surrounding air. Chemical conditioning increases the permeability of water vapor through cuticles. Both result in a reduction of the surface resistance to moisture losses. This can be reflected by introducing a reduction factor when estimating the surface resistance. Precise data of the effect of conditioning are not yet available. Smith (1985) used a value of 0.5 for the reduction factor. In this model, the reduction factor, denoted as CMECH, was set to 0.5.

The foregoing discussion dealt with the drying process where leaves lose moisture. When rewetting (rain or dew) occurs the surface

resistance has no effect on the condensation of water on leaf surfaces. In this case, the surface resistance component was set to zero in the model.

4.5.3 Respiration on Leaf Surfaces

Respiration is a basic function of plant life. It is a process of carbohydrate oxidation governed by:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{heat} \qquad [141]$$

Respiration releases 10.72×10^6 J heat for each kilogram of carbon dioxide generated.

Respiration consists of maintenance respiration and growth respiration for growing plants. For cut alfalfa, the growth respiration eventually ceases; however, the maintenance respiration continues even after dried hay is in storage. The maintenance respiration is often referred to as 'dark respiration', since it is measured under dark conditions. Dark respiration is a function of temperature and water stress of the plant. Wood and Parker (1971) proposed an empirical function:

$$r_{sp} = 0.425 \times 10^{-6}[3.66M/(1+M)-1]K \qquad [142]$$

where r_{sp} = respiration rate, kg carbon dioxide/s-kg dry matter,

M = moisture content (dry basis), kg water/kg dry matter,

and K = function of temperature.

$$K = \begin{cases} 1.0 & (25° < T < 45°C) \\ 0.178e^{0.069T} & (5° < T < 25°) \end{cases}$$

The respiration heat flux for a layer of plants per unit land area was:

$$R_{sp} = 4.556K[3.66M/(1+M)-1]\partial m \quad [143]$$

where R_{sp} = respiration heat flux, W/m^2,

and ∂m = area density of a layer, kg dry matter/m^2.

For example, K=1 (air at 30°C), M=4.0 (freshly cut), ∂m=0.13 kg dry matter/m^2, $r_{sp}=0.82\times10^{-6}$ kg carbon dioxide/s-kg dry matter and R_{sp}=1.14 W/m^2. In the model, RSP and DD denoted R_{sp} and ∂m, respectively.

The respiration heat flux was an energy source in the drying process. Although respiration was negligible during the day time when strong solar energy was available, it played a role to compensate some thermal radiation losses at night when sun light was absent.

Respiration also caused a loss in dry matter and a gain in moisture. Generating 1.0 kg carbon dioxide leads to 0.68 kg dry matter loss and 0.41 kg moisture gain. However, respiration was so small for cut alfalfa, as shown, that the loss and the gain were neglected.

When $M < 0.376$, Equation [142] gave negative respiration. Wood and Parker (1971) indicated that respiration was slight when M was below 0.376. In the model, respiration was set to zero in such circumstances.

4.5.4 Energy Balance on Leaf Surfaces

The energy balance on a layer of leaves was described as:

$$R_n + R_{sp} + Q_r - \lambda E - Q = S \quad [144]$$

where R_n = net absorbed radiation flux, W/m^2,

R_{sp} = respiration heat flux, W/m^2,

Q_r = heat flux due to rain, W/m^2,

λE = latent heat flux, W/m^2,

Q = sensible heat flux, W/m^2,

and S = sensible heat storage flux, W/m^2.

The signs of these terms in the equation indicate that R_n, R_{sp} and Q_r were assumed to be inputs toward leaf surfaces, and λE and Q were losses from leaf surfaces. It was assumed that S was positive if leaf temperature increased; otherwise, negative.

R_n was the sum of the absorbed short-wave and long-wave radiation fluxes, described in Sections 4.1 and 4.2, respectively. During the day time, R_n was usually positive because solar radiation was predominant. R_n was negative at night when sun light was absent and there were losses of long-wave radiation. Simulated data showed that R_n could be from -20 to 200 W/m^2 in the top layer of a swath. R_{sp} and Q_r were just discussed in the preceding sections. Q_r was negligible.

The heat storage flux S was expressed as:

$$S = C\partial T/\partial t = C\Delta T/\Delta t$$

where $\partial T/\partial t$ = time derivative of temperature, °C/s,

ΔT = increment of temperature, °C,

Δt = increment of time, sec,

and C = heat capacity of leaves in the layer, $J/°C\text{-}m^2$,

$$C = c\partial m$$

where c = specific heat of alfalfa, J/kg°C,

and ∂m = area density of the layer, kg dry matter/m^2.

The specific heat of alfalfa dry matter is 1172.3 J/°C-kg dry matter, which is about 28% of that of water (Mohsenin, 1980). The

specific heat of alfalfa increases as the moisture content of alfalfa increases. Siebel (1892) proposed an approach to estimate specific heat for food materials:

$$c = (c_w M + c_s)/(1+M) \quad [145]$$

where c = overall specific heat of the material, J/kg°C,

c_w = specific heat of water, 4186.8 J/kg°C,

c_s = specific heat of dry matter, J/kg°C,

and M = moisture content of the material, kg water/kg dry matter.

This equation was valid for a wide range of moisture contents, except very low moisture contents. At very low moisture levels, the effect of bond water which has a higher specific heat than free water will cause appreciable errors (Mohsenin, 1980). The specific heat of alfalfa was approximated in this model as:

$$c = 4186.8(M+0.28)/(1+M) \quad [146]$$

Suppose that in a swath layer, M=4.0 kg water/kg dry matter (freshly cut alfalfa), ∂M=0.13 kg dry matter/m^2 (medium density) and ΔT=3 C in 1 hour (from measured data), then c=3584 J/kg°C, C=476.7 J/°C-m and S=0.4 W/m^2. This showed that the heat storage term was negligible in the energy balance on leaves. Therefore, Equation [144] was simplified to:

$$R_e - \lambda E - Q = 0 \quad [147]$$

Where R_e = energy source, W/m^2

$$R_e = R_n + R_{sp}$$

The energy 'source' term might be positive (source) or negative (sink). R_e was denoted as ENERGY in submodel DBLEAF.

4.5.4.1 The Latent Heat Flux

Recall that:

$$\lambda E = \lambda(\rho_{wl}-\rho_{wa})/r_v$$

The water vapor density in the air was approximated as:

$$\rho_w = \rho_a \varepsilon e_v / P_{atm} \quad [148]$$

where ρ_w = water vapor density, kg water/m^3,

ρ_a = dry air density, kg dry air/m^3,

P_{atm} = atmospheric pressure, 101325 Pa,

e_v = water vapor pressure, Pa,

and ε = ratio of molecular weight of water to dry air, 0.622.

Then,

$$\lambda E = \lambda \rho_a \varepsilon (e_{vl}-e_{va})/P_{atm} r_v = \rho c_p (e_{vl}-e_{va})/\gamma r_v \quad [149]$$

where λ = latent heat of vaporization, ~2.45×10^6 J/kg water,

ρc_p = volumetric heat capacity of the air, J/m^3°C,

e_{vl} = water vapor pressure in leaves, Pa,

e_{va} = water vapor pressure in the air, Pa,

r_v = resistance to moisture transfer, s/m,

and γ = psychrometric constant, ~0.67 Pa/°C.

$$\gamma = P_{atm} c_p / \varepsilon \lambda$$

The water vapor pressure e_v was expressed as:

$$e_v = r e_s \quad [150]$$

where e_s = saturation vapor pressure at a given temperature, Pa,

and r = relative humidity, decimal.

If subscripts a and l stood for air and leaves, respectively, then,

$$e_{va} = r_a e_{sa} \quad \text{and} \quad e_{vl} = r_l e_{sl}$$

The relative humidity in leaves r_l was often referred to as the

equilibrium relative humidity r_e.

4.5.4.2 Equilibrium Relative Humidity

Past research on drying has shown that any biological material tends to reach equilibrium with surrounding air. At equilibrium, the internal vapor density (or pressure) of the material equals that of the air, respectively. Otherwise, moisture transfer will occur. At equilibrium, the moisture content of the material is called the equilibrium moisture content, and accordingly the relative humidity inside the material is called equilibrium relative humidity. The equilibrium relative humidity is a function of the temperature and moisture content of the material.

Zink (1935), Dexter (1947), Dexter et al. (1947), Henderson and Perry (1955), and Shepherd (1958) provided some experimental data of the equilibrium relative humidity of alfalfa. Bakker (1961) did extensive experiments on adsorption and desorption of alfalfa. His tests covered temperature from 4.4 to 48.9 C, moisture content from 0.047 to & 2.23 (dry basis), relative humidity from 0.114 to 1.0, and four maturity levels (prebloom, 10% bloom, full bloom and mature).

Henderson (1952) suggested an equation for equilibrium relative humidity in biological materials:

$$r_e = 1 - e^{-aTM^n} \qquad [151]$$

where M = moisture content, kg water/kg dry matter,

T = temperature, °C,

a and n = empirical constant.

Thompson (1981) proposed another model based on Shepherd's data (1958).

$$r_e = [1-e^{-(a+bT)M}]^n \qquad [152]$$

Where a, b and n were empirical constants.

A nonlinear regression technique (NONLINEAR procedure, SPSS8.3, 1982) was used in this study to fit Bakker's data with both Henderson's and Thompson's approaches. Bakker (1961) found that Henderson's equation did not fit his experimental data well. Regression results showed that Thompson's equation works better than Henderson's. The coefficient of determination was 0.95 (desorption) or 0.98 (adsorption) for mature alfalfa when Thompson's equation was applied (Table 4), in comparison with that of 0.69 (desorption) or 0.73 (adsorption) for Henderson's equation.

Table 4 Empirical constants in Thompson's equation of equilibrium relative humidity based upon Bakker's data (1961)

Type	Maturity	a	b	n	r^2
Desorption	Mature	8.586	0.0382	2.077	0.95
Adsorption	Mature	11.86	0.0214	2.406	0.98
	Full Bloom	10.61	0.0807	2.733	0.97
	10% Bloom	9.982	0.0842	2.932	0.97
	Prebloom	8.614	0.0754	2.845	0.97

r^2 - the coefficient of determination of regression analysis

The phenomenon of reaching different equilibrium relative humidity during desorption and adsorption at the same temperature and moisture content of a material is known as the hysteresis effect. Literature has shown that the equilibrium relative humidity for adsorption is higher than that for desorption. This is presumably attributed to water vapor density (or pressure) increasing locally near the surface

when a material absorbs moisture.

Bakker (1961) did not give data of desorption of alfalfa for three of four maturity levels. However, he assumed that the difference in equilibrium relative humidity between adsorption and desorption for mature alfalfa at a given temperature and moisture content could be applied to other maturity stages. His approach was adapted in the model. In submodel DBLEAF, EQRH was used to denote r_e and estimated in function subprogram RHE. Interpolation was used to estimate the equilibrium relative humidity when bloom levels were other than 0%, 10% or 100%. Table 5 lists some estimated values of the equilibrium relative humidity r_e for desorption of mature alfalfa at various temperature and moisture contents. The table shows that the equilibrium relative humidity increased as either temperature or the moisture content of alfalfa increased. The equilibrium relative humidity of mature alfalfa was near unity when the moisture content was above 0.5, depending upon alfalfa temperature.

Table 5 Estimated equilibrium relative humidity of mature alfalfa in desorption at various temperature and moisture contents

	Dry-Basis Moisture Content (kg water/kg dry matter)						
Temperature(°C)	0.05	0.10	0.50	0.60	0.62	0.65	0.68
10	0.12	0.34	0.98	0.99	0.99	0.99	1.00
20	0.13	0.36	0.98	0.99	0.99	1.00	1.00
30	0.14	0.37	0.98	0.99	1.00	1.00	1.00
40	0.15	0.39	0.99	1.00	1.00	1.00	1.00

4.5.4.3 **Modified Monteith-Penman Equation**

Recall that:

$R_e - \lambda E - Q = 0$

$\rho E = \rho c_p(e_{vl}-e_{va})/\gamma r_v$

$Q = \rho c_p(T_l-T_a)/r_h$

$e_v = r_e e_s$

The second and third equations were in the same form since $(e_{vl}-e_{va})/\lambda$ had the dimension of temperature. When leaf and air temperatures were close, the following first-order Taylor's-series expansion was valid:

$$e_{sl} = e_{sa} + s(T_l-T_a) \quad [153]$$

where T_l = leaf temperature, °C,

T_a = air temperature, °C,

e_{sl} = saturation vapor pressure at leaf temperature, Pa,

e_{sa} = saturation vapor pressure at air temperature, Pa,

and s = derivative of e_s with respect to T, Pa/°C.

$$s = \partial e_s/\partial T \quad [154]$$

The quantity s was known as the slope of the curve of saturation-pressure-temperature at a given temperature. The function form of the saturation-pressure-temperature curve was adapted from ASAE Data 271.2 (1984). For air from 10° to 40°C, s was 0.8 to 3.9 Pa/°C, respectively; and for air at 30°C, s=2.44 Pa/°C. When used in Equation [153], s was estimated at the arithmetic mean of the leaf and air temperatures.

Based upon the first five equations listed in this section, Thompson (1981) obtained the following equations:

$$\lambda E = (r_e s R_e + \delta)/(\gamma^* + r_e s) \quad [155]$$

$$Q = (\gamma^* R_e - \delta)/(\gamma^* + r_e s) \quad [156]$$

where λE = latent heat flux, W/m^2,

Q = sensible heat flux, W/m^2,

R_e = energy source, W/m^2,

r_e = equilibrium relative humidity, decimal,

γ^* = apparent psychrometric constant, $Pa/°C$,

and δ = driving force, $WPa/m^2 °C$.

The apparent psychrometric constant was:

$$\gamma^* = \gamma(r_v/r_h) \quad [157]$$

where r_v = resistance to moisture transfer, s/m,

r_h = resistance to heat transfer, s/m.

The driving force, denoted as DRV in the model, was:

$$\delta = \rho c_p(r_e e_{sa} - e_{va})/r_h \quad [158]$$

where ρc_p = volumetric heat capacity of the air, $J/m^3 °C$,

r_e = equilibrium relative humidity of the material, decimal,

e_{sa} = saturation vapor pressure at air temperature, Pa,

and e_{va} = vapor pressure of the air, Pa.

Goudriaan (1977) named the term δ as 'driving force' to reflect a virtual vapor pressure deficit ($r_e e_{sa} - e_{va}$). The driving force δ was positive as long as the equilibrium relative humidity of alfalfa was higher than the relative humidity of the air. This was typical for field drying if the alfalfa moisture content was not very low. Even if δ was negative, λE might still be positive as long as $r_e s R_e$ was larger than δ in magnitude. This explained why alfalfa could be dried to a very low moisture content with an equilibrium relative humidity even below the relative humidity of the air in the field environment.

If R_e was negative, then Q was negative which occurred normally

from sunset to next sunrise. When $Q < 0$, leaf temperature was lower than air temperature. This might exist even after sunrise if short-wave radiation was low. Leaf temperature is higher than air temperature when $Q > 0$, which existed during most of daytime and perhaps for a short period after sunset. When $R_e > 0$, λE was positive since $\delta > 0$, according to Equation [155]. On the other hand, λE might still be positive even when $R_e < 0$. This implied that the duration for $\lambda E > 0$ was longer than that for $Q > 0$, within a diurnal time cycle. During most of daytime, both λE and Q were positive, i.e. leaf temperature was higher than that of the air and leaves lose moisture. At night, both λE and Q were negative, i.e. leaf temperature was below that of the air and rewetting occurred. Near sunset or sunrise, the situation was complicated. Q and λE might be either both positive or negative; or one might be positive while the other was negative.

When alfalfa was freshly cut, $r_e s > \gamma^*$ and δ was quite large, the period of losing leaf moisture ($\lambda E > 0$) was longest. It was also possible for leaf temperature to be below air temperature if there was such a large vapor pressure deficit in the air that $Q < 0$. This might occur only at the beginning of field drying when γ^* was small. As the moisture content of alfalfa decreased, δ and r_e decreased, but γ^* increased rapidly. Hence, the duration of $Q > 0$ increased while that of $\lambda E > 0$ decreased. At a certain moisture content and below, the period of $Q > 0$ became longer than that of $\lambda E > 0$.

For living plants and open water surfaces, the equilibrium relative humidity was unity. Then, Equations [155], [156] and [157] became:

$$\lambda E = (sR_e + \delta)/(\gamma^* + s) \qquad [159]$$

$$Q = (\gamma^* R_e - \delta)/(\gamma^* + s) \qquad [160]$$

$$\delta = \rho c_p (e_{sa} - e_{va})/r_h \quad [161]$$

Equation [159] has been well known as the Monteith-Penman equation which has been successfully applied to many crops and natural water surfaces for a variety of climates throughout the World. Equation [155] was a modification of the Monteith-Penman equation.

4.5.4.4 Leaf Temperature

Leaf temperature was estimated from Equation [174) as:

$$T_l = T_a - r_h Q/\rho c_p \quad [162]$$

where T_l = leaf temperature, °C,

T_a = air temperature, °C,

r_h = boundary resistance to heat transfer, s/m,

ρc_p = volumetric heat capacity of the air, $J/m^3 °C$,

and Q = sensible heat flux, W/m^2.

Solutions should be obtained with iteration techniques, since the Monteith-Penman equation is an implicit formula. R_e, δ, γ^*, r_e and s are functions of temperature and/or the moisture content of the material. R_e is not independent of leaf temperature and moisture status since long-wave radiation and respiration are functions of leaf temperature. Absorption, reflection and transmission of short-wave radiation are affected by leaf moisture content. However, the effect of leaf moisture on short-wave radiation is only minor in comparison with the leaf area index, solar angle and sky cover. Short-wave radiation can be assumed to be nearly independent of leaf temperature and moisture. Long-wave radiation is proportional to the fourth power of the absolute temperature of a body, which changes slightly when apparent

temperature changes. For example, when temperature changes from 30°C by 5 and 10°C, long-wave radiation changes by 6 and 14%, respectively. The magnitude of respiration heat is very small as shown earlier, so its effect on the determination of leaf temperature is negligible. In addition, iteration is necessary because r_e changes significantly between adsorption and desorption.

In this model, leaf temperature T_l (denoted as DBL) in each swath layer was estimated in subroutine DBLEAF within a loop till a convergence requirement was met. In the loop, the long-wave radiation profile inside the swath was reestimated only if the difference in temperature between two successive estimates was greater than 7°C.

Essentially, the leaf temperature estimated from Equation [162] was leaf-surface temperature. A conductive heat transfer exists inside a leaf if its surface temperature differs from that of its interior. Uneven temperatures are often neglected because a leaf can be treated as a 'lumped-capacity' system, i.e. with uniform temperature throughout the leaf body. This can be checked by estimating a characteristic time or a Biot number:

$$\tau = (\Delta x)^2/\alpha \qquad [163]$$

$$Bi = h(\Delta x)/k < 0.1\text{~}0.2 \qquad [164]$$

where τ = characteristic time, s,

Bi = Biot number, dimensionless,

h = convective heat-transfer coefficient, W/m^2,

k = heat conductivity of the body, W/m°C,

α = thermal diffusivity of the body, m^2/s,

and Δx = characteristic dimension, m.

The characteristic time indicates how fast heat can diffuse

throughout a body. If τ is very small, the conduction heat transfer can be neglected. For alfalfa stems, $\alpha=98.3\times10^{-9}$ m^2/s (Mohsenin, 1980). A leaf was considered as a flat plate and isothermal in two plane dimensions, but not through its thickness. The characteristic dimension is one half of its thickness, assumed to be 0.0005 m. Thus, $\tau=0.63$ s. Should a temperature profile along the leaf thickness be studied, a time step of less than 0.63 s would be required. This is obviously impractical for this study. Compared with relatively slow changes in field environment during a diurnal cycle, the conductive process in leaves was negligible, i.e. it was assumed that leaves could respond to environmental changes immediately.

The Biot number is the ratio of resistance to heat transfer of conduction to that of convection. A small Biot number indicates that conductive transfer inside a body is faster than convective transfer at its surface. If Bi<0.1~0.2, non-uniformity of body temperature is negligible. According to the author's measurement on 10 samples of alfalfa plants, the dry matter density of alfalfa leaves was 74.5 kg/m^3. Suppose that h=20 W/m^2 and M=1.0 (dry basis), then $\rho c=0.399\times10^6$ $J/m^3°C$, $k=\alpha\rho c=0.039$ W/m°C, and Bi=0.13. This also shows that a 'lumped-capacity' assumption was reasonable.

4.6 Rewetting and Redrying

Leaves gain moisture from dew or rain. This process is also referred to as rewetting. This section focuses mainly on modeling of rewetting due to dew and rain. Discussion on changes in the moisture content of alfalfa in drying, rewetting and redrying

is also presented. The calculation of alfalfa moisture contents was carried out by subprogram DFMCL.

4.6.1 Rain Interception

Rainfall is partly caught by leaves. Since rain is a bulk flow of water, it does not follow the rate equation derived from diffusion theory. Smith (1985) proposed a model:

$$I_r = R(1-e^{-\alpha L}) \qquad [165]$$

where I_r = intercepted rain, kg water/m^2,

R = rain incident, kg water/m^2,

L = downward leaf area index, m^2 leaf/m^2,

and α = extinction coefficient, m^2/m^2 leaf.

This equation was assumed to be valid for both a whole canopy and a layer of leaves when an appropriate L value was used.

The extinction coefficient α was a function of the interception capacity I_c of the canopy (or layer), and existing intercepted rainfall (Thompson, 1981 and Smith, 1985). They reported that I_c was about 0.1-0.2 kg water per unit dry matter. Their model for α was:

$$\alpha = \begin{cases} 0.4 & I_r<0.5I_cL \\ 0.15 & 0.5I_cL<I<I_cL \\ 0.0 & \text{otherwise} \end{cases} \quad \text{for}$$

Thus, the intercepted rain for a layer was

$$I_r = \begin{cases} \min[0.5I_c\partial L,\ R(1-e^{-0.4\partial L})] & I_r<0.5I_c\partial L \\ \min[I_c\partial L,\ 0.5I_c\partial L+(R-0.5I_c\partial L)(1-e^{-0.15\partial L})] & \text{otherwise} \end{cases} \quad \text{for}$$

Unintercepted rainfall, if any, flowed to the next layer.

Rain was assumed to fall evenly during the time interval of

recording. For example, when data from the local weather service were used, the time interval was 3 hours. Any precipitation recorded was divided by 10800 seconds, and then multiplied by a time step used for integration to get the available rainfall during the time step. Calculated I_r was divided by the time step to obtain a rain interception flux I, denoted by RAIN and estimated in subroutine FRAIN.

Rain interception was also accompanied with energy exchange. However, the magnitude of the energy flux was small and negligible.

4.6.2 Dew

When leaf temperature is below the dew point of its surrounding air, water vapor in the air condenses on leaf surfaces which is called dew. Dew deposition is the counterprocess of moisture evaporation on leaf surfaces.

It has been observed that dew deposition on leaves has two forms: film and dropwise, as classified in condensation theory. However, there was a lack of information about direct application of existing theory on condensation to dew formulation on plants. No special provision was made in the present model.

It was assumed that dew formation was governed by the same rate equation described in Equation [136]. However, the surface resistance had no effect on dew deposition at all. As aforementioned, r_{vs} was set to zero, when E was negative, which implied the moisture transfer flux was from the air to leaves.

4.6.3 Rewetting

Van Elderen et al. (1972) studied moisture uptake in grass swards. They classified moisture of plants into three types. The first was 'internal moisture', either originally held or absorbed from surfaces by plants. The second type was 'surface moisture' which was tightly held on leaf surfaces when dew or rain occurred. The third type was 'runable moisture', that was less associated with plants when dew or rain was present. Their approach was adapted in the model.

When condensation or rain interception occurred, water first formed a thin film on leaf surfaces. The film thickness increased to a certain limit. Within the thin film, the closer to the leaf surface water molecules were, the tighter they were held by the surface. Drops might be formed as well. Water drops were less associated with the surface than the film. When further deposition of water exceeded the holding capacity of the leaf surface, the water drops ran off the surface. The water drops and some water in the film which were less associated with the surface became runable moisture. When the film and/or drops existed on a leaf surface, the leaf interior absorbed moisture from the surface water. After the water nearest to the surface was absorbed, other water was attracted to the surface and became firmly held by the surface. When redrying occurred, the water less associated with the surface was evaporated first, then, the water firmly held by the surface. Until all surface water was completely dried, no internal moisture could be drawn from the plant.

Subroutine DFMCL handled the estimation of moisture contents.

4.6.4 Internal Moisture

Internal moisture was represented by the internal moisture content (dry basis). The internal moisture content was denoted as ENTMC in the model. Before cut alfalfa died, it could be completely recovered from water stress, if sufficient moisture was provided for a long period. Therefore, the internal moisture content had a maximum. In this model, the maximum internal moisture content, denoted as XMAXMC, was set to 7.0 (dry basis) according to Van Elderen et al. (1972).

When dew was present, cut alfalfa absorbed some moisture from leaf surfaces to the plant interior. Van Elderen et al. (1972) showed that the maximum absorption rate of ryegrass was proportional to the deficit of internal moisture from its maximum. The proportional coefficient was called the specific moisture flux of internal moisture. They found a value of 11.1×10^{-6} kg water/s for each kilogram of water deficit. In the model, this value was presumed to be valid for alfalfa. Thus, for absorption:

$$\partial M/\partial t = R_M(M_{max}-M)\partial m \qquad [166]$$

where $\partial M/\partial t$ = rate of change in internal moisture, kg water/s-m^2,

M = internal moisture content, kg water/kg dry matter,

R_M = specific moisture flux of M, kg water/s-kg water,

M_{max} = maximum M, kg water/kg dry matter,

and ∂m = area density, kg dry matter/m^2.

In the model, RENTMC, ENTMC, SMFE, XMAXMC and DD stored data of $\partial M/\partial t$, M, R_M, M_{max} and ∂m.

A positive $\partial M/\partial t$ indicated an increase in M, which resulted from a positive available moisture flux. The available moisture flux for a

layer consisted of any dew, negative convective moisture flux, rain interception or excess moisture flux from an upper layer.

$$E_a = D_{ew}/\partial t + I_r - E + E_{ex} \quad [167]$$

where E_a = available moisture flux, kg water/s-m^2,

D_{ew} = existing dew, kg water/m^2,

∂t = time step of integration, sec,

I_r = rain interception flux, kg water/s-m^2,

E = convective moisture flux, kg water/s-m^2,

and E_{ex} = excess moisture flux from upper layer, kg water/s-m^2.

In the model, RMOIST, DEW, DT and EXCESS stood for E_a, D_{ew}, ∂t and E_{ex}, respectively.

In this model, it was assumed that as long as there was moisture either existing on or moving toward leaf surfaces, the internal moisture increased. This meant that the alfalfa interior had the highest priority to absorb moisture from its surface.

The opposite process of adsorption is desorption. It was assumed that the internal moisture could be lost only if there was no dew, rain, nor excess flux from upper layers. In addition, the convective moisture flux should be positive, i.e. from leaves toward the air. Under these conditions, the desorption was totally controlled by the diffusion mechanism.

In oven drying, the internal moisture content can approximately drop to zero. In the field, the internal moisture could be reduced to a very low level despite the air humidity; but rarely down to zero. In this model, a value of 0.05 (dry basis) was assumed as the minimum internal moisture content, named XMINMC.

For desorption, the rate of change in internal moisture was:

$$\partial M/\partial t = \max\{-E, \partial m(M_{min}-M)/\partial t)\} \quad [168]$$

If the magnitude of the convective moisture flux E was greater than the maximum possible flux $\partial m(M-M_{min})/\partial t$, the size of the time step ∂t was reduced to such that during one time step the internal moisture content could not drop below M_{min}. In addition to this, if the internal moisture content reached its minimum, the surface resistance r_{vs} was set to a very large value to prevent further decrease in the internal moisture content.

4.6.5 Surface Moisture

Surface moisture was represented by a surface moisture content M_s (dry basis), denoted as SFCMC. The surface moisture exists in films on leaf surfaces, and is quite firmly held by leaves. Van Elderen et al. (1972) found that the surface moisture content could reach a maximum of 1.5 (dry basis), and the specific moisture flux for surface moisture was 0.25×10^{-3} kg water/s per kg of water deficit from its maximum. For absorption, the rate of change in surface moisture was:

$$\partial M_s/\partial t = \min\{E_a, R_s(M_{smax}-M_s)\partial m\} \quad [169]$$

where $\partial M_s/\partial t$ = rate of change in surface moisture, kg water/s-m^2,

E_a = available moisture flux, kg water/s-m^2,

M_s = surface moisture content, kg water/kg dry matter,

M_{smax} = maximum M_s, kg water/kg dry matter,

R_s = specific moisture flux, kg water/s-kg water,

and ∂m = area density, kg dry matter/m^2.

In the model, RSFCMC, SFCMC, SFCMAX and SMFS denoted $\partial M_s/\partial t$, M_s, M_{smax} and R_s, respectively.

The available moisture flux RMOIST was reduced since some was absorbed by the interior, which had first priority. In the model, the surface moisture had second priority to increase and decrease. This meant that when rewetting occurred, the surface moisture might increase if there was extra moisture available besides that absorbed by the leaf interior. The extra moisture came from either existing runable moisture, rain, or convective flux. The surface moisture might decrease during rewetting, if there was little or no runable moisture, rain, nor negative convective flux, but a large deficit in internal moisture. The second priority also meant that the surface moisture could not be dried as long as any runable moisture existed; but should be dried out first before any decrease of internal moisture could occur.

For desorption, the rate of change in surface moisture was:

$$\partial M_s/\partial t = \max\{E_a, -M_s \partial m/\partial t\} \qquad [170]$$

Where the available moisture flux should be negative. The surface moisture could diminish completely since it was like 'free' water. Evaporation of the surface moisture was not controlled by the surface resistance. For dry leaves, the surface moisture content was zero.

4.6.6 Runable Moisture

Runable moisture was represented by the runable moisture content, denoted as RUNMC in the model. Runable moisture exists in drops and/or films on leaf surfaces. Van Elderen et al. (1972) found that the maximum runable moisture content was 1.0 (dry basis), and the specific running-off flux for runable moisture was $0.208 \cdot 10^{-3}$ kg water/s per kg water available, respectively.

Runable moisture was assumed to have the least priority of increase, but the first priority to decrease. The only chance to increase runable moisture was due to rain or negative convective moisture flux; and the internal moisture content reached its maximum. For adsorption, the rate of change in runable moisture was:

$$\partial M_r/\partial t = \min\{E_a, (M_{rmax}-M_r)\partial m/\partial t\} \quad [171]$$

where $\partial M_r/\partial t$ = rate of change in runable moisture, kg water/s-m^2,

E_a = available moisture flux, kg water/s-m^2,

M_r = runable moisture content, kg water/kg dry matter,

M_{rmax} = maximum M_r, kg water/kg dry matter,

∂m = area density, kg dry matter/m^2,

and ∂t = time step, sec.

E_a was the remaining moisture flux after a portion was absorbed by the leaf interior with a portion firmly held by the surface. In the model, RRUNMC, RUNMC and RUNMAX stood for $\partial M_r/\partial t$, M_r and M_{rmax}, respectively.

It was further assumed that there was a run-off flux, as long as runable moisture existed.

$$E_r = R_r M_r \partial m \quad [172]$$

where E_r = run-off flux, kg water/s-m^2,

and R_r = specific running-off flux, kg water/s-kg water,

Thus, if there was runable moisture on leaf surfaces, any available moisture flux toward the surface would be reduced due to the run-off flux. The run-off flux was a portion of the excess flux available to the next layer in the swath. Other sources came from excess rain or any extra available moisture after increases in these three types of moisture.

Besides the run-off flux and conversion to internal or

surface moisture, runable moisture could be easily dried by evaporation, since it was free water. For desorption, the rate of change in runable moisture was:

$$\partial M_r/\partial t = -M_r \partial m/\partial t \quad [173]$$

where $\partial M_r/\partial t$ = rate of change in runable moisture, kg water/s-m^2,
This equation implied that runable moisture could be dried at any rate, as long as required energy was available.

4.6.7 Determination of Moisture Contents

Dew and intercepted rain were considered as the combination of the surface and runable moisture. In the model, the following expressions were used:

$$D_{ew} = (M_s+M_r)\partial m \quad [174]$$

$$\partial D_{ew}/\partial t = (\partial M_s/\partial t+\partial M_r/\partial t)\partial m \quad [175]$$

where D_{ew} = dew on leaf surfaces, kg water/m^2,
and $\partial D_{ew}/\partial t$ = rate of dew formation, kg water/s-me2.
In the model, DEW and RDEW denoted D_{ew} and $\partial D_{ew}/\partial t$, respectively. The duration of dew t_{dew}, denoted as TDW, was accumulated as long as there was dew in a layer.

When rates of change in the three types of moisture were determined, each moisture after one time step was estimated. The overall moisture content of alfalfa, M_c (kg water/kg dry matter), was:

$$M_c = M + M_s + M_r \quad [176]$$

Since evaporation of dew was different from drying of internal moisture, it was necessary to separate these two processes. In the model, the time step of integration was adjusted so that in one step

only dew might dry completely. Then, from the next step, internal moisture began to dry.

Figure 6 shows a simulated moisture profile inside a swath in East Lansing, Michigan on August 14 to 16 of 1984.

4.7 Balance of Moisture and Energy in Air Spaces

Conservation of energy and mass is a universal law. From a mass and energy balance, temperature and humidity status in air spaces within a swath can be estimated. Submodel MATRIX simulated exchanges of water vapor and sensible heat and estimated temperature and humidity status of air spaces inside a swath. The name of 'matrix' implied that a matrix method was used to solve a system of simultaneous finite difference equations.

4.7.1 Moisture Balance in Air Space of a Swath Layer

Moisture balance in the air space of a swath layer was written as:

$$E_{aa,i+1} - E_{aa,i} + E_{la,i} = 0 \qquad (i=1,\ 2 \text{ and } 3) \qquad [177]$$

where $E_{aa,i+1}$ = moisture flux into the ith layer, kg water/m^2s,

$E_{aa,i}$ = moisture flux out of the ith layer, kg water/m^2s,

and $E_{la,i}$ = moisture flux inside the ith layer, kg water/m^2s.

$E_{la,i}$ was the moisture flux from leaves toward the air space inside the ith layer. $E_{aa,i}$ and $E_{aa,i+1}$ were the water vapor fluxes between air spaces. $E_{aa,i}$ was from the ith layer to the adjacent layer above while $E_{aa,i+1}$ was from the adjacent layer below into the layer. At the top of the swath, $E_{aa,i}$ was toward the atmosphere. At the bottom of

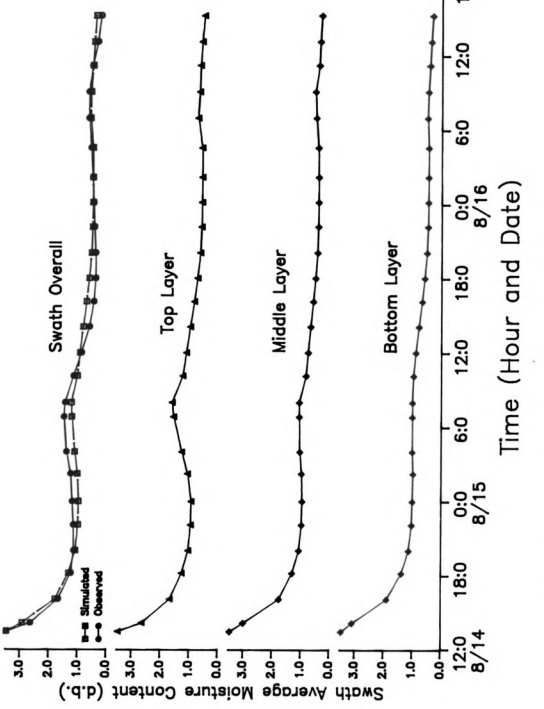

Figure 6. A simulated profile of the alfalfa moisture content within a swath in East Lansing, Michigan on August 14-16, 1984.

the swath, $E_{aa,i+1}$ was from the soil surface into the swath.

A moisture storage term was ignored in Equation [177]. The characteristic time for moisture diffusion was:

$$\tau = (\Delta x)^2/D$$

Where D was the diffusivity of water vapor in air, ~25.6×10 m^2/s (Holman, 1981). The characteristic dimension for the air space of a swath layer was the dimension of air gaps along the vertical direction. Suppose a 0.1 m thick swath with a porosity of 0.1 was divided into three layers, then Δx=0.0017 m and τ=0.11 s. Thus, a uniform distribution of water vapor in the air space of a swath layer could be reasonably assumed.

Fluxes in Equation [177] were approximately expressed as:

$$E_{la,i} = (\rho_{wl,i} - \rho_{wa,i})/r_{v,i}$$

$$E_{aa,i} = (\rho_{wa,i} - \rho_{wa,i-1})/r_{sv,i} \qquad (i=1, 2 \text{ and } 3)$$

$$E_{aa,i+1} = (\rho_{wa,i+1} - \rho_{wa,i})/r_{sv,i+1}$$

where $\rho_{wl,i}$ = vapor density in leaves of the ith layer, kg water/m^3,

$\rho_{wa,i}$ = vapor density in the air space of the layer, kg water/m^3,

$r_{sv,i}$ = resistance to moisture transfer in air space, s/m,

and $r_{v,i}$ = resistance to moisture transfer on leaf surfaces, s/m.

For the top layer of the swath (i=1), ρ_{wa0} was ρ_{wr}, the vapor density at the reference height. For the bottom layer of the swath (i=3), ρ_{wa4} and r_{sv4} were the vapor density and resistance to moisture transfer at the soil surface, i.e. ρ_{wg} and r_{svg}, respectively.

A system of simultaneous equations was constructed:

$$\left.\begin{aligned} A_{11}\rho_{wa1} + A_{12}\rho_{wa2} &= B_1 \qquad \text{(top layer)} \\ A_{21}\rho_{wa1} + A_{22}\rho_{wa2} + A_{23}\rho_{wa3} &= B_2 \qquad \text{(middle layer)} \\ A_{32}\rho_{wa2} + A_{33}\rho_{wa3} &= B_3 \qquad \text{(bottom layer)} \end{aligned}\right\} \quad [178]$$

with

$$A_{i,i} = 1/r_{sv,i} + 1/r_{sv,i+1} + 1/r_{v,i}$$

$$A_{i,i-1} = -1/r_{sv,i}$$

$$A_{i,i+1} = -1/r_{sv,i+1} \qquad (i=1, 2 \text{ and } 3)$$

$$B_1 = \rho_{wl1}/r_{v1} + \rho_{wr}/r_{sv1}$$

$$B_2 = \rho_{wl2}/r_{v2}$$

$$B_3 = \rho_{wl3}/r_{v3} + \rho_{wg}/r_{svg}$$

where ρ_{wr} = water vapor density at reference height, kg water/m^3, and ρ_{wg} = water vapor density at the soil surface, kg water/m^3.

This system of simultaneous equations was solved in subroutine MATRIX. Arrays RVA, RVL, RSV, RBV, and variable RVR and RVS stored $\rho_{wa,i}$, $\rho_{wl,i}$, $r_{sv,i}$, $r_{v,i}$, ρ_{wr} and ρ_{ws}, respectively.

Accompanied with a moisture balance, there was a latent heat balance. When each term in Equation [177] was multiplied by corresponding latent heat of vaporization, that equation became a latent heat balance equation. The latent heat of vaporization changed slightly as temperature changed; therefore, it was assumed that the latent heat balance automatically held as long as the moisture balance held.

4.7.2 Sensible Heat Balance in Air Spaces

Total energy in the air space of a swath layer consisted of sensible, latent and radiation heat. It was assumed earlier that radiation energy exchanged only on leaf and soil surfaces. Latent heat was assumed to be balanced along with water vapor balance in air spaces. Thus, total energy would be balanced if sensible heat was balanced.

For sensible heat transfer in air space of the sample swath layer described in the preceding section, the characteristic time τ was 0.12 s, as calculated from Equation [163] with the thermal diffusivity of the air at 30°C of 22.8×10^{-6} W/m²°C. Therefore, a heat storage term was excluded from the sensible heat balance, and uniformly distributed temperature was assumed within the air space of each layer.

A sensible heat balance equation was written as:

$$Q_{aa,i+1} - Q_{aa,i} + Q_{la,i} = 0 \qquad (i=1, 2 \text{ and } 3) \qquad [179]$$

where $Q_{aa,i}$ = heat flux out of the ith layer, W/m²,

$Q_{aa,i+1}$ = heat flux into the ith layer, W/m²,

and $Q_{la,i}$ = heat flux from leaves to air space, W/m².

Fluxes in Equation [179] were approximately expressed as:

$$\left.\begin{aligned} Q_{aa,i+1} &= h_{aa,i+1}(T_{a,i+1} - T_{a,i}) \\ Q_{aa,i} &= h_{aa,i}(T_{a,i} - T_{a,i-1}) \\ Q_{la,i} &= h_{la,i}(T_{l,i} - T_{a,i}) \end{aligned}\right\} \quad (i=1, 2 \text{ and } 3)$$

where $h_{aa,i}$ = heat-transfer coefficient between layers, W/m²°C,

$h_{la,i}$ = heat-transfer coefficient from leaves to air, W/m²C.

$T_{a,i}$ = air temperature in the ith layer, °C,

and $T_{l,i}$ = leaf temperature in the ith layer, °C.

T_{a4}, Q_{aa4} and h_{aa4} were the temperature, heat flux and heat-transfer coefficient at the soil surface, respectively. T_{a0} was the air temperature at the reference height.

Similar to the water vapor balance, a system of simultaneous equations was formulated:

$$\left.\begin{aligned} C_{11}T_{a1} + C_{12}T_{a2} &= D_1 \\ C_{21}T_{a1} + C_{22}T_{a2} + C_{23}T_{a3} &= D_2 \\ C_{32}T_{a2} + C_{33}T_{a3} &= D_3 \end{aligned}\right\} \qquad [180]$$

with

$$C_{i,i} = h_{aa,i} + h_{aa,i+1} + h_{la,i}$$

$$C_{i,i-1} = -h_{aa,i} \quad \} \ (i=1,\ 2 \text{ and } 3)$$

$$C_{i,i+1} = -h_{aa,i+1}$$

$$D_1 = h_{la1}T_{l1} + h_{aa1}T_r$$

$$D_2 = h_{la2}T_{l2}$$

$$D_3 = h_{la3}T_{l3} + h_{aa4}T_g$$

where T_r = air temperature at reference height, °C,

and T_g = temperature at soil surface, °C.

This set of simultaneous equations was also solved in subroutine MATRIX, where arrays DBA, DBL, HAA, HLA, and variables DBR and DBG denoted $T_{a,i}$, $T_{l,i}$, $h_{aa,i}$, $h_{la,i}$, T_r and T_g, respectively. Figures 7 and 8 show simulated profiles of temperature and water vapor density within a swath in East Lansing, Michigan on August 14 to 16 of 1984.

4.8 Exchanges in Soil

Soil is a reservoir of both heat and water. This section discusses modeling of heat exchanges at the soil surface and inside the soil. Water status of the soil will be discussed briefly.

Submodel DBSOIL associated with subprogram GROUND simulated exchanges inside soil and at the soil surface, respectively. Subroutine SOILI initialized a soil temperature profile at the beginning of a simulation. Sensible heat fluxes between adjacent layers of soil were calculated in subroutine DFDBS.

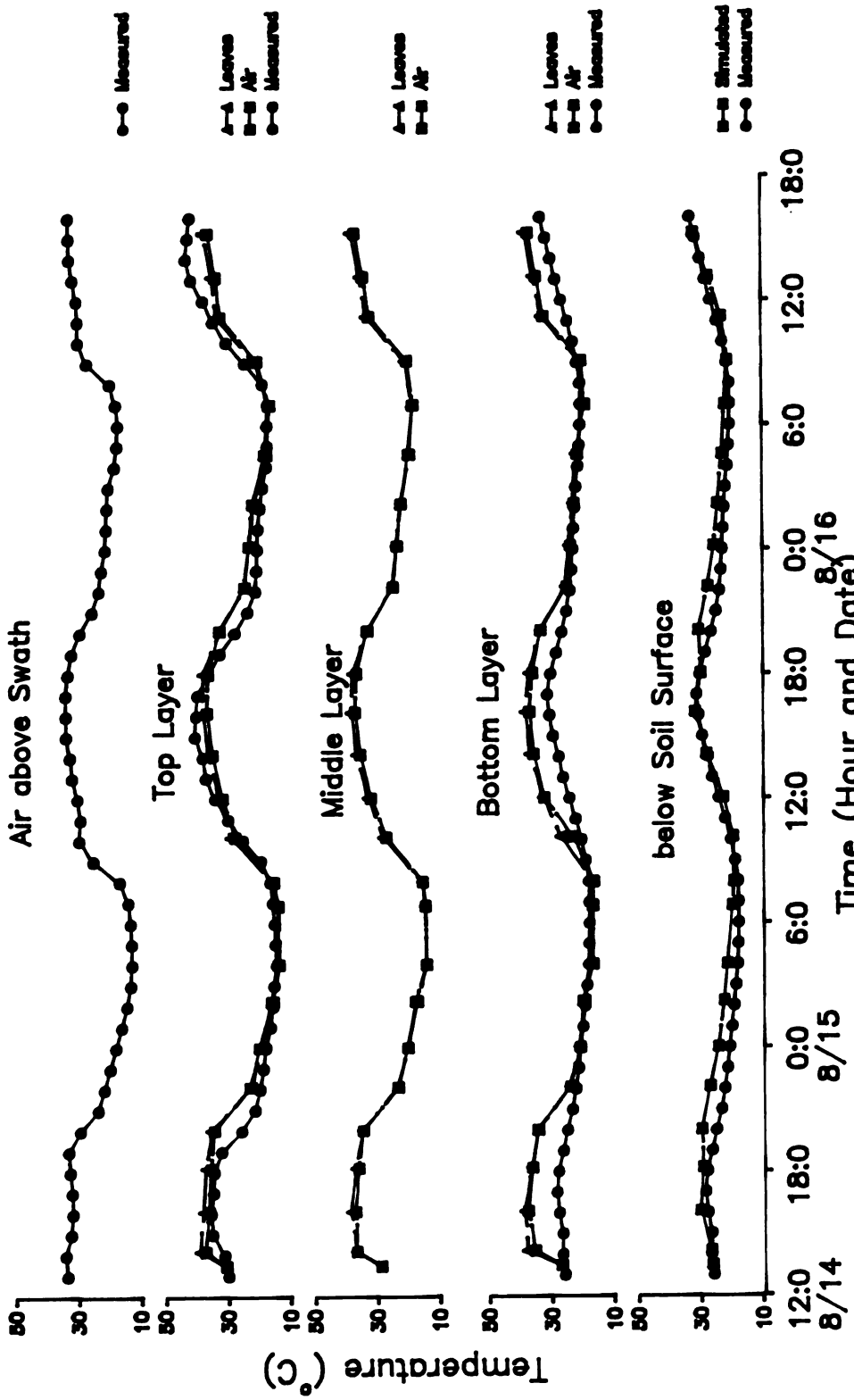

Figure 7. A simulated profile of air temperature for a swath in East Lansing, Michigan on August 14-16, 1984.

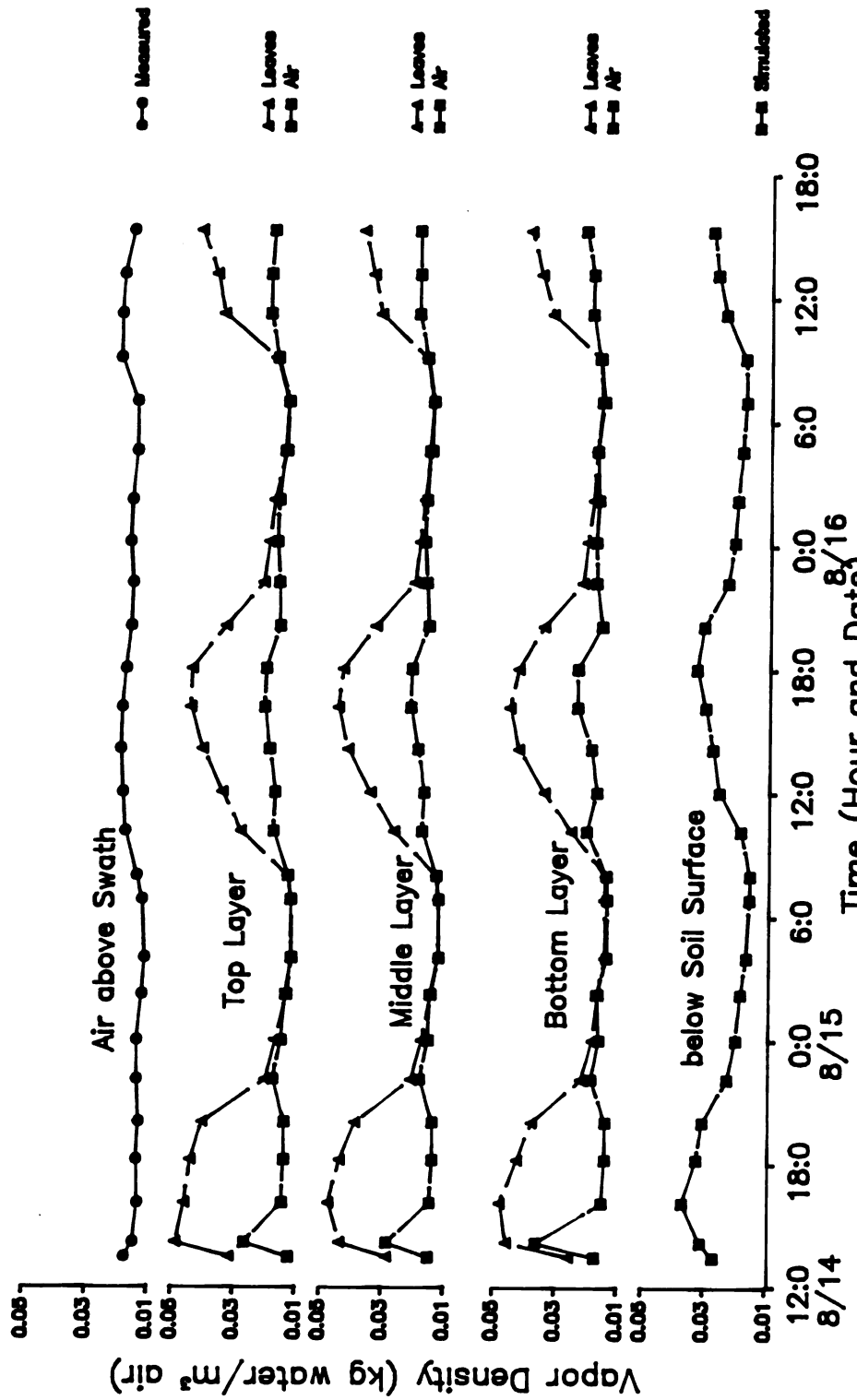

Figure 8. A simulated profile of water vapor density in the air spaces of a swath in East Lansing, Michigan on August 14-16, 1984.

4.8.1 Energy Balance at Soil Surface

The soil surface is a convective boundary for the soil underneath. Exchanges of sensible, latent and radiation heat take place on the soil surface. The soil surface was assumed to be a flat plate with an infinitesimal thickness (Holman, 1981), and a balance equation was written as:

$$R_n - Q - \lambda E = G \qquad [181]$$

where R_n = net absorbed radiation flux, W/m^2,

Q = upward sensible heat flux, W/m^2,

λE = upward latent heat flux, W/m^2,

and G = downward heat flux into soil, W/m^2.

Each term was expressed as:

$$Q = h_{ag}(T_g - T_{a3})$$

$$\lambda E = v_{ag}(\rho_{wg} - \rho_{wa3})$$

$$G = h_{s1}(T_g - T_{s1})$$

where h_{ag} = heat-transfer coefficient at the soil surface, $W/m^2{}^\circ C$,

v_{ag} = latent heat transfer coefficient, Wm/kg water,

h_{s1} = heat-transfer coefficient inside the soil, $W/m^2{}^\circ C$,

T_g = temperature at the soil surface, °C,

T_{a3} = temperature in the bottom layer of the swath, °C,

T_{s1} = temperature of the top layer of the soil, °C,

ρ_{wg} = vapor density at the soil surface, kg water/m^3,

and ρ_{a3} = vapor density in the bottom layer of the swath, kg water/m^3.

The latent heat transfer coefficient between the soil surface and the bottom layer of the swath was:

$$v_{ag} = \lambda / r_{svg}$$

where λ = latent heat of vaporization, J/kg water,

and r_{svg} = resistance to moisture transfer at the soil surface, s/m.

The conductive heat-transfer coefficient in the top layer of soil was:

$$h_{s1} = k_s/(0.5\Delta z)$$

where k_s = thermal conductivity of the soil, W/m°C,

and Δz = thickness of the top layer of the soil, m.

The temperature at the soil surface was, thus, estimated as:

$$T_g = [(R_n - \lambda E) + h_{ag}T_{a3} + h_{s1}T_{s1}]/(h_{ag} + h_{s1}) \quad [182]$$

This is an implicit formula, since the latent heat flux depends on temperature. In the model, T_g was estimated in subroutine GROUND through an iteration procedure. In the submodel, RVA(3), RVG, DBA(3), DBG, DBS(1), HAA(4) and VAA(4) denoted ρ_{wa3}, ρ_{wg}, T_{a3}, T_g, T_{s1}, h_{ag} and v_{ag}, respectively. The estimation of h_{ag} and v_{ag} was discussed in Section 4.4.3. In this model, h_{ag} and v_{ag} were estimated in function subprogram RSHGND.

4.8.2 Relative Humidity at Soil Surface

Vapor density at the soil surface was an important parameter for estimation of soil surface temperature and the vapor exchange between the soil surface and the swath. Water vapor density in air is a function of temperature and relative humidity of the air. Air is often treated as a mixture of ideal gases of dry air and water vapor. According to the ideal gas law,

$$\rho_w = e_v/R_wT = r_ae_s/R_wT \quad [183]$$

where ρ_w = vapor density in the air, kg water/m^3,

T = absolute temperature of the air, °K,

e_v = vapor pressure in the air, Pa,

e_s = saturation vapor pressure at T, Pa,

r_a = relative humidity of the air, decimal,

and R_w = gas constant of water vapor, 461 J/°K-kg water.

When T is known, e_s can be estimated, and then ρ_w can be predicted from known T and r_a. In the soil, the relative humidity can be estimated from the osmotic potential of the soil.

$$r_s = e^{-V\psi_\pi/RT} \qquad [184]$$

where r_s = relative humidity in soil, decimal,

V = molecular volume of water, 0.0188 m^3/kg mole,

ψ_π = osmotic potential in the soil, Pa,

R = universal gas constant, 8314 J/°K-kg mole,

and T = absolute temperature of the soil, °K.

In unsaturated soil, total water potential ψ is the sum of the osmotic potential ψ_π and the water potential due to capillary effects ψ_c, both are negative. If the total water potential of a soil is -1.5×10^6 Pa, then the soil is said to be at the wilting point. On the other hand, a soil is at field capacity if the total water potential is -33×10^3 Pa. It can be shown that for such a wide range of the total water potential of a soil, the relative humidity in the soil changes very slightly. Suppose the osmotic potential of a soil varies from -1.5×10^6 to -33×10^3 Pa, then the relative humidity of the soil changes just from 0.989 to 1.00. This indicates that the relative humidity of the soil is very close to unity; therefore, the water vapor density at a soil surface can be assumed to be near the saturation vapor density at the surface temperature.

In the model, the relative humidity at the soil surface was set at a constant value of 0.99. Based upon the foregoing discussion, neither water movement nor moisture transfer in soil was modeled in this study.

4.8.3 Soil Temperature Profile

A temperature profile in a soil is the result of a conductive heat-transfer process in the soil. To model this process, a heat balance equation was formed as:

$$Q_{s,i} - Q_{s,i+1} = S_{s,i} \qquad (i=1 \text{ to } 10) \qquad [185]$$

where $Q_{s,i}$ = heat flux into the ith layer, W/m^2,

$Q_{s,i+1}$ = heat flux out of the ith layer, W/m^2,

and $S_{s,i}$ = heat storage flux in the ith layer, W/m^2.

In the model, downward heat fluxes in the soil had a positive sign.

In soil, the storage term could not be neglected, because the soil had a large heat capacity. In this model, a soil of 0.5 m in depth was divided into 10 layers. Each layer was 0.05 m deep. The thermal conductivity k and volumetric heat capacity ρc of the soil were assumed to be 1.3 $W/m°C$ and 2×10^6 $J/m^3°C$, respectively (Goudriaan, 1977). Hence, $\alpha = 0.65 \times 10^{-6}$ m^2/s, and $\tau = 3846$ s. At the top layer of the soil, its center was 0.025 m below the soil surface. The characteristic time for the top layer was 961 s. These show that the conductive heat transfer inside the soil was a slow process, in comparison with those in swathes. Since the heat capacity in soil was very large, it was necessary to include a storage term in the heat balance equation [185].

Although heat storage was no longer negligible for slow heat

transfer in soil, a 'lumped-capacity' approach was still applicable. Since wind speed was near zero at the soil surface, a very small convective heat-transfer coefficient was expected at the soil surface. Thus, it was possible to meet the Biot number criterion. Suppose at the soil surface, T=30°C=303°K, ΔT=10°C, X=1 m, Δz=0.025 m and k_s=1.3 W/m°C, then Gr=1.26x10^9, GrPr=0.885x10^9, c=0.15, m=0.33, h=3.8 W/m^2°C and Bi=0.07<0.1. Therefore, the lumped-capacity assumption was also used in modeling the conductive heat transfer in the soil.

The one-dimensional heat conduction is governed by Fourier's law:

$$Q = -k\partial T/\partial z$$

where Q = heat flux, W/m^2,

k = thermal conductivity, W/m°C,

and $\partial T/\partial z$ = temperature gradient across ∂z, °C/m.

A backward finite difference formula was employed to express each term in Equation [186] as:

$$\left.\begin{aligned} Q_{s,i} &= k_s(T_{s,i-1} - T_{s,i})/\Delta z \\ Q_{s,i+1} &= k_s(T_{s,i} - T_{s,i+1})/\Delta z \end{aligned}\right\} \quad (i=1 \text{ to } 10)$$

$$S_{s,i} = \rho c \Delta z(T_{s,i} - T_{x,i})/\Delta t$$

where k_s = thermal conductivity of the soil, W/m°C,

Δt = time step, s,

Δz = thickness of the soil layer, m,

$T_{x,i}$ = present soil temperature of the layer, °C,

and $T_{s,i}$ = future soil temperature of the layer, °C.

$T_{s,i-1}$, $T_{s,i}$ and $T_{s,i+1}$ were soil temperatures in three adjacent layers after one time step Δt from a given time. Using backward finite difference formulae has the advantage of releasing a stability constraint on time steps for numerical integration. Should forward

difference formulae be applied, the stability constraint requires time steps much smaller than the characteristic time τ (Holman, 1981). Backward finite differences are implicit formulae which may be solved with various methods, such as matrix, iteration and relaxation methods. In this model, a matrix method was used. A set of simultaneous equations was formulated:

$$G_{11}T_{s1} + G_{12}T_{s2} = F_1$$

$$G_{i,i-1}T_{s,i-1} + G_{i,i}T_{s,i} + G_{i,i+1}T_{s,i+1} = F_i \quad \}(i=2 \text{ to } 9) \quad [186]$$

$$G_{910}T_{s9} + G_{1010}T_{s10} = F_{10}$$

with

$$G_{i,i-1} = -\alpha\Delta t/(\Delta z)^2$$

$$G_{i,i} = 1 + 2\alpha\Delta t/(\Delta z)^2 \qquad (i=2 \text{ to } 9)$$

$$G_{i,i+1} = -\alpha\Delta t/(\Delta z)^2$$

$$F_i = T_{x,i}$$

$$G_{11} = 1 + 3\alpha\Delta t/(\Delta z)^2$$

$$F_1 = T_{x1} + 2T_g\alpha\Delta t)/(\Delta z)^2$$

$$G_{1010} = 1 + 3\alpha\Delta t/(\Delta z)^2$$

$$F_{10} = T_{x10} + 2T_d\alpha\Delta t/(\Delta z)^2$$

where T_g = soil surface temperature, °C,

T_d = soil temperature at 0.5 m depth, °C,

Δt = time step, s,

Δz = thickness of a soil layer, m,

and α = thermal diffusivity of the soil, m^2/s.

As mentioned in Chapter 3, soil temperature below 0.5 m was assumed to be a constant during diurnal cycles.

This set of equations was solved in subroutine DBSOIL. Arrays DBS, DXS, DEP, and variables ALF, DT, DBG and array element DBS(11) were

used to denote $T_{s,i}$, $T_{x,i}$, Δz, α, Δt, T_g and T_d, respectively. Figure 9 shows a soil temperature profile simulated for the field in East Lansing, Michigan on August 14 to 16 f 1984.

4.9 Model Structure

The preceding sections of this Chapter described each submodel individually. In this section, the integration of all submodels into a complete simulation model is discussed. The whole model consisted of an initialization section, a simulator section and an output section. The block diagram of the model is shown in Figure 10. A list of FORTRAN code for the ALFDRY model is given in Appendix A.

4.9.1 Initialization Section

In the initialization section, data of thermal properties of air, water vapor, soil and other important constants were initialized in subprograms AIRPAR and MISPAR, accordingly. Data of sky cover and precipitation from local weather service and microclimatological data measured in fields were read from specified weather data files in subprograms DAYWTR and MICWTR, respectively. The latitude, longitude, altitude and time-zone meridian of the location being studied was read to provide information for simulation of short-wave radiation. Temporal data of the year, date and time for beginning and finishing a field drying process were required. Spatial information of the swath, such as the dry-matter area density, initial moisture content, ratio of leaf area index to yield, maturity and cutting,

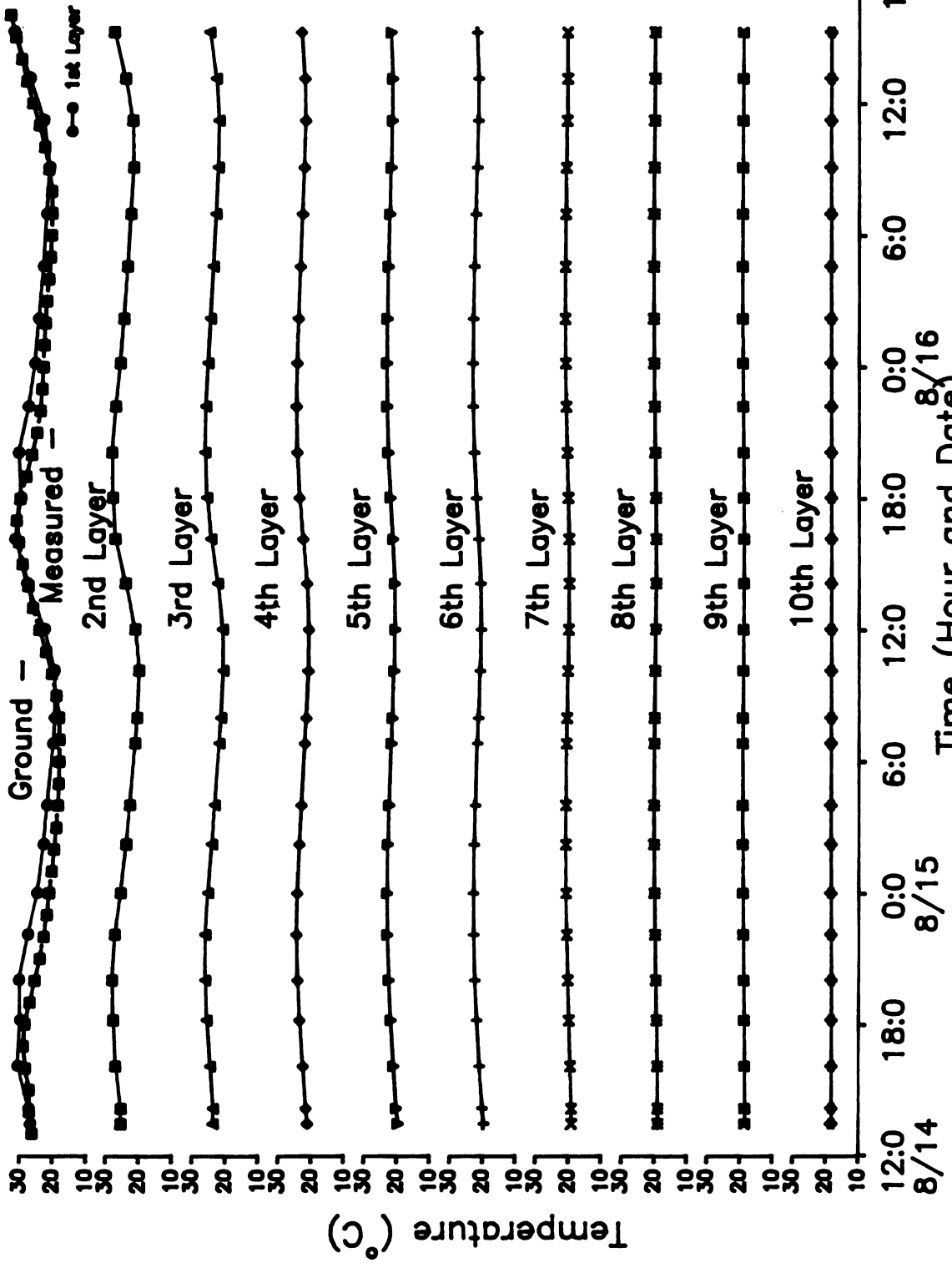

Figure 9. A simulated profile of soil temperature underneath a swath in East Lansing, Michigan on August 14-16, 1984.

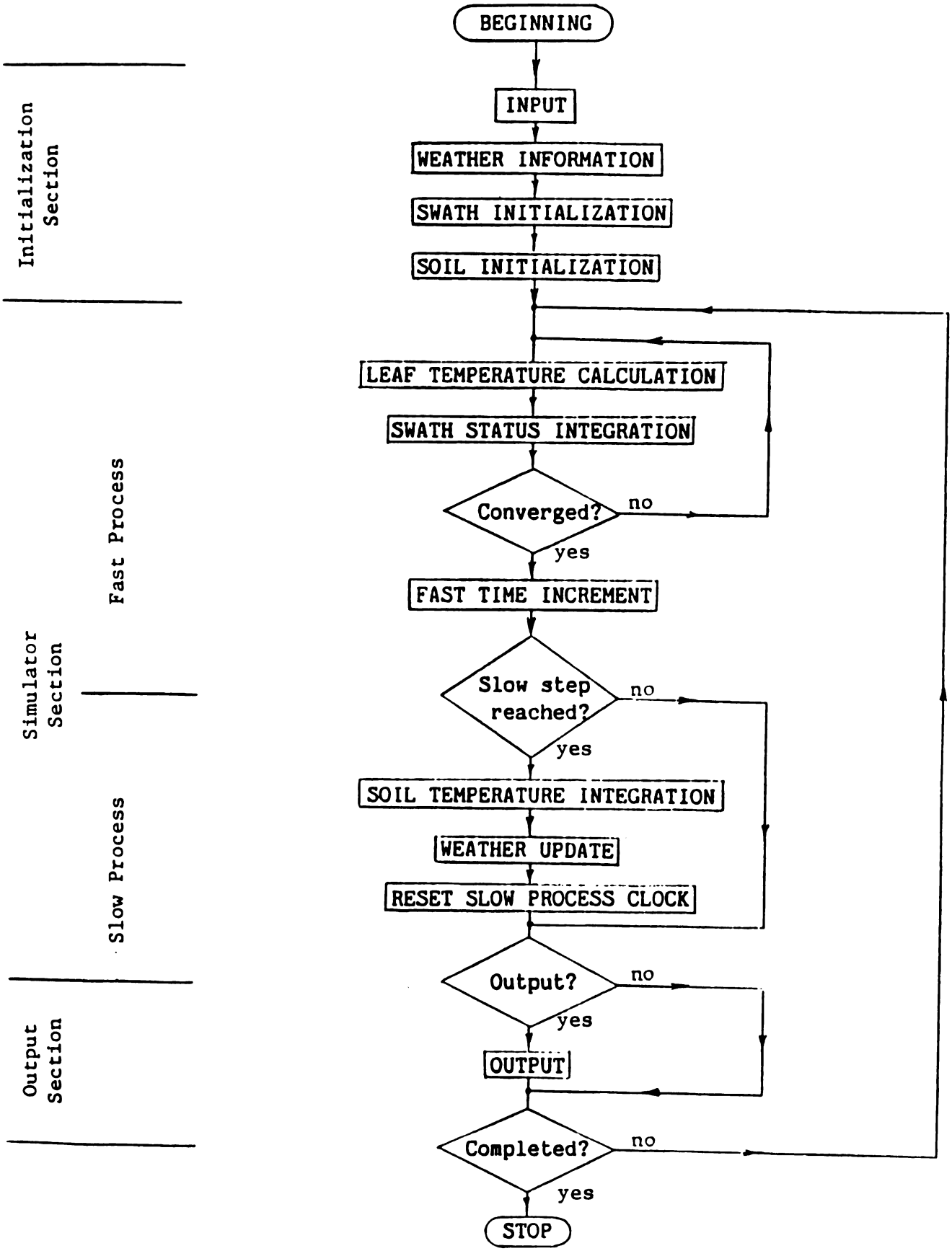

Figure 10. Block diagram of the ALFDRY simulation model.

was read. To control a simulation, the sizes of time steps for integration and output intervals were also needed. The reference height of microclimatological measurements was an important parameter.

At the initialization stage, initial values of state variables, such as temperature and vapor density of leaves and air spaces within the swath, and soil temperature were estimated in subprogram SWATHI and SOILI, respectively. It was assumed that initial profiles of temperature and relative humidity were linear along the vertical direction. So, data at two positions, the soil surface and reference height, were required. These data were obtained by using interpolation techniques from measured data. It was assumed that initial leaf temperature was the same as the air temperature in each layer of the swath, respectively. In addition, vapor density, pressure and relative humidity of leaves were assumed to be saturated at leaf temperature. Since heat and vapor transfer processes inside a swath were fast processes, temperature and vapor status would be adjusted to proper states by the model a short time after initialization. It was further assumed that there was no surface and runable moisture, i.e. no dew, and that alfalfa moisture content was uniform throughout the whole swath at initial time.

There was lack of information on diurnal patterns of temperature of local soils. To initialize a soil temperature profile, data given by Carson and Moses (1963) were adapted. They measured soil temperature at depths of 0.01, 0.1, 0.2, 0.5 and 1.0 m, and at 2:00, 6:00, 10:00, 14:00, 18:00 and 22:00 in Argonne, Illinois on a typical summer day, July 27, 1963. In the model, these temperature data were stored in a two-dimensional array. An interpolation method was

used to get a tentative soil temperature profile for a given initial time. No special provision was made to distinguish variation of the temperature profile on different dates. The soil temperature in the top layer was set to the local soil temperature measured just underneath the soil surface. Soil temperature in other layers were adjusted proportionally.

Profiles of wind, short- and long-wave radiation and resistances to heat and moisture transfer within the swath were also estimated at initial time. Initial values of various fluxes of moisture and heat, and of rates of changes in state variables were determined, accordingly.

4.9.2 Simulator Section

The simulator section was the main body of the model. It estimated rates of change and fluxes for various state variables, and integrated step by step to simulate the status of the soil-swath-atmosphere continuum.

Two key points need to be emphasized: 1) handling 'fast' and 'slow' processes in a simulation model, and 2) choosing proper size(s) of time step(s) for integration.

As discussed previously, sensible and latent heat transfer at leaf surfaces, and sensible heat and vapor transfer in air spaces of a swath were 'fast' processes with time constants of less than one second. On the other hand, sensible heat transfer inside the soil was a 'slow' process with a time constant of one thousand seconds to over an hour. Application of one single time step would not be appropriate for both kinds of processes. If a time step was very small,

say one or several seconds, much computer time would be wasted in unnecessary estimations of soil temperature which was insensitive to environmental changes. On the other hand, accuracy in estimating swath status might be reduced heavily if a time step was very large, say about one hour or longer. The approach in this model was to use different time steps for different processes. Fast (or soft) processes were integrated with a small time step while slow (or stiff) processes were integrated with a large time step. During most time of a simulation run, estimation of soil temperature was bypassed while estimation of temperature and moisture status within the swath was executing. Soil temperature profiles were estimated only when the time of integration of fast processes was accumulated up to the slow time step. Updating of weather conditions, such as solar irradiance, sky cover fraction, rain, wind speed, temperature and relative humidity at the reference height, and profiles of wind, short- and long-wave radiation within the swath, was also bypassed because weather information was measured at intervals of one hour or longer. The algorithm for bypassing the slow process and weather updating is also shown in Figure 10.

To determine the sizes of the two time steps, the frequency of measurement of weather and microclimate data were considered. Literature has indicated that there are various fluctuations of both high and low frequencies in the boundary layer of the atmosphere (Rosenberg et al., 1983). Microclimatological data are normally determined by averaging measurements over an interval of a half to one hour (Monteith, 1973; Goudriaan, 1977; and Rosenberg et al., 1983). With such a low time resolution on microclimatological data, a step size in the order of seconds was not meaningful. Test runs of the model with

various step sizes were made for a typical drying test: Trial 5 (0.448 kg dry matter/m^2, at East Lansing, Michigan on August 14 to 16 of 1984). Simulation results showed that changes in simulation accuracy were insignificant when the fast time step was increased from 6 s up to 60 s and 600 s while the slow time step was 1 hour. The total sum of squares (SSTO) for Trial 5 was 14.06; and the sum of squares due to error (SSE) was 1.32, 1.30 and 1.05 for the fast step of 6, 60 and 600 s, respectively. The coefficient of determination (r^2) was 0.91, 0.91 and 0.92, respectively. Figure 11 shows a comparison between measured and predicted drying curves for Trial 5 with the fast step of 6, 60 and 600 s, respectively. The predicted drying curves with the fast step of 6 and 60 s were almost identical, which suggested that the fast time step did not need to be smaller than 1 minute. The increase in SSE was presumably attributed to accumulated numerical errors in simulation runs with small steps.

The sizes of time steps influence effective utilization of computers, and computational costs. For simulation of Trial 5, a 49-hour drying process, one run with two steps of 600 s and 1 hour required about 18 minutes on a COMPAQ-286 microcomputer with an 80287 math coprocessor running at 10 mHz. When the small step was reduced to 60 or 6 s, it took about 1.5 or 12.4 hours, respectively, for execution on the same microcomputer. On the main frame computer CDC750 of Michigan State University, it cost $2.95 at an economic rate for one simulation run of the model for Trial 5 with the two steps of 600 s and 1 hour. Should the fast step be reduced to 60 or 6 s, the computing cost would be expected to increase to about $15 or $124, respectively. Running the simulation with a very small step size was not practical.

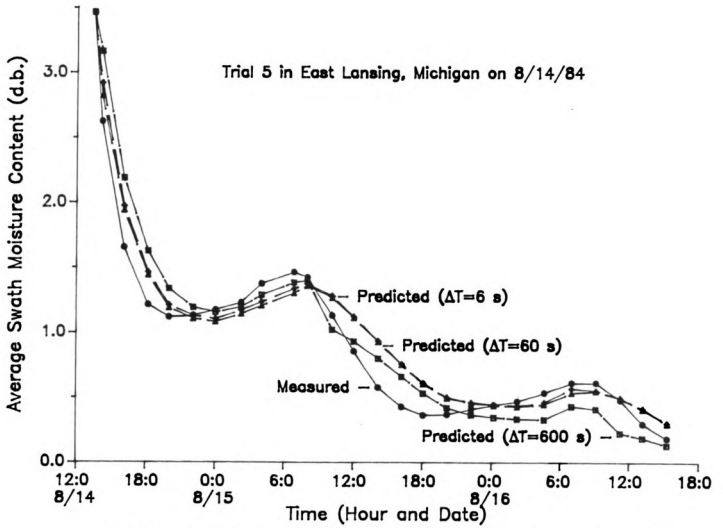

Figure 11. Comparison between measured and predicted drying curves with a slow step of 1 hr and a fast step of 6, 60 or 600 s.

4.9.3 Output Section

The model was able to print both a summary and a detailed report upon user-specified time intervals simulated. The summary contained information on the year, date, time, predicted moisture content averaged over the whole swath, measured moisture content (if available), and residual. It also gave statistical information, such as the total sum of squares (SSTO), the sum of squares due to regression (SSR) and the sum of squares due to error (SSE), the coefficient of determination (r^2), the mean sum of squares of residuals (MSE) and F-statistics after simulating a whole case set of field drying.

The report gave detailed information about weather conditions at the reference height, profiles of temperature, moisture and various fluxes associated with leaves in each layer of the swath, profiles of temperature, humidity and various fluxes associated with air space in each layer of the swath, profiles of short- and long-wave radiation in the swath, and the temperature profile inside the soil.

4.9.4 Psychrometric Library

In the model, determination of psychrometric parameters in the moist air was often required. The task was carried out by calling a series of function subprograms. The formulae of those functions were obtained from ASAE Data 271.2 (1984). These function subprograms were grouped in a psychrometric package. A list of FORTRAN code for the psychrometric package is shown in Appendix B.

CHAPTER 5

FIELD EXPERIMENT

Experiments were conducted to collect essential information on the process of alfalfa drying in the field environment. Information obtained was used to estimate unknown parameters of the model, such as the empirical constants a and b in Equation [139] relating leaf surface resistance to leaf temperature and moisture content, and to validate the model. Experiments were carried out on farms in East Lansing, Michigan in 1984, and in Fresno, California in 1985.

5.1 Measurement of Swath Drying

Periodic weighing is a convenient method to monitor the progress of drying of biological materials. Alfalfa swaths are usually hundreds of meters in length, so taking measurements on a whole swath is impractical and impossible. Selecting a certain amount of alfalfa from a real swath, and then weighing the sample material at time intervals can provide representative information about the drying rate of a whole swath and even all swaths under similar conditions.

In this study, a procedure of weighing trays with alfalfa samples was employed. This method has been applied in hay research at the USDA Dairy Forage Research Center at Michigan State University since 1977 (Rotz and Chen, 1985). Trays were made of metal wire mesh. The

dimensions of each tray were 0.5x0.5x0.1 m. The empty weight of each tray was predetermined.

After alfalfa was cut, trays were randomly put at several positions (center and edge) along a fresh swath. The alfalfa beneath a tray was separated from other alfalfa in the swath, and placed into the tray (Figure 12). The tray loaded with alfalfa was then weighed and the gross weight was recorded. Some trays were loaded with the exact amount of alfalfa taken from a swath, which represent the density of natural swaths. Other trays were loaded with more or less alfalfa to form artificial 'higher' or 'lower' densities than that of the actual swaths. In East Lansing, Michigan, three samples were taken for each density treatment; and in Fresno, California, the number of samples was two.

Drying tests were combined with other tests to determine the effectiveness of chemical conditioning. For this work, samples were only taken from swaths of control treatments (mechanical, but no chemical conditioning). All trays were arranged as if they were in a real swath to dry. This was done by putting trays aside real swaths with two or three trays in a row. The trays were surrounded with alfalfa to avoid edge effects (Figure 13). The gross weights of all sample trays were measured at 2 h intervals. Some measurements were taken throughout nights during the harvest season of 1984. A KTRON digital balance with an accuracy of ±0.002 kg in the range of 0~6 kg was used.

When swaths were baled, sample materials were removed from their trays and placed in paper bags with known weights. Sample bags were oven-dried at a temperature of either 65°C for 72 hours or 104°C for 24 hours depending upon whether nutritional analysis was planned, according

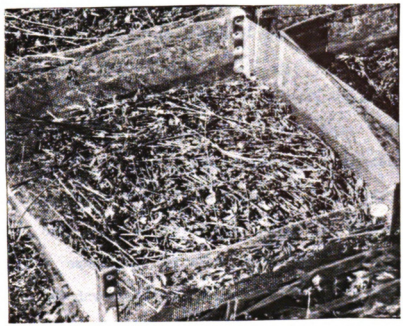

Figure 12. A tray with an alfalfa sample drying in the field.

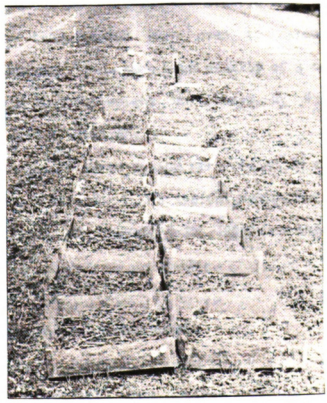

Figure 13. Arrangement of sample trays in the field.

to ASAE Standard S358.1 (ASAE, 1984). The dry-matter weight of each sample was the final gross weight of each sample bag minus the bag's weight, respectively.

The wet weight of an alfalfa sample was the gross weight of the corresponding sample and tray minus the tray's empty weight. The moisture weight of a sample was obtained by subtracting the sample's dry-matter weight from its wet weight. This was based upon the assumption of no loss in dry matter. Then, the moisture content (dry basis) of a sample was estimated by dividing the sample's moisture weight by its dry-matter weight. This calculation was done to each measurement of each sample to provide a series of moisture content data for each test.

A mean moisture content was obtained by averaging moisture content measurements over all samples of a given density at each measurement time. The same tray samples were used to calculate the mean tray dry-matter weight. The mean area density of a sampled swath was the averaged tray dry-matter weight multiplied by 4, since each tray had a horizontal area of 0.25 m^2.

Measured data of swath drying were stored in a file named DRYCASE which is given in Appendix C. A typical drying curve for Trial 5 (East Lansing, Michigan on August 14-16, 1984) was shown in Figure 11 of Section 4.9.2.

5.2 Micrometeorological Measurements

Micrometeorological data were acquired with two portable microprocessor-based weather stations. One unit was used to measure

microclimatological data at a reference height about 0.6 m above the ground. The other unit was used to measure psychrometric data inside swaths. Each unit consisted of a micrologger and associated sensors. Those sensors included temperature probes, relative humidity probes, pyranometers, anenometers and soil moisture blocks. Figure 14 shows one weather station and its components used in this study.

5.2.1 Microloggers

The data loggers used in this study were CR-21 units manufactured by Campbell Scientific, Inc. Each CR-21 was battery-powered and equipped with a microprocessor, a real time clock, a serial data interface, and a programmable analog-to-digital converter. This miniature, nine-channel, computerized data recorder handled up to seven analog inputs and two pulse inputs. It provided DC and AC excitation voltages to meet requirements of certain transducers. The CR-21's were factory-programmed to convert voltage signals of certain types of sensors, into digital signals of measured quantities (temperature, humidity, solar irradiance, wind speed, etc.). The CR-21 scanned each channel once every 10 seconds, and each scan took about 0.3 to 2 seconds depending on a user-programmed input table. The CR-21 dumped stored data to cassette tapes for storage at a user-specified interval. In this study, the CR-21's were programmed to output averaged hourly data.

The micrologger had an amplifier accuracy of ±0.5% of reading or 2 times the resolution of a measured quantity, whichever was larger. The resolution was ±0.005 mV in the range of -2 to 25 mv, and ±1 mV in the

Figure 14. A micrologger with associated sensors and a cassette recorder.

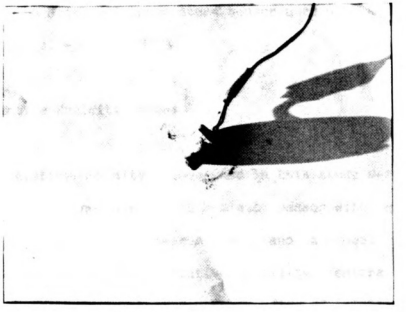

Figure 15. A soil moisture block.

range of -0.2 to 2.5 V, according to manufacturer's specifications.

The CR-21 required a working environment of -25 to 50C, and 0.0 to 0.95 relative humidity. In this study, each CR-21 unit was set in a metal box. It was found that the CR-21's stopped working when the metal boxes were exposed to very high solar radiation. Therefore, the boxes were covered with cut alfalfa to shade the instrument.

5.2.2 Temperature Probes

Temperature probes used were Campbell Model 101 temperature sensors manufactured by Fenval Electronics. Each sensor was a thermistor (ϕ0.2x25.4 mm) setting in a water-resistant probe with a 249 kΩ pickoff resistor.

According to manufacturer's specifications, the greatest system error for a Model 101 temperature sensor used with a CR-21 was $\pm$0.6°C in the range of -30° to 47°C.

