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DEVELOPMENT OF THE SMART WEAPONS OPERABILITY ENHANCEMENT INTERIM THERMAL MODEL

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The Balanced Technology Initiative (BTI) on Smart Weapons Operability Enhancement (SWOE) has as a goal to model the radiant field from complex natural backgrounds. In order to achieve this goal, one must be able to model the thermal structure of the natural background. The physical processes controlling this thermal structure are three-dimensional in nature so a full three dimensional treatment of the physics is necessary in order to properly describe the radiant field.

The development of a three dimensional thermal model of the natural background is a significant undertaking. As a first step in the development, an Interim Thermal Model (ITM) was developed to model the environmental conditions for a variety of land surfaces and weather conditions. The ITM calculates the thermal balance for land surfaces with and without vegetation, winter surfaces, and bodies of water. In addition, a standalone 3-D model of the thermal balance for individual trees is also available as a component of the ITM.

A first generation User Interface System (UIS) has also been developed for use with the ITM. Developed to operate on SUN computers, the UIS allows the user to study in detail the thermal balance for a single set of land and environmental conditions or to set up and perform calculations for a series of land surface types. A simpler version of the User Interface System is also available for users that do not have a SUN computer.

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Contents

Figures

Tables

ACKNOWLEDGEMENT

The development of the BTI/SWOE Interim Thermal Model involved contributions from other individuals and agencies that deserve recognition. The U.S. Army Waterways Experiment Station (WES) provided the original CE-QUAL-R1, CT-STM, VEGIE, and TVCM computer codes and databases. The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) provided the SNTHERM.89 code. The contributions and suggestions from Mr. Randy Scoggins and Dr. Rose Kress of WES and Ms. Rachel Jordan of CRREL are greatly appreciated.

Development of the
Smart Weapons Operability Enhancement
Interim Thermal Model

1 INTRODUCTION

1.1 Background and Purpose of Research

The Balanced Technology Initiative (BTI) on Smart Weapons Operability Enhancement (SWOE) has as a goal to model the radiant field from complex natural backgrounds. In order to achieve this goal, one must be able to model the thermal structure of the natural background. The physical processes controlling this thermal structure are three dimensional in nature, as noted in Figure 1, so a full three dimensional treatment of the physics is necessary in order to properly describe the radiant field. For example, the radiant field from the tree, $F(\epsilon_v, T_v)$, is a function of the temperature and emissivity of the various vegetative components, T_v and ϵ_v, respectively. Also, the radiant field of the ground, $F(\epsilon_g, T_g)$, is a function of the temperature profile within the soil.

The development of a three dimensional thermal model of the natural background is a significant undertaking. As a first step in the development, a Model Evaluation Team (MET) was formed to make a review of available 1-D models that could be used in the thermal model development effort. The MET committee

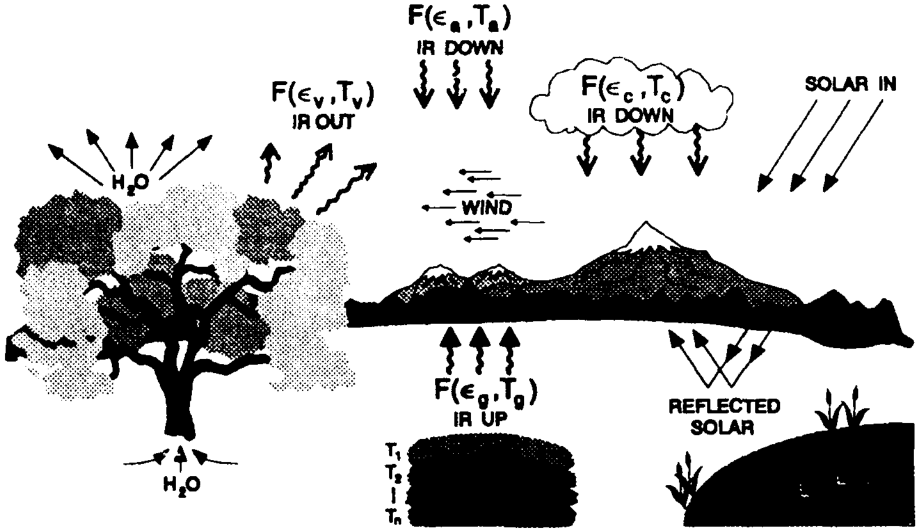

Figure 1. Radiant Scene Structure in a SWOE Scene Simulation

submitted to the BTI/SWOE program recommendations on what models or modules could be used to serve as an Interim Thermal Model (ITM) while the 3-D package was under development.[1] The purpose of this research was to implement those recommendations and develop an Interim 1-D Thermal Model package for the SWOE modeling community.

1.2 Summary of the Committee Recommendations

The MET committee provided recommendations on: 1.) a model to serve as a basic model framework, 2.) new formulations for the material-atmospheric energy fluxes, 3.) models for use with specific types of materials, and 4.) future research directions to treat the background materials not addressed by the recommended models. The C language version of the Terrain Surface Temperature Model (CTSTM), developed by the Army Waterways Experiment Station (WES),[2] was selected as the basic model framework.

CTSTM was recommended as the heat conduction model for use with land surfaces with no vegetation. The submodel to CTSTM named VEGIE,[3] which

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[1] Balick, L.K., Hummel, J.R., Smith, J.A. and Kimes, D.S. (1990) "One Dimensional Temperature Modeling Techniques for the BTI/SWOE: Review and Recommendations", SWOE Program Office, US Army Cold Regions Research and Engineering Laboratory, Hanover, NH, SWOE Report 90-1, August.

[2] Balick, L.K., Link, L.E., Scoggins, R.K., and Solomon, J.L. (1981) "Thermal Modeling of Terrain Surface Elements", U.S. Army Engineer Waterways Experiment Station, EL-81-2, March, ADA 098019.

[3] Balick, L.K., Scoggins, R. K., and Link, Jr. L.E. (1981) "Inclusion of a Simple Vegetation

was also developed by WES, was selected for use with simple vegetation, such as grasses and crops. The Thermal Vegetation Canopy Model (TVCM), developed by the Colorado State University[4] for WES was recommended for use with horizontally homogeneous canopies. The winter surface model[5] of the Army Cold Regions Research and Engineering Laboratory (CRREL), SNTHERM.89, was chosen for snow and ice conditions. Finally, the thermal balance module, CE-THERM-R1, from the water quality model CE-QUAL-R1 that was also developed by WES[6] was recommended for bodies of fresh water.

Later on, the ITM development effort was revised and the heat conduction framework in CRREL's SNTHERM.89 was recommended as the replacement for CTSTM. This was done because SNTHERM.89 had many features already incorporated into the model that were required by the SWOE program. For example, SNTHERM.89 included a soil heat conduction model as well as a snow and ice formulation. This allows the code to be used for winter and non-winter conditions. SNTHERM.89 divides the surface materials into a system of dry and moist soil components. Also, the role of dry and moist air in the thermal balance of the surface was also considered, thereby, allowing SNTHERM.89 to be used for porous materials. Finally, SNTHERM.89 includes a moisture transport model for snow and ice and researchers at CRREL are developing a soil moisture model as well. Upon evaluation of the effort required to modify CTSTM to include the ability to model porous materials and moisture transport, it was determined that the effort required to add the vegetative models VEGIE and TVCM to SNTHERM.89 was a smaller effort and more prudent use of SWOE resources. This allowed for a more rapid development of the thermal modeling capabilities of the SWOE program and also meant that one model would be used for heat conduction calculations in surfaces rather than two as in the original MET recommendations. For reference, Table 1 compares the features in SWOETHRM and CTSTM.

Layer in Terrain Temperature Models for Thermal Infrared (IR) Signature Prediction", U.S. Army Engineer Waterways Experiment Station, EL-81-4, August, ADA 104469.

4 Smith, J.A., Ranson, K.J., Nguyen, D., Balick, L.K., Link, L.E., Fritschen, L., and Hutchison, B.A. (1981) Thermal Vegetation Canopy Model Studies, *Remote Sens. Environ.*, **11**:311-326.

5 R. Jordan, "SNTHERM.89: A One-Dimensional Temperature Model for A Snow Cover", U.S. Army Cold Regions Research and Engineering Laboratory, in progress.

6 Waterways Experiment Station (1986) "CE-QUAL-R1: A Numerical One-Dimensional Model of Reservoir Water Quality; User's Manual", US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Instruction Report E-82-1, July, ADA 171649.

Table 1. Comparison of Model Features of SWOETHRM and CTSTM

FEATURE	SWOETHRM	CTSTM
Surface Types		
Non-Winter Surfaces	Yes	Yes
Winter Surfaces	Yes	No
Non-Vegetated	Yes	Yes
Simple Vegetation	Yes	Yes
Forest Canopies	Yes	Yes
Subsurface Layering	Yes	Yes
Thermal Conduction	Yes	Yes
Convective Cooling	Yes	Yes
Vaporization	Surface and In-Depth	Surface
Melting/Freezing	Yes	No
Mass Addition	Yes	No
Fluid Flow	Yes	No

1.3 Organization of Report

This report details the technical features of the SWOE ITM and provides a Users Guide on how to use the model. Section 2 gives a description of the ITM and its components. Section 3 describes the data requirements for the ITM. Section 4 gives results from sensitivity calculations made with the ITM. Section 5 is the Users Guide for the ITM. Finally, Section 6 provides a summary and recommendations for future work with the ITM.

2 DESCRIPTION OF THE SWOE ITM

2.1 Overview

The SWOE ITM is designed as a tool for smart weapons tester/designers to use in understanding the performance of present and future Electro-Optical (EO) sensors. It is designed as one component in a larger simulation system that will produce radiant fields from a simulated scene that can be "handed off" to EO sensor performance models. The complete SWOE package will allow the user community to test sensor concepts for realistic environmental conditions. It is hoped that this capability will lead to considerable savings in development costs and shortening the time required to go from the drawing board to the production line. Figure 2 gives a schematic representative of the intended SWOE system.