5.2.3 Relative Humidity Probes

The relative humidity probes used in this study were Campbell Model 201. Each contained a relative humidity sensor with $\pm$1% calibration, made by Phys-Chemical Research Corp., and a Model 101 temperature sensor. In moist air, relative humidity sensors changed their resistance as humidity changed. The reading of relative humidity was linear in the range of 0.0 to 0.97 with an error of $\pm$3%, according to manufacturer's specifications. Temperature over normal ranges did not affect the relative humidity sensors.

This kind of sensor is susceptible to organic solvents, ironic-laden liquids, oil vapor, sulfur, water condensation and immersion. It was found in this study that a few readings were above 1.0 at night, which was caused by dew formation. These readings were then corrected to 1.0, accordingly.

5.2.4 Pyranometer

LI-206S pyranometers manufactured by LI-COR, Inc. were used. Each was a silicon device which produced millivolts when exposed to sunlight. Each pyranometer was individually calibrated in the factory and a conversion coefficient was provided. The conversion coefficients of two pyranometers used in this study were 119.8 and 139.2 $W/m^2/mv$, respectively. The measurement range of the pyranometer was 0 to 1300 W/m^2, according to manufacturer's specifications. A few readings were found to be slightly negative at night, and accordingly, corrected to be zero. The measurement accuracy was ±5.99 and ±6.96 W/m^2, respectively.

5.2.5 Anenometer

The anenometer, made by WEATHERtronics Inc., was a three-cup type. It outputted pulses when a DC voltage was provided. The CR-21 counted the pulses and converted pulse counts to wind speed in m/s.

5.2.6 Soil Moisture Sensors

Soil moisture sensors used were Campbell Model 221 manufactured by DELMHORST (Figure 15). Each sensor was a cylindrical block composed of gypsum cast around two concentric electrodes. Electrical current flow was confined in the interior of the block, so the effect of soil conductivity was reduced. The gypsum on the outer electrode associated with the soil created a buffer against soil salts which might influence the block's conductivity. The sensors changed their resistance as soil moisture changed. The sensors were excited by an AC voltage with zero DC component. The CR-21's provided a square-wave AC excitation of 4 V and 700 Hz.

The CR-21's outputted voltage data corresponded to the resistance of soil moisture blocks. It was necessary to convert the voltage output to soil moisture parameters. The manufacturer provided calibrated data relating soil water potential vs. voltage output of the CR-21. An approximation method of third-order splines were applied to the nonlinear function of soil water potential vs. voltage output of the CR-21. Each segment of the function was approximated with a third-order polynomial. Each pair of adjacent polynomials had common first- and second-order derivatives at their interception point. At the two end points of the function, the second-order derivatives of corresponding polynomials were assumed to be zero. Figure 16 shows the approximation curve.

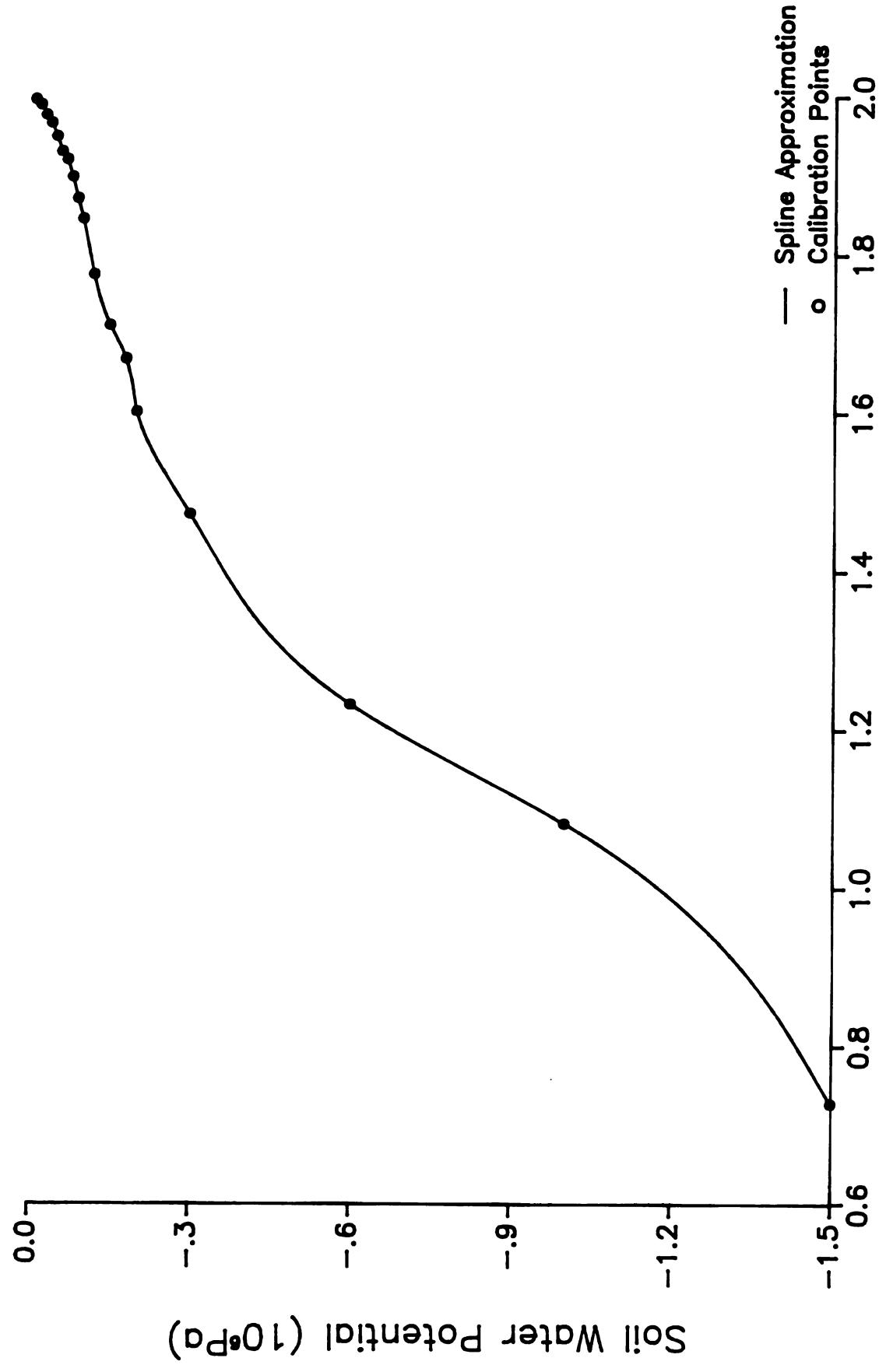

Figure 16. The calibration curve for soil moisture blocks.

5.2.7 Measurement Procedure

One weather station was set up to measure temperature, relative humidity and wind speed at a reference height, solar irradiance at the top of swaths, relative humidity inside a swath, and soil moisture. The reference height was the height of the rotating cups of the anenometer above the ground. Figures 13 and 17 show the station in the field.

The other weather station was used to measure temperature and relative humidity at the top and bottom of a swath, soil temperature and moisture beneath the swath. One humidity probe was put on the top of a swath. The probe was covered with a very thin layer of alfalfa to avoid direct sunshine. Figure 18 shows the position of the humidity probe. Another humidity probe was placed on the ground inside the swath. Since the diameter of the probe shelter was about 3 cm, the sensor measured temperature and relative humidity at a height of about 1.5 cm.

Soil moisture blocks were placed in the soil about 1.5 cm below the surface. One was in the open field, and the other was under the swath. A temperature probe was also placed in the soil very close to the soil surface underneath the swath.

Both weather stations were programmed to dump averaged data of all sensors at an hourly interval to a cassette. Data stored on cassette tapes were uploaded to the main frame computer, CDC750, of Michigan State University and stored in data files. Appendix D lists the content of data file WTRMIC. Figures 19, 20 and 21 show some measured micrometeorological data of solar irradiance, wind speed at the reference height, and temperature and relative humidity at four locations of the swath.

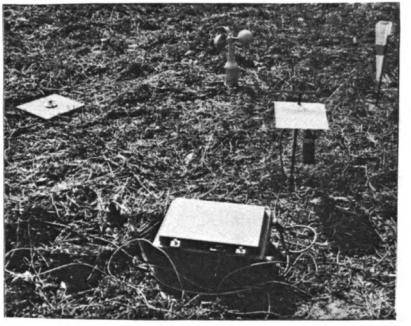

Figure 17. A microweather unit in the field.

Figure 18. A relative humidity probe in the top layer of a swath.

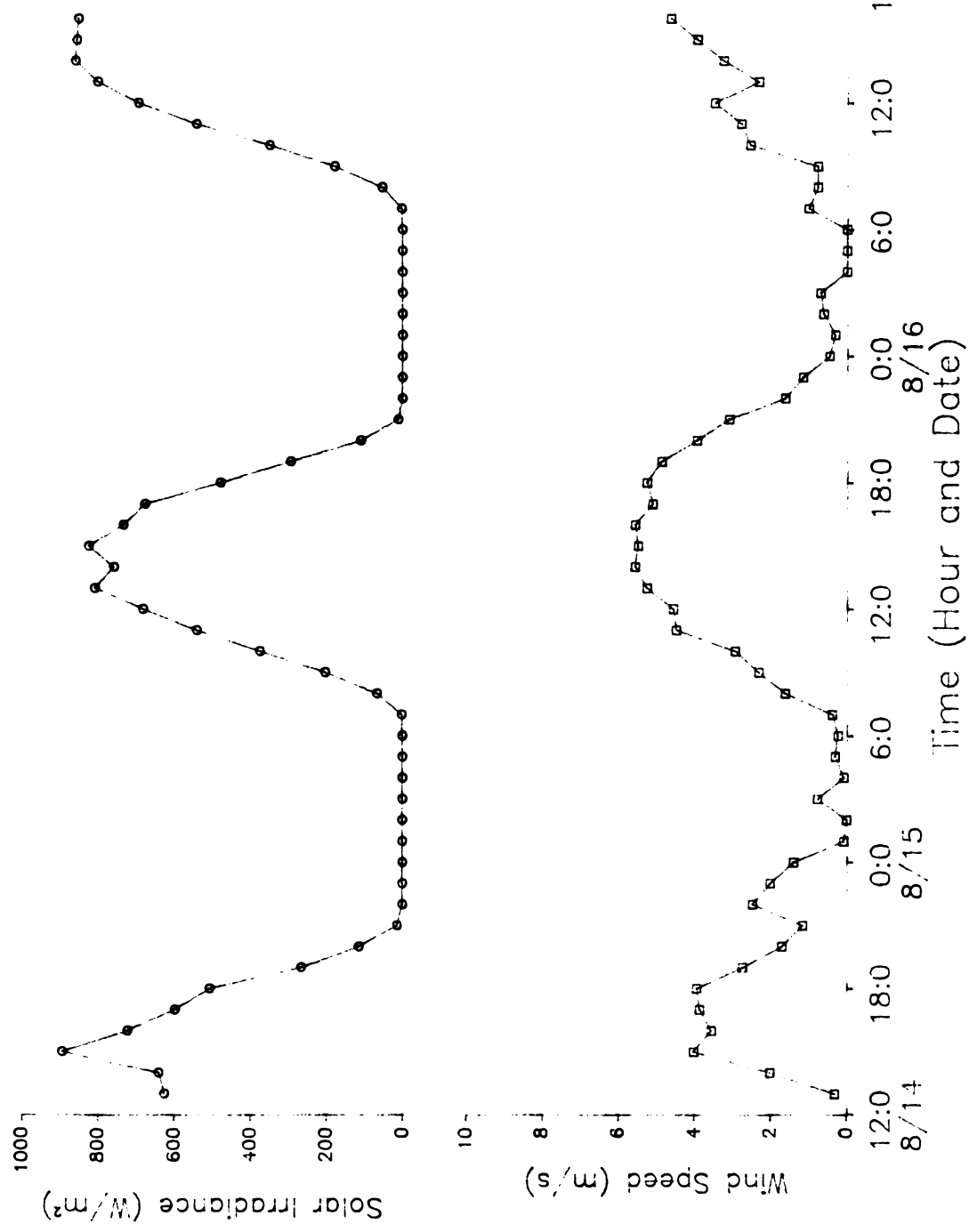

Figure 19. Solar irradiance and wind speed at a reference height of 0.6 m measured in East Lansing, Michigan on August 14-16, 1984.

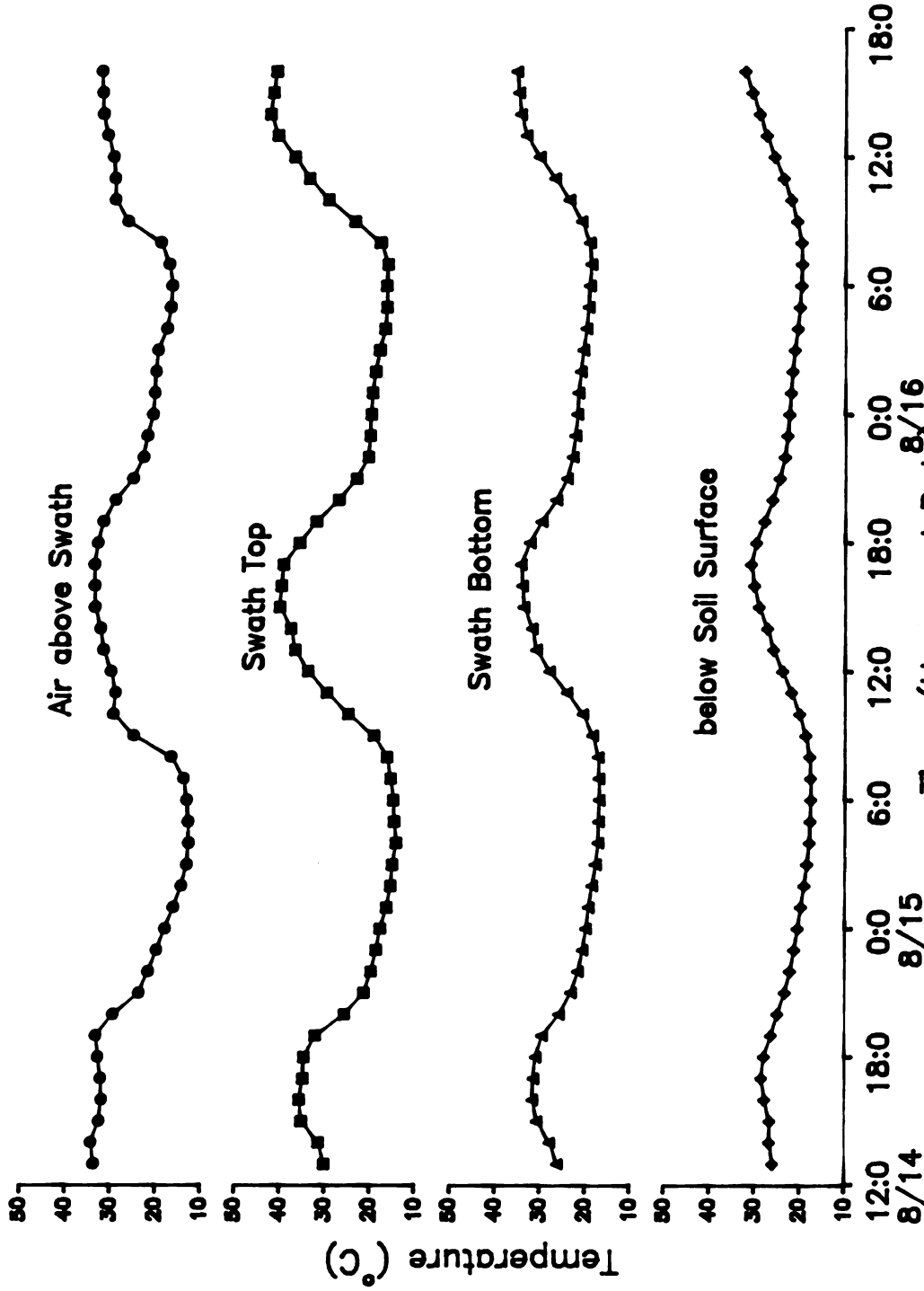

Figure 20. Temperature above a swath, at the top and bottom of the swath and below the soil surface underneath the swath measured in East Lansing, Michigan on August 14-16, 1984.

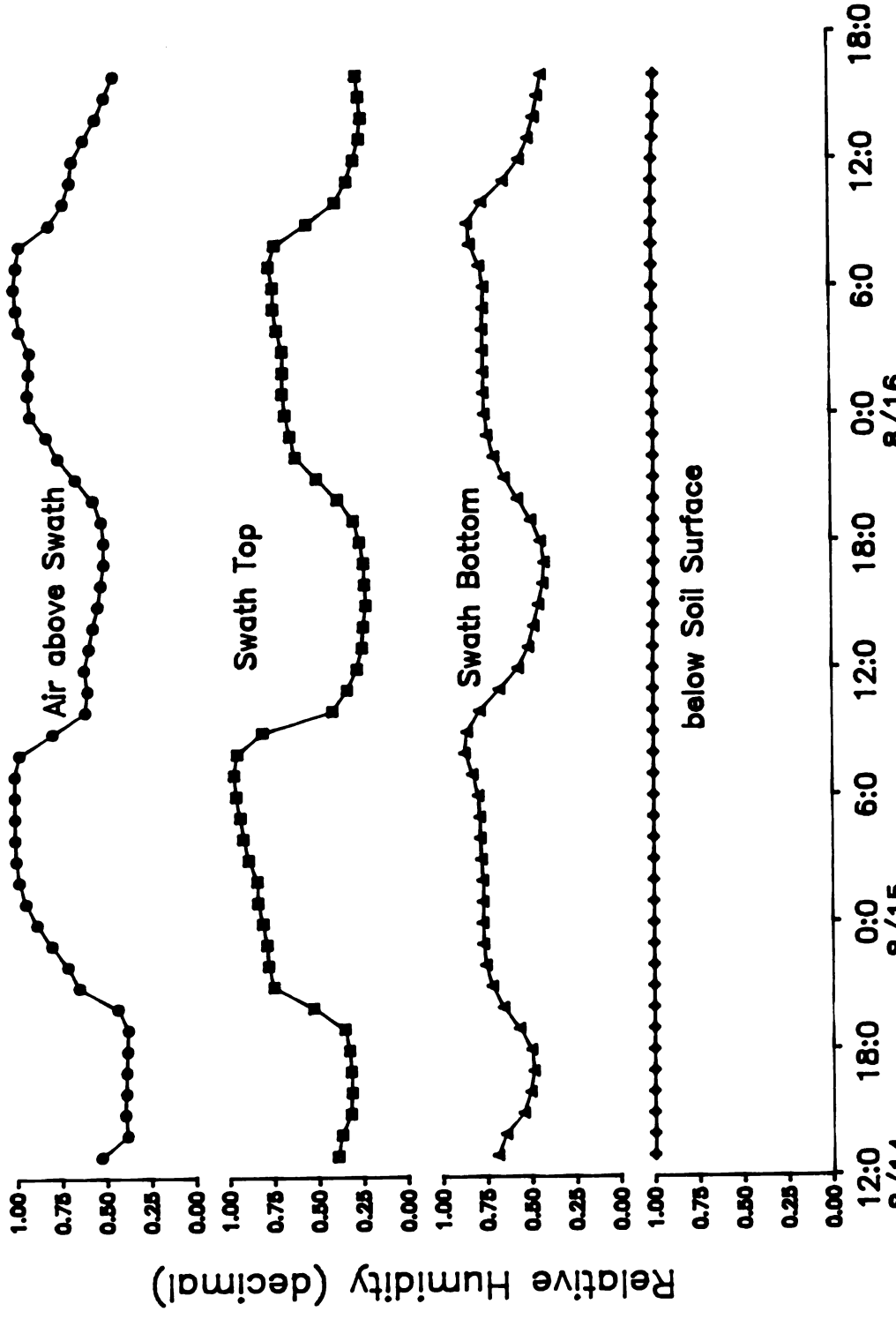

Figure 21. Relative humitidies above a swath, at the top and bottom of the swath, and below the soil surface underneath the swath measured at East Lansing, Michigan on August 14-16, 1984.

5.3 Local Climatological Information

Information of sky cover fraction, precipitation and other weather data were obtained from the local station of the National Weather Service. The local weather data were measured at the Lansing Airport, 11 km North-West of the field site. Data file WTRDAY is listed in Appendix E.

For drying tests in Fresno, California, a zero sky cover fraction was assumed since the sky was very clear during the tests.

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CHAPTER 6

PARAMETER ESTIMATION

This chapter discusses statistical estimation of two parameters of the simulation model. Techniques used were derivative-free optimization and nonlinear regression. The statistical parameters estimated were two coefficients which relate leaf surface resistance to the moisture content of leaves in Equation [139]. These parameters, however, were estimated by relating them to the average swath moisture content in lieu of the leaf moisture content.

6.1 The Complexity of the Problem

As discussed in Section 4.5, leaf surface resistance to moisture removal is an internal property of leaves. Information on this resistance required microscopic study beyond the scope of this study. One alternative was to characterize this resistance through macroscopic behavior of leaves. Monteith et al. (1965) extended the concept of leaf resistance to a bulk canopy resistance which behaved like the leaf resistance, and could be derived from micrometeorological observations. Rosenberg et al. (1983) reviewed extensively others' research with a similar thought. Monteith et al. (1965) found that measured leaf resistance was linearly correlated to bulk canopy resistance, estimated from an energy balance with micrometeorological data in a barley field.

Their approach was adapted in this study, however, the procedure was reversed such that leaf resistance described in Equation [139] was characterized from macroscopic drying of swaths. Estimation of leaf resistance to moisture removal for drying plants may be easier than for living plants, because the leaf resistance of drying plants was presumably uninfluenced by light intensity and temperature, but merely affected by the water stress in leaves.

The estimation of parameters in this study was a complicated problem. First, the measured quantity was the average moisture content of the swath rather than the leaf resistance itself, since determination of moisture contents was of practical interest, and easier than measurement of leaf resistance. Thus, the parameters of this study were not estimated directly with Equation [139], but through an indirect function between leaf resistance and the average moisture content of the swath.

Secondly, the problem was nonlinear, not only due to the nonlinearity of Equation [139], but also due to the complexity of the functional relationship between the average moisture content of the swath and leaf resistance. Actually, this relationship was unable to be described with an explicit algebraic form. An implicit function was:

$$AMC = f(r_l,...) = f(10^{a-bRWC},...) = f(10^{a-bM/M_0},...) \quad [187]$$

where AMC = average swath moisture content, kg water/kg dry matter,

r_l = leaf resistance to moisture transfer, s/m,

RWC = relative water content of leaves, decimal,

M = leaf internal moisture content, kg water/kg dry matter,

M_0 = initial moisture of leaves, kg water/kg dry matter,

a and b = statistical parameters to be estimated, dimensionless.

The average moisture content of the swath was defined as the dependent variable (statistics term), or system output (system science term). The quantities, except coefficients a and b, included in the parentheses of Equation [186] were independent variables (statistics term). These independent variables were a combination of the system input (the initial swath moisture content), environmental variables (solar radiation, air temperature and humidity, wind speed at the reference height), state variables (leaf resistance, temperature and moisture contents, aerodynamic resistance, air temperature and humidity above and within the swath, soil temperature and moisture, etc.), and system parameters (alfalfa maturity, swath density, leaf area index, conditioning factor, etc.) from the viewpoint of system science. The coefficients a and b were called statistical parameters in order to be distinguished from leaf resistance, a state variable, and other system parameters. The function in Equation [186] was called a regression function, response function or prediction function.

In addition, all state variables were not evenly distributed throughout the swath. As discussed in Chapters 3 and 4, state variables varied from time to time, and from layer to layer along the vertical direction in the swath.

Thirdly, the average moisture content of the swath at a particular time was not determined by those independent variables aforementioned at that instantaneous time, but by the past history of all these variables since the beginning of drying (even before cutting). This means that each quantity on the right side of Equation [186] represented a series of values of that quantity from the time of cutting on. One may say that the average moisture content of the swath was a function of the

history of itself. Likewise, leaf resistance was also a function of its own past history, although it was calculated from instantaneous moisture contents of leaves through Equation [139].

Fourthly, the leaf resistance was a continuous function but with discontinuity at the transition between adsorption and desorption. This implied that first-order partial derivatives of the leaf resistance with respect to the statistical parameters a and b were piecewisely continuous with discontinuity of the first kind. This kind of stepwise change in leaf resistance might cause oscillation during simulation.

Fifthly, there were only discrete data available for the dynamic process. The discreteness existed in all data, both field measured and simulated. Measured data were taken at 1- or 2-hour intervals. Predicted data were integrated at 600-second or 1-hour intervals. Discrete data could represent partial but incomplete information about the history of the process.

In addition to those reasons above, there were other factors which caused difficulty in applying techniques of parameter estimation. Beck and Arnold (1977) outlined basic statistical assumptions commonly used in regression analysis. Those assumptions and the deviation of this model are discussed as follows.

1) Regression models, or regression functions, should have correct forms, not empirical approximations or best guesses. The model of this study was a mathematically simplified approximation of a complicated field drying phenomenon. The model was comprised of several submodels and many sub-submodels, each of which was a mathematical approximation of a specific physical or physiological process. In the model studied, some empirical functions were adapted from past research.

Those numerical techniques used in the model were also approximations of analytical methods. Generally speaking, there are always some approximations when natural phenomena are modeled.

2) Errors about the quantities studied are either measurement errors or model errors, but not both. In this study, there were errors both in the measurements and the model. Measurement errors were due to instruments, inappropriate operations, and other random factors. Errors in the model were caused by approximation, numerical techniques, truncating and round-off in implementation on digital computers. For example, Holman (1981) pointed out that there may be ±20% or more uncertainty in calculating convection heat transfer coefficients and ±10% in surface radiation properties. Measurement errors of temperature, relative humidity, solar irradiance, wind speed, and soil moisture may be negligible in the study.

3) Errors are random with zero mean, constant variance and normal distribution. Generally, random errors exist in properly conducted measurements and carefully calibrated instruments. Model errors due to approximation, numerical methods and truncating or round-off were probably systematic rather than random, but the occurrence, direction and magnitude of these errors seem unpredictable. In this study, all errors were assumed to be pseudo-random.

4) Errors are uncorrelated. This might not be true for the model studied, since any error at a time step on a simulation run might be carried over to the next step. In addition, Beck and Arnold (1977) pointed out that application of modern digital data acquisition instruments may induce some correlated errors in time series. For this study, it was desirable to form an autocorrelated

error model. However, preliminary tests showed that some statistical sensitivities were lost when such an error model was formed. Furthermore, when the model is used to predict a drying process without measurements, an autocorrelated model will be inconvenient because it needs measured data to adjust simulation outcomes. Therefore, a uncorrelated error model was assumed in this study.

5) Independent variables are not stochastic. In this study, only a few variables were measured directly, such as soil temperature, air temperature, relative humidity, wind speed and solar irradiance at the reference height. Some quantities, such as vapor pressure, density and other psychrometric properties of the air above the swath, and soil moisture, were calculated from those measured variables. Even the dependent variable, the average swath moisture content, was indirectly calculated from weight measurements of sample trays and sample bags. Many quantities were estimated, such as psychrometric properties of the air spaces inside the swath, alfalfa moisture contents of swath layers, temperature in soil layers, and radiation profiles inside the swath. Thus, errors existed in all quantities. According to the theory of parameter estimation, the number of dependent variables should include all stochastic quantities. This will require huge computer memory and high computing costs. In this study, non-stochastic independent variables were assumed, since those quantities measured with accurate sensors were errorless as assumed.

6) The parameters being estimated are deterministic, i.e. non-stochastic. Leaf resistance of alfalfa, if directly measured, might show random patterns. For example, leaf resistance, characterized by the two parameters, might vary as the variety, maturity level, cutting,

location, rewetting/redrying, and history of water stress varied. In this study, emphases were put on the date of cutting. It was assumed that alfalfa cut on the same date had the same maturity level and history of water stress, and a similar drying-rewetting-redrying pattern. The variety factor was combined with the location and year (East Lansing, Michigan, 1984 or Fresno, California, 1985). No special provision was made to take these into account.

7) Statistical information is known for stochastic variables (quantities). Information on mean, variance and distribution pattern for each measured quantity was unknown in this study. Only one measurement was taken at a time for each of those quantities measured with the data loggers, due to a limited number of available channels on the loggers. There were only two or three replicates of measurements of the average moisture content of the swath.

All of the factors mentioned above caused difficulty in the estimation of parameters in this study. However, some techniques of parameter estimation could still be applied, since they were better and more efficient than trial-and-error methods, and more economic and less time-consuming than conducting extensive experiments. These procedures also reveal direction for future research.

6.2 Methodology of Parameter Estimation

Parameter estimation can be considered a process of optimization. In the process, an objective function, a particular form of the sum of squares of residuals, is minimized which leads to a set of statistical parameters. In this study, the objective function was the ordinary form

of the sum of squares of residuals (SSE).

Normally, the error model of a measured quantity is described as:

$$e_i = Y_i - \eta_i \qquad (i=1,\ldots,n) \qquad [187]$$

where e_i = residual of the ith observation,

Y_i = ith measurement of the quantity,

and η_i = ith prediction of the quantity.

$$\eta_i = \eta_i(b_1,\ldots,b_p) \qquad [188]$$

Where p is the number of the parameters, and b_j is the jth parameter (j=1 to p). Equation [187] can also be rewritten in a matrix form, denoted by underlined letters throughout this Chapter:

$$\underline{e} = \underline{Y} - \underline{\eta} \qquad [189]$$

where $\underline{e}$ = residual vector (nx1),

$\underline{Y}$ = measurement vector (nx1),

and $\underline{\eta}$ = prediction vector (nx1).

$$\underline{\eta} = \underline{\eta}(\underline{b}) \qquad [190]$$

where $\underline{b}$ = parameter vector (px1).

The parameter vector $\underline{b}$ identifies a point in a p-dimensional space, the feasible domain of p parameters.

Each prediction η_i is an estimate of the true quantity studied, and each residual e_i is an estimate of the error existing in prediction and measurement. If a prediction function is perfect, then the residual is merely a measurement error. If the error is random and uncorrelated, it is often assumed to be normally distributed with a zero mean, and either constant or varying variances.

The sum of squares of residuals is expressed as:

$$S = \sum_{i=1}^{n}(e_i^2) = \underline{e}^T\underline{e} \qquad [191]$$

where S = sum of squares of residuals,

e_i = ith residual,

$\underline{e}$ = residual vector (nx1),

and $^{\tau}$ = denotation of matrix transpose.

For nonlinear problems, various optimization procedures have been developed. They can be classified into two categories: derivative-free methods and gradient methods. Gradient methods require evaluations of both regression functions and partial derivatives with respect to the statistical parameters. For example, ordinary least-squares estimation (OLS) for nonlinear problems gives:

$$\underline{b}^* = \underline{b} + (\underline{X}^{\tau}\underline{X})^{-1}\underline{X}^{\tau}\underline{e} = \underline{b} + \underline{P}\underline{X}^{\tau}\underline{e} \qquad [192]$$

where $\underline{b}^*$ = estimate of the parameter vector (px1),

$\underline{b}$ = guess of the parameter vector (px1),

$\underline{e}$ = residual vector (nx1),

$\underline{X}$ = sensitivity matrix (nxp),

and $\underline{P}$ = P matrix (pxp).

$$\underline{P} = (\underline{X}^{\tau}\underline{X})^{-1} \qquad [193]$$

$$\underline{X} = \underline{\nabla_{\beta}}\underline{\eta}^{\tau}(\underline{b}) = [X_{ij}] = [(\partial\eta/\partial b_j)_i] \qquad [194]$$

where $\underline{\nabla}_{\beta}$ = matrix derivative operator (px1),

$\underline{\eta}(\underline{b})$ = prediction function vector (nx1),

and X_{ij} = sensitivity coefficient.

The notation of $(\partial\eta/\partial b_j)_i$ means that the partial derivative is taken with respect to the jth parameter (j=1 to p) and evaluated for the ith observation (i=1 to n). In this study, sensitivity coefficients were approximated with forward finite differences:

$$X_{ij} = [\eta_i(\ldots,b_j+\Delta b_j,\ldots)-\eta_i(\ldots,b_j,\ldots)]/\Delta b_j \qquad [195]$$

where b_j = jth parameter,

and Δb_j = small increment of b_j.

Equation [192] shows that both the prediction function η and sensitivity coefficients need to be computed when OLS is applied. In addition, gradient methods also require the guess of the parameters to be within the neighborhood of their expected values. This is due to the Gauss linearization with truncated Taylor's series expansions which are commonly used in solving nonlinear problems. Kuster and Mize (1973) pointed out that when numerical derivative approximation is employed, the efficiency of derivative-free methods could be similar to that of gradient methods.

In this study, both derivative-free search and ordinary least-squares estimation were used. Because of the complexity of the problem studied, multimodolity of the sum squares of residuals in the p-dimensional space was assumed. Thus, a derivative-free procedure was applied first to search guesses of the parameter vector at which S was near its global minimum rather than a local minimum within feasible domains of the parameters. Then, ordinary least-squares estimation was used to improve the estimation and obtain some statistical information about the problem.

6.3 A Modified Simplex Search Procedure

The derivative-free procedure used in this study (program SEARCH, Appendix F) was a modification and combination of algorithms by Nelder and Mead (1964) and by Box (1965). Both of their algorithms have utilized a geometric figure, called simplex, with at least p+1 vertices. Each vertex is a point, representing a set of parameters, in the

p-dimensional space. Each coordinate of a vertex corresponds to a parameter value.

The algorithm of Box (1965) was developed to find the optimum of multivariable nonlinear functions subject to certain constraints. There can be explicit and implicit constraints. Explicit constraints are lower and upper limits of the parameters; implicit constraints are relationships among parameters. For the model of this study, it was assumed that:

$$3.0 \leq a \leq 5.9, \qquad 0.1 \leq b \leq 4.5, \qquad 1.5 \leq a-b \leq 4.4 \qquad [196]$$

These constraints implied that when leaves were completely dried (RWC=0.0), leaf resistance to moisture transfer could not be higher than $1.0\times10^{5.9}$ s/m, according to the assumption that leaf resistance of alfalfa was less than that of cotton. It also implied that alfalfa leaf resistance was at least $10^{1.5}$ s/m for freshly cut leaves (RWC=1.0).

A major feature of the Box algorithm is that it generates initial sets of parameters randomly chosen within their feasible domains, respectively. One initial point (set of parameters) is given by users based upon their justification, and the other points are generated by the algorithm according to given constraints. The random selection is very helpful to search the global optimum of an objective function.

The Box algorithm also checks the satisfaction of all given constraints whenever a new point is tried. If any explicit limit is violated, the corresponding parameter is moved a very small distance inwards from the violated boundary. If any implicit constraint is violated at a point, each of those parameters (coordinates) restricted by that constraint is moved by one half of the distance from the violating point toward the centroid of the other points. The check

process is repeated as necessary until all constraints are satisfied.

It may fall into an infinite loop, if the virtual centroid itself violates any implicit constraint. This situation is uncontrollable by users. In this study, a modification was made such that when an implicit constraint was violated, each violating coordinate (parameter) was moved by one half of the distance from its current position (value) toward the medium between its upper and lower limits. Mathematically, this can be expressed as:

$$b_{j,new} = 0.5(b_{j,old} + 0.5(bl_j + bh_j)) \quad [197]$$

where j = index of the parameter violating an implicit constraint,

$b_{j,new}$ = new coordinate (value) of the parameter,

$b_{j,old}$ = old coordinate (value) of the parameter,

bl_j = lower limit of the parameter,

and bh_j = upper limit of the parameter.

One can easily control the mediums by selecting appropriate ranges of bl_j's and bh_j's.

The algorithm by Nelder and Mead (1964) is an iterative procedure which repeatedly replaces worst vertices (parameter sets) with improved vertices and changes the shape and size of the simplex in the p-dimensional space until specified convergence criteria are reached. The term of 'worst vertex' refers to the vertex (point) at which the objective function has the worst value in comparison with other points around a particular simplex in an iteration. The intermediate goal of the replacement is to find an improved point which is at least better than the second-worst vertex in an iteration. The techniques used to search an improved point are reflection, contraction, expansion and shrinkage. Reflection, contraction or expansion is with respects to a

centroid, the center of all vertices other than the worst vertex. Expansion is useful in finding a global optimum since it searched outside a current simplex to avoid falling into a local optimum. Reflection and contraction were carried out in subprogram BROAD. Expansion was performed in subprogram EXPAND, and shrinking - in SHRINK.

In this study, some modifications were made to improve the original algorithm by Nelder and Mead (1964). It was noticed that each coordinate of any trial point was changed with the same proportion during reflection, contraction, expansion and shrinking, as described above. This was not adequate to locate an improved point in some cases. In these cases, an additional search was made in each dimension (coordinate, parameter) of the worst vertex. This individual parameter search was carried out in subroutine LINMIN. In LINMIN, efforts were made to find a better value of one particular parameter along its own scale while the other parameters were fixed. Geometrically, the individual search was along the axis of a particular coordinate in the p-dimensional space. This individual search was conducted on every adjustable parameter (some parameters can be fixed as desired).

If the individual search could not reach the iteration goal, the search turned to consider the centroid of the old simplex. The worst vertex was replaced with the centroid only if the centroid was better than the best vertex.

An iteration was terminated if the intermediate goal was reached or if all trials described above failed. In the latter case, i.e. the old simplex was retained for the next iteration, the worst and second-worst vertices were replaced with two randomly generated vertices. So, each

iteration began with a new simplex. The whole search process was terminated if it reached either a number of iterations, a convergence criterion, or a number of consecutive failures at fulfilling the iteration goal.

6.4 Ordinary Least-Squares Estimation of Parameters

In regression analysis, various techniques have been developed, such as ordinary least-squares estimation (OLS), weighted least-squares estimation (WLS), maximum likelihood estimation (ML), and maximum a posteriori estimation (MAP). Beck and Arnold (1977) pointed out that maximum a posteriori estimation (MAP) is a general form of parameter estimation. OLS, WLS or ML estimation is special cases of MAP estimation. Ordinary least-squares estimation is widely used in parameter estimation because it can be done without any statistical assumptions. With certain assumptions, some statistical information can also be obtained.

The resultant parameters, obtained from the global search presented in the preceding section, were used as guesses in a procedure of ordinary least-squares estimation. The algorithm used in this study was proposed by Beck (1985) and modified by the author. A list of FORTRAN code of the program ARNLIN is given in Appendix G. In Appendix H, a sample file of input parameter data required by SEARCH, ARNLIN and ALFDRY is given. The algorithm employed a technique of sequential estimation to avoid matrix inverse of $\underline{X}^T\underline{X}$ (in Equation [193]) and an interpolation method to refine the estimation. Detailed information of the algorithm can be found in Beck and Arnold (1977).

The MAP estimator can be expressed as:

$$\underline{b}^* = \underline{b} + \underline{P}[\underline{X}^T\underline{W}\underline{e}+\underline{U}(\underline{\mu}-\underline{b})] \quad [198]$$

where $\underline{b}^*$ = estimate of parameter vector (px1),

$\underline{b}$ = guess of parameter vector (px1),

$\underline{\mu}$ = mean parameter vector (px1),

$\underline{W}$ = inverse covariance matrix of observations (nxn),

$\underline{U}$ = inverse covariance matrix of parameters (pxp),

$\underline{e}$ = residual vector (nx1),

$\underline{X}$ = sensitivity matrix (nxp),

and $\underline{P}$ = P matrix (pxp),

$$\underline{P} = (\underline{X}^T\underline{W}\underline{X}+\underline{U}) \quad [199]$$

$$\underline{U} = \underline{V}^{-1}$$

$$\underline{W} = \underline{\psi}^{-1}$$

Where $\underline{V}$ and $\underline{\psi}$ are covariance matrices of parameters and observations, respectively.

Equations [188] and [189] of MAP estimation becomes identical to Equations [192] and [193] of OLS estimation when $\underline{W}$ is identity $\underline{I}_n$ and $\underline{U}$ is null. Vector $\underline{\mu}$ and matrices $\underline{V}$ and $\underline{\psi}$ are of prior statistical information.

For sequential estimation with a single response, Beck and Arnold (1977) derived the following sequence of equations:

$$\underline{A}(i) = \underline{P}(i-1)\underline{X}^T(i)$$

$$\Delta(i) = W(i)+\underline{X}(i)\underline{A}(i)$$

$$\underline{K}(i) = \underline{P}(i-1)\underline{X}^T(i)/\Delta(i) \qquad (i=1 \text{ to } n) \quad [200]$$

$$\underline{P}(i) = \underline{P}(i-1)-\underline{K}(i)\underline{X}(i)\underline{P}(i-1)$$

$$\underline{b}^*(i) = \underline{b}^*(i-1)+\underline{K}(i)\{e(i)-\underline{X}(i)[\underline{b}^*(i-1)-\underline{b}]\}$$

where $\underline{A}(i)$ = column vector (px1),

$\underline{K}(i)$ = column vector (px1),

$\underline{b}^*(i)$ = parameter vector with i data (px1),

$\underline{b}^*(i-1)$ = parameter vector with i-1 data (px1),

$\underline{b}$ = guess of parameter vector (px1),

$\underline{X}(i)$ = ith row vector of the sensitivity matrix (1xp),

$\underline{P}(i)$ = P matrix with i data (pxp),

$\underline{P}(i-1)$ = P matrix with i-1 data (pxp),

e(i) = ith residual (1x1),

W(i) = scale (1x1),

and W(i) = scale (1x1).

$$W(i) = W_{ii} = 1/\sigma^2 \qquad \text{for } W=\sigma^{-2}\underline{I}_n \qquad [201]$$

It is seen from Equation [201] that matrix inversion is replaced with scale division, and the sensitivity matrix is replaced with a row vector. This sequence of equations was processed during each iteration (see subroutine ARMAP). When i=1, $\underline{b}^*(0)=\underline{b}$ which was the guess of parameters, either initially given for the first iteration or obtained in a preceding iteration otherwise. However, the same initial matrices of $\underline{P}$ and $\underline{W}$ were used at the beginning of all iterations, because statistical information obtained could not be applied to the same data set.

In this study, it was assumed that $\sigma^2=1.0$, $\underline{W}=\underline{I}_n$ and the $\underline{P}$ matrix was diagonal. A very large value (10^7) was assigned to each diagonal element of $\underline{P}$ which indicated that the guess of parameters was uncertain since prior statistical information was unknown. The inverse of the P matrix was near null, therefore, a MAP estimate was reduced to an OLS estimate. Measured data were included into the sequential estimation one datum by one datum. Intermediate $\underline{P}$ matrix and $\underline{b}^*$ vector

were yielded accordingly. After a whole set of n data were processed, a new estimate of $\underline{b}$ as well as estimates of the $\underline{P}$ matrix and others were obtained.

Beck and Arnold (1977) showed that the $\underline{P}$ matrix is very important in parameter estimation. If $\underline{P}^{-1}$ is a nonsingular matrix, i.e. its determinant is nonzero, then the set of parameters can be estimated simultaneously. Otherwise, parameters are highly correlated or linearly dependent, which causes difficulties in estimation. The $\underline{P}$ matrix is related to the covariance matrix and the correlation matrix of parameters, and can be used to estimate confidence regions (or intervals) of parameters. For OLS estimation with standard assumptions (additive, uncorrelated errors with zero mean and constant variance), the covariance matrix of parameters is:

$$\underline{V}(\underline{b}) = s^2\underline{P} \qquad [202]$$

where $\underline{V}(\underline{b})$ = estimated covariance matrix of $\underline{b}$ (pxp),

$\underline{P}$ = P matrix (pxp),

and s^2 = estimated standard deviation of observations.

$$s^2 = S/(n-p) \qquad [203]$$

The correlation matrix of parameters is:

$$\underline{r} = [r_{jk}] = [P_{jk}/\sqrt{P_{jj}P_{kk}}] \qquad (j,k=1,2,\ldots,p) \qquad [204]$$

where $\underline{r}$ = correlation matrix of $\underline{b}$, (pxp)

r_{jk} = correlation coefficient,

P_{jk}, P_{jj} and P_{kk} = elements of $\underline{P}$.

It is noticed that the MAP estimator gives only the direction toward a stationary point which is necessary but not sufficient for determining an optimum for the sum of squares of residuals. Beck and Arnold (1977) also pointed out that the Gauss linearization may cause

oscillation and non-convergence for some nonlinear problems, thus, a refinement process is often added to nonlinear estimation. The interpolation method used by Beck (1985), however, does not ensure that the sum of squares of residuals decreases after refinement. In this study, a modified procedure was tried to reduce the problem (see subroutine REFINE).

In each iteration, the refinement was divided into two stages and began with the increment of vector b resulting from the sequential estimation described above.

$$\underline{\Delta b}^* = \alpha \underline{\Delta b} = \alpha(\underline{b}^* - \underline{b}) \qquad [205]$$

where $\underline{\Delta b}^*$ = adjusted increment vector of $\underline{b}$ (px1),

$\underline{\Delta b}$ = estimated increment vector of $\underline{b}$ (px1),

$\underline{b}^*$ = estimate of $\underline{b}$ (px1),

$\underline{b}$ = guess of $\underline{b}$ (px1),

and α = scale factor (1.0 to 0.01).

A quadratic form of the sum of squares of residuals with respect to α was assumed

$$S = S_1 + a_1 h + a_2 h \qquad [206]$$

where S = sum of squares of residuals,

S_1 = S at $\underline{b}$,

h = scale factor,

a_1 and a_2 = coefficients to be determined.

with

$$S = S_1 \qquad (h=0.0)$$

$$S_2 = S_1 + a_1\alpha + a_2\alpha^2 \qquad (h=\alpha)$$

$$S_3 = S_1 - a_1\alpha + a_2 2^2 \qquad (h=-\alpha)$$

These led to:

$$a_1 = 0.5(S_2-S_3)/\alpha \qquad [207]$$

$$a_2 = 0.5(S_2+S_3-2S_1)/\alpha \qquad [208]$$

If $a_2>0.0$, the geometry of Equation [206] was concave and, hence, a stationary point at which $\partial S/\partial h=0.0$ was found:

$$h = -a_1/2a_2 \qquad [209]$$

Otherwise, i.e. $a_2 \leq 0.0$, Equation [206] gave either a convex curve or a straight line. In this case, h was calculated as:

$$h = \begin{cases} \alpha & (S_2<S_3) \\ 0.0 & (S_1=S_2=S_3) \\ -\alpha & (S_2>S_3) \end{cases} \qquad [210]$$

Then, an adjusted parameter vector was found:

$$\underline{b}^{**} = \underline{b} + h\Delta\underline{b} \qquad [211]$$

Since the quadratic form was only an assumption, the sum of squares of residuals had to be checked to see whether $S(\underline{b}^{**})$ was actually smaller than $S(\underline{b})$. If not, α was halved, and the refinement process was repeated until either $S(\underline{b}^{**})<S(\underline{b})$ or $\alpha<0.01$. In the first stage of the refinement process above, the scale factor h was the same for each parameter, i.e. the adjusted parameter vector $\underline{b}^{**}$ was obtained by moving the guess vector b along the direction given by the MAP estimator presented earlier.

When the sum of squares of residuals did not decrease even for $\alpha<0.01$ in the first stage of the process, refinement of each individual parameter was conducted. This was the second stage of the refinement process. The procedure used in the second stage of refinement was the same as that in the first stage, however, only one parameter was allowed to vary at a time. Values of h_j (j=1 to p) could vary for different parameters. This meant that an adjusted parameter vector might be

obtained by moving the guess vector in a direction differing from that given by the MAP estimator.

$$\Delta b_j^* = \alpha_j b = \alpha_j (b_j^* - b_j) \qquad (j=1,\ldots,p) \qquad [212]$$

$$b_j^{**} = b_j + h_j \Delta b_j \qquad [213]$$

When a reduction in the sum of squares of residuals was reached, the estimation was forwarded to the next iteration which used the resultant adjusted parameter vector $\underline{b}^{**}$ as its guess vector. The entire estimation was finished when either a certain number of iterations were conducted or no reduction of the sum of squares of residuals was found in an iteration.

After the estimation, confidence intervals (regions) were constructed. Beck and Arnold (1977) gave a general form of confidence regions for nonlinear problems:

$$S(\underline{b}) = S_{min} + ps^2 F(1-\alpha;p,n-p) \qquad [214]$$

where $S(\underline{b})$ = tolerable sum of squares,

S_{min} = estimated minimum sum of squares,

p = number of parameters,

s^2 = estimated variance of observations,

F = F statistics,

n = number of observations,

$n-p$ = degree of freedom,

and $1-\alpha$ = confidence level.

This equation defines contours of the confidence regions, i.e. hypersurfaces. Any point (set of parameters) at which the sum of squares is not larger than $S(\underline{b})$ is within the confidence region. However, it is not as easy to determine an explicit confidence region with Equation [214] when p is greater than three or a problem is very

complicated, like the model of this study. Joint confidence intervals with the Bonferroni method (Neter and Wasserman, 1974) were, however, constructed in this study:

$$b-\Delta\beta_j \leq \beta_j \leq b_j+\Delta\beta_j \qquad (j=1,\ldots,p) \qquad [215]$$

where β_j = jth parameter,

b_j = estimate of β_j,

and $\Delta\beta_j$ = one half of the confidence interval of b_j.

$$\Delta\beta_j = s(b_j)t(1-\alpha/2p;n-p) \qquad [216]$$

where t = t statistics,

α = level of significance,

p = number of parameters,

n = number of observations,

and $s(b_j)$ = estimated standard error of b_j.

$$s(b_j) = \sqrt{s^2 P_{jj}} \qquad [217]$$

where s^2 = estimated standard deviation of observations,

and P_{jj} = jth diagonal element of P matrix.

Neter and Wasserman (1974) indicated that (1) the Bonferroni method tends to be correct more than $100(1-\alpha)$ percent of the time when covariance between each pair of parameters are large; however, (2) the Bonferroni approach does not utilize existing relationships among parameters. Geometrically, the Bonferroni family confidence intervals are hypercuboids in comparison with hypersurfaces. Nevertheless, the Bonferroni method is easy to apply and helpful for conveying information about the magnitudes of parameters.

The degree of the relationship between a dependent variable and its estimate with a regression model is often described with the adjusted coefficient of determination.

$$r^2 = 1-[(n-1)/(n-p)]SSE/SSTO \quad [218]$$

where r^2 = adjusted coefficient of determination,

n = number of observations,

p = number of parameters,

SSE = sum of squares of residuals,

and $SSTO$ = total sum of squares.

$$SSTO = \sum_{i=1}^{n}(y_i-\bar{y})^2 = \underline{Y}^T\underline{Y}-n\bar{y}^2 \quad [219]$$

where y_i = ith observation,

$\bar{y}$ = mean of n observations,

and $\underline{Y}$ = observation vector (nx1).

For a given set of data (i.e. known S and n) and a particular model (i.e. known p), the smaller the sum of squares of residuals, the higher the adjusted coefficient of determination. So, r^2 is a descriptive measure which interprets how much the total variation of a dependent variable is reduced by employing a set of parameters into that model.

6.5 Results of Parameter Estimation

As mentioned in Section 6.1, the statistical parameters of the model studied, might vary from trial to trial, according to the history of water stress that the alfalfa received before cutting, and other factors of the environment and the plant. In this study, alfalfa cut on the same day at the same site was assumed to bear a similar history of water stress, a similar maturity level in a similar environment. Based upon these, measured drying data was divided into nine groups (Table 6). Each group consisted of several trials with a similar initial moisture

content but different swath area densities cut on the same date. Trials of Group 1 were conducted during the second cutting in East Lansing, Michigan on July 23, 1984. Groups 2 to 4 were mown during the third cutting in the same area in August of 1984. The remaining groups were tested during the fourth cutting in Fresno, California in 1985. Due to lack of information, the ratio of leaf area index to yield for the fourth cutting of alfalfa in Fresno, California was assumed to be the same as that of the third cutting in Michigan (Table 2).

It was also thought that first-day's drying differed from successive-days' drying due to rewetting and redrying. Thus, two pairs of the parameters were tentatively designated. One pair (a and b) was for first-day's drying and the other pair (a_2 and b_2) was for successive-days' drying. Parameter estimation was conducted for nine trials (one from each group). Preliminary results showed that the introduction of the second pair of parameters was unnecessary. It did not reduce the sum of squares of residuals much, and it did cause difficulty with estimation. The sensitivity coefficients of a_2 and b_2 were very small in magnitude (in the order of thousandths of those of a). There were two columns of near null in the sensitivity matrices. This led to ill-conditioned P matrices and correlation matrices. Hence, the second pair (a_2 and b_2) was removed from the estimation.

The estimated parameters with 96% joint confidence intervals are shown in Table 7, and elements of the P matrices and estimated correlation coefficients are listed in Table 8.

It is observed from Table 7 that the estimated parameters varied among trials. This might be attributed to 1) inherent characteristics of the alfalfa plant, 2) the correlation between the parameters a and b,

Table 6 Grouping drying trials based upon the date of cutting

Group	Trial	Date	M_0	D	Bloom	L/Y
1	1	7/23-7/23/84	3.7719	0.4245	25%	5.300
	2		3.5471	0.2624		
	3		3.6842	0.5205		
	4		4.3121	0.3564		
2	5	8/14-8/16/84	3.4636	0.4481	0%	6.620
	6		3.4021	0.2766		
	7		3.6700	0.3349		
3	8	8/21-8/22/84	3.5889	0.2620	5%	6.620
	9		3.3506	0.4599		
	10		3.0579	0.4516		
	11		4.0177	0.4333		
4	12	8/30-8/31/84	2.6453	0.3292	8%	6.620
	13		2.6739	0.5444		
	14		3.6745	0.3905		
	15		4.4951	0.4189		
5	21	7/30-7/31/85	3.6850	0.4820	5%	6.620
	22	7/30-8/01/85	4.0000	0.8944		
	23	7/30-8/02/85	3.9750	2.0340		
	24	7/30-7/31/85	3.7250	0.4860		
	25	7/30-8/01/85	3.9300	0.9322		
	26	7/30-8/02/85	4.2200	1.9392		
	27	7/30-8/01/85	4.1100	1.2044		
6	28	7/31-8/01/85	3.0450	0.7206	45%	6.620
	29	7/31-8/02/85	3.3400	1.3458		
	30	7/31-8/02/85	3.3850	2.3758		
	31	7/31-8/01/85	2.6600	0.8380		
	32	7/31-8/02/85	2.8250	1.5612		
	33	7/31-8/02/85	2.9550	2.5840		
7	34	8/02-8/03/85	3.1550	0.7724	35%	6.620
	35		3.2150	1.4960		
	36		3.4600	2.2452		
8	37	8/03-8/04/85	2.9350	0.7866	40%	6.620
	38		3.1450	1.5754		
	39		3.1700	2.5390		
9	40	8/05-8/06/85	3.1100	0.9305	100%	6.620
	41		3.2500	1.5535		
	42		3.4650	2.2950		
	43		3.0150	0.7360		
	44		3.1700	1.5780		
	45		3.3700	2.3608		

Initial moisture content (M_0) - kg water/kg dry matter
Swath area density (D) - kg dry matter/m^2
Leaf area index/yield (L/Y) - m^2 leaf/kg dry matter

Table 7 Estimated parameters (a and b) with 96% confidence intervals, the sum of squares of residuals (SSE) and the adjusted coefficient of determination (r^2) for nine selected trials

Group	Trial	a	b	SSE	r^2
1	4	4.539 0.315	1.464 0.399	0.010	0.998
2	5	5.094 0.118	2.237 0.306	0.703	0.948
3	9	4.834 0.390	1.831 0.968	0.208	0.981
4	13	4.879 0.152	1.760 0.341	0.122	0.979
5	25	4.427 0.180	1.102 0.334	0.278	0.982
6	32	3.963 0.075	0.320 0.152	0.209	0.973
7	35	4.238 0.218	0.843 0.462	0.440	0.938
8	38	4.495 0.235	2.560 0.275	0.232	0.970
9	44	4.232 0.411	2.456 0.548	0.042	0.992

Table 8 Elements of the P matrix (P_{aa}, P_{ab} and P_{bb}), the correlation coefficient (r_{ab}), the standard deviation (s^2) and the number of observations (n) for the nine selected trials

Group	Trial	P_{aa}	P_{ab}	P_{bb}	r_{ab}	s^2	n
1	4	1.6078	1.9342	2.5773	0.958	0.003	5
2	5	0.0771	0.1659	0.5157	0.832	0.029	26
3	9	1.5019	3.6899	9.2653	0.989	0.015	16
4	13	0.3851	0.8136	1.9373	0.942	0.009	16
5	25	0.2164	0.3797	0.7412	0.948	0.021	15
6	32	0.0449	0.0213	0.1850	0.234	0.017	14
7	35	0.1216	0.2062	0.5485	0.798	0.049	11
8	38	0.2696	-0.1093	0.3678	-0.347	0.026	11
9	44	2.2903	-0.8989	4.0677	-0.295	0.009	10

and 3) other factors. In Table 8, five out of nine values of r_{ab} were below 0.9 which is a critical value commonly used for declaration of high correlations (Beck and Arnold, 1977). Although r_{ab} was mostly higher than 0.9 for the data of East Lansing, Michigan, it spread widely for those of Fresno, California. These showed that a and b were intercorrelated to an extent. However, the inconsistency of the high value of r_{ab} suggested other influences on the variation of the

parameters. During the sequential estimation, intermediate results showed that the parameters a and b varied from time to time as each case of observed data was included. This meant that these two parameters were probably a function of time or the moisture content of the alfalfa plant. Also as expected, the parameters varied among trials. At present, the variation pattern of the parameters was not clearly exposed with the limited experiments of this study. Thorough physiological study of the alfalfa plant before and after cutting is required, which is beyond the scope of this study. The accuracy and detail of the measured data and other information used in this study might also affect the estimation results. For example, some measurements were taken during night periods in East Lansing, Michigan. These observations gave information on the progress of swath rewetting. By using the technique of sequential estimation, these data were helpful to adjust the estimates of a and b accordingly. Information on the local weather and plant characteristics for Fresno, California was not sufficient. As mentioned earlier, some characteristics were assumed or assigned to be the same as those of East Lansing, Michigan.

The estimated 96% joint confidence intervals were quite small. Most of them ranged from 4% to 60% of the magnitude of the respective parameter. The 96% confidence interval for parameter a was smaller than that of parameter b, as seen in Table 7. This was attributed mostly to the difference in the main diagonal elements of the P matrix, which indicated that the estimate of a was more certain than that of b, since the correlation between these two parameters affected the estimation.

Neter and Wasserman (1974) pointed out that high correlations often cause difficulties in parameter estimation and may lead to erratic

inferences on estimated parameters, however, the high correlations are usually not a problem when inferences on the response functions or predictions of future observations are made within the range of the observations used to determine the parameters. For this study, the initial moisture content of alfalfa and the area density of the swath varied over wide ranges normally encountered in hay production. It was expected that predictions made by using the model with these estimated parameters would not lead to erroneous outcomes. This will be shown during model validation in the next chapter.

Since the results of parameter estimation showed deviations between various trials, it was necessary to test whether those differences were significant. An F-test showed that the 4 trials (Trials 4, 5, 9 and 13) selected from the East Lansing group most likely had a common variance with a 95% confidence. Similar hypotheses were concluded for the 5 trials (Trials 25, 32, 35, 38 and 44) selected from the Fresno group, and for all the 9 trials. Another F-test indicated that the 4 East Lansing trials could be pooled together to have one common pair of the parameters a and b with a 95% confidence. However, a hypothesis that the 5 Fresno trials had separate pairs of the parameters a and b could not be rejected at the same confidence level. Consequently, the 9 trials from both locations would not have a common pair of the parameters a and b.

Figures 22 to 30 show simulated drying curves for the nine trials. In Appendix I, a sample output of ARNLIN for Trial 5 is given.

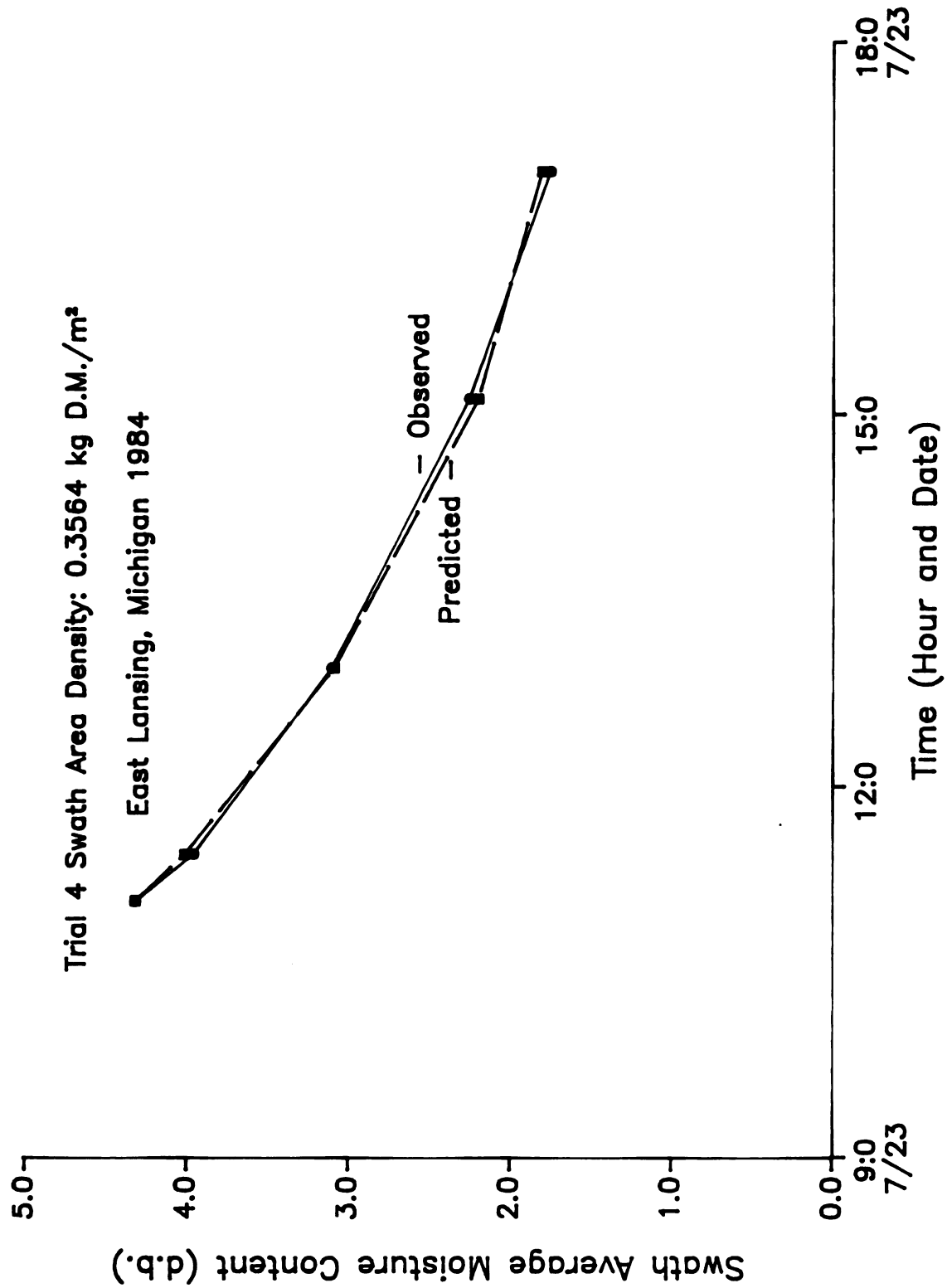

Figure 22. Predicted and observed drying curves for Trial 4 with parameter a=4.539 and b=1.464.

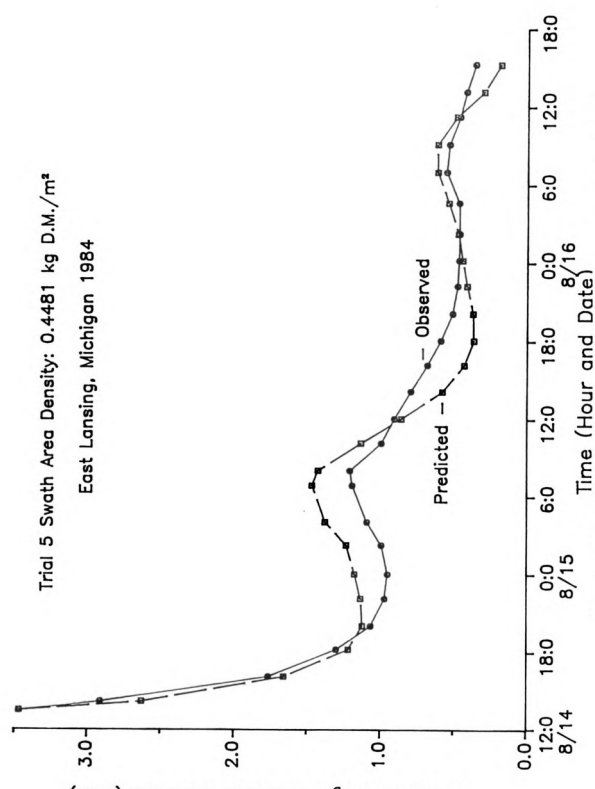

Figure 23. Predicted and observed drying curves for Trial 5 with parameter a=5.094 and b=2.237.

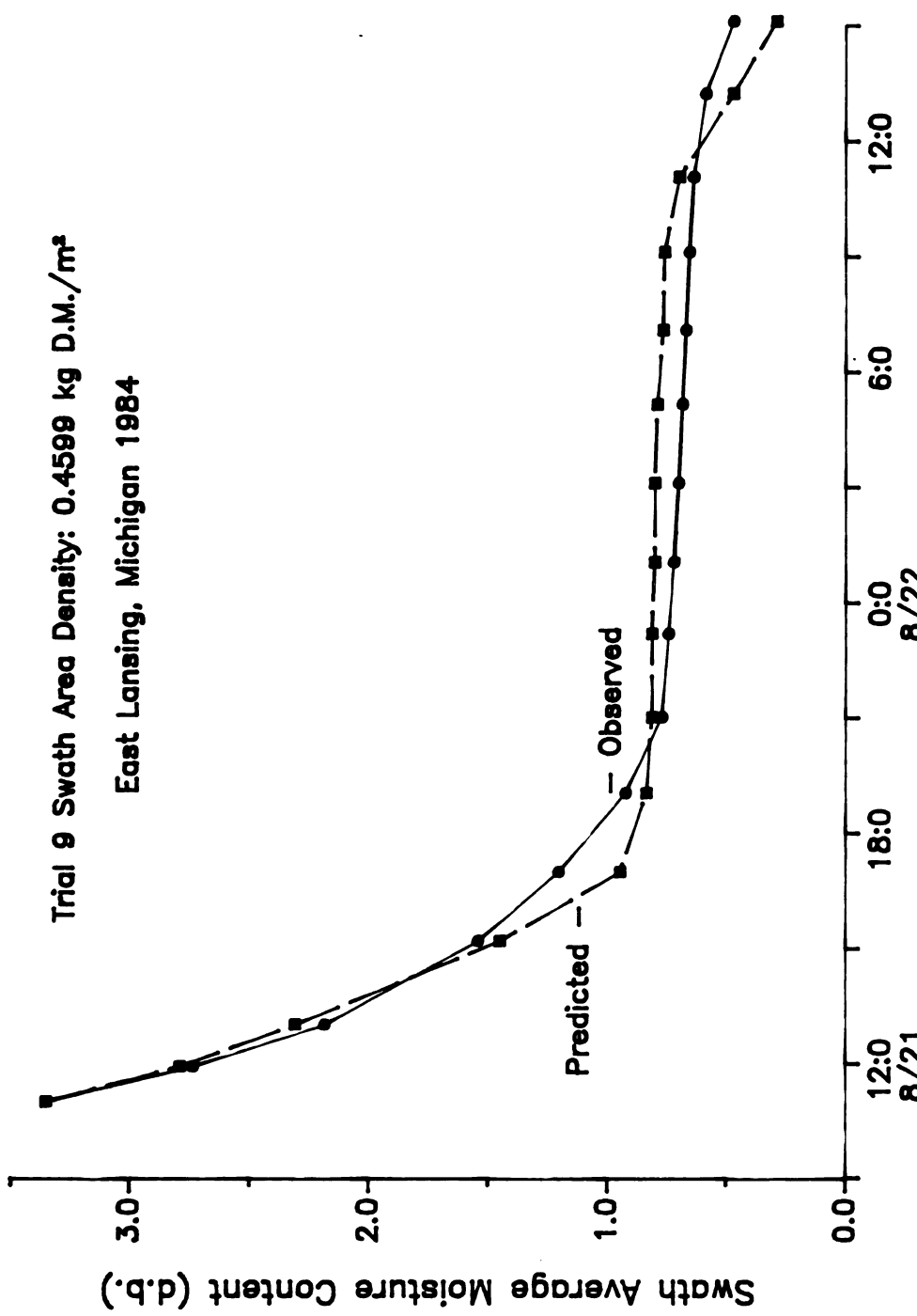

Figure 24. Predicted and observed drying curves for Trial 9 with parameter a=4.834 and b=1.831.

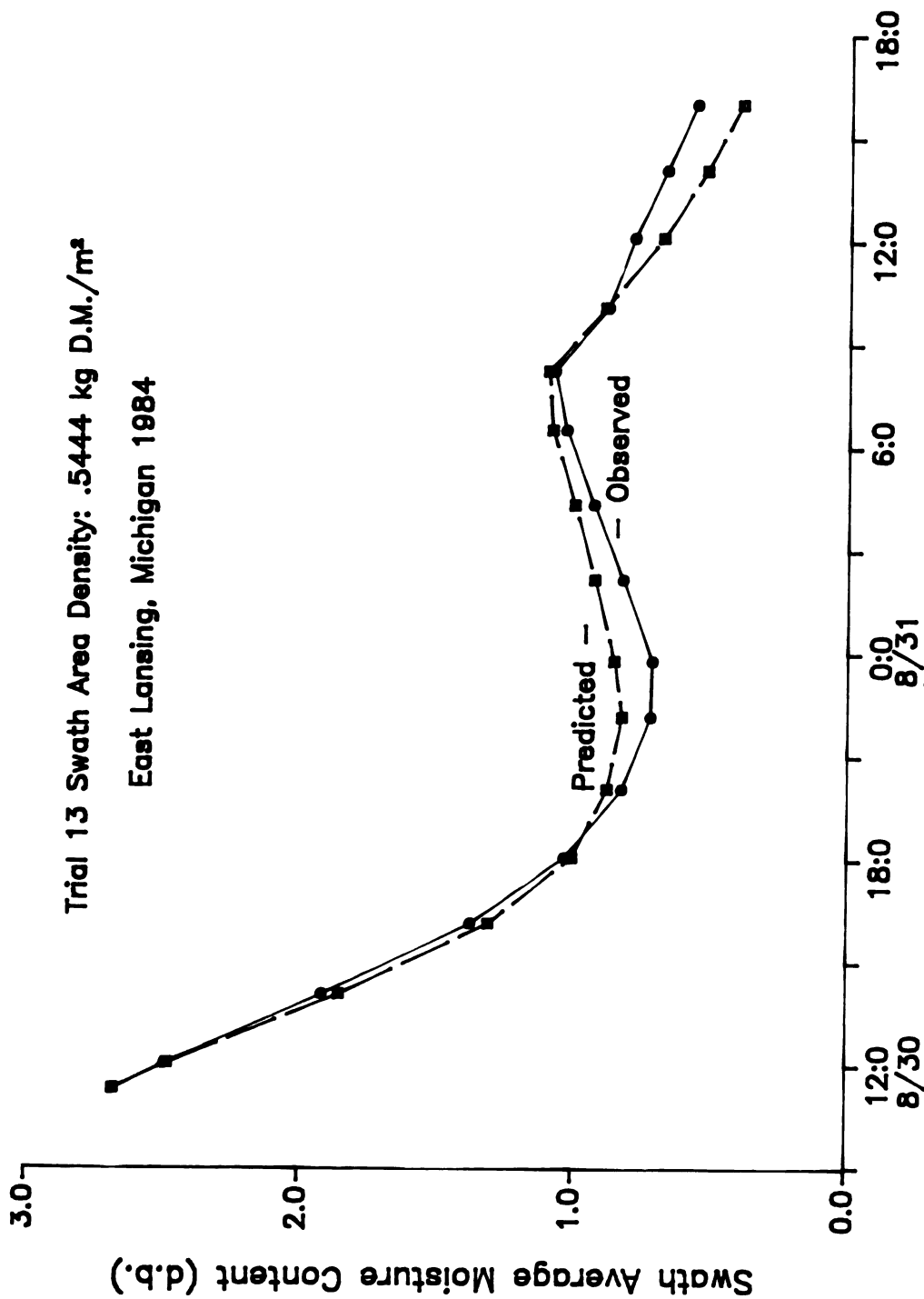

Figure 25. Predicted and observed drying curves for Trial 13 with parameter a=4.879 and b=1.760.

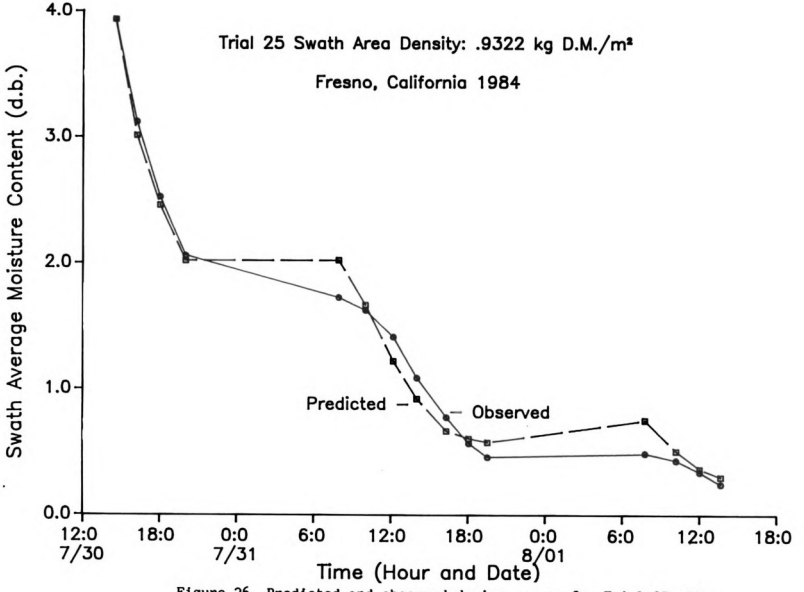

Figure 26. Predicted and observed drying curves for Trial 25 with parameter a=4.427 and b=1.102.

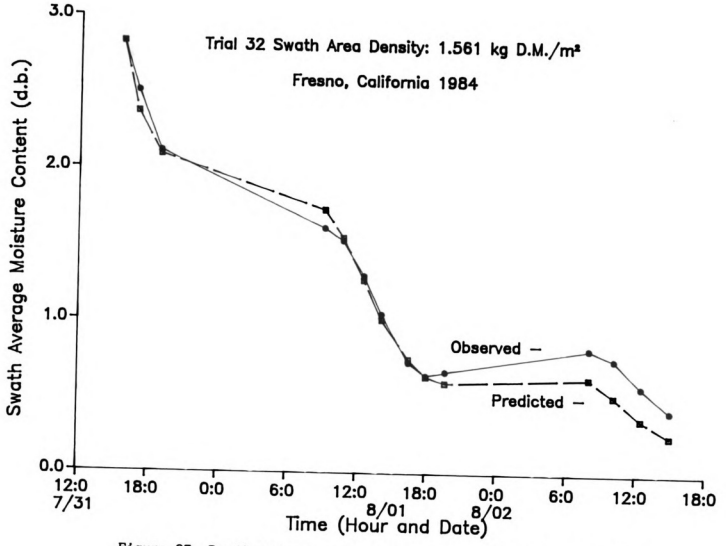

Figure 27. Predicted and observed drying curves for Trial 32 with parameter a=3.393 and b=0.320.

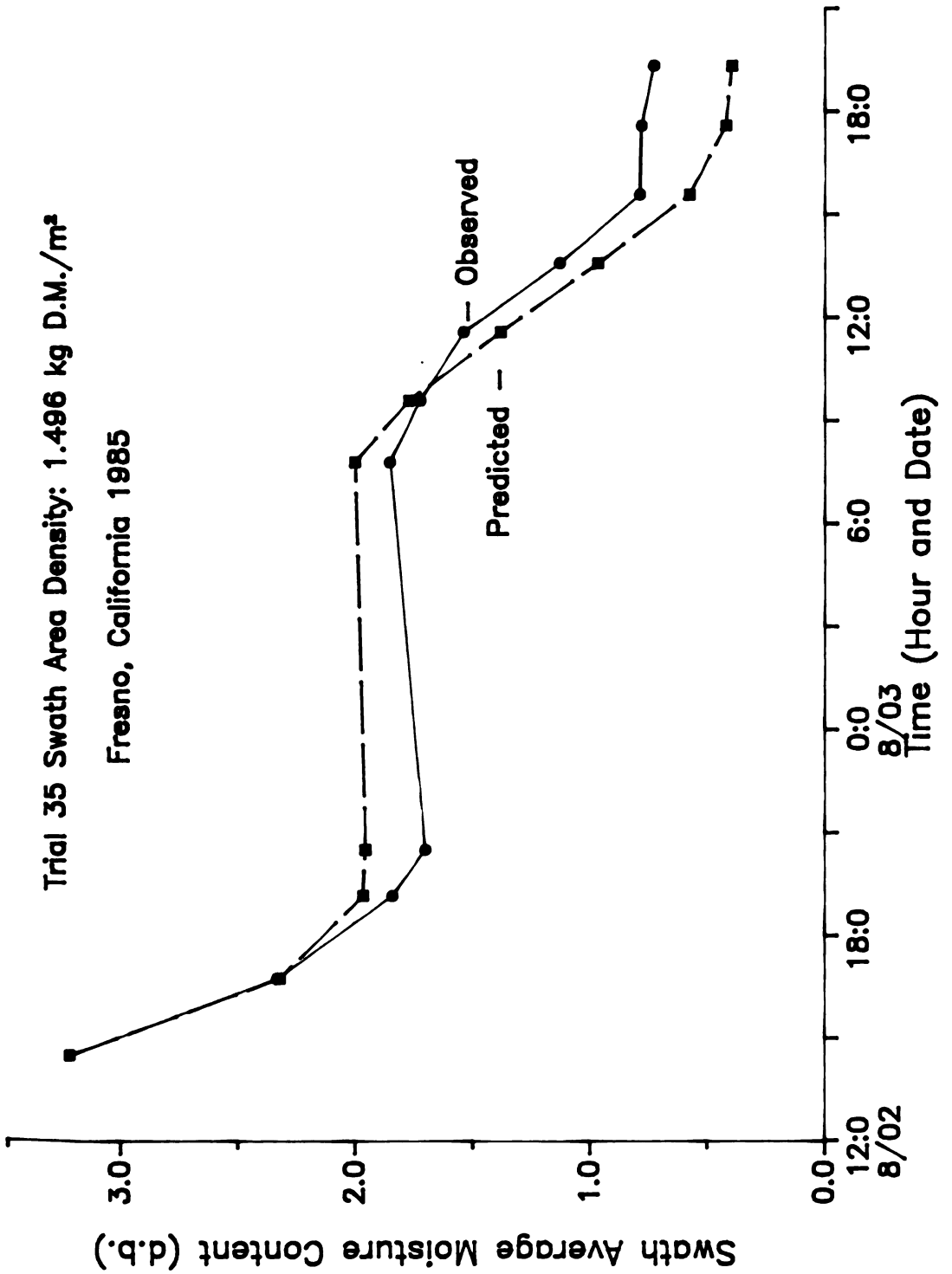

Figure 28. Predicted and observed drying curves for Trial 35 with parameter a=4.238 and b=0.843.

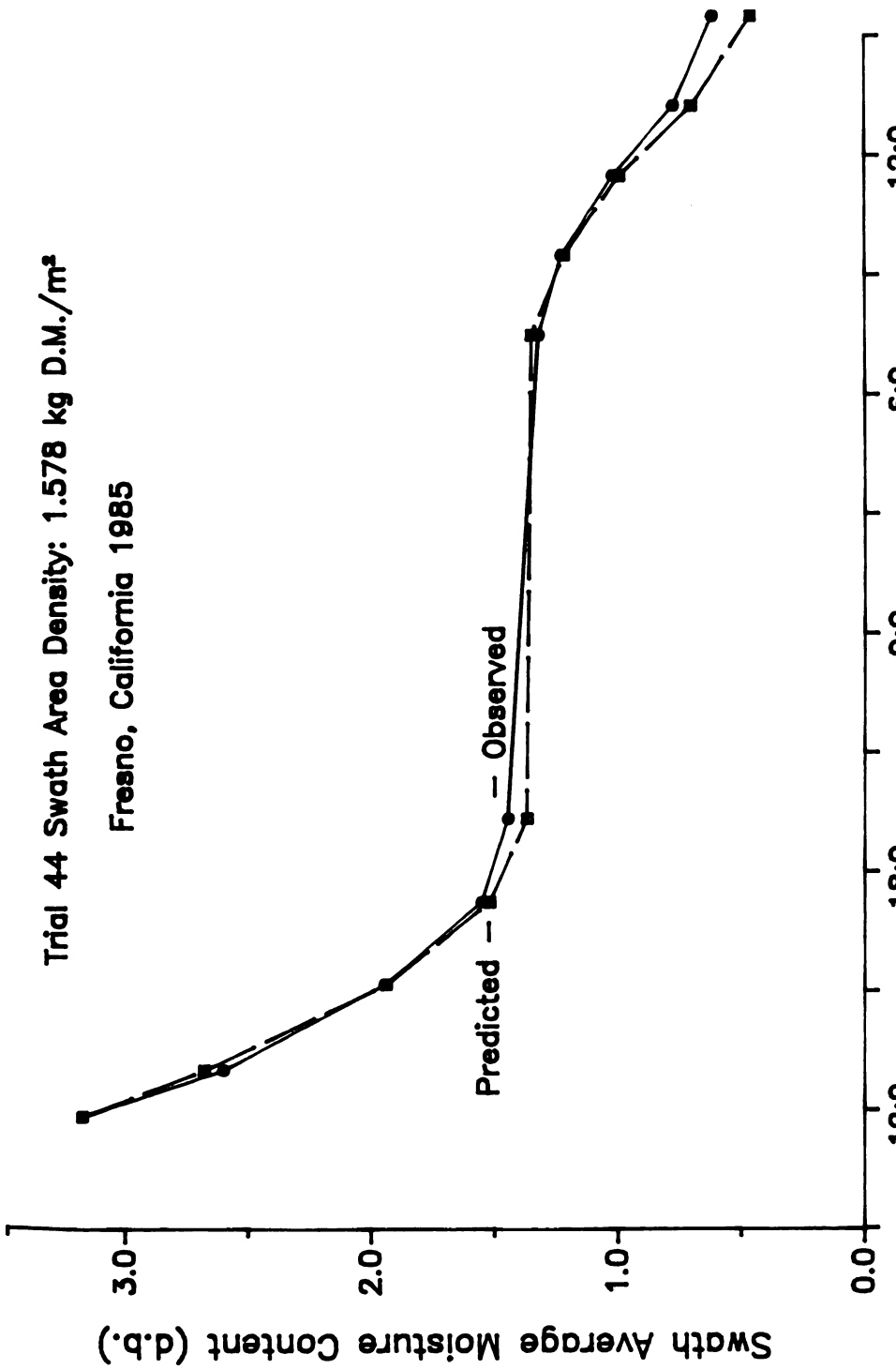

Figure 30. Predicted and observed drying curves for Trial 44 with parameter a=4.232 and b=2.456.

CHAPTER 7

MODEL VALIDATION AND SENSITIVITY ANALYSIS

Through parameter estimation, the model was fitted to a portion of observed drying data. This was illustrated by low values for the sum of squares of residuals (SSE) and high values for the adjusted coefficient of determination (r^2) listed in Table 7, and shown in Figures 22 to 30. Further tests on the model were needed to see how well it predicted other observations, and to find how sensitive it was to disturbances in important parameters and variables. In this chapter, validation and sensitivity analysis of the model are presented.

7.1 Model Validation

Validation of the studied model was performed through simulating field drying of the remaining 31 trials (381 observations) not used in parameter estimation. Inferences were made based upon the simulation results from all trials and observations. The trials were distinguished in several different ways: by cutting date, by location and by the entirety. The entire experiment of this study consisted of 2 location groups, 9 cutting date groups, 40 trials and 505 observations. The East Lansing group included 4 date groups (Groups 1 to 4), 15 trials (Trials 1 to 15) and 190 observations; and the Fresno group - 5 date groups (Group 5 to 9), 25 trials (Trials 21 to 45) and 315 observations.

The model's performance was tested through 4 treatments. Three treatments dealt with the selection of the parameters a and b based upon the cutting date, the location or the whole experiment. During these three treatments when various values of the parameters a and b were used, the sum of squares of residuals (SSE) and the adjusted coefficient of determination (r^2) were examined for each individual trial. The overall performance for the population of each date group, each location group and the whole experiment was also summarized. The fourth treatment was the use of weather data from the local weather service instead of those from field measurements. Trial 5 was selected to test the model's predictability with the use of data from the local weather service.

Table 9 cites minimum values of r^2 for various sample sizes from Wang (1977). For a preferred confidence level (α) and a known sample size (n), a regression model with two parameters can be declared to be meaningful, if it results in an r^2 above a corresponding value given in the table. As discussed earlier in the preceding chapter, it is preferred to have r^2 as close to unity as possible. Note that the coefficient of determination used in construction of Table 9 is the ordinary definition of r^2:

$$r^2 = 1 - SSE/SSTO \qquad [220]$$

where r^2 = coefficient of determination,

SSE = sum of squares of residuals,

and SSTO = total sum of squares.

The adjusted coefficient of determination defined in Equation [218] is always smaller than the ordinary coefficient of determination unless SSE is zero, i.e. r^2 is unity - a perfect model. Inferences would be

Table 9 Minimum values of the coefficient of determination (r^2) for declaration of regression models with two parameters†

n-2	α=5%	α=1%	n-2	α=5%	α=1%	n-2	=5%	=1%
1	0.997	1.000	16	0.468	0.590	35	0.325	0.418
2	0.950	0.990	17	0.456	0.575	40	0.304	0.393
3	0.878	0.959	18	0.444	0.561	45	0.288	0.372
4	0.811	0.917	19	0.433	0.549	50	0.273	0.354
5	0.754	0.874	20	0.423	0.537	60	0.250	0.325
6	0.707	0.834	21	0.413	0.526	70	0.232	0.302
7	0.666	0.798	22	0.404	0.515	80	0.217	0.283
8	0.632	0.765	23	0.396	0.505	90	0.205	0.267
9	0.602	0.735	24	0.388	0.496	100	0.195	0.254
10	0.576	0.708	25	0.381	0.487	125	0.174	0.228
11	0.553	0.684	26	0.374	0.478	150	0.159	0.208
12	0.532	0.661	27	0.367	0.470	200	0.138	0.181
13	0.514	0.641	28	0.361	0.463	300	0.113	0.148
14	0.497	0.623	29	0.355	0.456	400	0.098	0.128
15	0.482	0.606	30	0.349	0.449	1000	0.062	0.081

† From Wang (1977)

conservative if they are made by comparing values of the adjusted coefficient of determination with those of Table 9.

7.1.1 Validation by Nine Cutting Date Groups

The performance of the model in predicting drying of alfalfa cut on the same date under various conditions of the swath and the plant was evaluated first. Each trial of the nine date groups was simulated by use of one respective set of estimated parameters (Table 7) along with other swath and plant conditions (Table 6 in Chapter 6). As a sample, data of the average swath moisture content (both measured and simulated) and residuals for Trial 5 are given in Appendix J. A summary of the total sum of squares (SSTO), the sum of squares of residuals (SSE) and the adjusted coefficient of determination (r^2) for the

population of each trial, date group, location and the whole experiment is shown in the left three columns of Table 10.

Under this treatment, the adjusted coefficient of determination (r^2) ranged from 0.657 to 0.998 among the 40 trials with sample populations from 4 to 26, and from 0.809 to 0.973 among the nine date groups with various sample sizes from 17 to 106. It was seen that most of these r^2 values were much higher than those required for the 99% confidence (Table 9). As for individual trials, only Trial 2 resulted in an r^2 value (0.760) slightly below 0.811 for 95% confidence; however, the ordinary r^2 of Trial 2 was 0.84 which was above 0.811. Trials 6 and 8 also had relatively low r^2 in comparison with other trials in Date groups 2 and 3, respectively. It should be noted that these three trials were conducted with extremely low swath densities, 0.2620 to 0.2776 kg dry matter/m^2. For trials in Fresno, California, Trials 30, 33, 36, 39, 42 and 45 showed relatively low r^2 values and had the highest swath density, 2.245 to 2.584 kg dry matter/m^2. For the remaining trials with the swath density between 0.3292 and 1.9392 kg dry matter/m^2, the performance of the model was good and resulted in r^2 values from 0.850 to 0.998 with a majority above 0.90. In every date group, except Group 7, there was one or two trial(s) resulting in the same or better r^2 than the respective one from those nine selected trials.

The r^2 values for the East Lansing group (0.960), the Fresno group (0.921) and the entire experiment as a whole (0.937), were sufficiently high. These results presented above show that all observed drying processes were closely simulated by using the model with the nine sets of estimated parameters.

Table 10 Summary of the total sum of squares (SSTO), the sum of squares of residuals (SSE) and the adjusted coefficient of determination (r^2) from three treatments of validation

				Date		Location		Entirety	
Group	Trial	n	SSTO	SSE	r^2	SSE	r^2	SSE	r^2
	1	4	4.31	0.30	0.894	0.47	0.837	0.38	0.869
	2	4	4.37	0.70	0.760	0.90	0.691	0.77	0.735
	3	4	3.37	0.02	0.991	0.02	0.990	0.02	0.990
	4	5	4.81	0.01	0.998	0.04	0.990	0.03	0.993
1		17	19.15	1.03	0.942	1.43	0.920	1.20	0.933
	5	26	14.06	0.70	0.948	1.16	0.914	1.44	0.893
	6	26	12.87	1.60	0.870	0.97	0.922	0.86	0.930
	7	19	14.79	0.70	0.950	0.79	0.943	0.93	0.933
2		71	42.77	3.01	0.929	2.92	0.931	3.23	0.923
	8	16	12.92	1.58	0.869	1.68	0.861	1.26	0.895
	9	16	11.42	0.21	0.981	0.21	0.980	0.22	0.979
	10	10	8.75	0.15	0.980	0.16	0.979	0.13	0.983
	11	10	11.03	0.17	0.982	0.18	0.982	0.21	0.978
3		52	47.46	2.11	0.955	2.23	0.952	1.82	0.961
	12	16	6.36	0.46	0.923	0.21	0.964	0.16	0.972
	13	16	6.22	0.12	0.979	0.22	0.961	0.31	0.947
	14	9	7.49	0.54	0.918	0.20	0.970	0.14	0.979
	15	9	7.31	0.27	0.958	0.84	0.869	1.07	0.832
4		50	47.80	1.38	0.970	1.47	0.969	1.68	0.964
E. Lansing		190	190.70	7.53	0.960	8.06	0.958	7.93	0.958
	21	9	7.73	0.41	0.939	0.61	0.910	0.28	0.959
	22	15	15.54	0.38	0.974	0.82	0.943	0.41	0.972
	23	21	20.45	0.81	0.959	1.07	0.945	1.12	0.942
	24	9	9.01	0.28	0.965	0.48	0.939	0.35	0.955
	25	15	16.56	0.28	0.982	0.52	0.966	0.42	0.973
	26	21	23.35	0.76	0.966	1.16	0.948	0.89	0.960
	27	16	20.68	0.24	0.988	0.34	0.983	0.25	0.987
5		106	118.30	3.16	0.973	5.00	0.957	3.72	0.968
	28	10	6.39	0.85	0.850	0.20	0.966	0.04	0.992
	29	15	10.19	0.22	0.977	0.19	0.980	0.10	0.989
	30	16	10.45	3.34	0.657	2.39	0.755	3.13	0.679
	31	9	5.15	0.52	0.885	0.86	0.810	0.48	0.894
	32	14	8.49	0.21	0.973	0.35	0.956	0.27	0.966
	33	20	12.90	3.25	0.734	3.01	0.753	3.61	0.704
6		84	55.26	8.40	0.846	7.00	0.875	7.63	0.860
	34	9	5.77	0.53	0.896	0.88	0.825	0.37	0.926
	35	11	7.88	0.44	0.938	0.49	0.931	0.74	0.896
	36	16	13.61	4.17	0.672	4.52	0.644	4.51	0.645
7		36	27.70	5.14	0.809	5.89	0.801	5.62	0.790
	37	6	5.38	0.03	0.994	0.02	0.996	0.07	0.984
	38	11	8.66	0.23	0.970	0.25	0.968	0.45	0.943
	39	12	8.81	1.89	0.764	2.04	0.745	2.61	0.674
8		29	23.13	2.15	0.904	2.31	0.896	3.13	0.860
	40	9	6.66	0.25	0.958	1.71	0.707	2.35	0.597
	41	10	7.14	0.16	0.975	1.77	0.721	2.78	0.562
	42	11	7.86	1.05	0.852	3.49	0.506	4.28	0.395
	43	9	6.38	0.47	0.916	0.75	0.865	1.32	0.763
	44	10	6.45	0.04	0.992	0.91	0.842	1.49	0.740
	45	11	7.08	1.11	0.827	3.01	0.528	3.55	0.443
9		60	45.42	3.07	0.931	11.04	0.739	15.77	0.647
Fresno		315	277.50	21.92	0.921	31.85	0.885	35.89	0.870
Overall		505	469.12	29.45	0.937	39.91	0.914	43.82	0.906

7.1.2 Validation by Two Location Groups

It is not convenient to use the model with a series of statistical parameter sets for predicting future drying cases. Therefore, the second treatment was to check the model's performance with two sets of statistical parameters for two locations of this study. The set of parameters for the East Lansing group was obtained by another run of parameter estimation with the joined population (63 observations) from Trials 4, 5, 9 and 13. This was due to the inference about the common parameters for the East Lansing group (see the preceding chapter). Even though the inference did not favor a common pair of parameters for the Fresno group, as described in the previous chapter, a set of parameters a and b was also obtained from regression of the combined population of Trials 25, 32, 35, 38 and 44 (61 observations). Table 11 gives values of these two sets of parameters. Simulation results for each location group are summarized in the middle two columns of Table 10.

The resultant SSE (8.06) and r^2 (0.958) from employing one single set of parameters for the whole East Lansing group were almost the same as those (SSE=7.53 and r^2=0.960) obtained under the previous treatment with four sets of parameters. Similar tendency was found for Date groups 1 to 4 under this treatment. For Trials 1, 2, 5, 13 and 15, SSE was increased somewhat, so r^2 decreased. Trials 6 and 14, inversely, resulted in decreases in SSE and increases in r^2.

For the Fresno group as a whole, SSE was markedly increased from 21.92 to 31.85, and thus, r^2 was reduced from 0.921 to 0.885, but r^2 was still much higher than the minimum required (Table 9). Increases in SSE and decreases in r^2 were observed from all date groups of the Fresno

Table 11 The sets of the statistical parameters (a and b) used during model validation

Treatment		a	b
Cutting Date	1	4.539	1.464
	2	5.094	2.237
	3	4.834	1.831
	4	4.879	1.760
	5	4.427	1.102
	6	3.963	0.320
	7	4.238	0.843
	8	4.975	2.560
	9	4.232	2.456
Location	East Lansing	4.836	1.822
	Fresno	4.730	1.883
Entirety Population		4.823	1.849

group, especially Group 9. Increases in SSE were substantial for all trials in Date group 9. The r^2 value of Trial 42 (0.506) was below the minimum 0.602 (Table 9). These noticeable differences in the simulation results between the two location groups may be attributed to three reasons. First, the swath density for the Fresno group varied over a very wide range from 0.482 to 2.584 kg dry matter/m^2, in comparison with that from 0.262 to 0.544 kg dry matter/m^2 for the East Lansing group. Secondly, information needed by the model was less accurate for the Fresno group than the East Lansing group. Thirdly, there was no overnight measurement of tray weights during the test period in Fresno, California. All five sets of parameters for trials of this location were estimated without adjustment to rewetting information. This affected the performance of the model predicting drying alfalfa in that specific area. Nevertheless, all 25 date groups, and the Fresno group as a whole still had r^2 values from 0.739 to 0.957 which were

sufficiently higher than those respective minimum values (Table 9).

For the entire experiment population, SSE increased from 29.45 to 39.91, r^2 decreased from 0.937 to 0.914. This value was still good due to the large SSTO (469.12) and the large sample size (505).

The results of the second treatment indicated that it would be possible to apply one set of statistical parameters to the model for making reasonably accurate predictions of field drying of alfalfa at a particular location.

7.1.3 Validation by the Entire Experiment as a Whole

Furthermore, the third treatment was to use a single set of statistical parameters for all observations of this study. This set of parameters (Table 11) was obtained from a regression of all 9 selected trials (124 observations). Simulation results are summarized in the right two columns of Table 10.

Regarding the entire experiment as a whole, SSE was slightly increased to 43.82, and r^2 changed slightly to 0.906 in comparison with those from the second treatment. For the East Lansing group as a whole, SSE (7.93) was nearly unchanged from those (7.53 and 8.06) of the first and second treatments, respectively; and r^2 remained around 0.96. For the Fresno group, SSE was slightly increased to 35.89 from 31.85 of the second treatment, so r^2 changed a little from 0.885 to 0.870.

As to individual date groups, Groups 3 and 5 had reduced SSE and improved r^2 from those of the second treatment, respectively. Group 3 had the lowest SSE and the highest r^2 under this treatment compared to the other two treatments. Group 9 had an increase in SSE and a

decrease in r^2. Increases in SSE for Groups 2, 4 and 9 were quite significant.

Among the forty trials, Trials 6, 8, 10, 10, 12, 14, 21, 28 and 29 had the lowest SSE and the highest r^2 under this treatment relative to the other two. Values of SSE and r^2 for Trials 2 and 15 of the East Lansing group, and Trials 33 and 40 to 45 of the Fresno group were the worst under the third treatment. The r^2 values of Trials 2 (0.735), 40 (0.597), 41 (0.562), 42 (0.395) and 45 (0.443) were below the minimum values given in Table 9, respectively. For the remaining trials, results under the third treatment were between those from the other two treatments discussed above. It should be pointed out that the two field experiments of this study are 4000 km apart with different climates, soils, patterns of alfalfa growth and hay production. The performance of the model using one set of parameters to simulate field drying cases at both locations was good.

Figures 31 to 33 show scatter diagrams of observed versus predicted drying data. The relationship between field measured and model predicted data was described with a linear function:

$$MC_m = \alpha + \beta MC_p \qquad [221]$$

where MC_m = measured average swath moisture content,

MC_p = predicted average swath moisture content,

α = interception of the line,

and β = slope of the line.

Table 12 lists values of α and β for the East Lansing group, the Fresno group and the the entire experiment from the results of the three treatments. If the model was perfect, α and β would be zero and unity,

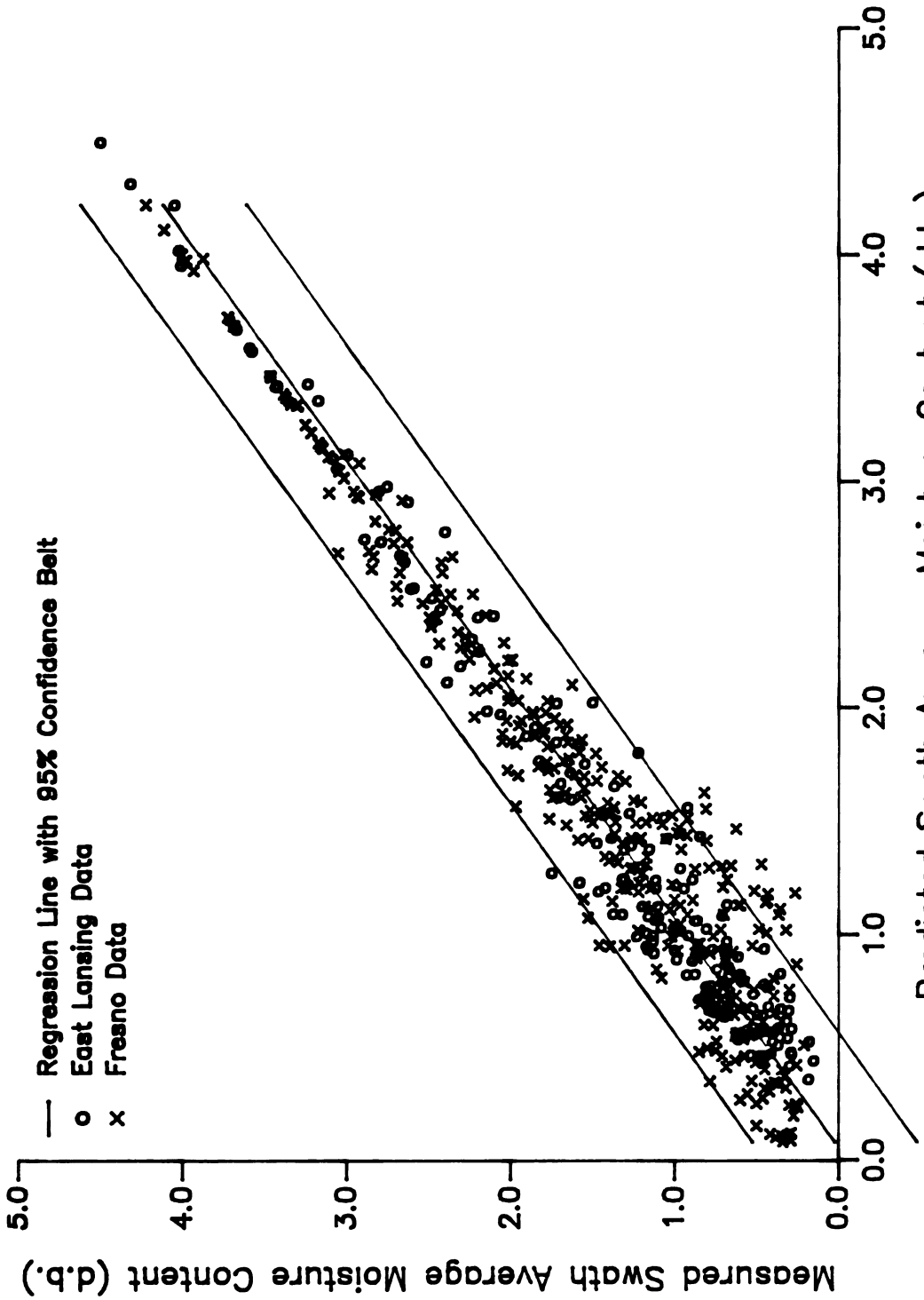

Figure 31. Measured versus simulated average swath moisture content with nine sets of statistical parameters over a range of field conditions in East Lansing, Michigan and Fresno, California.

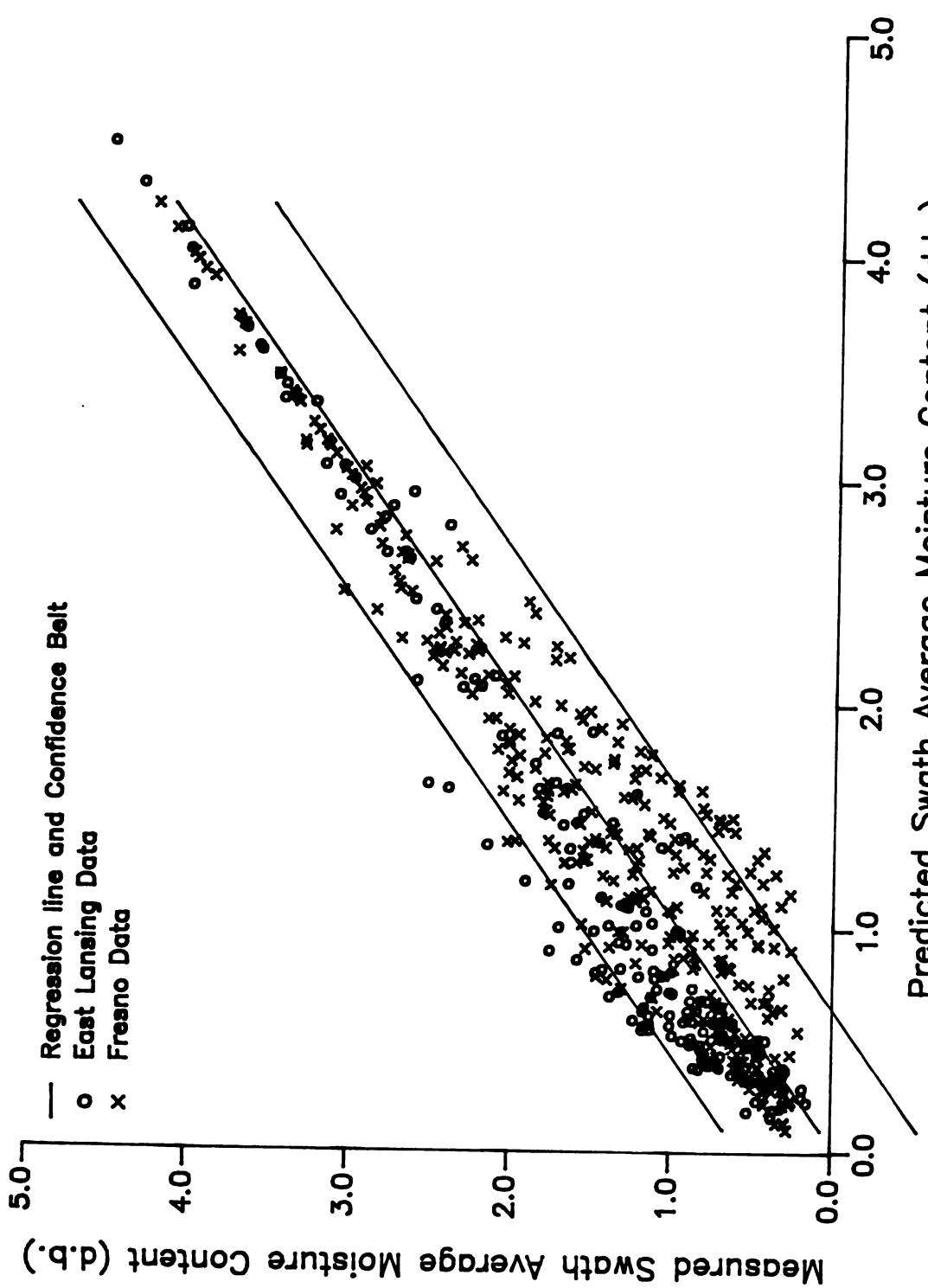

Figure 32. Measured versus simulated average swath moisture content with two sets of statistical parameters over a range of field conditions in East Lansing, Michigan and Fresno, California.

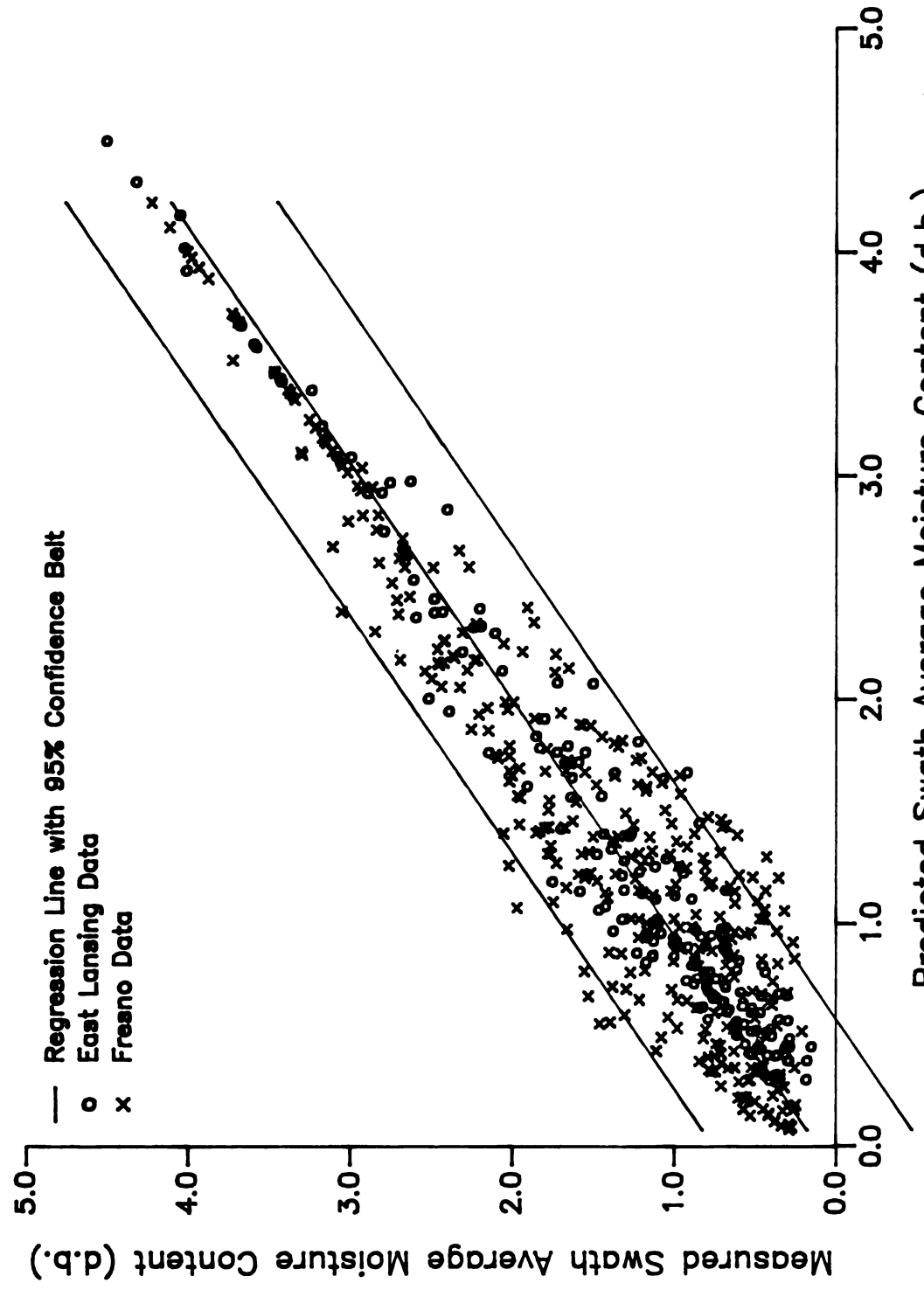

Figure 33. Measured versus simulated average swath moisture content with one set of statistical parameters over a range of field conditions in East Lansing, Michigan and Fresno, California.

Table 12 Values of the intercept (α) and slope (β) of Equation [221] obtained from scatter diagrams of three treatments

Treatment	East Lansing		Fresno		Entirety	
	β	α	β	α	β	α
By Cut Date	1.0137	-0.0930	0.9884	-0.0583	0.9986	-0.0729
By Location	0.9840	0.0001	0.9453	0.1081	0.9618	0.0644
By Entirety	0.9286	0.2641	0.9842	-0.0367	0.9403	0.1126

respectively. It was seen that those values of α and β in Table 12 were close to the preferred values. In Figures 31 to 33, 95% confidence prediction intervals are also drawn. It can be seen that most of the observed drying data points fell into these confidence prediction belts. In the range of low swath moisture contents, data points diverged, and a few points were outside the confidence belt. This was due to accumulated errors of the model.

7.1.4 Validation by Use of Different Weather Data

As discussed in Chapter 4, the model was developed to use a few weather variables as environmental inputs. They were air temperature and relative humidity, wind speed at a reference height above the swath, solar irradiance at the swath top, precipitation and the sky cover fraction. These weather data could be obtained from microclimatic measurement or through the local weather service. In all discussions so far, the first four quantities were directly measured at a height about 0.6 m above the ground, and the other two were from the local weather service.

The fourth treatment was to check whether the model could work

normally if all weather data were from the local weather service. The model estimated solar irradiance since it was not measured at the local weather station. This test was conducted to all 4 date groups, 15 trials and 190 observations of the East Lansing group. The set of statistical parameters a and b used was the same set applied under treatment 2. Simulation results are summarized in Table 13.

Table 13 Summary of the sum of squares of residuals (SSE) and the adjusted coefficient of determination (r^2) for the East Lansing group by use of local weather service data

Group	Trial	SSE	r2	Group	Trial	SSE	r2
	1	0.69	0.759		5	0.83	0.938
	2	1.22	0.583		6	1.99	0.839
	3	0.07	0.967		7	0.69	0.951
	4	0.08	0.977				
1		2.06	0.885	2		3.51	0.917
	8	1.85	0.847		12	0.34	0.943
	9	0.25	0.976		13	0.51	0.912
	10	0.26	0.967		14	0.21	0.968
	11	0.16	0.984		15	1.03	0.839
3		2.52	0.946	4		2.09	0.956
				East Lansing overall:		10.19	0.946

These results were very close to those under the second treatment listed in Table 10. Trials 1 and 2 had relatively low r^2 values, they were below the minimums for 95% confidence given in Table 9. The results for the East Lansing group as a whole were almost the same as those of the second treatment.

In summary, through these four treatment tests, it was proved that the model had the ability to predict field drying of alfalfa using type of weather information. various circumstances.

7.2 Sensitivity Analysis

Through sensitivity analysis, effects of various parameters and variables can be identified quantitatively. Sensitivity analysis of the model studied was done by examining sensitivity coefficients of the average swath moisture content (the dependent variable and system output), with respect to ten important parameters and variables of the model. They were the two statistical parameters in Equation [139], the assumed initial moisture content (MCO), and seven system parameters. They included the swath area density (DENS), the ratio of leaf area index to yield (LAI/YLD), the crop maturity (BLOOM), the conditioning factor (CME), leaf moisture content at hydration (FMC), resistance to moisture transfer at the soil surface (RVS) and the ratio of swath thickness to area density (ZC/DENS).

Since different parameters have various dimensions (units) and magnitudes, it is best to form normalized sensitivity coefficients which are dimensionless in order to compare the relative importance of each parameter. In this study, normalized sensitivity coefficients were constructed as:

$$X'_{ij} = X_{ij}\Delta\beta_j/\eta_j = (\partial\eta/\partial_j)_i\Delta\beta_j/\eta_i \qquad [222]$$

$$(i=1,\ldots,n;\ j=1,\ldots,q)$$

where X'_{ij} = normalized sensitivity coefficient, dimensionless,

X_{ij} = original sensitivity coefficient, dimensional,

$\Delta\beta_j$ = increment of the jth parameter, dimensional,

and η_i = ith predicted moisture content, kg water/kg dry matter. Here, β_j is one of the ten parameters to be examined (q=10). The value of β_j was 10% of β_j (or 0.1 if β_j=0). The quantity $100X_{ij}^{\dagger}$ was the percentage of change in η_i due to an increment $\Delta\beta_j$ in β_j. Normalized sensitivity coefficients were calculated in programs ARNLIN and ALFDRY (see Appendices I, and J). In ARNLIN, normalized sensitivity coefficients for two statistical parameters a and b were denoted with BX(1) and BX(2). The other eight normalized sensitivity coefficients were denoted with SMCO, SDEN, SL/Y, SBLM, SCME, SFMC, SRVS and SZ/D, respectively, in ALFDRY.

It should be pointed out that these sensitivity coefficients, like the studied model itself, were nonlinear functions of all of the ten selected parameters and variables as well as others. These sensitivity coefficients were complicated functions of time and the history of the average swath moisture content. These sensitivity coefficients described the response of the average swath moisture content to small disturbances of these parameters and variables, respectively, under given conditions. However, they may not be indicative of the directions of changes in the average swath moisture content with large changes of these parameters.

Figures 34 to 36 show typical curves of the ten normalized sensitivity coefficients versus time for Trial 5 tested in East Lansing, Michigan on August 14 to 16 of 1984. In Figure 34, curves of BX(1) and BX(2) are plotted. Curves of the other eight sensitivity coefficients are shown in Figures 35 and 36, respectively. It was noticed that these eight normalized sensitivity coefficients for the

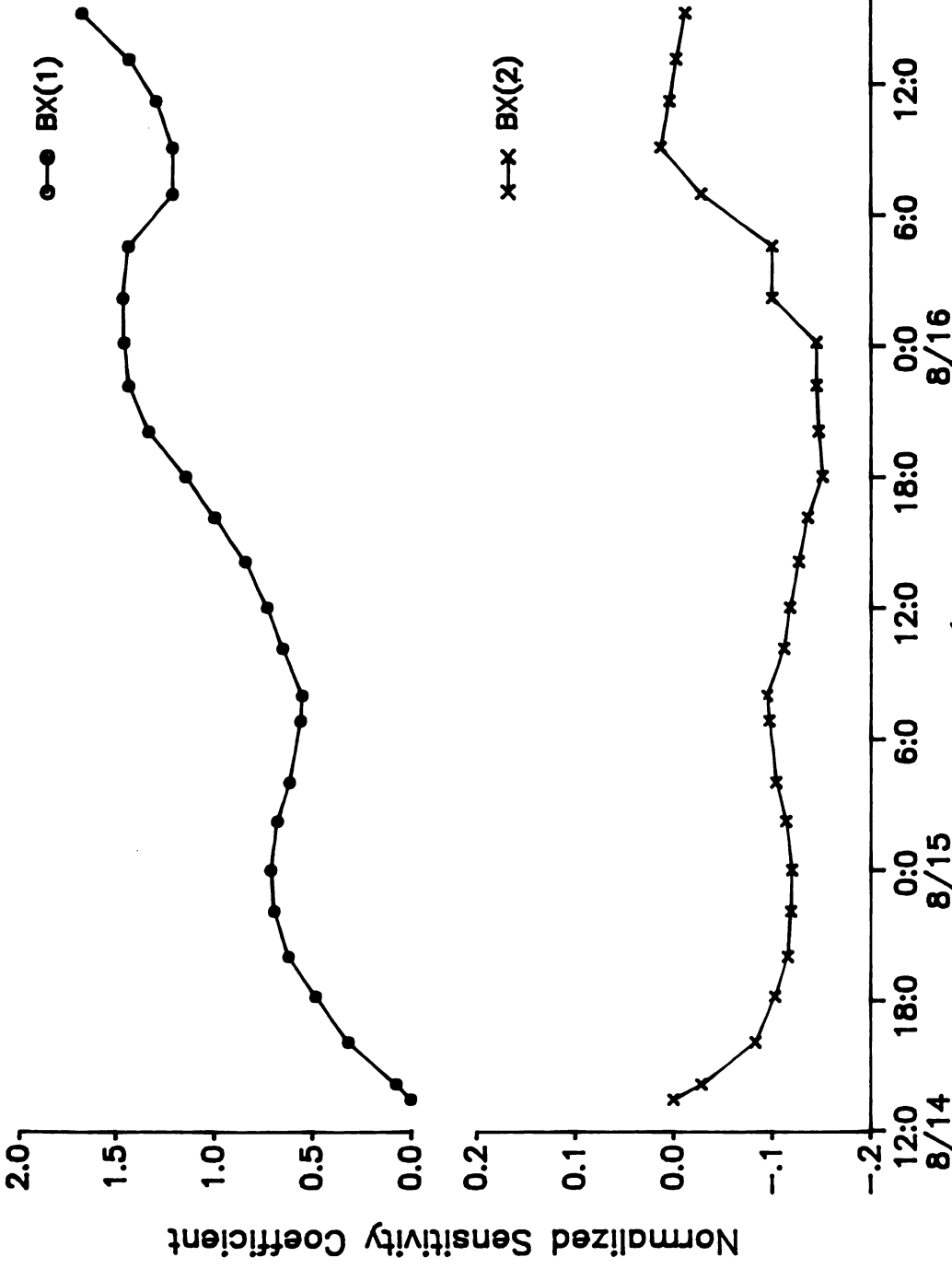

Figure 34. Normalized sensitivity coefficients of two statistical parameters BX(1) and BX(2) for Trial 5.

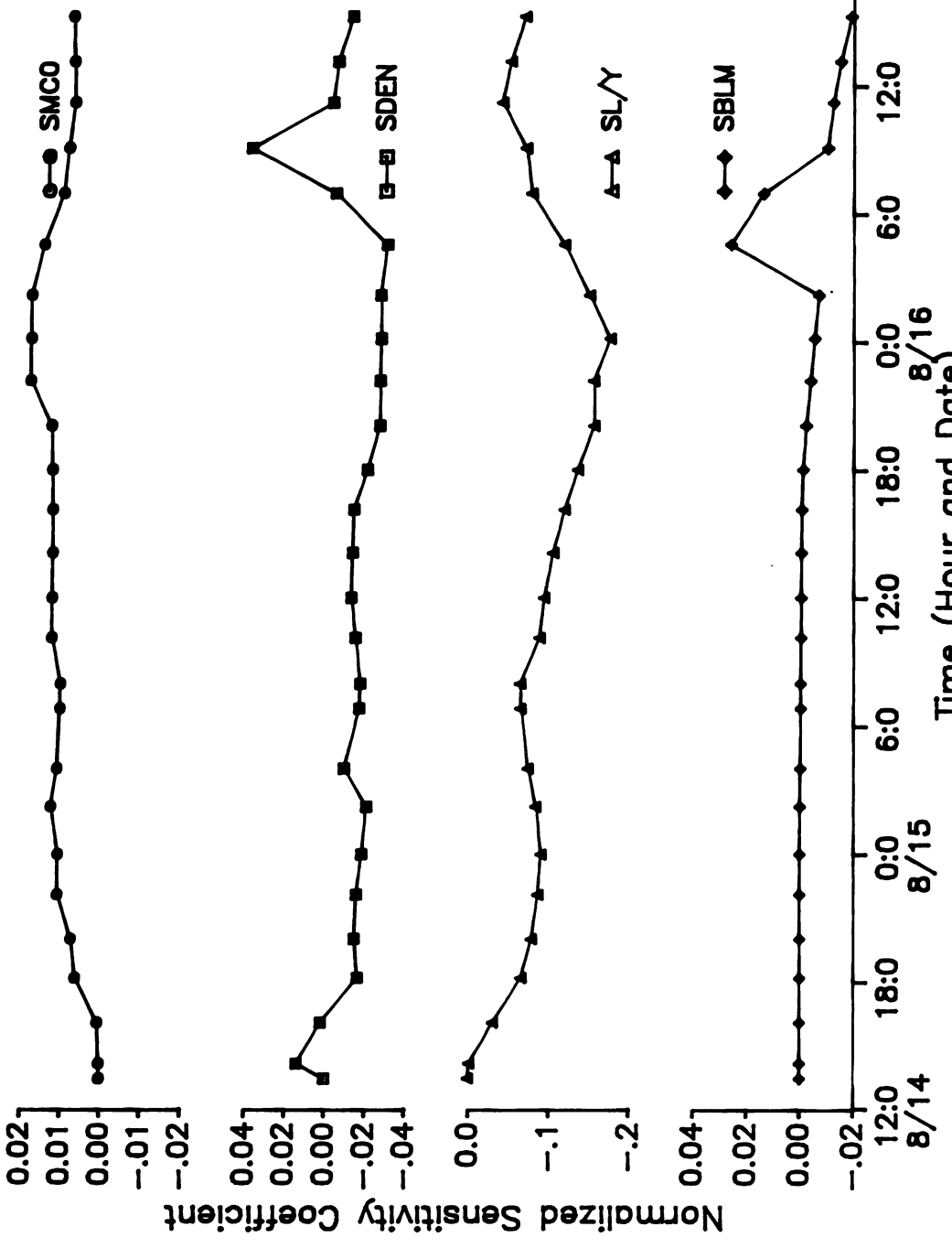

Figure 35. Normalized sensitivity coefficients of initial moisture (SMCO), swath density (SDEN), the ratio of leaf area index to yield (SL/Y) and crop maturity (SBLM) for Trial 5.

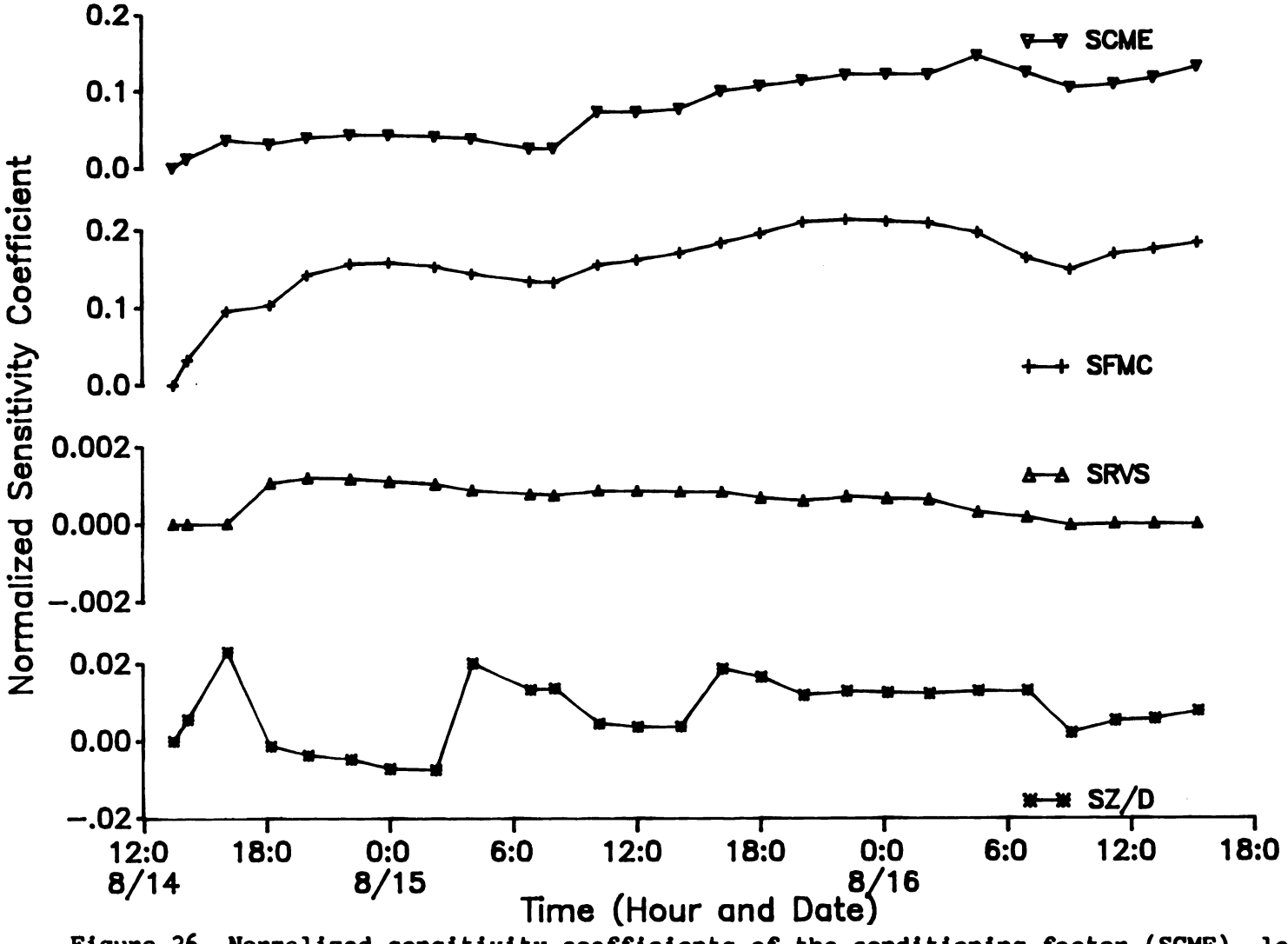

Figure 36. Normalized sensitivity coefficients of the conditioning factor (SCME), leaf moisture content at full hydration (SFMC), soil surface resistance (SRVS), and the ratio of swath thickness to density (SZ/D) for Trial 5.

same Trial 5 varied among the three validation treatments. This was evidence of dependence of sensitivity coefficients to the statistical parameters a and b. The data used in Figures 35 and 36 were taken from corresponding output of Trial 5 in Appendix J.

7.2.1 Effects of Two Statistical Parameters

According to Equation [139], it was expected that parameter a had a positive effect on average swath moisture content. This was proved by all positive values of BX(1) for Trial 5 and other trials. Parameter a mainly determined the magnitude of leaf resistance. An increment in a caused an increase in leaf resistance, which resulted in slowing field drying, i.e. longer time to dry alfalfa to a certain extent, or a higher swath moisture content for a given period of time. BX(1) gradually increased as drying progressed, especially in the day time. This meant that the swath moisture content was more and more affected by parameter a at low alfalfa moisture contents as seen from Equation [139]. At night, BX(1) was reduced accordingly because leaf resistance had no influence after dew started. But, BX(1) did not return to zero as shown in Figure 34, since the influence history of BX(1) still remained.

The magnitude of BX(1) was up to 1.66 occurring at the end of drying in the typical trial, i.e. a 10% increase in parameter a (5.094) could cause 166% prediction variation on the final swath moisture content for Trial 5. This was very significant. In other words, the system output was very sensitive to the accuracy of parameter a.

Parameter b had a negative effect on leaf resistance, i.e. a high

value of b would lead to a low leaf resistance according to Equation [139]. Hence, an increment of b could result in a low swath moisture content. This can be seen from negative values of the BX(2) curve in Figure 34. The magnitude of BX(2) increased as drying time progressed; however, BX(2) decreased near the end of field drying (Figure 34). This decrease in the influence of b was due to the ratio of M to M_0 in Equation [139] which became smaller and smaller as drying advanced. BX(2) also decreased temporarily at night because of dew formulation.

There were two instances of positive BX(2) occurring at the morning of the third day according to Figure 34. This oscillation may be attributed to two reasons. First, the increase of b lowered leaf resistance, which reduced leaf and swath moisture content. When simulated leaf moisture content was low enough that its equilibrium relative humidity was below that of the surrounding air, rewetting took place. Secondly, as discussed in Section 7.1, the discontinuity of leaf resistance at transition between adsorption and desorption might induce such an oscillation.

The magnitude of BX(2) was about one tenth of that of BX(1) which indicated the model was less sensitive to parameter b than parameter a.

The intercorrelation between a and b is also seen in Figure 34. The two curves, excluding two positive points of BX(2), were near symmetric with respect to the horizontal axis if vertical coordinates of one curve was multiplied by a scale factor. Recall that r_{ab} for Trial 5 in Table 8 was 0.832. This quite high value of r_{ab} was visually confirmed with Figure 34.

7.2.2 The Effect of Initial Moisture Content

A positive effect on the swath moisture content due to an increment of the initial moisture content of leaves was expected. The higher the initial moisture content, the more moisture to be removed, thus a longer drying time is required or a higher swath moisture content is observed after a certain period of time. In the model studied, the moisture content of leaves at full hydration was assumed to be the same as the initial moisture content of leaves due to internal adjustment of leaves. Thus the increment of MCO had an influence on leaf resistance in the model which was also in favor of increasing leaf resistance and swath moisture content. Positive values on the curve of SMCO in Figure 35 represented the effect of initial moisture content. The magnitude of SMCO was 0.017, i.e. a maximum 1.7% deviation in simulated swath moisture content corresponded to a 10% increase in MCO. This was small.

One negative SMCO occurring at the beginning of drying was found in Figure 35. Similar circumstances were observed from simulation results of other trials. In a few cases, negative SMCO lasted for a period of time. These were unexpected and presumably due to some numerical instability of the model in those cases.

7.2.3 The Effect of Swath Area Density

The effect of swath area density (DENS) on the average swath moisture content was complicated because DENS determined not only the amount of moisture in alfalfa plants to be dried but also the leaf area

index and the swath thickness in the model. The latter two factors affected profiles of radiation and wind speed inside the swath. The overall effect due to change in DENS was characterized by the dominant factor.

Various patterns of the normalized sensitivity coefficient SDEN of DENS were observed from simulation results. When the swath area density was low, like those of the East Lansing group, and leaves wilted, an increase in DENS might lead to increasing interception of solar radiation due to an increase in the leaf area index, hence, speeding up drying (negative SDEN), especially at the late stage of drying. This is seen from Figure 35. However, at the beginning of drying when leaves are not wilted, the increment of the leaf area index would not increase light interception but decrease wind speed and light penetration, as well as increase the amount of moisture, so swath drying was reduced (positive SDEN) as shown in Figure 35. On the other hand, when the swath was very dense, like those of the Fresno group, light penetration and wind speed were limited and radiation interception was saturated by overlapping leaves within the swath, an increment of the swath density resulted in further reduction of light penetration and interception in deep layers. In this case, the whole process of drying slowed down (positive SDEN) as seen in Appendix J.

For Trial 5, the magnitude of negative SDEN increased as drying progressed in the day time, and continued rising up 2 to 4 am, then lowered till the next morning. This was probably due to the heat capacity of the swath. Starting from sunrise, alfalfa plants gradually absorbed solar energy, spent some for drying and stored some to raise swath temperature. Stored energy supported drying in the evening and at

early night until dew occurred. An increment of the swath density increased the swath heat capacity and, thus, helped to extend the duration of drying. The magnitude of SDENS was less than 0.032 which was not very noticeable.

There was a positive SDEN found near the end of drying. This abnormal oscillation case might be caused by the same reasons discussed in the preceding section.

7.2.4 The Effect of the Ratio of Leaf Area Index to Yield

The ratio of leaf area index to yield (LAI/YLD) determined the leaf area index for a given swath density. As mentioned in the preceding section, an increment of the leaf area index had influences on light interception, penetration and wind speed which affected moisture removal of the swath. The dominant factor characterized the behavior of the sensitivity coefficient SL/Y of LAI/YLD. For Trial 5, the effect of LAI/YLD was in favor of fast drying which was represented by negative SL/D in Figure 35. The magnitude of SL/Y increased as the swath gradually dried. At night, the negative effect of leaf area index temporarily dropped because an increase in leaf surface area enhanced thermal radiation losses from plants. At the late stage of drying due to leaf wilting, the influence of leaf area index was reduced. The maximum magnitude of SL/Y was about 17.7% which was quite significant.

7.2.5 The Effect of Alfalfa Maturity

The maturity of alfalfa was rated as percentage of crop in full bloom (BLOOM). In the model studied, the maturity affected equilibrium relative humidity of leaves which determined whether moisture transfer on leaf surface was desorption or adsorption. The effect of equilibrium relative humidity was noticeable only when leaf moisture content was low. Therefore, at the early stage of drying, normalized sensitivity coefficients SBLM of the bloom level were zero. According to Bakker's data (1961), equilibrium relative humidity increased as the bloom level increased. Thus, an increment of the bloom level favored fast drying (negative SBLM). The magnitude of negative SBLM was less than 0.02 which was unimportant.

Two positive values of SBLM were found near the end of drying. This oscillation may be caused by the similar factors mentioned in Section 7.2.2.

7.2.6 The Effect of the Conditioning Factor

The conditioning factor (CME) determined the reduction in leaf resistance due to mechanical (or chemical) treatment during cutting. CME was assigned a value of 0.5 in the model. Obviously, an increase in CME would cause an increase in leaf resistance, thus, slowing a drying process. SCME gradually increased as drying proceeded, and dropped at night due to dew as shown in Figure 36. The magnitude of SCME was 14% for Trial 5.

7.2.7 The Effect of Leaf Moisture Content at Full Hydration

The leaf moisture content at full hydration (FMC or M_f) was used in Equation [139]. As expressed in that equation, an increase in M_f would result in increasing leaf resistance, thus, delaying field drying, as shown by positive SFMC in Figure 36. Similar to other parameters directly related to leaf resistance in Equation [139] discussed above, the effect of FMC increased as field drying advanced (leaf resistance increased) in the day time, and reduced at night due to dew (when leaf resistance had no effect on moisture transfer). The magnitude of SFMC was 21% whose significance was high, second to parameter a for Trial 5.

7.2.8 The Effect of Soil Surface Resistance to Moisture Transfer

The resistance to moisture transfer at the soil surface (RVS) affected moisture transfer between the soil surface and the bottom layer of the swath. When moisture content in the bottom layer was high, an increment of RVS would reduce moisture transfer from the bottom layer to soil, thus, delaying drying. On the other hand, when swath moisture content was low, an increase in RVS could prevent absorption of moisture from soil, hence, enhancing drying. This was seen from the SRVS curve of Figure 36.

The magnitude of SRVS was expected to be small since the wind speed at the soil surface inside the swath was zero and, thus, no strong transfer activity took place. For Trial 5, the maximum SRVS was only 0.12%. It was assumed that RVS for the East Lansing group was 10 s/m

and 1000 s/m for the Fresno group in this study. Such a large difference in RVS for the two locations did not induce large variation in the magnitude of SRVS. This was further evidence that the model was not sensitive to changes in RVS.

7.2.9 The Effect of the Ratio of Swath Thickness to Density

The ratio of swath thickness to density (ZC/DENS) was an indication of swath porosity. For a given swath density, a high swath thickness Z_c meant a relatively loose swath. Air movement inside a loose swath would enhance heat and moisture transfer. The curve of SZ/D in Figure 36 showed that an increment of ZC/DENS promoted moisture losses from alfalfa plants (negative SZ/D) at the early stage of drying. However, air movement inside the swath also enhanced possible moisture transfer from the surrounding air to leaves. This became significant when alfalfa moisture content was low at the late stage of drying (Figure 36). This suggested that raking in hay production is useful not only due to turning alfalfa plants but also by increasing swath compactness. The magnitude of SZ/D was only 2% for Trial 5.

In the model, swath thickness was assumed to be proportional to swath density. Actually, the ratio of swath thickness to density should decrease as density increases because of gravitational forces. As field drying proceeded, especially after leaves wilted, the swath became compacted. These were not yet taken into account in the model.

In summary, through the sensitivity analysis, it was found that (1) Sensitivity coefficients of the model were complicated nonlinear functions of the average swath moisture content, two statistical

parameters and other variables and parameters; (2) The sensitivity coefficients of the model varied from trial to trial and from time (observation) to time (observation); (3) The model was most sensitive to changes in parameter a; and (4) Other important parameters were parameter b, leaf moisture content at full hydration, the ratio of leaf area index to yield, the conditioning factor and the swath area density.

In Appendix K, a sample output of profiles of short-wave and long-wave radiation, soil temperature, leaf temperature and moisture content, air-space temperature and humidity in three layers of the swath for Trial 5 is given.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations can be drawn from this study.

8.1 Conclusions

1. Modeling of the soil-swath-atmosphere continuum under conditions of field drying alfalfa is appropriate. Through this modeling, the physical and physiological processes of field drying can be closely studied.
2. Under field drying conditions, plants can be primarily represented by leaves, since transfer of heat and moisture takes place mostly on leaf surfaces.
3. The Monteith-Penman equation can be applied to drying plants with modification to consider the effects of the equilibrium relative humidity of plant leaves, and leaf resistance to moisture transfer under severe water stress.
4. Leaf resistance to moisture transfer can be approximated with the exponential function form of Equation [139].
5. Without detailed physiological information on leaf resistance to moisture transfer under severe water stress within various swath layers, this resistance can be approximated from macroscopic

information about its overall effect on the average swath moisture content.

6. Overnight measurements of rewetting processes are important and worthwhile to the development of a comprehensive model of field drying.
7. Sequential parameter estimation is effective in modeling complicated biological systems. Derivative-free techniques of optimization are also very helpful to determine proper values for parameters in complicated nonlinear problems.
8. The simulation model ALFDRY was shown to be valid by comparing its predictions of the average swath moisture content with field observed drying data under various conditions in East Lansing, Michigan and Fresno, California. The adjusted coefficient of determination between field measured data of the average swath moisture content and model predictions were 0.937 (by cutting date, use of 9 sets of the parameters a and b), 0.914 (by location, use of 2 sets of the parameters a and b) and 0.906 (by the entirety, use of 1 set of the parameters a and b) over the entire experiment population (2 locations, 9 cutting dates, 40 trials and 505 observations), respectively.
9. The simulation model can predict the average swath moisture content of field drying alfalfa over a wide range of swath densities (0.262 to 2.55 kg dry matter/m^2), initial moisture contents (2.65 to 4.50 kg water/kg dry matter), maturity levels (0 to 100% bloom) and meteorological conditions with reasonable accuracy.
10. The model was most sensitive to changes in the statistical parameter a of Equation [139]. Other important quantities for the model are

the statistical parameter b in Equation [139], the leaf moisture content at full hydration, the mechanical/chemical conditioning factor, the leaf area index and the swath density.

11. The model required input weather data of air temperature, relative humidity, wind speed, solar irradiance at a reference height above a swath, precipitation and sky cover fraction to make predictions of field drying. This weather information may be measured at the site or obtained from the local weather service.
12. A set of two statistical parameters in Equation [139] is needed for the model. Obtaining one set of these two statistical parameters for a particular location under normal conditions of hay production is sufficient to make reasonable predictions.

8.2 Recommendations

1. Continuous testing the model at various locations in order to expand its prediction ability is needed.
2. Further research on leaf resistance to moisture transfer, especially under a history of severe water stress is essential.
3. Thorough investigation on exchanges within plant canopies (swaths) is recommended.
4. Research to determine accurate information on the leaf area index, the leaf moisture content at full hydration, the swath porosity and their changes during field drying is suggested.