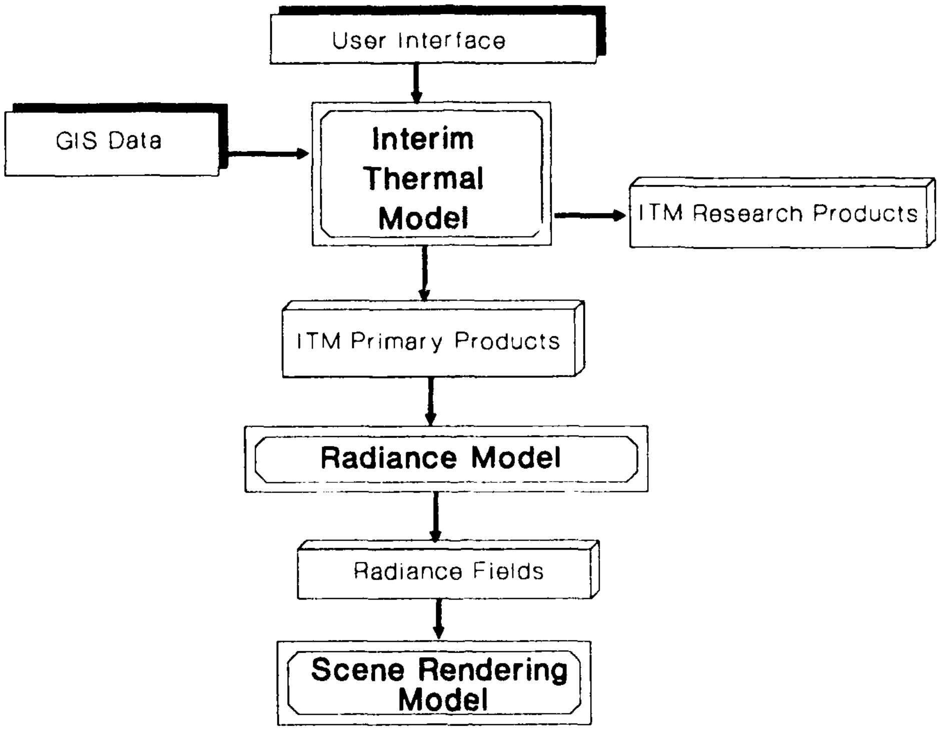

Figure 2. Schematic Representation of the SWOE Simulation System

A User Interface System allows the user to specify the conditions for a given SWOE simulation system. These conditions will determine what Geophysical Information System (GIS) databases must be accessed to provide the environmental data and terrain information required for the energy budget calculations by lthe ITM. The ITM can be used as both a stand-alone research tool to provide detailed research products or be used to provide the primary input products, temperature fields, for the SWOE radiance model.[7]

The ITM programs were developed to operate under the UNIX operating system. The individual program elements have been developed using standard FORTRAN 77 or C. They have been designed to be as hardware independent as possible.

2.2 Conditions Treated by ITM

The SWOE ITM is designed to model the thermal balance conditions for a variety of conditions. The conditions include:

- Land Surfaces Without Vegetation
- Land Surfaces With Vegetation
- Winter Surfaces
- Bodies of Water
- Individual Trees

In order to model these conditions, three computer models are incorporated into the SWOE ITM. Two of the models, SWOETHRM and CE-THERM-R1, are accessed via a first generation User Interface System that is described in Section 4. A third, stand-alone model, TREETHERM, is also available to model the thermal balance in three dimensions of individual trees.[8] Figure 3 gives a schematic overview of the SWOE ITM.

SWOETHRM is used to model the vertical thermal balance for land surfaces with and without vegetation and for winter surfaces. CE-THERM-R1 is used to determine the thermal balance for bodies of water. In the sections that follow, summaries of the technical details for each model component will be given. In almost every case, a detailed technical report has been issued by the agency that developed the original model. Those reports will be referenced for specific technical details rather than duplicating them here.

The SWOETHRM and CE-THRM-R1 models are written in FORTRAN 77 and have been developed to run in the UNIX operating system. Should the user wish to make any changes to the source code, it must be noted that some of the variables utilize variable names longer than 6 characters. Therefore, the FORTRAN compiler being utilized must be able to permit variables longer than 6 characters. The SWOETHRM and CE-THERM-R1 are linked by a common input section that

[7] Conant, J.A. and Hummel, J.R. (1991) "Thermal and Radiometric Modeling of Terrain Backgrounds," SPIE Proceedings of Characterization, Propagation, and Simulation of Sources and Backgrounds, in press.

[8] Hummel, J.R., Jones, J.R., Longtin, D.R., and Paul, N.L. (1991) "Development of a 3-D Tree Thermal Response Model for Energy Budget and Scene Simulation Studies", Phillips Laboratory, Geophysics Directorate, Hanscom AFB, Massachusets, PL-TR-91-2108.

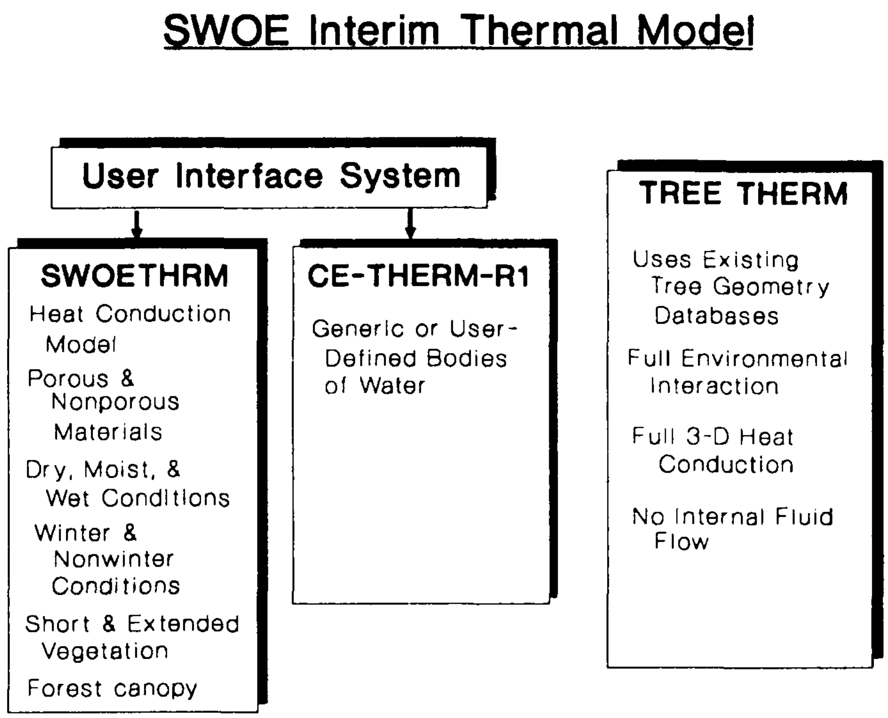

Figure 3. Schematic Overview of the SWOE Interim Thermal Model

allows the codes to be run in batch mode. The UIS was developed to run on a SUN^{TM} computer. However, it must be stressed that a SUN^{TM} computer system is not required to run SWOETHRM and CE-THERM-R1.

2.3 Land Surfaces

SWOETHRM calculates thermal conditions for land surfaces using a modified version of the vertical heat conduction formulation in CRREL's SNTHERM.89.[5] This model has been incorporated into the SWOE ITM, thereby allowing its use for winter and non-winter conditions. The "science" in SNTHERM.89 has not been changed so the code reproduces the same results as would a standalone version of SNTHERM.89. Modifications have been made to the code, however, to incorporate the different input/output requirements of the SWOE program. These modifications are discussed in Appendix A.

The model has been modified to include the effects of simple vegetation and extended forest canopies on the surface energy budget. This was done by adding VEGIE[3] and the forest canopy portion of TVCM[4] to SWOETHRM. SWOETHRM is, therefore, able to model the thermal balance conditions for winter and non-winter conditions and land surfaces with and without vegetation.

The vertical heat conduction model is based on the vertical heat balance equation

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(k_z \frac{\partial T}{\partial z}\right) + Q_{z,t} \qquad (1)$$

where ρ is the density of the material in kg/m^3, c is the specific heat in J/kg-K, T is the temperature in K, t is the time in seconds, k_z is the conductivity in the z direction in W/m-K, and $Q_{z,t}$ is the total surface flux. The partial derivatives are approximated with finite differences using the Crank-Nicolson method.

The model currently handles five different material types or layers. A numerical solution is obtained by subdividing the layers into horizontally infinite control volumes, as shown in Figure 4, each of which is then subject to the governing equations for heat and mass balance. During the winter, snow can build up on the soil surface and melt away. This requires a numerical grid scheme that automatically adds or removes computational nodes. The numerical solution requires an initial soil temperature and moisture profile that is provided in a default data file. Appendix B describes the data inputs and lists the default data included with the ITM.

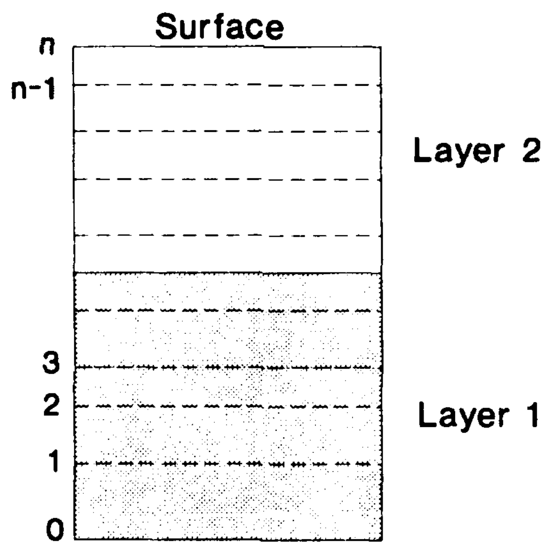

Figure 4. Schematic Representation of the Numerical Grid Scheme Used by SWOETHRM

The governing equations are subject to meteorologically-determined boundary conditions at the air interface. Surface fluxes are computed from user-supplied meteorological observations of air temperature, dew point, wind speed, and precipitation. If available, measured values of solar and incoming infrared radiation are used. In lieu of radiation measurements, the solar and infrared fluxes are calculated via simple parameterizations.