APPENDIX A

FORTRAN Code of the ALFDRY Simulation Model

```
C-----------------------------------------------------------------------
      PROGRAM ATEST
C-----------------------------------------------------------------------
      INCLUDE 'comsch.f'
C      LOGICAL FLAG
      CHARACTER LOCA(2)*22
      INTEGER OV
      COMMON /OUTF/OV
      COMMON /GHI/TSS(4),SSR(4),ESS(4),SME(4),R2C(4),R2D(4),FR(4),
     +           SY(4),SY2(4),NDF(4)
      COMMON ISB,ISE
      DATA LOCA /'EAST LANSING, MICHIGAN','FRESNO, CALIFORNIA    '/

C      CALL INVALOP(FLAG)
C      CALL OVEFL(FLAG)
C      CALL UNDFL(FLAG)
C      CALL DVCHK(FLAG)

      CALL READIN

      FT1='(4A6,1A7,8A10)'
      FT2='(2I3,F6.2,2F6.3,F7.3,8F10.5)'
      LK=1
      DO 19 J=2,4,2
        SY(J)=0.0
        SY2(J)=0.0
        ESS(J)=0.0
19    CONTINUE
      I2=0
      I=0
C-----REPEAT
3       I=I+1
        IF(I.GT.1.AND.IS(I).NE.IS(MAX0(1,I-1))) THEN
          CALL STOUT(1,I1,IS(I-1))
C          CALL STOUT(3,I1,IS(I-1))
        ENDIF
        IF(ID(I).EQ.1) THEN
          CALL DAYTM
          WRITE(*,'(T56,A)') CLOCK
          IF(IPRT.GT.0) WRITE(OV,301) 'CASE:',IS(I),LOCA(LC(I))
301       FORMAT(/A30,I5,A30)
          WRITE(*,'(A10,I5,A30)') 'CASE:',IS(I),LOCA(LC(I))
          WRITE(*,69)'MC0',VI(I,1),'DENS',VI(I,2),'LAI/Y',VI(I,3),
     +               'BLOOM',VI(I,4),'CME',VI(I,5),'FM0',VI(I,6),
     +               'RSOIL',VI(I,7),'ZC/DENS',VI(I,8)
C          WRITE(OF,'(T56,A)') CLOCK
C          WRITE(OF,'(A10,I5,A30)') 'CASE:',IS(I),LOCA(LC(I))
C          WRITE(OF,69)'MC0',VI(I,1),'DENS',VI(I,2),'LAI/Y',VI(I,3),
C     +                'BLOOM',VI(I,4),'CME',VI(I,5),'FM0',VI(I,6),
C     +                'RSOIL',VI(I,7),'ZC/DENS',VI(I,8)
          DO 20 J=1,N
            W(J)=VI(I,J)
20        CONTINUE
        END IF
        CALL MODEL
        IF(IPRT.GT.0) CALL WRTOUT(MD(I),T(I),Y(I),ETA(I))
```



```
        CALL SENSIT
        E(I)=Y(I)-ETA(I)
C        IF(ID(I).EQ.1) THEN
C          G(I)=Y(I)
C          H(I)=ETA(I)
C          F(I)=E(I)
C        ELSE
C          G(I)=Y(I)-RHO*Y(I-1)
C          H(I)=ETA(I)-RHO*ETA(I-1)
C          F(I)=E(I)-RHO*E(I-1)
C        ENDIF
        DO 25 J=1,N
          BX(I,J)=X(I,J)/ETA(I)
25      CONTINUE
        IF(ID(I).EQ.1) THEN
C          WRITE(OF,FT1)'YRDAY','TIME','Y(I)','E(I)','R(I)','SMC0',
C     +                 'SDEN','SL/Y','SBLM','SCME','SFMC','SRVS','SZ/D'
          WRITE(*,FT1)'YRDAY','TIME','Y(I)','E(I)','R(I)','SMC0',
     +                'SDEN','SL/Y','SBLM','SCME','SFMC','SRVS','SZ/D'
          I1=0
          DO 22 J=1,3,2
            SY(J)=0.0
            SY2(J)=0.0
            ESS(J)=0.0
22        CONTINUE
        ENDIF
C        WRITE(OF,FT2)IY(I),MD(I),T(I),Y(I),ETA(I),E(I),(BX(I,J),J=1,N)
        WRITE(*,FT2)IY(I),MD(I),T(I),Y(I),ETA(I),E(I),(BX(I,J),J=1,N)
        CALL FLUSH(6)
        I1=I1+1
        I2=I2+1
        DO 4 J=1,4
          IF(J.LE.2) THEN
            SY(J)=SY(J)+Y(I)
            SY2(J)=SY2(J)+Y(I)**2
            ESS(J)=ESS(J)+E(I)**2
C          ELSE
C            SY(J)=SY(J)+G(I)
C            SY2(J)=SY2(J)+G(I)**2
C            ESS(J)=ESS(J)+F(I)**2
          ENDIF
4       CONTINUE
        IF(I.LT.NC) GOTO 3
C-----UNTIL(I.EQ.NC)
      CALL STOUT(1,I1,IS(I-1))
C       CALL STOUT(3,I1,IS(I-1))
      IF(ISB.LT.ISE) THEN
        CALL STOUT(2,I2,IS(I-1))
C         CALL STOUT(4,I2,IS(I-1))
      END IF
69    FORMAT(4(1X,A,F7.4,2X)/2(1X,A,F7.4,2X),2X,A,F7.0,2X,A,F7.4)

      END
C-----------------------------------------------------------------------
      SUBROUTINE READIN
C-----------------------------------------------------------------------
```

```
      INCLUDE 'comsch.f'
      CHARACTER DFL*40,OVT*7,OUT*7,OFL*7,A*1
      INTEGER OV
      COMMON /OUTF/OV
      COMMON ISB,ISE

C      OFL='dout   '
      OVT='cout   '
      A=' '

      PA=7
      WD=8
      WM=9
      DR=10
      OU=11
C      OF=12
      OV=13
      OPEN(DR,FILE='drycase',STATUS='OLD')
      OPEN(WD,FILE='wtrday',STATUS='OLD')
      OPEN(WM,FILE='wtrmic',STATUS='OLD')
      WRITE(*,*) ' ENTER THE NAME OF THE PARAMETER FILE: '
      READ(*,'(A40)') DFL
      OPEN(PA,FILE=DFL,STATUS='OLD')
      DO 999 J=PA,DR
        REWIND J
999   CONTINUE
      WRITE(*,*)' ENTER SET RANGE TO BEGIN & END (1, 48): '
      READ(*,*) ISB,ISE
      NT=0

      READ(PA,*) ISW,FM0,RSVI(1),RSVI(2),VI(1,5),ZCDE,YLD0
      READ(PA,*) DTP,DTS,RHOI,SIGMA2,ALPH,BTA,GAMMA,PHI,DELTA
      READ(PA,*) (O(J,1),J=1,N)
      READ(PA,*) NP,MODL,MAX,IOPT,IPRT,KM,KL,KMAX
      READ(PA,*) (B(J),J=1,6)
      READ(PA,*) (JFIX(J),J=1,6)
      DO 2 J=1,NP
        DO 2 L=1,NP
          PS(L,J)=0
          P(L,J)=0
2     CONTINUE
      DO 6 J=1,6
        READ(PA,*) (PS(J,L),L=1,J)
6     CONTINUE
      READ(PA,*) (BL(J),J=1,KM)
      READ(PA,*) (BH(J),J=1,KM)
      CLOSE(PA)
      IF(IOPT.EQ.1) THEN
        OUT='tout   '
      ELSE IF(IOPT.GT.1) THEN
        OUT='aout   '
      ENDIF
      NP1=NP+1
      IF(NP.GT.3) THEN
        NP2=NP+2
        KM=NP2
```



```
        BL(KM)=BL(7)
        BH(KM)=BH(7)
        BL(NP1)=BL(6)
      ELSE
        KM=NP1
        BL(KM)=BL(6)
        BH(KM)=BH(6)
      ENDIF
      KODE=1
      NFIX=0
      DO 37 J=1,NP
C        CB(J)=0.5*(BL(J)+BH(J))
        JFIX(J)=MAX0(0,MIN0(1,JFIX(J)))
        NFIX=NFIX+JFIX(J)
37    CONTINUE
C      KL=MAX0(NP1,MIN0(KL,K-1))
C      KL1=KL-1
      ISB=MIN0(48,MAX0(1,IABS(ISB)))
      ISE=MIN0(48,MAX0(1,ISB,IABS(ISE)))
      IF(ISB.LT.ISE) A='c'
      IF(ISB.LT.10) THEN
C        WRITE(OFL(5:6),'(I1,A1)') ISB,A
        WRITE(OUT(5:6),'(I1,A1)') ISB,A
        WRITE(OVT(5:6),'(I1,A1)') ISB,A
      ELSE
C        WRITE(OFL(5:7),'(I2,A1)') ISB,A
        WRITE(OUT(5:7),'(I2,A1)') ISB,A
        WRITE(OVT(5:7),'(I2,A1)') ISB,A
      ENDIF
C      OPEN(OF,FILE=OFL,STATUS='UNKNOWN')
      IF(IPRT.GT.0) THEN
        OPEN(OV,FILE=OVT,STATUS='UNKNOWN')
        WRITE(*,'(A,A/)')' OUTPUT FILE NAME IS ',OVT
C        WRITE(OF,'(A,A/)') ' THE OUTPUT FILE NAME IS ',OVT
      ENDIF
      I=0
C-----REPEAT
10      I=I+1
C-------REPEAT
17        READ(DR,*,END=11)IY(I),MD(I),T(I),Y(I),(VI(I,J),J=1,5),
     +                         IM(I),ID(I),IS(I),LC(I)
          IF(IS(I).LT.ISB) GOTO 17
C-------UNTIL(IS(I).GE.ISB)
        IF(IS(I).LE.ISE) THEN
          SIG2(I)=SIGMA2
          SIG(I)=SQRT(SIG2(I))
          VI(I,3)=AMIN1(VI(I,3),YLD0)
          VI(I,6)=AMIN1(FM0,VI(I,1))
          VI(I,7)=RSVI(LC(I))
          VI(I,8)=ZCDE
          GOTO 10
        ENDIF
C-----UNTIL(IS(J).GT.ISE.OR.EOF(DR))
11    CLOSE(DR)
      NC=I-1
      NPP=NP-NFIX
```

```
      IF(IOPT.GT.0) THEN
        OPEN(OU,FILE=OUT,STATUS='UNKNOWN')
        IF(IOPT.EQ.1) THEN
          DO 123 L=1,KL
            READ(OU,*) (BSV(L,J),J=1,NP)
123       CONTINUE
          READ(OU,*) L1
          DO 124 J=1,NP
            B(J)=BSV(L1,J)
124       CONTINUE
          RHO=RHOI
        ELSE IF(IOPT.NE.0) THEN
          READ(OU,'(/////////////////)')
          READ(OU,*) RHO,SIGMA2,(STAT(1,J),J=1,8),(B(J),J=1,NP)
        ENDIF
        CLOSE(OU)
      ENDIF
449   IF(NP.LT.4) THEN
        B(4)=B(1)
        B(5)=B(2)
      ENDIF
      WRITE(*,66)'ISW',ISW,'FMC',FM0,'DTF',DTF,'DTS',DTS
      WRITE(*,67)'SIG2',SIGMA2,'RHO',RHOI,('O',J,O(J,1),J=1,N)
      WRITE(*,'(/8X,''NC'',8X,''NP'',6X,''NFIX'',8X,''NT'',5X,
     +      ''ITMAX'',5X,''MODEL'',6X,''IOPT'',6X,''IPRT'')')
      WRITE(*,'(8I10,4F10.4)') NC,NP,NFIX,NT,MAX,MODL,IOPT,IPRT
      WRITE(*,'(/6(6X,A,I1,A,5X))') ('B(',I,')',I=1,6)
      WRITE(*,'(6(1X,E13.6,1X))') (B(J),J=1,6)
      WRITE(*,'(6(4X,A,I1,A,4X))') ('JFIX(',J,')',J=1,6)
      WRITE(*,'(6(I9,6X))') (JFIX(J),J=1,6)
      WRITE(*,'(10(4X,A,I1,A,4X))') ('BL(',I,')',I=1,KM)
      WRITE(*,'(10(1X,E11.4,1X))') (BL(I),I=1,KM)
      WRITE(*,'(10(4X,A,I1,A,4X))') ('BH(',I,')',I=1,KM)
      WRITE(*,'(10(1X,E11.4,1X))') (BH(I),I=1,KM)
C        WRITE(OF,66)'ISW',ISW,'FMC',FM0,'DTF',DTF,'DTS',DTS
C        WRITE(OF,67)'SIG2',SIGMA2,'RHO',RHOI,('O',J,O(J,1),J=1,N)
C        WRITE(OF,'(/8X,''NC'',8X,''NP'',6X,''NFIX'',8X,''NT'',5X,
C     +      ''ITMAX'',5X,''MODEL'',6X,''IOPT'',6X,''IPRT'')')
C        WRITE(OF,'(8I10,4F10.4)') NC,NP,NFIX,NT,MAX,MODL,IOPT,IPRT
C        WRITE(OF,'(/6(6X,A,I1,A,5X))') ('B(',I,')',I=1,6)
C        WRITE(OF,'(6(1X,E13.6,1X))') (B(J),J=1,6)
C        WRITE(OF,'(6(4X,A,I1,A,4X))') ('JFIX(',J,')',J=1,6)
C        WRITE(OF,'(6(I9,6X))') (JFIX(J),J=1,6)
C        WRITE(OF,'(10(4X,A,I1,A,4X))') ('BL(',I,')',I=1,KM)
C        WRITE(OF,'(10(1X,E11.4,1X))') (BL(I),I=1,KM)
C        WRITE(OF,'(10(4X,A,I1,A,4X))') ('BH(',I,')',I=1,KM)
C        WRITE(OF,'(10(1X,E11.4,1X))') (BH(I),I=1,KM)
      CALL FLUSH(6)
66    FORMAT(1X,A,I4,3X,A,F6.2,2(3X,A,F6.0),1X,A,F5.2,2(3X,A,F6.0),
     +      3X,A,E12.5,3X,A,F7.3)
67    FORMAT(1X,A,F8.4,2X,A,F6.3,10(2X,A1,I1,F7.4))

      RETURN
    END
C-----------------------------------------------------------------------
    SUBROUTINE STOUT(J,IC,ISET)
```



```
C-----------------------------------------------------------------------
      INCLUDE 'comsch.f'
      COMMON /GHI/TSS(4),SSR(4),ESS(4),SME(4),R2C(4),R2D(4),FR(4),
     +            SY(4),SY2(4),NDF(4)

      IF(J.EQ.2) THEN
        WRITE(*,'(1X,A)') 'OVERALL'
C       WRITE(OF,'(1X,A)') 'OVERALL'
      ELSE
        WRITE(*,*)
C       WRITE(OF,*)
      ENDIF
      IF(ISET.LE.4.OR.ISET.EQ.27) THEN
        NNP=2
      ELSE
        NNP=NPP
      ENDIF
      TSS(J)=SY2(J)-SY(J)*SY(J)/IC
      SSR(J)=TSS(J)-ESS(J)
      R2C(J)=SSR(J)/TSS(J)
      NDF(J)=MAX0(IC-NNP,1)
      R2D(J)=1-(1-R2C(J))*(IC-1)/NDF(J)
      SME(J)=ESS(J)/NDF(J)
      FR(J)=SSR(J)/SME(J)
C      WRITE(OF,14) 'SSTO',TSS(J),'SSR',SSR(J),'SSE',ESS(J),
C     +            'R2',R2C(J),'R2A',R2D(J)
C      WRITE(OF,15) 'N',IC,'NP',NP,'DF',NDF(J),'MSE',SME(J),'F',FR(J)
      WRITE(*,14) 'SSTO',TSS(J),'SSR',SSR(J),'SSE',ESS(J),
     +            'R2',R2C(J),'R2A',R2D(J)
      WRITE(*,15) 'N',IC,'NP',NP,'DF',NDF(J),'MSE',SME(J),'F',FR(J)

14    FORMAT(3(1X,A,F8.2,3X),2(1X,A,F8.4,3X))
15    FORMAT(3(1X,A,I4,3X),2(1X,A,F10.4,3X),A,I4)

      RETURN
    END
C-----------------------------------------------------------------------
    SUBROUTINE MODEL
C-----------------------------------------------------------------------
      INCLUDE 'comsch.f'
C
      LL=ISW*10+LK
      KK=ID(I)
      ETA(I)=AMC(B,W,IY(I),MD(I),T(I),Y(I),IM(I),DTF,DTS,LC(I),KK,LL)

      RETURN
    END
C-----------------------------------------------------------------------
    SUBROUTINE SENSIT
C-----------------------------------------------------------------------
      INCLUDE 'comsch.f'
C
      IF(ID(I).EQ.1) THEN
        DO 10 J=1,N
          IF(ABS(VI(I,J)).LT.1.0E-9) THEN
            O(J,2)=O(J,1)
```

```
            O(J,3)=O(J,1)
          ELSE
            O(J,2)=VI(I,J)*O(J,1)
            O(J,3)=VI(I,J)*(1.0+O(J,1))
          END IF
10      CONTINUE
      END IF
      LL=ISW*10+LK
      DO 2 J=1,N
        KK=1000*J+ID(I)
        W(J)=O(J,3)
        X(I,J)=(AMC(B,W,IY(I),MD(I),T(I),Y(I),IM(I),DTF,DTS,LC(I),
     +           KK,LL)-ETA(I))
        W(J)=VI(I,J)
        IF(ID(I).EQ.1) X(I,J)=0.0
2     CONTINUE
C
      RETURN
      END
C-----------------------------------------------------------------------
      SUBROUTINE DAYTM
C-----------------------------------------------------------------------
      CHARACTER CLOCK*25
C      CHARACTER*8 TIME,DATE
C      CHARACTER CT*8,DAY*9
      COMMON /FGH/CLOCK

C-------TMDAY(CLOCK) IS IN  LANGUAGE FOR HP9000/300
C      CALL TMDAY(CLOCK)
C-------FOR OTHER SYSTEMS-----------------------------
C      WRITE(CLOCK,'(25('' ''))')
C-------FOR PRIME750/550
C      CT=TIME()
C      DAY=DATE()
C-------FOR VAX/VMS AND IBM/PC COMPATIBLES
C      CALL TIME(CT)
C      CALL DATE(DAY)
C      WRITE(CLOCK(1:19),'(A,2X,A)') CT,DAY
C-------FOR VAX/UNIX AND SUN'S
      CALL FDATE(CLOCK)

      RETURN
      END
C-----------------------------------------------------------------------
C     COMMON BLOCK FILE COMSCH.F
C-----------------------------------------------------------------------
      PARAMETER (M=505,N=8,K=10)
      CHARACTER CLOCK*25,FT1*26,FT2*30,FT3*32,FT4*18,FT5*27
      DOUBLE PRECISION P,PS,R
      INTEGER WD,WM,PA,OU,OF,DR
      COMMON /IOFL/WD,WM,PA,OU,OF,DR
      COMMON /NLIN/ETA(M),Y(M+1),SIG2(M),B(6),Z(M,6),BS(6),X(M,N),
     +             V(K,M,6),I,MODL,NP,IPRT,JFIX(6),IOPT,MAX
      COMMON /PPP/P(6,6),PS(6,6),R(6,6),BX(M,N),BZ(M,6)
      COMMON /ABC/T(M+1),RSVI(2),DTF,DTS,FMO,O(N,3),VI(M,N),W(N),
     +            IM(M),ID(M),IS(M),LC(M),IY(M),MD(M+1),LK,ISW,LJ
```



```
      COMMON /DEF/DB(6),BSS(6),SEP,HH,ALFA,GG,RHO,L,NPP,IT,NC,NT,IND,
     +            SE,G(M),H(M),F(M),E(M),SIG(M)
      COMMON /BCD/BSV(K,K),BC(6),BL(K),BH(K),S(K),CB(K),ALPH,GAMMA,
     +            DELTA,BTA,PHI,KL,KM,KMAX,KODE,NP1,NP2,I1,I2,I3,KL1
      COMMON /CDE/SST,SSE,ST,R2A,R2B,R1A,R1B,STAT(K,8),NNP
      COMMON /EFG/S0,S1,S2,S3,S4,S5,S6,L0,L1,L2,L3,L4,L5,L6
      COMMON /FGH/CLOCK
      COMMON /FMT/FT1,FT2,FT3,FT4,FT5
C-----------------------------------------------------------------------
      FUNCTION AMC(B,V,JYR,LDAY,T,DMC,IMC,DTF,DTS,LOC,IID,ISPT)
C-----------------------------------------------------------------------
      PARAMETER (N=3,M=10,K=8)
      REAL MCL,LAT,LON,LST,LAI,MC0,ALST(4,2),B(6),V(K)
      COMMON /TIMES/MDAY,JDAY,HOUR
      COMMON /PARIN/IYR,MDAYI,HRI,HRF,MDAYF,LEAP,JDAYI,JDAYF,
     +              DTP,XMC,SIMUL,DTFAST,DTSLOW
      COMMON /RADLW/RNLW(N),RNLWG,EMG
      COMMON /RADSW/RNSW(N),RNSWG,RSG
      COMMON /ABV/DBR,RHR,RVR,PVR,UR,CV,RCPR,PSCR,RIR,RSHR,RSVR
      COMMON /TOP/DBC,PVC,RVC,UC
      COMMON /LAYRS/MCL(N),PVA(N),PVL(N),RWS(N),DBA(N),DBL(N),RHA(N),
     +       RVA(N),RVL(N),RCP(N),PSC(N),HLA(N),VLA(N),RBH(N),RBV(N),
     +       RIA(N),WDA(N),DLO(N),ERH(N),VCP(N),DEW(N),TDW(N),FAC(N),
     +       DL(N),DZ(N),DD(N),HW(N),HAA(N+1),VAA(N+1),RSH(N+1),
     +       RSV(N+1)
      COMMON /GND/CLOD,DBG,RHG,PVG,RVG,UG,RCPG,PSCG,RSHG,RSVG,RVS
      COMMON /LAND/COND,VHCP,DEP(M),DBS(M+1),Q(M+1),COND2,ALF,VT
      COMMON /FLUX/FXHAA(N+1),FXVAA(N+1),FXHLA(N),FXVLA(N),FXSHA(N),
     +             FXSHL(N),FXLHA(N),FXLHL(N),FVAA(N+1),FVLA(N),
     +             FXRVA(N),FXHSS(M+1),FXSHS(M),FXSHG,FXLHG,FXSTG,
     +             FXRSP(N),FXRAIN(N),RAIN(N),FXHLR,FXVLR
      COMMON /SAV/SHRI(0:K),SDHR(0:K),SDBR(0:K),SRVR(0:K),SPVR(0:K),
     +       SCV(0:K),SRSHR(0:K),SRSVR(0:K),SRCPR(0:K),SRAIN(N,0:K),
     +       SRNLW(N,0:K),SRNLWG(0:K),SRNSW(N,0:K),SRNSWG(0:K),
     +       SDBG(0:K),SPVG(0:K),SRVG(0:K),SUG(0:K),SRHG(0:K),DHR,
     +       SRSHG(0:K),SRSVG(0:K),SDBS(M,0:K),SRAING(0:K),SZC(0:K),
     +       SDBL(N,0:K),SRVL(N,0:K),SPVL(N,0:K),SRBV(N,0:K),SUR(0:K),
     +       SRBH(N,0:K),SRCP(N,0:K),SVLA(N,0:K),SHLA(N,0:K),SUC(0:K),
     +       SFVLA(N,0:K),SHAA(N+1,0:K),SVAA(N+1,0:K),SRSH(N+1,0:K),
     +       SRSV(N+1,0:K),SMCL(N,0:K),SENT(N,0:K),SSFC(N,0:K),
     +       SRUN(N,0:K),SDEW(N,0:K),STDW(N,0:K),SRWS(N,0:K),
     +       SWDA(N,0:K),SFAC(N,0:K),SDL(N,0:K),SDZ(N,0:K),SDD(N,0:K),
     +       SDLO(N,0:K),SRWO(N,0:K),IS(N,0:K),JD(0:K),LE(0:K),MD(0:K)
      COMMON /MOIST/ENTMC(N),SFCMC(N),RUNMC(N),RUNOFF(N),EXCESS(N),
     +              RENTMC(N),RSECMC(N),RRUNMC(N),SMFR,SMFE,SMFS
      COMMON /GRAIN/RAING
      COMMON /RWSO/RWSO(N),IDEW(N),ID
      COMMON /RHEQ/BLOOM,IAD(N)
      COMMON /HT/ZR,ZC,D,Z0
      COMMON /LOCAL/LAT,LON,LST,ALT
      COMMON /SWATH/LAI,DENS,VO,WL,MC0,EMC,RSFC
      COMMON /RATE/RDBA(N),RDBL(N),RRVA(N),RMCL(N),RDEW(N),
     +       RTDW(N),RDBS(M)
      COMMON /SOL/SL0,SLDIR0,SLSKY0,SMU2
      COMMON /SUNH/HSUN,TSOLAR,TRISE,TSET
      COMMON /WTRD/HRL(10),DAL(10),RHL(10),CVL(10),PCL(10),WAL(10),LL
```

```
      COMMON /WTRM/TL(25),RDB(25),RRH(25),SLL(25),URL(25),FDB(25),
     +             FRH(25),BDB(25),BRH(25),SDB(25),SRH(25),SL2(25),
     +             WD2(25),TDB(25),RH2(25),IL
      COMMON /CPH2O/CPW
      COMMON /LMT/XMCMAX,XMCMIN,SFCMAX,RUNMAX
      COMMON /FF/ALPHA,ALFA1,ALFA2,FMC,CMECH,C1,C2,C3,C4,ISW
      SAVE
      DATA INDEX/0/
C-----LATITUDE,LONGITUDE,MERIDIAN AND ALTITUDE AT E. LANSING,MI
      DATA (ALST(J,1),J=1,4)/42.7833,84.60,75.0,0.2563/
C-----LATITUDE,LONGITUDE,MERIDIAN AND ALTITUDE AT FRESNO,CA
      DATA (ALST(J,2),J=1,4)/36.77,119.7,120.0,0.09936/

      IF(INDEX.EQ.0) THEN
        LAT=ALST(1,LOC)
        LON=ALST(2,LOC)
        LST=ALST(3,LOC)
        ALT=ALST(4,LOC)
        DTFAST=DTF
        DTSLOW=DTS
        INDEX=1
      ENDIF

C-----CONTROL SWITCHS
      I=IID/1000
      ID=IID-I*1000
      ISW=ISPT/10
      IPT=ISPT-ISW*10
      ALPHA=B(6)

      ALFA1=B(1)
      C1=B(2)
      ALFA2=B(4)
      C2=B(5)
      C5=B(3)
      C3=B(6)

      MDAYF=LDAY
      MC0=V(1)
      FMC=V(6)
      CMECH=V(5)
      BLOOM=V(4)
      RVS=V(7)
      IF(ID.EQ.1) THEN
        DENS=V(2)
        LAI=V(3)*DENS
        ZC=V(8)*DENS
        IYR=JYR
        MIC=IMC
        IF(DMC.LT.MC0-1.2) THEN
C---------FOR CASES 16, 17, 18 & 19 ONLY
          JDAYI=2
        ELSE
          JDAYI=1
        ENDIF
        JDAYF=1
```



```
C-------------------------------------------------INITIALIZATION
      HOUR=T
      HRI=T
      MDAY=MDAYF
      CALL YRDATE(JDAY,MDAY,IYR,LEAP,0)
C-----WEATHER DATA FROM LOCAL STATION
      CALL DAYWTR
C-----MICROCLIMATOLOGICAL DATA,IF AVAILABLE
      IF(MIC.GT.0) THEN
        ZR=0.606425
        CALL MICWTR
        SLO=APL2(HRI,TL,SLL,IL)
        SDBS(1,I)=APL2(HRI,TL,SDB,IL)
        RHG=APL2(HRI,TL,SRH,IL)
        IWTR=1
      ELSE
        ZR=2.0
        IWTR=0
      ENDIF
      CALL ABVI
      CALL AIR(HRI,IWTR)
      CALL SOILI(HRI,MIC,SDBS(1,I))
      CALL SWATHI(MIC,HRI,DMC)
      CALL FRAIN(HRI)
      DBG=DBS(1)
      DO 16 J=1,N
        IF(DMC.LT.MC0-1.2) THEN
C---------FOR CASES 16, 17, 18 & 19 ONLY
          IDEW(J)=1
          IF(ENTMC(J).GT.0.8*MC0) THEN
            DL(J)=DL0(J)
          ELSE
            DL(J)=AMIN1(EXP(-C5*(1.0-ENTMC(J)/MC0))*DL0(J),DL(J))
          ENDIF
        ELSE
          IDEW(J)=0
        ENDIF
        DEW(J)=0.0
        TDW(J)=0.0
        IAD(J)=0
16    CONTINUE
C-----FIND THE FIRST TIME INTERVAL TO UPDATE RAINFALL DATA
      HR=-2.0
C-----REPEAT
3       CONTINUE
        HR=HR+3
        IF(HRI.GT.HR.AND.HR.LT.22.0) GOTO 3
C-----UNTIL(HRI.LE.HR.OR.HR.GE.22.0)
      DHR=HR-HRI
C-----FIND INITIAL STATES OF THE SYSTEM
      CALL SWRAD(MIC)
      CALL LWRAD
      CALL ABOVE(DBR-DBC,PVR-PVC)
      CALL INSIDE
      CALL GROUND
      DO 99 J=1,N
```

```
            CALL RESIST(J,DB,PV,PSC(J),RCP(J),HW(J))
99          CONTINUE
C             CALL DBLEAF
              CALL RATES
              CALL DFDBS
              CALL STORE(I,I,1)
            ELSE
              CALL FETCH(I)
C-------------RESET CLOCK FOR DEW DURATION
              DO 123 J=1,N
                TDW(J)=0.0
123           CONTINUE
C             SIMULATION
              IF(JDAYF.EQ.2) JDAYI=JDAYI-1
              JDAYF=1
              ACHR=0.0
              ACDT=0.0
              HOUR=HRI
              HRF=T
              IF(T.LT.HRI) HRF=HRF+24
C-------------REPEAT
6             CONTINUE
C-------------CHECK STEP SIZE
              DT=AMAX1(1.0,AMIN1(DTFAST,DTSLOW-ACDT,3600*(HRF-HOUR)))
C-------------INTEGRATE ONE STEP
              CALL MATRIX
              CALL DFMCL(DT)
              CALL DBLEAF
              DO 22 J=1,N
                IF(ENTMC(J).GT.0.8*MC0) THEN
                  DL(J)=DL0(J)
                ELSE
                  DL(J)=AMIN1(EXP(-C5*(1.0-ENTMC(J)/MC0))*DL0(J),DL(J))
                ENDIF
22            CONTINUE
              CALL INSIDE
C-------------UPDATE  TIME
              HRDT=DT/3600.0
              HOUR=HOUR+HRDT
              ACDT=ACDT+DT
              ACHR=ACHR+HRDT
              IF(HOUR.GT.24.0) THEN
C---------------CHANGE DATE AND TIME
                JDAY=JDAY+1
                CALL YRDATE(JDAY,MDAY,IYR,LEAP,1)
                JDAYI=JDAYI+1
                JDAYF=2
C               ALPHA=A6
                CALL DAYWTR
                IF(MIC.GT.0) CALL MICWTR
                HOUR=HOUR-24
                HRF=HRF-24
                HSUN=BETA(HOUR-1.0,JDAY)
              ENDIF
              IF(ACHR.GE.DHR) THEN
C---------------UPDATE RAINFALL DATA
```



```
                CALL FRAIN(HOUR)
                DHR=DHR+3
              ENDIF
              IF(ACDT.GE.DTSLOW.OR.HOUR.GE.HRF) THEN
C-------------UPDATE SLOW PROCESS,WEATHER,RESISTANCE,FLUXES & RATES
                CALL DBS01L(ACDT)
                IF(MIC.GT.0) THEN
                  SL0=APL2(HOUR,TL,SIL,IL)
                  RH0=APL2(HOUR,TL,SRH,IL)
                ENDIF
                CALL AIR(HOUR,IWTR)
                CALL SWRAD(MIC)
                CALL LWRAD
                CALL INSIDE
                CALL ABOVE(DBR-DBC,PVR-PVC)
                DO 98 J=1,N
                  CALL RESIST(J,DB,PV,PSC(J),RCP(J),HW(J))
98              CONTINUE
                CALL GROUND
                CALL RATES
                CALL DFDBS
                ACDT=0.0
              ENDIF
              IF(HOUR.LT.HRF.OR.MDAY.LT.MDAYF) GOTO 6
C-------------UNTIL(HOUR.EQ.HRF.AND.MDAY.EQ.MDAYF)
            ENDIF

            AMC=0.0
            DO 2 J=1,N
              AMC=AMC+MCL(J)
2           CONTINUE
            AMC=AMC/N
C           IF(IPT.EQ.1) CALL WRTOUT(MDAY,HOUR,DMC,AMC)
            HRI=T
            CALL STORE(I,I,1)

            RETURN
          END
C-----------------------------------------------------------------------
C   'STORE' & 'FETCH' ARE FOR COMPUTING SENSITIVITY COEFFICIENTS
C-----------------------------------------------------------------------
          SUBROUTINE STORE(I1,I2,I3)

            PARAMETER (N=3,M=10,K=8)
            REAL MCL
            COMMON /TIMES/MDAY,JDAY,HOUR
            COMMON /PARIN/IYR,MDAYI,HRI,HRF,MDAYF,LEAP,JDAYI,JDAYF,
     +                    DTF,XMC,SIMUL,DTFAST,DTSLOW
            COMMON /RADLW/RNLW(N),RNLWG,EMG
            COMMON /RADSW/RNSW(N),RNSWG,RSG
            COMMON /ABV/DBR,RHR,RVR,PVR,UR,CV,RCPR,PSCR,RIR,RSHR,RSVR
            COMMON /TOP/DBC,PVC,RVC,UC
            COMMON /LAYRS/MCL(N),PVA(N),PVL(N),RWS(N),DBA(N),DBL(N),RHA(N),
     +             RVA(N),RVL(N),RCP(N),PSC(N),HLA(N),VLA(N),RIR(N),RSV(N),
     +             RIA(N),WDA(N),DLD(N),ERH(N),VCP(N),DEW(N),TDW(N),FAC(N),
     +             DL(N),DZ(N),DD(N),HW(N),HAA(N+1),VAA(N+1),RSH(N+1),
```

```
     +          RIA(N),WDA(N),DLO(N),ERH(N),VCP(N),DEW(N),TDW(N),FAC(N),
     +          DL(N),DE(N),DD(N),HW(N),HAA(N+1),VAA(N+1),RSH(N+1),
     +          RSV(N+1)
     COMMON /GND/CLOD,DBG,RHG,PVG,RVG,UG,RCPG,PSCG,RSHG,RSVG,RVS
     COMMON /LAND/COND,VHCP,DEP(M),DBS(M+1),Q(M+1),COND2,ALF,VT
     COMMON /FLUX/FXHAA(N+1),FXVAA(N+1),FXHLA(N),FXVLA(N),FXSHA(N),
     +          FXSHL(N),FXLHA(N),FXLHL(N),FVAA(N+1),FVLA(N),
     +          FXRVA(N),FXHSS(M+1),FXSHS(M),FXSHG,FXLHG,FXSTG,
     +          FIRSP(N),FXRAIN(N),RAIN(N),FXHLR,FXVLR
     COMMON /SAV/SBRI(0:K),SDBR(0:K),SDBR(0:K),SRVR(0:K),SPVR(0:K),
     +          SCV(0:K),SRSHR(0:K),SRSVR(0:K),SRCPR(0:K),SRAIN(N,0:K),
     +          SRNLW(N,0:K),SRNLWG(0:K),SRNSW(N,0:K),SRNSWG(0:K),
     +          SDBG(0:K),SPVG(0:K),SRVG(0:K),SUG(0:K),SRHG(0:K),DHR,
     +          SRSHG(0:K),SRSVG(0:K),SDBS(M,0:K),SRAING(0:K),SZC(0:K),
     +          SDBL(N,0:K),SRVL(N,0:K),SPVL(N,0:K),SRBV(N,0:K),SUR(0:K),
     +          SRBH(N,0:K),SRCP(N,0:K),SVLA(N,0:K),SHLA(N,0:K),SUC(0:K),
     +          SFVLA(N,0:K),SHAA(N+1,0:K),SVAA(N+1,0:K),SRSH(N+1,0:K),
     +          SRSV(N+1,0:K),SMCL(N,0:K),SENT(N,0:K),SSPC(N,0:K),
     +          SRUN(N,0:K),SDEW(N,0:K),STDW(N,0:K),SRWS(N,0:K),
     +          SWDA(N,0:K),SPAC(N,0:K),SDL(N,0:K),SDZ(N,0:K),SDO(N,0:K),
     +          SDLO(N,0:K),SRWO(N,0:K),IS(N,0:K),JD(0:K),LE(0:K),MD(0:K)
     COMMON /MOIST/ENTMC(N),SPCMC(N),RUNMC(N),RUNOFF(N),EXCESS(N),
     +          RENTMC(N),RSECMC(N),RRUNMC(N),SMFR,SMFE,SMFS
     COMMON /GRAIN/RAING
     COMMON /RWSO/RWSO(N),IDEW(N),ID
     COMMON /RHEQ/BLOOM,IAD(N)
     COMMON /HT/ZR,ZC,D,ZO
     SAVE

     MDAY=MD(I)
     JDAY=JD(I)
     LEAP=LE(I)
     ZC=SZC(I)
     CALL DAYWTR
     CALL HICWTR
     CALL ABVI
     HRI=SHRI(I)
     IHH=SDHH(I)
     DBR=SDBR(I)
     PVR=SPVR(I)
     RVR=SRVR(I)
     RCPR=SRCPR(I)
     CV=SCV(I)
     RSHR=SRSHR(I)
     RSVR=SRSVR(I)
     DBG=SDBG(I)
     RHG=SRHG(I)
     PVG=SPVG(I)
     RVG=SRVG(I)
     RSHG=SRSHG(I)
     RSVG=SRSVG(I)
     RAING=SRAING(I)
     RNLWG=SRNLWG(I)
     RNSWG=SRNSWG(I)
     UR=SUR(I)
     UC=SUC(I)
```



```
     UG=SUG(I)
     DO 73 J=1,N
       IAD(J)=IS(J,I)
       DL(J)=SDL(J,I)
       DZ(J)=SDZ(J,I)
       DO(J)=SDO(J,I)
       DLO(J)=SDLO(J,I)
       WDA(J)=SWDA(J,I)
       DBL(J)=SDBL(J,I)
       RVL(J)=SRVL(J,I)
       PVL(J)=SPVL(J,I)
       HLA(J)=SHLA(J,I)
       VLA(J)=SVLA(J,I)
       RBH(J)=SRBH(J,I)
       RBV(J)=SRBV(J,I)
       HAA(J)=SHAA(J,I)
       RSH(J)=SRSH(J,I)
       RSV(J)=SRSV(J,I)
       FVLA(J)=SFVLA(J,I)
       RNLW(J)=SRNLW(J,I)
       RNSW(J)=SRNSW(J,I)
       RAIN(J)=SRAIN(J,I)
       DEW(J)=SDEW(J,I)
       TDW(J)=STDW(J,I)
       MCL(J)=SMCL(J,I)
       ENTMC(J)=SENT(J,I)
       SPCMC(J)=SSPC(J,I)
       RUNMC(J)=SRUN(J,I)
       RCP(J)=SRCP(J,I)
       PAC(J)=SPAC(J,I)
       RWSO(J)=SRWO(J,I)
       RWS(J)=SRWS(J,I)
73   CONTINUE
     J=N+1
     HAA(J)=SHAA(J,I)
     VAA(J)=SVAA(J,I)
     RSH(J)=SRSH(J,I)
     RSV(J)=SRSV(J,I)
     DO 74 J=1,10
       DBS(J)=SDBS(J,I)
74   CONTINUE

     RETURN
     END
C-----------------------------------------------------------------------
C    PHYSICAL PROPERTIES OF AIR AT VARIOUS TEMPERATURES
C-----------------------------------------------------------------------
     BLOCK DATA AIRPAR
C
C      T     - AIR TEMPERATURE (K)
C      PATM  - ATMOSPHERIC PRESSURE (101325.0 PA)
C      K     - THERMAL CONDUCTIVITY (W/M-C)
C      IM    - KENIMATIC VISCOSITY (SQ. M/SL)
C      IH    - THERMAL DIFFUSIVITY (SQ. M/SL)
C      IV    - WATER VAPOR DIFFUSIVITY IN  THE AIR (SQ. M/SL)
C      DC    - DIFFUSIVITY FOR CO2 IN THE AIR (SQ. M/SL)
```

```
C       PR   - PRANDTL NUMBER (DIMENSIONLESS)
C       MA   - MOLECULAR WEIGHT OF AIR (KG AIR/MOL)
C       MW   - MOLECULAR WEIGHT OF WATER (KG WATER/MOL)
C       VW   - MOLECULAR VOLUME OF WATER (CUBIC M WATER/MOL)
C       VA   - MOLECULAR VOLUME OF AIR (CUBIC M AIR/MOL)
C       CPW  - SPECIFIC HEAT OF WATER (J/KG-C)
C
        REAL KLIST,MW,MA
        COMMON /PRES/PATM
        COMMON /AIRP/TLIST(11),KLIST(11),DMLIST(11),DHLIST(11),
     +                DVLIST(11),DCLIST(11),PRLIST(11)
        COMMON /MOLECU/MW,MA,VW,VA
        COMMON /CPH2O/CPW
        SAVE
        DATA PATM/101325.0/
        DATA TLIST /-5.,0.,5.,10.,15.,20.,25.,30.,35.,40.,45./
        DATA KLIST /.0240,.0243,.0246,.0250,.0253,.0257,.0260,
     +              .0264,.0267,.0270,.0274/
        DATA DMLIST/1.29E-5,1.33E-5,1.37E-5,1.42E-5,1.46E-5,1.51E-5,
     +              1.55E-5,1.60E-5,1.64E-5,1.69E-5,1.74E-5/
        DATA DHLIST/1.83E-5,1.89E-5,1.95E-5,2.02E-5,2.08E-5,2.15E-5,
     +              2.22E-5,2.28E-5,2.35E-5,2.42E-5,2.49E-5/
        DATA DVLIST/2.05E-5,2.12E-5,2.20E-5,2.27E-5,2.34E-5,2.42E-5,
     +              2.49E-5,2.57E-5,2.64E-5,2.72E-5,2.80E-5/
        DATA DCLIST/1.24E-5,1.29E-5,1.33E-5,1.38E-5,1.42E-5,1.47E-5,
     +              1.51E-5,1.56E-5,1.60E-5,1.65E-5,1.70E-5/
        DATA PRLIST/.7049,.7037,.7026,.7030,.7019,.7023,.6982,
     +              .7018,.6978,.6983,.6988/
        DATA MW,MA,VW,VA/18.032,28.966,18.8,29.9/
        DATA CPW/4186.8/
C
      END
C-----------------------------------------------------------------------
C     MISCELLANEOUS PARAMETERS AND DATA
C-----------------------------------------------------------------------
      BLOCK DATA MISPAR
C
        PARAMETER (N=3,M=10)
        REAL LAI,MC0
        COMMON /PAR/PI
        COMMON /EPS/EPS
        COMMON /SWATH/LAI,DENS,VO,WL,MC0,EMC,RSPC
        COMMON /HT/ZR,ZC,D,Z0
        COMMON /EDISNI/CD,WI,XIML
        COMMON /ABV/DBR,RHR,RVR,PVR,UR,CV,RCPR,PSCR,RIR,RSHR,RSVR
        COMMON /GND/CLOD,DBG,RHG,PVG,RVG,UG,RCPG,PSCG,RSHG,RSVG,RVS
        COMMON /RADLW/RNLW(N),RNLWG,EMG
        COMMON /RADSW/RNSW(N),RNSWG,RSG
        COMMON /LAND/COND,VHCP,DEP(M),DBS(M+1),Q(M+1),COND2,ALF,VT
        COMMON /STAB/A1,B1,A2,B2,P1,Q1,R1,P2,Q2,R2
        COMMON /ALFA/ALF1,ALF2
        COMMON /LMT/XMCMAX,XMCMIN,SFCMAX,RUNMAX
        COMMON /MOIST/ENTMC(N),SFCMC(N),RUNMC(N),RUNOFF(N),EXCESS(N),
     +                RENTMC(N),RSFCMC(N),RRUNMC(N),SMFR,SMFE,SMFS
        COMMON /TEP/IC,TXL(40),PL(40)
        SAVE
```



```
C        DATA LAIYLD /7.40,5.30,6.62/
C-------ASSUME ZERO RESISTANCE FOR VAPOR TRANSFER FROM WET SOIL
        DATA RVS/0.0/
C-------REFERENCE HEIGHT OF MEASUREMENTS OF MICROCLIMATE
        DATA ZR/0.606425/
        DATA PI/3.1415926536/
        DATA EPS/1.0E-3/
        DATA WL,CD,WI,CLOD,RHG/0.0125,0.8,0.55,0.05,0.99/
        DATA EMG,EMC,RSG/0.95,0.96,0.15/
        DATA COND,VHCP/1.3,2.0E+6/
        DATA  A1,B1,A2,B2,P1,Q1,R1,P2,Q2,R2
     +      /1.0,5.0,1.0,5.0,1.0,-16.0,-0.25,1.0,-16.0,-0.5/
        DATA XMCMAX,XMCMIN,SFCMAX,RUNMAX,SMFE,SMFS,SMFR,ALF1,ALF2
     +       /7.0,0.05,1.5,1.,1.1111E-5,2.5E-4,2.08333E-4,1.E-6,1.E0/
        DATA IC/0/
C
      END
C-----------------------------------------------------------------------
C     DAILY WEATHER DATA FROM LOCAL STATION
C-----------------------------------------------------------------------
      SUBROUTINE DAYWTR
C
C-------THE SIZE OF N AND L DEPEND ON THE SIZE OF DATA FILE 'WTRDAY'
        PARAMETER (N=154,L=18)
        INTEGER LY(2,2),LD(2,L,3)
        LOGICAL OK
        INTEGER WD,WM,PA,OU,OF,DR
        COMMON /IOFL/WD,WM,PA,OU,OF,DR
        COMMON /WUV/IYD(N,2),WTR(N,6)
        COMMON /TIMES/MDAY,JDAY,HOUR
        COMMON /PARIN/IYR,MDAYI,HRI,HRF,MDAYF,LEAP,JDAYI,JDAYF,
     +                DTP,XMC,SIMUL,DTFAST,DTSLOW
C-------THE SIZE OF 10 CORRESPONDS FROM -2:00 TO 25:00 AT 3H INTERVALS
        COMMON /WTRD/HRL(10),DAL(10),RHL(10),CVL(10),PCL(10),WAL(10),LL
        SAVE
        DATA I,K,KK,IND,JD,LY,LD,II,JJ/117*0,2*1/
C-------------------------------WIND SPEED CONVERSION FROM KNOTS TO M/SEC
        DATA C/0.514096/
C
        IF(IND.EQ.0) THEN
          REWIND WD
C-------REPEAT
1         CONTINUE
          I=I+1
          READ(WD,*,END=3) (IYD(I,J),J=1,2),(WTR(I,J),J=1,6)
C-----------------------------------CONVERT TEMPERATURE FROM F TO C
          WTR(I,3)=(WTR(I,3)-32)/1.8
C-------------------------------CONVERT WIND SPEED FROM KNOTS TO M/SL
          WTR(I,5)=WTR(I,5)*C
C-------------------CONVERT PRECIPITATION FROM INCHES TO KG H2O/SQ.M
          WTR(I,6)=25.4*WTR(I,6)
          KI=MAXO(1,K)
          IF(LY(KI,1).NE.IYD(I,1)) THEN
            K=K+1
            LY(K,1)=IYD(I,1)
            IF(K.GT.1) THEN
```

```
              LD(K-1,KK,3)=I-1
              LY(K-1,2)=KK
            ENDIF
            KK=0
          ENDIF
          KI=MAX0(1,KK)
          IF(LD(K,KI,1).NE.IYD(I,2)) THEN
            KK=KK+1
            LD(K,KK,1)=IYD(I,2)
            LD(K,KK,2)=I
            IF(KK.GT.1) LD(K,KK-1,3)=I-1
          ENDIF
          IF(I.LT.N) GOTO 1
C---------UNTIL(I.EQ.N)
3         CLOSE(WD)
          IND=1
          LD(K,KK,3)=N
          LY(K,2)=KK
        ENDIF
        IF(IYR.NE.LY(JJ,1)) THEN
          JJ=0
C---------REPEAT
4           CONTINUE
            JJ=JJ+1
            IF(IYR.NE.LY(JJ,1).AND.JJ.LT.K) GOTO 4
C---------UNTIL(IYR.EQ.LY(JJ,1).OR.JJ.EQ.K)
          IF(IYR.NE.LY(JJ,1)) THEN
            STOP 1
          ENDIF
        ENDIF
        IF(JDAY.NE.JD+1) THEN
          II=0
C---------REPEAT
5           CONTINUE
            II=II+1
            IF(MDAY.NE.LD(JJ,II,1).AND.II.LT.LY(JJ,2)) GOTO 5
C---------UNTIL(MDAY.EQ.LD(JJ,II,1).OR.II.EQ.LY(JJ,2))
        ELSE
          II=II+1
        ENDIF
        IF(MDAY.NE.LD(JJ,II,1)) THEN
          STOP 2
        ELSE
          M=LD(JJ,II,2)
          I=MAX0(1,M-1)
          CALL YRDATE(JD,IYD(I,2),IYR,LEAP,0)
          IF(JDAY.NE.JD+1) I=M
        ENDIF
        OK=.TRUE.
        J=1
C-------REPEAT
6         CONTINUE
          HRL(J)=WTR(I,1)+24.0*MAX0(-1,MIN0(1,IYD(I,2)-MDAY))
          CVL(J)=WTR(I,2)
          DAL(J)=WTR(I,3)
          RHL(J)=WTR(I,4)
```



```
          WAL(J)=WTR(I,5)
          PCL(J)=WTR(I,6)
          I=I+1
          J=J+1
          IF(I.LE.N.AND.J.LE.10) THEN
            IF(MDAY.NE.IYD(I,2)) THEN
              CALL YRDATE(JD,IYD(I,2),IYR,LEAP,0)
              IF(JD.NE.JDAY+1) OK=.FALSE.
            ENDIF
          ELSE
            OK=.FALSE.
          ENDIF
          IF(OK) GOTO 6
C---------UNTIL(.NOT.OK)
        LL=J-1
        JD=JDAY
C
        RETURN
      END
C-----------------------------------------------------------------------
C     HOURLY MICROCLIMATOLOGICAL DATA IN SWATH
C-----------------------------------------------------------------------
      SUBROUTINE MICWTR
C
C---------THE SIZE OF N AND L DEPEND ON THE SIZE OF DATA FILE 'WTRMIC'
        PARAMETER (N=320,L=18)
        INTEGER LY(2,2),LD(2,L,3)
        LOGICAL OK
        INTEGER WD,WM,PA,OU,OF,DR
        COMMON /IOFL/WD,WM,PA,OU,OF,DR
        COMMON /XYZ/IYD(N,2),WTR(N,11)
        COMMON /TIMES/MDAY,JDAY,HOUR
        COMMON /PARIN/IYR,MDAYI,HRI,HRF,MDAYF,LEAP,JDAYI,JDAYF,
     +                DTP,XMC,SIMUL,DTFAST,DTSLOW
C---------THE SIZE OF 25 CORRESPONDS FROM 0:00 TO 24:00 AT 1H INTERVALS
        COMMON /WTRM/TL(25),RDB(25),RRH(25),SLL(25),URL(25),FDB(25),
     +               FRH(25),EDB(25),BRH(25),SDB(25),SRH(25),SL2(25),
     +               WD2(25),TDB(25),RH2(25),IL
        SAVE
        DATA I,K,KK,IND,JD,LY,LD,JJ,II/117*0,2*1/

        IF(IND.EQ.0) THEN
          REWIND WM
C---------REPEAT
1           CONTINUE
            I=I+1
            READ(WM,*,END=3)(IYD(I,J),J=1,2),(WTR(I,J),J=1,11)
            KI=MAX0(1,K)
            IF(LY(KI,1).NE.IYD(I,1)) THEN
              K=K+1
              LY(K,1)=IYD(I,1)
              IF(K.GT.1) THEN
                LD(K-1,KK,3)=I-1
                LY(K-1,2)=KK
              ENDIF
              KK=0
```

```
            ENDIF
            KI=MAX0(1,KK)
            IF(LD(K,KI,1).NE.IYD(I,2)) THEN
              KK=KK+1
              LD(K,KK,1)=IYD(I,2)
              LD(K,KK,2)=I
              IF(KK.GT.1) LD(K,KK-1,3)=I-1
            ENDIF
            IF(I.LT.N) GOTO 1
C         UNTIL(I.EQ.N)
3           CLOSE(WM)
            IND=1
            LD(K,KK,3)=N
            LY(K,2)=KK
          ENDIF
          IF(IYR.NE.LY(JJ,1)) THEN
            JJ=0
C         REPEAT
4             CONTINUE
              JJ=JJ+1
              IF(IYR.NE.LY(JJ,1).AND.JJ.LT.K) GOTO 4
C         UNTIL(IYR.EQ.LY(JJ,1).OR.JJ.EQ.K)
            IF(IYR.NE.LY(JJ,1)) THEN
              STOP 3
            ENDIF
          ENDIF
          IF(JDAY.NE.JD+1) THEN
            II=0
C         REPEAT
5             CONTINUE
              II=II+1
              IF(MDAY.NE.LD(JJ,II,1).AND.II.LT.LY(JJ,2)) GOTO 5
C         UNTIL(MDAY.EQ.LD(JJ,II,1).OR.II.EQ.LY(JJ,2))
          ELSE
            II=II+1
          ENDIF
          IF(MDAY.NE.LD(JJ,II,1)) THEN
            STOP 4
          ELSE
            M=LD(JJ,II,2)
            I=MAX0(1,M-1)
            CALL YRDATE(JD,IYD(I,2),IYR,LEAP,0)
            IF(JDAY.NE.JD+1.OR.ABS(WTR(I,1)-24.0).GT.0.1) I=M
          ENDIF
          OK=.TRUE.
          J=1
C       REPEAT
6           CONTINUE
            TL(J)=WTR(I,1)+24.0*MIN0(0,I-M)
            SLL(J)=WTR(I,2)
            URL(J)=WTR(I,3)
            RDB(J)=WTR(I,4)
            FDB(J)=WTR(I,5)
            BDB(J)=WTR(I,6)
            SDB(J)=WTR(I,7)
            RRH(J)=WTR(I,8)
```



```
            FRH(J)=WTR(I,9)
            BRH(J)=WTR(I,10)
            SRH(J)=WTR(I,11)
            I=I+1
            J=J+1
            IF(I.GT.N.OR.J.GT.25) THEN
              OK=.FALSE.
            ELSE IF(IYD(I,2).NE.MDAY) THEN
              OK=.FALSE.
            ENDIF
            IF(OK) GOTO 6
C         UNTIL(.NOT.OK)
          IL=J-1
          JD=JDAY

          RETURN
        END
C-------------------------------------------------------------------------------
C       DETERMINE ATMOSPHERIC PROPERTIES ABOVE THE SWATH
C-------------------------------------------------------------------------------
        SUBROUTINE AIR(HOUR,IWTR)
C
          COMMON /WTRD/HRL(10),DAL(10),RHL(10),CVL(10),PCL(10),WAL(10),LL
          COMMON /ABV/DBR,RHR,RVR,PVR,UR,CV,RCPR,PSCR,RIR,RSHR,RSVR
          COMMON /WTRM/TL(25),RDB(25),RRH(25),SLL(25),URL(25),FDB(25),
     +                 FRH(25),BDB(25),BRH(25),SDB(25),SRH(25),SL2(25),
     +                 WD2(25),TDB(25),RH2(25),IL
          SAVE

          IF(IWTR.GT.0) THEN
C           MICROCLIMATOLOGICAL DATA AVAILABLE
            DBR=APL2(HOUR,TL,RDB,IL)
            RHR=APL2(HOUR,TL,RRH,IL)
            UR=APL2(HOUR,TL,URL,IL)
          ELSE
C           DATA AVAILABLE FROM LOCAL WEATHER SERVICE
            DBR=APL2(HOUR,HRL,DAL,LL)
            RHR=APL2(HOUR,HRL,RHL,LL)
            UR=APL2(HOUR,HRL,WAL,LL)
          ENDIF
          CV=APL2(HOUR,HRL,CVL,LL)
          RVR=RWDBRH(DBR,RHR)
          PVR=PSDB(DBR)*RHR
          RCPR=RADBRH(DBR,RHR)*CPPV(PVR)
C         PSCR=PCDBRH(DBR,RHR)

          RETURN
        END
C-------------------------------------------------------------------------------
C       RAIN FALL FLUX
C-------------------------------------------------------------------------------
        SUBROUTINE FRAIN(HOUR)
C
          PARAMETER (N=3,M=10)
          REAL MCL,WMAX(N)
          COMMON /LAYRS/MCL(N),PVA(N),PVL(N),RWS(N),DBA(N),DBL(N),RHA(N),
```

```
     +           RVA(N),RVL(N),RCP(N),PSC(N),HLA(N),VLA(N),RBH(N),RBV(N),
     +           RIA(N),WDA(N),DLO(N),ERH(N),VCP(N),DEW(N),TEW(N),FAC(N),
     +           DL(N),DZ(N),DD(N),HW(N),HAA(N+1),VAA(N+1),RSH(N+1),
     +           RSV(N+1)
      COMMON /FLUX/FXHAA(N+1),FXVAA(N+1),FXHLA(N),FXVLA(N),FXSHA(N),
     +           FXSHL(N),FXLHA(N),FXLHL(N),FVAA(N+1),FVLA(N),
     +           FXRVA(N),FXHSS(M+1),FXSHS(M),FXSHG,FXLHG,FXSTG,
     +           FXRSP(N),FXRAIN(N),RAIN(N),FXHLE,FXVLE
      COMMON /WTRD/HRL(10),DAL(10),RHL(10),CVL(10),PCL(10),WAL(10),LL
      COMMON /GRAIN/RAING
      SAVE
C      DATA INDEX/0/

C       IF(INDEX.EQ.0) THEN
         DO 62 I=1,N
          WMAX(I)=0.15*DL(I)
62       CONTINUE
C        INDEX=1
C       ENDIF
        I=1
C-------REPEAT
60       CONTINUE
         I=I+1
         IF(HOUR.GT.HRL(I).AND.I.LT.LL) GOTO 60
C------UNTIL(HOUR.LE.HRL(I))
        R=PCL(I)/10800
        DO 61 I=1,N
         IF(R.GT.0) THEN
           WHALF=0.5*WMAX(I)
           RTRY=R*(1-EXP(-0.4*DL(I)))
           IF(RTRY.LE.WHALF) THEN
            RAIN(I)=RTRY
           ELSE
            RAIN(I)=AMIN1(WHALF*(R-WHALF)*(1-EXP(-0.15*DL(I))),
     +                  WMAX(I))
           ENDIF
           R=R-RAIN(I)
         ELSE
           RAIN(I)=0.0
         ENDIF
61      CONTINUE
C-------------RAINFALL DOWN TO THE GROUND
        RAING=R

        RETURN
       END
C-----------------------------------------------------------------------
C     SHORT-WAVE RADIATION FIELD INSIDE CANOPY
C-----------------------------------------------------------------------
      SUBROUTINE SWRAD(MIC)
C
       PARAMETER (N=3)
       REAL C(N),R(N),U(N),V(N),A(2*N,2*N),AB(2*N,2*N+1)
       REAL H(2*N),F(2*N),LAI,MCO,MCL
       COMMON /TIMES/MDAY,JDAY,HOUR
       COMMON /ABV/DBR,RHR,RVR,PVR,UR,CV,RCPR,PSCR,RIR,RSHR,RSVR
```



```
       COMMON /SWATH/LAI,DENS,VO,WL,MCO,EMC,RSFC
       COMMON /LAYRS/MCL(N),PVA(N),PVL(N),RWS(N),DBA(N),DBL(N),RHA(N),
     +           RVA(N),RVL(N),RCP(N),PSC(N),HLA(N),VLA(N),RBH(N),RBV(N),
     +           RIA(N),WDA(N),DLO(N),ERH(N),VCP(N),DEW(N),TEW(N),FAC(N),
     +           DL(N),DZ(N),DD(N),HW(N),HAA(N+1),VAA(N+1),RSH(N+1),
     +           RSV(N+1)
       COMMON /SOL/SLO,SLDIR0,SLSKY0,SMU2
       COMMON /SUN$/HSUN,TSOLAR,TRISE,TSET
       COMMON /SWRD/RE,TE,SLDIR(N),SLSKY(N),DFDIR(N),DFDIRD(0:N),
     +           DFDIRU(0:N),DFSKYD(0:N),DFSKYU(0:N),SL(0:N),W(N)
       COMMON /RADSW/RNSW(N),RNSWG,RSG
       COMMON /EPS/EPS
       SAVE

C-------FIND SUN ELEVATION ANGLE (WITH TIME SAVING 1 HOUR)
       HSUN=BETA(HOUR-1.0,JDAY)
       IF(HSUN.LT.1.0E-6) THEN
C--------NO SHORT-WAVE RADIATION AT NIGHT
         SLO=0.0
         SLDIR0=0.0
         SLSKY0=0.0
         DO 15 I=0,N
          DFDIRD(I)=0.0
          DFDIRU(I)=0.0
          DFSKYD(I)=0.0
          DFSKYU(I)=0.0
          IF(I.GT.0) THEN
           SLDIR(I)=0.0
           SLSKY(I)=0.0
           RNSW(I)=0.0
          ENDIF
          SL(I)=0.0
15       CONTINUE
       ELSE
C--------SHORT-WAVE RADAITION DURING DAYTIME
         CALL SOLAR(MIC)
         SMU2=2*SIN(HSUN)
         SMU2=SIGN(1.0,SMU2)*AMAX1(1.0E-9,ABS(SMU2))
         DO 1 I=1,N
C----------LEAF SCATTERING COEFFICIENT
          W(I)=AMAX1(0.0,AMIN1(1.0,2*REFL(MCL(I))))
C----------EXTINCTION COEFFICIENT
          XX=1-W(I)
          C(I)=SQRT(XX)
          R(I)=(1-C(I))/(1+C(I))
          R(I)=SIGN(1.0,R(I))*AMAX1(1.0E-9,ABS(R(I)))
          IF(ABS(SMU2*C(I)-1.0).LT.1.0E-30) THEN
           D=AMAX1(1.0E-9,AMIN1(1.0,1-R(I)))
           U(I)=-(C(I)*DL(I)+0.5*R(I))/D
           V(I)=(C(I)*R(I)*DL(I)+0.5)/D
          ELSE
           UV=1-XX*SMU2**2
           UV=SIGN(1.0,UV)/AMAX1(1.0E-9,ABS(UV))
           U(I)=(1+SMU2)*UV
           V(I)=(1-SMU2)*UV
          ENDIF
```

```
1         CONTINUE
C
          L=2*N
          L1=L-2
          DO 3 I=1,L
            DO 2 J=1,L
              A(I,J)=0.0
2           CONTINUE
3         CONTINUE
          A(1,1)=1.0
          A(1,2)=1.0
          DO 4 I=2,L1,2
            J=I-1
            K=I/2
            A(I,J)=EXP(-C(K)*DL(K))
            A(I,J+1)=1/A(I,J)
            A(I,J+2)=-1.0
            A(I,J+3)=-1.0
            A(I+1,J)=R(K)*A(I,J)
            A(I+1,J+1)=1/A(I+1,J)
            A(I+1,J+2)=-R(K+1)
            A(I+1,J+3)=1/A(I+1,J+2)
4         CONTINUE
          A(L,L-1)=(R(N)-RSG)*EXP(-C(N)*DL(N))
          A(L,L  )=(1/R(N)-RSG)*EXP(C(N)*DL(N))
          DO 6 I=1,L
            DO 5 J=1,L
              AB(I,J)=A(I,J)
5           CONTINUE
6         CONTINUE
C---------FOR DIFFUSE RADIATION DUE TO DIRRECT BEAM RADIATION
          J=L+1
          X=0.25*SMU2*SLDIR0
          AB(1,J)=X*W(1)*U(1)
          SUML=0.0
          DO 7 I=2,L1,2
            K=I/2
            SUML=SUML+DL(K)
            SX=AMIN1(50.0,SUML/SMU2)
            AB(I,J)=X*(W(K)*U(K)-W(K+1)*U(K+1))*EXP(-SX)
            AB(I+1,J)=X*(W(K+1)*V(K+1)-W(K)*V(K))*EXP(-SX)
7         CONTINUE
          SX=AMIN1(50.0,LAI/SMU2)
          AB(L,J)=X*(2*RSG-W(N)*(RSG*U(N)+V(N)))*EXP(-SX)
C---------SOLUTION
          CALL GAUSS(L,AB)
          DO 8 I=1,L
            H(I)=AB(I,J)
8         CONTINUE
C
C---------FOR DIFFUSE RADIATION DUE TO DIFFUSE SKY RADIATION
          DO 10 I=1,L
            DO 9 K=1,L
              AB(I,K)=A(I,K)
9           CONTINUE
10        CONTINUE
```



```
          SUML=0.0
          CALL PQ(0.0,W(1),P,Q)
          AB(1,J)=-SLSKY0*P
          DO 11 I=2,L1,2
            K=I/2
            SUML=SUML+DL(K)
            CALL PQ(SUML,W(K+1),PP,QQ)
            CALL PQ(SUML,W(K),P,Q)
            AB(I,J)=SLSKY0*(PP-P)
            AB(I+1,J)=SLSKY0*(QQ-Q)
11        CONTINUE
          CALL PQ(LAI,W(N),P,Q)
          AB(L,J)=SLSKY0*(2*RSG*E(0.5*LAI,3)+RSG*P-Q)
C---------SOLUTION
          CALL GAUSS(L,AB)
          DO 12 I=1,L
            F(I)=AB(I,J)
12        CONTINUE
C
C---------DIFFUSE RADIATION AT CANOPY TOP
          CALL DIRDF(0.0,0.0,H(1),H(2),W(1),DFDIRD(0),DFDIRU(0))
          CALL SKYDF(0.0,0.0,F(1),F(2),W(1),DFSKYD(0),DFSKYU(0))
C
C---------NET DOWNWARD SHORT-WAVE RADIATION AT CANOPY TOP
          SL(0)=SLDIR0+SLSKY0+DFDIRD(0)+DFSKYD(0)-DFDIRU(0)
     +          -DFSKYU(0)
C
C---------DIRRECT,DIFFUSE AND NET DOWNWARD RADIATION INSIDE CANOPY
          SUML=0.0
          DO 13 I=1,N
            SUML=SUML+DL(I)
            J=2*I-1
            K=2*I
            SX=AMIN1(50.0,SUML/SMU2)
            SLDIR(I)=SLDIR0*EXP(-SX)
            SLSKY(I)=SLSKY0*2*E(0.5*SUML,3)
            CALL DIRDF(DL(I),SUML,H(J),H(K),W(I),DFDIRD(I),DFDIRU(I))
            CALL SKYDF(DL(I),SUML,F(J),F(K),W(I),DFSKYD(I),DFSKYU(I))
C-----------NET DOWNWARD SHORT-WAVE RADIATION FOR EACH LAYER
            SL(I)=SLDIR(I)+SLSKY(I)+DFDIRD(I)+DFSKYD(I)-DFDIRU(I)
     +            -DFSKYU(I)
C-----------NET DOWNWARD SHORT-WAVE RADIATION ABSORBED BY EACH LAYER
            IF(I.EQ.1) THEN
              RNSW(1)=SL(0)-SL(1)
            ELSE
              RNSW(I)=SL(I-1)-SL(I)
            ENDIF
13        CONTINUE
          ENDIF
C---------NET DOWNWARD RADIATION ON THE GROUND
          RNSWG=SL(N)
C---------EFFECTIVE REFLECTION AND TRANSMISSION COEFFICIENTS
          SS=AMAX1(1.0E-6,SL0)
          RE=(DFDIRU(0)+DFSKYU(0))/SS
          TE=(SLDIR(N)+SLSKY(N)+DFDIRD(N)+DFSKYD(N))/SS
C
```

```
        RETURN
      END
C-----------------------------------------------------------------------
C     SUN ELEVATION
C-----------------------------------------------------------------------
      FUNCTION BETA(HOUR,JDAY)
C
C   LAT=LOCAL LATITUDE (DEGREES)
C   LON=LOCAL LONGITUDE (DEGREES WEST)
C   LST=STANDARD MERIDIAN FOR THE LOCAL TIME ZONE (DEGREES WEST)
C
        REAL LAT,LON,LST
        COMMON /PARIN/IYR,MDAYI,HRI,HRF,MDAYF,LEAP,JDAYI,JDAYF,
     +                DTP,XMC,SIMUL,DTFAST,DTSLOW
        COMMON /LOCAL/LAT,LON,LST,ALT
        COMMON /PAR/PI
        COMMON /SUNH/HSUN,TSOLAR,TRISE,TSET
        SAVE
        DATA RAD,JDAY0/0.0174532,0/
C
        IF(JDAY.NE.JDAY0) THEN
C-------------------------------SOLAR DECLINATION ANGLE (RADIANS)
          D=23.45*RAD*COS(2*PI*(JDAY-172-LEAP)/(365+LEAP))
C-------------------------------SUNSET AND SUN-RISE
          RLAT=RAD*LAT
          COSH=-TAN(RLAT)*TAN(D)
          HSET=ACOS(COSH)
          HRISE=-HSET
          C=2*PI*(JDAY-81-LEAP)/(365+LEAP)
          E=9.87*SIN(2*C)-7.53*COS(C)-1.5*SIN(C)
          DLONG=(4*(LST-LON)+E)/60
          TSET=HSET/(15*RAD)+12-DLONG
          TRISE=HRISE/(15*RAD)+12-DLONG
          JDAY0=JDAY
        ENDIF
C-------------------------------SOLAR TIME (HOUR)
        TSOLAR=HOUR+DLONG
C-------------------------------HOUR ANGLE (RADIANS)
        H=RAD*15*(TSOLAR-12)
C-------------------------------SUN ELEVATION ANGLE (RADIANS)
        IF(HOUR.LE.TRISE.OR.HOUR.GE.TSET) THEN
          BETA=0.0
        ELSE
          BETA=ASIN(COS(RLAT)*COS(H)*COS(D)+SIN(RLAT)*SIN(D))
        ENDIF
C
        RETURN
      END
C-----------------------------------------------------------------------
C     LEAF REFLECTANCE AS A FUNCTION OF MOISTURE CONTENT
C-----------------------------------------------------------------------
      FUNCTION REFL(MC)
C
        REAL MC
        REFL=0.45-0.0525*AMIN1(MC,4.0)
C
```



```
        RETURN
      END
C-----------------------------------------------------------------------
C     SOLAR RADIATION AT CANOPY TOP
C-----------------------------------------------------------------------
      SUBROUTINE SOLAR(MIC)
C
        COMMON /ABV/DBR,RHR,RVR,PVR,UR,CV,RCPR,PSCR,RIR,RSHR,RSVR
        COMMON /TIMES/MDAY,JDAY,HOUR
        COMMON /SUNH/HSUN,TSOLAR,TRISE,TSET
        COMMON /SOL/SLO,SLDIR0,SLSKY0,SMU2
        SAVE
C
C-------FRACTION OF DIFFUSE SKY TO TOTAL RADIATION IN CLEAR SKY
        FR=DIFFR(57.23578*HSUN)
C-------TOTAL SOLAR RADIATION WITH PARTIAL SKY COVER
        IF(MIC.EQ.0) THEN
C---------MEASSURED SOLAR RADIATION DATA NOT AVAILABLE
          IF(ABS(1-FR).LE.1.0E-6) THEN
            B=1.0
          ELSE
            B=1-FR
          ENDIF
          SLO=(1-0.83*CV)*BEAMCL(HSUN,JDAY,ALT)/B
        ENDIF
C-------DIRRECT BEAM AND DIFFUSE SKY RADIATION
        SLDIR0=(1-FR)*(1-CV)*SLO/(1-0.83*CV)
        SLSKY0=SLO-SLDIR0
C
        RETURN
      END
C-----------------------------------------------------------------------
C     FRACTION OF DIFFUSE SKY RADIATION TO TOTAL SOLAR RADIATION
C-----------------------------------------------------------------------
      FUNCTION DIFFR(HSUN)
C
        REAL HSUNL(7),FRDIF(7)
        SAVE
        DATA HSUNL/0.0,5.0,15.0,25.0,35.0,45.0,90.0/
        DATA FRDIF/1.0,1.0,0.32,0.22,0.18,0.16,0.13/
C
        DIFFR=APL2(HSUN,HSUNL,FRDIF,7)
C
        RETURN
      END
C-----------------------------------------------------------------------
C     SOLAR BEAM RADIATION AT CANOPY TOP FOR STANDARD CLEAR SKY
C-----------------------------------------------------------------------
      FUNCTION BEAMCL(HSUN,JDAY,ALT)
C
        DATA SC,RA,RB,RK/1375.0,0.97,0.99,1.02/
C
C-------------------------------------------------STATEMENT FUNCTION
        SA0(ALT)=0.4237-0.00821*(6.0-ALT)**2
        SA1(ALT)=0.5055+0.00595*(6.5-ALT)**2
        SAK(ALT)=0.2711+0.01858*(2.5-ALT)**2
```

```
C
C-----------------------------------------------------ALTITUDE<=2.5KM
      ALT=AMIN1(ALT,2.5)
      A0=RA*SA0(ALT)
      A1=RB*SA1(ALT)
      AK=RK*SAK(ALT)
C
      SINB=SIN(HSUN)
      X=AMAX1(0.02,SINB/AK)
      TAUB=A0+A1*EXP(-1/X)
C-------------SOLAR BEAM RADIATION FOR STANDARD SKY WITH 23KM VISIBILITY
      BEAMCL=SC*SINB*(1+0.033*COS(6.2831853*JDAY/365))*TAUB

      RETURN
    END
C-----------------------------------------------------------------------
C     EXTINCTION OF DIFFUSE RADIATION DUE TO SKY RADIATION
C-----------------------------------------------------------------------
      SUBROUTINE PQ(X,W,P,Q)
C
C   X-DOWNWARD ACCUMULATED LEAF AREA INDEX
C   W-LEAF SCATTERING COEFFICIENT
C
      COMMON /PAR/PI
      SAVE
      DATA C/0.02/
C
      A=SQRT(1-W)
C      C=1/50.0
C-------------------------SET LOOP SIZE
      M=103
C-------------------------ADJUST LOOP SIZE TO AVOID SINGULAR POINT
      IF(A.GT.0.5) THEN
        R=2*M*ACOS(0.5/A)/PI
        IF(ABS(R-INT(R)).LE.1.0E-6) THEN
          M=101
        ENDIF
      ENDIF
      D=0.5*PI/M
      E=0.5*W*D
      P=0.0
      Q=0.0
      J=M-1
      DO 1 I=1,J
        B=D*I
        COSB2=2*COS(B)
        F=(1-W)*COSB2**2-1
        SIN2B=SIN(2*B)
        SL=SIN2B*(COSB2+1)/F
        H=SIN2B*(COSB2-1)/F
        IF(ABS(X).LT.1.0E-30) THEN
          P=P+SL
          Q=Q+H
        ELSE
          Y=AMAX1(C,COSB2/X)
          EY=EXP(-1/Y)
```



```
          P=P+SL*EY
          Q=Q+H*EY
        ENDIF
1     CONTINUE
      P=E*P
      Q=E*Q
C
      RETURN
    END
C-----------------------------------------------------------------------
C     DIFFUSE RADIATION DUE TO DIRRECT BEAM SOLAR RADIATION
C-----------------------------------------------------------------------
      SUBROUTINE DIRDF(X,SX,A,B,W,DFDIRD,DFDIRU)
C
      COMMON /SOL/SL0,SLDIR0,SLSKY0,SMU2
      SAVE
C
      XX=1-W
      C=SQRT(XX)
      R=(1-C)/(1+C)
      R=AMAX1(1.0E-9,ABS(R))
      IF(ABS(SMU2*C-1.0).LT.1.0E-30) THEN
        D=AMAX1(1.0E-9,AMIN1(1.0,1-R))
        U=-(C*X+0.5*R)/D
        V=(C*R*X+0.5)/D
      ELSE
        UV=1-XX*SMU2**2
        UV=SIGN(1.0,UV)/AMAX1(1.0E-9,ABS(UV))
        U=(1+SMU2)*UV
        V=(1-SMU2)*UV
      ENDIF
      CX=AMIN1(50.0,C*X)
      G=A*EXP(-CX)
      H=B*EXP(CX)
      XS=AMIN1(50.0,SX/SMU2)
      F=0.25*W*SMU2*SLDIR0*EXP(-XS)
      DFDIRD=G+H-F*U
      DFDIRU=R*G+H/R+F*V
C
      RETURN
    END
C-----------------------------------------------------------------------
C     DIFFUSE RADIATION DUE TO DIFFUSE SKY RADIATION
C-----------------------------------------------------------------------
      SUBROUTINE SKYDF(X,SX,A,B,W,DFSKYD,DFSKYU)
C
      COMMON /SOL/SL0,SLDIR0,SLSKY0,SMU2
      SAVE
C
      XX=1-W
      C=SQRT(XX)
      R=(1-C)/(1+C)
      R=AMAX1(1.0E-9,ABS(R))
      CX=AMIN1(50.0,C*X)
      G=A*EXP(-CX)
      H=B*EXP(CX)
```

```
      CALL PQ(SX,W,P,Q)
      DFSKYD=G+H+SLSKY0*P
      DFSKYU=R*G+H/R+SLSKY0*Q
C
      RETURN
      END
C-----------------------------------------------------------------------
C     THERMAL RADIATION FIELD WITHIN THE CANOPY
C-----------------------------------------------------------------------
      SUBROUTINE LWRAD
C
      PARAMETER (N=3,M=10)
      REAL LAI,MC0,MCL,A(2*N),AB(2*N,2*N+1)
      COMMON /PAR/PI
      COMMON /ABV/DBR,RHR,RVR,PVR,UR,CV,RCPR,PSCR,RIR,RSHR,RSVR
      COMMON /WTRD/HRL(10),DAL(10),RHL(10),CVL(10),PCL(10),WAL(10),LL
      COMMON /LAYRS/MCL(N),PVA(N),PVL(N),RWS(N),DBA(N),DBL(N),RHA(N),
     +        RVA(N),RVL(N),RCP(N),PSC(N),HLA(N),VLA(N),RBH(N),RBV(N),
     +        RIA(N),WDA(N),DL0(N),ERH(N),VCP(N),DEW(N),TDW(N),FAC(N),
     +        DL(N),DZ(N),DD(N),HW(N),HAA(N+1),VAA(N+1),RSH(N+1),
     +        RSV(N+1)
      COMMON /SWATH/LAI,DENS,VO,WL,MC0,EMC,RSFC
C      COMMON /LAND/COND,VHCP,DEP(M),DBS(M+1),Q(M+1),COND2,ALF,VT
      COMMON /LWRD/EMR,RLG,EMA(N),EML(N),EL(N),EA(0:N),EB(0:N),
     +           ED(0:N),EU(0:N),ENET(0:N)
      COMMON /RADLW/RNLW(N),RNLWG,EMG
      COMMON /GND/CLOD,DBG,RHG,PVG,RVG,UG,RCPG,PSCG,RSHG,RSVG,RVS
      SAVE
C
C-------STATEMENT FUNCTION-----------------------------------------------
C---------------------THERMAL RADIATION EMITTED BY A SURFACE (W/SQ. M)
      THE(EM,DB)=5.9967E-8*EM*(DB+273.16)**4
C---------------------ATTENUATION COEFFICIENT OF THERMAL RADIATION
      AD(X)=2*E(0.5*X,3)
C---------------------EMISSIVITY OF CLEAR SKIES
      EMCL(RV)=AMIN1(1.0,1.542737*RV**0.142857)
C
C---------------------ATMOSPHERE EMISSIVITY OF PARTIALLY CLOUDY SKIES
      EMR=(1-CV)*EMCL(RVR)+CV*(1-8/(DBR+273.16))
C---------------------THERMAL RADIATION EMITTED BY ATMOSPHERE
      EA0=THE(EMR,DBR)
C---------------------THERMAL RADIATION EMITTED FROM SWITH LAYERS
      DO 1 I=1,N
        EMA(I)=EMCL(RVA(I))
        EML(I)=0.96
        EL(I)=THE(EML(I),DBL(I))
1     CONTINUE
C---------------------THERMAL RADIATION EMITTED FROM SOIL FURFACE
      EB0=THE(EMG,DBG)
C---------------------SOIL REFLECTANCE TO THERMAL RADIATION
      RLG=1-EMG
C---------------------PREPARING COEFFICIENTS MATRIX
      L=2*N
      DO 4 I=1,L
        DO 3 J=1,L
          AB(I,J)=0.0
```



```
3       CONTINUE
4     CONTINUE
      L=L+1
      AB(1,1)=PI
      AB(1,L)=EA0-EL(1)
      L1=L-3
      DO 5 I=2,L1,2
        J=I-1
        K=I/2
        AB(I,J)=PI*AD(DL(K))
        AB(I,J+2)=-PI
        AB(I,L)=EL(K+1)-EL(K)
        AB(I+1,J+1)=PI
        AB(I+1,J+3)=-PI*AD(DL(K))
        AB(I+1,L)=EL(K+1)-EL(K)
5     CONTINUE
      L=L-1
      AB(L,L-1)=-RLG*PI*AD(DL(N))
      AB(L,L)=PI
      AB(L,L+1)=EB0-EMG*EL(N)
C-----------------------SOLVING LINEAR EQUATIONS
      CALL GAUSS(L,AB)
      DO 6 I=1,L
        A(I)=AB(I,L+1)
6     CONTINUE
C-----------------------THERMAL RADIATION ABOVE THE CANOPY
      EA(0)=EA0
      EB(0)=EB0*AD(LAI)
      CALL TRM(0.0,A(1),A(2),DL(1),EL(1),ED(0),EU(0))
      ENET(0)=ED(0)-EU(0)
C-----------------------THERMAL RADIATION FIELD WITHIN THE CANOPY
      SUML=0.0
      DO 2 I=1,N
        SUML=SUML+DL(I)
        EA(I)=EA0*AD(SUML)
        EB(I)=EB0*AD(LAI-SUML)
        CALL TRM(DL(I),A(2*I-1),A(2*I),DL(I),EL(I),ED(I),EU(I))
C-----------------------NET DOWNWARD THERMAL RADIATION
        ENET(I)=ED(I)-EU(I)
C-----------------------THERMAL RADIATION ABSORBED BY SWATH LAYERS
        IF(I.EQ.1) THEN
          RNLW(1)=ENET(0)-ENET(1)
        ELSE
          RNLW(I)=ENET(I-1)-ENET(I)
        ENDIF
2     CONTINUE
C-----------------------THERMAL RADIATION REACHING THE GROUND
      RNLWG=ENET(N)
C
      RETURN
      END
C-----------------------------------------------------------------------
C     DOWNWARD AND UPWARD THERMAL RADIATION WITHIN CANOPY
C-----------------------------------------------------------------------
      SUBROUTINE TRM(X,A,B,DL,EL,ED,EU)
C
```

```
      COMMON /PAR/PI
      COMMON /EPS/EPS
      SAVE

C-----------------------------------------------------STATEMENT FUNCTION
      AD(X)=2*E(0.5*X,3)
C
      IF(ABS(X).LT.1.0E-30) THEN
        ED=PI*A+EL
        EU=PI*B*AD(DL)+EL
      ELSE IF(ABS(X-DL).LT.1.0E-30) THEN
        ED=PI*A*AD(DL)+EL
        EU=PI*B+EL
      ELSE
        ED=PI*A*AD(X)+EL
        EU=PI*B*AD(DL-X)+EL
      ENDIF
C
      RETURN
      END
C-----------------------------------------------------------------------
C     GAUSSIAN ELEMINATION METHOD OF SOLVING LINEAR EQUATIONS
C-----------------------------------------------------------------------
      SUBROUTINE GAUSS(N,AB)
C
      REAL AB(N,N+1)
      SAVE
      DATA EPS/1.0E-30/
C
      PV=1.0
      K=1
      N1=N+1
C-----WHILE ((PV.NE.0.).AND.(K.LE.N))
47      CONTINUE
        IF((ABS(PV).LT.EPS).OR.(K.GT.N)) GOTO 48
C-------SELECT A PIVOT ELEMENT OF A COLUMN
        C=AB(K,K)
        M=K
        DO 44 I=K+1,N
          IF(ABS(AB(I,K)).GT.ABS(C)) THEN
            C=AB(I,K)
            M=I
          ENDIF
44      CONTINUE
C-------CHECK THE PIVOT ELEMENT
        IF(ABS(C).GT.EPS) THEN
          IF(M.NE.K) THEN
C-----------EXCHANGE TWO RESPECTIVE ROWS
            DO 43 J=1,N1
              A=AB(K,J)
              AB(K,J)=AB(M,J)
              AB(M,J)=A
43          CONTINUE
          ENDIF
C---------GET A PIVOT ROW (NOTE: AB(K,K)=1.0)
          C=1.0/C
```



```
          DO 40 J=K,N1
            AB(K,J)=AB(K,J)*C
40        CONTINUE
C---------ROW OPERATE AND ELEMINATE (AB(I,K)=0.,I.NE.K,I=1,N)
          NK=N1+K
          DO 42 I=1,N
            IF(I.NE.K) THEN
              DO 41 L=K,N1
                J=NK-L
                AB(I,J)=AB(I,J)-AB(I,K)*AB(K,J)
41            CONTINUE
            ENDIF
42        CONTINUE
        ELSE
C---------CONSIDER THE PIVOT ELEMENT AS ZERO
          PV=0.0
          WRITE(*,*) 'THIS IS A SYSTEM OF DEPENDENT OR ',
     +               'CONTRADICTORY EQUATIONS.'
          DO 3 I=1,N
            WRITE(*,'(11E10.3)') (AB(I,J),J=1,N1)
3         CONTINUE
          GOTO 48
        ENDIF
        K=K+1
        GOTO 47
48      CONTINUE
C-------END WHILE

      RETURN
      END
C-----------------------------------------------------------------------
C     INTEGRAL EXPONENTIAL OF THE N-TH ORDER
C-----------------------------------------------------------------------
      FUNCTION E(X,N)
C
      EXTERNAL EINT
      COMMON /ET/Y,M
      COMMON /PAR/PI
      SAVE

      Y=X
      M=N
      E=GAUINT(0.0,0.5*PI,EINT)
C
      RETURN
      END
C-----------------------------------------------------------------------
C     NUMERICAL INTEGRATION OF GAUSS QUADRATURE
C-----------------------------------------------------------------------
      FUNCTION GAUINT(A,B,FUNC)
C
C   FUNC-NAME OF THE EXTERNAL FUNCTION TO BE INTEGRATED
C   A    - LOWER LIMIT OF INTEGRATION
C   B    - UPPER LIMIT OF INTEGRATION
C
      EXTERNAL FUNC
```

```
      DOUBLE PRECISION T(10),D(10)
      SAVE
      DATA T /-.9739065285,-.8650633667,-.6794095683,-.4333953941,
     +        -.1488743390,0.1488743390,0.4333953941,0.6794095683,
     +        0.8650633667,0.9739065285/
      DATA D/0.0666713443,0.1494513492,0.2190863625,0.2692667193,
     +        0.2955242247,0.2955242247,0.2692667193,0.2190863625,
     +        0.1494513492,0.0666713443/
C
      AB=B+A
      BA=B-A
      GAUINT=0.0
      DO 2 J=1,10
        X=0.5*(BA*T(J)+AB)
        GAUINT=GAUINT+D(J)*FUNC(X)
2     CONTINUE
      GAUINT=0.5*BA*GAUINT
C
      RETURN
    END
C-----------------------------------------------------------------------
C     INTEGRAND OF THE INTEGRAL EXPONENTIAL
C-----------------------------------------------------------------------
    FUNCTION EINT(B)
C
      COMMON /ET/Y,M
      COMMON /PAR/PI
      SAVE

      IF(ABS(B-0.5*PI).LT.1.0E-30) THEN
        IF(M.EQ.1) THEN
          EINT=EXP(50.0)
        ELSE
          EINT=0.0
        ENDIF
      ELSE
        COSB=AMAX1(1.0E-30,COS(B))
        EINT=SIN(B)*COSB**(M-2)
        IF(ABS(Y).GT.0.0) THEN
          A=ALOG(EINT)
          YCOSB=AMAX1(-50.0+A,AMIN1(50.0+A,Y/COSB))
          EINT=EINT*EXP(-YCOSB)
        ENDIF
      ENDIF
C
      RETURN
    END
C-----------------------------------------------------------------------
C     CONVERTE DATE BETWEEN CALENDAR DATE AND DAY OF THE YEAR
C-----------------------------------------------------------------------
    SUBROUTINE YRDATE(JULIAN,MONDAY,IYR,LEAP,I)

      INTEGER CAL(13)
      SAVE
      DATA CAL/0,31,59,90,120,151,181,212,243,273,304,334,365/
      DATA IYR0/0/
```



```
      IF(IYR.NE.IYR0) THEN
        IF(4*(IYR/4).EQ.IYR) THEN
          LEAP=1
        ELSE
          LEAP=0
        ENDIF
        IYR0=IYR
      ENDIF

      IF(I.EQ.0) THEN
C-------------CONVERTTO DAY OF THE YEAR FROM CALENDAR DATE
        MONDAY=MIN0(1231,MAX0(101,MONDAY))
        MON=MONDAY/100
        DAY=MONDAY-100*MON
        JULIAN=CAL(MON)+DAY+LEAP*MIN0(1,MON/3)
      ELSE
C-------------CONVERT FROM DAY OF THE YEAR TO CALENDAR DATE
        JULIAN=MIN0(365+LEAP,MAX0(1,JULIAN))
        MON=0
C---------REPEAT
1         CONTINUE
          MON=MON+1
          IF(JULIAN-LEAP*MIN0(1,MON/2).GT.CAL(MON+1)) GOTO 1
C---------UNTIL(JULIAN-LEAP*MIN0(1,MON/2).LE.CAL(MON+1))
        MONDAY=100*MON+JULIAN-CAL(MON)-LEAP*MIN0(1,MON/3)
      ENDIF

      RETURN
    END
C-----------------------------------------------------------------------
C   AERODYNAMICS & STRATIFICATION ABOVE THE CANOPY
C-----------------------------------------------------------------------
    SUBROUTINE ABVI
C
C------ D    -ZERO PLANE DISPLACEMENT (M)
C------ Z0   -ROUGHNESS LENGTH  (M)
C------ ZR   -REFERENCE HEIGHT (M)
C------ ZC   -CROP HEIGHT (M)
C------ BM   -LN((ZR-D)/Z0)
C------ BMC  -LN((ZC-D)/Z0)
C------ BH   -LN((ZR-D)/(ZC-D))
C
      REAL   LOGZC,LOGD,LOGZ0
      COMMON /HT/ZR,ZC,D,Z0
      COMMON /Z/ZS(5),AM(5),AC(5),AH(5)
      COMMON /IABV/BM,BH,BMC,DZ,DZC,DZH
      SAVE
C
C---------------------FIND ZERO DISPLACEMENT AND ROUGHNESS HEIGHT
      LOGZC=ALOG10(ZC)
      LOGZ0=0.997*LOGZC-0.883
      LOGD=0.9793*LOGZC-0.1536
      D=10.**LOGD
      Z0=10.00**LOGZ0
C---------------------STRATIFICATION ABOVE THE CANOPY
```

```
      DZ=ZR-D-Z0
      DZC=ZC-D-Z0
      DZH=ZR-ZC
      ZRD=ZR-D
      ZCD=ZC-D
C
      ZS(1)=ZRD
      ZS(5)=ZCD
      DZS=0.25*DZH
      DO 40   J=2,4
        ZS(J)=ZS(5)+DZS*(5-J)
40    CONTINUE
C
      BM=ALOG(ZRD/Z0)
      BMC=ALOG(ZCD/Z0)
      BH=BM-BMC

      AM(1)=BM
      AM(2)=DZ
      AM(3)=0.5*(ZRD**2-Z0**2)
      AM(4)=(ZRD**3-Z0**3)/3
      AM(5)=0.25*(ZRD**4-Z0**4)
C
      AC(1)=BMC
      AC(2)=DZC
      AC(3)=0.5*(ZCD**2-Z0**2)
      AC(4)=(ZCD**3-Z0**3)/3.0
      AC(5)=0.25*(ZCD**4-Z0**4)
C
      AH(1)=BH
      AH(2)=DZH
      AH(3)=0.5*(ZRD**2-ZCD**2)
      AH(4)=(ZRD**3-ZCD**3)/3
      AH(5)=0.25*(ZRD**4-ZCD**4)
C
      RETURN
    END
C-----------------------------------------------------------------------
C     TURBULENCE AND WIND PROFILE ABOVE THE CANOPY
C-----------------------------------------------------------------------
    SUBROUTINE ABOVE(DDB,DPV)
C
      COMMON /HT/ZR,ZC,D,Z0
      COMMON /IABV/BM,BH,BMC,DZ,DZC,DZH
      COMMON /ABVO/TP,UR2,L,RI,USTAR
      COMMON /ABV/DBR,RHR,RVR,PVR,UR,CV,RCPR,PSCR,RIR,RSHR,RSVR
      COMMON /TOP/DBC,PVC,RVC,UC
      COMMON /GND/CLOD,DBG,RHG,PVG,RVG,UG,RCPG,PSCG,RSHG,RSVG,RVS
      SAVE
C
      UR2=AMAX1(1.0E-9,UR*UR)
      TPR=DBR+0.001*PVR+0.01*ZR+273.16
      TPC=DBC+0.001*PVC+0.01*ZC+273.16
      TP=0.5*(TPR+TPC)
      DTP=DDB+0.001*DPV+0.01*DZC
```



```
      IF(DTP.LT.0.0.AND.DPV.GT.0.0) THEN
C-------------------------------HEAT FLUX UP & MOISTURE FLUX DOWN
        RSVR=RSHABV(-DTP)
        RSHR=RSHABV(DTP)
      ELSE
        RSHR=RSHABV(DTP)
        RSVR=RSHR
      ENDIF
C
      RETURN
    END
C-----------------------------------------------------------------------
C     WIND SPEED & RESISTANCE TO HEAT AND MOISTURE TRANSFER ABOVE CANOPY
C-----------------------------------------------------------------------
    FUNCTION RSHABV(DTP)
C
      REAL   KARMAN,INTH,INTM,INTMC,L,KLIST
      COMMON /PRES/PATM
      COMMON /AIRP/TLIST(11),KLIST(11),DMLIST(11),DHLIST(11),
     +            DVLIST(11),DCLIST(11),PRLIST(11)
      COMMON /HT/ZR,ZC,D,Z0
      COMMON /Z/ZS(5),AM(5),AC(5),AH(5)
      COMMON /IABV/BM,BH,BMC,DZ,DZC,DZH
      COMMON /ITERA/INTH,INTM,CM(5),CH(5)
      COMMON /STAB/A1,B1,A2,B2,P1,Q1,R1,P2,Q2,R2
      COMMON /ABVO/TP,UR2,L,RI,USTAR
      COMMON /ABV/DBR,RHR,RVR,PVR,UR,CV,RCPR,PSCR,RIR,RSHR,RSVR
      COMMON /TOP/DBC,PVC,RVC,UC
      COMMON /GND/CLOD,DBG,RHG,PVG,RVG,UG,RCPG,PSCG,RSHG,RSVG,RVS
      COMMON /EPS/EPS
      SAVE
      DATA KARMAN,IND/0.42,0/
C
      IF(IND.EQ.0) THEN
        IND=1
        RICR=B2/B1**2
        A=BM*BM
        A1BM=A1*BM
        A1BMC=A1*BMC
        A2BH=A2*BH
        A2BHG=A2BH/9.81
        B1DZ=B1*DZ
        B1DZ2=B1DZ**2
        B1DZBM=2*B1DZ*BM
        B1DZC=B1*DZC
        B2DZH=B2*DZH
        B2DZHG=B2DZH/9.81
        DTPCRC=B2DZHG/B1DZ2
      ENDIF

      IF(ABS(DTP).LE.0.001) THEN
C-------------------------------------------NEUTRAL CONDITION
        INTM=BM
        INTH=A2BH
        INTMC=BMC
        RI=0.0
```

```
        ELSE IF(DTP.GT.0.001) THEN
C-------------------------------------------STABLE
          TPUR2=TP*UR2
          DTPCR=DTPCRC*TPUR2
          IF(DTP.LT.DTPCR) THEN
C-----------------------------------------MODERATELY STABLE
            TPURDT=TPUR2/DTP
            B=B1DZBM-A2BHG*TPURDT
            C=B1DZ2-B2DZHG*TPURDT
            L=0.5*(SQRT(B**2-4*A*C)-B)/A
            INTM=A1BM+B1DZ/L
            INTH=A2BH+B2DZH/L
            INTMC=A1BMC+B1DZC/L
            RI=DZH*INTH/(L*(INTM-INTMC)**2)
          ELSE
C-----------------------------------------FULL INVERSION (DTP>DTPCR)
            INTM=1.0E10
            INTH=1.0E10
            INTMC=1.0E10
            RI=RICR
          ENDIF
        ELSE
C-----------------------------------------UNSTABLE (DTP < -0.001)
          TRIAL=-1000.0
          CALL ITER(DTP,TRIAL,0.001)
          INTMC=CM(1)*AC(1)+CM(2)*AC(2)+CM(3)*AC(3)+
     +          CM(4)*AC(4)+CM(5)*AC(5)
          RI=DZH*INTH/(L*(INTM-INTMC)**2)
        ENDIF
        USTAR=AMAX1(1.0E-9,KARMAN*UR/INTM)
        UC=UR*INTMC/INTM
C       IF(-1.0.LE.RI.AND.RI.LT.RICR ) THEN
        IF(-1.0.LE.RI) THEN
C-----------------------------------------MODERATELY UNNEUTRAL
          RSHABV=INTH/(KARMAN*USTAR)
        ELSE
C-----------------------------------------FREE CONVECTION
          HC=HCONV(UC,DBR,DBC,DZH,0.01)
          TAV=AMAX1(-10.0,AMIN1(50.0,0.5*(DBR+DBC)))
          PAV=AMIN1(PSDB(TAV),0.5*(PVR+PVC))
          RCPP=RADBPV(TAV,PAV)*CPPV(PAV)
          RSHABV=RCPP/HC
        ENDIF
C
        RETURN
      END
C-------------------------------------------------------------------------
C   NUMERICAL ITERATION TO FIND DZETA UNDER UNSTABLE CONDITIONS
C-------------------------------------------------------------------------
      SUBROUTINE ITER(DTP,TRIAL,EPS)
C
        REAL   L,INTH,INTM
        COMMON /HT/ZR,ZC,D,Z0
        COMMON /ITERA/INTH,INTM,CM(5),CH(5)
        COMMON /Z/ZS(5),AM(5),AC(5),AH(5)
        COMMON /STAB/A1,B1,A2,B2,P1,Q1,R1,P2,Q2,R2
```



```
        COMMON /ABVO/TP,UR2,L,RI,USTAR
        SAVE
C
        J=0
        L=TRIAL
C-------REPEAT
1         CONTINUE
          TRIAL=L
          J=J+1
          CALL INVEXC(ZS,AM,P1,Q1,R1,TRIAL,INTM,CM)
          CALL INVEXC(ZS,AH,P2,Q2,R2,TRIAL,INTH,CH)
          L=TP*INTH*UR2/(9.81*DTP*INTM**2)
          IF((ABS(1-TRIAL/L)).GT.EPS.AND.J.LT.4) GOTO 1
C-------UNTIL(ABS(1-TRIAL/L).LE.EPS)
C
        RETURN
      END
C-------------------------------------------------------------------------
C   INTEGRATION OF THE INVERSE EXCHANGE COEFFICIENT W.R.T HEIGHT
C-------------------------------------------------------------------------
      SUBROUTINE INVEXC(Z1,Z2,P,Q,R,L,INT,C)
C
        REAL   Z1(5),Z2(5),INT,C(5),AB(5,6),L
C
C-----------------------------------FIND VALUES OF CORRECTION FACTORS
        DO 1   I=1,5
          AB(I,1)=1.0
          AB(I,2)=Z1(I)
          AB(I,3)=Z1(I)**2
          AB(I,4)=Z1(I)*AB(I,3)
          AB(I,5)=Z1(I)*AB(I,4)
          AB(I,6)=P*(1+Q*Z1(I)/L)**R
1       CONTINUE
C-----------------------------------FIND PARAMETERS OF TAYLOR SERIES
        CALL GAUSS(5,AB)
C-----------------------------------INTEGRATION
        DO 2   I=1,5
          C(I)=AB(I,6)
2       CONTINUE
        INT=C(1)*Z2(1)+C(2)*Z2(2)+C(3)*Z2(3)+
     +      C(4)*Z2(4)+C(5)*Z2(5)
C
        RETURN
      END
C-------------------------------------------------------------------------
C   CONVECTION HEAT-TRANSFER COEFFICIENT OVER A HORIZONTAL PLANE
C-------------------------------------------------------------------------
      FUNCTION HCONV(V,TU,TL,X,COSB)
C
C       HCONV - CONVECTION HEAT-TRANSFER COEFFICIENT (W/SQ. M-C)
C       V     - AIR VELOCITY (M/S)
C       TU    - TEMPERATURE OF THE UPPER SUBJECT (C)
C       TL    - TEMPERATURE OF THE LOWER SUBJECT (C)
C       TW    - TEMPERATURE OF THE PLATE (C)
C       TA    - TEMPERATURE OF THE FLOW (C)
C       X     - CHARACTERISTIC DIMENSION (M)
```

```
C       COSB  - COSINE OF THE ANGLE FROM THE VERTICAL TO THE PLATE
C       INCL  - INDICATOR OF THE  PLATE POSITION
C       K     - THERMAL CONDUCTIVITY OF AIR (W/M-C)
C       DM    - KENIMATIC VISCOSITY OF AIR (SQ. M/S)
C       RE    - REYNOLDS NUMBER (DIMENSIONLESS)
C       PR    - PRANDTL NUMBER (DIMENSIONLESS)
C       GR    - GRASHOF NUMBER (DIMENSIONLESS)
C       GRC   - CRITICAL GR VALUES FOR VARIOUS COSB VALUES

        REAL K,KLIST,GRCL(4),COSBL(4)
        COMMON /PRES/PATM
        COMMON /AIRP/TLIST(11),KLIST(11),DMLIST(11),DHLIST(11),
     +              DVLIST(11),DCLIST(11),PRLIST(11)
        SAVE
        DATA COSBL /0.258819,0.5000000,0.8660254,0.9659258/
        DATA GRCL / 1.0E6,  1.0E8,  2.0E9,  5.0E9/
C
C-------------------------------------------FORCED CONVECTION EFFECT
        TF=0.5*(TU+TL)+273.16
        K=APL2(TF,TLIST,KLIST,11)
        DM=APL2(TF,TLIST,DMLIST,11)
        PR=APL2(TF,TLIST,PRLIST,11)
        XK=K/X
        RE=AMAX1(0.0,V*X/DM)
        IF(RE.GT.5.0E5) THEN
C---------------------------------------TURBULENT CONDITION
          IF(RE.LT.1.0E7) THEN
            HCONVF=XK*(0.037*RE**0.8-850.0)*PR**0.3333
          ELSE
            HCONVF=XK*(0.2275*RE/ALOG(RE)**2.584-850.0)*PR**0.3333
          ENDIF
        ELSE
C---------------------------------------LAMINAR CONDITION
          HCONVF=1.1*SQRT(RE)*XK*PR**0.3333
        ENDIF
C
C-------------------------------------------NATURAL CONVECTION EFFECT
        INCL=SIGN(1.1,COSB)
        BCOS=ABS(COSB)
        IF(INCL.GE.0) THEN
          TW=TL
          TA=TU
        ELSE
          TW=TU
          TA=TL
        ENDIF
        IF(BCOS.LT.COSBL(1)) THEN
C---------NEAR HORIZONTAL POSITION
          GR=9.81*ABS(TL-TU)*X**3/(TF*DM**2)
          IF(GR.LT.1700.0) THEN
C---------PURE CONDUCTION
            HCONVN=XK
          ELSE
C---------NATURAL CONVECTION
            GRPR=GR*PR
            IF(TU.LT.TL) THEN
```



```
C-----------HOT SURFACE FACING UP OR COLD SURFACE FACING DOWN
              IF(GRPR.LT.8.0E6) THEN
C-------------------------------------LAMINAR CONDITION
                HCONVN=0.54*GRPR**0.25*XK
              ELSE
C-------------------------------------TURBULENT CONDITION
                HCONVN=0.15*GRPR**0.3333*XK
              ENDIF
            ELSE
C-----------HOT SURFACE FACING DOWN OR COLD SURFACE FACING UP
              HCONVN=0.58*XK*GRPR**0.2
            ENDIF
          ENDIF
        ELSE IF(BCOS.GT.COSBL(4)) THEN
C---------NEAR VERTICAL POSITION
          GR=9.81*ABS(TL-TU)*X**3/(TF*DM**2)
          IF(GR.LT.2000.0) THEN
C---------PURE CONDUCTION
            HCONVN=XK
          ELSE
C---------NATURAL CONVECTION
            GRPR=GR*PR
            IF(GRPR.LT.1.0E9) THEN
              HCONVN=0.59*XK*GRPR**0.25
            ELSE
              HCONVN=0.10*XK*GRPR**0.3333
            ENDIF
          ENDIF
        ELSE
C---------INCLINED SURFACES
          TF=0.75*TW+0.25*TA
          K=APL2(TF,TLIST,KLIST,11)
          DM=APL2(TF,TLIST,DMLIST,11)
          PR=APL2(TF,TLIST,PRLIST,11)
          XK=K/X
          TF=0.25*TW+0.75*TA
          GR=9.81*ABS(TL-TU)*X**3/(TF*DM**2)
          IF(GR.LT.2000.0) THEN
C---------PURE CONDUCTION
            HCONVN=XK
          ELSE
C---------NATURAL CONVECTION
            GRPR=GR*PR
            IF(TL.LT.TU) THEN
C-----------HOT SURFACE FACING-DOWN OR COOL SURFACE FACING-UP
              HCONVN=0.56*XK*(GRPR*BCOS)**0.25
            ELSE
C-----------HOT SURFACE FACING-UP OR COOL SURFACE FACING-DOWN
              GRC=APL2(BCOS,COSBL,GRCL,4)
              HCONVN=XK*(0.56*(GRPR*BCOS)**0.25+0.14*
     +                AMAX1(0.0,GRPR**0.3333-(GRC*PR)**0.3333))
            ENDIF
          ENDIF
        ENDIF
C-------COMBINATION OF BOTH EFFECTS
        HCONV=HCONVF+HCONVN
```

```
C       WRITE(*,*) 'FORCED',HCONVF,' FREE',HCONVN
C
        RETURN
      END
C-----------------------------------------------------------------------
C    INITIALIZATION OF SWATH TEMPERATURES,HUMIDITIES AND M.C.
C-----------------------------------------------------------------------
      SUBROUTINE SWATHI(MIC,HRI,XMC0)
C
        PARAMETER (N=3,M=10)
        REAL MC0,MCL,LAI
        COMMON /LAYRS/MCL(N),PVA(N),PVL(N),RWS(N),DBA(N),DBL(N),RHA(N),
     +          RVA(N),RVL(N),RCP(N),PSC(N),HLA(N),VLA(N),RBH(N),RBV(N),
     +          RIA(N),WDA(N),DL0(N),ERH(N),VCP(N),DEW(N),TDW(N),FAC(N),
     +          DL(N),DZ(N),DD(N),HW(N),HAA(N+1),VAA(N+1),RSH(N+1),
     +          RSV(N+1)
        COMMON /SWATH/LAI,DENS,VO,WL,MC0,EMC,RSFC
        COMMON /WTRD/HRL(10),DAL(10),RHL(10),CVL(10),PCL(10),WAL(10),LL
        COMMON /WTRM/TL(25),RDB(25),RRH(25),SLL(25),URL(25),FDB(25),
     +               FRH(25),BDB(25),BRH(25),SDB(25),SRH(25),SL2(25),
     +               WD2(25),TDB(25),RH2(25),IL
        COMMON /ABV/DBR,RHR,RVR,PVR,UR,CV,RCPR,PSCR,RIR,RSHR,RSVR
        COMMON /TOP/DBC,PVC,RVC,UC
        COMMON /HT/ZR,ZC,D,Z0
        COMMON /GND/CLOD,DBG,RHG,PVG,RVG,UG,RCPG,PSCG,RSHG,RSVG,RVS
        COMMON /LAND/COND,VHCP,DEP(M),DBS(M+1),Q(M+1),COND2,ALF,VT
        COMMON /MOIST/ENTMC(N),SFCMC(N),RUNMC(N),RUNOFF(N),EXCESS(N),
     +                RENTMC(N),RSFCMC(N),RRUNMC(N),SMFR,SMFE,SMFS
        SAVE

C        DBG=DBS(1)
C        RVG=RWDBRH(DBG,RHG)
C
C-------------------------------ASSUME UNIFORM LEAF AREA DISTRIBUTION
        A=ZC/N
        B=LAI/N
        C=DENS/N
        DO 50 I=1,N
          DZ(I)=A
          DL0(I)=B
          DL(I)=B
          DD(I)=C
          ENTMC(I)=XMC0
          SFCMC(I)=0.0
          RUNMC(I)=0.0
          MCL(I)=XMC0
50      CONTINUE
        IF(MIC.GT.0) THEN
          DBF=APL2(HRI,TL,FDB,IL)
          DBB=APL2(HRI,TL,BDB,IL)
          RHF=APL2(HRI,TL,FRH,IL)
          RHB=APL2(HRI,TL,BRH,IL)
          IF(N.GT.1) THEN
            DBA(1)=DBF
            DBA(N)=DBB
            RHA(1)=RHF
```



```
            RHA(N)=RHB
            RVA(1)=RWDBRH(DBA(1),RHA(1))
            RVA(N)=RWDBRH(DBA(N),RHA(N))
            PVA(1)=PSDB(DBA(1))*RHA(1)
            PVA(N)=PSDB(DBA(N))*RHA(N)
            DBL(1)=DBA(1)
            DBL(N)=DBA(N)
            RVL(1)=RWDBRH(DBL(1),1.0)
            RVL(N)=RWDBRH(DBL(N),1.0)
            K=N-1
            DB=(DBA(1)-DBA(N))/K
            DR=(RHA(1)-RHA(N))/K
            DO 51 I=2,K
              DBA(I)=DBA(1)-DB*(I-1)
              RHA(I)=RHA(1)-DR*(I-1)
              RVA(I)=RWDBRH(DBA(I),RHA(I))
              PVA(I)=PSDB(DBA(I))*RHA(I)
              DBL(I)=DBA(I)
              RVL(I)=RWDBRH(DBL(I),1.0)
51          CONTINUE
          ELSE
            DBA(1)=0.5*(DBF+DBB)
            RHA(1)=0.5*(RHF+RHB)
            PVA(1)=PSDB(DBA(1))*RHA(1)
            RVA(1)=RWDBRH(DBA(1),RHA(1))
            DBL(1)=DBA(1)
            RVL(1)=RWDBRH(DBL(1),1.0)
          ENDIF
        ELSE
          DO 52 I=1,N
            DBA(I)=DBR+N-I
            RHA(I)=RHR+0.1*I
            RVA(I)=RWDBRH(DBA(I),RHA(I))
            PVA(I)=PSDB(DBA(I))*RHA(I)
            DBL(I)=DBA(I)
            RVL(I)=RWDBRH(DBL(I),1.0)
52        CONTINUE
        ENDIF
        ZZ=0.5*DZ(1)/(ZR-ZC+0.5*DZ(1))
        DBC=DBA(1)+(DBR-DBA(1))*ZZ
        RHC=RHA(1)+(RHR-RHA(1))*ZZ
        PVC=PSDB(DBC)*RHC
        RVC=RWDBPV(DBC,PVC)

        RETURN
      END
C-----------------------------------------------------------------------
C    WIND SPEED,TRANSFER RESISTANCES INSIDE THE SWATH
C-----------------------------------------------------------------------
      SUBROUTINE INSIDE
C
        PARAMETER (N=3)
        REAL   L,LAI,MC0,KLIST,MCL
        COMMON /AIRP/TLIST(11),KLIST(11),DMLIST(11),DHLIST(11),
     +               DVLIST(11),DCLIST(11),PRLIST(11)
        COMMON /HT/ZR,ZC,D,Z0
```

```
      COMMON /PAR/PI
      COMMON /SWATH/LAI,DENS,VO,WL,MC0,EMC,RSPC
      COMMON /ABV/DBR,RHR,RVR,PVR,UR,CV,RCPR,PSCR,RIR,RSHR,RSVR
      COMMON /LAYRS/MCL(N),PVA(N),PVL(N),RWS(N),DBA(N),DBL(N),RHA(N),
     +        RVA(N),RVL(N),RCP(N),PSC(N),HLA(N),VLA(N),RBH(N),RBV(N),
     +        RIA(N),WDA(N),DLO(N),ERH(N),VCP(N),DEW(N),TDW(N),FAC(N),
     +        DL(N),DZ(N),DD(N),HW(N),HAA(N+1),VAA(N+1),RSH(N+1),
     +        RSV(N+1)
      COMMON /TOP/DBC,PVC,RVC,UC
      COMMON /EDISNI/CD,WI,XIML
      COMMON /GND/CLOD,DBG,RHG,PVG,RVG,UG,RCPG,PSCG,RSHG,RSVG,RVS
      COMMON /INS/CA,CC,DB1,DB2,DZI,EXPADZ,L,RCPI,RII,TP,U2,Z2,Z1
      COMMON /STAB/A1,B1,A2,B2,P1,Q1,R1,P2,Q2,R2
      SAVE


      U2=AMAX1(1.0E-10,UC)
      Z2=ZC
C-----------------------FOR TRANSFER BETWEEN ADJACENT LAYERS OF AIR SPACES
      DO 152 I=1,N
        DBA(I)=AMAX1(-17.77,AMIN1(50.0,DBA(I)))
        IF(I.EQ.1) THEN
          DZI=0.5*DZ(1)
          DLI=0.5*DL(1)
          PV2=PVC
          TP2=DBC+0.001*PVC+0.01*ZC+273.16
          DB2=DBC
        ELSE
          DZI=0.5*(DZ(I-1)+DZ(I))
          DLI=0.5*(DL(I-1)+DL(I))
          TP2=TP1
          PV2=PV1
          Z2=Z1
          DB2=DB1
        ENDIF
        Z1=Z2-DZI
        TP1=DBA(I)+0.001*PVA(I)+0.01*Z1+273.16
        PV1=PVA(I)
        DTP=TP2-TP1
        DPV=PV2-PV1
        TP=0.5*(TP2+TP1)
        XIML=SQRT(4*WL*DZI/(PI*DLI))
        CC=XIML*WI
        CA=SQRT(0.5*CD*DLI/(CC*DZI))
        DB1=DBA(I)
C        DTT=DB2-DB1
        TAV=AMAX1(-17.0,0.5*(DB1+DB2))
        PAV=AMIN1(PSDB(TAV),0.5*(PV1+PV2))
        RCP(I)=RADBPV(TAV,PAV)*CPPV(PAV)
        RCPI=RCP(I)
      IF(DTP.LT.0.0.AND.DPV.GT.0.0) THEN
        RSV(I)=RSHINS(-DTP)
        RSH(I)=RSHINS(DTP)
      ELSE
        RSH(I)=RSHINS(DTP)
        RSV(I)=RSH(I)
```



```
        ENDIF
        U2=AMAX1(1.0E-10,U2*1/EXPADZ)
        WDA(I)=U2
        IF(I.EQ.1) THEN
          DB2=DBR
          PV2=PVR
          TAV=AMAX1(-17.0,0.5*(DB2+DB1))
          PAV=AMIN1(PSDB(TAV),0.5*(PV1+PV2))
          RCP(I)=RADBPV(TAV,PAV)*CPPV(PAV)
          RSH(1)=RSH(1)+RSHR
          RSV(1)=RSV(1)+RSVR
        ENDIF
        HAV=HAPV(PAV)
        PSC(I)=PCDBHA(TAV,HAV)
        HW(I)=HLDB(TAV)
        HAA(I)=RCP(I)/RSH(I)
        VAA(I)=HW(I)/RSV(I)
152     CONTINUE

        RETURN
      END
C-----------------------------------------------------------------------
C   WIND PROFILE AND RESISTANCE TO SENSIBLE HEAT TRANSFER INSIDE SWATH
C-----------------------------------------------------------------------
      FUNCTION RSHINS(DTP)
C
        REAL L,LAI,MC0
        COMMON /SWATH/LAI,DENS,VO,WL,MC0,EMC,RSPC
        COMMON /INS/CA,CC,DB1,DB2,DZI,EXPADZ,L,RCPI,RII,TP,U2,Z2,Z1
        COMMON /STAB/A1,B1,A2,B2,P1,Q1,R1,P2,Q2,R2
        COMMON /EDISNI/CD,WI,XIML
        COMMON /EPS/EPS
        COMMON /ESP/ESP
        SAVE
        DATA INDEX /0/
C
        IF(INDEX.EQ.0) THEN
          RICR=B2/B1**2
          INDEX=1
        ENDIF

C       IF(U2.LT.1.0E-4) THEN
C---------FREE CONVECTION OR PURE CONDUCTION
C         RSHINS=RCPI/HCONV(U2,DB2,DB1,DZI,0.01)
C         RSHINS=1.0E10
C       ELSE
          U2=AMAX1(1.0E-4,U2)
          IF(ABS(DTP).LE.0.001) THEN
C-------------------------------------------------------NEUTRAL CONDITIONS
            PHM=1.0
            A=CA
            EXPADZ=EXP(A*DZI)
            WA=AMAX1(1.0E-10,U2*(1-1/EXPADZ)/(A*DZI))
            PHH=1.0
            RSHINS=AMAX1(1.0E-10,AMIN1(1.0E10,DZI/(WA*CC)))
          ELSE
```

```
C-------------------------------------------------------UNNEUTRAL
            RII=0.1*SIGN(1.0,DTP)
C-----------REPEAT
10            CONTINUE
              TRIAL=RII
              CALL PHIHM(TRIAL,PHH,PHM)
              A=AMAX1(1.0E-10,AMIN1(30/DZI,CA*SQRT(PHM)))
              EXPADZ=EXP(A*DZI)
              WA=AMAX1(1.0E-10,U2*(1-1/EXPADZ)/(A*DZI))
              RII=9.81*XIML**2*DTP/(TP*DZI*WA**2)
              IF(ABS(1-TRIAL/RII).GT.0.05) GOTO 10
C-----------UNTIL(ABS(1-TRIAL/RII).LE.0.05)
            IF(RII.GT.RICR) THEN
              RSHINS=1.0E10
C              RSHINS=RCPI/HCONV(U2,DB2,DB1,DZI,0.01)
            ELSE IF(RII.GT.0.0) THEN
              RSHINS=AMAX1(1.0E-10,AMIN1(1.0E10,DZI*PHH/(WA*CC)))
            ELSE IF(RII.GT.-1.0) THEN
C-------------------------------------------------MODERATE LAPSE
              RSHMAX=P2*DZI*SQRT(Q2*DZI*TP/(DTP*9.81))/(CC*XIML)
              RSHINS=AMAX1(1.0E-10,AMIN1(RSHMAX,DZI*PHH/(WA*CC)))
            ELSE
C-----------------------------------FREE CONVECTION
              RSHINS=RCPI/HCONV(U2,DB2,DB1,DZI,0.01)
            ENDIF
          ENDIF
C       ENDIF

        RETURN
      END
C-----------------------------------------------------------------------
C    CORRECTION FACTOR FOR MOMENTUM TRANSFER ABOVE THE CONOPY
C-----------------------------------------------------------------------
      SUBROUTINE PHIHM(RI,PHIH,PHIM)
C
        COMMON /STAB/A1,B1,A2,B2,P1,Q1,R1,P2,Q2,R2
        SAVE
        DATA INDEX /0/
C
        IF(INDEX.EQ.0) THEN
          RICR=B2/B1**2
          INDEX=1
        ENDIF
        IF(RI.GT.RICR) THEN
          PHIM=1.0E10
          PHIH=1.0E10
        ELSE
          ZETA=ZETARI(RI)
          IF(RI.LT.0.0) THEN
            PHIM=P1*(1+Q1*ZETA)**R1
            PHIH=P2*(1+Q2*ZETA)**R2
          ELSE
            PHIM=A1+B1*ZETA
            PHIH=A2+B2*ZETA
          ENDIF
        ENDIF
```



```
C
        RETURN
      END
C-----------------------------------------------------------------------
C    RICHARDSON'S NUMBERS AND ZETA
C-----------------------------------------------------------------------
      FUNCTION ZETARI(RI)
C
C---RI   - RICHARDSON'S NUMBER (DIMENSIONLESS)
C---ZETA - MONIN-OBUKHOV STABILITY PARAMETER (DIMENSIONLESS)
C
        REAL RIL(12),ZL(12)
        COMMON /STAB/A1,B1,A2,B2,P1,Q1,R1,P2,Q2,R2
        SAVE
        DATA INDEX/0/
        DATA ZL /-2.0,-1.0,-0.5,0.0,0.2,0.4,1.0,2.0,10.0,
     +           100.0,1.0E5,1.0E8/
C
        IF(INDEX.EQ.0) THEN
          DO 1   I=1,12
            IF(ZL(I).LT.0.0) THEN
              RIL(I)=ZL(I)*P2*(1+Q2*ZL(I))**R2/(P1*(1+Q1*ZL(I))**(2*R1))
            ELSE
              RIL(I)=ZL(I)*(A2+B2*ZL(I))/(A1+B1*ZL(I))**2
            ENDIF
1         CONTINUE
          RIL(4)=0.0
          INDEX=1
        ENDIF
        ZETARI=APL2(RI,RIL,ZL,12)
C
        RETURN
      END
C-----------------------------------------------------------------------
C    LEAF ENERGY BALANCE & LEAF TEMPERATURE
C-----------------------------------------------------------------------
      SUBROUTINE DBLEAF
C
        PARAMETER (N=3,M=10)
        REAL MCL
        COMMON /ABV/DBR,RHR,RVR,PVR,UR,CV,RCPR,PSCR,RIR,RSHR,RSVR
        COMMON /LAYRS/MCL(N),PVA(N),PVL(N),RWS(N),DBA(N),DBL(N),RHA(N),
     +          RVA(N),RVL(N),RCP(N),PSC(N),HLA(N),VLA(N),RBH(N),RBV(N),
     +          RIA(N),WDA(N),DLO(N),ERH(N),VCP(N),DEW(N),TDW(N),FAC(N),
     +          DL(N),DZ(N),DD(N),HW(N),HAA(N+1),VAA(N+1),RSH(N+1),
     +          RSV(N+1)
        COMMON /FLUX/FXHAA(N+1),FXVAA(N+1),FXHLA(N),FXVLA(N),FXSHA(N),
     +               FXSHL(N),FXLHA(N),FXLHL(N),FVAA(N+1),FVLA(N),
     +               FXRVA(N),FXHSS(M+1),FXSHS(M),FXSHG,FXLHG,FXSTG,
     +               FXRSP(N),FXRAIN(N),RAIN(N),FXHLR,FXVLR
        COMMON /RADLW/RNLW(N),RNLWG,EMG
        COMMON /RADSW/RNSW(N),RNSWG,RSG
        COMMON /MOIST/ENTMC(N),SFCMC(N),RUNMC(N),RUNOFF(N),EXCESS(N),
     +                RENTMC(N),RSFCMC(N),RRUNMC(N),SMFR,SMFE,SMFS
        COMMON /CPH2O/CPW
        COMMON /FF/ALPHA,ALFA1,ALFA2,FMC,CMECH,C1,C2,C3,C4,ISW
```

```
      COMMON /RHEQ/BLOOM,IAD(3)
      COMMON /LMT/XMCMAX,XMCMIN,SFCMAX,RUNMAX
      COMMON /ALFA/ALF1,ALF2
      SAVE
      DATA IND/0/

C      IF(IND.EQ.0) THEN
C        IAD=0
C        IND=1
C      ENDIF

      DO 120 I=1,N
        J=0
C-------REPEAT
121       CONTINUE
          J=J+1
          DXL=DBL(I)
          CALL RESIST(I,T,P,PCS,ROCP,HL)
          F=AMAX1(1.0,ALPHA*FAC(I))
          PCSS=PCS*RBV(I)/RBH(I)
          S=DPSDT(T)
          IF(ISW.EQ.0.AND.DEW(I).LE.0.0) THEN
            ERH(I)=RHE(ENTMC(I),DBL(I),IAD(I),BLOOM)
          ELSE
            ERH(I)=1.0
          ENDIF
          DRV=ROCP*(PSDB(DBA(I))*ERH(I)-PVA(I))/RBH(I)
          FXRAIN(I)=CPW*RAIN(I)*(DBR-DBL(I))
          FXRSP(I)=4.556*AMIN1(1.0,0.17813*EXP(0.069*DBL(I)))*DD(I)
     +                *(3.66*ENTMC(I)/(1.0+ENTMC(I))-1.0)
C          FXRSP(I)=3.672*DLO(I)*EXP(0.07*(DBL(I)-30))
          ENERGY=FXRSP(I)+RNSW(I)+RNLW(I)+FXRAIN(I)
          FXVLA(I)=(DRV+S*ERH(I)*ENERGY)/(PCSS+F*S*ERH(I))
C          FXVLA(I)=AMAX1(0.0,FXVLA(I))
          IF(FXVLA(I).GT.0.0) THEN
C-----------DRYING
            IAD(I)=0
          ELSE
C-----------REWETTING
            IAD(I)=1
          ENDIF
          IF(MCL(I).LE.XMCMIN) FXVLA(I)=AMIN1(0.0,FXVLA(I))
          FXHLA(I)=ENERGY-F*FXVLA(I)
          DBL(I)=DBA(I)+FXHLA(I)*RBH(I)/ROCP
          DBL(I)=AMAX1(DBA(I)-10.0,AMIN1(DBL(I),DBA(I)+10,50.0))
C         WRITE(*,*) I,DBL(I),DBA(I),ROCP,PCS,RBH(I),RBV(I),
C     +    RWS(I),DRV,ENERGY,FXVLA(I),FXHLA(I)
          IF(ABS(DBL(I)-DXL).GT.7.0) CALL LWRAD
          IF(ABS(1-DXL/DBL(I)).GT.0.01.AND.J.LT.5) GOTO 121
C-------UNTIL(ABS(1-DXL/DBL(I).LE.0.01.OR.J.EQ.5)
C         FXHLA(I)=ROCP*(DBL(I)-DBA(I))/RBH(I)
C         FXVLA(I)=(ENERGY-FXHLA(I))/F
        RVL(I)=RWDBRH(DBL(I),ERH(I))
        PVL(I)=PSDB(DBL(I))
        FVLA(I)=(RVL(I)-RVA(I))/RBV(I)
120   CONTINUE
```



```
      RETURN
      END
C-----------------------------------------------------------------------
C     EQUILIBRIUM RELATIVE HUMIDITY OF ALFALFA
C-----------------------------------------------------------------------
      FUNCTION RHE(MC,TL,IAD,BLOOM)
C
        REAL MC,A(3,5),BLM(3)
        SAVE
C-------BLOOM LEVEL
        DATA BLM /0.0,0.1,1.0/
C-------DESORPTION FOR MATURE ALFALFA
        DATA (A(J,5),J=1,3)/8.5859632,0.038198351,2.0773297/
C-------ADSORPTION FOR MATURE ALFALFA (>100% BLOOM)
        DATA (A(J,4),J=1,3)/11.86,0.0214,2.406/
C-------ADSORPTION FOR FULL BLOOM ALFALFA (100% BLOOM)
        DATA (A(J,3),J=1,3)/10.61,0.0807,2.733/
C-------ADSORPTION FOR 1/10 BLOOM ALFALFA (10% BLOOM)
        DATA (A(J,2),J=1,3)/9.982,0.0842,2.932/
C-------ADSORPTION FOR PREBLOOM ALFALFA (0% BLOOM)
        DATA (A(J,1),J=1,3)/8.614,0.0754,2.845/
C-----PARAMETERS ESTIMATED BASED UPON BAKKER'S DATA (1961)

        IF(BLOOM.GT.1.0) THEN
C---------MATURE
          IF(IAD.EQ.0) THEN
C-----------DESOPTION
            I=5
          ELSE
C-----------ADSORPTION
            I=4
          ENDIF
          C=AMIN1(50.0,MC*(A(1,I)+A(2,I)*TL))
          RHE=(1-EXP(-C))**A(3,I)
        ELSE
          IF(BLOOM.LE.0.0) THEN
C-----------PREBLOOM
            C=AMIN1(50.0,MC*(A(1,1)+A(2,1)*TL))
            RHE=(1-EXP(-C))**A(3,1)
          ELSE
            IF(BLOOM.GT.0.1) THEN
              I=3
              J=2
            ELSE IF(BLOOM.GT.0.0) THEN
              I=2
              J=1
            ENDIF
            C=AMIN1(50.0,MC*(A(1,I)+A(2,I)*TL))
            RHEI=(1-EXP(-C))**A(3,I)
            C=AMIN1(50.0,MC*(A(1,J)+A(2,J)*TL))
            RHEJ=(1-EXP(-C))**A(3,J)
C-----------INTERPOLATED ADSORPTION
            RHE=RHEJ+(BLOOM-BLM(J))*(RHEI-RHEJ)/(BLM(I)-BLM(J))
          ENDIF
          IF(IAD.EQ.0) THEN
```

```
C----------DESORPTION
           C=AMIN1(50.0,MC*(A(1,5)+A(2,5)*TL))
           RHD=(1-EXP(-C))**A(3,5)
           C=AMIN1(50.0,MC*(A(1,4)+A(2,4)*TL))
           RHA=(1-EXP(-C))**A(3,4)
           DRH=RHA-RHD
           RHE=RHE-DRH
         ENDIF
       ENDIF
       RHE=AMIN1(1.0,AMAX1(0.0,RHE))
C
       RETURN
      END
C-------------------------------------------------------------------------
C     TRANSFER COEFFICIENTS AND RESISTANCE BETWEEN ALFALFA & AIR
C-------------------------------------------------------------------------
      SUBROUTINE RESIST(I,T,P,PCS,ROCP,HL)
C
        PARAMETER (N=3,M=10)
        REAL LAI,MCL,MC0,KLIST
        COMMON /LAYRS/MCL(N),PVA(N),PVL(N),RWS(N),DBA(N),DBL(N),RHA(N),
     +          RVA(N),RVL(N),RCP(N),PSC(N),HLA(N),VLA(N),RBH(N),RBV(N),
     +          RIA(N),WDA(N),DLO(N),ERH(N),VCP(N),DEW(N),TDW(N),FAC(N),
     +          DL(N),DZ(N),DD(N),HW(N),HAA(N+1),VAA(N+1),RSH(N+1),
     +          RSV(N+1)
        COMMON /FLUX/FXHAA(N+1),FXVAA(N+1),FXHLA(N),FXVLA(N),FXSHA(N),
     +               FXSHL(N),FXLHA(N),FXLHL(N),FVAA(N+1),FVLA(N),
     +               FXRVA(N),FXHSS(M+1),FXSHS(M),FXSHG,FXLHG,FXSTG,
     +               FXRSP(N),FXRAIN(N),RAIN(N),FXHLR,FXVLR
        COMMON /PAR/PI
        COMMON /PARIN/IYR,MDAYI,HRI,HRF,MDAYF,LEAP,JDAYI,JDAYF,
     +                DTP,XMC,SIMUL,DTFAST,DTSLOW
        COMMON /AIRP/TLIST(11),KLIST(11),DMLIST(11),DHLIST(11),
     +               DVLIST(11),DCLIST(11),PRLIST(11)
        COMMON /SWATH/LAI,DENS,VO,WL,MC0,EMC,RSFC
        COMMON /TIMES/MDAY,JDAY,HOUR
        COMMON /MOIST/ENTMC(N),SFCMC(N),RUNMC(N),RUNOFF(N),EXCESS(N),
     +                RENTMC(N),RSFCMC(N),RRUNMC(N),SYFR,SMFE,SMFS
        COMMON /FF/ALPHA,ALFA1,ALFA2,FMC,CMECH,C1,C2,C3,C4,ISW
        COMMON /LMT/XMCMAX,XMCMIN,SFCMAX,RUNMAX
        COMMON /RWSO/RWS0(N),IDEW(N),ID
        SAVE

        IF(ID.EQ.1) THEN
          RWS0(I)=RBVMC(MC0,ALFA1,C1)
        ENDIF

        T=0.5*(DBA(I)+DBL(I))
        P=AMIN1(PSDB(T),0.5*(PVA(I)+PSDB(DBL(I))))
        HA=HAPV(P)
        PCS=PCDBHA(T,HA)
        ROCP=RADBPV(T,P)*CPPV(P)
        HL=HLDB(T)
        DH=APL2(T,TLIST,DHLIST,11)
        DV=APL2(T,TLIST,DVLIST,11)
        DHDV23=(DH/DV)**0.66667
```



```
C-------BOUNDARY RESISTANCE TO HEAT AND MOISTURE TRANSFER AT TWO SIDES
        RBHU=ROCP/HCONV(2*WDA(I)/PI,DBA(I),DBL(I),WL,0.7070)
        RBHD=ROCP/HCONV(2*WDA(I)/PI,DBL(I),DBA(I),WL,-0.7070)

C-------LEAF SURFACE RESISTANCE (STOMATAL RESISTANCE)
        IF(JDAYI.LE.1) THEN
          A=ALFA1
          B=C1
        ELSE
          A=ALFA2
          B=C2
        ENDIF
        RWS(I)=RBVMC(ENTMC(I),A,B)

C-------LEAF RESISTANCE TO MOISTURE TRANSFER
        IF(DEW(I).GT.0.0.OR.RVA(I).GT.RVL(I)) THEN
C---------WET LEAF SURFACE OR ADSORPTION
          IDEW(I)=1
          FAC(I)=1.0
          RBVU=DHDV23*RBHU
          RBVD=DHDV23*RBHD
        ELSE
C---------DRY LEAF SURFACE AND DESORPTION
          FAC(I)=RWS(I)/RWS0(I)
          RBVU=DHDV23*RBHU+RWS(I)
          RBVD=DHDV23*RBHD+RWS(I)
        ENDIF

C-------OVERALL RESISTANCE
        RBH(I)=RBHU*RBHD/(RBHU+RBHD)/DLO(I)
        RBV(I)=RBVU*RBVD/(RBVU+RBVD)/DLO(I)
C-------SENSIBLE AND LATENT HEAT TRANSFER COEFFICIENTS
        HLA(I)=ROCP/RBH(I)
        VLA(I)=HL/RBV(I)

        RETURN
      END
C-------------------------------------------------------------------------
C     STOMATAL RESISTANCE AS A FUNCTION OF RELATIVE WATER CONTENT
C-------------------------------------------------------------------------
      FUNCTION RBVMC(MC,A,B)
C
C---RBV - STAMATAL RESISTANCE TO HEAT & WATER VAPOR TRANSFER (SEC./M)
C---MC  - MOISTURE CONTENT OF PLANT (KG WATER/KG DRY MATTER)

        REAL MC
        COMMON /FF/ALPHA,ALFA1,ALFA2,FMC,CMECH,C1,C2,C3,C4,ISW
        COMMON /LMT/XMCMAX,XMCMIN,SFCMAX,RUNMAX
        SAVE

        IF(MC.LE.XMCMIN) THEN
          RBVMC=1.0E8
        ELSE
          RBVMC=10.0**(A-B*AMIN1(1.0,MC/FMC))
        ENDIF
        RBVMC=CMECH*RBVMC
```

```
      RETURN
      END
C-----------------------------------------------------------------------
C     INTEGRATION OF FINITE DIFFERENCES BY MATRIX METHOD
C-----------------------------------------------------------------------
      SUBROUTINE MATRIX
C
      PARAMETER (N=3,M=10)
      REAL AB(2*N,2*N+1),LAI,MCL,MC0
C      REAL DBX(N)
C      LOGICAL REPEAT
      COMMON /LAYRS/MCL(N),PVA(N),PVL(N),RWS(N),DBA(N),DBL(N),RHA(N),
     +        RVA(N),RVL(N),RCP(N),PSC(N),HLA(N),VLA(N),RBH(N),RBV(N),
     +        RIA(N),WDA(N),DLO(N),ERH(N),VCP(N),DEW(N),TDW(N),FAC(N),
     +        DL(N),DZ(N),DD(N),HW(N),HAA(N+1),VAA(N+1),RSH(N+1),
     +        RSV(N+1)
      COMMON /FLUX/FXHAA(N+1),FXVAA(N+1),FXHLA(N),FXVLA(N),FXSHA(N),
     +              FXSHL(N),FXLHA(N),FXLHL(N),FVAA(N+1),FVLA(N),
     +              FXRVA(N),FXHSS(M+1),FXSHS(M),FXSHG,FXLHG,FXSTG,
     +              FXRSP(N),FXRAIN(N),RAIN(N),FXHLR,FXVLR
      COMMON /SWATH/LAI,DENS,VO,WL,MC0,EMC,RSPC
      COMMON /RADLW/RNLW(N),RNLWG,EMG
      COMMON /RADSW/RNSW(N),RNSWG,RSG
      COMMON /RATE/RDBA(N),RDBL(N),RRVA(N),RMCL(N),RDEW(N),
     +             RTDW(N),RDBS(M)
      COMMON /TOP/DBC,PVC,RVC,UC
      COMMON /ABV/DBR,RHR,RVR,PVR,UR,CV,RCPR,PSCR,RIR,RSHR,RSVR
      COMMON /GND/CLOD,DBG,RHG,PVG,RVG,UG,RCPG,PSCG,RSHG,RSVG,RVS
      COMMON /CPH2O/CPW
      COMMON /MOIST/ENTMC(N),SFCMC(N),RUNMC(N),RUNOFF(N),EXCESS(N),
     +              RENTMC(N),RSFCMC(N),RRUNMC(N),SMFR,SMFE,SMFS
      COMMON /ALFA/ALF1,ALF2
      COMMON /LMT/XMCMAX,XMCMIN,SFCMAX,RUNMAX
      SAVE

C       JJ=0
C-----REPEAT
C1       CONTINUE
C        JJ=JJ+1
C        DO 2 I=1,N
C          DBX(I)=DBA(I)
C2       CONTINUE
C        REPEAT=.FALSE.
C-------------------------INITIALIZE THE COEFFICIENT MATRIX
         K=2*N
         L=K+1
         DO 41 I=1,K
           DO 40 J=1,K
             AB(I,J)=0.0
40         CONTINUE
41       CONTINUE
C--------------------COEFFICIENTS IN FIRST LAYER
C---------------------FOR WATER VAPOR DENSITY IN AIR SPACE (RVA)
         AB(1,1)= 1/RSV(2)+1/RSV(1)+1/RBV(1)
         AB(1,3)=-1/RSV(2)
```



```
         AB(1,L)= RVR/RSV(1)+RVL(1)/RBV(1)
C---------------------FOR TEMPERATURE OF AIR SPACE (DBA)
         AB(2,2)= HAA(2)+HAA(1)+HLA(1)
         AB(2,4)=-HAA(2)
         AB(2,L)= HAA(1)*DBR+HLA(1)*DBL(1)
C--------------------COEFFECIENTS IN MIDDLE LAYERS
         N1=N-1
         DO 42 I=2,N1
           K=2*I-1
           J=I-1
           L1=I+1
C---------------------FOR WATER VAPOR DENSITIES IN AIR SPACE
           AB(K,K-2)=-1/RSV(I)
           AB(K,K )= 1/RSV(L1)+1/RSV(I)+1/RBV(I)
           AB(K,K+2)=-1/RSV(L1)
           AB(K,L )= RVL(I)/RBV(I)
C---------------------FOR TEMPERATURE OF AIR SPACES
           K=K+1
           AB(K,K-2)=-HAA(I)
           AB(K,K )= HAA(L1)+HAA(I)+HLA(I)
           AB(K,K+2)=-HAA(L1)
           AB(K,L )= HLA(I)*DBL(I)
42       CONTINUE
C--------------------COEFFICIENTS IN THE LAST LAYER NEAR GROUND
         K=L-2
         J=N+1
C---------------------FOR WATER VAPOR DENSITY IN AIR SPACE
         AB(K,K-2)=-1/RSV(N)
         AB(K,K )= 1/RSVG+1/RSV(N)+1/RBV(N)
         AB(K,L )= RVG/RSVG+RVL(N)/RBV(N)
C---------------------FOR TEMPERATURE OF AIR SPACE
         K=K+1
         AB(K,K-2)=-HAA(N)
         AB(K,K )= HAA(J)+HAA(N)+HLA(N)
         AB(K,L )= HAA(J)*DBG+HLA(N)*DBL(N)
C--------------------SOLVE SYSTEM OF LINEAR EQUATIONS BY GAUSS ELIMINATION
         CALL GAUSS(K,AB)
         DO 44 I=1,N
           K=2*I-1
           DBA(I)=AMAX1(DBL(I)-5.0,AMIN1(45.0,AB(K+1,L)))
           RVA(I)=AMAX1(0.0,AMIN1(RWDBRH(DBA(I),1.),AB(K,L)))
           PVA(I)=AMIN1(PSDB(DBA(I)),PVDBRV(DBA(I),RVA(I)))
C            IF(J.EQ.1.OR.ABS(1-DBX(I)/DBA(I)).GT.0.01) REPEAT=.TRUE.
44       CONTINUE
C        IF(REPEAT.AND.JJ.LT.10) GOTO 1
C-------UNTIL(.NOT. REPEAT.OR.JJ.EQ.10)
C-----------------------AT THE TOP OF THE SWATH
       R1=RSHR*RCP(1)
       R2=(RSH(1)-RSHR)*RCPR
       DBC=(R1*DBA(1)+R2*DBR)/(R1+R2)
       R3=RSV(1)-RSVR
       RVC=(R3*RVR+RSVR*RVA(1))/RSV(1)
       PVC=PVDBRV(DBC,RVC)

C        CALL DBLEAF
C        CALL INSIDE
```

```
      RETURN
      END
C-----------------------------------------------------------------------
C     RATES OF CHAGES IN MOISTURE CONTENT,DEW & DEW DURATION
C-----------------------------------------------------------------------
      SUBROUTINE DFMCL(DT)
C
      PARAMETER (N=3,M=10)
      REAL MCL
      COMMON /LAYRS/MCL(N),PVA(N),PVL(N),RWS(N),DBA(N),DBL(N),RHA(N),
     +       RVA(N),RVL(N),RCP(N),PSC(N),HLA(N),VLA(N),RBH(N),RBV(N),
     +       RIA(N),WDA(N),DLO(N),ERH(N),VCP(N),DEW(N),TDW(N),FAC(N),
     +       DL(N),DZ(N),DD(N),HW(N),HAA(N+1),VAA(N+1),RSH(N+1),
     +       RSV(N+1)
      COMMON /FLUX/FXHAA(N+1),FXVAA(N+1),FXHLA(N),FXVLA(N),FXSHA(N),
     +       FXSHL(N),FXLHA(N),FXLHL(N),FVAA(N+1),FVLA(N),
     +       FXRVA(N),FXHSS(M+1),FXSHS(M),FXSHG,FXLHG,FXSTG,
     +       FXRSP(N),FXRAIN(N),RAIN(N),FXHLR,FXVLR
      COMMON /RATE/RDBA(N),RDBL(N),RRVA(N),RMCL(N),RDEW(N),
     +       RTDW(N),RDBS(M)
      COMMON /MOIST/ENTMC(N),SFCMC(N),RUNMC(N),RUNOFF(N),EXCESS(N),
     +       RENTMC(N),RSFCMC(N),RRUNMC(N),SMFR,SMFE,SMFS
      COMMON /LMT/XMCMAX,XMCMIN,SFCMAX,RUNMAX
      COMMON /ALFA/ALF1,ALF2
      COMMON /GRAIN/RAING
      SAVE

C       J=0
C-------REPEAT
C-------RENTMC,RSFCMC & RRUNMC -- (KG WATER/SEC-SQ. M LAND)
C1        CONTINUE
C         J=J+1
C         DT0=DT
          DO 11 I=1,N
            DDT=DD(I)/DT
            IF(I.EQ.1) THEN
              RMOIST=RAIN(I)-FVLA(I)
            ELSE
              RMOIST=RAIN(I)-FVLA(I)+EXCESS(I-1)
            ENDIF
            IF(DEW(I).GT.0.0) THEN
C-----------DEW IS PRESENT
              RUNOFF(I)=SMFR*DD(I)*RUNMC(I)
              RMOIST=RMOIST-RUNOFF(I)
              RENTMC(I)=SMFE*AMAX1(0.0,XMCMAX-ENTMC(I))*DD(I)
C              RENTMC(I)=(RWDBRH(DBL(I),1.0)-RWDBRH(DBL(I),ERH(I)))/
C     +                  RWS(I)*2*DLO(I)
              RMOIST=RMOIST-RENTMC(I)
              IF(DEW(I)+RMOIST*DT.LE.-ALF1) THEN
C-------------TOTAL DEW EVAPORATED TO THE AIR & ABSORBED BY PLANTS
                DT=AMIN1(DT,AMAX1(ALF2,-DEW(I)/RMOIST))
                DDT=DD(I)/DT
                RSFCMC(I)=-SFCMC(I)*DDT
                RRUNMC(I)=-RUNMC(I)*DDT
                EXCESS(I)= RUNOFF(I)
```



```
              ELSE
                AVAIL=RMOIST+RUNMC(I)*DDT
C-------------DECREASE OR INCREASE IN SURFACE MC
                RSFCMC(I)=AMIN1(AVAIL,
     +                    SMFS*AMAX1(0.0,SFCMAX-SFCMC(I))*DD(I))
C-------------DECREASE OR INCREASE IN RUNNABLE MC
                RMOIST=RMOIST-RSFCMC(I)
                RRUNMC(I)=AMIN1(RMOIST,AMAX1(0.0,RUNMAX-RUNMC(I))*DDT)
                EXCESS(I)=RUNOFF(I)+AMAX1(0.0,RMOIST-RRUNMC(I))
              ENDIF
            ELSE
C-------------DEW IS ABSENT
              RUNOFF(I)=0.0
              IF(RMOIST.LE.0.0) THEN
C-------------DRYING
                RSFCMC(I)=0.0
                RRUNMC(I)=0.0
                EXCESS(I)=0.0
                DENTMC=-(ENTMC(I)-XMCMIN)*DD(I)
                IF(DENTMC+RMOIST*DT.LT.-ALF1) THEN
C---------------INTERNAL MC REDUCES TO MINIMUM
                  DT=AMIN1(DT,AMAX1(ALF2,-DENTMC/RMOIST))
                  RENTMC(I)=-DENTMC/DT
                ELSE
                  RENTMC(I)=RMOIST
                ENDIF
              ELSE
C-------------REWETTING
                RENTMC(I)=AMIN1(SMFE*AMAX1(0.0,XMCMAX-ENTMC(I))*DD(I),
     +                    RMOIST)
                RMOIST=RMOIST-RENTMC(I)
                RSFCMC(I)=AMAX1(0.0,AMIN1(RMOIST,SFCMAX*SMFS*DD(I)))
                RMOIST=RMOIST-RSFCMC(I)
                RRUNMC(I)=AMAX1(0.0,AMIN1(RMOIST,RUNMAX*DDT))
                EXCESS(I)=AMAX1(0.0,RMOIST-RRUNMC(I))
              ENDIF
            ENDIF
11        CONTINUE
C           IF(DT0.GT.DT.AND.J.LT.2) GOTO 1
C---------UNTIL(DT0.EQ.DT.OR.J.EQ.2)
          DO 12 I=1,N
            RDEW(I)=RSFCMC(I)+RRUNMC(I)
C-----------RENTMC,RSFCMC & RRUNMC -- (MC D.B./SEC)
            RENTMC(I)=RENTMC(I)/DD(I)
            RSFCMC(I)=RSFCMC(I)/DD(I)
            RRUNMC(I)=RRUNMC(I)/DD(I)
            RMCL(I)=RENTMC(I)+RSFCMC(I)+RRUNMC(I)
            ENTMC(I)=AMAX1(XMCMIN,AMIN1(XMCMAX,ENTMC(I)+DT*RENTMC(I)))
            SFCMC(I)=AMAX1(0.0,AMIN1(SFCMAX,SFCMC(I)+DT*RSFCMC(I)))
            RUNMC(I)=AMAX1(0.0,AMIN1(RUNMAX,RUNMC(I)+DT*RRUNMC(I)))
            MCL(I)=ENTMC(I)+SFCMC(I)+RUNMC(I)
            DEW(I)=DD(I)*(SFCMC(I)+RUNMC(I))
            IF(DEW(I).GT.0.0.OR.FVLA(I).LT.0.0) THEN
              RTDW(I)=1.0
            ELSE
              RTDW(I)=0.0
```

```
          ENDIF
          TDW(I)=TDW(I)+DT*RTDW(I)/3600
12      CONTINUE
        RAING=RAING+EXCESS(N)

        RETURN
      END
C-----------------------------------------------------------------------
C     INITIALIZATION OF SOIL LAYERS
C-----------------------------------------------------------------------
      SUBROUTINE SOILI(HRI,MIC,DBS1)
C
        PARAMETER (M=10)
        REAL TA(5),ZL(5),T(5,6)
        COMMON /LAND/COND,VHCP,DEP(M),DBS(M+1),Q(M+1),COND2,ALF,VT
        SAVE
C-------SOIL TEMPERATURE DATA (DEPTH 0.01-1.0M) IN SUMMER
        DATA ZL             /0.01,0.10,0.20,0.50,1.00/
C     2:00
        DATA (T(J,1),J=1,5)/17.5,18.0,19.7,18.7,16.3/
C     6:00
        DATA (T(J,2),J=1,5)/16.8,16.8,18.8,18.7,16.3/
C    10:00
        DATA (T(J,3),J=1,5)/21.9,20.2,18.6,18.5,16.3/
C    14:00
        DATA (T(J,4),J=1,5)/28.1,25.9,20.4,18.5,16.3/
C    18:00
        DATA (T(J,5),J=1,5)/24.6,24.4,22.1,18.3,16.3/
C    22:00
        DATA (T(J,6),J=1,5)/20.5,20.9,21.3,18.4,16.3/
        DATA IND/0/

        IF(IND.EQ.0) THEN
          IND=1
          DP=0.5/M
          N=M+1
          DO 5 I=1,M
            DEP(I)=DP
            IF(I.EQ.1) THEN
              Q(I)=1/DEP(I)
            ELSE
              Q(I)=1/(DEP(I-1)+DEP(I))
            ENDIF
5         CONTINUE
          Q(N)=1/DEP(M)
          COND2=2*COND
          ALF=COND2/VHCP
          VT=1/VHCP
        ENDIF

        HR=AMIN1(24.0,AMAX1(0.0,HRI))
        IF(HR.LT.2.0) HR=24+HR
        I=0
C-------REPEAT
1         CONTINUE
          I=I+1
```



```
          IF(HR.GT.2+4*(I-1)) GOTO 1
C-------UNTIL(HR.LE.2+4*(I-1))
        IF(I.EQ.1.OR.I.EQ.7) THEN
          L=6
          K=1
        ELSE
          L=I-1
          K=I
        ENDIF
        DT=HR-2-4*(L-1)
        DO 2 J=1,4
          TA(J)=0.25*(T(J,K)-T(J,L))*DT+T(J,L)
2       CONTINUE
        TA(5)=T(5,1)
        Z=0.0
        DO 3 J=1,M
          DBS(J)=APL2(Z+0.5*DEP(J),ZL,TA,5)
          Z=Z+DEP(J)
3       CONTINUE
        DBS(N)=APL2(0.5,ZL,TA,5)
        IF(MIC.GT.0.0) THEN
          X=DBS1/DBS(1)
          DO 4 I=1,M
            DBS(I)=X*DBS(I)
4         CONTINUE
          DBS(N)=X*DBS(N)
        ENDIF
C
        RETURN
      END
C-----------------------------------------------------------------------
C     ENERGY BALANCE AND TEMPERATURE AT THE GROUND (SOIL SURFACE)
C-----------------------------------------------------------------------
      SUBROUTINE GROUND
C
        PARAMETER (N=3,M=10)
        REAL   MCL
        COMMON /LAYRS/MCL(N),PVA(N),PVL(N),RWS(N),DBA(N),DBL(N),RHA(N),
     +          RVA(N),RVL(N),RCP(N),PSC(N),HLA(N),VLA(N),RBH(N),RBV(N),
     +          RIA(N),WDA(N),DLO(N),ERH(N),VCP(N),DEW(N),TDW(N),FAC(N),
     +          DL(N),DZ(N),DD(N),HW(N),HAA(N+1),VAA(N+1),RSH(N+1),
     +          RSV(N+1)
        COMMON /FLUX/FXHAA(N+1),FXVAA(N+1),FXHLA(N),FXVLA(N),FXSHA(N),
     +                FXSHL(N),FXLHA(N),FXLHL(N),FVAA(N+1),FVLA(N),
     +                FXRVA(N),FXHSS(M+1),FXSHS(M),FXSHG,FXLHG,FXSTG,
     +                FXRSP(N),FXRAIN(N),RAIN(N),FXHLR,FXVLR
        COMMON /RADLW/RNLW(N),RNLWG,EMG
        COMMON /RADSW/RNSW(N),RNSWG,RSG
        COMMON /GND/CLOD,DBG,RHG,PVG,RVG,UG,RCPG,PSCG,RSHG,RSVG,RVS
        COMMON /LAND/COND,VHCP,DEP(M),DBS(M+1),Q(M+1),COND2,ALF,VT
        COMMON /ABV/DBR,RHR,RVR,PVR,UR,CV,RCPR,PSCR,RIR,RSHR,RSVR
        COMMON /CPH2O/CPW
        COMMON /GRAIN/RAING
        SAVE
        DATA IND/0/
C
```

```
          IF(IND.EQ.0) THEN
            L=N+1
            H=COND2/DEP(1)
            IND=1
          ENDIF

          J=0
C---------REPEAT
181         CONTINUE
            J=J+1
            TG=DBG
            CALL RESGND
C             T=AMAX1(10.0,AMIN1(50.0,0.5*(DBG+DBA(N))))
C             P=AMIN1(PSDB(T),0.5*(PVG+PVA(N)))
C             PCS=PCDBPV(T,P)
C             PCSS=PCS*RSVG/RSHG
C             ROCP=RADBPV(T,P)*CPPV(P)
              FRAINC=CPW*RAINC*(DBA(N)-DBG)
              FXLHG=VAA(L)*(RVG-RVA(N))
C-----------GROUND SOIL TEMPERATURE
              DBG=(RNSWG+RNLWG+FRAING-FXLHG+HAA(L)*DBA(N)
     +              +H*DBS(1))/(HAA(L)+H)
            DBG=AMAX1(0.0,AMIN1(DBG,50.0))
            IF(ABS(1-TG/DBG).GT.0.01.AND.J.LT.3) GOTO 181
C---------UNTIL(ABS(1-TG/DBG).LE.0.01.OR.J.EQ.3)
C---------LATENT,SENSIBLE AND STORAGE HEAT FLUXES
C           FXSTG=H*(DBG-DBS(1))
            FXSHG=HAA(L)*(DBG-DBA(N))
            FXLHG=VAA(L)*(RVG-RVA(N))
            FXSTG=RNSWG+RNLWG-FXSHG-FXLHG

          RETURN
        END
C-------------------------------------------------------------------------------
C       AERODYNAMIC RISISTANCE AT THE SOIL SURFACE
C-------------------------------------------------------------------------------
        SUBROUTINE RESGND
C
          PARAMETER (N=3,M=10)
          REAL    L,MCL,KLIST,MCO,LAI
          COMMON /LAYRS/MCL(M),PVA(N),PVL(N),RWS(N),DBA(N),DBL(N),RHA(N),
     +                  RVA(N),RVL(N),RCP(N),PSC(N),HLA(N),VLA(N),RBH(N),RBV(N),
     +                  RIA(N),WDA(N),DLO(N),ERH(N),VCP(N),DEW(N),TDW(N),FAC(N),
     +                  DL(N),DZ(N),DD(N),HW(N),HAA(N+1),VAA(N+1),RSH(N+1),
     +                  RSV(N+1)
          COMMON /PAR/PI
          COMMON /AIRP/TLIST(11),KLIST(11),DMLIST(11),DHLIST(11),
     +                  DVLIST(11),DCLIST(11),PRLIST(11)
          COMMON /EDISN1/CD,WI,XIML
          COMMON /INS/CA,CC,DB1,DB2,DZI,EXPADZ,L,RCPI,RII,TP,U2,Z2,Z1
          COMMON /SWATH/LAI,DENS,WO,WL,MCO,EMC,RSFC
          COMMON /STAB/A1,B1,A2,B2,P1,Q1,R1,P2,Q2,R2
          COMMON /GND/CLOD,DBG,RHG,PVG,RVG,GG,RCPG,PSCG,RSHG,RSVG,RVS
          COMMON /LAND/COND,VHCP,DEP(M),DBS(M+1),Q(M+1),COND2,ALF,VT
          SAVE
```



```
            RVG=RWDBRH(DBG,RHG)
            PVG=PSDB(DBG)*RHG
            DB2=DBA(N)
            DB1=DBG
            PV2=PVA(N)
            PV1=PVG
            TAV=0.5*(DB2+DB1)
            PAV=AMIN1(PSDB(TAV),0.5*(PV1+PV2))
C           DTT=DB2-DB1
            RCPG=RADBPV(TAV,PAV)*CPPV(PAV)
            HAV=HAPV(PAV)
            PSCG=PCDBHA(TAV,HAV)
            HLG=HLDB(TAV)
            Z2=0.5*DZ(N)
            Z1=0.0
            TP2=DB2+0.001*PV2+0.01*Z2+273.16
            TP1=DBG+0.001*PV1+273.16
            DTP=TP2-TP1
            DPV=PV2-PV1
            DZI=Z2-Z1
            DLI=0.5*DLO(N)
            XIML=SQRT(4*WL*DZI/(PI*DLI))
            CC=XIML*WI
            CA=SQRT(0.5*CD*DLI/(CC*DZI))
            RCPI=RCPG
            IF(DTP.LE.0.0.AND.DPV.GT.0.0) THEN
              RSVG=RSHINS(-DTP)
              RSHG=RSHINS(DTP)
            ELSE
              RSHG=RSHINS(DTP)
              RSVG=RSHG
            ENDIF
            UG=AMAX1(1.0E-10,WDA(N)/EXPADZ)
            DHG=APL2(DBG,TLIST,DHLIST,11)
            DVG=APL2(DBG,TLIST,DVLIST,11)
            DB=DBG+(DB2-DB1)*CLOD/DZI
            RBS=RCPG/HCONV(UG,DB,DBG,CLOD,0.0)
            RSHG=RSHG+RBS
            RSVG=(DHG/DVG)**0.6667*RBS+RSVG+RVS
            J=N+1
            HAA(J)=RCPG/RSHG
            VAA(J)=HLG/RSVG
            RSH(J)=RSHG
            RSV(J)=RSVG

          RETURN
        END
C-------------------------------------------------------------------------------
C       SOIL TEMPERATURE (BACKWARD FORMULATION OF FINITE DIFFERENCES)
C-------------------------------------------------------------------------------
        SUBROUTINE DBSOIL(DT)
C
          PARAMETER (N=3,M=10)
          REAL DXS(M),AG(M,M+1),P(M)
          COMMON /FLUX/FXHAA(N+1),FXVAA(N+1),FXHLA(N),FXVLA(N),FXSHA(N),
     +                 FXSHL(N),FXLHA(N),FXLHL(N),FVAA(N+1),FVLA(N),
```

```
     +                FXRVA(N),FXHSS(M+1),FXSHS(M),FXSHG,FXLHG,FXSTG,
     +                FXRSP(N),FXRAIN(N),RAIN(N),FXHLR,FXVLR
      COMMON /LAND/COND,VHCP,DEP(M),DBS(M+1),Q(M+1),COND2,ALF,VT
      COMMON /RATE/RDBA(N),RDBL(N),RRVA(N),RMCL(N),RDEW(N),
     +                RTDW(N),RDBS(M)
      COMMON /GND/CLOD,DBG,RHG,PVG,RVG,UG,RCPG,PSCG,RSHG,RSVG,RVS
      SAVE

      L=M+1
      DO 2 I=1,M
        DXS(I)=DBS(I)
        P(I)=DT*ALF/DEP(I)
        DO 3 J=1,L
          AG(I,J)=0.0
3     CONTINUE
2     CONTINUE
C-------------------------------------SET UP COEFFICIENT MATRIX
      AG(1,1)= 1+P(1)*(Q(1)+Q(2))
      AG(1,2)=-P(1)*Q(2)
      AG(1,L)= DXS(1)+P(1)*Q(1)*DBG
      K=M-1
      DO 5 I=2,K
        AG(I,I-1)=-P(I)*Q(I)
        AG(I,I  )= 1+P(I)*(Q(I)+Q(I+1))
        AG(I,I+1)=-P(I)*Q(I+1)
        AG(I,L  )= DXS(I)
5     CONTINUE
      AG(M,K)=-P(M)*Q(M)
      AG(M,M)= 1+P(M)*(Q(M)+Q(L))
      AG(M,L)= DXS(M)+P(M)*Q(L)+DBS(L)
C-------------------------------------SOLVE WITH MATRIX METHOD
      CALL GAUSS(M,AG)
      DO 6 I=1,M
        DBS(I)=AG(I,L)
6     CONTINUE

      RETURN
     END
C-----------------------------------------------------------------------
C     RATE OF CHANGE IN SOIL TEMPERATURES
C-----------------------------------------------------------------------
      SUBROUTINE DFDBS
C
      PARAMETER (N=3,M=10)
      COMMON /LAND/COND,VHCP,DEP(M),DBS(M+1),Q(M+1),COND2,ALF,VT
      COMMON /FLUX/FXHAA(N+1),FXVAA(N+1),FXHLA(N),FXVLA(N),FXSHA(N),
     +                FXSHL(N),FXLHA(N),FXLHL(N),FVAA(N+1),FVLA(N),
     +                FXRVA(N),FXHSS(M+1),FXSHS(M),FXSHG,FXLHG,FXSTG,
     +                FXRSP(N),FXRAIN(N),RAIN(N),FXHLR,FXVLR
      COMMON /RATE/RDBA(N),RDBL(N),RRVA(N),RMCL(N),RDEW(N),
     +                RTDW(N),RDBS(M)
      COMMON /GND/CLOD,DBG,RHG,PVG,RVG,UG,RCPG,PSCG,RSHG,RSVG,RVS
      SAVE

      L=M+1
C     FXHSS(1)=COND2*(DBG-DBS(1))*Q(1)
      FXHSS(1)=FXSTG
      DO 1 I=2,M
        FXHSS(I)=COND2*(DBS(I-1)-DBS(I))*Q(I)
1     CONTINUE
      FXHSS(L)=COND2*(DBS(M)-DBS(L))*Q(L)
      DO 2 I=1,M
        FXSHS(I)=FXHSS(I)-FXHSS(I+1)
        RDBS(I)=VT*FXSHS(I)/DEP(I)
2     CONTINUE
C
      RETURN
     END
C-----------------------------------------------------------------------
C     RATE OF CHANGES IN VARIOUS STATE PARAMETERS IN THE SWATH
C-----------------------------------------------------------------------
      SUBROUTINE RATES
C
      PARAMETER (N=3,M=10)
      REAL  LAI,MCO,MCL
      COMMON /LAYRS/MCL(N),PVA(N),PVL(N),RWS(N),DBA(N),DBL(N),RHA(N),
     +                RVA(N),RVL(N),RCP(N),PSC(N),HLA(N),VLA(N),RBH(N),RBV(N),
     +                RIA(N),WDA(N),DLG(N),ERH(N),VCP(N),DEW(N),TDW(N),FAC(N),
     +                DL(N),DZ(N),DD(N),HW(N),HAA(N+1),VAA(N+1),RSH(N+1),
     +                RSV(N+1)
      COMMON /FLUX/FXHAA(N+1),FXVAA(N+1),FXHLA(N),FXVLA(N),FXSHA(N),
     +                FXSHL(N),FXLHA(N),FXLHL(N),FVAA(N+1),FVLA(N),
     +                FXRVA(N),FXHSS(M+1),FXSHS(M),FXSHG,FXLHG,FXSTG,
     +                FXRSP(N),FXRAIN(N),RAIN(N),FXHLR,FXVLR
      COMMON /ABV/DBR,RHR,RVR,PVR,UR,CV,RCPR,PSCR,RIR,RSHR,RSVR
      COMMON /SWATH/LAI,DENS,VO,WL,MCO,EMC,RSFC
      COMMON /GND/CLOD,DBG,RHG,PVG,RVG,UG,RCPG,PSCG,RSHG,RSVG,RVS
      COMMON /MOIST/ENTMC(N),SFCMC(N),RUNMC(N),RUNOFF(N),EXCESS(N),
     +                RENTMC(N),RSECMC(N),RRUNMC(N),SMFR,SMFE,SMFS
      COMMON /RATE/RDBA(N),RDBL(N),RRVA(N),RMCL(N),RDEW(N),
     +                RTDW(N),RDBS(M)
      COMMON /RADSW/RNSW(N),RNSWG,RSG
      COMMON /RADLW/RNLW(N),RNLWG,EMG
      COMMON /CPH2O/CPW
      SAVE

      L=N+1
C-----RATE OF CHANGES IN VAPOR DENSITIES OF AIR SPACES IN SWATH
      FVAA(1)=(RVA(1)-RVR)/RSV(1)
      FVLA(1)= (RVL(1)-RVA(1))/RBV(1)
      FVAA(L)=(RVG-RVA(N))/RSVG
      DO 190 I=2,N
        FVAA(I)=(RVA(I)-RVA(I-1))/RSV(I)
        FVLA(I)= (RVL(I)-RVA(I))/RBV(I)
190   CONTINUE
C
      DO 191 I=1,N
        FXRVA(I)=FVAA(I+1)-FVAA(I)+FVLA(I)
        RRVA(I)=FXRVA(I)/(DZ(I))
191   CONTINUE
C
C     RATE OF CHANGES IN TEMPERATURES OF AIR SPACES IN THE SWATH
```

```
        FXHAA(1)=HAA(1)*(DBA(1)-DBR)
        FXVAA(1)=VAA(1)*(RVA(1)-RVR)
        FXHLA(1)=HLA(1)*(DBL(1)-DBA(1))
        FXVLA(1)=VLA(1)*(RVL(1)-RVA(1))
        FXLHA(1)= HW(1)*FXRVA(1)
        DO 200 I=2,N
          FXHAA(I)=HAA(I)*(DBA(I)-DBA(I-1))
          FXVAA(I)=VAA(I)*(RVA(I)-RVA(I-1))
          FXHLA(I)=HLA(I)*(DBL(I)-DBA(I))
          FXVLA(I)=VLA(I)*(RVL(I)-RVA(I))
          FXLHA(I)= HW(I)*FXRVA(I)
200     CONTINUE
        FXHAA(L)=HAA(L)*(DBG-DBA(N))
        FXVAA(L)=VAA(L)*(RVG-RVA(N))
C
        DO 201 I=1,N
          FXSHA(I)=FXHAA(I+1)-FXHAA(I)+FXVAA(I+1)-FXVAA(I)
     +            +(FXVLA(I)+FXHLA(I))-FXLHA(I)
          RDBA(I)=FXSHA(I)/(RCP(I)*DZ(I))
          FXRAIN(I)=CPW*RAIN(I)*(DBR-DBL(I))
          FXRSP(I)=4.556*AMIN1(1.0,0.17813*EXP(0.069*DBL(I)))*DD(I)
     +             *(3.66*ENTMC(I)/(1.0+ENTMC(I))-1.0)
201     CONTINUE

        RETURN
      END
C-----------------------------------------------------------------------
C     PRINT OUT RESULTS
C-----------------------------------------------------------------------
      SUBROUTINE WRTOUT(MDAY,HOUR,DMC,AMC)
C      SUBROUTINE WRTOUT(MC,MDAY,HOUR,J)
C
        PARAMETER (N=3,M=10)
        CHARACTER RMC*7
        REAL MCL
        INTEGER OV
        COMMON /OUTF/OV
        COMMON /LAYRS/MCL(N),PVA(N),PVL(N),RWS(N),DBA(N),DBL(N),RHA(N),
     +          RVA(N),RVL(N),RCP(N),PSC(N),HLA(N),VLA(N),RBH(N),RBV(N),
     +          RIA(N),WDA(N),DL0(N),ERH(N),VCP(N),DEW(N),TDW(N),FAC(N),
     +          DL(N),DZ(N),DD(N),HW(N),HAA(N+1),VAA(N+1),RSH(N+1),
     +          RSV(N+1)
        COMMON /FLUX/FXHAA(N+1),FXVAA(N+1),FXHLA(N),FXVLA(N),FXSHA(N),
     +               FXSHL(N),FXLHA(N),FXLHL(N),FVAA(N+1),FVLA(N),
     +               FXRVA(N),FXHSS(M+1),FXSHS(M),FXSHG,FXLHG,FXSTG,
     +               FXRSP(N),FXRAIN(N),RAIN(N),FXHLR,FXVLR
        COMMON /ABV/DBR,RHR,RVR,PVR,UR,CV,RCPR,PSCR,RIR,RSHR,RSVR
        COMMON /TOP/DBC,PVC,RVC,UC
        COMMON /GND/CLOD,DBG,RHG,PVG,RVG,UG,RCPG,PSCG,RSHG,RSVG,RVS
        COMMON /LAND/COND,VHCP,DEP(M),DBS(M+1),Q(M+1),COND2,CKVHC,VT
        COMMON /LWRD/EMR,RLG,EMA(N),EML(N),EL(N),EA(0:N),EB(0:N),
     +               ED(0:N),EU(0:N),ENET(0:N)
        COMMON /SWRD/RE,TE,SLDIR(N),SLSKY(N),DFDIR(N),DFDIRD(0:N),
     +               DFDIRU(0:N),DFSKYD(0:N),DFSKYU(0:N),SL(0:N),W(N)
        COMMON /RADSW/RNSW(N),RNSWG,RSG
        COMMON /RADLW/RNLW(N),RNLWG,EMG
```



```
        COMMON /RATE/RDBA(N),RDBL(N),RRVA(N),RMCL(N),RDEW(N),
     +               RTDW(N),RDBS(M)
        COMMON /PARIN/IYR,MDAYI,HRI,MDAYF,HRF,LEAP,JDAYI,JDAYF,
     +                DTP(1),XMC(1),SIMUL,DTFAST,DTSLOW
C--DTP & XMC USED TO STORE GIVEN DATA OF TIME & MOISTURE CONTENT
        COMMON /SUNH/HSUN,TSOLAR,TRISE,TSET
        COMMON /SOL/SL0,SLDIR0,SLSKY0,SMU2
        COMMON /HT/ZR,ZC,D,Z0
        COMMON /PAR/PI
        SAVE
        DATA X,RAD/1000.0,0.0174532/

        WRITE(RMC,'(F7.4)') DMC
C        IF( MC .GT. 0 ) THEN
C          WRITE(RMC,'(F7.4)') XMC( J )
C        ELSE
C          WRITE(RMC,'('''       ''')')
C        END IF

C        AMC=0.0
C        DO 73 I=1,N
C          AMC=AMC+MCL(I)
C73      CONTINUE
C        AMC=AMC/N
C        ERR=XMC(J)-AMC
C        PCT=100*ERR/XMC(J)
        ERR=DMC-AMC
        PCT=100*ERR/DMC

        WRITE(OV,907)'DATE','HOUR','MC MODEL','MC FIELD','HSUN','SOLAR',
     +               'DBR','RVR','WIND','COVER','ZR','ERROR','PERCENT'
907     FORMAT(/A8,12A10)
        WRITE(OV,908)MDAY,HOUR,AMC,RMC,HSUN/RAD,SL0,DBR,RVR*X,UR,CV,ZR,
     +               ERR,PCT
908     FORMAT(I8,F10.2,F10.4,A10,F10.2,F10.1,2F10.2,4F10.4,F10.2)
C       CALL TIME(CT)
C        WRITE(6,926) IYR,MDAY,HOUR,AMC,RMC,ERR,PCT,CT
C        WRITE(*,926) IYR,MDAY,HOUR,AMC,RMC,ERR,PCT,CT
C926     FORMAT(I4,I4,F6.2,F7.4,A7,F7.4,F7.2,10X,'(',A,')')
        WRITE(OV,'(/A,A/)')' MC,TEMP, VAPOR DENSITY, DEW AND DURATION,'
     +                     ,' RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:'
        WRITE(OV,909)'LAYER','MC','DL','DBL','RVL','DEW','TDEW','RAIN',
     +               'FAC','FVLA','SWRN','LWRN','FXHLA','FXVLA',
     +               'FXRSP','FXRAIN'
909     FORMAT(8A7,A10,A6,6A9)
        DO 70 I=1,N
          WRITE(OV,910)I,MCL(I),DL(I),DBL(I),RVL(I)*X,DEW(I),TDW(I),
     +                 RAIN(I),FAC(I),X*FVLA(I),RNSW(I),RNLW(I),
     +                 FXHLA(I),FXVLA(I),FXRSP(I),FXRAIN(I)
70      CONTINUE
910     FORMAT(I7,F7.4,F7.3,2F7.2,F7.4,F7.3,F7.3,E10.3,F6.3,6F9.3)
        WRITE(OV,'(/A,A/)')' TEMPERATURE, VAPOR DENSITY, MOISTURE AND',
     +                     ' ENERGY FLUXES IN AIR SPACES OF SWATH:'
        WRITE(OV,912)'LAYER','DBA','RVA','WDA','FVLA','FVAA','FXHLA',
     +               'FXVLA','FXHAA','FXVAA','FXSHA','FXLHA','RBH',
     +               'RBV','RSH','RSV'
```

```
912     FORMAT(6A7,3(A8,A9),4A9)
        WRITE(OV,'(A7,2F7.2,F7.3,T112,2E9.2)')  'TOP',DBC,RVC*X,UC,
     +        RSHR,RSVR
        DO 71 I=1,N
          WRITE(OV,913)I,DBA(I),RVA(I)*X,WDA(I),FVLA(I)*X,
     +                 FVAA(I)*X,FXHLA(I),FXVLA(I),FXHAA(I),
     +                 FXVAA(I),FXSHA(I),FXLHA(I),RBH(I),RBV(I),
     +                 RSH(I),RSV(I)
71      CONTINUE
913     FORMAT(I7,2F7.2,F7.3,2F7.4,3(F8.3,F9.3),2E9.2,2E9.2)
        L=N+1
        WRITE(OV,25)'GND',DBG,RVG*X,UG,FXHAA(L),FXVAA(L),RSH(L),RSV(L)
25      FORMAT(A7,2F7.2,F7.3,31X,F8.3,F9.3,T112,2E9.2)
C-------------------------------OUTPUT SHORT-WAVE RADIATION
        WRITE(OV,'(/T10,A/)')'SHORT-WAVE RADIATION FIELD IN SWATH:'
        IF(HSUN.LE.0.0) THEN
          WRITE(OV,'(/T10,A/)')'NO SHORT-WAVE RADIATION AT NIGHT'
        ELSE
          WRITE(OV,915)'SUN ELEVATION ( DEGREES ):',HSUN/RAD,
     +                 '    EFFECTIVE REFLECTANCE:',RE,
     +                 '    EFFECTIVE TRANSMITTANCE:',TE
915       FORMAT(5X,A,F10.2,2(A,F10.4))
          WRITE(OV,916)'LAYER','MC','SCAT','SLDIR','SLSKY','DFDIRDN',
     +                 'DFSKYDN','DFDIRUP','DFSKYUP','NET DOWN',
     +                 'ABSORBED'
916       FORMAT(/A7,9X,A2,7X,A4,2(6X,A5),4(4X,A7),2(3X,A8))
          WRITE(OV,917)'TOP',SLDIR0,SLSKY0,DFDIRD(0),DFSKYD(0),
     +                 DFDIRU(0),DFSKYU(0),SL(0)
917       FORMAT(A7,22X,7F11.4)
          DO 72 I=1,N
            WRITE(OV,918)I,MCL(I),W(I),SLDIR(I),SLSKY(I),DFDIRD(I),
     +                   DFSKYD(I),DFDIRU(I),DFSKYU(I),SL(I),RNSW(I)
72        CONTINUE
918       FORMAT(I7,10F11.4)
        END IF
C-------------------------------OUTPUT LONG-WAVE RADIATION FIELD
        WRITE(OV,'(/T10,A/)')'LONG-WAVE RADIATION FIELD IN SWATH:'
        WRITE(OV,'(5X,2(A25,F10.4))')'ATMOSPHERE EMISSIVITY:',EMR,
     +                               'GROUND EMISSIVITY:',EMG
        WRITE(OV,919)'LAYER','DBA','DBL','EMA','EML','RAD AIR','RAD ALF'
     +              ,'RAD GND','DOWN',' UP ','NET DOWN','ABSORBED'
919     FORMAT(/A7,4(6X,A3),3(4X,A7),2(7X,A4),2(3X,A8))
        WRITE(OV,920)'TOP',DBC,EMR,EA(0),EB(0),ED(0),EU(0),ENET(0)
920     FORMAT(A7,F9.2,9X,F9.4,9X,F11.4,11X,4F11.4)
        DO 74 I=1,N
          WRITE(OV,921)I,DBA(I),DBL(I),EMA(I),EML(I),EA(I),EL(I),
     +                 EB(I),ED(I),EU(I),ENET(I),RNLW(I)
74      CONTINUE
921     FORMAT(I7,2F9.2,2F9.4,7F11.4)
        WRITE(OV,922)'GND',DBG,EMG
922     FORMAT(A7,F9.2,18X,F9.4)
C-----------OUTPUT TEMPERATURES AND HEAT FLUXES IN SOIL LAYERS
        WRITE(OV,'(/T10,A/)')'TEMPERATURES AND HEAT FLUXES IN SOIL:'
        WRITE(OV,923)'10 LAYERS DEEP DOWN TO 0.5 M ',
     +               'SOIL HEAT CONDUCTIVITY:',COND,
     +               'VOLUMETRIC HEAT CAPACITY:',VHCP
```



```
923     FORMAT(5X,A,A25,F10.4,A30,E12.4/)
        WRITE(OV,924)'LAYER:','GND',(I,I=1,M),
     +               'THICKNESS:',(DEP(I),I=1,M),
     +               'TEMPERATURE:',DBG,(DBS(I),I=1,M),
     +               'HEAT FLUX:',FXSTG,(FXHSS(I),I=1,M)
924     FORMAT(T2,A,T20,A10,10(I10)/T2,A,T30,10F10.2/T2,A,T20,11F10.2
     +       /T2,A,T20,11F10.4/10(5X,8('*')))

        RETURN
      END
```