Water infiltration is based on gravitational flow. This approach does not included the effects of capillary pressure, which is required for a complete representation of water flow in soil. Therefore, the gravitational flow is used to represent the water infiltration only through snow. Water reaching the soil interface is currently assumed to be drained off. A full soil infiltration model based on capillary pressure is under development and will be added to SWOETHRM when available.

The thermal balance through surfaces is performed by treating the surface materials by mixture theory. Soils are examples of porous media which are characterized by a mixture of solids, an immobile matrix, and an interstitial system of generally evenly distributed voids. Water, in its various phases, is considered a part of the system.

The void space in the mixture is assumed to be completely filled with an immiscible mixture of fluids. The fluids considered are air, liquid water, and mobile ice (when present). The air component is assumed to consist of miscible dry and moist components. The dry air component is relatively inactive in the thermal process but the water vapor can be a significant player as a result of its consumption of heat during sublimation.

In the current model configuration, five constituents are studied: dry air, dry soil solids, ice, liquid water, and water vapor. All five constituents are assumed to be in local thermal equilibrium and the modeled system is assumed to be horizontally homogeneous.

2.4 Winter Conditions

For winter conditions, SWOETHRM is comprehensive in scope, being adaptable to a full range of winter meteorological conditions, such as snowfall, sleet, freeze-thaw cycles, and transitions between bare and snow covered ground. Although surface temperature prediction is the primary objective, transport of liquid water and water vapor are included as required components of the heat balance equation. Snow cover densification and metamorphosis and their resulting impact on optical and thermal properties are included, as well as the automatic treatment of snow accumulation and ablation. Water flow within snow is modeled with a gravity flow algorithm, and extends to the saturated case of water ponding on ice lenses or frozen soil. Phase-change, water flow and temperature are coupled through the use of a freezing curve. Although the model is primarily intended for use in snow, it will accommodate the bare soil case. The fluid-flow algorithm, however, does not consider capillary tension and therefore will not provide a completely accurate representation of water flow in soil.

2.5 Surfaces With Vegetation

The ITM can treat two types of vegetation on the surface. One is the presence of simple vegetation, such as grass or crops, and the second is extended forests.

2.5.1 Surfaces With Simple Vegetation

A simple surface energy budget model nicknamed VEGIE calculates temperatures of simple vegetation, such as grasslands and crops.[3] The model, which is based primarily on the work of Deardorff,[9] was developed and implemented by WES into the 1-D thermal model CTSTM.[2] VEGIE has been implemented in SWOEHTRM with no changes to the "science." However, a few changes have been made to the computer code in order to integrate VEGIE with SWOETHRM and these are discussed in Appendix A.

Briefly, the energy budget for simple vegetation is given by

$$F = a(S + L + R) - H - E = 0 \tag{2}$$

where a is the fractional foliage cover, S and L are global shortwave and longwave terms respectively, and R is a "net" longwave term for the interaction between the vegetation, the ground and their loss to the sky. Both the shortwave and longwave terms are broadband values. The terms H and E represent sensible and evaporative losses, respectively, for simple vegetation. Energy storage and conduction by simple vegetation are neglected. Steady state conditions are assumed in VEGIE.

Simple vegetation temperatures are obtained in VEGIE by means of a root-finding algorithm called the *regula falsi* technique. Using the previous simple vegetation temperature as an initial guess, the algorithm evaluates the energy budget equation for progressively higher (and lower) values of simple vegetation temperature until a temperature is found where the sum of the energy budget terms is zero. This temperature then represents the new simple vegetation temperature. Figure 5 shows results from a calculation with simple vegetation assumed.

Inputs to VEGIE can be divided into two general categories: meteorological variables and parameters characterizing the simple vegetation. Here the meteorological variables include global solar and longwave fluxes, air and ground temperatures, relative humidity, air pressure and wind speed. (In SWOETHRM simulations, the ground temperature from the previous time step is used.) The

[9] Deardorff, J.W. (1978) Efficient Prediction of Ground Surface Temperature and Moisture, With Inclusion of a Layer of Vegetation, *J. Geophys. Res.*, **83**:1889-1903.

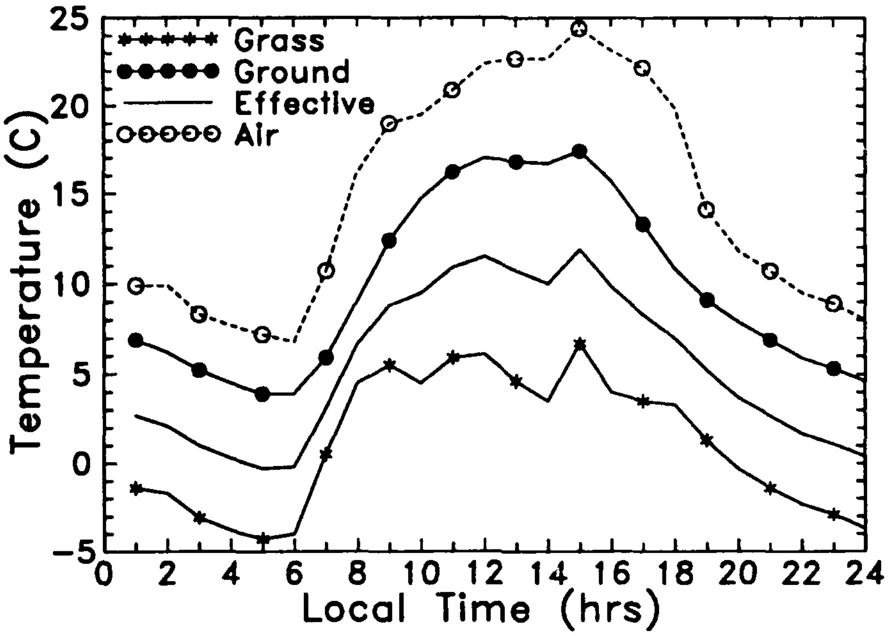

Figure 5. Example of Temperatures from VEGIE Coupled with SWOETHRM. The case represents simple grass with bare soil underneath. The meteorological conditions are for mid-March with clear skies. The effective temperature represents a weighted average of the grass and ground temperatures

vegetation inputs include the fractional foliage cover, longwave emissivity, shortwave absorptivity and foliage height of the simple vegetation. The foliage cover fraction is an area average shielding factor associated with the degree to which the foliage shields the underlying ground from shortwave radiation. It is assumed to be independent of solar zenith angle.

Sensitivity studies from WES indicate that foliage temperatures are rather insensitive to changes in the vegetation input parameters. However, the effective temperature of a vegetated surface, which represents a contribution from the foliage and underlying ground, depends strongly on fractional foliage cover.

Three types of simple vegetation are included as default types of simple vegetation: “grasslands”, “medium vegetation”, and “high vegetation.” The labels used are somewhat general and refer more to the classes and types and of vegetation (crops, shrubs, meadows, etc.) rather than the size of the vegetation. Appendix B describes the input requirements for VEGIE and lists the values supplied as default data.

2.5.2 Surfaces With Extended Forest Canopies

The treatment for surfaces with extended forest canopies is based on the Thermal Vegetation Canopy Model which calculates foliage temperatures within a forest canopy.[4] Briefly, TVCM divides a forest canopy into three horizontal layers plus two additional layers for the ground and atmosphere. Each canopy layer is then described by an energy budget in which the fluxes from other canopy layers, the ground and the atmosphere are considered. Specifically, expressions for the following energy components are included:

1. Shortwave absorption
2. Longwave transfer from canopy layers, ground and atmosphere
3. Sensible heat
4. Evapotranspiration

Heat exchange by conduction is considered negligible and spectral effects within the shortwave and longwave regions are assumed to be insignificant. Also, steady state conditions are assumed in TVCM.

TVCM was originally developed as a stand-alone model. For the purposes of SWOE, the three canopy layers from TVCM have been interfaced with SWOE-THRM. In the discussions to follow, the use of the term "TVCM" will refer to the canopy portion of the model. As with VEGIE, the "science" in TVCM has not been modified but code changes were required in order to integrate with SWOETHRM. These changes are discussed in Appendix A.

An attractive feature of TVCM is that the geometrical properties of the forest canopy have been separated from the energy terms. This formulation leads to the development of shortwave and longwave transfer matrices that, in physical terms, describe how much radiation reaches a canopy layer from other layers in the model. These matrices, which can be precalculated for a particular type of forest canopy, are then convolved with the appropriate meteorological variables to obtain energy budgets for the canopy layers. In turn, the energy budget equations are solved by means of a modified iterative Newton-Raphson technique where the air temperature is used as an initial guess for the canopy layer temperatures. Figure 6 shows results from a calculation with an extended forest canopy assumed.

Inputs to TVCM can be divided into two general categories: meteorological variables and parameters characterizing the layered forest canopy. The meteorological variables include global solar flux, air and ground temperatures, relative humidity and wind speed. The canopy input parameters include the longwave emissivity and shortwave absorptivity for each canopy layer, the stomatal resistance and inputs describing radiative transfer within the canopy. For the radiative transfer inputs, predetermined shortwave and longwave transfer matrices can be

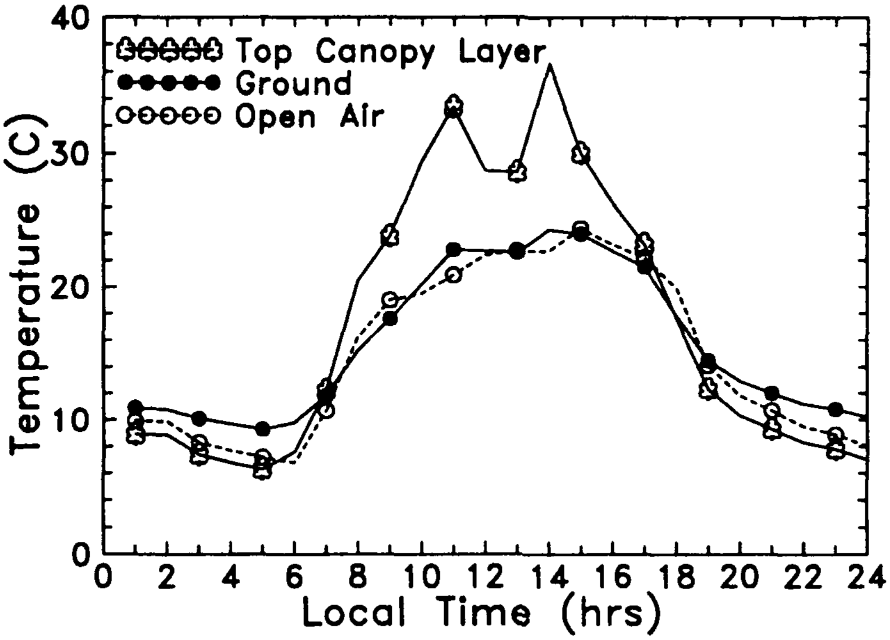

Figure 6. Example of Temperatures from TVCM Coupled with SWOETHRM. The case represents a deciduous forest of oak and hickory with bare soil underneath. The meteorological conditions are for mid-March with clear skies

inputted directly or they can be calculated internally by TVCM. In the second option, information describing leaf distributions and orientation within the canopy must be provided.

Two types of extended forests are included as defaults, a "coniferous forest" and a "deciduous forest." The coniferous forest is representative of a Douglas fir forest and the deciduous forest is representative of an oak/hickory forest. Section 3.2 describes what parameters are used to describe these default forests and Appendix B describes the input requirements and lists the default values supplied with the ITM.

2.6 Bodies of Water

CE-THERM-R1 is the thermal response model that is a part of the water quality model CE-QUAL-R1.[6] CE-QUAL-R1 describes the vertical distribution of thermal energy and biological and chemical materials in a reservoir through time. It is used to study preimpoundment and postimpoundment water quality problems and the effects of reservoir management operations on water quality. Although a part of CE-QUAL-R1, CE-THERM-R1 can be run as a stand-alone model describing profiles for temperature, total dissolved solids, and suspended solids. The science in CE-THERM-R1 was not changed but modifications were made to the code in order to integrate the code with the ITM. Appendix A describes the changes made to the code.

In CE-THERM-R1, temperature and concentration gradients are computed only in the vertical direction. The reservoir is conceptualized as a vertical sequence of horizontal layers where thermal energy and materials are uniformly distributed in each layer. The mathematical structure of the model is based on horizontal layers whose thicknesses depend on the balance of inflowing and outflowing waters. Variable layer thicknesses permit accurate mass balancing during periods of large inflow and outflow.

The distribution of inflowing waters among the horizontal layers is based on density differences. Simulations of surface flows, interflows, and underflows are possible. Similarly, outflowing waters are withdrawn from layers after considering layer densities, discharge rates, and outlet configuration.

Reservoir outflows may take place according to a specified schedule of port releases. Alternately, specification of total release and desired release temperatures can be made. In this case, the model will select port flows. In addition, both continuous (normal) and scheduled operations can be simulated. Continuous operation refers to normally uninterrupted port of weir outflows. Scheduled operation refers to fluctuating generation outflows or pumpback inflows.

Vertical transport of thermal energy and materials occurs through entrainment and turbulent diffusion. Entrainment is a transport process that sharpens gradients and determines the depth of the upper mixed region and the onset of stratification. It is calculated from the turbulent kinetic energy influx generated by wind shear and convective mixing. Turbulent diffusion is a transport process that reduces gradients and is calculated using a turbulent diffusion coefficient that is dependent on wind speed, inflow and outflow magnitudes, and density stratification.

The model can perform stochastic simulations using Monte Carlo methods. Statistical data describing biological and chemical coefficients are used to provide probabilistic estimates of key output variables.

Default conditions for CE-THERM-R1 are based on conditions for DeGray Lake in Arkansas. These data were supplied with the code as distributed by WES. Appendix B lists the default data. Due to the extensive nature of the data requirments, the reader is referred to the CE-QUAL-R1 manual for information on the input parameters.

3 ITM DATA REQUIREMENTS

A goal in the development of the ITM was to make the specifying of the required data files as simple as possible. In order to do this, the required data were grouped into categories. The categories are:

- Environmental Data
- Land Use and Terrain Data
- Computational Control Parameters

The various data files were organized in as logical of a format as possible. For example, the environmental parameters were structured around the types of data one would obtain from conventional weather services. Also, a standard set of units was adopted for the data bases. The individual program modules internally performed unit conversions if they required data in units other than that used as the standard.

3.1 Environmental Data

The environmental data are provided to the ITM are primarily based on conventional surface weather data. In the SWOE ITM, the environmental file serves two purposes:

1. The file provides common meteorological conditions for SWOETHRM, CE-THERM-R1, and TREETHERM
2. The file establishes the start and stop times, and the simulation interval, where the SWOE ITM calculates surface temperatures.

The surface temperatures calculated by the SWOE ITM are calculated at the time interval of the environmental data. Currently, a maximum of 144 records of environmental data are allowed in one file. Appendix B describes the format of the environmental data file and contains a listing of the default environmental data file and other input files that have been delivered with the SWOE ITM.

The environmental data also contains data for the total, direct, and diffuse solar flux and the downwelling infrared flux. If actual measurements are available, it is assumed that they will be used. If not, values calculated from the SWOE Atmospheric Package are used. At this time, the SWOE Atmospheric Package has not been integrated with the SWOE ITM. Instead, a preliminary atmospheric radiation package was developed and provided with the ITM to calculate the solar and infrared fluxes.

3.2 Preliminary Atmospheric Radiation Package

The preliminary atmospheric radiation package includes short routines to calculate the incident solar and downwelling infrared radiation. The solar routine is an empirical approach that includes direct and diffuse solar fluxes and the infrared parameterization is tied to surface weather conditions. Both radiation routines include the effects of clouds but do not permit the use of a three dimensional cloud distribution model.

The values produced by the preliminary atmospheric radiation package are used whenever a flag, fluxflag, contained in the control file is set equal to one. Additionally, the environmental file is modified so that it contains the fluxes calculated by SWOETHRM. Any existing data in the flux columns is overwritten. If the user has global solar and downwelling infrared flux data, the fluxflag parameter should be set to zero. SWOETHRM will then internally estimate the direct and diffuse components of the global solar fluxes.

3.3 Land Use and Terrain Data

Information must be provided to tell the ITM what type of surface is being modeled. This information includes the land use category, the orientation of the surface, and a description of the underlying materials.

The land use information is given to the ITM by using a set of default land use categories. Those being adopted are those that have been used in CTSTM and for previous SWOE demonstrations. Table 2 lists the land use categories that have been used by WES, as well as their broadband graybody emissivities and shortwave absorption. The use of these categories as default ITM values allows for easy comparison of SWOETHRM results against those from CTSTM.

The orientation of the surface is described via the slope and aspect of the surface. These parameters are used to adjust the solar flux data, which are given for a horizontal surface. The slope is the elevation angle relative to a horizontal surface. The aspect is the azimuthal angle relative to magnetic north. The slope is given as an angle between 0 and 90° and the aspect as an angle clockwise between 0 and 360°. When water bodies are selected, slope and aspect values of 0° are the only values permitted.

For the SWOE ITM, physical parameters describing each land use category are contained in separate input files. These data provide the physical parameters for the heat conduction calculations. When vegetation is assumed, these data describe the particular form of vegetation. (Appendix B provides specific details about these files and lists the default values provided with the ITM.) When using the SWOE ITM, these files must be present in the user's directory or an appropriate path specification declared. For reference, Tables 3 and 4 list some of the parameters

Table 2. Land Use Categories and Corresponding Radiative Values Used in Previous SWOE Simulations

CATEGORY	GRAYBODY EMISSIVITY	SHORTWAVE ABSORPTION
Deciduous Forest	0.98	0.75
Coniferous Forest	0.98	0.75
Medium Vegetation	0.85	0.96
High Vegetation	0.85	0.96
Grasslands	0.98	0.80
Bare	*	*
Urban Area	0.99	0.60
Water Body	0.97	0.4
Snow Covered Surfaces	0.97	0.22

* Use Values for Specific Material

adopted in the land use data files supplied with SWOETHRM. Table 3 contains the sample values for the foliage cover fractions and foliage heights used by the forest and vegetation classes. These values have been adopted without change from those values used by WES with CTSTM. Table 4 contains the sample values of the material properties proposed for SWOETHRM. Again, the majority of the values used are the same as those used by WES with CTSTM. The values listed are used to describe the properties for the topmost layer of the surfaces being modeled. The material properties listed for the deciduous and coniferous forests represent the vegetative debris materials found on the forest floor. It is noted that the Relative Saturation column refers to data used only by CTSTM. In SWOETHRM, the user inputs a moisture profile of bulk water density, in kg m^{-3}, for the given material.

The user may want to change the values listed in the tables to meet the needs of a given simulation. In that case, the user is urged to consult appropriate references on surface material properties, such as those compiled by CRREL.[10]

SWOETHRM also requires a number of parameters to describe the properties of the underlying materials. At present, two sample data files for describing the

[10] Farouki, O.T. (1981) "Thermal Properties of Soils," US Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, CRREL Monograph 81-1, December.