APPENDIX B

FORTRAN Code of the Psychrometric Library

```
C-------------------------------------------------------------------------
C                  PSYCHROMETRIC PACKAGE
C
C                        YI CHEN
C
C
C     ORIGINALLY DEVELOPED BY L. E. LEREW. MODIFIED BY J. E. DIXON.
C     FURTHER IMPROVED BY Y. CHEN.
C
C     SI UNITS
C
C     COMMON /PRES/ PATM              --REQUIRED IN CALLING PROGRAMS
C     PATM = 'BAROMETRIC PRESSURE'    --REQUIRED IN CALLING PROGRAMS
C
C     PARAMETERS
C       CP    - SPECIFIC HEAT (J/KG-K)
C       DB    - DRY BULB TEMPERATURE (C)
C       DP    - DEW-POINT TEMPERATURE (C)
C       DPSDT - SLOPE OF PS VS. DB CURVE (PA/C)
C       EN    - SPECIFIC ENTHALPY (J/KG DRY AIR)
C       HA    - HUMIDITY RATIO (DECIMAL)
C       HL    - LATENT HEAT OF VAPORIZATION OR SABLIMATION (J/KG)
C       HW    - SPECIFIC ENTHALPY OF WATER VAPOR (J/KG WATER VAPOR)
C       PATM  - ATMOSPHERIC PRESSURE (PA)
C       PC    - PSYCHROMETRIC CONSTANT (PA/K)
C       PS    - SATURATION VAPOR PRESSURE (PA)
C       PV    - VAPOR PRESSURE (PA)
C       RA    - DENSITY OF MOIST AIR (KG MOIST AIR/CUBIC M)
C       RH    - RELATIVE HUMIDITY (DECIMAL)
C       RV,RW - DENSITY OF WATER VAPOR IN THE AIR (KG H2O/CUBIC M)
C       TA    - ABSOLUTE TEMPERATURE (K)
C       VS    - SPECIFIC VOLUME (CUBIC M/KG DRY AIR)
C       WB    - WET BULB TEMPERATURE (C)
C
C     FUNCTIONS AND SUBROUTINES CONTAINED
C       CPDBRH(DB, RH)                          (BY CHEN )
C       CPHA(HA)                                (BY CHEN )
C       CPPV(PV)                                (BY CHEN )
C       DBPS(PS)                                (BY CHEN )
C       DBENRV(EN, RV)                          (BY CHEN )
C       DBDPEN(DP, EN)                          (BY CHEN )
C       DPDBEN(DB, EN)                          (BY CHEN )
C       DPHA(HA)                                (BY CHEN )
C       DPPV(PV)                                (BY CHEN )
C       ENDBDP(DB, DP)
C       HADBRH(DB, RH)
C       HADP(DP)
C       HAPV(PV)
C       HLDB(DB)                                (BY CHEN )
C       HWDBDP(DB, DP)                          (BY CHEN )
C       PCDBHA(DB, HA)                          (BY CHEN )
C       PCDBPV(DB, PV)                          (BY CHEN )
C       PCDBRH(DB, RH)                          (BY CHEN )
C       PCWBPV(WB, PV)                          (BY CHEN )
C       PSDB(DB)                                (BY CHEN )
C       PVDBRV(DB, RV)                          (BY CHEN )
```



```
C       PVDBVS(DB, VS)
C       PVDBWB(DB, WB)                          (BY CHEN )
C       PVHA(HA)
C       RADBHA(DB, HA)                          (BY CHEN )
C       RADBPV(DB, PV)                          (BY CHEN )
C       RADBRH(DB, RH)                          (BY CHEN )
C       RHDBHA(DB, HA)
C       RHDBPV(DB, PV)                          (BY CHEN )
C       RWDBHA(DB, HA)                          (BY CHEN )
C       RWDBPV(DB, PV)                          (BY CHEN )
C       RWDBRH(DB, RH)                          (BY CHEN )
C       VSDBHA(DB, HA)
C       WBDBHA(DB, HA)                          (BY CHEN )
C
C       PFILL .                                 (BY CHEN)
C       APL2(X,XLIST,YLIST,N)                   (BY CHEN)
C-------------------------------------------------------------------------
C     SPECIFIC HEAT OF MOIST AIR (J/KG-K)
C-------------------------------------------------------------------------
      FUNCTION CPDBRH(DB,RH)
C
        PV=PSDB(DB)*RH
        HA=HAPV(PV)
        CPDBRH=(1006.9254+1875.6864*HA)/(1+HA)
C
        RETURN
      END
C-------------------------------------------------------------------------
      FUNCTION CPPV(PV)
C-------------------------------------------------------------------------
        VP=PV
        AH=HAPV(VP)
        GOTO 192
C
      ENTRY CPHA(HA)
        AH=HA

192     CPPV=(1006.9254+1875.6864*AH)/(1+AH)
        CPHA=CPPV

        RETURN
      END
C-------------------------------------------------------------------------
C     DRY-BULB TEMPERATURE (C)
C-------------------------------------------------------------------------
      FUNCTION DBDPEN(DP,EN)

        REAL T(11),E(11)

        DP=AMAX1(0.0,AMIN1(DP,100.0))
        DB=DP
        ES=ENDBDP(DB,DP)
        EL=ENDBDP(DB,0.0)

        EN=AMAX1(EL,AMIN1(EN,ES))
C-------REPEAT
```

```
1         CONTINUE
          DU=DB
          DB=DB+1.0
          EL=ENDBDP(DB,DP)
          IF(EN.GT.EL.AND.DB.LT.99.0) GOTO 1
C--------UNTIL(EN.LE.EL.OR.DB.EQ.100.0)
        IF(ABS(EN-EL).LT.1.0E-10) THEN
          DBDPEN=DB
        ELSE
          DT=0.1*(DB-DU)
          DO 2 J=1,11
            T(J)=DU+DT*(J-1)
            E(J)=ENDBDP(T(J),DP)
2         CONTINUE
          DBDPEN=APL2(EN,E,T,11)
        ENDIF

        RETURN
      END
C-------------------------------------------------------------------------
      FUNCTION DBENRV(EN,RV,PV)
C-------------------------------------------------------------------------
        A=287*RV/0.62194
        DL=0.0
        C=100.0
C-------REPEAT
1         CONTINUE
          WB=DL
          C=0.1*C
C---------REPEAT
2           CONTINUE
            DL=WB
            WB=WB+C
            EH=ENDBDP(WB,WB)
            IF(EN.GT.EH)GO TO 2
C---------UNTIL(EN.LE.EH)
          IF(EN.LT.EH.AND.WB-DL.GE.0.001) GOTO 1
C-------UNTIL(EN.EQ.EH.OR.WB-DL.LT.0.001)
        IF(ABS(EN-EH).GT.0.01) WB=0.5*(WB+DL)
        DL=WB
        DU=PSDB(WB)/A-273.16

        IF(ABS(DL-DU).LT.1.0E-4) THEN
          DBENRV=WB
        ELSE
          C=DU-DL
C---------REPEAT
3           CONTINUE
            C=0.1*C
            DU=DL
C-----------REPEAT
4             CONTINUE
              DL=DU
              DU=DU+C
              P=A*(DU+273.16)
              DP=DPHA(HAPV(P))
```



```
              EH=ENDBDP(DU,DP)
              IF(EN.GT.EH) GOTO 4
C-----------UNTIL(EN.LE.EH)
            IF(EN.LT.EH.AND.C.GE.0.0001) GOTO 3
C---------UNTIL(EN.EQ.EH.OR.C.LT.0.0001)
          DBENRV=0.5*(DL+DU)
        ENDIF
        PV=A*(DBENRV+273.16)

        RETURN
      END
C-------------------------------------------------------------------------
      FUNCTION DBPS(PS)
C-------------------------------------------------------------------------
        COMMON /TEP/ IC,TXL(40),PL(40)
        SAVE /TEP/

        IF(IC.EQ.0) CALL PFILL
        DBPS=APL2(PS,PL,TXL,40)

        RETURN
      END
C-------------------------------------------------------------------------
C     DEW-POINT TEMPERATURE (C)
C-------------------------------------------------------------------------
      FUNCTION DPDBEN(DB,EN)

        REAL T(11),E(11)

        DB=AMAX1(0.00,AMIN1(DB,100.0))
        DP=AMIN1(100.0,DB)
        ES=ENDBDP(DB,DP)
        EL=ENDBDP(DB,0.0)

        EN=AMAX1(EL,AMIN1(EN,ES))
        IF(ABS(EN-ES).LT.0.001) THEN
          DPDBEN=DP
        ELSE
C---------REPEAT
3           CONTINUE
            DU=DP
            DP=AMAX1(0.0,(DP-1.0))
            EL=ENDBDP(DB,DP)
            IF((EL.GT.EN).AND.(DP.GT.0.0)) GOTO 3
C---------UNTIL((EL.LE.EN).OR.(DP.EQ.0.0))
          IF(ABS(EN-EL).LT.1.0E-3) THEN
            DPDBEN=DP
          ELSE
            DT=(DU-DP)*0.1
            DO 4 J=1,11
              T(J)=DP+DT*(J-1)
              E(J)=ENDBDP(DB,T(J))
4           CONTINUE
            DPDBEN=APL2(EN,E,T,11)
          ENDIF
        ENDIF
```

```
        RETURN
      END
C-----------------------------------------------------------------------
      FUNCTION DPHA(HA)
C-----------------------------------------------------------------------
        COMMON /TEP/ IC,TXL(40),PL(40)
        SAVE /TEP/

        VP=PVHA(HA)
        GOTO 10

       ENTRY DPPV(PV)
         VP=PV

10      IF(IC.EQ.0) CALL PFILL

        DPHA=APL2(VP,PL,TXL,40)
        DPPV=DPHA

        RETURN
      END
C-----------------------------------------------------------------------
C   SLOPE OF THE SATURATION PRESSURE CURVE AT GIVEN TEEMPERATURE
C-----------------------------------------------------------------------
      FUNCTION DPSDT(T)

C------ DPSDT - SLOPE OF THE SATURATION PRESSURE CURVE (PA/K)
C------ T     - AIR TEMPERATURE (C)
C------ TA    - ABSOLUTE TEMPERATURE (K)

        SAVE A,B,C,D,E,F,G,V,W
C------ ADAPTED FROM PSYCHROMETRIC DATA (ASAE D271.2)
        DATA A,B,C,D /-27405.526,97.5413,-0.146244,0.12558E-3 /
        DATA E,F,G / -0.48502E-7,4.34903,0.39381E-2 /
        DATA V,W / 6270.3605,0.46057 /

        TA=AMIN1(533.16,AMAX1(255.38,T+273.16))

        IF(TA.LE.273.16) THEN
          DPSDT=PSDB(T)*(V/TA-W)
        ELSE
          DPSDT=PSDB(T)/(TA*(F-G*TA))**2*(-A*F+TA*(2*A*G+TA*(B*G+C*F+
     +          TA*(2*D*F+TA*(3*E*F-D*G-TA*2*E*G)))))
        ENDIF

        RETURN
      END
C-----------------------------------------------------------------------
C     SPECIFIC ENTHAPY OF THE MOIST AIR (J/KG DRY AIR)
C-----------------------------------------------------------------------
      FUNCTION ENDBDP(DB,DP)

        COMMON /PRES/ PATM
        SAVE /PRES/
        DB=AMAX1(0.0,AMIN1(DB,100.0))
```



```
        DP=AMAX1(0.0,AMIN1(DB,DP))

        HA=HADP(DP)
        HL=HLDB(DP)

        EN1=1006.9254*DB+HL*HA+1875.6864*HA*(DB-DP)

        IF(DP.LE.0.0) THEN
          EN2=-HA*(333432.1-2030.598*DP)
        ELSE
          EN2=4186.8*HA*DP
        ENDIF

        ENDBDP=EN1+EN2

        RETURN
      END
C-----------------------------------------------------------------------
C     HUMIDITY RATIO (KG WATER/KG DRY AIR)
C-----------------------------------------------------------------------
      FUNCTION HADBRH(DB,RH)

        HADBRH=HAPV(RH*PSDB(DB))

        RETURN
      END
C-----------------------------------------------------------------------
      FUNCTION HADP(DP)
C-----------------------------------------------------------------------
        HADP=HAPV(PSDB(DP))

        RETURN
      END
C-----------------------------------------------------------------------
      FUNCTION HAPV(PV)
C-----------------------------------------------------------------------
        COMMON /PRES/ PATM
        SAVE /PRES/

        HAPV=0.62194*PV/(PATM-PV)

        RETURN
      END
C-----------------------------------------------------------------------
C     LATENT HEAT OF WATER (J/KG WATER)
C-----------------------------------------------------------------------
      FUNCTION HLDB(DB)

        DB=AMAX1(0.0,AMIN1(DB,100.0))
        TA=DB+273.16

        IF(DB.LT.0.0) THEN
          HLDB=2839683.144-212.56384*(TA-255.38)
        ELSE IF(DB.LT.65.56) THEN
          HLDB=2502535.259-2385.76424*(TA-273.16)
        ELSE
```

```
        HLDB=SQRT(7329155978000.0-15995964.08*TA**2)
      ENDIF

      RETURN
    END
C-------------------------------------------------------------------------------
C     SPECIFIC ENTHAPY OF WATER VAPOR (J/KG WATER)
C-------------------------------------------------------------------------------
    FUNCTION HWDBDP(DB,DP)


      DB=AMAX1(0.0,AMIN1(DB,100.0))
      DP=AMAX1(0.0,AMIN1(DB,DP))
      HW1=HLDB(DP)+1875.6864*(DB-DP)

      IF(DP.LT.0.0) THEN
        HW2=-333432.1+2030.598*DP
      ELSE
        HW2=4186.8*DP
      ENDIF
      HWDBDP=HW1+HW2

      RETURN
    END
C-------------------------------------------------------------------------------
C     PSYCHROMETRIC CONSTANT OF THE AIR
C-------------------------------------------------------------------------------
    FUNCTION PCDBRH(DB,RH)

      COMMON /PRES/ PATM
      SAVE /PRES/

      VP=PSDB(DB)*RH
      GOTO 171

    ENTRY PCDBPV(DB,PV)
      VP=PV

171   AH=HAPV(VP)
      GOTO 172

    ENTRY PCDBHA(DB,HA)
      AH=HA
      VP=PVHA(AH)

172   BW=WBDBHA(DB,AH)
      GOTO 173

    ENTRY PCWBPV(WB,PV)
      BW=WB
      VP=PV

173   PS=PSDB(BW)
      HL=HLDB(BW)

      PCDBRH=1006.954*(PATM-PS)*(1+0.15577*VP/PATM)/(0.62194*HL)
```



```
      PCWBPV=PCDBRH
      PCDBHA=PCDBRH
      PCDBPV=PCDBRH

      RETURN
    END
C-------------------------------------------------------------------------------
C     SATURATION PRESSURE OF WATER VAPOR IN THE AIR (PA)
C-------------------------------------------------------------------------------
    FUNCTION PSDB(DB)

      SAVE R,A,B,C,D,E,F,G
      DATA R,A,B /22105649.25,-27405.526,97.5413/
      DATA C,D,E /-0.146244,0.12558E-3,-0.48502E-7/
      DATA F,G /4.34903,0.39381E-2/

      DB=AMAX1(0.0,AMIN1(DB,100.0))
      TA=DB+273.16

      IF(DB.LT.0.0) THEN
        PSDB=EXP(31.9602-6270.3605/TA-0.46057*ALOG(TA))
      ELSE
        PSDB=R*EXP((A+TA*(B+TA*(C+TA*(D+TA*E))))/(TA*(F-TA*G)))
      ENDIF

      RETURN
    END
C-------------------------------------------------------------------------------
C     VAPOR PRESSURE IN THE AIR (PA)
C-------------------------------------------------------------------------------
    FUNCTION PVDBRV(DB,RV)

      DB=AMAX1(0.0,AMIN1(100.0,DB))
      TA=DB+273.16
      PVDBRV=287*TA*RV/0.62194

      RETURN
    END
C-------------------------------------------------------------------------------
    FUNCTION PVDBVS(DB,VS)
C-------------------------------------------------------------------------------
      COMMON /PRES/ PATM
      SAVE /PRES/

      TA=AMAX1(0.0,AMIN1(100.0,DB))+273.16
      PVDBVS=PATM-287.0*TA/VS

      RETURN
    END
C-------------------------------------------------------------------------------
    FUNCTION PVDBWB(DB,WB)
C-------------------------------------------------------------------------------
      COMMON /PRES/ PATM
      SAVE /PRES/

      PS=PSDB(WB)
```

```
        A=0.62194*HLDB(WB)
        B=1006.9254*(PS-PATM)*(WB-DB)

        PVDBWB=(A*PS-B)/(A+B*0.15577/PATM)

        RETURN
      END
C-----------------------------------------------------------------------
      FUNCTION PVHA(HA)
C-----------------------------------------------------------------------
        COMMON /PRES/ PATM
        SAVE /PRES/

        PVHA=HA*PATM/(0.62194+HA)

        RETURN
      END
C-----------------------------------------------------------------------
C     DENSITY OF MOIST AIR (KG MOIST AIR/CUBIC M)
C-----------------------------------------------------------------------
      FUNCTION RADBRH(DB,RH)

        COMMON /PRES/ PATM
        SAVE /PRES/

        AH=HADBRH(DB,RH)
        GOTO 171

      ENTRY RADBHA(DB,HA)
        AH=HA

171     VP=PVHA(AH)
        GOTO 172

      ENTRY RADBPV(DB,PV)
        VP=PV

172     DA=DB+273.16
        RADBRH=(PATM-0.37806*VP)/(287*DA)
        RADBHA=RADBRH
        RADBPV=RADBRH

        RETURN
      END
C-----------------------------------------------------------------------
C     RELATIVE HUMIDITY OF THE AIR (DECIMAL)
C-----------------------------------------------------------------------
      FUNCTION RHDBHA(DB,HA)

        RHDBHA=PVHA(HA)/PSDB(DB)

        RETURN
      END
C-----------------------------------------------------------------------
      FUNCTION RHDBPV(DB,PV)
C-----------------------------------------------------------------------
```



```
        RHDBPV=PV/PSDB(DB)

        RETURN
      END
C-----------------------------------------------------------------------
C     WATER VAPOR DENSITY IN THE AIR (KG WATER/CUBIC M)
C-----------------------------------------------------------------------
      FUNCTION RWDBRH(DB,RH)

        AH=HADBRH(DB,RH)
        GOTO 181

      ENTRY RWDBHA(DB,HA)
        AH=HA

181     VP=PVHA(AH)
        GOTO 182

      ENTRY RWDBPV(DB,PV)
        VP=PV

182     DA=DB+273.16
        RWDBRH=0.62194*VP/(287*DA)
        RWDBHA=RWDBRH
        RWDBPV=RWDBRH

        RETURN
      END
C-----------------------------------------------------------------------
C     SPECIFIC VOLUME OF THE MOIST AIR (CUBIC M/KG DRY AIR)
C-----------------------------------------------------------------------
      FUNCTION VSDBHA(DB,HA)

        COMMON /PRES/ PATM
        SAVE /PRES/

        TA=DB+273.16
        VSDBHA=287.0*TA/(PATM-PVHA(HA))

        RETURN
      END
C-----------------------------------------------------------------------
C     WET-BULB TEPERATURE (C)
C-----------------------------------------------------------------------
      FUNCTION WBDBHA(DB,HA)

        REAL T(11),P(11)

        DB=AMAX1(0.0,AMIN1(DB,100.0))
        HA=AMAX1(0.0,AMIN1(HA,HADP(DB)))
        DP=AMIN1(0.0,AMIN1(100.0,DPHA(HA)))
        PV=PVHA(HA)
        IF(DP.LT.DB) THEN
          N=11
          DT=(DB-DP)/(N-1)
          DO 2 J=1,N
```

```
            T(J)=DP+DT*(J-1)
            P(J)=PVDBWB(DB,T(J))
2         CONTINUE
          WBDBHA=APL2(PV,P,T,N)
        ELSE
          WBDBHA=0.5*(DB+DP)
        ENDIF

        RETURN
      END
C-------------------------------------------------------------------------
C     DATA INITIALIZATION OF SATURATION PRESSURE VS. TEMPERATURE
C-------------------------------------------------------------------------
      SUBROUTINE PFILL

        PARAMETER (TUP=100.0,TLOW=0.0)
        COMMON /TEP/ IC,TXL(40),PL(40)
        SAVE /TEP/

        DT=(TUP-TLOW)/39
        IC=1

        DO 2 J=1,40
          TXL(J)=TLOW+DT*(J-1)
          PL(J)=PSDB(TXL(J))
2       CONTINUE

        RETURN
      END
C-------------------------------------------------------------------------
C     LINEAR APPROXIMATION WITH EXTRAPOLATION
C-------------------------------------------------------------------------
      FUNCTION APL2(X,XL,YL,N)

C------ APL2  - LINEAR INTERPOLATION OF A TABULATED FUNCTION AT X
C------ XL    - LIST OF TABULATED INDEPENDENT VARIABLE DATA
C------ YL    - LIST OF DEPEDENT VARIABLE DATA
C------ N     - NUMBER OF KNOWN PAIRS OF DATA
C------ X     - INDEPENDENT VARIABLE VALUE

        REAL XL(N),YL(N)

        IF(X.LE.XL(1)) THEN
          J=2
        ELSE IF(X.GT.XL(N)) THEN
          J=N
        ELSE
          J=1
C---------REPEAT
1           CONTINUE
            J=J+1
            IF(X.GT.XL(J)) GOTO 1
C---------UNTIL(X.LE.XL(J))
        ENDIF

        DX=XL(J)-XL(J-1)
```



```
        IF(ABS(DX).LT.1.0E-9) THEN
          APL2=0.5*(YL(J)+YL(J+1))
        ELSE
          APL2=(YL(J)-YL(J-1))*(X-XL(J-1))/(XL(J)-XL(J-1))+YL(J-1)
        ENDIF

        RETURN
      END
```