Table 3. ITM Default Foliage Cover Fractions and Foliage Heights for Vegetated Surfaces

CATEGORY	FOLIAGE COVER FRACTION	FOLIAGE HEIGHT (cm)
Deciduous Forest	0.95	-
Coniferous Forest	0.95	-
High Vegetation	0.70	50
Medium Vegetation	0.40	100
Grasslands	0.50	50

underlying surface have been delivered with the ITM, one for a bare surface of silt over sand and one for a snow covered surface. Additional default data files should be developed, with the assistance of the SWOE Database Task Area team, for use with other representative surfaces, such as forest floors, road surfaces, deserts, etc. Appendix B lists the sample data files included with the ITM.

3.4 Control Parameters for Running the SWOE ITM

The execution of a given SWOE simulation is controlled by a file, *itm90.inp*, that contains a number of control parameters required by SWOETHRM. As will be discussed in Section 5, the user need not be concerned about developing or using the file *itm90.inp* when the user employs the User Interface System. The UIS creates the file internally based on entries made by the user in response to queries from the UIS. The user only has to be concerned about the file *itm90.inp* if the user is running SWOETHRM on a computer platform that does not contain the UIS or is not a SUN™ platform.

Table 5 describes the structure of the output file. The file contains the surface temperatures calculated for each of the land use categories, slope, and aspect combinations. This is the output file that would be used to produce the input conditions required by the SWOE radiance model. Appendix B describes where the research grade output will be written.

Table 4. ITM Material Properties Used for the Topmost Layers

Surface Type	Graybody Emissivity	Shortwave Absorption	Relative Saturation*	Typical Thickness (cm)	Diffusivity (cm^2/min)	Heat Conductivity (cal/min cm K)
Asphalt	0.96	0.90	0.00	20	0.10	0.22
Basalt	0.90	0.70	0.10	20	0.54	0.31
Gravelly Clay	0.90	0.90	0.20	30	1.54	0.18
Bare Sand	0.90	0.60	0.10	30	1.944	0.084
Bare Clay	0.95	0.40	0.20	30	0.3024	0.18
Bare Silt	0.90	0.80	0.30	30	0.14	0.20
Deciduous Forest	0.70	0.93	0.10	5	0.74	0.01
Coniferous Forest	0.70	0.93	0.10	5	0.74	0.01
High Vegetation	0.90	0.90	0.2	50	1.536	0.18
Medium Vegetation	0.90	0.60	0.3	30	1.944	0.0840
Grasslands	0.98	0.80	–	50	–	–
Water Body	0.97	0.4	-	100	0.0858	0.0840
Snow	0.97	0.22	0	5	30.0	0.0108

* Values Used by CTSTM. In SWOETHRM, the user must provide a moisture profile for the given material.

Table 5. Output Structure for the Output File FOUT

RECORD	DESCRIPTION
1	Descriptive Header
2	Day and Time of Calculation
3	Starting Julian Day and Hour of Simulation
4	Ending Julian Day and Hour of Simulation
5	Simulation Year and Simulation Interval in Hours
6	Land Category, Slope and Aspect Class
7	Temperature (C) for the Conditions in Record 6
8...	Repeat of Records 6 & 7 For Remaining Conditions

4 SENSITIVITY CALCULATIONS WITH SWOETHRM

A series of sensitivity calculations have been performed with the ITM and the results compared against those from CTSTM. During the testing of SWOETHRM against CTSTM, two errors were discovered in CTSTM. The errors are:

1. When the extended forest canopy model (TVCM) was utilized, the global solar fluxes from CTSTM were passed into TVCM with the wrong units.

2. When CTSTM uses direct and diffuse solar fluxes from the meteorological file, the correction for surface slope and azimuth was wrong. Specifically, the code included an additional correction for the solar zenith angle which should not be applied to fluxes in the meteorological file.

The errors in CTSTM were corrected and the following comparisons of SWOETHRM made using the corrected version of CTSTM.

Calculated surface temperatures from the SWOE ITM are compared against those from CTSTM for 20 September 1989 at Hunter-Liggett, California. This date was chosen because it represents the conditions used in the SWOE Year 2 demonstration. For reference, Table 6 lists the weather data for 20 September 1989 at Hunter-Liggett, California.

The calculations were performed with three land use categories: a bare soil consisting of a silt layer on top of clay, medium vegetation, and a deciduous forest. Seeing that no bodies of water were present, only SWOETHRM was used by the ITM. The calculations for both SWOETHRM and CTSTM were performed with the shortwave and longwave fluxes being precalculated and inputted with the meteorological data file. They were calculated using the preliminary atmospheric radiation package that is used with the ITM. For comparison purposes, the CTSTM temperature simulations were also performed using solar and infrared fluxes that were calculated internally by CTSTM. As shown in Figure 7, there is a significant difference in the solar fluxes produced by the two approaches right after sunrise. Finally, the temperature simulations were performed for horizontal surfaces.

Figure 8 compares the bare soil temperatures from SWOETHRM against those from CTSTM. The comparison shows that the daytime temperatures of the bare soil from SWOETHRM are almost 5° C lower than those from CTSTM. In order to understand the differences between the two sets of results, a comparison of the individual heat flux terms was made.

Figure 9 compares the individual heat flux terms for the calculation. As shown in the Figure, the sensible heat fluxes are similar for SWOETHRM and CTSTM. SWOETHRM, however, has more latent cooling than does CTSTM. The additional latent cooling in SWOETHRM most likely results from two sources. First, the

Table 6. Weather Data for the Hunter-Liggett Demonstration. The data are for Julian Day 263, 20 September 1989

TIME (LST)	TEMP (C)	RH (%)	VISIBILITY (km)	CLOUD OBS	CLOUD COVER (%)	WIND SPEED (m/sec)	WIND DIRECTION (deg)	SURFACE PRESS (mb)
0100	10.6	89	25	Clear	0	0.31	128	968.8
0200	10.5	90	25	Clear	0	0.67	76	969.2
0300	9.4	90	25	Clear	0	0.05	Calm	969.2
0400	9.5	91	25	Clear	0	0.21	91	969.4
0500	8.7	91	25	Clear	0	0.62	56	969.6
0600	8.2	91	16	St	100	0.57	65	969.9
0700	10.8	91	2	Fog	100	0.10	Calm	970.6
0800	13.0	87	2	Fog	100	0.26	246	970.8
0900	15.2	77	16	St	50	0.98	17	971.1
1000	19.1	55	25	Clear	0	1.34	93	971.1
1100	21.3	43	25	Clear	0	1.59	67	970.6
1200	23.7	34	25	Clear	0	1.39	31	970.1
1300	25.2	21	25	Clear	0	1.95	89	969.6
1400	26.7	21	25	Clear	0	1.49	351	969.0
1500	27.6	18	25	Clear	0	1.39	59	968.5
1600	27.4	17	25	Clear	0	2.36	57	968.1
1700	26.1	20	25	Clear	0	3.03	49	968.3
1800	24.3	23	25	Clear	0	1.18	50	968.3
1900	19.6	41	25	Clear	0	0.26	220	968.5
2000	18.5	45	25	Clear	0	1.13	137	969.0
2100	16.3	54	25	Clear	0	0.72	162	969.3
2200	15.2	59	25	Clear	0	0.51	105	969.5
2300	12.7	75	25	Clear	0	0.36	36	970.0
2400	12.3	81	25	Clear	0	0.21	Calm	970.0

default soil properties used by SWOETHRM contains somewhat more moisture than that assumed in the CTSTM calculations. Without a precise measure of the soil moisture content on the given day, there is no way to determine which value is correct. However, one could adjust the values to "fine tune" the calculations to match. Second, SWOETHRM separately considers dry and moist soil terms with a more sophisticated treatment.

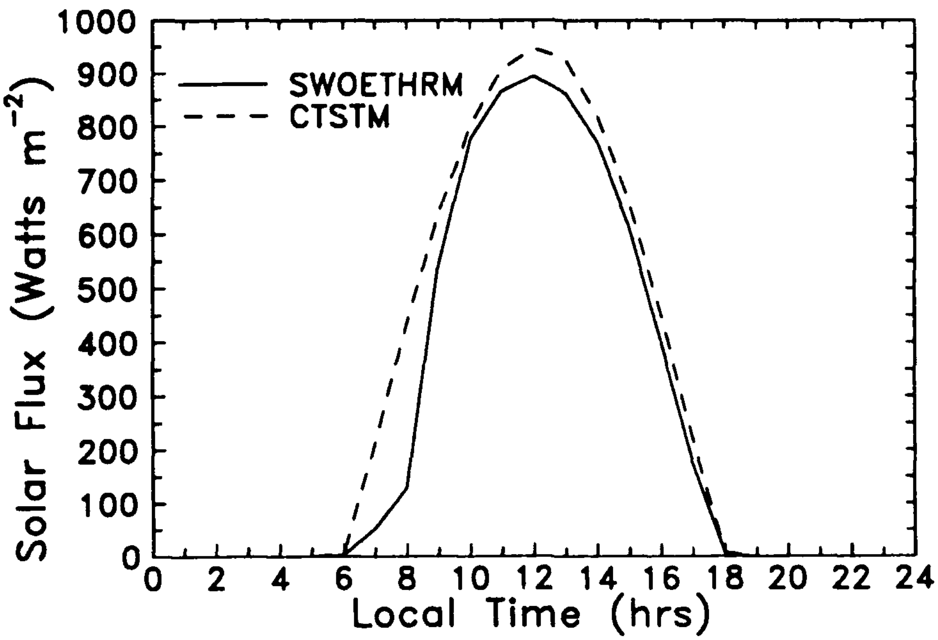

Figure 7. Comparison of Solar Fluxes Calculated Internally by CTSTM Against Those Calculated Using the Preliminary Atmospheric Radiation Package. Calculations were performed for conditions on 20 September 1989 at Hunter-Liggett, CA

Figure 10 compares the effective temperatures of medium vegetation (with bare soil underneath) from SWOETHRM against those from CTSTM. The CTSTM results are shown using the CTSTM-derived solar fluxes and those from the preliminary atmospheric radiation package. The effective temperature, T_e, represents the radiometric temperature of a plot of land that contains a mixture of the vegetation and the bare soil

$$\epsilon_e T_e^4 = f \epsilon_f T_f^4 + (1 - f) \epsilon_g T_g^4 \tag{3}$$

where ϵ_e is the effective emissivity of the plot of soil+vegetation, f is the foliage cover fraction, ϵ_f is the emissivity of the foliage, T_f is the temperature of the foliage, ϵ_g is the emissivity of the underlying ground, and T_g is the temperature of the ground. The effective temperature is obtained by solving for T_e.

As shown in Figure 10, the CTSTM temperatures are about 10° C lower throughout the simulation. Here, the differences are mostly due to the way CTSTM obtains its effective temperatures from its vegetation and underlying ground temperatures. As discussed in Appendix A, the effective temperatures from CTSTM must be used cautiously because they are often not bounded by the individual temperatures of the vegetation and underlying ground. CTSTM assumes that the

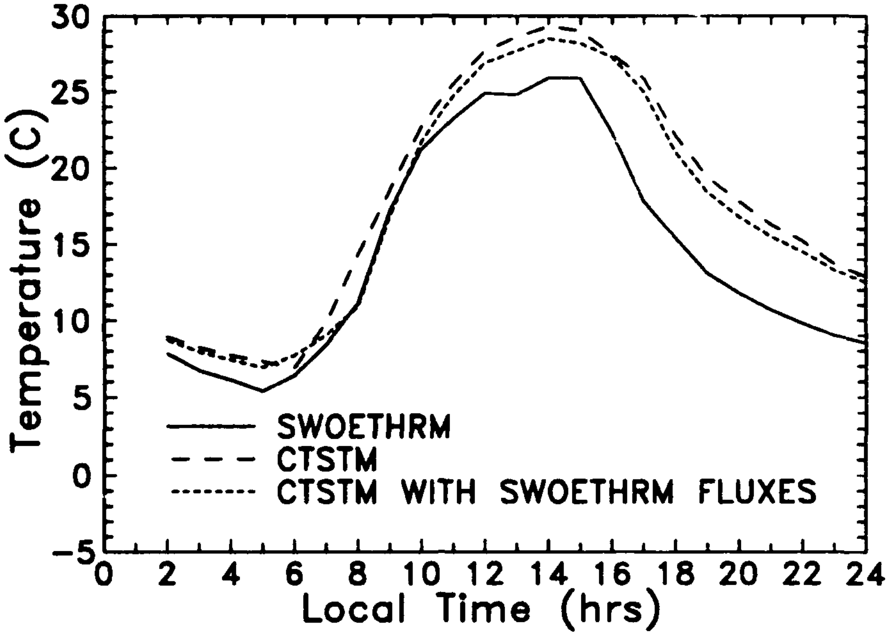

Figure 8. Bare Soil Temperatures From SWOETHRM and CTSTM as a Function of Time. Calculations were performed for conditions on 20 September 1989 at Hunter-Liggett, CA

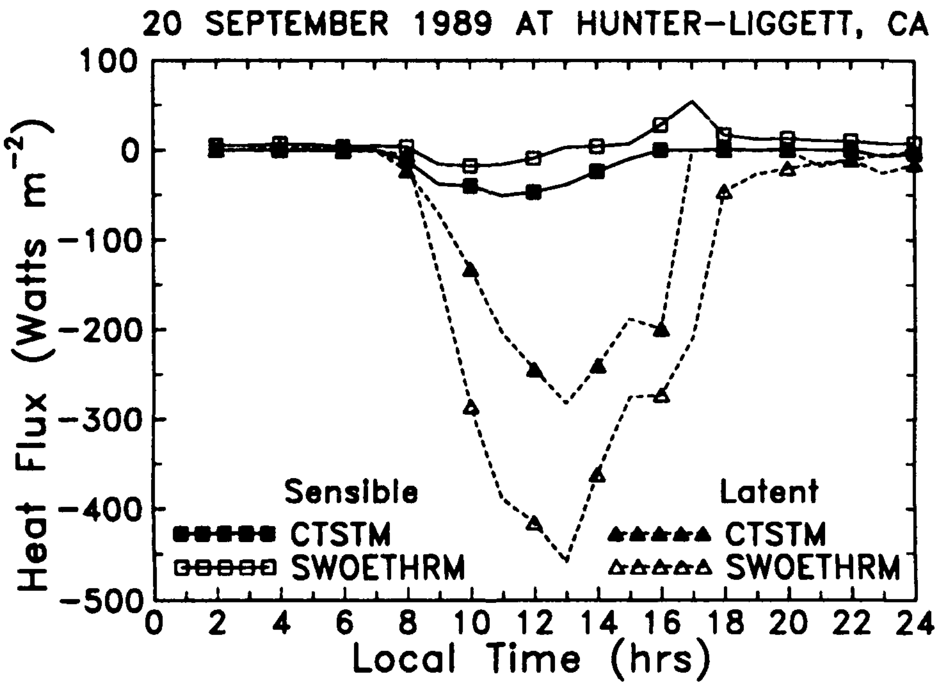

Figure 9. Comparison of the Sensible and Latent Heat Fluxes From SWOETHRM and CTSTM as a Function of Time for a Bare Soil Calculation. The CTSTM calculations were made using the SWOETHRM solar fluxes

effective emissivity in Eq.(3) is one.[3] In SWOETHRM, we have assumed that ϵ_e is a weighted average of the foliage and ground emissivities. Therefore, it is perhaps more fruitful to compare the individual vegetation and ground temperatures as predicted by the two codes.

Figure 11, for example, shows medium vegetation temperatures from SWOETHRM and CTSTM. The CTSTM results are given using both the internally generated solar and infrared fluxes and those generated externally by the preliminary atmospheric radiation package. The comparisons all show a gradual dropoff in medium vegetation temperature between 1000 and 1500 hrs which is due to convective cooling by the wind. When SWOETHRM and CTSTM use the same solar and infrared fluxes, the agreement between the two sets of results is generally good. The nightime differences of 2° C from the CTSTM values using the internally generated solar/infrared fluxes can be traced to longwave source contributions from the atmosphere and underlying ground.

Figure 12 shows the ground temperatures under the vegetation as predicted by SWOETHRM and CTSTM. The ground is shaded by the vegetation so the bare soil values are lower than those given by Figure 9. The differences between the SWOETHRM and CTSTM are, again, due primarily to the latent heat flux differences.

Figure 13 compares deciduous forest temperatures from SWOETHRM against those from CTSTM. When solar fluxes from the meteorological file are used, SWOETHRM and CTSTM predict the same temperatures for the top canopy layer because the underlying ground temperature has little or no impact on the top canopy layer. When solar fluxes are calculated internally by CTSTM, forest temperatures are marginally higher except for the time period between 600 and 900 hrs. Sky conditions were cloudy during this three hour period (see Table 11) which suggests that the higher forest temperatures are related to the way CTSTM computes solar flux during cloudy conditions.

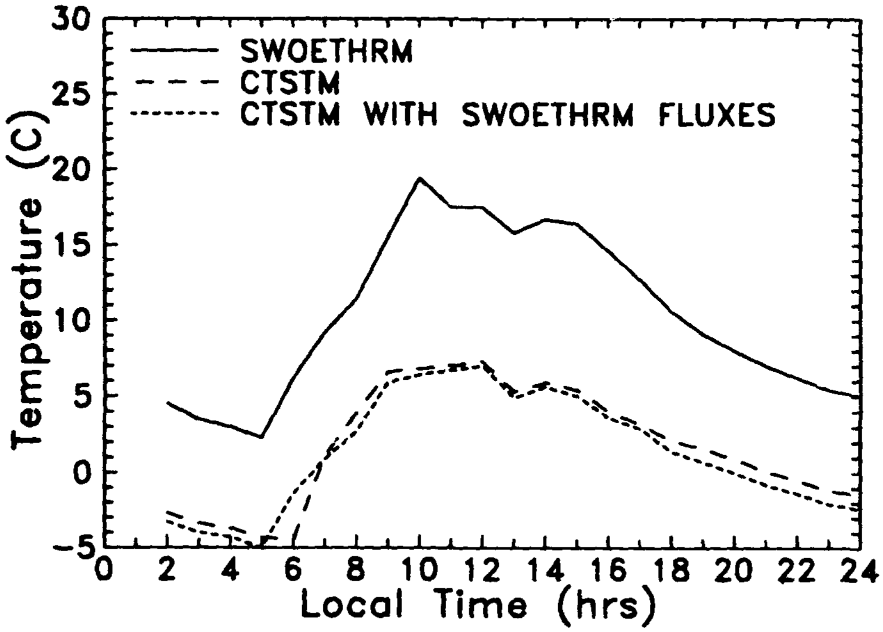

Figure 10. Effective Temperatures as a Function of Time for Medium Vegetation With Bare Soil Underneath From SWOETHRM and CTSTM