APPENDIX C

Drying Data, File DRYCASE

```
84 723 11.18 3.7119 3.7119 0.4245 5.300 0.250 0.5  0  1  1  1  Group 1 1
84 723 11.91 2.9913 3.7119 0.4245 5.300 0.250 0.5  0  2  1  1
84 723 14.21 1.7200 3.7119 0.4245 5.300 0.250 0.5  0  3  1  1
84 723 16.11 1.0665 3.7119 0.4245 5.300 0.250 0.5  0  4  1  1
84 723 11.18 3.5741 3.5741 0.2624 5.300 0.250 0.5  0  1  2  1          2
84 723 11.91 2.8010 3.5741 0.2624 5.300 0.250 0.5  0  2  2  1
84 723 14.21 1.5005 3.5741 0.2624 5.300 0.250 0.5  0  3  2  1
84 723 16.11 0.9209 3.5741 0.2624 5.300 0.250 0.5  0  4  2  1
84 723 10.58 3.6842 3.6842 0.5205 5.300 0.250 0.5  0  1  3  1          3
84 723 12.91 2.4784 3.6842 0.5205 5.300 0.250 0.5  0  2  3  1
84 723 15.16 1.6730 3.6842 0.5205 5.300 0.250 0.5  0  3  3  1
84 723 16.99 1.2825 3.6842 0.5205 5.300 0.250 0.5  0  4  3  1
84 723 11.07 4.3121 4.3121 0.3564 5.300 0.250 0.5  0  1  4  1          4
84 723 11.45 4.0055 4.3121 0.3564 5.300 0.250 0.5  0  2  4  1
84 723 12.95 3.0812 4.3121 0.3564 5.300 0.250 0.5  0  3  4  1
84 723 15.12 2.1906 4.3121 0.3564 5.300 0.250 0.5  0  4  4  1
84 723 16.95 1.7993 4.3121 0.3564 5.300 0.250 0.5  0  5  4  1
84 814 13.47 3.4636 3.4636 0.4481 6.620 0.000 0.5  0  1  5  1  Group 2 5
84 814 14.17 2.6246 3.4636 0.4481 6.620 0.000 0.5  0  2  5  1
84 814 16.10 1.6545 3.4636 0.4481 6.620 0.000 0.5  0  3  5  1
84 814 18.20 1.2142 3.4636 0.4481 6.620 0.000 0.5  0  4  5  1
84 814 20.03 1.1190 3.4636 0.4481 6.620 0.000 0.5  0  5  5  1
84 814 22.11 1.1308 3.4636 0.4481 6.620 0.000 0.5  0  6  5  1
84 815  0.01 1.1725 3.4636 0.4481 6.620 0.000 0.5  0  7  5  1
84 815  2.24 1.2297 3.4636 0.4481 6.620 0.000 0.5  0  8  5  1
84 815  4.02 1.3749 3.4636 0.4481 6.620 0.000 0.5  0  9  5  1
84 815  6.84 1.4642 3.4636 0.4481 6.620 0.000 0.5  0 10  5  1
84 815  8.00 1.4227 3.4636 0.4481 6.620 0.000 0.5  0 11  5  1
84 815 10.15 1.1310 3.4636 0.4481 6.620 0.000 0.5  0 12  5  1
84 815 12.03 0.8572 3.4636 0.4481 6.620 0.000 0.5  0 13  5  1
84 815 14.13 0.5772 3.4636 0.4481 6.620 0.000 0.5  0 14  5  1
84 815 16.16 0.4284 3.4636 0.4481 6.620 0.000 0.5  0 15  5  1
84 815 18.04 0.3629 3.4636 0.4481 6.620 0.000 0.5  0 16  5  1
84 815 20.10 0.3690 3.4636 0.4481 6.620 0.000 0.5  0 17  5  1
84 815 22.20 0.4105 3.4636 0.4481 6.620 0.000 0.5  0 18  5  1
84 816  0.18 0.4404 3.4636 0.4481 6.620 0.000 0.5  0 19  5  1
84 816  2.21 0.4700 3.4636 0.4481 6.620 0.000 0.5  0 20  5  1
84 816  4.59 0.5356 3.4636 0.4481 6.620 0.000 0.5  0 21  5  1
84 816  6.98 0.6130 3.4636 0.4481 6.620 0.000 0.5  0 22  5  1
84 816  9.10 0.6130 3.4636 0.4481 6.620 0.000 0.5  0 23  5  1
84 816 11.23 0.4821 3.4636 0.4481 6.620 0.000 0.5  0 24  5  1
84 816 13.15 0.2975 3.4636 0.4481 6.620 0.000 0.5  0 25  5  1
84 816 15.26 0.1845 3.4636 0.4481 6.620 0.000 0.5  0 26  5  1
84 814 13.47 3.4201 3.4201 0.2716 6.620 0.000 0.5  0  1  6  1          6
84 814 14.17 2.3993 3.4201 0.2716 6.620 0.000 0.5  0  2  6  1
84 814 16.10 1.3678 3.4201 0.2716 6.620 0.000 0.5  0  3  6  1
84 814 18.20 0.9646 3.4201 0.2716 6.620 0.000 0.5  0  4  6  1
84 814 20.03 0.8762 3.4201 0.2716 6.620 0.000 0.5  0  5  6  1
84 814 22.11 0.9153 3.4201 0.2716 6.620 0.000 0.5  0  6  6  1
84 815  0.01 1.0037 3.4201 0.2716 6.620 0.000 0.5  0  7  6  1
84 815  2.24 1.1607 3.4201 0.2716 6.620 0.000 0.5  0  8  6  1
84 815  4.02 1.3080 3.4201 0.2716 6.620 0.000 0.5  0  9  6  1
84 815  6.84 1.4747 3.4201 0.2716 6.620 0.000 0.5  0 10  6  1
84 815  8.00 1.3863 3.4201 0.2716 6.620 0.000 0.5  0 11  6  1
84 815 10.15 0.9936 3.4201 0.2716 6.620 0.000 0.5  0 12  6  1
84 815 12.03 0.7086 3.4201 0.2716 6.620 0.000 0.5  0 13  6  1
```



```
84 815 14.13 0.4530 3.4201 0.2716 6.620 0.000 0.5  0 14  6  1
84 815 16.16 0.3550 3.4201 0.2716 6.620 0.000 0.5  0 15  6  1
84 815 18.04 0.2960 3.4201 0.2716 6.620 0.000 0.5  0 16  6  1
84 815 20.10 0.3158 3.4201 0.2716 6.620 0.000 0.5  0 17  6  1
84 815 22.20 0.3743 3.4201 0.2716 6.620 0.000 0.5  0 18  6  1
84 816  0.18 0.4236 3.4201 0.2716 6.620 0.000 0.5  0 19  6  1
84 816  2.21 0.4628 3.4201 0.2716 6.620 0.000 0.5  0 20  6  1
84 816  4.59 0.5613 3.4201 0.2716 6.620 0.000 0.5  0 21  6  1
84 816  6.98 0.6594 3.4201 0.2716 6.620 0.000 0.5  0 22  6  1
84 816  9.10 0.6691 3.4201 0.2716 6.620 0.000 0.5  0 23  6  1
84 816 11.23 0.4923 3.4201 0.2716 6.620 0.000 0.5  0 24  6  1
84 816 13.15 0.2859 3.4201 0.2716 6.620 0.000 0.5  0 25  6  1
84 816 15.26 0.1786 3.4201 0.2716 6.620 0.000 0.5  0 26  6  1
84 814 13.05 3.6700 3.6700 0.3349 6.620 0.000 0.5  0  1  7  1          7
84 814 14.13 2.8900 3.6700 0.3349 6.620 0.000 0.5  0  2  7  1
84 814 15.46 2.0600 3.6700 0.3349 6.620 0.000 0.5  0  3  7  1
84 814 16.96 1.6300 3.6700 0.3349 6.620 0.000 0.5  0  4  7  1
84 814 18.96 1.3200 3.6700 0.3349 6.620 0.000 0.5  0  5  7  1
84 814 20.38 1.3200 3.6700 0.3349 6.620 0.000 0.5  0  6  7  1
84 815  7.01 1.7500 3.6700 0.3349 6.620 0.000 0.5  0  7  7  1
84 815  8.96 1.5800 3.6700 0.3349 6.620 0.000 0.5  0  8  7  1
84 815 11.21 1.1700 3.6700 0.3349 6.620 0.000 0.5  0  9  7  1
84 815 12.88 0.8700 3.6700 0.3349 6.620 0.000 0.5  0 10  7  1
84 815 15.30 0.5900 3.6700 0.3349 6.620 0.000 0.5  0 11  7  1
84 815 16.47 0.5200 3.6700 0.3349 6.620 0.000 0.5  0 12  7  1
84 815 18.47 0.4600 3.6700 0.3349 6.620 0.000 0.5  0 13  7  1
84 815 20.47 0.5200 3.6700 0.3349 6.620 0.000 0.5  0 14  7  1
84 816  6.50 0.7900 3.6700 0.3349 6.620 0.000 0.5  0 15  7  1
84 816  8.47 0.7200 3.6700 0.3349 6.620 0.000 0.5  0 16  7  1
84 816 10.47 0.5200 3.6700 0.3349 6.620 0.000 0.5  0 17  7  1
84 816 12.47 0.3100 3.6700 0.3349 6.620 0.000 0.5  0 18  7  1
84 816 14.47 0.2900 3.6700 0.3349 6.620 0.000 0.5  0 19  7  1
84 821 11.00 3.5889 3.5889 0.2620 6.620 0.050 0.5  0  1  8  1  Group 3 8
84 821 11.93 2.7516 3.5889 0.2620 6.620 0.050 0.5  0  2  8  1
84 821 13.02 2.1990 3.5889 0.2620 6.620 0.050 0.5  0  3  8  1
84 821 15.20 1.2217 3.5889 0.2620 6.620 0.050 0.5  0  4  8  1
84 821 17.00 0.8442 3.5889 0.2620 6.620 0.050 0.5  0  5  8  1
84 821 19.05 0.6807 3.5889 0.2620 6.620 0.050 0.5  0  6  8  1
84 821 21.02 0.6816 3.5889 0.2620 6.620 0.050 0.5  0  7  8  1
84 821 23.19 0.7008 3.5889 0.2620 6.620 0.050 0.5  0  8  8  1
84 822  1.06 0.6912 3.5889 0.2620 6.620 0.050 0.5  0  9  8  1
84 822  3.11 0.6912 3.5889 0.2620 6.620 0.050 0.5  0 10  8  1
84 822  5.16 0.6912 3.5889 0.2620 6.620 0.050 0.5  0 11  8  1
84 822  7.09 0.6702 3.5889 0.2620 6.620 0.050 0.5  0 12  8  1
84 822  9.12 0.6606 3.5889 0.2620 6.620 0.050 0.5  0 13  8  1
84 822 11.07 0.5986 3.5889 0.2620 6.620 0.050 0.5  0 14  8  1
84 822 13.24 0.4360 3.5889 0.2620 6.620 0.050 0.5  0 15  8  1
84 822 15.12 0.3031 3.5889 0.2620 6.620 0.050 0.5  0 16  8  1
84 821 11.00 3.3506 3.3506 0.4599 6.620 0.050 0.5  0  1  9  1          9
84 821 11.93 2.7877 3.3506 0.4599 6.620 0.050 0.5  0  2  9  1
84 821 13.02 2.3059 3.3506 0.4599 6.620 0.050 0.5  0  3  9  1
84 821 15.20 1.4475 3.3506 0.4599 6.620 0.050 0.5  0  4  9  1
84 821 17.00 0.9431 3.3506 0.4599 6.620 0.050 0.5  0  5  9  1
84 821 19.05 0.8326 3.3506 0.4599 6.620 0.050 0.5  0  6  9  1
84 821 21.02 0.8098 3.3506 0.4599 6.620 0.050 0.5  0  7  9  1
84 821 23.19 0.8097 3.3506 0.4599 6.620 0.050 0.5  0  8  9  1
```

```
84 822  1.06 0.7981 3.3506 0.4599 6.620 0.050 0.5  0  9  9  1
84 822  3.11 0.7980 3.3506 0.4599 6.620 0.050 0.5  0 10  9  1
84 822  5.16 0.7866 3.3506 0.4599 6.620 0.050 0.5  0 11  9  1
84 822  7.09 0.7633 3.3506 0.4599 6.620 0.050 0.5  0 12  9  1
84 822  9.12 0.7575 3.3506 0.4599 6.620 0.050 0.5  0 13  9  1
84 822 11.07 0.6937 3.3506 0.4599 6.620 0.050 0.5  0 14  9  1
84 822 13.24 0.4677 3.3506 0.4599 6.620 0.050 0.5  0 15  9  1
84 822 15.12 0.2875 3.3506 0.4599 6.620 0.050 0.5  0 16  9  1
84 821 11.50 3.0579 3.0579 0.4516 6.620 0.050 0.5  0  1 10  1          10
84 821 12.25 2.6056 3.0579 0.4516 6.620 0.050 0.5  0  2 10  1
84 821 14.00 1.8277 3.0579 0.4516 6.620 0.050 0.5  0  3 10  1
84 821 16.00 1.1163 3.0579 0.4516 6.620 0.050 0.5  0  4 10  1
84 821 18.00 0.7710 3.0579 0.4516 6.620 0.050 0.5  0  5 10  1
84 821 20.00 0.6853 3.0579 0.4516 6.620 0.050 0.5  0  6 10  1
84 822  8.18 0.6146 3.0579 0.4516 6.620 0.050 0.5  0  7 10  1
84 822 10.00 0.5683 3.0579 0.4516 6.620 0.050 0.5  0  8 10  1
84 822 12.00 0.4018 3.0579 0.4516 6.620 0.050 0.5  0  9 10  1
84 822 14.25 0.1521 3.0579 0.4516 6.620 0.050 0.5  0 10 10  1
84 821 10.50 4.0177 4.0177 0.4333 6.620 0.050 0.5  0  1 11  1          11
84 821 11.42 3.4290 4.0177 0.4333 6.620 0.050 0.5  0  2 11  1
84 821 14.00 2.2360 4.0177 0.4333 6.620 0.050 0.5  0  3 11  1
84 821 16.00 1.5480 4.0177 0.4333 6.620 0.050 0.5  0  4 11  1
84 821 18.00 1.2642 4.0177 0.4333 6.620 0.050 0.5  0  5 11  1
84 821 20.00 1.1966 4.0177 0.4333 6.620 0.050 0.5  0  6 11  1
84 822  8.18 1.1628 4.0177 0.4333 6.620 0.050 0.5  0  7 11  1
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85 801 18.00 1.2650 2.9550 2.5840 6.620 0.500 0.5  1  9 33  2
85 801 19.65 1.2050 2.9550 2.5840 6.620 0.500 0.5  1 10 33  2
85 802  8.00 1.1750 2.9550 2.5840 6.620 0.500 0.5  1 11 33  2
85 802 10.16 1.0550 2.9550 2.5840 6.620 0.500 0.5  1 12 33  2
85 802 12.50 0.8750 2.9550 2.5840 6.620 0.500 0.5  1 13 33  2
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85 802 19.83 0.4400 2.9550 2.5840 6.620 0.500 0.5  1 16 33  2
85 803  7.41 0.5150 2.9550 2.5840 6.620 0.500 0.5  1 17 33  2
85 803  9.85 0.4350 2.9550 2.5840 6.620 0.500 0.5  1 18 33  2
85 803 12.17 0.3200 2.9550 2.5840 6.620 0.500 0.5  1 19 33  2
85 803 14.99 0.2550 2.9550 2.5840 6.620 0.500 0.5  1 20 33  2
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85 802 20.50 1.3950 3.1550 0.7724 6.620 0.350 0.5  1  4 34  2
85 803  7.78 1.5550 3.1550 0.7724 6.620 0.350 0.5  1  5 34  2
85 803  9.58 1.2150 3.1550 0.7724 6.620 0.350 0.5  1  6 34  2
85 803 11.58 0.7900 3.1550 0.7724 6.620 0.350 0.5  1  7 34  2
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85 802 19.16 1.9650 3.2150 1.4960 6.620 0.350 0.5  1  3 35  2
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85 805 11.83 3.0150 3.0150 0.7360 6.620 1.000 0.5  1  1 43  2      -4
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85 806 13.25 1.0750 3.3700 2.3608 6.620 1.000 0.5  1  9 45  2
85 806 15.50 0.7900 3.3700 2.3608 6.620 1.000 0.5  1 10 45  2
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85 806 16.75 0.6800 3.3700 2.3608 6.620 1.000 0.5  1 11 45  2
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APPENDIX D

Measured Weather Data, File WTRMIC

84	723	11.0	628.0	5.132	29.84	32.80	28.98	25.04	.5433	.3373	.4993	.9994	MI
84	723	12.0	729.0	4.245	31.71	36.54	32.35	23.35	.5236	.2878	.4596	.9994	
84	723	13.0	812.0	5.096	33.02	37.80	34.29	24.35	.5108	.2615	.4229	.9994	
84	723	14.0	850.0	6.099	33.92	38.59	35.58	25.32	.4933	.2475	.3888	.9993	
84	723	15.0	848.0	6.639	34.86	41.07	38.43	26.03	.4704	.2347	.3690	.9993	
84	723	16.0	760.0	7.103	35.23	39.66	37.42	26.49	.4521	.2380	.3560	.9992	
84	723	17.0	633.0	7.103	35.16	38.25	36.41	26.59	.4427	.2413	.3430	.9992	
84	724	10.0	420.0	3.784	25.50	22.95	21.81	21.98	.6167	.4679	.8830	.9995	
84	724	11.0	561.0	3.706	25.55	30.49	24.98	22.27	.6191	.3414	.7884	.9994	
84	724	12.0	812.0	4.787	28.06	33.65	28.15	23.06	.5548	.2906	.6751	.9994	
84	724	13.0	872.0	4.787	28.92	36.03	32.27	23.90	.5044	.2639	.5509	.9994	
84	724	14.0	571.0	4.245	30.00	33.56	32.33	24.53	.4328	.2682	.4678	.9993	
84	724	15.0	287.0	3.475	27.54	28.59	27.96	24.33	.4935	.3171	.5556	.9993	
84	724	16.0	373.0	3.164	28.60	31.01	29.74	24.25	.4423	.2901	.5009	.9992	
84	724	17.0	487.0	3.164	29.84	31.83	30.77	24.36	.4251	.2803	.4810	.9992	
84	724	18.0	348.0	4.014	28.32	29.91	29.08	24.43	.4166	.2912	.4577	.9991	
84	724	19.0	313.0	4.092	29.30	27.92	27.96	24.17	.4171	.3213	.4890	.9989	
84	724	20.0	215.0	3.784	29.99	26.38	27.02	23.76	.4171	.3339	.4947	.9987	
84	724	21.0	38.0	2.085	25.29	22.19	21.49	23.22	.4937	.4464	.6577	.9986	
84	724	22.0	1.0	1.774	20.89	19.26	18.25	22.68	.6287	.5978	.7697	.9985	
84	724	23.0	0.0	2.855	18.98	18.38	17.16	22.12	.6829	.6276	.7861	.9985	
84	724	24.0	0.0	3.550	18.13	17.82	16.84	21.57	.6998	.6229	.7757	.9985	
84	725	1.0	0.0	2.702	16.85	16.39	15.59	21.08	.7702	.6604	.7923	.9984	
84	725	2.0	0.0	2.007	15.53	15.00	14.50	20.66	.8420	.7085	.8140	.9983	
84	725	3.0	0.0	1.156	13.62	12.84	14.24	20.25	.9470	.7919	.8730	.9982	
84	725	4.0	0.0	0.153	12.21	10.80	12.73	19.89	.9990	.8700	.8660	.9981	
84	725	5.0	0.0	0.000	11.76	11.01	12.41	19.55	1.000	.9140	.8700	.9980	
84	725	6.0	0.0	0.000	12.33	12.51	13.49	19.37	1.000	.9270	.8960	.9980	
84	725	7.0	7.0	0.000	12.42	12.19	13.31	19.17	1.000	.9230	.8970	.9979	
84	725	8.0	65.0	0.075	14.24	14.68	14.72	19.07	.9870	.8450	.8980	.9978	
84	725	9.0	311.0	0.848	21.92	22.99	18.55	19.35	.6902	.4888	.8240	.9979	
84	725	10.0	419.0	2.394	22.86	25.07	21.80	19.92	.6315	.3920	.6993	.9980	
84	725	11.0	594.0	2.702	24.20	29.09	25.42	20.70	.5865	.3187	.5735	.9979	
84	725	12.0	676.0	2.085	25.11	32.44	27.40	21.68	.5592	.2836	.5156	.9975	
84	725	13.0	890.0	2.624	26.72	37.77	33.32	22.95	.5096	.2453	.3857	.9967	
84	725	14.0	884.0	2.163	27.33	38.65	34.04	24.22	.4600	.2442	.3269	.9959	
84	814	13.0	625.0	0.309	33.57	30.00	26.07	25.91	.5290	.3932	.6891	.9986	
84	814	14.0	640.0	2.007	34.12	31.27	27.76	26.61	.3828	.3709	.6433	.9969	
84	814	15.0	893.0	4.014	32.35	35.05	30.55	26.54	.3941	.3198	.5433	.9993	
84	814	16.0	722.0	3.550	31.78	35.49	31.54	27.70	.3874	.3130	.5049	.9993	
84	814	17.0	597.0	3.859	32.01	34.68	31.33	28.35	.3852	.3176	.4861	.9992	
84	814	18.0	506.0	3.936	32.60	34.43	30.82	27.76	.3794	.3270	.4990	.9992	
84	814	19.0	265.0	2.730	33.04	31.98	29.36	26.22	.3750	.3506	.5663	.9992	
84	814	20.0	114.0	1.699	29.20	25.51	25.64	24.82	.4315	.5256	.6551	.9992	
84	814	21.0	14.0	1.156	23.46	21.21	23.02	23.20	.6482	.7463	.7179	.9991	
84	814	22.0	0.0	2.469	21.41	19.61	21.45	22.05	.7092	.7760	.7517	.9991	
84	814	23.0	0.0	2.007	19.57	18.44	20.44	21.13	.7990	.7842	.7655	.9991	
84	814	24.0	0.0	1.390	17.69	17.57	19.68	20.37	.8810	.8060	.7678	.9990	
84	815	1.0	0.0	0.075	15.80	16.12	19.07	19.65	.9430	.8320	.7663	.9990	
84	815	2.0	0.0	0.000	14.05	15.25	18.29	18.93	.9790	.8350	.7669	.9989	
84	815	3.0	0.0	0.770	12.82	14.87	17.51	18.31	.9950	.8840	.7737	.9988	
84	815	4.0	0.0	0.075	12.38	14.00	17.00	17.77	1.000	.9130	.7810	.9987	
84	815	5.0	0.0	0.309	12.51	14.43	16.85	17.58	1.000	.9290	.7826	.9986	
84	815	6.0	0.0	0.231	12.81	14.65	16.72	17.45	1.000	.9520	.7905	.9985	
84	815	7.0	2.0	0.384	13.55	15.22	16.80	17.50	1.000	.9630	.8217	.9985	
84	815	8.0	67.0	1.621	16.29	16.02	16.95	17.69	.9720	.9440	.8639	.9985	

84	815	9.0	203.0	2.316	24.57	18.95	18.22	18.57	.7871	.8030	.8506	.9985
84	815	10.0	374.0	2.933	29.11	24.64	20.41	19.93	.6032	.4090	.7787	.9985
84	815	11.0	540.0	4.479	28.65	29.36	23.95	21.75	.5884	.3263	.6678	.9984
84	815	12.0	681.0	4.554	29.64	33.54	27.83	23.77	.6080	.2702	.5623	.9981
84	815	13.0	807.0	5.249	31.30	36.40	30.74	25.79	.5798	.2399	.5029	.9971
84	815	14.0	757.0	5.560	31.94	37.31	31.68	27.14	.5567	.2330	.4728	.9944
84	815	15.0	823.0	5.482	33.18	39.80	33.53	28.96	.5289	.2176	.4447	.9910
84	815	16.0	732.0	5.560	33.21	39.40	33.86	30.04	.5108	.2259	.4202	.9894
84	815	17.0	675.0	5.096	33.25	38.94	34.15	30.68	.4938	.2301	.4119	.9886
84	815	18.0	477.0	5.249	32.51	35.44	32.19	29.57	.4936	.2515	.4315	.9879
84	815	19.0	293.0	4.865	31.31	31.73	29.56	27.75	.5064	.2856	.4858	.9874
84	815	20.0	109.0	3.936	28.58	26.81	26.29	25.97	.5529	.3741	.5595	.9873
84	815	21.0	11.0	3.089	24.68	22.82	23.95	24.36	.6501	.4911	.6321	.9875
84	815	22.0	0.0	1.621	22.43	20.24	22.70	23.25	.7459	.6070	.6907	.9878
84	815	23.0	0.0	1.156	21.57	19.82	22.12	22.68	.8110	.6374	.7261	.9880
84	815	24.0	0.0	0.461	20.35	19.58	21.68	22.27	.9010	.6634	.7418	.9883
84	816	1.0	0.0	0.309	19.96	19.29	21.42	21.96	.9140	.6776	.7462	.9884
84	816	2.0	0.0	0.617	19.67	18.62	20.90	21.56	.9060	.6757	.7466	.9886
84	816	3.0	0.0	0.695	19.22	17.75	20.37	21.12	.8990	.6765	.7490	.9887
84	816	4.0	0.0	0.000	17.22	16.49	19.67	20.45	.9580	.7072	.7505	.9888
84	816	5.0	0.0	0.000	16.39	16.16	19.19	19.98	.9750	.7259	.7453	.9889
84	816	6.0	0.0	0.000	16.07	16.18	18.91	19.66	.9870	.7263	.7420	.9891
84	816	7.0	2.0	1.004	16.75	15.92	18.60	19.53	.9720	.7502	.7649	.9892
84	816	8.0	53.0	0.770	18.64	17.61	18.98	19.66	.9540	.7140	.8167	.9894
84	816	9.0	178.0	0.770	25.90	23.25	20.80	20.61	.7876	.5363	.8306	.9894
84	816	10.0	348.0	2.546	28.74	29.10	23.53	21.96	.7081	.3762	.7501	.9892
84	816	11.0	540.0	2.780	28.79	33.35	26.70	23.64	.6693	.3102	.6278	.9884
84	816	12.0	692.0	3.475	29.13	36.56	30.17	25.67	.6554	.2704	.5373	.9856
84	816	13.0	798.0	2.316	30.43	40.31	33.05	27.44	.5910	.2385	.4855	.9775
84	816	14.0	857.0	3.241	31.41	41.98	34.32	28.96	.5240	.2279	.4538	.9730
84	816	15.0	853.0	3.936	31.56	41.30	34.74	30.57	.4722	.2404	.4318	.9723
84	816	16.0	849.0	4.631	31.71	40.62	35.16	32.18	.4204	.2529	.4098	.9716
84	821	11.0	496.0	5.710	27.31	25.09	20.64	27.85	.4935	.4046	.7327	.9997
84	821	12.0	718.0	5.404	25.86	28.48	22.53	22.01	.4952	.3500	.6740	.9996
84	821	13.0	817.0	4.940	27.40	32.46	25.53	24.00	.4552	.2979	.6013	.9994
84	821	14.0	856.0	5.404	29.15	34.73	29.65	26.52	.4077	.2868	.5087	.9992
84	821	15.0	835.0	6.099	29.70	34.91	37.04	28.21	.3844	.2795	.3915	.9992
84	821	16.0	761.0	6.099	30.40	34.57	35.17	28.78	.3669	.2755	.3464	.9991
84	821	17.0	635.0	6.330	30.80	33.57	31.37	28.25	.3480	.2768	.3758	.9991
84	821	18.0	465.0	6.564	31.33	31.49	28.50	26.56	.3336	.2989	.4329	.9988
84	821	19.0	253.0	5.404	29.88	27.96	25.59	25.22	.3566	.3511	.5300	.9985
84	821	20.0	65.0	3.784	25.65	23.52	22.72	24.08	.4716	.4851	.6637	.9984
84	821	21.0	8.0	1.234	21.77	19.67	20.53	23.06	.6623	.6805	.8130	.9982
84	821	22.0	0.0	0.617	19.58	17.47	19.24	22.24	.7800	.8220	.8640	.9982
84	821	23.0	0.0	0.695	19.44	17.74	19.12	21.76	.8080	.8400	.8730	.9981
84	821	24.0	0.0	1.699	19.87	18.56	19.24	21.45	.7950	.8130	.8790	.9981
84	822	1.0	0.0	2.855	20.01	18.73	19.08	21.22	.7960	.8040	.8730	.9980
84	822	2.0	0.0	1.004	18.95	17.79	18.83	20.90	.8580	.8620	.8880	.9979
84	822	3.0	0.0	1.079	19.04	18.15	19.00	20.75	.8730	.8560	.8770	.9979
84	822	4.0	0.0	2.624	19.30	18.53	18.99	20.63	.8660	.8480	.8770	.9978
84	822	5.0	0.0	3.164	19.58	18.88	19.05	20.51	.8610	.8350	.8710	.9977
84	822	6.0	0.0	3.319	19.85	18.97	19.05	20.43	.8570	.8340	.8650	.9977
84	822	7.0	0.0	3.397	19.88	19.10	19.09	20.35	.8620	.8360	.8640	.9976
84	822	8.0	7.0	3.089	20.22	19.68	19.43	20.36	.8640	.8290	.8650	.9975
84	822	9.0	16.0	3.550	20.50	20.09	19.67	20.41	.8630	.8200	.8570	.9974
84	822	10.0	57.0	2.702	21.44	21.46	20.51	20.62	.8510	.7688	.8380	.9974

84	822	11.0	215.0	2.780	23.20	24.63	22.58	21.17	.8430	.6621	.7805	.9973	
84	822	12.0	564.0	3.319	26.22	29.16	25.84	22.72	.7568	.4182	.6572	.9973	
84	822	13.0	814.0	3.550	28.51	32.96	30.25	25.92	.5604	.3035	.5020	.9966	
84	822	14.0	860.0	3.628	29.98	35.56	38.70	28.67	.4367	.2803	.3453	.9942	
84	822	15.0	807.0	3.859	31.00	36.57	43.75	30.36	.3544	.2716	.2777	.9915	
84	822	16.0	570.0	3.550	30.50	32.76	35.75	29.50	.3481	.2914	.3127	.9903	
84	830	11.0	287.0	5.461	25.57	22.44	22.89	22.56	.8287	.7482	.7637	.9995	
84	830	12.0	423.0	5.780	25.55	25.28	24.28	22.90	.7844	.6203	.6874	.9994	
84	830	13.0	599.0	6.099	25.53	28.45	25.55	23.24	.7401	.4309	.6832	.9993	
84	830	14.0	772.0	4.787	27.51	33.47	29.42	24.25	.6586	.3029	.5997	.9992	
84	830	15.0	753.0	4.940	28.63	34.17	30.86	25.12	.5449	.2538	.5039	.9992	
84	830	16.0	663.0	6.177	28.27	33.52	30.71	25.50	.4474	.2334	.4729	.9991	
84	830	17.0	566.0	5.869	28.89	31.99	30.16	25.56	.3466	.2199	.4308	.9991	
84	830	18.0	428.0	8.106	28.26	29.14	28.14	25.06	.2999	.2287	.4249	.9990	
84	830	19.0	253.0	7.025	26.88	25.04	24.61	23.85	.2771	.2575	.4401	.9988	
84	830	20.0	84.0	7.334	23.56	20.63	20.83	22.38	.3085	.3606	.4859	.9986	
84	830	21.0	2.0	5.560	19.74	17.10	17.84	21.02	.3130	.4079	.5675	.9985	
84	830	22.0	0.0	3.089	17.80	14.25	15.94	20.01	.3755	.5352	.6829	.9983	
84	830	23.0	0.0	0.000	13.71	9.44	13.29	19.01	.6605	.8010	.7821	.9982	
84	830	24.0	0.0	0.075	11.45	8.04	12.09	18.10	.8200	.8720	.8090	.9980	
84	831	1.0	0.0	0.075	9.70	7.17	10.85	17.37	.9300	.8800	.8150	.9978	
84	831	2.0	0.0	0.075	9.09	6.76	10.70	16.76	.9680	.8880	.8130	.9976	
84	831	3.0	0.0	0.153	8.60	6.51	10.44	16.27	.9870	.8970	.8170	.9974	
84	831	4.0	0.0	0.000	8.39	6.25	10.19	15.79	.9940	.9010	.8160	.9972	
84	831	5.0	0.0	0.075	8.58	6.17	10.00	15.39	.9950	.9020	.8160	.9971	
84	831	6.0	0.0	0.153	8.24	6.10	9.33	15.07	1.000	.9030	.8150	.9969	
84	831	7.0	0.0	0.075	8.21	5.72	9.40	14.73	1.000	.8160	.8160	.9967	
84	831	8.0	45.0	0.000	11.81	8.58	10.57	14.64	.9730	.8880	.8120	.9966	
84	831	9.0	205.0	0.770	20.71	16.68	14.12	15.30	.7647	.7244	.7925	.9966	
84	831	10.0	362.0	3.089	21.47	22.58	18.88	16.66	.7328	.4687	.7084	.9966	
84	831	11.0	519.0	4.401	21.84	26.08	22.97	18.26	.6797	.3474	.5701	.9965	
84	831	12.0	631.0	5.018	23.37	29.68	26.15	20.01	.5761	.2699	.4954	.9963	
84	831	13.0	663.0	5.869	24.34	30.85	28.22	21.61	.4664	.2351	.4267	.9956	
84	831	14.0	640.0	6.950	24.13	29.27	27.83	22.30	.4404	.2363	.4148	.9941	
84	831	15.0	773.0	8.184	24.88	31.76	30.34	23.71	.4084	.2024	.3639	.9926	
84	831	16.0	678.0	8.029	25.20	31.23	30.31	24.46	.3834	.1908	.3479	.9908	MI
85	730	14.0	913.0	2.980	29.00	33.01	26.18	26.01	.2800	.8830	.8830	.9900	CA
85	730	15.0	870.0	1.080	30.00	31.40	25.84	24.87	.2240	.8490	.8490	.9900	
85	730	16.0	776.0	0.000	30.75	29.79	26.89	25.45	.2030	.7410	.7410	.9900	
85	730	17.0	640.0	0.000	30.50	26.08	26.51	25.84	.2060	.7370	.7370	.9900	
85	730	18.0	465.0	2.320	29.00	21.90	23.82	25.20	.2460	.8690	.8690	.9900	
85	730	19.0	251.0	8.800	26.91	19.60	22.61	24.57	.4410	.8080	.8080	.9900	
85	730	20.0	57.0	6.330	22.00	17.30	19.60	23.71	.5270	.8620	.8620	.9900	
85	730	21.0	1.0	3.550	19.10	17.87	18.30	22.63	.6580	.9130	.9130	.9900	
85	730	22.0	0.0	4.320	17.66	18.43	17.24	21.57	.7050	.9380	.9380	.9900	
85	730	23.0	0.0	3.090	15.65	19.00	16.34	20.72	.8300	.9440	.9440	.9900	
85	730	24.0	0.0	2.160	14.02	19.57	16.05	20.03	.9210	.9480	.9480	.9900	
85	731	1.0	0.0	3.010	14.01	12.88	15.86	19.45	.9200	.9510	.9510	.9900	?
85	731	2.0	0.0	4.010	13.19	7.54	15.53	18.93	.9530	.9500	.9500	.9900	?
85	731	3.0	0.0	4.170	12.84	2.21	15.24	18.42	.9760	.9530	.9530	.9900	?
85	731	4.0	0.0	5.100	12.73	3.13	14.94	18.00	.9880	.9570	.9570	.9900	
85	731	5.0	0.0	3.400	12.33	8.47	15.04	17.68	.9990	.9650	.9650	.9900	
85	731	6.0	0.0	2.780	11.72	13.80	14.90	17.42	1.000	.9620	.9620	.9900	
85	731	7.0	36.0	1.850	11.98	19.14	14.81	17.19	.9990	.9610	.9610	.9900	
85	731	8.0	200.0	3.710	15.17	24.48	15.21	17.21	.9270	.9570	.9570	.9900	
85	731	9.0	391.0	4.480	18.34	29.81	16.57	17.49	.8110	.9390	.9390	.9900	

85	731	10.0	576.0	4.940	20.79	35.15	18.69	18.03	.6990	.9100	.9100	.9900	
85	731	11.0	736.0	3.630	23.75	38.37	20.50	18.63	.5960	.8620	.8620	.9900	
85	731	12.0	850.0	3.860	25.85	41.59	22.12	19.27	.5220	.8630	.8630	.9900	
85	731	13.0	909.0	3.710	27.72	40.75	23.73	20.02	.4770	.8400	.8400	.9900	
85	731	14.0	920.0	4.870	28.67	39.15	24.30	20.90	.4430	.8550	.8550	.9900	
85	731	15.0	876.0	5.100	29.68	35.74	24.87	20.79	.4130	.8340	.8340	.9900	
85	731	16.0	784.0	5.100	30.05	32.32	25.50	20.83	.3870	.7970	.7970	.9900	
85	731	17.0	637.0	5.480	29.89	28.72	24.89	21.35	.3760	.7590	.7590	.9900	
85	731	18.0	456.0	6.020	28.76	25.03	25.21	21.66	.4110	.6210	.6210	.9900	
85	731	19.0	212.0	3.160	26.57	20.95	24.59	23.28	.4270	.6120	.6120	.9900	
85	731	20.0	52.0	3.550	23.60	16.85	21.90	22.59	.5210	.6620	.6620	.9900	
85	731	21.0	1.0	5.640	20.67	12.74	19.11	22.28	.6130	.7050	.7050	.9900	
85	731	22.0	0.0	4.010	18.36	8.64	17.31	21.92	.6520	.7150	.7150	.9900	
85	731	23.0	0.0	3.010	16.73	4.54	15.90	21.55	.7330	.7670	.7670	.9900	
85	731	24.0	0.0	3.320	15.28	0.43	14.91	21.18	.7940	.7990	.7990	.9900	
85	801	1.0	0.0	3.940	14.41	4.81	14.10	20.83	.8410	.8290	.8290	.9900	?
85	801	2.0	0.0	1.930	13.60	0.51	13.69	20.50	.8870	.8520	.8520	.9900	?
85	801	3.0	0.0	1.700	12.74	3.79	13.39	20.17	.9300	.8770	.8770	.9900	
85	801	4.0	0.0	0.000	10.66	8.08	13.84	19.74	.9850	.9150	.9150	.9900	
85	801	5.0	0.0	0.230	11.23	12.38	13.09	19.26	.9930	.9080	.9080	.9900	
85	801	6.0	0.0	0.000	10.60	16.68	12.31	18.89	1.000	.9250	.9250	.9900	
85	801	7.0	36.0	0.000	10.19	20.98	11.85	18.58	1.000	.9530	.9530	.9900	
85	801	8.0	193.0	1.000	14.70	25.27	14.62	18.44	.9510	.9310	.9310	.9900	
85	801	9.0	388.0	1.700	18.34	29.57	17.70	18.92	.7750	.9260	.9260	.9900	
85	801	10.0	572.0	2.620	21.97	33.87	20.78	19.39	.6140	.9050	.9050	.9900	
85	801	11.0	724.0	2.860	24.49	36.34	23.77	20.14	.5500	.8750	.8750	.9900	
85	801	12.0	831.0	4.170	26.26	38.43	28.56	20.79	.5130	.7340	.7340	.9900	
85	801	13.0	892.0	4.940	27.97	38.75	31.85	21.30	.4680	.5930	.5930	.9900	
85	801	14.0	883.0	4.630	29.51	38.41	34.15	21.55	.4090	.5140	.5140	.9900	
85	801	15.0	859.0	4.630	30.52	36.93	32.45	21.64	.3610	.4650	.4650	.9900	
85	801	16.0	755.0	4.710	31.37	35.44	31.00	21.66	.3400	.4650	.4650	.9900	
85	801	17.0	614.0	4.550	31.50	31.38	29.43	21.64	.3150	.4890	.4890	.9900	
85	801	18.0	434.0	5.170	29.68	27.21	27.54	21.57	.3480	.5110	.5110	.9900	
85	801	19.0	238.0	4.550	27.55	24.94	26.75	21.51	.4080	.5260	.5260	.9900	
85	801	20.0	48.0	3.550	24.56	22.66	24.11	21.47	.5220	.6080	.6080	.9900	
85	801	21.0	0.0	1.620	21.13	20.39	20.69	21.40	.6640	.6910	.6910	.9900	
85	801	22.0	0.0	0.080	18.68	18.11	18.94	21.27	.7950	.7680	.7680	.9900	
85	801	23.0	0.0	0.460	17.92	15.84	18.04	21.05	.8400	.8120	.8120	.9900	
85	801	24.0	0.0	0.700	16.93	13.56	17.00	20.84	.8390	.8240	.8240	.9900	
85	802	1.0	0.0	0.230	15.71	2.22	15.76	20.64	.8670	.8310	.8310	.9900	
85	802	2.0	0.0	0.150	15.62	5.82	15.45	20.39	.8580	.8390	.8390	.9900	
85	802	3.0	0.0	0.000	14.11	9.43	14.60	20.15	.9190	.8450	.8450	.9900	
85	802	4.0	0.0	0.000	13.52	13.03	14.32	19.87	.9610	.8570	.8570	.9900	
85	802	5.0	0.0	0.080	12.82	16.64	15.18	19.62	.9750	.8950	.8950	.9900	
85	802	6.0	0.0	0.000	13.09	20.24	15.01	19.30	.9780	.8980	.8980	.9900	
85	802	7.0	35.0	0.310	12.71	23.85	15.58	19.06	.9830	.9130	.9130	.9900	
85	802	8.0	195.0	1.390	16.26	27.45	16.28	18.99	.9200	.9130	.9130	.9900	
85	802	9.0	386.0	2.390	20.50	31.05	18.90	19.30	.7840	.9000	.9000	.9900	
85	802	10.0	570.0	5.400	24.37	34.66	22.52	19.84	.6240	.8160	.8160	.9900	
85	802	11.0	724.0	6.640	27.16	37.93	28.07	20.44	.5420	.6530	.6530	.9900	
85	802	12.0	749.0	5.020	29.48	39.58	33.31	22.78	.4710	.5300	.5300	.9900	
85	802	13.0	847.0	5.710	31.78	40.35	29.61	24.44	.3780	.6190	.6190	.9900	
85	802	14.0	917.0	6.020	32.82	40.25	29.95	23.61	.3630	.6160	.6160	.9900	
85	802	15.0	870.0	4.940	33.76	40.15	29.36	24.37	.3470	.6610	.6610	.9900	
85	802	16.0	770.0	4.250	34.17	39.87	29.61	24.95	.3270	.6460	.6460	.9900	
85	802	17.0	628.0	3.630	34.05	39.42	29.01	25.30	.3160	.6440	.6440	.9900	

85	802	18.0	446.0	2.780	33.53	36.17	28.38	25.43	.3210	.6600	.6600	.9900
85	802	19.0	248.0	1.230	31.69	32.39	27.08	25.42	.3720	.7060	.7060	.9900
85	802	20.0	63.0	0.000	27.25	29.12	23.91	25.21	.4660	.7600	.7600	.9900
85	802	21.0	0.0	0.000	19.49	28.38	19.94	24.64	.7660	.8620	.8620	.9900
85	802	22.0	0.0	0.000	16.66	27.64	18.07	23.88	.9080	.8940	.8940	.9900
85	802	23.0	0.0	0.000	15.74	26.90	16.60	23.19	.9250	.9060	.9060	.9900
85	802	24.0	0.0	0.000	14.97	26.15	16.25	22.64	.9510	.9240	.9240	.9900
85	803	1.0	0.0	0.000	14.81	2.34	16.00	22.14	.9690	.9280	.9280	.9900
85	803	2.0	0.0	0.000	13.83	5.19	16.05	21.76	.9850	.9270	.9270	.9900
85	803	3.0	0.0	0.000	13.17	8.05	15.25	21.32	.9910	.9260	.9260	.9900
85	803	4.0	0.0	0.000	13.27	10.91	15.37	20.94	.9920	.9330	.9330	.9900
85	803	5.0	0.0	0.000	12.32	13.76	14.49	20.62	.9870	.9270	.9270	.9900
85	803	6.0	0.0	0.000	11.46	16.62	14.00	20.23	1.000	.9250	.9250	.9900
85	803	7.0	32.0	0.000	13.22	19.48	13.62	19.90	.9740	.9410	.9410	.9900
85	803	8.0	188.0	0.000	20.82	22.34	16.96	19.98	.7130	.9610	.9610	.9900
85	803	9.0	379.0	0.000	26.38	25.19	22.15	20.58	.4750	.9060	.9060	.9900
85	803	10.0	564.0	0.620	32.02	29.40	29.21	21.72	.3860	.7840	.7840	.9900
85	803	11.0	722.0	2.090	34.02	35.48	32.58	23.48	.3620	.6820	.6820	.9900
85	803	12.0	840.0	0.620	36.25	39.93	34.97	25.30	.3000	.6130	.6130	.9900
85	803	13.0	908.0	1.540	36.83	42.16	36.01	27.00	.2480	.5690	.5690	.9900
85	803	14.0	918.0	2.160	37.15	43.30	37.17	28.31	.2410	.4810	.4810	.9900
85	803	15.0	874.0	1.850	37.96	42.95	37.31	29.26	.2380	.4330	.4330	.9900
85	803	16.0	771.0	0.000	38.50	42.24	37.00	29.73	.2460	.4470	.4470	.9900
85	803	17.0	621.0	0.000	37.94	41.01	35.93	29.57	.2700	.4510	.4510	.9900
85	803	18.0	437.0	0.000	37.37	38.33	33.82	29.10	.3000	.4840	.4840	.9900
85	803	19.0	239.0	2.550	33.97	33.65	32.08	28.60	.3650	.4900	.4900	.9900
85	803	20.0	55.0	3.780	29.05	28.96	27.93	28.02	.3800	.4670	.4670	.9900
85	803	21.0	0.0	6.180	24.82	24.27	24.36	27.29	.4460	.4930	.4930	.9900
85	803	22.0	0.0	5.330	23.18	19.59	22.69	26.56	.5200	.5340	.5340	.9900
85	803	23.0	0.0	3.780	22.06	14.90	21.70	25.93	.5550	.5560	.5560	.9900
85	803	24.0	0.0	1.620	20.68	10.22	20.34	25.38	.6320	.6170	.6170	.9900
85	804	1.0	0.0	0.000	17.55	7.81	18.49	24.79	.8540	.7200	.7200	.9900
85	804	2.0	0.0	0.000	16.69	10.06	17.56	24.13	.8690	.7790	.7790	.9900
85	804	3.0	0.0	0.000	15.39	12.31	16.60	23.58	.9160	.8010	.8010	.9900
85	804	4.0	0.0	0.310	15.46	14.56	16.10	23.08	.9080	.8250	.8250	.9900
85	804	5.0	0.0	0.000	14.85	16.81	15.88	22.75	.9090	.8380	.8380	.9900
85	804	6.0	0.0	0.000	13.70	19.06	15.52	22.27	.9380	.8360	.8360	.9900
85	804	7.0	29.0	0.000	16.59	21.31	14.60	21.81	.8310	.8480	.8480	.9900
85	804	8.0	190.0	0.150	24.35	23.56	18.38	21.81	.5630	.8510	.8510	.9900
85	804	9.0	384.0	1.080	29.43	25.81	25.72	22.20	.3880	.6260	.6260	.9900
85	804	10.0	568.0	0.850	34.51	30.49	31.81	22.97	.3060	.5320	.5320	.9900
85	804	11.0	724.0	1.310	35.31	36.36	36.57	24.39	.3140	.4570	.4570	.9900
85	804	12.0	840.0	0.700	36.09	39.99	40.11	26.06	.2970	.3680	.3680	.9900
85	804	13.0	904.0	1.770	36.76	42.52	40.69	27.68	.2910	.3500	.3500	.9900
85	804	14.0	916.0	1.310	38.06	43.13	41.91	29.05	.2900	.3350	.3350	.9900
85	804	15.0	873.0	1.310	39.15	42.81	41.64	30.07	.2530	.2970	.2970	.9900
85	804	16.0	777.0	0.000	38.82	40.06	39.79	30.23	.1260	.1370	.1370	.9900
85	804	17.0	632.0	5.020	37.94	37.46	39.09	30.01	.1210	.1250	.1250	.9900
85	804	18.0	446.0	8.030	36.18	37.50	37.07	29.62	.1700	.1760	.1760	.9900
85	804	19.0	241.0	6.180	33.66	37.54	33.85	29.15	.2480	.2670	.2670	.9900
85	804	20.0	62.0	6.490	29.10	37.58	28.69	28.64	.3490	.3660	.3660	.9900
85	804	21.0	0.0	6.260	25.31	37.63	24.81	28.05	.4430	.4450	.4450	.9900
85	804	22.0	0.0	5.790	23.48	37.67	22.93	27.36	.4720	.4760	.4760	.9900
85	804	23.0	0.0	3.780	21.61	37.71	21.02	26.70	.5060	.5100	.5100	.9900
85	804	24.0	0.0	3.710	20.99	37.75	20.20	26.06	.5090	.5220	.5220	.9900
85	805	1.0	0.0	1.470	18.94	18.61	18.73	25.51	.5550	.5480	.5480	.9900

85	805	2.0	0.0	2.160	18.88	20.52	18.07	24.95	.5690	.5750	.5750	.9900
85	805	3.0	0.0	2.320	18.18	22.42	17.91	24.47	.6090	.5920	.5920	.9900
85	805	4.0	0.0	0.230	15.32	24.33	15.88	24.01	.7640	.6700	.6700	.9900
85	805	5.0	0.0	0.000	13.03	26.24	14.97	23.49	.9320	.7210	.7210	.9900
85	805	6.0	0.0	0.000	11.49	28.15	14.58	22.86	.9730	.7430	.7430	.9900
85	805	7.0	29.0	0.000	14.03	30.05	14.34	22.34	.8940	.7840	.7840	.9900
85	805	8.0	192.0	0.000	23.72	31.96	18.90	22.23	.5760	.8070	.8070	.9900
85	805	9.0	374.0	0.000	24.16	33.87	27.37	24.11	.5730	.4780	.4780	.9900
85	805	10.0	554.0	0.000	28.40	35.78	32.21	24.65	.4440	.3410	.3410	.9900
85	805	11.0	725.0	0.000	31.42	37.68	31.60	26.06	.3510	.4030	.4030	.9900
85	805	12.0	845.0	0.000	34.07	39.59	31.31	26.89	.2980	.8220	.8220	.9900
85	805	13.0	913.0	0.000	36.13	41.50	34.39	29.89	.2580	.8210	.8210	.9900
85	805	14.0	922.0	0.000	39.53	39.53	36.76	34.94	.2060	.7280	.7280	.9900
85	805	15.0	871.0	0.000	40.00	37.56	39.50	36.27	.1940	.6790	.6790	.9900
85	805	16.0	760.0	0.000	38.13	34.31	40.00	36.46	.2200	.6680	.6680	.9900
85	805	17.0	614.0	0.000	36.35	30.81	34.69	36.24	.2250	.6640	.6640	.9900
85	805	18.0	437.0	0.000	36.05	26.56	33.17	35.30	.2080	.6650	.6650	.9900
85	805	19.0	237.0	0.700	33.95	22.04	29.01	33.22	.2150	.6890	.6890	.9900
85	805	20.0	59.0	1.770	28.59	20.66	23.96	30.57	.2970	.7530	.7530	.9900
85	805	21.0	0.0	3.480	21.34	20.83	18.46	28.26	.6180	.9460	.9460	.9900
85	805	22.0	0.0	3.860	19.96	21.00	16.45	26.61	.6450	.9600	.9600	.9900
85	805	23.0	0.0	2.780	18.85	21.17	15.73	25.47	.6720	.9690	.9690	.9900
85	805	24.0	0.0	0.000	16.89	21.34	14.29	24.50	.7580	.9810	.9810	.9900
85	806	1.0	0.0	0.000	14.61	13.89	12.17	23.59	.9360	.9740	.9740	.9900
85	806	2.0	0.0	0.000	14.26	14.91	10.61	22.80	.9370	.9800	.9800	.9900
85	806	3.0	0.0	0.000	12.93	15.94	11.95	22.20	.9620	.9810	.9810	.9900
85	806	4.0	0.0	0.150	13.35	16.96	11.54	21.74	.9540	.9740	.9740	.9900
85	806	5.0	0.0	0.000	11.30	17.99	9.68	21.18	.9900	.9640	.9640	.9900
85	806	6.0	0.0	0.310	11.80	19.01	10.08	20.65	.9890	.9810	.9810	.9900
85	806	7.0	20.0	1.160	12.61	20.04	11.09	20.41	.9530	.9880	.9880	.9900
85	806	8.0	184.0	2.620	15.61	21.06	13.54	20.48	.8940	.9730	.9730	.9900
85	806	9.0	399.0	3.480	20.56	22.09	23.17	21.39	.7370	.8460	.8460	.9900
85	806	10.0	582.0	2.930	24.56	24.49	32.50	23.21	.6060	.7090	.7090	.9900
85	806	11.0	709.0	2.010	28.51	28.26	40.66	26.63	.4730	.5730	.5730	.9900
85	806	12.0	848.0	0.000	31.37	32.36	47.39	30.73	.4010	.4450	.4450	.9900
85	806	13.0	913.0	0.000	34.55	36.79	50.31	34.62	.3430	.3450	.3450	.9900
85	806	14.0	920.0	0.000	36.72	39.93	51.53	37.61	.2580	.2790	.2790	.9900
85	806	15.0	865.0	0.000	38.48	42.64	50.56	38.50	.2350	.2940	.2940	.9900
85	806	16.0	765.0	0.000	38.32	42.92	45.77	38.22	.2090	.4240	.4240	.9900
85	806	17.0	614.0	0.000	37.65	40.66	40.75	37.89	.2200	.4280	.4280	.9900

APPENDIX E

Local Weather Data, File WTRDAY

```
84 722 22.0 0.6 78.0 0.62  7.0 0.00
84 723  1.0 0.9 77.0 0.60  8.0 0.00
84 723  4.0 1.0 74.0 0.69  8.0 0.00
84 723  7.0 0.5 74.0 0.76 10.0 0.00
84 723 10.0 0.2 84.0 0.55 16.0 0.00
84 723 13.0 0.1 90.0 0.50 18.0 0.00
84 723 16.0 0.7 92.0 0.47 18.0 0.00
84 723 19.0 1.0 84.0 0.57 12.0 0.00
84 723 22.0 1.0 74.0 0.90  4.0 0.03
84 724  1.0 1.0 72.0 0.97  6.0 0.00
84 724  4.0 1.0 69.0 0.90  5.0 0.00
84 724  7.0 0.7 68.0 0.87  3.0 0.00
84 724 10.0 0.9 75.0 0.60  5.0 0.00
84 724 13.0 1.0 80.0 0.45  9.0 0.00
84 724 16.0 0.5 81.0 0.42  8.0 0.00
84 724 19.0 0.3 78.0 0.49  7.0 0.00
84 724 22.0 0.1 67.0 0.63  7.0 0.00
84 725  1.0 0.0 61.0 0.75  5.0 0.00
84 725  4.0 0.7 56.0 0.87  0.0 0.00
84 725  7.0 0.8 59.0 0.90  0.0 0.00
84 725 10.0 0.6 72.0 0.57  4.0 0.00
84 725 13.0 0.3 77.0 0.45  6.0 0.00
84 725 16.0 0.2 80.0 0.35  4.0 0.00
84 725 19.0 0.1 78.0 0.44  8.0 0.00
84 725 22.0 0.0 62.0 0.78  0.0 0.00
84 726  1.0 0.1 60.0 0.85  1.0 0.00
84 813 22.0 0.0 64.0 0.84  0.0 0.00
84 814  1.0 0.0 61.0 0.93  0.0 0.00
84 814  4.0 0.0 57.0 0.97  0.0 0.00
84 814  7.0 0.0 60.0 0.97  0.0 0.00
84 814 10.0 0.0 76.0 0.67  4.0 0.00
84 814 13.0 0.3 82.0 0.47  3.0 0.00
84 814 16.0 0.4 85.0 0.43  8.0 0.00
84 814 19.0 0.7 78.0 0.56  5.0 0.00
84 814 22.0 0.2 65.0 0.84  6.0 0.00
84 815  1.0 0.0 62.0 0.87  3.0 0.00
84 815  4.0 0.0 59.0 0.93  4.0 0.00
84 815  7.0 0.4 63.0 0.87  5.0 0.00
84 815 10.0 0.0 79.0 0.62 10.0 0.00
84 815 13.0 0.4 84.0 0.57 10.0 0.00
84 815 16.0 0.4 86.0 0.51 10.0 0.00
84 815 19.0 0.6 79.0 0.60  6.0 0.00
84 815 22.0 0.6 72.0 0.73  0.0 0.00
84 816  1.0 0.8 72.0 0.71  6.0 0.00
84 816  4.0 0.0 66.0 0.84  3.0 0.00
84 816  7.0 0.0 66.0 0.90  0.0 0.00
84 816 10.0 0.0 78.0 0.64  5.0 0.00
84 816 13.0 0.0 86.0 0.43  5.0 0.00
84 816 16.0 0.3 86.0 0.43  7.0 0.00
84 816 19.0 0.6 80.0 0.63  4.0 0.00
84 816 22.0 0.0 69.0 0.87  0.0 0.00
84 817  1.0 0.1 66.0 0.90  5.0 0.00
84 820 22.0 0.3 63.0 0.68  6.0 0.00
84 821  1.0 0.0 61.0 0.81  7.0 0.00
84 821  4.0 0.2 57.0 0.84  6.0 0.00
84 821  7.0 0.1 59.0 0.75  8.0 0.00
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Lansing Airport data
data are at 3-hour interval


```
84 821 10.0 0.0 73.0 0.50  9.0 0.00
84 821 13.0 0.1 81.0 0.41 10.0 0.00
84 821 16.0 0.5 84.0 0.37 13.0 0.00
84 821 19.0 0.8 78.0 0.49  9.0 0.00
84 821 22.0 1.0 69.0 0.71  8.0 0.00
84 822  1.0 1.0 71.0 0.68  7.0 0.00
84 822  4.0 1.0 70.0 0.76  7.0 0.00
84 822  7.0 1.0 69.0 0.81  4.0 0.00
84 822 10.0 1.0 73.0 0.82  9.0 0.00
84 822 13.0 0.2 81.0 0.49 14.0 0.00
84 822 16.0 0.4 84.0 0.38 10.0 0.00
84 822 19.0 0.2 76.0 0.60 14.0 0.00
84 822 22.0 0.7 68.0 0.78  8.0 0.00
84 823  1.0 0.3 60.0 0.90  5.0 0.00
84 829 22.0 1.0 81.0 0.72  8.0 0.00
84 830  1.0 1.0 81.0 0.74  6.0 0.00
84 830  4.0 1.0 76.0 0.85 15.0 0.11
84 830  7.0 1.0 66.0 0.97 11.0 0.08
84 830 10.0 0.9 72.0 0.87 13.0 0.00
84 830 13.0 0.3 78.0 0.62  9.0 0.00
84 830 16.0 0.2 80.0 0.37 10.0 0.00
84 830 19.0 0.0 71.0 0.34 10.0 0.00
84 830 22.0 0.0 57.0 0.62  4.0 0.00
84 831  1.0 0.0 51.0 0.83  5.0 0.00
84 831  4.0 0.0 51.0 0.90  4.0 0.00
84 831  7.0 0.0 51.0 0.90  3.0 0.00
84 831 10.0 0.4 68.0 0.71  9.0 0.00
84 831 13.0 0.5 74.0 0.46 14.0 0.00
84 831 16.0 0.8 76.0 0.39 13.0 0.00
84 831 19.0 1.0 68.0 0.53  5.0 0.00
84 831 22.0 1.0 64.0 0.61  5.0 0.00
84 901  1.0 1.0 61.0 0.72  5.0 0.00
85 729 22.0 0.0  0.0 0.00  0.0 0.00
85 730  1.0 0.0  0.0 0.00  0.0 0.00
85 730  4.0 0.0  0.0 0.00  0.0 0.00
85 730  7.0 0.0  0.0 0.00  0.0 0.00
85 730 10.0 0.0  0.0 0.00  0.0 0.00
85 730 13.0 0.0  0.0 0.00  0.0 0.00
85 730 16.0 0.0  0.0 0.00  0.0 0.00
85 730 19.0 0.0  0.0 0.00  0.0 0.00
85 730 22.0 0.0  0.0 0.00  0.0 0.00
85 731  1.0 0.0  0.0 0.00  0.0 0.00
85 731  4.0 0.0  0.0 0.00  0.0 0.00
85 731  7.0 0.0  0.0 0.00  0.0 0.00
85 731 10.0 0.0  0.0 0.00  0.0 0.00
85 731 13.0 0.0  0.0 0.00  0.0 0.00
85 731 16.0 0.0  0.0 0.00  0.0 0.00
85 731 19.0 0.0  0.0 0.00  0.0 0.00
85 731 22.0 0.0  0.0 0.00  0.0 0.00
85 801  1.0 0.0  0.0 0.00  0.0 0.00
85 801  4.0 0.0  0.0 0.00  0.0 0.00
85 801  7.0 0.0  0.0 0.00  0.0 0.00
85 801 10.0 0.0  0.0 0.00  0.0 0.00
85 801 13.0 0.0  0.0 0.00  0.0 0.00
85 801 16.0 0.0  0.0 0.00  0.0 0.00
85 801 19.0 0.0  0.0 0.00  0.0 0.00
```

Assumed for Fresno, CA

85	801	22.0	0.0	0.0	0.00	0.0	0.00
85	802	1.0	0.0	0.0	0.00	0.0	0.00
85	802	4.0	0.0	0.0	0.00	0.0	0.00
85	802	7.0	0.0	0.0	0.00	0.0	0.00
85	802	10.0	0.0	0.0	0.00	0.0	0.00
85	802	13.0	0.0	0.0	0.00	0.0	0.00
85	802	16.0	0.0	0.0	0.00	0.0	0.00
85	802	19.0	0.0	0.0	0.00	0.0	0.00
85	802	22.0	0.0	0.0	0.00	0.0	0.00
85	803	1.0	0.0	0.0	0.00	0.0	0.00
85	803	4.0	0.0	0.0	0.00	0.0	0.00
85	803	7.0	0.0	0.0	0.00	0.0	0.00
85	803	10.0	0.0	0.0	0.00	0.0	0.00
85	803	13.0	0.0	0.0	0.00	0.0	0.00
85	803	16.0	0.0	0.0	0.00	0.0	0.00
85	803	19.0	0.0	0.0	0.00	0.0	0.00
85	803	22.0	0.0	0.0	0.00	0.0	0.00
85	804	1.0	0.0	0.0	0.00	0.0	0.00
85	804	4.0	0.0	0.0	0.00	0.0	0.00
85	804	7.0	0.0	0.0	0.00	0.0	0.00
85	804	10.0	0.0	0.0	0.00	0.0	0.00
85	804	13.0	0.0	0.0	0.00	0.0	0.00
85	804	16.0	0.0	0.0	0.00	0.0	0.00
85	804	19.0	0.0	0.0	0.00	0.0	0.00
85	804	22.0	0.0	0.0	0.00	0.0	0.00
85	805	1.0	0.0	0.0	0.00	0.0	0.00
85	805	4.0	0.0	0.0	0.00	0.0	0.00
85	805	7.0	0.0	0.0	0.00	0.0	0.00
85	805	10.0	0.0	0.0	0.00	0.0	0.00
85	805	13.0	0.0	0.0	0.00	0.0	0.00
85	805	16.0	0.0	0.0	0.00	0.0	0.00
85	805	19.0	0.0	0.0	0.00	0.0	0.00
85	805	22.0	0.0	0.0	0.00	0.0	0.00
85	806	1.0	0.0	0.0	0.00	0.0	0.00
85	806	4.0	0.0	0.0	0.00	0.0	0.00
85	806	7.0	0.0	0.0	0.00	0.0	0.00
85	806	10.0	0.0	0.0	0.00	0.0	0.00
85	806	13.0	0.0	0.0	0.00	0.0	0.00
85	806	16.0	0.0	0.0	0.00	0.0	0.00
85	806	19.0	0.0	0.0	0.00	0.0	0.00
85	806	22.0	0.0	0.0	0.00	0.0	0.00
85	807	1.0	0.0	0.0	0.00	0.0	0.00