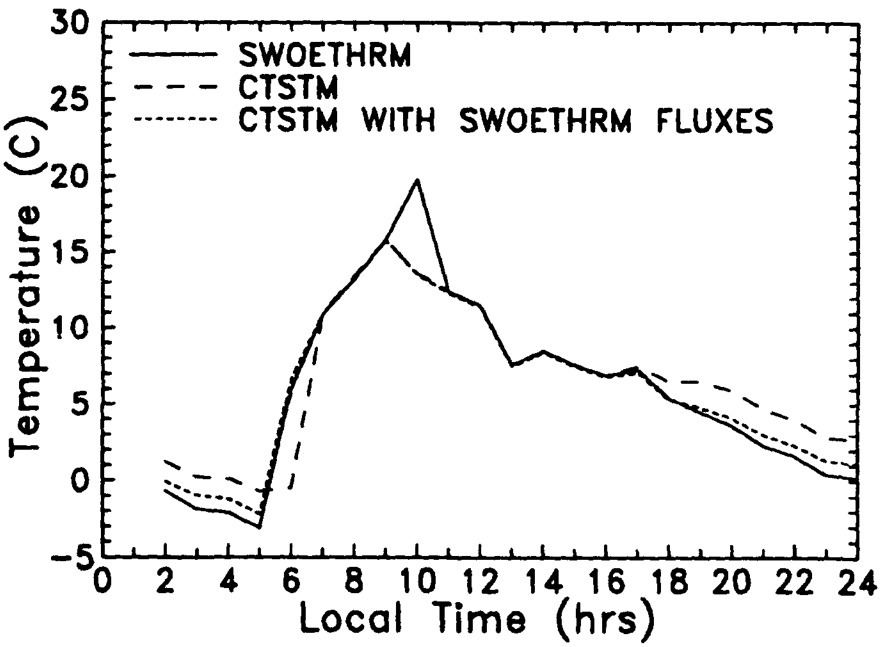

Figure 11. Medium Vegetation Temperatures as a Function of Time From SWOE-THRM and CTSTM. The CTSTM values are given using the CTSM-derived solar fluxes and those produced by the temporary ITM-atmospheric package

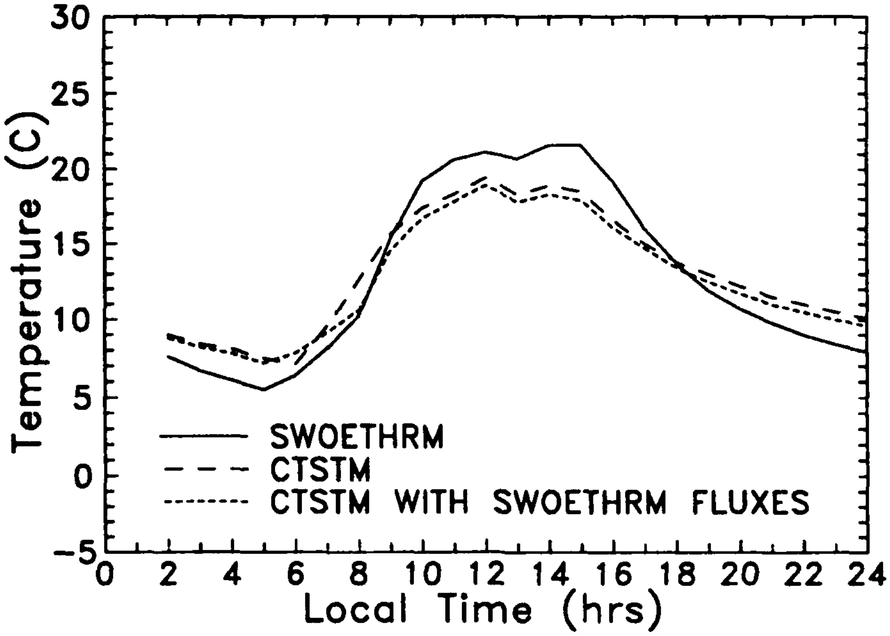

Figure 12. Ground Temperatures as a Function of Time Under Medium Vegetation From SWOETHRM and CTSTM. The CTSTM values are given using the CTSTM-derived solar fluxes and those produced by the preliminary atmospheric radiation package

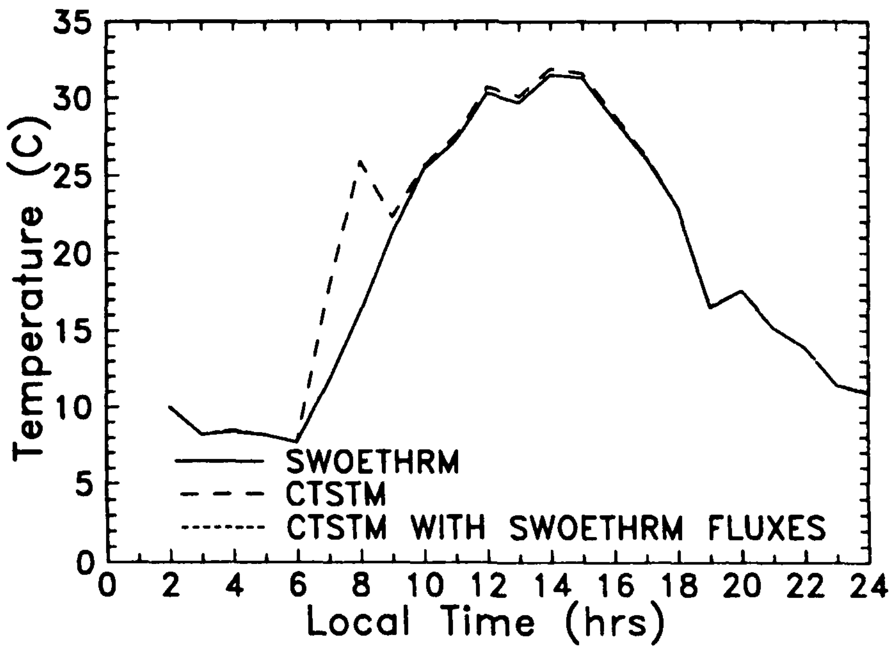

Figure 13. Comparison of Deciduous Forest Temperatures From SWOETHRM Against Those From CTSTM. The temperatures represent the top layer of the forest canopy

5 USERS GUIDE FOR ITM

The SWOE ITM has been designed to be easy to use. A series of sample data files have been included with the software package. These data files are based on conditions and data for Hunter-Liggett, California, the site of the SWOE demonstration for the second year of the SWOE program. Appendix B describes and lists the sample data files.

A first generation User Interface System (UIS) has been developed to aid the user in performing calculations with the ITM. The UIS was developed on a SUN^{TM} computer system operating under the UNIX operating system. This requirement currently restricts the use of the UIS to SUN^{TM} platforms. In a proposed follow-on effort, it is planned to convert the UIS to a hardware independent system using X-Windows. A simpler, hardware independent version of the User Interface System has also been developed for users who do not have access to a SUN^{TM} computer. This version is described in Section 5.7. It is again stressed that running the ITM program is not restricted to SUN^{TM} platforms.

5.1 Description of the SWOE User Interface System

The SWOE User Interface System provides easy-to-use menus for setting up, performing and analyzing results from the SWOE ITM. The UIS has been designed with error checking abilities to help prevent the user from making incorrect or unrealistic calculations.

With the UIS, the user can specify which land use categories are to be included, define the slope and aspect classes within a scene, give the name of the meteorological data file to be used, and specify the output file to which the simulation results will be written. The Interface System will create the control parameters necessary to run the ITM (as described in Section 3.3) along with the simulation file containing the land use categories and slope and aspect classes. After all of the above data have been specified, the user can perform the ITM calculations and subsequently view the output file created by the simulation. In addition, for research applications in which only one land use category with specific slope and aspect angles is being analyzed, the user can graphically display the calculated temperatures versus time.

In order to use the SWOE UIS, the user must be on a SUN^{TM} computer and within the Suntools^{TM} environment. The UIS must be executed from the directory containing the UIS code and the input data files. At the command line prompt, the user should type *itm_menu* and press RETURN to start the UIS. Figure 14 shows the main start-up menu that will appear on the screen.

The UIS begins by offering two options to the user. The first option is for a "Single Polygon Simulation" that is intended for use mainly for research appli-

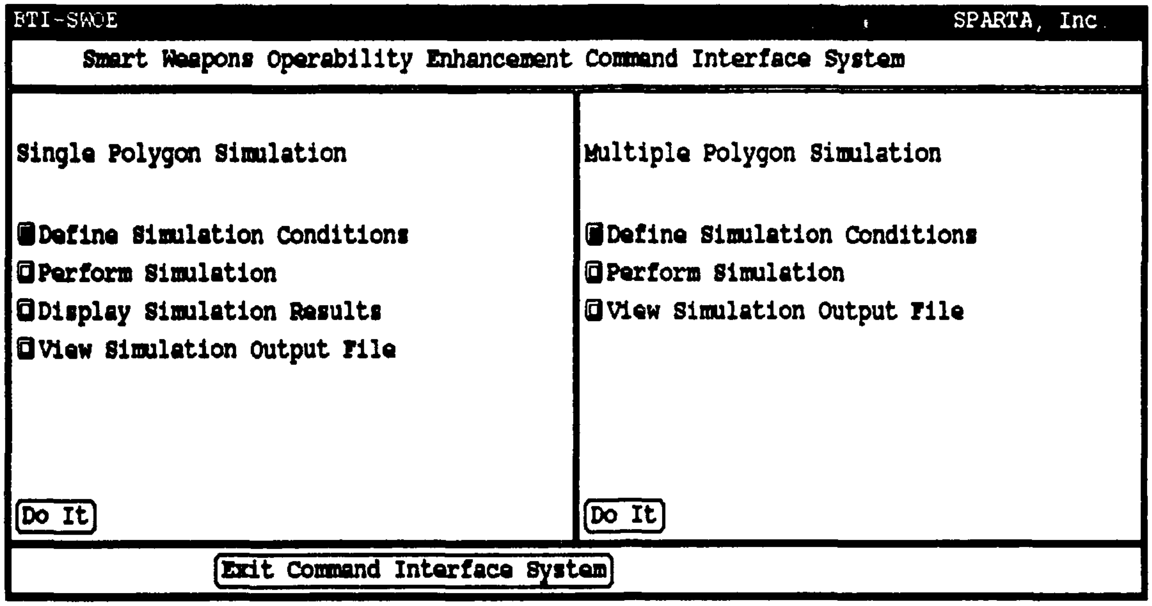

Figure 14. SWOE User Interface System Main Menu

cations in which a more detailed analysis of a single polygon (*i.e.* one land use category with specific slope and aspect angles) can be made. The second option is for “Multiple Polygon Simulations” for scene simulations using multiple land use categories and various slope and aspect angles. Within each of these option choices, the user can

- Define the Simulation Conditions
- Perform the Simulation
- Graphically Display the Simulation Results (Single Polygon case ONLY)
- View the Simulation Output File

In order to select an option, the user must move the cursor arrow over the desired option and press the leftmost button of the “mouse”. The box next to the chosen option should then be filled. To execute the chosen option, the user must move the cursor arrow over the “Do It” button, located near the bottom of the screen, and press the leftmost button of the “mouse”. Note that there are two “Do It” buttons, each one executes the chosen option for either the “Single Polygon” or “Multiple Polygon” case. The UIS then proceeds to display a series of windows that describe the features to each chosen option. To exit the UIS, the user moves the cursor over the “Exit Command Interface System” button and presses the leftmost button of the “mouse”.