APPENDIX F

FORTRAN Code of SEARCH

```
C-----------------------------------------------------------------------
      PROGRAM SEARCH
C-----------------------------------------------------------------------
        INCLUDE 'comsch.f'
C-------INPUT
        CALL READIN
C-------SEARCH PROCEDURE
        CALL COMPLE
C
      END
C-----------------------------------------------------------------------
      SUBROUTINE READIN
C-----------------------------------------------------------------------
        INCLUDE 'comsch.f'
C        LOGICAL FLAG
        CHARACTER DFL*40,OUT*7,OFL*7,A*1,LOCA(2)*22
        DATA LOCA /'EAST LANSING, MICHIGAN','FRESNO, CALIFORNIA    '/
C        DATA OFL /'sout    '/
        DATA OUT /'tout    '/, A/' '/
C
C --- NDP ARITHMETIC EXCEPTION SUBROUTINES FOR 8087/80287
C         CALL INVALOP(FLAG)
C         CALL OVEFL(FLAG)
C         CALL UNDFL(FLAG)
C         CALL DVCHK(FLAG)

        PA=7
        WD=8
        WM=9
        DR=10
        OU=11
C        OF=12
        LK=0
        OPEN(DR,FILE='drycase',STATUS='OLD')
        OPEN(WD,FILE='wtrday',STATUS='OLD')
        OPEN(WM,FILE='wtrmic',STATUS='OLD')
        WRITE(*,*) 'ENTER THE NAME OF THE PARAMETER FILE: '
        READ(*,'(A40)') DFL
        OPEN(PA,FILE=DFL,STATUS='OLD')
        DO 999 J=PA,DR
          REWIND J
999     CONTINUE
        WRITE(*,*)'ENTER SET RANGE TO BEGIN & END (1, 48): '
        READ(*,*) ISB,ISE
        NT=0

C --- START INPUT
        READ(PA,*) ISW,FM0,RSVI(1),RSVI(2),VI(1,5),ZCDE,YLD0
        READ(PA,*) DTP,DTS,RHOI,SIGMA2,ALPH,BTA,GAMMA,PHI,DELTA
        READ(PA,*) (O(J,1),J=1,6)
        READ(PA,*) NP,MODL,MAX,IOPT,IPRT,KM,KL,KMAX
        READ(PA,*) (B(J),J=1,6)
        READ(PA,*) (JFIX(J),J=1,6)
        DO 6 J=1,6
          READ(PA,*)
C          READ(PA,*) (PS(J,K),K=1,J)
```



```
6       CONTINUE
        READ(PA,*) (BL(J),J=1,KM)
        READ(PA,*) (BH(J),J=1,KM)
        CLOSE(PA)
        I=0
C-------REPEAT
10        I=I+1
C---------REPEAT
17          READ(DR,*,END=11)IY(I),MD(I),T(I),Y(I),(VI(I,J),J=1,5),
     +                       IM(I),ID(I),IS(I),LC(I)
            IF(IS(I).LT.ISB) GOTO 17
C---------UNTIL(IS(I).GE.ISB)
          IF(IS(I).LE.ISE) THEN
            SIG2(I)=SIGMA2
            SIG(I)=SQRT(SIG2(I))
            VI(I,3)=AMIN1(VI(I,3),YLD0)
            VI(I,6)=AMIN1(FM0,VI(I,1))
            VI(I,7)=RSVI(LC(I))
            VI(I,8)=ZCDE
            GOTO 10
          ENDIF
C-------UNTIL(IS(J).GT.ISE.OR.EOF(DR))
11      CLOSE(DR)
        NC=I-1
        NP1=NP+1
        KL=MAX0(NP1,MIN0(KL,K-2))
        KL1=KL-1
        ISB=MIN0(48,MAX0(1,IABS(ISB)))
        ISE=MIN0(48,MAX0(1,ISB,IABS(ISE)))
        IF(ISB.LT.ISE) A='c'
        IF(ISB.LT.10) THEN
C          WRITE(OFL(5:6),'(I1,A1)') ISB,A
          WRITE(OUT(5:6),'(I1,A1)') ISB,A
        ELSE
C          WRITE(OFL(5:7),'(I2,A1)') ISB,A
          WRITE(OUT(5:7),'(I2,A1)') ISB,A
        ENDIF
C        OPEN(OF,FILE=OFL,STATUS='UNKNOWN')
        OPEN(OU,FILE=OUT,STATUS='UNKNOWN')
        WRITE(*,*) 'THE OUTPUT FILE NAME IS ',OUT
        IF(IOPT.NE.0) THEN
          DO 123 L=1,KL
            READ(OU,*) (BSV(L,J),J=1,NP),(STAT(L,J),J=1,8)
123       CONTINUE
          READ(OU,*) L1
          DO 125 I=1,NC
            READ(OU,*,END=126) IYD,TI,(V(L1,I,J),J=1,6)
125       CONTINUE
        ELSE
          L1=1
          DO 124 J=1,NP
            BSV(1,J)=B(J)
124       CONTINUE
        ENDIF
126     NFIX=0
        DO 37 J=1,NP
```

```
          IF(IOPT.NE.0) B(J)=BSV(L1,J)
          JFIX(J)=MAX0(0,MIN0(1,JFIX(J)))
          NFIX=NFIX+JFIX(J)
37      CONTINUE
        IF(NP.LT.4) THEN
          B(4)=B(1)
          B(5)=B(2)
        ENDIF
        NNP=MAX0(1,NC-NP+NFIX)
        NPP=NP-NFIX
        IF(NP.GT.3) THEN
          NP2=NP+2
          KM=NP2
          BL(KM)=BL(7)
          BH(KM)=BH(7)
          BL(NP1)=BL(6)
          BH(NP1)=BH(6)
        ELSE
          KM=NP1
          BL(KM)=BL(6)
          BH(KM)=BH(6)
        ENDIF
        DO 5 J=1,KM
          CB(J)=0.5*(BH(J)+BL(J))
5       CONTINUE
C-------OUTPUT INPUT DATA AND PARAMETERS
        WRITE(*,'(A10,I5,A30)') 'CASE:',IS(1),LOCA(LC(1))
        WRITE(*,68)'MCI',Y(1),'MC0',VI(1,1),'DENS',VI(1,2),'LAI/YLD',
     +       VI(1,3),'BLM',VI(1,4),'CME',VI(1,5),'RSOIL',VI(1,7),
     +       'ZC/DENS',ZCDE
        WRITE(*,66)'ISW',ISW,'FMC',FM0,'DTF',DTF,'DTS',DTS
        WRITE(*,67)'SIG2',SIGMA2,'RHO',RHOI,('O',J,O(J,1),J=1,NP)
        WRITE(*,'(/1X,''NC'',5X,''NP'',3X,''NFIX'',5X,''NT'',2X,
     +       ''ITMAX'',2X,''MODEL'',3X,''IOPT'',3X,''IPRT'',
     +       5X,''KL'',5X,''KM'',2X,''KTMAX'')')
        WRITE(*,'(I3,10I7)')NC,NP,NFIX,NT,MAX,MODL,IOPT,IPRT,KL,KM,KMAX
        WRITE(*,'(/1X,6(A,F8.5,2X))')'ALPHA',ALPH,'BETA',BTA,'GAMMA',
     +                               GAMMA,'PHI',PHI,'DELTA',DELTA
        WRITE(*,'(/6(6X,A,I1,A,5X))') ('B(',J,')',J=1,6)
        WRITE(*,'(6(1X,E13.6,1X))') (B(J),J=1,6)
        WRITE(*,'(6(4X,A,I1,A,4X))') ('JFIX(',J,')',J=1,6)
        WRITE(*,'(6(I9,6X))') (JFIX(J),J=1,6)
        WRITE(*,'(/10(4X,A,I1,A,4X))') ('BL(',J,')',J=1,KM)
        WRITE(*,'(10(E13.6))') (BL(J),J=1,KM)
        WRITE(*,'(/10(4X,A,I1,A,4X))') ('BH(',J,')',J=1,KM)
        WRITE(*,'(10(E13.6))') (BH(J),J=1,KM)
C        WRITE(OF,'(A10,I5,A30)') 'CASE:',IS(1),LOCA(LC(1))
C        WRITE(OF,68)'MCI',Y(1),'MC0',VI(1,1),'DENS',VI(1,2),'LAI/YLD',
C     +       VI(1,3),'BLM',VI(1,4),'CME',VI(1,5),'RSOIL',VI(1,7),
C     +       'ZC/DENS',ZCDE
C        WRITE(OF,68) 'MCI',Y(1),'MC0',MOC(1),'DENS',DNE(1),'LAI/YLD',
C     +              YL(1),'BLM',BLM(1),'CME',CEM(1),'RSOIL',RSVI(LC(1))
C        WRITE(OF,66)'ISW',ISW,'FMC',FM0,'DTF',DTF,'DTS',DTS
C        WRITE(OF,67)'SIG2',SIGMA2,'RHO',RHOI,('D',J,D(J,1),J=1,NP)
C        WRITE(OF,'(/1X,''NC'',5X,''NP'',3X,''NFIX'',5X,''NT'',2X,
C     +       ''ITMAX'',2X,''MODEL'',3X,''IOPT'',3X,''IPRT'',
```



```
C     +       5X,''KL'',5X,''KM'',2X,''KTMAX'')')
C        WRITE(OF,'(I3,10I7)')NC,NP,NFIX,NT,MAX,MODL,IOPT,IPRT,KL,KM,KMAX
C        WRITE(OF,'(/1X,6(A,F8.5,2X))')'ALPHA',ALPH,'BETA',BTA,'GAMMA',
C     +                               GAMMA,'PHI',PHI,'DELTA',DELTA
C        WRITE(OF,'(/6(6X,A,I1,A,5X))') ('B(',J,')',J=1,6)
C        WRITE(OF,'(6(1X,E13.6,1X))') (B(J),J=1,6)
C        WRITE(OF,'(6(4X,A,I1,A,4X))') ('JFIX(',J,')',J=1,6)
C        WRITE(OF,'(6(I9,6X))') (JFIX(J),J=1,6)
C        WRITE(OF,'(/10(4X,A,I1,A,4X))') ('BL(',J,')',J=1,KM)
C        WRITE(OF,'(10(E13.6))') (BL(J),J=1,KM)
C        WRITE(OF,'(/10(4X,A,I1,A,4X))') ('BH(',J,')',J=1,KM)
C        WRITE(OF,'(10(E13.6))') (BH(J),J=1,KM)
         CALL FLUSH(6)
66       FORMAT(1X,A,I4,3X,A,F6.2,2(3X,A,F6.0),1X,A,F5.2,2(3X,A,F6.0),
     +        3X,A,E12.5,3X,A,F7.3)
67       FORMAT(1X,A,F8.4,2X,A,F6.3,8(2X,A1,I1,F7.4))
68       FORMAT(1X,3(A,F7.4,2X),3(A,F6.3,2X),A,F6.0,2X,A,F7.4)
C
         RETURN
        END
C-------------------------------------------------------------------------
        SUBROUTINE COMPLE
C-------------------------------------------------------------------------
        INCLUDE 'comsch.f'
        DATA ESP /1.0E-30/

        WRITE(FT1,'(A1,I1,A)') '(',NP,'F10.6,8F10.5)      '
        S4=1.0E30
        L4=0
        L2=1
        L0=KL+1
        S(L0)=1.0E30
        IF(KM.GT.NP) THEN
          KODE=NP1
        ELSE
          KODE=0
        ENDIF
        CALL DAYTM
        WRITE(*,15) 'INITIAL COMPLEX:',CLOCK
C        WRITE(OF,15) 'INITIAL COMPLEX:',CLOCK
15      FORMAT(/1X,A,T55,A)
C        WRITE(OF,'(/A3,6(6X,A,I1,A,5X))') 'L',('B(',J,')',J=1,NP)
        WRITE(*,'(A3,6(6X,A,I1,A,5X))') 'L',('B(',J,')',J=1,NP)
        IF(IOPT.EQ.0) THEN
C-------SET INITIAL COMPLEX POINTS
          DO 65 L=2,KL
            DO 50 J=1,NP
              IF(JFIX(J).EQ.1) BSV(L,J)=BSV(1,J)
50          CONTINUE
            CALL POINT(L)
65        CONTINUE
          S2=1.0E30
          REWIND OU
        ENDIF
C-------CHECK CONSTRAINTS AND CALCULATE OBJECTIVE FUNCTIONS
        DO 66 L=1,KL
```

```
          IF(IOPT.EQ.0) THEN
            S(L)=1.0E30
            CALL EVALU(L)
            WRITE(OU,'(13F10.6)') (BSV(L,J),J=1,NP),(STAT(L,J),J=1,8)
            WRITE(*,'(I3,6(1X,E13.6,1X))') L,(B(J),J=1,NP)
C            WRITE(OF,'(I3,6(1X,E13.6,1X))') L,(B(J),J=1,NP)
          ELSE
            S(L)=STAT(L,6)
            WRITE(*,'(I3,6(E14.6,1X))') L,(BSV(L,J),J=1,NP)
C            WRITE(OF,'(I3,6(E14.6,1X))') L,(BSV(L,J),J=1,NP)
          ENDIF
66      CONTINUE
        WRITE(*,'(10(A7,I2,A1,3X))') ('S(',L,')',L=1,KL)
        WRITE(*,'(10E13.5)') (S(L),L=1,KL)
C       WRITE(OF,'(10(A7,I2,A1,3X))') ('S(',L,')',L=1,KL)
C       WRITE(OF,'(10E13.5)') (S(L),L=1,KL)
        IT=0
        I2=0
        KT=0
C-------SEARCH LOOP
80        IT=IT+1
          I1=0
          I3=0
          IF(KODE.GT.0) KODE=NP1
          CALL DAYTM
          WRITE(*,16) 'ITERATION:',IT,CLOCK
C          WRITE(OF,16) 'ITERATION:',IT,CLOCK
16        FORMAT(/1X,A,I5,T55,A)
          CALL FLUSH(6)
C
C---------FIND THE BEST, WORST AND 2ND WORST POINTS
          L5=L2
          S5=S2
          CALL SORT
          IF(IOPT.EQ.0.AND.IT.EQ.1) THEN
            WRITE(OU,*) L1
            DO 67 I=1,NC
              WRITE(OU,777) IY(I),MD(I),T(I),(V(L1,I,J),J=1,6)
67          CONTINUE
          ENDIF
          CALL FLUSH(OU)
          REWIND OU
C---------CHECK CONVERGENCE CRITERION (PHI=1.0001 TO 1.01)
          IF(S2.LE.PHI*S1) THEN
            KT=KT+1
          ELSE
            KT=0
          ENDIF
          IF(KT.LT.KMAX) THEN
            IF(IT.GT.1.AND.L2.EQ.L5.AND.S2.GE.S5-ESP) THEN
C-----------REPEATED OLD WORST POINT, TRY DIFFERENT COMPLEX
              DO 90 L=1,KL
                IF(L.EQ.L2.OR.L.EQ.L3) THEN
                  CALL POINT(L)
                  S(L)=1.0E30
                  CALL EVALU(L)
```



```
                ENDIF
90            CONTINUE
              CALL SORT
              KP=KP+1
            ELSE
              KP=0
            ENDIF
          ENDIF
          IF(KT.LT.KMAX.AND.KF.LE.KL) THEN
C-----------BROAD SEARCH
            CALL BROAD
            CALL DAYTM
            WRITE(*,17) 'COMPLEX SEARCH',I3,CLOCK
C            WRITE(OF,17) 'COMPLEX SEARCH',I3,CLOCK
            CALL FLUSH(6)
            L6=0
            I3=0
            IF(S(L2).GE.S3) THEN
C-------------SHRINK OR REFLECT THE COMPLEX
              CALL SHRINK
              CALL DAYTM
              WRITE(*,17) 'SHRINK SEARCH',I3,CLOCK
C              WRITE(OF,17) 'SHRINK SEARCH',I3,CLOCK
              CALL FLUSH(6)
              I3=0
            ENDIF
            IF(L6.EQ.KL1) THEN
C-------------TURN TO INDIVIDUAL PARAMETER SEARCH
              L=L0+1
              S(L)=1.0E30
              J=0
C-------------WHILE(JC.LE.NP)
170             IF(J.EQ.NP) GOTO 171
                J=J+1
                IF(KODE.GT.0) KODE=J
                IF(JFIX(J).EQ.0) CALL LINMIN(J)
                GOTO 170
171             CONTINUE
C-------------END WHILE
              CALL DAYTM
              WRITE(*,17) 'INDIVIDUAL SEARCH',I3,CLOCK
C              WRITE(OF,17) 'INDIVIDUAL SEARCH',I3,CLOCK
              CALL FLUSH(6)
            ENDIF
            IF(S(L2).GE.S3) THEN
              IF(S0.LT.S1) THEN
                S(L2)=S0
                DO 176 J=1,NP
                  BSV(L2,J)=BC(J)
176             CONTINUE
                DO 172 J=1,8
                  STAT(L2,J)=STAT(L0,J)
172             CONTINUE
                DO 174 I=1,NC
                  DO 175 J=1,6
                    V(L2,I,J)=V(L0,I,J)
```

```
      CALL EVALU(L2)
C-----EVALUATE THE REFLECTED POINT
      IF(S(L2).LT.S1) THEN
C-------GET A NEW BEST POINT, EXPAND
        CALL EXPAND(L2,L1)
      ELSE IF(S(L2).GE.S3) THEN
C-------FIND THE OBJECTIVE FUNCTION AT THE CENTROID
        DO 159 J=1,NP
          BSV(L0,J)=BC(J)
159     CONTINUE
        CALL EVALU(L0)
        S0=S(L0)
        IF(S0.GE.S3) THEN
C---------TRY A POINT OUTWARD THE CENTROID (GAMMA=1.1 TO 2.0)
          FA=GAMMA
        ELSE
C---------TRY A POINT TOWARD THE CENTROID (BTA=0.25 TO 0.75)
          FA=BTA
        ENDIF
        DO 163 J=1,NP
          IF(S(L2).LT.S2) BS(J)=BSV(L2,J)
          IF(JFIX(J).EQ.0) BSV(L2,J)=BC(J)+FA*(BS(J)-BC(J))
163     CONTINUE
C-------EVALUATE THE CONTRACTED POINT
        S2=AMIN1(S2,S(L2))
        CALL EVALU(L2)
        IF(S(L2).LT.S1) THEN
          IF(FA.GT.1.0) CALL EXPAND(L2,L1)
        ELSE IF(S(L2).GT.S3) THEN
C---------CHANGE THE SEARCH DIRECTION
          DO 165 J=1,NP
            IF(S(L2).LT.S2) BS(J)=BSV(L2,J)
            IF(JFIX(J).EQ.0) THEN
C-------------A MIDDLE POINT BETWEEN THE WORST AND BEST POINTS
              BSS(J)=BTA*(BS(J)+BSV(L1,J))
C-------------ITS REFLECTED POINT WITH RESPECT TO THE CENTROID
              BSV(L2,J)=BC(J)+ALPH*(BC(J)-BSS(J))
            ELSE
              BSS(J)=BS(J)
            ENDIF
165       CONTINUE
          S2=AMIN1(S2,S(L2))
          CALL EVALU(L2)
          IF(S(L2).LT.S1) THEN
            CALL EXPAND(L2,L1)
          ELSE IF(S(L2).GT.S2) THEN
C-----------TRY THE MIDDLE POINT
            DO 166 J=1,NP
              IF(JFIX(J).EQ.0) BSV(L2,J)=BSS(J)
166         CONTINUE
            CALL EVALU(L2)
            IF(S(L2).LT.S1) CALL EXPAND(L2,L1)
          ENDIF
          IF(S(L2).GT.S3) THEN
C-----------MOVE THE POINT TOWARD THE CENTROID
            DO 167 J=1,NP
```



```
              IF(JFIX(J).EQ.0) THEN
                IF(S(L2).LT.S2) BS(J)=BSV(L2,J)
                BSV(L2,J)=BC(J)+BTA*(BC(J)+BSV(L2,J))
              ENDIF
167         CONTINUE
            S2=AMIN1(S2,S(L2))
            CALL EVALU(L2)
          ENDIF
        ENDIF
        IF(S(L2).LT.S2) THEN
          S2=S(L2)
          DO 169 J=1,NP
            IF(JFIX(J).EQ.0) BS(J)=BSV(L2,J)
169       CONTINUE
        ELSE IF(S(L2).GT.S2) THEN
          S(L2)=S2
          DO 168 J=1,NP
            BSV(L2,J)=BS(J)
168       CONTINUE
        ENDIF
      ENDIF
C
      RETURN
      END
C-----------------------------------------------------------------------
      SUBROUTINE EXPAND(LL,LJ)
C-----------------------------------------------------------------------
      INCLUDE 'comsch.f'
C
      LJ=LL
C-----REPEAT (GAMMA=1.1 TO 2.0)
111     S1=S(LL)
        DO 161   J=1,NP
          BSS(J)=BSV(LL,J)
          IF(JFIX(J).EQ.0) BSV(LL,J)=BC(J)+GAMMA*(BSV(LL,J)-BC(J))
          IF(LL.EQ.L2) BS(J)=BSS(J)
161     CONTINUE
        CALL EVALU(LL)
        IF(S(LL).LT.S1) GOTO 111
C-----UNTIL(S(LL).GE.S1)
      DO 162 J=1,NP
        BSV(LL,J)=BSS(J)
162   CONTINUE
      S(LL)=S1
C
      RETURN
      END
C-----------------------------------------------------------------------
      SUBROUTINE LINMIN(J)
C-----------------------------------------------------------------------
      INCLUDE 'comsch.f'
      LOGICAL REPEAT
C      DATA EPS /0.001/
C
C-----BASE POINT AND STEP SIZE
      BSV(L2,J)=BS(J)
```

```
        DEB=AMIN1(0.1,0.1*BS(J))
        II=0
        11=0
C-------REPEAT
1         BSS(2)=BSV(L2,J)
          BSV(L2,J)=BSV(L2,J)+DEB
          CALL EVALU(L2)
          IF(S(L2).LT.S2) THEN
            IF(II.EQ.0) THEN
              S5=S2
              BSS(1)=BS(J)
            ELSE
              S6=S2
              BSS(3)=BS(J)
            ENDIF
            S2=S(L2)
            BS(J)=BSV(L2,J)
C-----------EXPAND
            DEB=GAMMA*DEB
          ELSE IF(S(L2).GT.S2) THEN
            II=II+1
            IF(II.EQ.1) THEN
C-------------CHANGE DIRECTION AND REDUCE STEP SIZE
              DEB=-0.5*BTA*DEB
              S6=S(L2)
              BSS(3)=BSV(L2,J)
              BSV(L2,J)=BSS(2)
            ELSE
              S5=S(L2)
              BSS(1)=BSV(L2,J)
            ENDIF
          ELSE
C-----------S(L2)=S2
            DEB=BTA*DEB
          ENDIF
          IF(II.LT.2) GOTO 1
C-------UNTIL(II.EQ.2)
        BSS(2)=BS(J)
C-------REPEAT FORMING A QUADRATIC CONCAVE CURVE
2         REPEAT=.FALSE.
          BSV(L2,J)=0.5*(S2*(BSS(3)**2-BSS(1)**2)+S5*(BSS(2)**2-
     +              BSS(3)**2)+S6*(BSS(1)**2-BSS(2)**2))/
     +              (S2*(BSS(3)-BSS(1))+S5*(BSS(2)-BSS(3))+
     +              S6*(BSS(1)-BSS(2)))
          IF(BSS(1).LT.BSV(L2,J).AND.BSV(L2,J).LT.BSS(3)) THEN
            IF(ABS(BSV(L2,J)-BSS(2)).GE.EPS*BSS(2)) THEN
              CALL EVALU(L2)
              IF(S(L2).GT.S2) THEN
                REPEAT=.TRUE.
                IF(BSV(L2,J).LT.BSS(2)) THEN
                  S5=S(L2)
                  BSS(1)=BSV(L2,J)
                ELSE
                  S6=S(L2)
                  BSS(3)=BSV(L2,J)
                ENDIF
```



```
              ELSE IF(S(L2).LT.S2) THEN
                REPEAT=.TRUE.
                IF(BSV(L2,J).LT.BSS(2)) THEN
                  S6=S2
                  BSS(3)=BSS(2)
                ELSE
                  S5=S2
                  BSS(1)=BSS(2)
                ENDIF
              ENDIF
            ENDIF
          ELSE IF(BSV(L2,J).LT.BSS(1).OR.BSS(3).LT.BSV(L2,J)) THEN
            CALL EVALU(L2)
          ENDIF
          IF(S(L2).LT.S2) THEN
            S2=S(L2)
            BSS(2)=BSV(L2,J)
          ENDIF
          IF(REPEAT) GOTO 2
C-------UNTIL(.NOT. REPEAT)
        S2=AMIN1(S2,S(L2))
        S(L2)=S2
        BS(J)=BSS(2)
        BSV(L2,J)=BS(J)
C
        RETURN
      END
C-----------------------------------------------------------------------
      SUBROUTINE SHRINK
C-----------------------------------------------------------------------
        INCLUDE 'comsch.f'
C
C-------CHECK THE OBJECTIVE FUNCTION AT THE CENTROID
        IF(S0.LT.S3) THEN
C---------SHRINK THE COMPLEX WITH RESPECT TO THE BEST POINT
          FA=BTA
        ELSE
C---------REFLECT THE COMPLEX WITH RESPECT TO THE BEST POINT
          FA=-BTA
        ENDIF
C-------PROCESS
        L5=L1
        11=0
        DO 69 L=1,KL
          IF(L.NE.L1) THEN
            S5=AMIN1(S(L),S2)
            DO 70 J=1,NP
              BSS(J)=BSV(L,J)
              IF(JFIX(J).EQ.0)
     +          BSV(L,J)=BSV(L1,J)+FA*(BSV(L,J)-BSV(L1,J))
70          CONTINUE
            CALL EVALU(L)
            IF(S(L).LT.S1) THEN
C-------------GET A NEW BEST POINT
              CALL EXPAND(L,L5)
            ELSE IF(S(L).GT.S5) THEN
```

```
C-------------RETAIN OLD POINT
              L6=L6+1
              DO 172 J=1,NP
                BSV(L,J)=BSS(J)
172           CONTINUE
              S(L)=S5
            ENDIF
          ENDIF
69      CONTINUE
        IF(L5.NE.L1) L1=L5
C
        RETURN
      END
C-----------------------------------------------------------------------
      SUBROUTINE SORT
C-----------------------------------------------------------------------
        INCLUDE 'comsch.f'

C-------FIND THE BEST AND WORST POINTS
        L1=1
        L2=1
        DO 193   L=2,KL
          IF(S(L1).GT.S(L)) L1=L
          IF(S(L2).LT.S(L)) L2=L
193     CONTINUE
C-------FIND THE 2ND WORST POINT
        S3=0.0
        DO 194   L=1,KL
          IF(L.NE.L2.AND.S(L).GT.S3) THEN
            S3=S(L)
            L3=L
          ENDIF
194     CONTINUE
        S1=S(L1)
        S2=S(L2)

        RETURN
      END
C-----------------------------------------------------------------------
      SUBROUTINE EVALU(LL)
C-----------------------------------------------------------------------
        INCLUDE 'comsch.f'

C-------COUNT THE NUMBER OF CALLING THIS SUBROUTINE
        I1=I1+1
        I2=I2+1
        I3=I3+1
C
        CALL CHECK(LL)
        DO 1 J=1,NP
          B(J)=BSV(LL,J)
1       CONTINUE
        IF(NP.LT.4) THEN
          B(4)=B(1)
          B(5)=B(2)
        ENDIF
```



```
        CALL FUNC(LL)
C
        RETURN
      END
C-----------------------------------------------------------------------
      SUBROUTINE CHECK(LL)
C-----------------------------------------------------------------------
        INCLUDE 'comsch.f'
C
C-------REPEAT
10        KT=0
C---------CHECK EXPLICIT CONSTRAINTS
          IF(KODE.EQ.NP1.OR.KODE.EQ.0) THEN
            DO 50 J=1,NP
              IF(JFIX(J).EQ.0)
     +        BSV(LL,J)=AMAX1(BL(J)+DELTA,AMIN1(BSV(LL,J),BH(J)-DELTA))
50          CONTINUE
          ELSE
            IF(JFIX(KODE).EQ.0) BSV(LL,KODE)=AMAX1(BL(KODE)+DELTA,
     +        AMIN1(BSV(LL,KODE),BH(KODE)-DELTA))
          ENDIF
          IF(KODE.GT.0.AND.KODE.NE.3) THEN
C-----------CHECK IMPLICIT CONSTRAINTS
            DO 100 J=NP1,KM
              K1=1+3*(J-NP1)
              K2=K1+1
              BB=BSV(LL,K1)-BSV(LL,K2)
              IF(BB.LT.BL(J).OR.BB.GT.BH(J)) THEN
                KT=1
                IF(KODE.EQ.NP1) THEN
                  DO 90 KK=K1,K2
                    BSV(LL,KK)=0.5*(BSV(LL,KK)+CB(KK))
90                CONTINUE
                ELSE
                  IF(KODE.EQ.K1) THEN
                    BSV(LL,K1)=0.5*(BSV(LL,K1)+BSV(LL,K2)+CB(J))
                  ELSE
                    BSV(LL,K2)=0.5*(BSV(LL,K2)+BSV(LL,K1)-CB(J))
                  ENDIF
                ENDIF
              ENDIF
100         CONTINUE
          ENDIF
          IF(KT.GT.0) GOTO 10
C-------UNTIL(KT.EQ.0)

        RETURN
      END
C-----------------------------------------------------------------------
      SUBROUTINE CENTR(LL)
C-----------------------------------------------------------------------
        INCLUDE 'comsch.f'

        DO 20 J=1,NP
          BC(J)=0.0
          DO 10 KK=1,KL
```

```
            BC(J)=BC(J)+BSV(KK,J)
10          CONTINUE
            BC(J)=(BC(J)-BSV(LL,J))/KL1
20        CONTINUE

          RETURN
        END
C-------------------------------------------------------------------------
        SUBROUTINE FUNC(LL)
C-------------------------------------------------------------------------
          INCLUDE 'comsch.f'
C
          SY=0.0
          SY2=0.0
          SA=0.0
          SB=0.0
          SSE=0.0
          SS=0.0
          DO 301 I=1,NC
            IF(ID(I).EQ.1) THEN
              DO 303 J=1,N
                W(J)=VI(I,J)
303           CONTINUE
            ENDIF
            CALL MODEL
            E(I)=Y(I)-ETA(I)
            SY=SY+Y(I)/SIG(I)
            SY2=SY2+Y(I)**2/SIG2(I)
            SSE=SSE+E(I)**2/SIG2(I)
            IF(ID(I).EQ.1) THEN
              F(I)=E(I)
              G(I)=Y(I)
              H(I)=ETA(I)
            ELSE
              F(I)=E(I)-RHO*E(I-1)
              G(I)=Y(I)-RHO*Y(I-1)
              H(I)=ETA(I)-RHO*ETA(I-1)
            ENDIF
            SA=SA+G(I)/SIG(I)
            SB=SB+G(I)**2/SIG2(I)
            SS=SS+F(I)**2/SIG2(I)
301       CONTINUE
          SST=SY2-SY**2/NC
          R2A=1-SSE/SST
          R2B=1-(NC-1)*SSE/(NNP*SST)
          ST=SB-SA**2/NC
          SE=SS
          R1A=1-SS/ST
          R1B=1-(NC-1)*SS/(NNP*ST)
          IF(LL.EQ.L0.OR.SS.LT.AMIN1(S(LL),S2)) THEN
            DO 302 I=1,NC
              V(LL,I,1)=Y(I)
              V(LL,I,2)=ETA(I)
              V(LL,I,3)=E(I)
              V(LL,I,4)=G(I)
              V(LL,I,5)=H(I)
```



```
              V(LL,I,6)=F(I)
302         CONTINUE
            STAT(LL,1)=SST
            STAT(LL,2)=SSE
            STAT(LL,3)=R2A
            STAT(LL,4)=R2B
            STAT(LL,5)=ST
            STAT(LL,6)=SS
            STAT(LL,7)=R1A
            STAT(LL,8)=R1B
          ENDIF
          S(LL)=SS

          RETURN
        END
C-------------------------------------------------------------------------
        SUBROUTINE DAYTM
C-------------------------------------------------------------------------
          INCLUDE 'comsch.f'
C          CHARACTER*8 TIME,DATE
C          CHARACTER*8 CT,DAY
C          CHARACTER CT*8,DAY*9

C--------TMDAY(CLOCK) IS IN  LANGUAGE FOR HP9000/300
C          CALL TMDAY(CLOCK)
C--------FOR VAX/UNIX AND SUN'S
          CALL FDATE(CLOCK)
C--------FOR OTHER SYSTEMS-----------------------------
C          WRITE(CLOCK,'(25A)') ' '
C--------FOR PRIME750/550
C          CT=TIME()
C          DAY=DATE()
C--------FOR VAX/VMS AND IBM/PC COMPATIBLE
C          CALL TIME(CT)
C          CALL DATE(DAY)
C--------
C          WRITE(CLOCK(1:19),'(A,2X,A)') CT,DAY

          RETURN
        END
C-------------------------------------------------------------------------
        SUBROUTINE MODEL
C-------------------------------------------------------------------------
          INCLUDE 'comsch.f'
C
          LL=ISW*10+LK
          KK=ID(I)
          ETA(I)=AMC(B,W,IY(I),MD(I),T(I),Y(I),IM(I),DTF,DTS,LC(I),KK,LL)

          RETURN
        END
```

```
C-----------------------------------------------------------------------
C     COMMON BLOCK FILE COMSCH.F
C-----------------------------------------------------------------------
      PARAMETER (M=505,N=8,K=10)
      CHARACTER CLOCK*25,FT1*26,FT2*30,FT3*32,FT4*18,FT5*27
      DOUBLE PRECISION P,PS,R
      INTEGER WD,WM,PA,OU,OF,DR
      COMMON /IOFL/WD,WM,PA,OU,OF,DR
      COMMON /NLIN/ETA(M),Y(M+1),SIG2(M),B(6),Z(M,6),BS(6),X(M,N),
     +             V(K,M,6),I,MODL,NP,IPRT,JFIX(6),IOPT,MAX
      COMMON /PPP/P(6,6),PS(6,6),R(6,6),BX(M,N),BZ(M,6)
      COMMON /ABC/T(M+1),RSVI(2),DTF,DTS,FM0,O(N,3),VI(M,N),W(N),
     +            IM(M),ID(M),IS(M),LC(M),IY(M),MD(M+1),LK,ISW,IJ
      COMMON /DEF/DB(6),BSS(6),SEP,HH,ALFA,GG,RHO,L,NPP,IT,NC,NT,IND,
     +            SE,G(M),H(M),F(M),E(M),SIG(M)
      COMMON /BCD/BSV(K,K),BC(6),BL(K),BH(K),S(K),CB(K),ALPH,GAMMA,
     +            DELTA,BTA,PHI,KL,KM,KMAX,KODE,NP1,NP2,I1,I2,I3,KL1
      COMMON /CDE/SST,SSE,ST,R2A,R2B,R1A,R1B,STAT(K,8),NNP
      COMMON /EFG/S0,S1,S2,S3,S4,S5,S6,L0,L1,L2,L3,L4,L5,L6
      COMMON /FGH/CLOCK
      COMMON /FMT/FT1,FT2,FT3,FT4,FT5
```

APPENDIX G

FORTRAN Code of ARNLIN

```
C-----------------------------------------------------------------------
      PROGRAM ARNLIN
C-------------------------WRITTEN BY JAMES V. BECK  NOVEMBER 1985
C-------------------------------MODIFIED BY YI CHEN, MARCH 1987
        CALL READIN
        CALL ARMAP

      END
C-----------------------------------------------------------------------
      SUBROUTINE READIN
C-----------------------------------------------------------------------
        INCLUDE 'comsch.f'
        CHARACTER DFL*40,OUT*7,OFL*7,A*1,LOCA(2)*22
C        LOGICAL FLAG
        DATA LOCA /'EAST LANSING, MICHIGAN','FRESNO, CALIFORNIA    '/

        OUT='tout   '
        OFL='aout   '
        A=' '

C --- NDP ARITHMETIC EXCEPTION SUBROUTINES FOR 8087/80287
C         CALL INVALOP(FLAG)
C         CALL OVEFL(FLAG)
C         CALL UNDFL(FLAG)
C         CALL DVCHK(FLAG)

        PA=7
        WD=8
        WM=9
        DR=10
        OU=11
C        OP=12
        LK=0
        OPEN(DR,FILE='drycase',STATUS='OLD')
        OPEN(WD,FILE='wtrday',STATUS='OLD')
        OPEN(WM,FILE='wtrmic',STATUS='OLD')
        WRITE(*,*) ' ENTER THE NAME OF THE PARAMETER FILE: '
        READ(*,'(A40)') DFL
        OPEN(PA,FILE=DFL,STATUS='OLD')
        DO 999 J=PA,DR
          REWIND J
999     CONTINUE
        WRITE(*,*)' ENTER SET RANGE TO BEGIN & END (1, 48): '
        READ(*,*) ISB,ISE
        NT=0

        READ(PA,*) ISW,FMO,RSVI(1),RSVI(2),VI(1,5),ZCDE,YLDO
        READ(PA,*) DTF,DTS,RHOI,SIGMA2,ALPH,BTA,GAMMA,PHI,DELTA
        READ(PA,*) (O(J,1),J=1,6)
        READ(PA,*) NP,MODL,MAX,IOPT,IPRT,KM,KL,KMAX
        READ(PA,*) (B(J),J=1,6)
        READ(PA,*) (JFIX(J),J=1,6)
        DO 2 J=1,NP
          DO 2 KK=1,NP
            PS(KK,J)=0
            P(KK,J)=0
```



```
2       CONTINUE
        DO 6 J=1,6
          READ(PA,*) (PS(J,KK),KK=1,J)
6       CONTINUE
        READ(PA,*) (BL(J),J=1,KM)
        READ(PA,*) (BH(J),J=1,KM)
        CLOSE(PA)
        WRITE(FT1,900) '(2A6,2(2A6,A7,',NP,'(A7,I1,A)))'
        WRITE(FT2,900) '(2I3,F6.2,2(2F6.3,F7.3,',NP,'F9.3))'
        WRITE(FT3,900) '(1X,2F6.3,2(2F10.5,2F7.3),',NP,'F9.6)'
        WRITE(FT4,900) '(I3,',NP,'F6.3,',NP*2,'F10.3)'
        WRITE(FT5,900) '(A3,',NP,'(A4,I1,A),',NP*2,'(A8,I1,A))'
900     FORMAT(A,I1,A,I2,A)
        NP1=NP+1
        IF(NP.GT.3) THEN
          NP2=NP+2
          KM=NP2
          BL(KM)=BL(7)
          BH(KM)=BH(7)
          BL(NP1)=BL(6)
          BH(NP1)=BH(6)
        ELSE
          KM=NP1
          BL(KM)=BL(6)
          BH(KM)=BH(6)
        ENDIF
        KODE=1
        NFIX=0
        DO 37 J=1,KM
          CB(J)=0.5*(BL(J)+BH(J))
          IF(J.LE.NP) THEN
            JFIX(J)=MAX0(0,MIN0(1,JFIX(J)))
            NFIX=NFIX+JFIX(J)
          ENDIF
37      CONTINUE
        KL=MAX0(NP1,MIN0(KL,K-1))
        KL1=KL-1
        ISB=MIN0(48,MAX0(1,IABS(ISB)))
        ISE=MIN0(48,MAX0(1,ISB,IABS(ISE)))
        IF(ISB.LT.ISE) A='c'
        IF(ISB.LT.10) THEN
          WRITE(OFL(5:6),'(I1,A1)') ISB,A
          WRITE(OUT(5:6),'(I1,A1)') ISB,A
        ELSE
          WRITE(OFL(5:7),'(I2,A1)') ISB,A
          WRITE(OUT(5:7),'(I2,A1)') ISB,A
        ENDIF
C        WRITE(*,*) ' THE OUTPUT FILE NAME IS ',OFL
        OPEN(OP,FILE=OFL,STATUS='UNKNOWN')
        I=0
C-------REPEAT
10        I=I+1
C---------REPEAT
17          READ(DR,*,END=11)IY(I),MD(I),T(I),Y(I),(VI(I,J),J=1,5),
     +                       IM(I),ID(I),IS(I),LC(I)
            IF(IS(I).LT.ISB) GOTO 17
```

```
C---------UNTIL(IS(I).GE.ISB)
          IF(IS(I).LE.ISE) THEN
            SIG2(I)=SIGMA2
            SIG(I)=SQRT(SIG2(I))
            VI(I,3)=AMIN1(VI(I,3),YLD0)
            VI(I,6)=AMIN1(FM0,VI(I,1))
            VI(I,7)=RSVI(LC(I))
            VI(I,8)=ZCDE
            GOTO 10
          ENDIF
C---------UNTIL(IS(J).GT.ISE.OR.EOF(DR))
11        CLOSE(DR)
          NC=I-1
          NNP=MAX0(1,NC-NP+NFIX)
          NPP=NP-NFIX
          IF(IOPT.EQ.0) THEN
C---------USING RESULTS FROM 'SEARCH'
            OPEN(OU,FILE=OUT,STATUS='OLD')
            DO 123 L=1,KL
              READ(OU,*) (BSV(L,J),J=1,NP)
123         CONTINUE
            READ(OU,*) L1
            CLOSE(OU)
            DO 124 J=1,NP
              B(J)=BSV(L1,J)
124         CONTINUE
            RHO=RHOI
          ELSE
C---------USING RESULTS FROM PREVIOUS RUN OF THIS ESTIMATION
            READ(OF,'(////////////////////)')

            DO 447 J=1,NP
              IF(ABS(B(J)).GT.1.0E-9) THEN
                O(J,2)=O(J,1)*B(J)
              ELSE
                O(J,2)=O(J,1)
              ENDIF
447         CONTINUE
            ISKIP=2*NP+6
            DO 446 I=1,ISKIP
              READ(OF,*)
446         CONTINUE
            DO 448 I=1,NC
              READ(OF,FT2,END=449)IY(I),MD(I),T(I),(V(1,I,J),J=1,3),
     +           (BX(I,J),J=1,NP),(V(1,I,J),J=4,6),(BZ(I,J),J=1,NP)
              F(I)=V(1,I,6)
              DO 443 J=1,NP
                X(I,J)=V(1,I,2)*BX(I,J)/O(J,2)
                Z(I,J)=V(1,I,5)*BZ(I,J)/O(J,2)
443           CONTINUE
448         CONTINUE
            REWIND OF
            READ(OF,'(////////////////)')
          ENDIF
449       S(1)=STAT(1,6)
          IF(NP.LE.3) THEN
```



```
            B(4)=B(1)
            B(5)=B(2)
          ENDIF
          WRITE(*,'(A10,I5,A30)') 'CASE:',IS(1),LOCA(LC(1))
          WRITE(*,68)'MCI',Y(1),'MC0',VI(1,1),'DENS',VI(1,2),'LAI/YLD',
     +       VI(1,3),'BLM',VI(1,4),'CME',VI(1,5),'RSOIL',VI(1,7),
     +       'ZC/DENS',ZCDE
          WRITE(*,66)'ISW',ISW,'FMC',FM0,'DTF',DTF,'DTS',DTS
          WRITE(*,67)'SIG2',SIGMA2,'RHO',RHOI,('O',J,O(J,1),J=1,NP)
          WRITE(*,'(/8X,''NC'',8X,''NP'',6X,''NFIX'',8X,''NT'',5X,
     +       ''ITMAX'',5X,''MODEL'',6X,''IOPT'',6X,''IPRT'')')
          WRITE(*,'(8I10,4F10.4)') NC,NP,NFIX,NT,MAX,MODL,IOPT,IPRT
          WRITE(*,'(/6(6X,A,I1,A,5X))') ('B(',I,')',I=1,6)
          WRITE(*,'(6(1X,E13.6,1X))') (B(J),J=1,6)
          WRITE(*,'(6(4X,A,I1,A,4X))') ('JFIX(',J,')',J=1,6)
          WRITE(*,'(6(I9,6X))') (JFIX(J),J=1,6)
          WRITE(*,'(10(4X,A,I1,A,4X))') ('BL(',I,')',I=1,KM)
          WRITE(*,'(10(1X,E11.4,1X))') (BL(I),I=1,KM)
          WRITE(*,'(10(4X,A,I1,A,4X))') ('BH(',I,')',I=1,KM)
          WRITE(*,'(10(1X,E11.4,1X))') (BH(I),I=1,KM)
          WRITE(*,'(/5X,6(A2,I1,A4,8X))') ('P(',J,',KP)',J=1,NP)
          IF(IOPT.EQ.0) THEN
            WRITE(OF,'(A10,I5,A30)') 'CASE:',IS(1),LOCA(LC(1))
            WRITE(OF,68)'MCI',Y(1),'MC0',VI(1,1),'DENS',VI(1,2),'LAI/YLD',
     +         VI(1,3),'BLM',VI(1,4),'CME',VI(1,5),'RSOIL',VI(1,7),
     +         'ZC/DENS',ZCDE
            WRITE(OF,66)'ISW',ISW,'FMC',FM0,'DTF',DTF,'DTS',DTS
            WRITE(OF,67)'SIG2',SIGMA2,'RHO',RHOI,('O',J,O(J,1),J=1,NP)
            WRITE(OF,'(/8X,''NC'',8X,''NP'',6X,''NFIX'',8X,''NT'',5X,
     +         ''ITMAX'',5X,''MODEL'',6X,''IOPT'',6X,''IPRT'')')
            WRITE(OF,'(8I10,4F10.4)') NC,NP,NFIX,NT,MAX,MODL,IOPT,IPRT
            WRITE(OF,'(/6(6X,A,I1,A,5X))') ('B(',I,')',I=1,6)
            WRITE(OF,'(6(1X,E13.6,1X))') (B(J),J=1,6)
            WRITE(OF,'(6(4X,A,I1,A,4X))') ('JFIX(',J,')',J=1,6)
            WRITE(OF,'(6(I9,6X))') (JFIX(J),J=1,6)
            WRITE(OF,'(10(4X,A,I1,A,4X))') ('BL(',I,')',I=1,KM)
            WRITE(OF,'(10(1X,E11.4,1X))') (BL(I),I=1,KM)
            WRITE(OF,'(10(4X,A,I1,A,4X))') ('BH(',I,')',I=1,KM)
            WRITE(OF,'(10(1X,E11.4,1X))') (BH(I),I=1,KM)
          ENDIF
C          WRITE(OF,'(/5X,6(A2,I1,A4,8X))') ('P(',J,',KP)',J=1,NP)
          DO 7 J=1,NP
C            WRITE(OF,'(7(D14.5,1X))') (PS(J,L),L=1,J)
            WRITE(*,'(7(D14.5,1X))') (PS(J,L),L=1,J)
7         CONTINUE
          CALL FLUSH(6)
66        FORMAT(1X,A,I4,3X,A,F6.2,2(3X,A,F6.0),1X,A,F5.2,2(3X,A,F6.0),
     +         3X,A,E12.5,3X,A,F7.3)
67        FORMAT(1X,A,F8.4,2X,A,F6.3,8(2X,A1,I1,F8.5))
68        FORMAT(1X,3(A,F7.4,2X),3(A,F6.3,2X),A,F6.0,2X,A,F7.4)

          RETURN
        END
C-------------------------------------------------------------------------
        SUBROUTINE ARMAP
C-------------------------------------------------------------------------
```

```
      INCLUDE 'comsch.f'
      REAL CG(6)
      LOGICAL FLAG
      DOUBLE PRECISION A(6),PSV(6,6),SUMP,PSQ1,PSQ2,PSQ
      DATA ESP /1.0E-30/

      IT=0
      I2=0
C      SIGMA2=SIG2(1)
C-------REPEAT
99      IT=IT+1
        I1=0
        FLAG=.TRUE.
        CALL DAYTM
C        WRITE(OF,13) 'ITERATION: ',IT,CLOCK
        WRITE(*,13) 'ITERATION: ',IT,CLOCK
13      FORMAT(/T5,A,I4,T55,A)
C ------- START BASIC LOOP GIVES SIGMA2, RHO, B(I) AND SE
704       CONTINUE
C          REWIND OF
          IF(MODL.GT.0) ROH=0.0
C---------EACH ITERATION WITH AN IMPROVED PARAMETER VECTOR
          DO 18 J=1,NP
            BS(J)=B(J)
            BSV(1,J)=B(J)
            CG(J)=0
18        CONTINUE
C          DO 700 I=1,NC
C            SIG2(I)=SIGMA2
C            SIG(I)=SQRT(SIG2(I))
C700       CONTINUE
C---------CALCULATE SUM OF SQUARES AND SENSITIVITY COEFFICIENTS
          IF(IT.EQ.1) THEN
            IF(IOPT.EQ.0) THEN
              CALL FUNC(1,1)
              CALL ZX(1,0)
            ENDIF
          ELSE
            CALL ZX(1,1)
          ENDIF
          SE=S(1)
C---------EACH ITERATION BEGINS WITH THE SAME PS MATRIX
          DO 19 J=1,NP
            DO 19 KK=1,NP
              P(KK,J)=PS(KK,J)
19        CONTINUE
C---------SEQUENTIAL ESTIMATION
C          WRITE(OF,FT5) 'I',('B(',J,')',J=1,NP),
C     +                   ('X(',J,')',J=1,NP),('Z(',J,')',J=1,NP)
          WRITE(*,FT5) 'I',('B(',J,')',J=1,NP),
     +                   ('X(',J,')',J=1,NP),('Z(',J,')',J=1,NP)
          CALL FLUSH(6)
          DO 705 I=1,NC
            DO 29 J=1,NP
              A(J)=0
29          CONTINUE
```



```
          DO 30 J=1,NP
            DO 30 KK=1,NP
              A(J)=A(J)+Z(I,KK)*P(J,KK)
30        CONTINUE
C          SUM=0
C          DO 20 KK=1,NP
C            DO 20 L=1,NP
C              SUM=SUM+Z(I,L)*P(KK,L)*Z(I,KK)
C20        CONTINUE
          DELT=0
          DO 20 J=1,NP
            DELT=DELT+Z(I,J)*A(J)
20        CONTINUE
          DELT=SIG2(I)+DELT
          C=0
          DO 40 J=1,NP
            C=C+Z(I,J)*(B(J)-BS(J))
            CG(J)=CG(J)+Z(I,J)*F(I)/SIG2(I)
40        CONTINUE
          C=F(I)-C
          DO 50 J=1,NP
            IF(JFIX(J).EQ.0) THEN
              B(J)=B(J)+A(J)*C/DELT
              CALL CHECK(J)
            ENDIF
50        CONTINUE

          DO 41 J=1,NP
            DO 41 KK=1,NP
              PSV(KK,J)=P(KK,J)
41        CONTINUE
          DO 52 J=1,NP
            DO 52 KL=J,NP
              SUMP=0
              DO 51 KK=1,NP
                DO 51 MK=1,NP
C                 IF(KK.EQ.J.OR.MK.EQ.KL) GOTO 51
                  IF(KK.NE.J.AND.MK.NE.KL) THEN
                    PSQ1=PSV(KK,MK)*PSV(KL,J)
                    PSQ2=PSV(KL,KK)*PSV(J,MK)
                    PSQ=PSQ1-PSQ2
                    IF(DABS(PSQ1)+DABS(PSQ2).LT.1.E-15) THEN
                      RP=PSQ * 1.E15
                    ELSE
                      RP=PSQ/(DABS(PSQ1)+DABS(PSQ2))
                    ENDIF
                    RP=ABS(RP)
                    RPP=RP-1.0E-12
                    IF(RPP.LE.0.0) THEN
                      PSQ=0
                    ENDIF
                    SUMP=SUMP+Z(I,MK)*Z(I,KK)*PSQ
                  ENDIF
51            CONTINUE
              IF(J.NE.KL.OR.(J.EQ.KL.AND.JFIX(J).EQ.0)) THEN
                P(KL,J)=(PSV(KL,J)*SIG2(I)+SUMP)/DELT
```

```
C                    P(KL,J)=P(KL,J)-A(J)*A(KL)/DELT
                   ENDIF
52               CONTINUE
                 DO 53 J=2,NP
                   KL=J-1
                   DO 53 KK=1,KL
                     P(KK,J)=P(J,KK)
53               CONTINUE
                 DO 128 KK=1,NP
                   DO 128 J=1,KK
                     R(KK,J)=P(KK,J)/SQRT(DABS(P(KK,KK)*P(J,J)))
128              CONTINUE

C                 WRITE(OF,FT4)I,(B(J),J=1,NP),(X(I,J),J=1,NP)
C     +                        ,(Z(I,J),J=1,NP)
                 WRITE(*,FT4)I,(B(J),J=1,NP),(X(I,J),J=1,NP)
     +                        ,(Z(I,J),J=1,NP)
                 CALL FLUSH(6)
705            CONTINUE
               CALL WRT1(1)
C               SIGMA2=S5/NC
               IF(MODL.GT.0) THEN
C                 ROH=AMIN1(1.0,AMAX1(0.0,ROH/S3))
                  ROH=S6
                  RDA=ABS(1-RHO/ROH)
                  IF(RDA.GE.0.01) THEN
                    RHO=ROH
C                    DO 141 J=1,NP
C                      PS(J,J)=1.0E+7*P(J,J)
C141                 CONTINUE
                     GOTO 704
                   ENDIF
                 ENDIF
C--------------UNTIL(MODL.EQ.0.OR.ABS(1-RHO/ROH).LT.0.01)
               CALL WRT2(1,0)
               I1=1+NPP
               I2=I2+I1
C--------------END BASIC LOOP, GIVES B(I) AND SE
C--------------START IMPROVEMENT SEARCH
               GG=0.0
               DO 102 J=1,NP
                 BSS(J)=BS(J)
                 DB(J)=B(J)-BS(J)
                 GG=GG+DB(J)*CG(J)
102            CONTINUE
C               WRITE(OF,305) 'G',GG,('DB',J,DB(J),J=1,NP)
               WRITE(*,305) 'G',GG,('DB',J,DB(J),J=1,NP)
               CALL FLUSH(6)
305            FORMAT(/1X,A,E12.4,8(2X,A,I1,F8.4))
C--------------SEARCH FOR IMPROVEMENT IN THE DIRECTION OF DB
               CALL REFINE(1,NP)
               IF(S(L).GE.S(1)) THEN
C----------------TURN TO INDIVIDUAL PARAMETER SEARCH
                 IND=0
                 FLAG=.FALSE.
                 DO 308 J=1,NP
```



```
                   B(J)=BSS(J)
                   DO 309 I=1,6
                     BSV(I,J)=BSS(J)
309                CONTINUE
308              CONTINUE
                 DO 306 J=1,NP
                   IF(JFIX(J).EQ.0) THEN
C                    WRITE(OF,'(/3X,A,I1,A)') 'SEARCH FOR B(',J,')'
                    WRITE(*,'(/3X,A,I1,A)') 'SEARCH FOR B(',J,')'
                    CALL FLUSH(6)
                    CALL REFINE(J,J)
                    DO 333 J4=1,6
                     DO 334 JK=1,J
                      BSV(J4,JK)=BSV(L,JK)
334                  CONTINUE
333                 CONTINUE
                    IF(S(L).LT.S(1)) THEN
                      CALL SUBSTI(L)
                      FLAG=.TRUE.
                    ENDIF
                  ENDIF
306              CONTINUE
               ELSE
                 CALL SUBSTI(L)
               ENDIF
C--------------END MODIFICATION PROCESS
C               WRITE(OF,'(/6(6X,A,I1,A,5X))') ('B(',I,')',I=1,NP)
C               WRITE(OF,'(6(1X,F13.6,1X))') (B(I),I=1,NP)
               WRITE(*,'(/6(9X,A,I1,A))') ('B(',I,')',I=1,NP)
               WRITE(*,'(6(F13.6))') (B(I),I=1,NP)
               CALL DAYTM
C               WRITE(OF,315)'IT',IT,'NP',NP,'INDEX',IND,CLOCK
               WRITE(*,315)'IT',IT,'NP',NP,'INDEX',IND,CLOCK
315            FORMAT(/3(1X,A,I3,4X),T55,A)
               WRITE(*,317) 'THE NUMBER OF FUNCTION EVALUATIONS:',I1
C               WRITE(OF,317) 'THE NUMBER OF FUNCTION EVALUATIONS:',I1
               CALL FLUSH(6)
317            FORMAT(/1X,A,I5)
               IF(FLAG) THEN
                 REWIND OF
                 READ(OF,'(////////////////)')
                 IF(IT.EQ.MAX) THEN
                   CALL WRT1(1)
                   CALL WRT2(1,1)
                 ENDIF
               ENDIF
               IF(FLAG.AND.IT.LT.MAX) GOTO 99
C--------------UNTIL(SEP.GT.SE.OR.IT.GE.MAX)
               WRITE(*,317) 'THE TOTAL NUMBER OF FUNCTION EVALUATIONS:',I2
C               WRITE(OF,317) 'THE TOTAL NUMBER OF FUNCTION EVALUATIONS:',I2

               RETURN
             END
C-------------------------------------------------------------------------
             SUBROUTINE REFINE(J1,J2)
C-------------------------------------------------------------------------
```

```
      INCLUDE 'comsch.f'
      CHARACTER CHA*2
      DATA CHA /'S '/
      DATA ESP /1.0E-30/

      IF(J2.GT.J1.AND.(JFIX(2).EQ.0.OR.JFIX(MIN0(NP,5)).EQ.0)) THEN
        KODE=2
      ELSE
        KODE=1
      ENDIF
      NN=MIN0(NPP,J2-J1+1)
      SEP=1.0E30
      ALFA=2.0
C-----WHILE(ALFA.GE.0.01)
110     ALFA=ABS(ALFA)*0.5
        IF(ALFA.LT.0.01) GOTO 109
        CALL DAYTM
        WRITE(*,'(/1X,A,F10.7,T55,A)')'ALFA',ALFA,CLOCK
C        WRITE(OF,'(/1X,A,F10.7,T55,A)')'ALFA',ALFA,CLOCK
        CALL FLUSH(6)
        DO 300 L=2,3
          IND=0
          WRITE(CHA(2:2),'(I1)') L
          DO 116 J=J1,J2
            IF(JFIX(J).EQ.0) CALL INDX(J,ALFA)
116       CONTINUE
          CALL FUNC(L,0)
C          WRITE(OF,108) 'ALFA',ALFA,CHA,S(L),'S1',S(1),
C     +                  ('B',J,B(J),J=1,NP)
          WRITE(*,108) 'ALFA',ALFA,CHA,S(L),'S1',S(1),
     +                 ('B',J,B(J),J=1,NP)
          CALL FLUSH(6)
          IF(S(L).LT.SEP) THEN
            SEP=S(L)
            LM=L
          ENDIF
          J=J1
C---------REPEAT
299         BSV(L,J)=B(J)
            J=J+1
            IF(J.LE.J2) GOTO 299
C---------UNTIL(J.GT.J2)
          ALFA=-ALFA
300     CONTINUE
108     FORMAT(A5,F8.4,2(2X,A,E13.6),6(2X,A,I1,F9.6))
C-------(S(2)=S(ALFA),S(3)=S(-ALFA),ALFA>0.01)
        ALFA=ABS(ALFA)
        IF(IND.LT.NN) THEN
C---------ASSUME (S=S(1)+B1*ALFA+B2*ALFA**2)
          B1=0.5*(S(2)-S(3))/ALFA
          B2=(0.5*(S(2)+S(3))-S(1))/ALFA**2
          IF(B2.GT.0.0) THEN
C-----------(SE<0.5*(S(ALFA)+S(-ALFA)))
            IF(ABS(B1).GT.0.0) THEN
C-------------(SMIN MAY EXIST AT DSEP/DALFA=0)
              HH=-0.5*B1/B2
```



```
              L=4
            ELSE
C-----------(S=SE+B2*HH**2>SE)
              HH=0.0
              L=1
            ENDIF
          ELSE
C---------A LINE OR CONCAVE CURVE (SE>=0.5*(S(ALFA)+S(-ALFA)))
            IF(B1.GT.0.0) THEN
C-----------(S(-ALFA)<SE,S(ALFA)>S(-ALFA)),EXPAND (ALPH=1.1 TO 1.3)
              HH=-ALFA*ALPH
              L=6
            ELSE IF(B1.LT.0) THEN
C-----------(S(ALFA)<SE,S(-ALFA)>S(ALFA))
              HH=ALFA*ALPH
              L=5
            ELSE
C-----------(S(-ALFA)=SE=S(ALFA))
              HH=0.0
              L=1
            ENDIF
          ENDIF
          WRITE(CHA(2:2),'(I1)') L
          IF(L.GT.1) THEN
            IND=0
            DO 302 J=J1,J2
              IF(JFIX(J).EQ.0) CALL INDX(J,HH)
302         CONTINUE
            IF(IND.LT.NN) THEN
              CALL FUNC(L,0)
              IF(S(L).LT.SEP) THEN
                SEP=S(L)
                LM=L
              ENDIF
              DO 303 J=J1,J2
                BSV(L,J)=B(J)
303           CONTINUE
            ELSE
              IND=NN
              S(L)=S(L-3)
            ENDIF
          ENDIF
C           WRITE(OF,108) 'HH',HH,CHA,S(L),'S1',S(1),
C     +                  ('B',J,BSV(L,J),J=1,NP)
          WRITE(*,108) 'HH',HH,CHA,S(L),'S1',S(1),
     +                 ('B',J,BSV(L,J),J=1,NP)
          CALL FLUSH(6)
          IF(L.GE.4 .AND. S(L).GE.S(L-3)) THEN
            L=L-3
            DO 307 J=J1,J2
              B(J)=BSV(L,J)
307         CONTINUE
          ENDIF
        ENDIF
        IF(IND.LT.NN.AND.ALFA.GT.0.01.AND.SEP.GE.S(1)+ESP) GOTO 110
C-------UNTIL(S(1).GT.SEP.OR..NOT.(IND.LT.NN.AND.ALFA.GT.0.01))
```

```
109     IF(S(1).LE.SEP) THEN
          L=1
        ELSE
          L=LM
        ENDIF
        DO 310 J=J1,J2
          B(J)=BSV(L,J)
310     CONTINUE

        RETURN
      END
C-----------------------------------------------------------------------
      SUBROUTINE WRT1(LL)
C-----------------------------------------------------------------------
        INCLUDE 'comsch.f'

        WRITE(*,'(/4X,A,2X,A,2(7X,A),5X,A,4X,A,2(7X,A),4X,A,3X,A,
     +       5(3X,A2,I1,A1,2X))') 'RHO','SIG2','SST','SSE','R2',
     +       'R2A','ST''','SE''','R2''','R2A''',('B(',J,')',J=1,NP)
        WRITE(*,FT3) RHO,S5/NNP,(STAT(LL,J),J=1,8),(BSV(LL,J),J=1,NP)
        WRITE(*,'(/5X,8(A2,I1,A4,8X))') ('P(',J,',KP)',J=1,NP)
        WRITE(OF,'(/4X,A,2X,A,2(7X,A),5X,A,4X,A,2(7X,A),4X,A,3X,A,
     +       5(3X,A2,I1,A1,2X))') 'RHO','SIG2','SST','SSE','R2',
     +       'R2A','ST''','SE''','R2''','R2A''',('B(',J,')',J=1,NP)
        WRITE(OF,FT3)RHO,S5/NNP,(STAT(LL,J),J=1,8),(BSV(LL,J),J=1,NP)
        WRITE(OF,'(/5X,8(A2,I1,A4,8X))') ('P(',J,',KP)',J=1,NP)
        DO 129 J=1,NP
          WRITE(OF,'(8(D14.5,1X))') (P(J,KK),KK=1,J)
          WRITE(*,'(8(D14.5,1X))') (P(J,KK),KK=1,J)
129     CONTINUE
        WRITE(*,'(/1X,A)') 'CORRELATION MATRIX'
        WRITE(OF,'(/1X,A)') 'CORRELATION MATRIX'
        DO 140 J=1,NP
          WRITE(OF,'(8(D14.5,1X))') (R(J,KK),KK=1,J)
          WRITE(*,'(8(D14.5,1X))') (R(J,KK),KK=1,J)
140     CONTINUE
        CALL DAYTM
        WRITE(OF,'(T55,A)') CLOCK
        WRITE(*,'(T55,A)') CLOCK
        CALL FLUSH(6)
        CALL FLUSH(OF)
C
        RETURN
      END
C-----------------------------------------------------------------------
      SUBROUTINE WRT2(LL,JI)
C-----------------------------------------------------------------------
        INCLUDE 'comsch.f'

        IF(JI.NE.0) CALL ZX(LL,1)
        DO 100 I=1,NC
          DO 703 J=1,NP
            BZ(I,J)=O(J,2)*Z(I,J)/H(I)
            BX(I,J)=O(J,2)*X(I,J)/ETA(I)
703       CONTINUE
          IF(I.EQ.1) THEN
```



```
            WRITE(OF,FT1) 'YRDAY','TIME','Y(I)','E(I)','R(I)',
     +                    ('BX(',J,')',J=1,NP)
     +                    ,'G(I)','H(I)','F(I)',('BZ(',J,')',J=1,NP)
            WRITE(*,FT1) 'YRDAY','TIME','Y(I)','E(I)','R(I)',
     +                    ('BX(',J,')',J=1,NP)
     +                    ,'G(I)','H(I)','F(I)',('BZ(',J,')',J=1,NP)
          ENDIF
          WRITE(OF,FT2) IY(I),MD(I),T(I),(V(LL,I,J),J=1,3),
     +                    (BX(I,J),J=1,NP)
     +                    ,(V(LL,I,J),J-4,6),(BZ(I,J),J=1,NP)
          WRITE(*,FT2) IY(I),MD(I),T(I),(V(LL,I,J),J=1,3),
     +                    (BX(I,J),J=1,NP)
     +                    ,(V(LL,I,J),J-4,6),(BZ(I,J),J=1,NP)
100     CONTINUE
        CALL FLUSH(6)
        CALL FLUSH(OF)

        RETURN
      END
C-----------------------------------------------------------------------
      SUBROUTINE ZX(LL,JI)
C-----------------------------------------------------------------------
        INCLUDE 'comsch.f'

        IF(JI.NE.0) THEN
          DO 104 J=1,NP
            B(J)=BSV(LL,J)
104       CONTINUE
          DO 101 I=1,NC
            ETA(I)=V(LL,I,2)
            CALL SENS
101       CONTINUE
        ENDIF
        DO 102 I=NC,1,-1
          DO 103 J=1,NP
            IF(JFIX(J).NE.0) THEN
              Z(I,J)=0.0
            ELSE
              IF(ID(I).EQ.1) THEN
                Z(I,J)=X(I,J)
              ELSE
                Z(I,J)=X(I,J)-RHO*X(I-1,J)
              ENDIF
            ENDIF
103       CONTINUE
102     CONTINUE

        RETURN
      END
C-----------------------------------------------------------------------
      SUBROUTINE SUBSTI(LL)
C-----------------------------------------------------------------------
        INCLUDE 'comsch.f'

        S(1)=S(LL)
        DO 330 I=1,NC
```

```
          DO 331 J=1,6
            V(1,I,J)=V(LL,I,J)
331       CONTINUE
330     CONTINUE
        DO 332 J=1,8
          STAT(1,J)=STAT(LL,J)
332     CONTINUE

        RETURN
      END
C-----------------------------------------------------------------------
      SUBROUTINE CHECK(J)
C-----------------------------------------------------------------------
        INCLUDE 'comsch.f'

        KT=0
C-------REPEAT
10        CONTINUE
C---------CHECK EXPLICIT CONSTRAINTS
          IF(KT.EQ.0.OR.KODE.LE.1) THEN
            B(J)=AMAX1(BL(J)+DELTA,AMIN1(B(J),BH(J)-DELTA))
          ELSE
            DO 123 J4=J1,J2
              B(J4)=AMAX1(BL(J4)+DELTA,AMIN1(B(J4),BH(J4)-DELTA))
123         CONTINUE
          ENDIF
          KT=0
          IF(J.NE.3.AND.KODE.GT.0) THEN
C-----------CHECK IMPLICIT CONSTRAINTS
            IF(J.LE.2) THEN
              J1=1
              J2=2
              J3=NP1
            ELSE
              J1=4
              J2=5
              J3=KM
            ENDIF
            BB=B(J1)-B(J2)
            IF(BB.LT.BL(J3).OR.BB.GT.BH(J3)) THEN
              IF(KODE.EQ.2) THEN
                B(J1)=0.5*(B(J1)+CB(J1))
                B(J2)=0.5*(B(J2)+CB(J2))
              ELSE
                IF(J.EQ.J1) THEN
                  B(J)=0.5*(B(J)+B(J2)+CB(J3))
                ELSE
                  B(J)=0.5*(B(J)+B(J1)-CB(J3))
                ENDIF
              ENDIF
              KT=1
            ENDIF
          ENDIF
          IF(KT.GT.0) GOTO 10
C-------UNTIL(KT.EQ.0)
```



```
        RETURN
      END
C-----------------------------------------------------------------------
      SUBROUTINE DAYTM
C-----------------------------------------------------------------------
        INCLUDE 'comsch.f'
C       CHARACTER*8 TIME,DATE
C       CHARACTER CT*8,DAY*9

C-------TMDAY(CLOCK) IS IN  LANGUAGE FOR HP9000/300
C       CALL TMDAY(CLOCK)
C-------FOR OTHER SYSTEMS-----------------------------
C       WRITE(CLOCK,'(25('' ''))')
C-------FOR PRIME750/550
C       CT=TIME()
C       DAY=DATE()
C-------FOR VAX/VMS AND IBM/PC COMPATIBLES
C       CALL TIME(CT)
C       CALL DATE(DAY)
C       WRITE(CLOCK(1:19),'(A,2X,A)') CT,DAY
C-------FOR VAX/UNIX AND SUN'S
        CALL FDATE(CLOCK)

        RETURN
      END
C-----------------------------------------------------------------------
      SUBROUTINE FUNC(LL,JI)
C-----------------------------------------------------------------------
        INCLUDE 'comsch.f'

        I1=I1+1
        I2=I2+1
        SS=0.0
        SY=0.0
        SY2=0.0
        S1=0.0
        S2=0.0
        S3=0.0
        SSE=0.0
        S5=0.0
        IF(MODL.GT.0) ROH=0
        IF(NP.LT.4) THEN
          B(4)=B(1)
          B(5)=B(2)
        ENDIF
        DO 301 I=1,NC
          IF(ID(I).EQ.1) THEN
            DO 303 J=1,N
              W(J)=VI(I,J)
303         CONTINUE
          ENDIF
          CALL MODEL
          IF(JI.NE.0) CALL SENS
          E(I)=Y(I)-ETA(I)
          SY=SY+Y(I)/SIG(I)
          SY2=SY2+Y(I)**2/SIG2(I)
```

```
          SSE=SSE+E(I)**2/SIG2(I)
          IF(ID(I).EQ.1) THEN
            F(I)=E(I)
            G(I)=Y(I)
            H(I)=ETA(I)
          ELSE
            F(I)=E(I)-RHO*E(I-1)
            G(I)=Y(I)-RHO*Y(I-1)
            H(I)=ETA(I)-RHO*ETA(I-1)
            IF(MODL.GT.0) ROH=ROH+E(I)*E(I-1)
          ENDIF
          S5=S5+F(I)**2
          SS=SS+F(I)**2/SIG2(I)
          S1=S1+G(I)/SIG(I)
          S2=S2+G(I)**2/SIG2(I)
          IF(MODL.GT.0.AND.I.LT.NC) THEN
            IF(IS(I+1).EQ.IS(I)) S3=S3+E(I)**2
          ENDIF
          V(LL,I,1)=Y(I)
          V(LL,I,2)=ETA(I)
          V(LL,I,3)=E(I)
          V(LL,I,4)=G(I)
          V(LL,I,5)=H(I)
          V(LL,I,6)=F(I)
301       CONTINUE
          SST=SY2-SY**2/NC
          R2A=1-SSE/SST
          R2B=1-(NC-1)*SSE/(NNP*SST)
          ST=S2-S1**2/NC
          R1A=1-SS/ST
          R1B=1-(NC-1)*SS/(NNP*ST)
          STAT(LL,1)=SST
          STAT(LL,2)=SSE
          STAT(LL,3)=R2A
          STAT(LL,4)=R2B
          STAT(LL,5)=ST
          STAT(LL,6)=SS
          STAT(LL,7)=R1A
          STAT(LL,8)=R1B
          S(LL)=SS
          IF(MODL.GT.0) S6=AMIN1(1.0,AMAX1(-1.0,ROH/S3))

          RETURN
        END
C-------------------------------------------------------------------------
        SUBROUTINE INDX(J,HV)
C-------------------------------------------------------------------------
          INCLUDE 'comsch.f'
          DATA ESP,EPSS/1.0E-30,0.0001/

          DELB=HV*DB(J)
          RATIO=DELB/ABS(BSS(J)+ESP)
          IF(ABS(RATIO).LE.EPSS) THEN
            IND=IND+1
C            WRITE(OF,314)'IT',IT,'NP',NP,'INDEX',IND,'IP',J,
C     +                'RATIO',RATIO,'EPSS',EPSS
```



```
            WRITE(*,314)'IT',IT,'NP',NP,'INDEX',IND,'IP',J,
     +                'RATIO',RATIO,'EPSS',EPSS
314         FORMAT(4(1X,A,I3,4X),2(1X,A,F8.4,3X))
          ENDIF
          B(J)=BSS(J)+DELB
          CALL CHECK(J)

          RETURN
        END
C-------------------------------------------------------------------------
        SUBROUTINE MODEL
C-------------------------------------------------------------------------
          INCLUDE 'comsch.f'

          LL=ISW*10+LK
          KK=ID(I)
          ETA(I)=AMC(B,W,IY(I),MD(I),T(I),Y(I),IM(I),DTF,DTS,LC(I),KK,LL)

          RETURN
        END
C-------------------------------------------------------------------------
        SUBROUTINE SENS
C-------------------------------------------------------------------------
          INCLUDE 'comsch.f'

          IF(I.EQ.1) THEN
            DO 10 J=1,NP
              IF(B(J).LT.1.0E-9) THEN
                O(J,2)=O(J,1)
                O(J,3)=O(J,1)
              ELSE
                O(J,2)=B(J)*O(J,1)
                O(J,3)=B(J)*(1.0+O(J,1))
              ENDIF
10          CONTINUE
          ENDIF
          LL=ISW*10+LK
          DO 11 J=1,NP
            IF(JFIX(J).NE.0) THEN
              X(I,J)=0.0
            ELSE
              KK=1000*J+ID(I)
              A=B(J)
              B(J)=O(J,3)
              X(I,J)=(AMC(B,W,IY(I),MD(I),T(I),Y(I),IM(I),DTF,DTS,LC(I),
     +                KK,LL)-ETA(I))/O(J,2)
              B(J)=A
            ENDIF
11        CONTINUE

          RETURN
        END
```

```
C-----------------------------------------------------------------------
C     COMMON BLOCK FILE COMSCH.F
C-----------------------------------------------------------------------
      PARAMETER (M=505,N=8,K=10)
      CHARACTER CLOCK*25,FT1*26,FT2*30,FT3*32,FT4*18,FT5*27
      DOUBLE PRECISION P,PS,R
      INTEGER WD,WM,PA,OU,OF,DR
      COMMON /IOFL/WD,WM,PA,OU,OF,DR
      COMMON /NLIN/ETA(M),Y(M+1),SIG2(M),B(6),Z(M,6),BS(6),X(M,N),
     +              V(K,M,6),I,MODL,NP,IPRT,JFIX(6),IOPT,MAX
      COMMON /PPP/P(6,6),PS(6,6),R(6,6),BX(M,N),BZ(M,6)
      COMMON /ABC/T(M+1),RSVI(2),DTF,DTS,FM0,O(N,3),VI(M,N),W(N),
     +            IM(M),ID(M),IS(M),LC(M),IY(M),MD(M+1),LK,ISW,IJ
      COMMON /DEF/DB(6),BSS(6),SEP,HH,ALPA,GG,RHO,L,NPP,IT,NC,NT,IND,
     +            SE,G(M),H(M),F(M),E(M),SIG(M)
      COMMON /BCD/BSV(K,K),BC(6),BL(K),BH(K),S(K),CB(K),ALPH,GAMMA,
     +            DELTA,BTA,PHI,KL,KM,KMAX,KODE,NP1,NP2,I1,I2,I3,KL1
      COMMON /CDE/SST,SSE,ST,R2A,R2B,R1A,R1B,STAT(K,8),NNP
      COMMON /EFG/S0,S1,S2,S3,S4,S5,S6,L0,L1,L2,L3,L4,L5,L6
      COMMON /FGH/CLOCK
      COMMON /FMT/FT1,FT2,FT3,FT4,FT5
```

APPENDIX H

A Sample of the Parameter Data File

```
0 7.0 10.0 1000.0 0.5 0.213 6.62
600.0 3600.0 0.0 1.0 1.3 0.5 2.1 1.0001 0.001
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
2 0 20 0 0 7 6 5
4.570449 1.632791 0.12 4.768590 1.689296 0.0
0 0 1 0 0 1
1.0E8     0      0      0      0      0
    0 1.0E8      0      0      0      0
    0      0 1.0E8      0      0      0
    0      0      0 1.0E8      0      0
    0      0      0      0 1.0E8      0
    0      0      0      0      0 1.0E8
3.00 0.10 0.00 3.00 0.10 1.50 1.50
5.90 4.40 0.20 5.90 4.40 4.80 4.80
```

APPENDIX I

ARNLIN Outputs for Nine Selected Trials

CASE: 4 EAST LANSING, MICHIGAN
MCI 4.3121 MC0 4.3121 DENS 0.3564 LAI/YLD 5.300 BLM 0.250 CME 0.500 RSOIL 10. ZC/DENS 0.2130
ISW 0 FMC 7.00 DTF 600. DTS 3600.
SIG2 1.0000 RHO 0.000 O1 0.10000 O2 0.10000

NC	NP	NFIX	NT	ITMAX	MODEL	IOPT	IPRT
5	2	0	0	20	0	0	0

B(1)	B(2)	B(3)	B(4)	B(5)	B(6)
0.453481e+01	0.145802e+01	0.120000e+00	0.453481e+01	0.145802e+01	0.000000e+00

JFIX(1)	JFIX(2)	JFIX(3)	JFIX(4)	JFIX(5)	JFIX(6)
0	0	1	0	0	1

BL(1)	BL(2)	BL(3)
0.3000e+01	0.1000e+00	0.1500e+01

BH(1)	BH(2)	BH(3)
0.5900e+01	0.4400e+01	0.4800e+01

RHO	SIG2	SST	SSE	R2	R2A	ST'	SE'	R2'	R2A'	B(1)	B(2)
0.000	0.002	4.80582	0.00724	0.998	0.998	4.80582	0.00724	0.998	0.998	4.538754	1.464223

P(1,KP)	P(2,KP)
0.16078d+01	
0.19432d+01	0.25573d+01

CORRELATION MATRIX

0.10000d+01	
0.95830d+00	0.10000d+01

Sun Aug 2 01:25:28 1987

YRDAY	TIME	Y(I)	E(I)	R(I)	BX(1)	BX(2)	G(I)	H(I)	F(I)	BZ(1)	BZ(2)
84723	11.07	4.312	4.312	0.000	0.000	0.000	4.312	4.312	0.000	0.000	0.000
84723	11.45	4.005	3.951	0.055	0.054	-0.026	4.005	3.951	0.055	0.054	-0.026
84723	12.95	3.081	3.097	-0.015	0.166	-0.062	3.081	3.097	-0.015	0.166	-0.062
84723	15.12	2.191	2.225	-0.034	0.366	-0.083	2.191	2.225	-0.034	0.366	-0.083
84723	16.95	1.799	1.746	0.053	0.443	-0.086	1.799	1.746	0.053	0.443	-0.086

CASE: 5 EAST LANSING, MICHIGAN
MCI 3.4636 MCO 3.4636 DENS 0.4481 LAI/YLD 6.620 BLM 0.000 CME 0.500 RSOIL 10. ZC/DENS 0.2130
ISW 0 FMC 7.00 DTF 600. DTS 3600.
SIG2 1.0000 RHO 0.000 O1 0.10000 O2 0.10000

NC	NP	NFIX	NT	ITMAX	MODEL	IOPT	IPRT
26	2	0	0	20	0	0	1

B(1)	B(2)	B(3)	B(4)	B(5)	B(6)
0.510782e+01	0.223017e+01	0.120000e+00	0.510782e+01	0.223017e+01	0.000000e+00

JFIX(1)	JFIX(2)	JFIX(3)	JFIX(4)	JFIX(5)	JFIX(6)
0	0	1	0	0	1

BL(1)	BL(2)	BL(3)
0.3000e+01	0.1000e+00	0.1500e+01

BH(1)	BH(2)	BH(3)
0.5900e+01	0.4400e+01	0.4800e+01

RHO	SIG2	SST	SSE	R2	R2A	ST'	SE'	R2'	R2A'	B(1)	B(2)
0.000	0.029	14.05713	0.70313	0.950	0.948	14.05713	0.70313	0.950	0.948	5.094225	2.237058

P(1,KP)	P(2,KP)
0.77061d-01	
0.16587d+00	0.51565d+00

CORRELATION MATRIX

0.10000d+01	
0.83211d+00	0.10000d+01

Fri Jul 31 22:38:16 1987

YRDAY	TIME	Y(I)	E(I)	R(I)	BX(1)	BX(2)	G(I)	H(I)	F(I)	BZ(1)	BZ(2)
84814	13.47	3.464	3.464	0.000	0.000	0.000	3.464	3.464	0.000	0.000	0.000
84814	14.17	2.625	2.907	-0.282	0.074	-0.028	2.625	2.907	-0.282	0.074	-0.028
84814	16.10	1.655	1.761	-0.107	0.317	-0.083	1.655	1.761	-0.107	0.317	-0.083
84814	18.20	1.214	1.297	-0.082	0.482	-0.103	1.214	1.297	-0.082	0.482	-0.103
84814	20.03	1.119	1.062	0.057	0.620	-0.116	1.119	1.062	0.057	0.620	-0.116
84814	22.11	1.131	0.968	0.163	0.693	-0.119	1.131	0.968	0.163	0.693	-0.119
84815	0.01	1.173	0.948	0.224	0.709	-0.120	1.173	0.948	0.224	0.709	-0.120
84815	2.24	1.230	0.991	0.238	0.676	-0.114	1.230	0.991	0.238	0.676	-0.114
84815	4.02	1.375	1.090	0.284	0.613	-0.104	1.375	1.090	0.284	0.613	-0.104
84815	6.84	1.464	1.190	0.274	0.557	-0.097	1.464	1.190	0.274	0.557	-0.097
84815	8.00	1.423	1.206	0.216	0.548	-0.095	1.423	1.206	0.216	0.548	-0.095
84815	10.15	1.131	0.993	0.138	0.648	-0.112	1.131	0.993	0.138	0.648	-0.112
84815	12.03	0.857	0.904	-0.046	0.726	-0.118	0.857	0.904	-0.046	0.726	-0.118
84815	14.13	0.577	0.793	-0.216	0.838	-0.127	0.577	0.793	-0.216	0.838	-0.127
84815	16.16	0.428	0.680	-0.251	0.992	-0.124	0.428	0.680	-0.251	0.992	-0.124
84815	18.04	0.363	0.589	-0.226	1.139	-0.136	0.363	0.589	-0.226	1.139	-0.136
84815	20.10	0.369	0.508	-0.139	1.325	-0.151	0.369	0.508	-0.139	1.325	-0.151
84815	22.20	0.410	0.474	-0.063	1.427	-0.147	0.410	0.474	-0.063	1.427	-0.147
84816	0.18	0.440	0.465	-0.024	1.451	-0.145	0.440	0.465	-0.024	1.451	-0.145
84816	2.21	0.470	0.461	0.009	1.456	-0.145	0.470	0.461	0.009	1.456	-0.145
84816	4.59	0.536	0.465	0.070	1.428	-0.100	0.536	0.465	0.070	1.428	-0.100
84816	6.98	0.613	0.551	0.062	1.204	-0.028	0.613	0.551	0.062	1.204	-0.028
84816	9.10	0.613	0.533	0.080	1.204	0.013	0.613	0.533	0.080	1.204	0.013
84816	11.23	0.482	0.461	0.021	1.287	0.004	0.482	0.461	0.021	1.287	0.004
84816	13.15	0.298	0.418	-0.120	1.424	-0.003	0.298	0.418	-0.120	1.424	-0.003
84816	15.26	0.184	0.357	-0.173	1.662	-0.012	0.184	0.357	-0.173	1.662	-0.012

CASE: 9 EAST LANSING, MICHIGAN
MCI 3.3506 MC0 3.3506 DENS 0.4599 LAI/YLD 6.620 BLM 0.050 CME 0.500 RSOIL 10. ZC/DENS 0.2130
ISW 0 FMC 7.00 DTF 600. DTS 3600.
SIG2 1.0000 RHO 0.000 O1 0.10000 O2 0.10000

NC	NP	NFIX	NT	ITMAX	MODEL	IOPT	IPRT
16	2	0	0	20	0	0	1

B(1)	B(2)	B(3)	B(4)	B(5)	B(6)
0.419720e+01	0.991535e+00	0.120000e+00	0.419720e+01	0.991535e+00	0.000000e+00
JFIX(1)	JFIX(2)	JFIX(3)	JFIX(4)	JFIX(5)	JFIX(6)
0	0	1	0	0	1

BL(1)	BL(2)	BL(3)
0.3000e+01	0.1000e+00	0.1500e+01
BH(1)	BH(2)	BH(3)
0.5900e+01	0.4400e+01	0.4800e+01

RHO	SIG2	SST	SSE	R2	R2A	ST'	SE'	R2'	R2A'	B(1)	B(2)
0.000	0.015	11.42186	0.20874	0.982	0.980	11.42186	0.20874	0.982	0.980	4.834455	1.831375

P(1,KP)	P(2,KP)
0.15019d+01	
0.36899d+01	0.92653d+01

CORRELATION MATRIX

0.10000d+01	
0.98917d+00	0.10000d+01

Fri Jul 31 23:13:37 1987

YRDAY	TIME	Y(I)	E(I)	R(I)	BX(1)	BX(2)	G(I)	H(I)	F(I)	BZ(1)	BZ(2)
84821	11.00	3.351	3.351	0.000	0.000	0.000	3.351	3.351	0.000	0.000	0.000
84821	11.93	2.788	2.740	0.048	0.117	-0.051	2.788	2.740	0.048	0.117	-0.051
84821	13.02	2.306	2.200	0.106	0.233	-0.078	2.306	2.200	0.106	0.233	-0.078
84821	15.20	1.447	1.547	-0.100	0.433	-0.079	1.447	1.547	-0.100	0.433	-0.079
84821	17.00	0.943	1.206	-0.263	0.595	-0.097	0.943	1.206	-0.263	0.595	-0.097
84821	19.05	0.833	0.924	-0.092	0.799	-0.133	0.833	0.924	-0.092	0.799	-0.133
84821	21.02	0.810	0.770	0.040	0.994	-0.137	0.810	0.770	0.040	0.994	-0.137
84821	23.19	0.810	0.739	0.071	1.019	-0.158	0.810	0.739	0.071	1.019	-0.158
84822	1.06	0.798	0.717	0.082	1.029	-0.159	0.798	0.717	0.082	1.029	-0.159
84822	3.11	0.798	0.696	0.102	1.057	-0.162	0.798	0.696	0.102	1.057	-0.162
84822	5.16	0.787	0.680	0.106	1.084	-0.163	0.787	0.680	0.106	1.084	-0.163
84822	7.09	0.763	0.666	0.098	1.111	-0.164	0.763	0.666	0.098	1.111	-0.164
84822	9.12	0.757	0.651	0.107	1.139	-0.165	0.757	0.651	0.107	1.139	-0.165
84822	11.07	0.694	0.634	0.060	1.171	-0.165	0.694	0.634	0.060	1.171	-0.165
84822	13.24	0.468	0.587	-0.120	1.266	-0.169	0.468	0.587	-0.120	1.266	-0.169
84822	15.12	0.287	0.472	-0.184	1.585	-0.160	0.287	0.472	-0.184	1.585	-0.160

CASE: 13 EAST LANSING, MICHIGAN
MCI 2.6739 MC0 2.6739 DENS 0.5444 LAI/YLD 6.620 BLM 0.075 CME 0.500 RSOIL 10. ZC/DENS 0.2130
ISW 0 FMC 7.00 DTF 600. DTS 3600.
SIG2 1.0000 RHO 0.000 O1 0.10000 O2 0.10000

NC	NP	NFIX	NT	ITMAX	MODEL	IOPT	IPRT
16	2	0	0	20	0	0	1

B(1)	B(2)	B(3)	B(4)	B(5)	B(6)
0.500782e+01	0.195654e+01	0.120000e+00	0.500782e+01	0.195654e+01	0.000000e+00
JFIX(1)	JFIX(2)	JFIX(3)	JFIX(4)	JFIX(5)	JFIX(6)
0	0	1	0	0	1

BL(1)	BL(2)	BL(3)
0.3000e+01	0.1000e+00	0.1500e+01
BH(1)	BH(2)	BH(3)
0.5900e+01	0.4400e+01	0.4800e+01

RHO	SIG2	SST	SSE	R2	R2A	ST'	SE'	R2'	R2A'	B(1)	B(2)
0.000	0.009	6.22463	0.12166	0.980	0.979	6.22463	0.12166	0.980	0.979	4.879282	1.759824

P(1,KP)	P(2,KP)
0.38512d+00	
0.81360d+00	0.19373d+01

CORRELATION MATRIX

0.10000d+01	
0.94192d+00	0.10000d+01

Fri Jul 31 22:45:38 1987

YRDAY	TIME	Y(I)	E(I)	R(I)	BX(1)	BX(2)	G(I)	H(I)	F(I)	BZ(1)	BZ(2)
84830	11.30	2.674	2.674	0.000	0.000	0.000	2.674	2.674	0.000	0.000	0.000
84830	12.05	2.478	2.482	-0.004	0.046	-0.024	2.478	2.482	-0.004	0.046	-0.024
84830	14.08	1.851	1.914	-0.063	0.189	-0.064	1.851	1.914	-0.063	0.189	-0.064
84830	16.15	1.307	1.383	-0.076	0.367	-0.101	1.307	1.383	-0.076	0.367	-0.101
84830	18.08	1.003	1.037	-0.033	0.562	-0.121	1.003	1.037	-0.033	0.562	-0.121
84830	20.06	0.876	0.827	0.049	0.738	-0.137	0.876	0.827	0.049	0.738	-0.137
84830	22.16	0.822	0.722	0.100	0.866	-0.147	0.822	0.722	0.100	0.866	-0.147
84830	23.79	0.852	0.716	0.136	0.878	-0.140	0.852	0.716	0.136	0.878	-0.140
84831	2.16	0.925	0.825	0.100	0.792	-0.107	0.925	0.825	0.100	0.792	-0.107
84831	4.34	0.999	0.933	0.066	0.704	-0.093	0.999	0.933	0.066	0.704	-0.093
84831	6.51	1.082	1.035	0.047	0.634	-0.083	1.082	1.035	0.047	0.634	-0.083
84831	8.23	1.097	1.080	0.017	0.622	-0.079	1.097	1.080	0.017	0.622	-0.079
84831	10.08	0.891	0.885	0.006	0.777	-0.091	0.891	0.885	0.006	0.777	-0.091
84831	12.11	0.680	0.790	-0.110	0.857	-0.102	0.680	0.790	-0.110	0.857	-0.102
84831	14.08	0.523	0.673	-0.150	1.003	-0.115	0.523	0.673	-0.150	1.003	-0.115
84831	16.00	0.396	0.565	-0.169	1.194	-0.120	0.396	0.565	-0.169	1.194	-0.120

CASE: 25 FRESNO, CALIFORNIA
MCI 3.9300 MC0 3.9300 DENS 0.9322 LAI/YLD 6.620 BLM 0.050 CME 0.500 RSOIL 1000. ZC/DENS 0.2130
ISW 0 FMC 7.00 DTF 600. DTS 3600.
SIG2 1.0000 RHO 0.000 O1 0.10000 O2 0.10000

NC	NP	NFIX	NT	ITMAX	MODEL	IOPT	IPRT
15	2	0	0	20	0	0	1

B(1)	B(2)	B(3)	B(4)	B(5)	B(6)
0.438979e+01	0.979124e+00	0.120000e+00	0.438979e+01	0.979124e+00	0.000000e+00

JFIX(1)	JFIX(2)	JFIX(3)	JFIX(4)	JFIX(5)	JFIX(6)
0	0	1	0	0	1

BL(1)	BL(2)	BL(3)
0.3000e+01	0.1000e+00	0.1500e+01

BH(1)	BH(2)	BH(3)
0.5900e+01	0.4400e+01	0.4800e+01

RHO	SIG2	SST	SSE	R2	R2A	ST'	SE'	R2'	R2A'	B(1)	B(2)
0.000	0.020	16.55930	0.26552	0.984	0.983	16.55930	0.26552	0.984	0.983	4.426862	1.102486

P(1,KP)	P(2,KP)
0.21643d+00	
0.37969d+00	0.74120d+00

CORRELATION MATRIX

0.10000d+01	
0.94800d+00	0.10000d+01

Fri Jul 31 23:14:27 1987

YRDAY	TIME	Y(I)	E(I)	R(I)	BX(1)	BX(2)	G(I)	H(I)	F(I)	BZ(1)	BZ(2)
85730	14.50	3.930	3.930	0.000	0.000	0.000	3.930	3.930	0.000	0.000	0.000
85730	16.18	3.010	3.119	-0.109	0.096	-0.022	3.010	3.119	-0.109	0.096	-0.022
85730	18.00	2.455	2.522	-0.067	0.189	-0.038	2.455	2.522	-0.067	0.189	-0.038
85730	20.00	2.015	2.055	-0.040	0.316	-0.068	2.015	2.055	-0.040	0.316	-0.068
85731	7.92	2.020	1.718	0.302	0.424	-0.079	2.020	1.718	0.302	0.424	-0.079
85731	10.00	1.665	1.631	0.034	0.454	-0.082	1.665	1.631	0.034	0.454	-0.082
85731	12.16	1.220	1.426	-0.206	0.566	-0.092	1.220	1.426	-0.206	0.566	-0.092
85731	14.00	0.920	1.104	-0.184	0.832	-0.077	0.920	1.104	-0.184	0.832	-0.077
85731	16.30	0.665	0.786	-0.121	1.224	-0.157	0.665	0.786	-0.121	1.224	-0.157
85731	18.05	0.605	0.576	0.029	1.740	-0.216	0.605	0.576	0.029	1.740	-0.216
85731	19.50	0.575	0.465	0.110	2.174	-0.255	0.575	0.465	0.110	2.174	-0.255
85801	7.75	0.750	0.529	0.221	1.504	-0.191	0.750	0.529	0.221	1.504	-0.191
85801	10.17	0.505	0.465	0.040	1.735	-0.173	0.505	0.465	0.040	1.735	-0.173
85801	12.01	0.365	0.369	-0.004	2.251	-0.182	0.365	0.369	-0.004	2.251	-0.182
85801	13.64	0.300	0.266	0.034	3.154	-0.171	0.300	0.266	0.034	3.154	-0.171

CASE: 35 FRESNO, CALIFORNIA
MCI 3.2150 MC0 3.2150 DENS 1.4960 LAI/YLD 6.620 BLM 0.350 CME 0.500 RSOIL 1000. ZC/DENS 0.2130
ISW 0 FMC 7.00 DTF 600. DTS 3600.
SIG2 1.0000 RHO 0.000 O1 0.10000 O2 0.10000

NC	NP	NFIX	NT	ITMAX	MODEL	IOPT	IPRT
11	2	0	0	20	0	0	1

B(1)	B(2)	B(3)	B(4)	B(5)	B(6)
0.423324e+01	0.827768e+00	0.120000e+00	0.423324e+01	0.827768e+00	0.000000e+00

JFIX(1)	JFIX(2)	JFIX(3)	JFIX(4)	JFIX(5)	JFIX(6)
0	0	1	0	0	1

BL(1)	BL(2)	BL(3)
0.3000e+01	0.1000e+00	0.1500e+01

BH(1)	BH(2)	BH(3)
0.5900e+01	0.4400e+01	0.4800e+01

RHO	SIG2	SST	SSE	R2	R2A	ST'	SE'	R2'	R2A'	B(1)	B(2)
0.000	0.047	7.88421	0.36593	0.954	0.948	7.88421	0.36593	0.954	0.948	4.238006	0.843029

P(1,KP)	P(2,KP)
0.12164d+00	
0.20618d+00	0.54851d+00

CORRELATION MATRIX

0.10000d+01	
0.79822d+00	0.10000d+01

Sat Aug 1 00:14:26 1987

YRDAY	TIME	Y(I)	E(I)	R(I)	BX(1)	BX(2)	G(I)	H(I)	F(I)	BZ(1)	BZ(2)
85802	14.50	3.215	3.215	0.000	0.000	0.000	3.215	3.215	0.000	0.000	0.000
85802	16.75	2.320	2.332	-0.012	0.153	-0.027	2.320	2.332	-0.012	0.153	-0.027
85802	19.16	1.965	1.841	0.124	0.270	-0.037	1.965	1.841	0.124	0.270	-0.037
85802	20.50	1.955	1.701	0.254	0.336	-0.039	1.955	1.701	0.254	0.336	-0.039
85803	7.78	2.000	1.860	0.140	0.302	-0.042	2.000	1.860	0.140	0.302	-0.042
85803	9.58	1.770	1.746	0.024	0.320	-0.055	1.770	1.746	0.024	0.320	-0.055
85803	11.58	1.380	1.518	-0.138	0.437	-0.032	1.380	1.518	-0.138	0.437	-0.032
85803	13.58	0.965	1.113	-0.148	0.705	-0.032	0.965	1.113	-0.148	0.705	-0.032
85803	15.58	0.575	0.790	-0.215	1.071	-0.040	0.575	0.790	-0.215	1.071	-0.040
85803	17.58	0.420	0.724	-0.304	0.988	-0.071	0.420	0.724	-0.304	0.988	-0.071
85803	19.33	0.395	0.689	-0.294	0.983	0.023	0.395	0.689	-0.294	0.983	0.023

CASE: 38 FRESNO, CALIFORNIA
MCI 3.1450 MC0 3.1450 DENS 1.5754 LAI/YLD 6.620 BLM 0.400 CME 0.500 RSOIL 1000. ZC/DENS 0.2130
ISW 0 FMC 7.00 DTF 600. DTS 3600.
SIG2 1.0000 RHO 0.000 O1 0.10000 O2 0.10000

NC	NP	NFIX	NT	ITMAX	MODEL	IOPT	IPRT
11	2	0	0	20	0	0	1

B(1)	B(2)	B(3)	B(4)	B(5)	B(6)
0.496598e+01	0.253396e+01	0.120000e+00	0.496598e+01	0.253396e+01	0.000000e+00
JFIX(1)	JFIX(2)	JFIX(3)	JFIX(4)	JFIX(5)	JFIX(6)
0	0	1	0	0	1

BL(1)	BL(2)	BL(3)
0.3000e+01	0.1000e+00	0.1500e+01
BH(1)	BH(2)	BH(3)
0.5900e+01	0.4400e+01	0.4800e+01

RHO	SIG2	SST	SSE	R2	R2A	ST'	SE'	R2'	R2A'	B(1)	B(2)
0.000	0.017	8.66062	0.14336	0.983	0.982	8.66062	0.14336	0.983	0.982	4.974516	2.559730

P(1,KP)	P(2,KP)
0.26964d+00	
-0.10925d+00	0.36781d+00

CORRELATION MATRIX

0.10000d+01	
-0.34690d+00	0.10000d+01

Sat Aug 1 03:40:51 1987

YRDAY	TIME	Y(I)	E(I)	R(I)	BX(1)	BX(2)	G(I)	H(I)	F(I)	BZ(1)	BZ(2)
85803	10.56	3.145	3.145	0.000	0.000	0.000	3.145	3.145	0.000	0.000	0.000
85803	11.69	2.695	2.532	0.163	0.068	-0.027	2.695	2.532	0.163	0.068	-0.027
85803	13.73	2.025	1.942	0.083	0.129	-0.064	2.025	1.942	0.083	0.129	-0.064
85803	15.73	1.500	1.474	0.026	0.220	-0.071	1.500	1.474	0.026	0.220	-0.071
85803	17.73	1.240	1.268	-0.028	0.284	-0.073	1.240	1.268	-0.028	0.284	-0.073
85803	19.41	1.130	1.185	-0.055	0.310	-0.068	1.130	1.185	-0.055	0.310	-0.068
85804	7.33	1.020	0.952	0.068	0.387	0.212	1.020	0.952	0.068	0.387	0.212
85804	9.33	0.865	0.851	0.014	0.407	0.219	0.865	0.851	0.014	0.407	0.219
85804	11.33	0.625	0.729	-0.104	0.415	0.270	0.625	0.729	-0.104	0.415	0.270
85804	13.33	0.390	0.582	-0.192	0.581	0.298	0.390	0.582	-0.192	0.581	0.298
85804	15.33	0.210	0.440	-0.230	0.804	0.256	0.210	0.440	-0.230	0.804	0.256

CASE: 44 FRESNO, CALIFORNIA
MCI 3.1700 MC0 3.1700 DENS 1.5780 LAI/YLD 6.620 BLM 1.000 CME 0.500 RSOIL 1000. ZC/DENS 0.2130
ISW 0 FMC 7.00 DTF 600. DTS 3600.
SIG2 1.0000 RHO 0.000 O1 0.10000 O2 0.10000 O3 0.10000

NC	NP	NFIX	NT	ITMAX	MODEL	IOPT	IPRT
10	3	1	0	20	0	0	1

B(1)	B(2)	B(3)	B(4)	B(5)	B(6)
0.423232e+01	0.245641e+01	0.120000e+00	0.423232e+01	0.245641e+01	0.000000e+00
JFIX(1)	JFIX(2)	JFIX(3)	JFIX(4)	JFIX(5)	JFIX(6)
0	0	1	0	0	1

BL(1)	BL(2)	BL(3)	BL(4)
0.3000e+01	0.1000e+00	0.0000e+00	0.1500e+01
BH(1)	BH(2)	BH(3)	BH(4)
0.5900e+01	0.4400e+01	0.2000e+00	0.4800e+01

RHO	SIG2	SST	SSE	R2	R2A	ST'	SE'	R2'	R2A'	B(1)	B(2)	B(3)
0.000	0.005	6.45046	0.04183	0.994	0.993	6.45046	0.04183	0.994	0.993	4.232319	2.456408	0.120000

P(1,KP)	P(2,KP)	P(3,KP)
0.22903d+01		
-0.89898d+00	0.40677d+01	
0.00000d+00	0.00000d+00	0.10000d+09

CORRELATION MATRIX

0.10000d+01		
-0.29453d+00	0.10000d+01	
0.00000d+00	0.00000d+00	0.10000d+01

Tue Aug 4 23:42:24 1987

YRDAY	TIME	Y(I)	E(I)	R(I)	BX(1)	BX(2)	BX(3)	G(I)	H(I)	F(I)	BZ(1)	BZ(2)	BZ(3)
85805	11.83	3.170	3.170	0.000	0.000	0.000	0.000	3.170	3.170	0.000	0.000	0.000	0.000
85805	13.00	2.675	2.582	0.093	0.014	0.005	0.000	2.675	2.582	0.093	0.014	0.005	0.000
85805	15.16	1.935	1.943	-0.008	0.049	-0.002	0.000	1.935	1.943	-0.008	0.049	-0.002	0.000
85805	17.25	1.515	1.560	-0.045	0.097	-0.008	0.000	1.515	1.560	-0.045	0.097	-0.008	0.000
85805	19.34	1.365	1.433	-0.068	0.066	-0.017	0.000	1.365	1.433	-0.068	0.066	-0.017	0.000
85806	7.50	1.345	1.278	0.067	-0.004	0.056	0.000	1.345	1.278	0.067	-0.004	0.056	0.000
85806	9.50	1.215	1.181	0.034	0.007	0.056	0.000	1.215	1.181	0.034	0.007	0.056	0.000
85806	11.50	0.990	0.978	0.012	0.094	0.055	0.000	0.990	0.978	0.012	0.094	0.055	0.000
85806	13.25	0.700	0.725	-0.025	0.170	0.064	0.000	0.700	0.725	-0.025	0.170	0.064	0.000
85806	15.50	0.460	0.601	-0.141	0.232	0.050	0.000	0.460	0.601	-0.141	0.232	0.050	0.000

APPENDIX J

ALFDRY Output for Cuting Date Group 2

ISW 0 FMC 7.00 DTF 600. DTS 3600.
SIG2 1.0000 RHO 0.000 O1 0.1000 O2 0.1000 O3 0.1000 O4 0.1000 O5 0.1000 O6 0.1000 O7 0.1000 O8 0.1000

NC	NP	NPIX	NT	ITMAX	MODEL	IOPT	IPRT
71	2	0	0	20	0	0	0

B(1)	B(2)	B(3)	B(4)	B(5)	B(6)
0.509422e+01	0.223706e+01	0.120000e+00	0.509422e+01	0.223706e+01	0.000000e+00
JPIX(1)	JPIX(2)	JPIX(3)	JPIX(4)	JPIX(5)	JPIX(6)
0	0	1	0	0	1

BL(1)	BL(2)	BL(3)
0.3000e+01	0.1000e+00	0.1500e+01

BH(1)	BH(2)	BH(3)
0.5900e+01	0.4400e+01	0.4800e+01

Sat Aug 1 03:49:13 1987

CASE: 5 EAST LANSING, MICHIGAN
MC0 3.4636 DENS 0.4481 LAI/Y 6.6200 BLOOM 0.0000
CME 0.5000 FM0 3.4636 RSOIL 10. ZC/DENS 0.2130

YRDAY	TIME	Y(I)	E(I)	R(I)	SMC0	SDEN	SL/Y	SBLM	SCME	SFMC	SRVS	SZ/D
84814	13.47	3.464	3.464	0.000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
84814	14.17	2.625	2.907	-0.282	-0.00002	0.01362	-0.00150	0.00000	0.01202	0.03225	0.00000	0.00556
84814	16.10	1.655	1.761	-0.107	0.00034	0.00159	-0.03090	0.00000	0.03598	0.09561	0.00001	0.02308
84814	18.20	1.214	1.297	-0.082	0.00590	-0.01670	-0.06621	0.00000	0.03065	0.10337	0.00106	-0.00133
84814	20.03	1.119	1.062	0.057	0.00690	-0.01517	-0.07906	0.00000	0.03888	0.14178	0.00119	-0.00373
84814	22.11	1.131	0.968	0.163	0.01040	-0.01629	-0.08695	-0.00001	0.04267	0.15632	0.00116	-0.00480
84815	0.01	1.173	0.948	0.224	0.01026	-0.01896	-0.09078	-0.00003	0.04215	0.15789	0.00109	-0.00725
84815	2.24	1.230	0.991	0.238	0.01204	-0.02136	-0.08436	-0.00011	0.03998	0.15225	0.00102	-0.00755
84815	4.02	1.375	1.090	0.284	0.01035	-0.01016	-0.07459	-0.00027	0.03706	0.14284	0.00086	0.02001
84815	6.84	1.464	1.190	0.274	0.00951	-0.01779	-0.06562	-0.00040	0.02407	0.13285	0.00076	0.01320
84815	8.00	1.423	1.206	0.216	0.00936	-0.01826	-0.06522	-0.00040	0.02421	0.13162	0.00073	0.01353
84815	10.15	1.131	0.993	0.138	0.01166	-0.01590	-0.08917	-0.00060	0.07151	0.15426	0.00085	0.00444
84815	12.03	0.857	0.904	-0.046	0.01153	-0.01376	-0.09502	-0.00062	0.07109	0.16075	0.00084	0.00356
84815	14.13	0.577	0.793	-0.216	0.01136	-0.01446	-0.10595	-0.00067	0.07495	0.16975	0.00082	0.00366
84815	16.16	0.428	0.680	-0.251	0.01133	-0.01516	-0.12012	-0.00085	0.09791	0.18232	0.00081	0.01854
84815	18.04	0.363	0.589	-0.226	0.01137	-0.02193	-0.13688	-0.00133	0.10449	0.19453	0.00066	0.01641
84815	20.10	0.369	0.508	-0.139	0.01154	-0.02815	-0.15694	-0.00247	0.11144	0.20914	0.00058	0.01174
84815	22.20	0.410	0.474	-0.063	0.01692	-0.02837	-0.15665	-0.00410	0.11862	0.21210	0.00069	0.01272
84816	0.18	0.440	0.465	-0.024	0.01669	-0.02889	-0.17688	-0.00563	0.11923	0.20981	0.00064	0.01235
84816	2.21	0.470	0.461	0.009	0.01656	-0.02869	-0.15136	-0.00715	0.11859	0.20729	0.00061	0.01208
84816	4.59	0.536	0.465	0.070	0.01334	-0.03195	-0.12012	0.02571	0.14301	0.19499	0.00028	0.01276
84816	6.98	0.613	0.551	0.062	0.00832	-0.00644	-0.07946	0.01363	0.12116	0.16262	0.00015	0.01285
84816	9.10	0.613	0.533	0.080	0.00702	0.03545	-0.07236	-0.01056	0.10126	0.14722	-0.00005	0.00202
84816	11.23	0.482	0.461	0.021	0.00552	-0.00500	-0.04308	-0.01256	0.10572	0.16798	-0.00001	0.00513
84816	13.15	0.298	0.418	-0.120	0.00571	-0.00755	-0.05361	-0.01531	0.11417	0.17390	-0.00001	0.00558
84816	15.26	0.184	0.357	-0.173	0.00592	-0.01477	-0.07123	-0.01926	0.12864	0.18205	-0.00001	0.00761

SSTO 14.06 SSR 13.35 SSE 0.70 R2 0.9500 R2A 0.9479
N 26 NP 2 DF 24 MSE 0.0293 F 455.7520

Sat Aug 1 03:59:56 1987

CASE: 6 EAST LANSING, MICHIGAN
MC0 3.4201 DENS 0.2716 LAI/Y 6.6200 BLOOM 0.0000
CME 0.5000 FM0 3.4201 RSOIL 10. ZC/DENS 0.2130

YRDAY	TIME	Y(I)	E(I)	R(I)	SMC0	SDEN	SL/Y	SBLM	SCME	SFMC	SRVS	SZ/D
84814	13.47	3.420	3.420	0.000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
84814	14.17	2.399	2.776	-0.377	-0.00001	0.01222	-0.01700	0.00000	0.00849	0.03756	0.00000	-0.00298
84814	16.10	1.368	1.653	-0.285	0.00185	0.01730	-0.04114	0.00000	0.03122	0.10033	-0.00001	0.00181

84814	18.20	0.965	1.290	-0.325	0.00279	-0.00075	-0.06520	0.00000	0.04159	0.11818	-0.00077	0.00379
84814	20.03	0.876	1.059	-0.183	0.02602	-0.01182	-0.08643	0.00000	0.04155	0.12176	-0.00073	0.00466
84814	22.11	0.915	0.993	-0.078	-0.01366	-0.01261	-0.08809	-0.00007	0.04724	0.12676	-0.00115	0.00350
84815	0.01	1.004	1.006	-0.002	-0.04021	-0.00579	-0.11244	-0.00014	0.04840	0.12764	-0.00071	0.00379
84815	2.24	1.161	1.080	0.081	-0.03914	-0.01084	-0.10205	-0.00020	0.04499	0.11851	-0.00084	0.00275
84815	4.02	1.308	1.245	0.063	-0.02939	-0.02454	-0.08747	0.00030	0.03893	0.10319	-0.00063	0.00489
84815	6.84	1.475	1.402	0.073	-0.02574	-0.02958	-0.07203	0.00252	0.03454	0.09129	-0.00063	0.00181
84815	8.00	1.386	1.426	-0.040	-0.02502	-0.03085	-0.07025	0.00242	0.03373	0.08937	-0.00068	0.00108
84815	10.15	0.994	1.214	-0.221	-0.03028	-0.02463	-0.08405	0.00271	0.03915	0.10304	-0.00078	0.00104
84815	12.03	0.709	1.081	-0.372	-0.02518	-0.02439	-0.09062	0.00269	0.04256	0.11101	-0.00071	0.00144
84815	14.13	0.453	0.934	-0.481	-0.02112	-0.02391	-0.10075	0.00262	0.05146	0.12297	-0.00067	0.00288
84815	16.16	0.355	0.824	-0.469	-0.01886	-0.02938	-0.11443	0.00252	0.05966	0.13227	-0.00112	0.00358
84815	18.04	0.296	0.720	-0.424	-0.01731	-0.03237	-0.12750	0.00246	0.06996	0.14360	-0.00111	0.00406
84815	20.10	0.316	0.616	-0.300	-0.01653	-0.03187	-0.14152	0.00209	0.08360	0.15813	-0.00118	0.00553
84815	22.20	0.374	0.578	-0.203	-0.01639	-0.03341	-0.14718	0.00140	0.08911	0.16350	-0.00127	0.00544
84816	0.18	0.424	0.567	-0.144	-0.01625	-0.03352	-0.14656	0.00068	0.09009	0.16403	-0.00133	0.00510
84816	2.21	0.463	0.568	-0.105	-0.01606	-0.04089	-0.15189	-0.00302	0.08590	0.15539	-0.00130	-0.00291
84816	4.59	0.561	0.577	-0.016	-0.02452	-0.03577	-0.13006	-0.01629	0.07123	0.13869	-0.00132	-0.00495
84816	6.98	0.659	0.725	-0.065	-0.01902	-0.03901	-0.08744	-0.01428	0.05662	0.10879	-0.00092	-0.00669
84816	9.10	0.669	0.687	-0.018	-0.01837	-0.04288	-0.03661	0.01857	0.09254	0.14597	-0.00138	0.03304
84816	11.23	0.492	0.643	-0.151	-0.01908	-0.08802	-0.16636	-0.03276	0.04922	0.10174	-0.07037	-0.03038
84816	13.15	0.286	0.581	-0.296	-0.01856	-0.08778	-0.17353	-0.03189	0.05801	0.11108	-0.06726	-0.02863
84816	15.26	0.179	0.525	-0.347	-0.01783	-0.10164	-0.19346	-0.03106	0.06677	0.11892	-0.06609	-0.02721

SSTO 12.87 SSR 11.26 SSE 1.60 R2 0.8755 R2A 0.8703
N 26 NP 2 DF 24 MSE 0.0668 F 168.7231

Sat Aug 1 04:10:08 1987

CASE: 7 EAST LANSING, MICHIGAN
MC0 3.6700 DENS 0.3349 LAI/Y 6.6200 BLOOM 0.0000
CME 0.5000 FM0 3.6700 RSOIL 10. ZC/DENS 0.2130

YRDAY	TIME	Y(I)	E(I)	R(I)	SMC0	SDEN	SL/Y	SBLM	SCME	SFMC	SRVS	SZ/D
84814	13.05	3.670	3.670	0.000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
84814	14.13	2.890	2.743	0.147	0.02768	0.00991	-0.02109	0.00000	0.03642	0.06319	0.00002	0.00040
84814	15.46	2.060	1.970	0.090	0.02116	0.01161	-0.03663	0.00000	0.04275	0.12467	0.00001	0.00119
84814	16.96	1.630	1.594	0.036	0.01717	0.00272	-0.05177	0.00000	0.04750	0.13353	-0.00040	0.00121
84814	18.96	1.320	1.244	0.076	0.06307	0.00226	-0.06427	0.00000	0.05785	0.14707	-0.00052	0.00304
84814	20.38	1.320	1.087	0.233	0.06932	0.00327	-0.07173	0.00000	0.06542	0.15661	-0.00052	0.00363
84815	7.01	1.750	1.271	0.479	0.05579	-0.01531	-0.05552	0.00002	0.05566	0.12859	-0.00087	-0.00402
84815	8.96	1.580	1.228	0.352	0.05621	-0.01638	-0.06002	-0.00009	0.05701	0.13197	-0.00097	-0.00683
84815	11.21	1.170	1.003	0.167	0.06363	-0.00464	-0.07379	-0.00026	0.06841	0.15553	-0.00109	-0.00643
84815	12.88	0.870	0.912	-0.042	0.06178	-0.00487	-0.08177	-0.00032	0.07452	0.16330	-0.00105	-0.00589
84815	15.30	0.590	0.790	-0.200	0.05708	-0.01926	-0.10858	-0.00050	0.08196	0.17152	-0.00113	-0.00391
84815	16.47	0.520	0.735	-0.215	0.05638	-0.03055	-0.12588	-0.00066	0.08554	0.17738	-0.00132	-0.00541
84815	18.47	0.460	0.639	-0.179	0.05619	-0.03194	-0.13958	-0.00117	0.09816	0.18989	-0.00134	-0.00415
84815	20.47	0.520	0.561	-0.042	0.05661	-0.03026	-0.14970	-0.00214	0.11061	0.20276	-0.00138	-0.00283
84816	6.50	0.790	0.663	0.127	0.04769	-0.05419	-0.07967	-0.00261	0.06382	0.12805	-0.00146	-0.00835
84816	8.47	0.720	0.685	0.035	0.05894	-0.03984	-0.05541	-0.00304	0.07546	0.13568	-0.00125	0.00313
84816	10.47	0.520	0.587	-0.067	0.08020	0.00127	-0.06478	0.02508	0.08343	0.17588	-0.00134	0.00113
84816	12.47	0.310	0.539	-0.229	0.07957	-0.00098	-0.07349	0.02157	0.09054	0.18001	-0.00134	0.00016
84816	14.47	0.290	0.478	-0.188	0.07914	-0.00286	-0.08689	0.02831	0.10142	0.18921	0.00680	0.02145

SSTO 14.79 SSR 14.09 SSE 0.70 R2 0.9524 R2A 0.9496
N 19 NP 2 DF 17 MSE 0.0414 F 340.3369

OVERALL
SSTO 42.77 SSR 39.77 SSE 3.01 R2 0.9297 R2A 0.9286
N 71 NP 2 DF 69 MSE 0.0436 F 911.8147

APPENDIX K

Detailed Report from ALFDRY for Trial 5

CASE: 5 EAST LANSING, MICHIGAN

DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
814	13.47	3.4636	3.4636	61.12	613.4	28.04	12.64	1.9450	0.3157	0.6064	0.0000	0.00

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	PAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	3.4636	0.989	30.04	30.39	0.0000	0.000	0.000	0.100e+01	0.065	192.601	-34.655	0.000	159.010	1.252	0.000
2	3.4636	0.989	29.04	28.78	0.0000	0.000	0.000	0.100e+01	0.045	125.591	-10.840	0.000	108.973	1.252	0.000
3	3.4636	0.989	28.04	27.25	0.0000	0.000	0.000	0.100e+01	0.014	80.304	5.440	0.000	35.156	1.252	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	29.98	16.98	0.372											0.29e+02	0.29e+02
1	30.04	17.13	0.225	0.0654	0.1363	0.000	159.010	71.600	331.670	-123.887	39.504	0.22e+02	0.20e+03	0.33e+02	0.33e+02
2	29.04	19.10	0.075	0.0448	0.0872	0.000	108.973	-52.066	211.943	52.170	-103.074	0.37e+02	0.22e+03	0.23e+02	0.23e+02
3	28.04	20.81	0.000	0.0144	0.0000	0.000	35.156	0.000	0.000	1.139	61.512	0.29e+03	0.45e+03	0.10e+11	0.10e+11
GND	28.67	27.73	0.000					1.145	26.350					0.65e+03	0.64e+03

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 61.12 EFFECTIVE REFLECTANCE: 0.1367 EFFECTIVE TRANSMITTANCE: 0.2482

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			483.8621	129.5187	0.0001	-0.0001	61.5033	22.3237	529.5538	
1	3.4636	0.5363	275.1097	57.8805	43.3262	15.8341	42.9803	12.2174	336.9530	192.6008
2	3.4636	0.5363	156.4193	28.8481	46.6702	14.6850	28.2034	7.0572	211.3620	125.5910
3	3.4636	0.5363	88.9354	15.0192	37.6551	10.6237	17.3294	3.8464	131.0576	80.3044

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.8727 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	29.98		0.8727		430.7145		53.5694	430.7145	483.4485	-52.7341	
1	30.04	30.04	0.8629	0.9600	192.4817	486.5124	102.8930	461.5769	479.6564	-18.0795	-34.6546
2	29.04	29.04	0.8765	0.9600	95.9344	480.1257	206.4433	471.8365	479.0755	-7.2391	-10.8404
3	28.04	28.04	0.8873	0.9600	49.9465	473.8021	461.9563	472.9236	485.6024	-12.6788	5.4397
GND	28.67			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	28.67	26.92	25.74	23.90	21.41	20.02	19.75	19.47	19.19	18.92	18.64
HEAT FLUX:	90.8842	90.8842	30.8208	47.8016	64.7823	35.9910	7.1998	7.1998	7.1998	7.1998	7.1998
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
814	14.17	2.8632	2.6246	60.69	594.1	28.43	12.65	2.5448	0.3390	0.6064	-0.2386	-9.09

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	2.7186	0.964	31.61	33.07	0.0000	0.000	0.000	0.303e+01	0.030	165.102	-34.929	83.081	72.490	1.140	0.000
2	2.8313	0.989	31.39	32.68	0.0000	0.000	0.000	0.256e+01	0.031	116.365	-15.643	35.889	75.815	1.160	0.000
3	3.0397	0.989	30.73	31.55	0.0000	0.000	0.000	0.188e+01	0.032	78.250	-0.833	6.378	77.270	1.194	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	30.02	15.67	0.478											0.24e+02	0.24e+02
1	30.30	16.11	0.228	0.0299	0.1056	83.081	72.490	67.484	256.962	33.945	2.405	0.19e+02	0.57e+03	0.33e+02	0.33e+02
2	30.56	17.35	0.086	0.0312	0.0768	35.889	75.815	18.653	186.571	13.974	0.512	0.27e+02	0.49e+03	0.16e+02	0.16e+02
3	30.45	19.15	0.033	0.0318	0.0458	6.378	77.270	-3.213	111.220	9.582	-33.940	0.52e+02	0.39e+03	0.39e+02	0.39e+02
GND	29.84	26.93	0.000					0.000	0.000					0.10e+11	0.10e+11

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 60.69 EFFECTIVE REFLECTANCE: 0.1660 EFFECTIVE TRANSMITTANCE: 0.2662

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			464.7487	129.3910	0.0002	0.0000	71.6166	27.0257	495.4976	
1	2.7186	0.6146	267.4620	58.9103	50.3154	19.1693	50.2998	15.1621	330.3951	165.1025
2	2.8313	0.6027	151.7160	29.3165	55.0164	18.1787	31.7027	8.4943	214.0306	116.3645
3	3.0397	0.5808	86.0599	15.2504	43.7528	13.0791	18.0362	4.3252	135.7807	78.2499

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.8762 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	30.02		0.8762		434.6912		54.8283	434.6912	495.7351	-61.0439	
1	30.30	31.61	0.8554	0.9600	197.9100	496.6985	103.5291	468.4673	494.5825	-26.1152	-34.9287
2	30.56	31.39	0.8645	0.9600	98.4894	495.2675	207.4086	483.2907	493.7630	-10.4722	-15.6430
3	30.45	30.73	0.8768	0.9600	51.2340	490.9937	461.2665	487.5513	497.1904	-9.6391	-0.8331
GND	29.84			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	29.84	27.42	25.67	23.81	21.83	20.50	19.89	19.52	19.21	18.92	18.64
HEAT FLUX:	126.1416	126.1416	45.4803	48.2029	51.5373	34.6567	15.7394	9.8561	8.0267	7.4591	7.2875
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
814	16.10	1.9243	1.6545	47.96	441.0	29.31	12.69	4.0614	0.4100	0.6064	-0.2698	-16.31

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	1.8667	0.936	32.45	34.58	0.0000	0.000	0.000	0.107e+02	0.011	121.818	-27.968	80.992	26.065	0.941	0.000
2	1.9034	0.937	33.00	35.59	0.0000	0.000	0.000	0.102e+02	0.012	78.263	-14.822	58.362	28.407	0.952	0.000
3	2.0028	0.940	32.93	35.46	0.0000	0.000	0.000	0.878e+01	0.013	49.109	-3.946	20.334	31.883	0.981	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	31.12	13.33	0.753											0.16e+02	0.16e+02
1	31.41	13.42	0.392	0.0107	0.0350	80.992	26.065	118.874	85.140	23.112	3.185	0.15e+02	0.20e+04	0.21e+02	0.21e+02
2	31.91	13.66	0.150	0.0117	0.0256	58.362	28.407	61.109	62.146	14.220	-0.315	0.22e+02	0.19e+04	0.95e+01	0.95e+01
3	32.23	13.96	0.059	0.0132	0.0138	20.334	31.883	17.003	33.388	-55.354	322.945	0.40e+02	0.16e+04	0.22e+02	0.22e+02
GND	25.71	31.39	0.040					-59.004	324.768					0.13e+03	0.13e+03

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 47.96 EFFECTIVE REFLECTANCE: 0.1986 EFFECTIVE TRANSMITTANCE: 0.2627

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			332.0417	108.9256	0.0000	0.0000	59.5822	27.9967	353.3884	
1	1.8667	0.7040	176.8632	50.6338	41.6563	19.7875	41.0968	16.2735	231.5704	121.8179
2	1.9034	0.7001	94.1314	26.0617	46.0710	19.8590	24.4777	8.3379	153.3074	78.2631
3	2.0028	0.6897	49.9904	13.9552	37.0447	14.8413	10.1270	1.5065	104.1982	49.1092

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.8869 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	31.12		0.8869		445.2003		56.4193	445.2003	504.3686	-59.1683	
1	31.41	32.45	0.8333	0.9600	206.9503	502.1770	104.5335	475.6915	506.8916	-31.2001	-27.9682
2	31.91	33.00	0.8355	0.9600	106.5194	505.7727	201.2748	491.8019	508.1798	-16.3779	-14.8222
3	32.23	32.93	0.8381	0.9600	57.0378	505.3135	421.7455	499.0532	511.4850	-12.4318	-3.9461
GND	25.71			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	25.71	29.06	26.43	24.34	22.62	21.31	20.41	19.79	19.34	18.98	18.66
HEAT FLUX:	-173.9981	-173.9981	68.2992	54.4861	44.7038	33.9572	23.5006	16.0905	11.7118	9.4194	8.3703
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
814	18.20	1.5445	1.2142	26.11	157.1	26.59	13.22	2.9818	0.6200	0.6064	-0.3303	-27.21

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	1.4990	0.924	29.39	29.33	0.0000	0.000	0.000	0.186e+02	0.005	59.637	-18.524	28.366	11.324	0.813	0.000
2	1.5240	0.925	29.53	29.57	0.0000	0.000	0.000	0.179e+02	0.005	27.202	-8.190	7.706	11.814	0.823	0.000
3	1.6106	0.927	29.63	29.72	0.0000	0.000	0.000	0.157e+02	0.006	13.505	-2.224	1.356	13.375	0.856	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	28.99	13.53	0.559											0.20e+02	0.20e+02
1	28.95	13.52	0.352	0.0047	0.0134	28.366	11.324	122.941	32.620	-49.543	2.421	0.18e+02	0.34e+04	0.23e+02	0.23e+02

2	29.35	13.62	0.137	0.0049	0.0097	7.706	11.814	45.075	23.673	-26.355	1.279	0.28e+02	0.33e+04	0.10e+02	0.10e+02
3	29.58	13.76	0.054	0.0055	0.0054	1.356	13.375	11.022	13.130	-9.667	0.247	0.42e+02	0.29e+04	0.25e+02	0.25e+02
GND	27.34	26.06	0.000					0.000	0.000					0.10e+11	0.10e+11

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 26.11 EFFECTIVE REFLECTANCE: 0.1995 EFFECTIVE TRANSMITTANCE: 0.1822

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			96.4485	60.6307	0.0000	0.0000	14.0234	17.3073	125.7484	
1	1.4990	0.7426	33.7651	28.4333	10.0515	12.0933	7.6557	10.5763	66.1111	59.6373
2	1.5240	0.7400	11.8098	14.7471	9.5991	12.5156	3.8596	5.9025	38.9094	27.2017
3	1.6106	0.7309	4.1177	7.9556	6.8325	9.7086	1.3092	1.9006	25.4045	13.5050

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.9194 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	28.99		0.9194		445.1301		53.9157	445.1301	483.4276	-38.2975	
1	28.95	29.39	0.8342	0.9600	208.7475	482.3373	99.0990	464.8887	484.6620	-19.7734	-18.5241
2	29.35	29.53	0.8351	0.9600	108.2686	483.2698	189.0012	474.6550	486.2386	-11.5837	-8.1897
3	29.58	29.63	0.8363	0.9600	58.4074	483.8724	390.2383	479.5613	488.9212	-9.3599	-2.2238
GND	27.34			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	27.34	27.03	25.74	24.36	23.02	21.83	20.87	20.13	19.55	19.09	18.69
HEAT FLUX:	16.0446	16.0446	33.5216	35.8752	35.0185	30.7856	24.9429	19.3355	14.9564	12.0312	10.4127
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
814	20.03	1.3880	1.1190	6.11	152.7	23.08	13.54	2.7470	0.5283	0.6064	-0.2690	-24.04

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	1.3470	0.919	25.73	23.99	0.0000	0.000	0.000	0.233e+02	0.002	38.585	-20.866	8.420	5.203	0.749	0.000
2	1.3704	0.920	25.64	23.85	0.0000	0.000	0.000	0.225e+02	0.002	19.331	-8.040	-0.110	4.880	0.759	0.000
3	1.4466	0.922	25.71	23.95	0.0000	0.000	0.000	0.201e+02	0.002	12.228	-1.714	4.606	4.427	0.792	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	25.53	14.73	0.517											0.22e+02	0.22e+02
1	25.60	14.92	0.305	0.0021	0.0530	8.420	5.203	116.529	129.594	-104.013	14.989	0.20e+02	0.43e+04	0.26e+02	0.26e+02
2	25.64	15.62	0.118	0.0020	0.0570	-0.110	4.880	4.257	139.218	-8.755	-0.309	0.31e+02	0.41e+04	0.12e+02	0.12e+02
3	25.53	17.25	0.046	0.0018	0.0549	4.606	4.427	-4.392	134.034	8.993	-129.602	0.46e+02	0.37e+04	0.30e+02	0.30e+02
GND	25.52	21.68	0.000					0.000	0.000					0.10e+11	0.10e+11

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 6.11 EFFECTIVE REFLECTANCE: 0.2775 EFFECTIVE TRANSMITTANCE: 0.2784

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			9.6046	143.1347	0.0000	-0.0001	0.4643	41.9167	110.3582	
1	1.3470	0.7586	0.1279	67.3669	0.2940	29.3987	0.0968	25.3173	71.7735	38.5848
2	1.3704	0.7561	0.0017	35.0476	0.1873	30.4909	0.0493	13.2353	52.4429	19.3306
3	1.4466	0.7481	0.0000	18.9656	0.1133	23.4419	0.0170	2.2892	40.2147	12.2282

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.9076 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	25.53		0.9076		419.1588		51.3017	419.1588	459.8919	-40.7331	
1	25.60	25.73	0.8460	0.9600	197.2787	459.4709	93.9861	440.4979	460.3654	-19.8676	-20.8656
2	25.64	25.64	0.8516	0.9600	102.6341	458.8650	178.5670	450.2252	462.0530	-11.8278	-8.0397
3	25.53	25.71	0.8638	0.9600	55.5392	459.2997	366.5089	455.0388	465.1530	-10.1142	-1.7136
GND	25.52			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	25.52	24.94	24.99	24.19	23.14	22.09	21.16	20.38	19.74	19.20	18.73
HEAT FLUX:	30.1005	30.1005	-1.3097	20.9280	27.4069	27.2094	24.1585	20.2751	16.6950	13.9783	12.3276
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
814	22.11	1.3095	1.1308	0.00	0.0	18.27	13.13	3.0280	0.1927	0.6064	-0.1787	-15.81

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	1.2728	0.917	19.39	16.68	0.0000	0.000	0.000	0.260e+02	0.001	0.000	-21.212	-26.086	1.428	0.485	0.000
2	1.2932	0.917	20.00	17.28	0.0000	0.000	0.000	0.252e+02	0.001	0.000	-6.706	-8.873	1.600	0.513	0.000
3	1.3625	0.919	20.73	18.03	0.0000	0.000	0.000	0.228e+02	0.001	0.000	2.535	0.640	1.791	0.563	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	19.58	13.80	0.563											0.21e+02	0.21e+02
1	19.80	13.92	0.358	0.0006	0.0351	-26.086	1.428	83.072	86.351	-60.202	-0.183	0.19e+02	0.47e+04	0.22e+02	0.22e+02
2	20.21	14.27	0.140	0.0007	0.0345	-8.873	1.600	49.037	84.660	-28.919	0.674	0.29e+02	0.46e+04	0.10e+02	0.10e+02
3	20.71	14.98	0.057	0.0007	0.0341	0.640	1.791	29.027	83.696	-23.820	-13.637	0.43e+02	0.42e+04	0.21e+02	0.21e+02
GND	21.19	18.53	0.039					4.610	68.226					0.13e+03	0.13e+03

SHORT-WAVE RADIATION FIELD IN SWATH:

NO SHORT-WAVE RADIATION AT NIGHT

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.8581 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	19.58		0.8581		371.1783		49.9068	371.1783	426.6005	-55.4222	
1	19.80	19.39	0.8377	0.9600	175.0037	421.7020	91.2851	397.8810	432.0916	-34.2106	-21.2117
2	20.21	20.00	0.8407	0.9600	91.1856	425.1920	173.1054	412.3216	439.8258	-27.5042	-6.7064
3	20.71	20.73	0.8466	0.9600	49.4222	429.4723	354.2399	421.4032	451.4424	-30.0392	2.5350
GND	21.19			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	21.19	23.17	23.86	23.61	22.95	22.15	21.33	20.57	19.90	19.31	18.76
HEAT FLUX:	-102.8746	-102.8746	-17.8629	6.3337	17.0835	21.0267	21.2423	19.6328	17.4498	15.4767	14.1540
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
815	0.01	1.2908	1.1725	0.00	0.0	17.22	12.61	2.0512	0.0660	0.6064	-0.1183	-10.09

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	PAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	1.2560	0.916	17.38	14.80	0.0000	0.000	0.000	0.267e+02	0.000	0.000	-23.042	-21.515	0.615	0.417	0.000
2	1.2749	0.917	17.85	15.22	0.0000	0.000	0.000	0.259e+02	0.000	0.000	-6.172	-4.763	0.677	0.437	0.000
3	1.3414	0.919	18.68	15.99	0.0000	0.000	0.000	0.235e+02	0.000	0.000	3.509	6.009	0.843	0.483	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	17.75	13.50	0.382											0.30e+02	0.30e+02
1	17.75	13.59	0.290	0.0002	0.0346	-21.515	0.615	23.091	85.032	-23.328	-21.401	0.21e+02	0.49e+04	0.28e+02	0.28e+02
2	17.97	13.91	0.113	0.0003	0.0256	-4.763	0.677	21.302	62.991	-1.273	0.027	0.32e+02	0.47e+04	0.13e+02	0.13e+02
3	18.45	14.51	0.047	0.0003	0.0253	6.009	0.843	24.813	62.319	-9.852	-31.564	0.47e+02	0.43e+04	0.24e+02	0.24e+02
GND	19.89	16.90	0.033					8.989	29.875					0.20e+03	0.20e+03

SHORT-WAVE RADIATION FIELD IN SWATH:

NO SHORT-WAVE RADIATION AT NIGHT

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.8356 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	17.75		0.8356		356.2603		48.9163	356.2603	415.1118	-58.8515	
1	17.75	17.38	0.8348	0.9600	168.0369	410.2281	89.4412	384.7731	420.5822	-35.8091	-23.0424
2	17.97	17.85	0.8376	0.9600	87.5876	412.8456	169.5325	399.6107	429.2482	-29.6375	-6.1716
3	18.45	18.68	0.8427	0.9600	47.4911	417.6169	346.6736	409.1410	442.2878	-33.1468	3.5093
GND	19.89			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	19.89	21.28	22.40	22.70	22.48	21.97	21.32	20.64	19.99	19.37	18.79
HEAT FLUX:	-72.0110	-72.0110	-29.1075	-8.0364	5.7569	13.4513	16.8349	17.5802	16.9993	16.0156	15.2154
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
815	2.24	1.2771	1.2297	0.00	0.0	15.98	12.18	1.7548	0.0000	0.6064	-0.0474	-3.85

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	1.2451	0.916	15.66	13.35	0.0000	0.000	0.000	0.271e+02	0.000	0.000	-24.098	-23.968	0.318	0.368	0.000
2	1.2622	0.916	16.13	13.73	0.0000	0.000	0.000	0.264e+02	0.000	0.000	-6.446	-6.167	0.410	0.384	0.000
3	1.3239	0.918	16.94	14.41	0.0000	0.000	0.000	0.241e+02	0.000	0.000	4.169	4.078	0.638	0.423	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	16.08	12.65	0.324											0.37e+02	0.37e+02
1	16.08	12.71	0.198	0.0001	0.0129	-23.968	0.318	2.911	31.843	-10.196	-2.111	0.21e+02	0.49e+04	0.41e+02	0.41e+02
2	16.32	12.92	0.078	0.0002	0.0119	-6.167	0.410	16.688	29.409	-4.242	0.114	0.38e+02	0.48e+04	0.18e+02	0.18e+02
3	16.75	13.26	0.034	0.0003	0.0118	4.078	0.638	18.622	29.104	-4.359	-1.305	0.54e+02	0.44e+04	0.29e+02	0.29e+02
GND	18.54	15.63	0.025					10.214	27.132					0.21e+03	0.21e+03

SHORT-WAVE RADIATION FIELD IN SWATH:

NO SHORT-WAVE RADIATION AT NIGHT

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.8218 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	16.08		0.8218		344.4453		47.9975	344.4453	405.5679	-61.1226	
1	16.08	15.66	0.8269	0.9600	162.5059	400.5994	87.7408	374.1064	411.1305	-37.0241	-24.0985
2	16.32	16.13	0.8289	0.9600	84.7262	403.1706	166.2578	389.4640	420.0423	-30.5784	-6.4457
3	16.75	16.94	0.8320	0.9600	45.9552	407.7072	339.7789	399.1162	433.8632	-34.7469	4.1686
GND	18.54			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	18.54	19.92	21.13	21.70	21.80	21.57	21.13	20.59	20.00	19.40	18.80
HEAT FLUX:	-72.0938	-72.0938	-31.2795	-14.8955	-2.6416	5.9991	11.3742	14.2116	15.3706	15.6227	15.5431
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT

815	4.02	1.2712	1.3749	0.00	0.0	15.01	11.93	2.0598	0.0027	0.6064	0.1037	7.54

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	1.2414	0.916	14.80	12.67	0.0000	0.000	0.000	0.272e+02	0.000	0.000	-24.474	-24.578	0.113	0.346	0.000
2	1.2571	0.916	15.21	12.99	0.0000	0.000	0.000	0.266e+02	0.000	0.000	-6.258	-6.096	0.190	0.360	0.000
3	1.3150	0.918	16.03	13.65	0.0000	0.000	0.000	0.244e+02	0.000	0.000	4.608	4.792	0.403	0.395	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	15.23	12.39	0.381											0.31e+02	0.31e+02
1	15.20	12.44	0.222	0.0000	0.0137	-24.578	0.113	6.261	33.658	-16.302	-6.970	0.20e+02	0.50e+04	0.37e+02	0.37e+02
2	15.40	12.62	0.087	0.0001	0.0108	-6.096	0.190	14.541	26.571	-1.691	0.006	0.37e+02	0.49e+04	0.16e+02	0.16e+02
3	15.82	12.91	0.037	0.0002	0.0107	4.792	0.403	18.954	26.379	-3.296	-3.608	0.53e+02	0.45e+04	0.28e+02	0.28e+02
GND	17.67	14.82	0.027					10.891	22.344					0.21e+03	0.21e+03

SHORT-WAVE RADIATION FIELD IN SWATH:

NO SHORT-WAVE RADIATION AT NIGHT

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.8199 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	15.23		0.8199		339.0673		47.5330	339.0673	400.7463	-61.6790	
1	15.20	14.80	0.8244	0.9600	159.9826	395.8282	86.8847	369.0467	406.2515	-37.2048	-24.4741
2	15.40	15.21	0.8260	0.9600	83.4193	398.1198	164.6153	384.4073	415.3541	-30.9468	-6.2581
3	15.82	16.03	0.8288	0.9600	45.2542	402.6333	336.3275	394.0486	429.6039	-35.5552	4.6084
GND	17.67			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	17.67	18.99	20.24	20.96	21.24	21.19	20.90	20.46	19.94	19.37	18.79
HEAT FLUX:	-68.7899	-68.7899	-32.3111	-18.7524	-7.3657	1.3834	7.5104	11.3927	13.5895	14.6755	15.1238
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
815	6.84	1.2619	1.4642	0.02	0.0	17.10	12.71	2.5431	0.3787	0.6064	0.2023	13.82

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	1.2311	0.915	15.93	13.57	0.0000	0.000	0.000	0.277e+02	0.000	0.007	-10.586	-13.217	0.415	0.371	0.000
2	1.2508	0.916	16.15	13.75	0.0000	0.000	0.000	0.269e+02	0.000	0.005	-1.308	-1.904	0.469	0.382	0.000
3	1.3037	0.918	16.59	14.12	0.0000	0.000	0.000	0.248e+02	0.000	0.003	5.131	5.113	0.598	0.408	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	16.20	12.69	0.462											0.26e+02	0.26e+02
1	16.16	12.71	0.270	0.0002	0.0000	-13.217	0.415	-36.377	0.091	26.570	17.458	0.22e+02	0.51e+04	0.32e+02	0.32e+02
2	16.20	12.81	0.105	0.0002	0.0070	-1.904	0.469	3.412	17.131	2.393	0.029	0.34e+02	0.49e+04	0.14e+02	0.14e+02
3	16.39	13.01	0.042	0.0002	0.0068	5.113	0.598	7.710	16.689	2.144	4.152	0.50e+02	0.46e+04	0.30e+02	0.30e+02
GND	16.95	14.22	0.029					4.747	20.238					0.15e+03	0.15e+03

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 0.02 EFFECTIVE REFLECTANCE: 0.3059 EFFECTIVE TRANSMITTANCE: 0.3105

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			0.0000	0.0361	0.0000	0.0000	0.0000	0.0110	0.0250	
1	1.2311	0.7707	0.0000	0.0170	0.0000	0.0077	0.0000	0.0069	0.0178	0.0072
2	1.2508	0.7687	0.0000	0.0089	0.0000	0.0081	0.0000	0.0039	0.0131	0.0048
3	1.3037	0.7631	0.0000	0.0048	0.0000	0.0064	0.0000	0.0013	0.0099	0.0031

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.8820 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	16.20		0.8820		375.4640		46.8988	375.4640	405.1791	-29.7151	
1	16.16	15.93	0.8269	0.9600	177.1988	402.0790	85.7066	389.5181	408.6477	-19.1295	-10.5856
2	16.20	16.15	0.8278	0.9600	92.4072	403.3065	162.3569	396.8022	414.6238	-17.8216	-1.3080
3	16.39	16.59	0.8297	0.9600	50.1409	405.7950	331.5870	401.5582	424.5108	-22.9526	5.1310
GND	16.95			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	16.95	17.88	19.09	19.92	20.39	20.54	20.44	20.16	19.76	19.29	18.77
HEAT FLUX:	-47.9283	-47.9283	-31.5257	-21.6221	-12.1125	-3.9502	2.4949	7.2197	10.4333	12.4319	13.4982
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
815	8.00	1.2555	1.4227	12.44	108.9	20.19	13.74	3.4273	0.2667	0.6064	0.1672	11.75

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	PAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	1.2253	0.915	18.16	15.51	0.0000	0.000	0.000	0.279e+02	0.000	50.534	-14.317	39.045	0.867	0.431	0.000
2	1.2447	0.916	17.65	15.04	0.0000	0.000	0.000	0.271e+02	0.000	12.919	-1.895	12.047	0.633	0.422	0.000
3	1.2966	0.917	17.57	14.97	0.0000	0.000	0.000	0.251e+02	0.000	6.004	5.329	8.425	0.581	0.435	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	18.24	13.68	0.621											0.20e+02	0.20e+02
1	17.64	13.71	0.364	0.0004	-0.0012	39.045	0.867	-130.284	-2.851	137.780	15.719	0.16e+02	0.51e+04	0.24e+02	0.24e+02
2	17.36	13.77	0.139	0.0003	0.0049	12.047	0.633	-31.551	12.003	39.501	-1.433	0.29e+02	0.50e+04	0.11e+02	0.11e+02
3	17.26	13.89	0.052	0.0002	0.0040	8.425	0.581	-4.098	9.939	13.583	5.230	0.45e+02	0.46e+04	0.29e+02	0.29e+02

GND 17.39 14.77 0.035 1.061 14.588 0.15e+03 0.15e+03

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 12.44 EFFECTIVE REFLECTANCE: 0.2042 EFFECTIVE TRANSMITTANCE: 0.1785

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			51.7481	57.1039	0.0000	0.0000	4.7269	17.4982	86.6269	
1	1.2253	0.7713	6.1838	26.9537	3.3438	12.1613	1.6093	10.9405	36.0928	50.5340
2	1.2447	0.7693	0.7379	14.0577	2.5056	12.8196	0.7337	6.2134	23.1737	12.9191
3	1.2966	0.7639	0.0877	7.6289	1.5792	10.1321	0.2409	2.0168	17.1701	6.0036

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.8726 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	18.24		0.8726		387.4712		46.9859	387.4712	414.6937	-27.2225	
1	17.64	18.16	0.8359	0.9600	182.8905	414.6594	85.8551	401.8263	414.7320	-12.9057	-14.3168
2	17.36	17.65	0.8364	0.9600	95.3869	411.7435	162.6139	407.0646	418.0749	-11.0103	-1.8954
3	17.26	17.57	0.8374	0.9600	51.7647	411.3097	332.0298	409.3093	425.6490	-16.3396	5.3294
GND	17.39			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	17.39	17.68	18.75	19.57	20.07	20.27	20.24	20.02	19.67	19.23	18.75
HEAT FLUX:	-14.8182	-14.8182	-27.8990	-21.1901	-12.9919	-5.4169	0.8704	5.6939	9.1269	11.3592	12.5963
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
815	10.15	1.2076	1.1310	35.90	477.1	26.25	15.24	5.1410	0.0200	0.6064	-0.0766	-6.77

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	1.1741	0.913	26.84	25.51	0.0000	0.000	0.000	0.301e+02	0.002	150.964	-33.856	126.775	4.553	0.665	0.000
2	1.1980	0.914	26.34	24.80	0.0000	0.000	0.000	0.291e+02	0.002	83.442	-17.805	64.408	4.376	0.677	0.000
3	1.2506	0.916	25.75	24.01	0.0000	0.000	0.000	0.269e+02	0.002	46.370	-11.498	20.425	4.310	0.703	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	25.66	15.24	0.944											0.13e+02	0.13e+02
1	25.49	15.27	0.584	0.0019	0.0016	126.775	4.553	-62.748	3.936	157.789	9.321	0.13e+02	0.55e+04	0.15e+02	0.15e+02
2	25.31	15.29	0.226	0.0018	0.0036	64.408	4.376	-31.739	8.710	85.303	-0.083	0.19e+02	0.53e+04	0.66e+01	0.66e+01
3	25.15	15.32	0.086	0.0018	0.0017	20.425	4.310	-10.842	4.249	31.267	0.062	0.35e+02	0.49e+04	0.18e+02	0.18e+02
GND	20.79	17.91	0.000					0.000	0.000					0.10e+11	0.10e+11

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 35.90 EFFECTIVE REFLECTANCE: 0.2108 EFFECTIVE TRANSMITTANCE: 0.2276

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			390.7233	86.4190	0.0000	0.0000	73.7583	26.8323	376.5518	
1	1.1741	0.7767	179.3113	40.8400	51.6957	18.6300	48.0444	16.8451	225.5875	150.9642
2	1.1980	0.7742	82.2367	21.3197	55.6157	19.6967	27.1101	9.6136	142.1451	83.4424
3	1.2506	0.7687	37.6623	11.5796	43.7237	15.6156	9.6276	3.1780	95.7756	46.3695

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.8511 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	25.66		0.8511		410.1874		48.9870	410.1874	462.5230	-52.3355	
1	25.49	26.84	0.8488	0.9600	193.8469	466.3281	89.4137	439.7971	458.2764	-18.4793	-33.8562
2	25.31	26.34	0.8490	0.9600	101.1938	463.1758	169.1583	452.1337	452.8084	-0.6747	-17.8046
3	25.15	25.75	0.8493	0.9600	54.9625	459.5794	344.8132	456.0671	445.2436	10.8235	-11.4982
GND	20.79			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	20.79	18.74	18.78	19.23	19.63	19.85	19.89	19.75	19.49	19.13	18.72
HEAT FLUX:	106.5991	106.5991	-1.0159	-11.8449	-10.3066	-5.8016	-0.8721	3.4973	6.9281	9.3305	10.7349
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
815	12.03	1.1012	0.8572	53.75	579.2	27.99	15.93	5.1410	0.2707	0.6064	-0.2440	-28.47

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	1.0717	0.910	30.30	30.81	0.0000	0.000	0.000	0.351e+02	0.002	121.119	-28.823	98.667	5.741	0.608	0.000
2	1.0924	0.911	30.62	31.35	0.0000	0.000	0.000	0.340e+02	0.003	84.820	-20.287	60.598	6.110	0.620	0.000
3	1.1396	0.912	30.68	31.46	0.0000	0.000	0.000	0.317e+02	0.003	56.490	-20.885	25.518	6.563	0.646	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	29.00	15.71	0.948											0.13e+02	0.13e+02
1	29.23	15.72	0.591	0.0024	-0.0146	98.667	5.741	103.420	-35.544	73.727	53.879	0.13e+02	0.64e+04	0.14e+02	0.14e+02
2	29.65	15.75	0.230	0.0025	0.0052	60.598	6.110	78.436	12.639	4.763	0.032	0.19e+02	0.62e+04	0.63e+01	0.63e+01
3	29.95	15.80	0.091	0.0027	0.0027	25.518	6.563	22.608	6.554	2.907	0.012	0.34e+02	0.58e+04	0.15e+02	0.15e+02
GND	25.26	23.12	0.000					0.000	0.000					0.10e+11	0.10e+11

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 53.75 EFFECTIVE REFLECTANCE: 0.2481 EFFECTIVE TRANSMITTANCE: 0.3378

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			460.8079	118.3871	0.0001	0.0000	105.9083	37.7700	435.5168	
1	1.0717	0.7875	262.0823	56.0826	72.4131	26.1614	78.4049	23.9368	314.3976	121.1192
2	1.0924	0.7853	148.9978	29.3381	85.4948	27.8623	48.3365	13.7784	229.5780	84.8195
3	1.1396	0.7803	84.6292	15.9677	72.8308	22.2466	17.9368	4.6491	173.0884	56.4897

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.8863 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	29.00		0.8863		437.1718		50.9750	437.1718	486.3967	-49.2249	
1	29.23	30.30	0.8524	0.9600	207.0978	488.1787	92.8394	464.0156	484.4171	-20.4015	-28.8234
2	29.65	30.62	0.8527	0.9600	108.3376	490.2465	175.1856	477.8264	477.9410	-0.1146	-20.2870
3	29.95	30.68	0.8530	0.9600	58.9645	490.6465	355.7096	484.5831	463.8128	20.7703	-20.8849
GND	25.26			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	25.26	21.53	20.13	19.70	19.65	19.69	19.67	19.56	19.34	19.04	18.68
HEAT FLUX:	193.8587	193.8587	36.3198	11.2587	1.2267	-0.9654	0.4266	3.0556	5.7121	7.8224	9.1443
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
815	14.13	0.9768	0.5772	60.47	550.9	29.31	15.99	5.1410	0.4000	0.6064	-0.3996	-69.23

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	0.9558	0.907	31.72	33.25	0.0000	0.000	0.000	0.417e+02	0.002	99.494	-21.979	80.315	5.478	0.537	0.000
2	0.9685	0.907	32.23	34.16	0.0000	0.000	0.000	0.409e+02	0.002	73.115	-13.534	61.125	5.863	0.545	0.000
3	1.0061	0.908	32.43	34.54	0.0000	0.000	0.000	0.387e+02	0.003	50.345	-9.710	38.443	6.309	0.569	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	30.66	16.10	0.949											0.12e+02	0.12e+02
1	30.84	16.12	0.593	0.0023	0.0092	80.315	5.478	128.023	22.316	28.666	-4.721	0.13e+02	0.76e+04	0.14e+02	0.14e+02
2	31.25	16.15	0.232	0.0024	0.0050	61.125	5.863	76.398	12.093	8.329	-0.016	0.19e+02	0.75e+04	0.63e+01	0.63e+01
3	31.56	16.19	0.092	0.0026	0.0026	38.443	6.309	23.609	6.208	14.831	0.104	0.27e+02	0.71e+04	0.15e+02	0.15e+02
GND	28.69	27.68	0.000					0.000	0.000					0.10e+11	0.10e+11

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 60.47 EFFECTIVE REFLECTANCE: 0.2651 EFFECTIVE TRANSMITTANCE: 0.3719

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			420.7466	130.1750	0.0001	0.0000	103.1989	42.8252	404.8976	
1	0.9558	0.7996	249.9042	61.8345	70.0341	29.5816	78.5246	27.4262	305.4037	99.4940
2	0.9685	0.7983	148.3979	32.4265	84.6550	31.7755	49.0609	15.9047	232.2892	73.1145
3	1.0061	0.7944	88.0615	17.6927	73.5520	25.5730	17.5325	5.4025	181.9442	50.3450

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.9021 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	30.66		0.9021		452.7711		54.7098	452.7711	498.6807	-45.9096	

1	30.84	31.72	0.8554	0.9600	215.0711	497.3787	99.3969	476.1896	500.1198	-23.9302	-21.9794
2	31.25	32.23	0.8557	0.9600	112.7849	500.7132	186.9956	489.0677	499.4640	-10.3964	-13.5338
3	31.56	32.43	0.8560	0.9600	61.5381	502.0665	377.9503	495.8992	496.5860	-0.6868	-9.7095
GND	28.69			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	28.69	25.20	22.41	20.96	20.23	19.87	19.65	19.45	19.23	18.96	18.66
HEAT FLUX:	181.2573	181.2573	72.5221	37.6784	18.9353	9.4587	5.7059	5.0925	5.8783	6.9991	7.8614
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
815	16.16	0.8620	0.4284	47.12	432.8	29.79	15.44	5.0313	0.4107	0.6064	-0.4336	-101.22

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	0.8486	0.903	32.38	34.43	0.0000	0.000	0.000	0.489e+02	0.002	95.616	-22.717	67.840	5.147	0.463	0.000
2	0.8545	0.903	32.79	35.19	0.0000	0.000	0.000	0.484e+02	0.002	62.846	-12.414	45.506	5.387	0.467	0.000
3	0.8830	0.904	33.04	35.65	0.0000	0.000	0.000	0.464e+02	0.002	39.958	-7.497	25.885	5.734	0.487	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	31.38	15.53	0.930											0.13e+02	0.13e+02
1	31.56	15.54	0.584	0.0021	0.0070	67.840	5.147	144.575	16.993	-7.242	-0.867	0.14e+02	0.89e+04	0.14e+02	0.14e+02
2	31.93	15.57	0.229	0.0022	0.0045	45.506	5.387	69.513	10.960	3.796	0.129	0.22e+02	0.88e+04	0.64e+01	0.64e+01
3	32.30	15.60	0.091	0.0024	0.0023	25.885	5.734	27.808	5.697	-1.926	0.040	0.33e+02	0.85e+04	0.15e+02	0.15e+02
GND	29.83	29.75	0.000					0.000	0.000					0.10e+11	0.10e+11

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 47.12 EFFECTIVE REFLECTANCE: 0.2588 EFFECTIVE TRANSMITTANCE: 0.3212

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			325.5525	107.2104	0.0000	0.0000	75.7111	36.2765	320.7753	
1	0.8486	0.8109	175.7845	51.0540	51.8186	24.9972	55.0508	23.4444	225.1591	95.6162
2	0.8545	0.8103	94.9042	26.8333	60.5975	27.0576	33.4081	13.6711	162.3133	62.8458
3	0.8830	0.8073	51.2066	14.6744	51.1972	21.9274	12.0110	4.6391	122.3556	39.9577

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.9009 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	31.38		0.9009		455.0624		55.6913	455.0624	503.2938	-48.2314	
1	31.56	32.38	0.8510	0.9600	216.7022	501.7259	100.9509	479.5046	505.0185	-25.5139	-22.7175
2	31.93	32.79	0.8512	0.9600	113.8958	504.4322	189.3964	492.5632	505.6634	-13.1002	-12.4138
3	32.30	33.04	0.8515	0.9600	62.2867	506.0514	381.2035	499.6335	505.2365	-5.6030	-7.4971
GND	29.83			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	29.83	27.59	24.50	22.44	21.15	20.36	19.87	19.52	19.22	18.94	18.65
HEAT FLUX:	116.7526	116.7526	80.3577	53.5912	33.5564	20.4110	12.8374	9.1114	7.6907	7.4188	7.5339
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
815	18.04	0.7704	0.3629	27.61	194.0	27.36	14.99	3.7426	0.5360	0.6064	-0.4075	-112.28

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	0.7614	0.900	30.79	31.59	0.0000	0.000	0.000	0.556e+02	0.002	64.822	-21.060	53.962	3.904	0.396	0.000
2	0.7635	0.901	31.03	32.01	0.0000	0.000	0.000	0.555e+02	0.002	30.550	-9.398	30.126	4.006	0.398	0.000
3	0.7862	0.901	31.17	32.25	0.0000	0.000	0.000	0.536e+02	0.002	15.261	-1.975	15.002	4.190	0.416	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	29.90	15.30	0.697											0.17e+02	0.17e+02
1	30.09	15.31	0.506	0.0016	0.0193	53.962	3.904	198.352	47.006	-89.874	-34.709	0.15e+02	0.10e+05	0.16e+02	0.16e+02
2	30.43	15.33	0.199	0.0016	0.0034	30.126	4.006	54.593	8.315	-5.393	-0.070	0.24e+02	0.10e+05	0.73e+01	0.73e+01
3	30.71	15.36	0.079	0.0017	0.0017	15.002	4.190	19.078	4.237	-4.078	-0.045	0.36e+02	0.98e+04	0.17e+02	0.17e+02
GND	28.57	27.78	0.000					0.000	0.000					0.10e+11	0.10e+11

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 27.61 EFFECTIVE REFLECTANCE: 0.2372 EFFECTIVE TRANSMITTANCE: 0.2202

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			128.1743	65.8531	0.0000	0.0000	23.2320	22.7914	148.0041	
1	0.7614	0.8201	48.5195	31.4232	16.3770	15.6755	13.9822	14.8309	83.1823	64.8218
2	0.7635	0.8198	18.3655	16.5451	16.8325	17.0686	7.4987	8.6805	52.6325	30.5497
3	0.7862	0.8174	6.9463	9.0643	12.8182	13.9042	2.4260	2.9358	37.3712	15.2613

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.9146 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	29.90		0.9146		447.2987		55.3438	447.2987	493.1600	-45.8613	
1	30.09	30.79	0.8492	0.9600	213.4382	491.3571	100.1368	470.3337	495.1354	-24.8017	-21.0596
2	30.43	31.03	0.8493	0.9600	112.3808	492.9297	187.4577	482.1481	497.5521	-15.4041	-9.3976
3	30.71	31.17	0.8496	0.9600	61.5681	493.7944	376.0688	488.2403	501.6698	-13.4295	-1.9746
GND	28.57			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	28.57	28.11	25.59	23.52	22.00	20.94	20.22	19.70	19.30	18.97	18.65

HEAT FLUX:	23.9418	23.9418	65.6330	53.7159	39.5746	27.5278	18.8676	13.3857	10.3044	8.7824	8.1473
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
815	20.10	0.7102	0.3690	5.10	1184.4	24.69	14.65	1.9536	0.6000	0.6064	-0.3412	-92.46

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	0.7010	0.899	26.39	24.78	0.0000	0.000	0.000	0.609e+02	0.001	193.140	-12.020	14.209	2.214	0.346	0.000
2	0.7034	0.899	26.60	25.08	0.0000	0.000	0.000	0.606e+02	0.001	127.961	-3.099	9.595	2.280	0.348	0.000
3	0.7261	0.899	26.84	25.43	0.0000	0.000	0.000	0.586e+02	0.001	85.770	3.760	9.015	2.430	0.367	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	26.49	14.73	0.370											0.30e+02	0.30e+02
1	26.12	14.72	0.237	0.0009	0.0022	14.209	2.214	52.256	5.259	-22.004	0.182	0.22e+02	0.11e+05	0.33e+02	0.33e+02
2	26.33	14.74	0.094	0.0009	0.0013	9.595	2.280	16.048	3.223	-1.699	0.847	0.34e+02	0.11e+05	0.15e+02	0.15e+02
3	26.47	14.76	0.038	0.0010	0.0007	9.015	2.430	4.755	1.790	19.479	151.778	0.50e+02	0.11e+05	0.34e+02	0.34e+02
GND	29.03	27.16	0.028					15.317	151.040					0.20e+03	0.20e+03

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 5.10 EFFECTIVE REFLECTANCE: 0.3498 EFFECTIVE TRANSMITTANCE: 0.3519

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			6.3629	1178.0681	0.0000	-0.0002	0.3005	413.9818	770.1484	
1	0.7010	0.8264	0.0408	562.9312	0.1861	284.4105	0.0685	270.4915	577.0085	193.1399
2	0.7034	0.8261	0.0003	296.7454	0.1253	310.8237	0.0370	158.6097	449.0480	127.9605
3	0.7261	0.8238	0.0000	162.7511	0.0805	253.9450	0.0121	53.4869	363.2776	85.7704

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.9214 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	26.49		0.9214		434.8401		53.2349	434.8401	466.2062	-31.3661	
1	26.12	26.39	0.8444	0.9600	207.7851	463.5072	96.1989	449.8088	469.1554	-19.3466	-12.0195
2	26.33	26.60	0.8446	0.9600	109.5325	464.8189	179.8253	457.6469	473.8941	-16.2472	-3.0994
3	26.47	26.84	0.8448	0.9600	60.0735	466.3117	360.0159	462.1737	482.1805	-20.0068	3.7596
GND	29.03			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	29.03	25.62	25.02	23.82	22.55	21.47	20.62	19.97	19.47	19.05	18.68
HEAT FLUX:	176.9138	176.9138	15.6868	31.3008	32.9126	28.1184	22.0579	16.8763	13.1688	10.8484	9.6244
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
815	22.20	0.6460	0.4105	0.00	0.0	22.22	14.32	0.2056	0.6133	0.6064	-0.2355	-57.37

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	0.6409	0.897	22.86	20.23	0.0000	0.000	0.000	0.665e+02	0.000	0.000	-5.712	-0.661	0.948	0.252	0.000
2	0.6387	0.897	23.48	20.96	0.0000	0.000	0.000	0.668e+02	0.000	0.000	-0.100	0.472	0.952	0.261	0.000
3	0.6584	0.897	24.45	22.18	0.0000	0.000	0.000	0.648e+02	0.000	0.000	1.932	11.519	1.014	0.297	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	29.80	24.40	0.050											0.21e+03	0.21e+03
1	23.02	15.43	0.000	0.0004	0.0000	-0.661	0.948	0.000	0.000	0.022	3.678	0.29e+03	0.12e+05	0.10e+11	0.10e+11
2	23.38	16.14	0.000	0.0004	0.0011	0.472	0.952	0.684	2.729	0.327	2.509	0.24e+03	0.12e+05	0.63e+03	0.63e+03
3	23.67	17.25	0.000	0.0004	0.0018	11.519	1.014	0.540	4.286	14.631	24.519	0.82e+02	0.12e+05	0.63e+03	0.63e+03
GND	25.38	23.53	0.000					3.669	27.773					0.56e+03	0.55e+03

SHORT-WAVE RADIATION FIELD IN SWATH:

NO SHORT-WAVE RADIATION AT NIGHT

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.9220 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	29.80		0.9220		420.8847		51.6645	420.8847	446.9348	-26.0500	
1	23.02	22.86	0.8502	0.9600	201.3973	442.0488	93.2437	431.9216	452.2596	-20.3380	-5.7121
2	23.38	23.48	0.8556	0.9600	106.2999	445.7394	174.0318	439.1271	459.3654	-20.2383	-0.0997
3	23.67	24.45	0.8638	0.9600	58.3732	451.6141	347.6303	445.6414	467.8120	-22.1707	1.9324
GND	25.38			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	25.38	26.41	25.44	24.12	22.90	21.84	20.96	20.24	19.65	19.15	18.71
HEAT FLUX:	-53.6132	-53.6132	25.1767	34.3623	31.7284	27.4903	22.9327	18.7225	15.3096	12.8878	11.4704
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
816	0.18	0.6340	0.4404	0.00	0.0	22.22	14.06	2.2415	0.7453	0.6064	-0.1936	-43.96

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	0.6340	0.896	22.71	20.05	0.0000	0.167	0.000	0.672e+02	0.000	0.000	-1.758	-2.543	0.965	0.244	0.000
2	0.6249	0.896	23.16	20.56	0.0000	0.167	0.000	0.681e+02	0.000	0.000	2.543	3.615	0.970	0.244	0.000
3	0.6431	0.897	23.67	21.19	0.0000	0.000	0.000	0.663e+02	0.000	0.000	7.711	6.843	0.998	0.268	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV

TOP	22.70	15.09	0.416											0.28e+02	0.28e+02
1	22.77	15.22	0.147	0.0004	0.0218	-2.543	0.965	12.496	53.488	-0.272	-5.988	0.28e+02	0.12e+05	0.53e+02	0.53e+02
2	23.04	15.63	0.060	0.0004	0.0190	3.615	0.970	14.787	46.515	-0.217	-0.011	0.42e+02	0.12e+05	0.22e+02	0.22e+02
3	23.34	16.25	0.027	0.0004	0.0186	6.843	0.998	10.968	45.522	-3.282	-8.844	0.58e+02	0.12e+05	0.33e+02	0.33e+02
GND	23.57	20.83	0.019					0.853	35.670					0.32e+03	0.31e+03

SHORT-WAVE RADIATION FIELD IN SWATH:

NO SHORT-WAVE RADIATION AT NIGHT

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.9388 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	22.70		0.9388		428.5704		51.8059	428.5704	445.5532	-16.9828	
1	22.77	22.71	0.8484	0.9600	205.1080	441.1477	93.4853	435.1284	450.3530	-15.2246	-1.7582
2	23.04	23.16	0.8517	0.9600	108.2887	443.8467	174.4271	439.6734	457.4414	-17.7680	2.5434
3	23.34	23.67	0.8564	0.9600	59.4826	446.9002	348.2519	443.4423	468.9213	-25.4790	7.7110
GND	23.57			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	23.57	24.76	24.56	23.85	22.95	22.03	21.18	20.44	19.81	19.25	18.74
HEAT FLUX:	-62.0021	-62.0021	5.2168	18.3360	23.5143	23.9190	21.9806	19.2324	16.5669	14.4624	13.1436
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
816	2.21	0.6141	0.4700	0.00	0.0	20.88	13.87	2.4625	0.4773	0.6064	-0.1441	-30.66

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	0.6141	0.896	21.57	18.73	0.0000	0.000	0.000	0.693e+02	0.000	0.000	-12.751	-13.485	0.792	0.211	0.000
2	0.6053	0.896	21.89	19.07	0.0000	0.000	0.000	0.702e+02	0.000	0.000	-4.467	-3.909	0.779	0.209	0.000
3	0.6229	0.896	22.24	19.49	0.0000	0.000	0.000	0.683e+02	0.000	0.000	0.971	2.614	0.733	0.228	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	21.82	14.67	0.459											0.25e+02	0.25e+02
1	21.80	14.65	0.290	0.0003	0.0280	-13.485	0.792	39.621	68.713	-34.338	-0.714	0.21e+02	0.13e+05	0.28e+02	0.28e+02
2	21.99	15.00	0.115	0.0003	0.0274	-3.909	0.779	18.805	67.170	-15.949	3.042	0.31e+02	0.13e+05	0.12e+02	0.12e+02
3	22.14	15.76	0.047	0.0003	0.0283	2.614	0.733	6.776	69.421	-4.171	-68.679	0.46e+02	0.12e+05	0.27e+02	0.27e+02
GND	22.76	18.54	0.000					0.000	0.000					0.10e+11	0.10e+11

SHORT-WAVE RADIATION FIELD IN SWATH:

NO SHORT-WAVE RADIATION AT NIGHT

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.9020 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	21.82		0.9020		404.3052		49.6836	404.3052	437.0534	-32.7482	
1	21.80	21.57	0.8439	0.9600	193.5842	434.3716	89.6181	419.9756	439.9727	-19.9971	-12.7511
2	21.99	21.89	0.8467	0.9600	102.2435	436.2741	167.1330	428.4687	443.9987	-15.5300	-4.4671
3	22.14	22.24	0.8527	0.9600	56.1826	438.3652	333.4628	433.6276	450.1284	-16.5008	0.9708
GND	22.76			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	22.76	23.08	23.50	23.28	22.72	22.02	21.28	20.57	19.92	19.33	18.77
HEAT FLUX:	-16.5008	-16.5008	-10.9955	5.7275	14.4545	18.3590	19.1891	18.3595	16.8966	15.4730	14.4855
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
816	4.59	0.5999	0.5356	0.00	0.0	18.89	13.79	1.2390	0.0000	0.6064	-0.0643	-12.01

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	PAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	0.6005	0.895	18.42	15.54	0.0000	0.000	0.000	0.707e+02	0.000	0.000	-21.899	-24.554	0.222	0.161	0.000
2	0.5914	0.895	18.80	15.87	0.0000	0.000	0.000	0.716e+02	0.000	0.000	-6.324	-8.413	0.226	0.160	0.000
3	0.6078	0.896	19.41	16.49	0.0000	0.000	0.000	0.699e+02	0.000	0.000	3.500	-0.326	0.259	0.177	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	18.87	14.29	0.228											0.52e+02	0.52e+02
1	18.87	14.37	0.170	0.0001	0.0126	-24.554	0.222	-0.479	30.996	-11.563	6.081	0.22e+02	0.13e+05	0.46e+02	0.46e+02
2	19.08	14.67	0.068	0.0001	0.0150	-8.413	0.226	12.516	36.851	-7.220	0.556	0.40e+02	0.13e+05	0.20e+02	0.20e+02
3	19.43	15.14	0.030	0.0001	0.0151	-0.326	0.259	13.719	37.171	-9.338	-13.413	0.56e+02	0.13e+05	0.31e+02	0.31e+02
GND	20.32	17.36	0.022					4.723	23.484					0.23e+03	0.23e+03

SHORT-WAVE RADIATION FIELD IN SWATH:

NO SHORT-WAVE RADIATION AT NIGHT

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.8366 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	18.87		0.8366		364.9626		49.1804	364.9626	420.4932	-55.5305	
1	18.87	18.42	0.8416	0.9600	174.8015	416.1206	88.6854	391.6181	425.2499	-33.6318	-21.8987
2	19.08	18.80	0.8441	0.9600	92.3482	418.2903	165.3387	405.5128	432.8210	-27.3082	-6.3236

3	19.43	19.41	0.8479	0.9600	50.7593	421.7981	329.7176	413.9995	444.8077	-30.8082	3.5000
GND	20.32			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	20.32	21.46	22.31	22.50	22.28	21.82	21.24	20.61	19.99	19.38	18.79
HEAT FLUX:	-59.0147	-59.0147	-22.0795	-4.9413	5.7812	11.9792	15.0873	16.2089	16.2185	15.7780	15.3405
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
816	6.98	0.6047	0.6130	1.29	3.8	18.89	14.56	0.0103	0.0000	0.6064	0.0083	1.36

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	PAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	0.6201	0.895	17.89	15.17	0.0000	0.723	0.000	0.100e+01	-0.004	0.573	-19.576	-7.826	-8.604	0.167	0.000
2	0.5911	0.895	18.14	15.37	0.0000	0.057	0.000	0.100e+01	-0.001	0.387	-5.174	-2.243	-1.512	0.152	0.000
3	0.6028	0.896	18.58	15.69	0.0000	0.000	0.000	0.704e+02	0.000	0.259	4.548	3.327	0.023	0.164	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	18.08	15.27	0.010											0.24e+20	0.24e+20
1	18.08	15.27	0.132	-0.0035	0.0000	-7.826	-8.604	0.000	0.000	-1.186	3.383	0.30e+02	0.28e+02	0.24e+20	0.24e+20
2	18.22	15.39	0.053	-0.0006	0.0049	-2.243	-1.512	6.641	11.985	-3.602	-3.453	0.45e+02	0.41e+02	0.26e+02	0.26e+02
3	18.41	15.57	0.023	0.0000	0.0041	3.327	0.023	5.283	10.043	3.453	2.078	0.63e+02	0.13e+05	0.43e+02	0.43e+02
GND	19.49	16.76	0.017					5.417	12.090					0.24e+03	0.24e+03

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 1.29 EFFECTIVE REFLECTANCE: 0.3599 EFFECTIVE TRANSMITTANCE: 0.3628

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			0.0000	3.7606	0.0000	0.0000	0.0000	1.3532	2.4073	
1	0.6201	0.8349	0.0000	1.8012	0.0000	0.9266	0.0000	0.8936	1.8343	0.5730
2	0.5911	0.8379	0.0000	0.9516	0.0000	1.0221	0.0000	0.5264	1.4473	0.3870
3	0.6028	0.8367	0.0000	0.5231	0.0000	0.8411	0.0000	0.1764	1.1879	0.2594

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.8431 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALP	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	18.08		0.8431		367.8204		48.5640	367.8204	416.8157	-48.9953	
1	18.08	17.89	0.8489	0.9600	176.1782	413.1163	87.5703	391.4205	420.8398	-29.4193	-19.5760
2	18.22	18.14	0.8498	0.9600	93.0796	414.5298	163.2511	403.4585	427.7036	-24.2451	-5.1742
3	18.41	18.58	0.8512	0.9600	51.1662	417.0212	325.5073	410.5256	439.3188	-28.7932	4.5481
GND	19.49			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	19.49	20.36	21.22	21.64	21.68	21.45	21.04	20.53	19.97	19.38	18.80
HEAT FLUX:	-45.1127	-45.1127	-22.5867	-10.7339	-1.0908	5.9741	10.6056	13.2941	14.6343	15.1708	15.3210
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
816	9.10	0.5736	0.6130	24.34	294.9	23.56	15.23	1.7993	0.0000	0.6064	0.0394	6.43

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	PAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	0.5202	0.893	25.77	23.50	0.0000	1.167	0.000	0.796e+02	0.001	114.631	-38.195	118.448	1.361	0.172	0.000
2	0.6033	0.895	25.44	23.45	0.0000	1.167	0.000	0.704e+02	0.000	47.316	-21.903	128.721	0.680	0.257	0.000
3	0.5972	0.895	22.94	20.23	0.0000	0.000	0.000	0.710e+02	0.000	20.718	3.049	32.327	0.383	0.218	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	23.34	15.23	0.329											0.37e+02	0.37e+02
1	23.86	15.41	0.194	0.0006	0.0041	118.448	1.361	8.076	9.943	52.515	419.427	0.19e+02	0.15e+05	0.45e+02	0.45e+02
2	22.62	19.88	0.068	0.0003	0.1752	128.721	0.680	-58.505	428.656	186.895	-427.646	0.26e+02	0.13e+05	0.26e+02	0.26e+02
3	21.10	18.20	0.000	0.0002	0.0000	32.327	0.383	0.000	0.000	32.339	0.480	0.69e+02	0.13e+05	0.10e+11	0.10e+11
GND	21.12	18.26	0.000					0.012	0.096					0.16e+04	0.15e+04

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 24.34 EFFECTIVE REFLECTANCE: 0.2194 EFFECTIVE TRANSMITTANCE: 0.1847

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			227.9797	66.8845	0.0000	0.0000	40.2533	24.4265	230.1844	
1	0.5202	0.8454	77.1754	32.0944	28.5043	16.7759	23.0029	15.9935	115.5537	114.6307
2	0.6033	0.8367	26.0577	16.9538	28.3841	18.3663	12.0925	9.4322	68.2373	47.3164
3	0.5972	0.8373	8.7956	9.3199	21.2622	15.0953	3.7979	3.1557	47.5193	20.7180

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.8486 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	23.34		0.8486		394.4165		49.3057	394.4165	455.7498	-61.3333	
1	23.86	25.77	0.8500	0.9600	189.2600	459.6726	88.7623	428.3596	451.4977	-23.1381	-38.1953
2	22.62	25.44	0.8815	0.9600	99.9764	457.6348	165.4538	443.6095	444.8451	-1.2355	-21.9025
3	21.10	22.94	0.8704	0.9600	54.9593	442.5493	329.7534	443.0572	447.3412	-4.2841	3.0486
GND	21.12			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	21.12	20.29	20.70	21.06	21.19	21.08	20.80	20.38	19.89	19.35	18.78
HEAT FLUX:	43.1267	43.1267	-10.5950	-9.3593	-3.3039	2.6759	7.4215	10.7512	12.8589	14.0584	14.6437
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
816	11.23	0.5330	0.4821	46.60	649.2	27.38	14.56	2.5705	0.0000	0.6064	-0.0509	-10.56

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	0.4807	0.892	30.68	30.58	0.0000	0.000	0.000	0.844e+02	0.001	133.918	-41.218	89.681	2.504	0.128	0.000
2	0.5598	0.894	30.99	31.58	0.0000	0.000	0.000	0.751e+02	0.001	90.051	-24.049	59.507	2.988	0.213	0.000
3	0.5585	0.894	30.81	31.27	0.0000	0.000	0.000	0.752e+02	0.001	56.290	-15.210	30.868	2.920	0.212	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	29.09	14.72	0.481											0.24e+02	0.24e+02
1	29.41	14.73	0.302	0.0010	0.0064	89.681	2.504	88.721	15.680	39.745	-7.595	0.17e+02	0.15e+05	0.27e+02	0.27e+02
2	29.80	14.76	0.120	0.0012	0.0023	59.507	2.988	38.808	5.558	27.149	0.076	0.24e+02	0.14e+05	0.12e+02	0.12e+02
3	29.95	14.79	0.048	0.0012	0.0011	30.868	2.920	6.453	2.644	24.414	0.277	0.33e+02	0.14e+05	0.28e+02	0.28e+02
GND	26.50	24.78	0.000					0.000	0.000					0.10e+11	0.10e+11

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 46.60 EFFECTIVE REFLECTANCE: 0.2711 EFFECTIVE TRANSMITTANCE: 0.3377

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			546.0110	103.2028	0.0000	0.0000	137.9408	38.0779	473.1952	
1	0.4807	0.8495	295.5958	49.5669	94.0016	26.1282	101.0059	25.0090	339.2776	133.9176
2	0.5598	0.8412	159.7584	26.1981	110.9411	28.6859	61.6009	14.7564	249.2261	90.0515
3	0.5585	0.8414	86.3458	14.4119	94.8361	23.6161	21.3478	4.9256	192.9364	56.2897

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.8431 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	29.09		0.8431		412.4527		52.8709	412.4527	490.0621	-77.6093	
1	29.41	30.68	0.8445	0.9600	198.0953	490.6134	95.1023	453.0739	489.4655	-36.3916	-41.2178
2	29.80	30.99	0.8447	0.9600	104.7014	492.6504	177.1445	473.6771	486.0192	-12.3421	-24.0494
3	29.95	30.81	0.8450	0.9600	57.5976	491.4879	352.6062	482.9490	480.0807	2.8683	-15.2104
GND	26.50			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	26.50	22.73	21.45	21.12	20.99	20.83	20.57	20.22	19.78	19.29	18.77
HEAT FLUX:	195.8047	195.8047	33.3214	8.5371	3.4642	4.1803	6.6539	9.2522	11.3470	12.7825	13.5942
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DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
816	13.15	0.4707	0.2975	59.76	807.5	30.00	13.04	2.6219	0.0150	0.6064	-0.1732	-58.22

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	0.4267	0.890	33.60	35.13	0.0000	0.000	0.000	0.915e+02	0.001	120.347	-43.824	81.355	3.086	0.064	0.000
2	0.4937	0.892	34.49	37.66	0.0000	0.000	0.000	0.828e+02	0.002	92.801	-27.463	62.222	3.804	0.143	0.000
3	0.4917	0.892	34.71	38.07	0.0000	0.000	0.000	0.831e+02	0.002	63.475	-19.122	24.713	3.848	0.141	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

LAYER	DBA	RVA	WDA	FVLA	FVAA	FXHLA	FXVLA	FXHAA	FXVAA	FXSHA	FXLHA	RBH	RBV	RSH	RSV
TOP	32.03	13.90	0.492											0.23e+02	0.23e+02
1	32.44	13.91	0.304	0.0013	0.0327	81.355	3.086	107.408	79.399	57.953	-68.527	0.17e+02	0.17e+05	0.27e+02	0.27e+02
2	33.25	13.95	0.122	0.0016	0.0032	62.222	3.804	84.145	7.646	6.617	0.028	0.23e+02	0.15e+05	0.11e+02	0.11e+02
3	33.80	13.98	0.051	0.0016	0.0016	24.713	3.848	28.546	3.863	-3.836	-0.012	0.43e+02	0.15e+05	0.23e+02	0.23e+02
GND	32.53	24.93	0.000					0.000	0.000					0.10e+11	0.10e+11

SHORT-WAVE RADIATION FIELD IN SWATH:

SUN ELEVATION (DEGREES): 59.76 EFFECTIVE REFLECTANCE: 0.2937 EFFECTIVE TRANSMITTANCE: 0.4109

LAYER	MC	SCAT	SLDIR	SLSKY	DFDIRDN	DFSKYDN	DFDIRUP	DFSKYUP	NET DOWN	ABSORBED
TOP			684.4265	123.0545	-0.0001	0.0000	191.0955	46.0806	570.3048	
1	0.4267	0.8552	408.9044	59.1751	128.4532	31.5695	147.7176	30.4270	449.9576	120.3473
2	0.4937	0.8482	244.0039	31.3172	158.2046	34.8259	93.2070	17.9877	357.1568	92.8008
3	0.4917	0.8484	145.6085	17.2491	140.1558	28.7707	32.1228	5.9793	293.6821	63.4747

LONG-WAVE RADIATION FIELD IN SWATH:

ATMOSPHERE EMISSIVITY: 0.8321 GROUND EMISSIVITY: 0.9500

LAYER	DBA	DBL	EMA	EML	RAD AIR	RAD ALF	RAD GND	DOWN	UP	NET DOWN	ABSORBED
TOP	32.03		0.8321		421.4727		55.6371	421.4727	511.6219	-90.1492	
1	32.44	33.60	0.8376	0.9600	202.6799	509.7616	99.9657	467.3048	513.6301	-46.3252	-43.8239
2	33.25	34.49	0.8379	0.9600	107.2643	515.7439	185.9133	492.4862	511.3482	-18.8620	-27.4633
3	33.80	34.71	0.8382	0.9600	59.0798	517.1621	369.2533	505.3137	505.0534	0.2603	-19.1222
GND	32.53			0.9500							

TEMPERATURES AND HEAT FLUXES IN SOIL:

10 LAYERS DEEP DOWN TO 0.5 M SOIL HEAT CONDUCTIVITY: 1.3000 VOLUMETRIC HEAT CAPACITY: 0.2000e+07

LAYER:	GND	1	2	3	4	5	6	7	8	9	10
THICKNESS:		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
TEMPERATURE:	32.53	26.87	23.79	22.22	21.40	20.91	20.52	20.13	19.70	19.24	18.75
HEAT FLUX:	293.9423	293.9423	80.1183	40.8615	21.2219	12.8006	10.1796	10.1784	11.0839	12.0555	12.7262
	********	********	********	********	********	********	********	********	********	********	********

DATE	HOUR	MC MODEL	MC FIELD	HSUN	SOLAR	DBR	RVR	WIND	COVER	ZR	ERROR	PERCENT
816	15.26	0.3998	0.1845	54.43	614.1	30.00	13.04	3.3451	0.2260	0.6064	-0.2153	-116.69

MC,TEMP, VAPOR DENSITY, DEW AND DURATION, RAIN,MOISTURE AND ENERGY FLUXES IN ALFALFA:

LAYER	MC	DL	DBL	RVL	DEW	TDEW	RAIN	FAC	FVLA	SWRN	LWRN	FXHLA	FXVLA	FXRSP	FXRAIN
1	0.3644	0.888	33.59	33.79	0.0000	0.000	0.000	0.100e+03	0.001	99.359	-33.527	55.346	2.738	-0.015	0.000
2	0.4181	0.890	34.36	36.46	0.0000	0.000	0.000	0.927e+02	0.001	72.507	-17.558	39.053	3.341	0.054	0.000
3	0.4169	0.890	34.90	37.50	0.0000	0.000	0.000	0.928e+02	0.001	48.206	-8.999	27.520	3.476	0.052	0.000

TEMPERATURE, VAPOR DENSITY, MOISTURE AND ENERGY FLUXES IN AIR SPACES OF SWATH:

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