5.2 Defining Simulation Conditions

5.2.1 Single Polygon Case

Figure 15 shows the menu for defining the simulation conditions for the Single Polygon case. This case will mainly be used for research applications in which a more detailed analysis of a single polygon in a scene is desired. A set of default values will appear for most parameters in the menu.

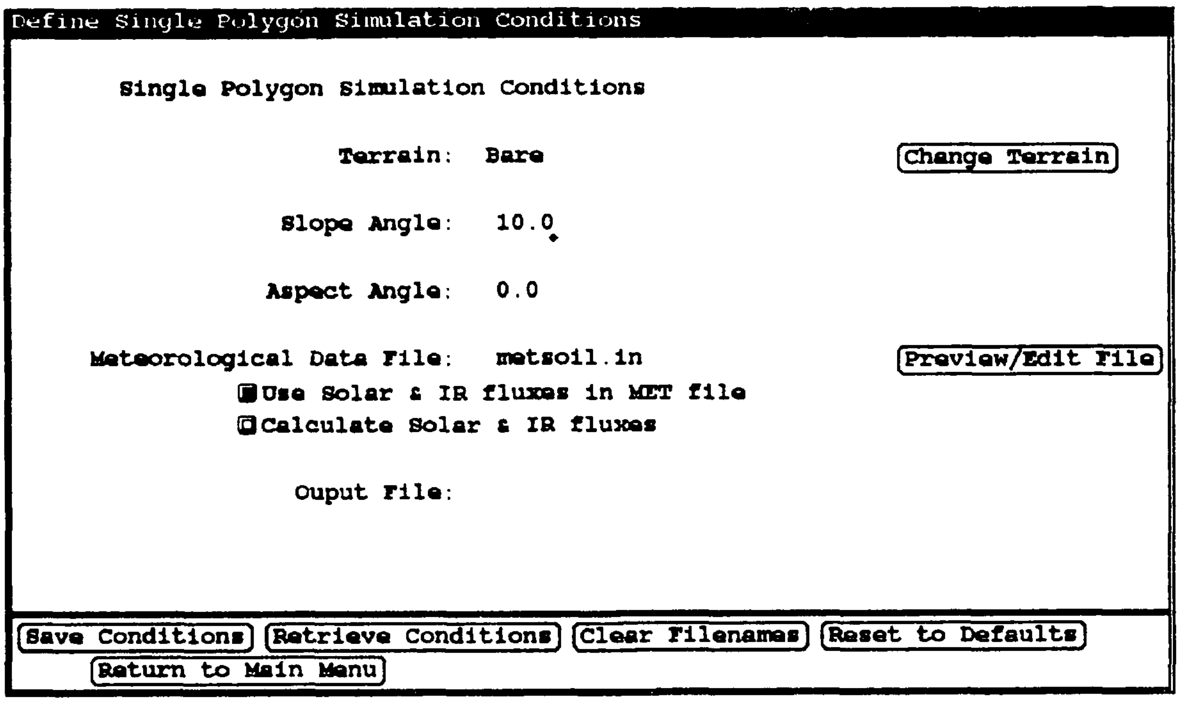

Figure 15. User Interface System Define Single Polygon Simulation Menu

5.2.1.1 Change Terrain

The user first selects the particular terrain of this polygon by selecting the Change Terrain button with the "mouse". This will display a menu of the available terrains as shown in Figure 16. The desired terrain is chosen by moving the "mouse" over the terrain type and pressing the leftmost button. The box next to that land use category will be filled. To return to the Simulation Definitions Menu the user must select the "O.K." button. The chosen terrain will appear on the menu.

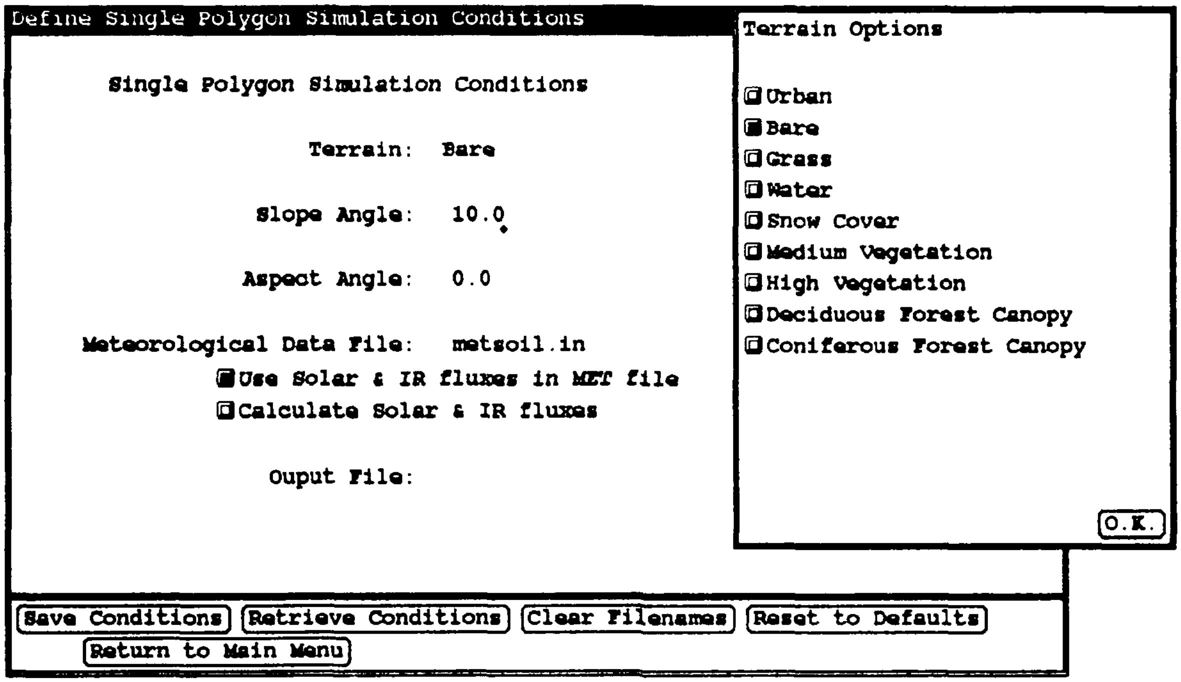

Figure 16. User Interface System Change Terrain Menu

5.2.1.2 Slope and Aspect Angles

The user must enter the specific slope and aspect angles for the simulation. First, the current entry must be deleted (unless, of course, it matches the user's needs) and the new value typed in. After hitting RETURN, the UIS will go to the next entry. Note that the cursor arrow must be on the menu in order to edit these entries. The blinking caret denotes the current entry to be edited. The slope and aspect angles are entered in degrees. The slope angle must be between 0 and 90 degrees, the aspect angle between 0 and 360 degrees. The UIS will perform error checking on these values and will not let the user return to the Main Menu until these angles are within range.

5.2.1.3 Input and Output Files

The user must enter the name of the meteorological data file in the same manner as for the "Multiple Polygon Simulation" option - by using the delete key to delete any current entry and typing in the new filename from the keyboard. The user may preview/edit this file by "clicking on" the "Preview/Edit File" button. When this is done the file (if it exists) is displayed and can be edited similar to files in the Suntools TextEditor window. Buttons for saving changes and exiting the viewing window are provided at the top of the window (see Figure 13). Along with entering the name of the meteorological data file, the user must choose the source for the solar and infrared flux data. The source can be either from within the meteorological data file or can be calculated by the interim atmospheric package. To choose the source of the flux data, the user must move the "mouse" over the desired option and press the leftmost button on the "mouse". The box indicating which option has been selected will be filled in. Finally, the user must enter the name of the output file to which the results of the simulation will be written. The UIS will check if this file exists when the user executes the perform simulation option from the Main Menu in order to avoid overwriting existing files.

5.2.1.4 Additional Features

Several options are provided at the bottom of the menu for extra features. Any of these buttons can be selected and executed at any time by moving the cursor arrow with the "mouse" over the particular button and again pressing the leftmost button of the "mouse". The "Save Conditions" option allows the user to save a Single Polygon Simulation definition to a file so that it can be easily recalled at a later time. The UIS will check that all of the parameters have been entered correctly. If errors have been made, the UIS will warn the user before saving the defined conditions. Subsequently, saved conditions can be retrieved by selecting the "Retrieve Conditions" option. Both the meteorological data and output file names can be immediately cleared by selecting the "Clear Filenames" option and the original defaults can be retrieved by selecting the "Reset to Defaults" option. Finally, the user must return to the Main Menu by selecting the "Return to Main Menu" button.

5.2.2 Multiple Polygon Case

When this option is selected, a screen containing the primary parameters that need to be defined for a given scene simulation will appear as shown in Figure 17. A set of default values will appear for specified parameters. A given simulation will be described in terms of five primary categories of information. These categories are:

1. Header for the Scene Description
2. Range of Slope Conditions in the Scene
3. Range of Aspect Conditions in the Scene
4. Land Use Categories in the Scene
5. Input and Output Files for the Simulation

The UIS was designed to employ an approach in which summaries of information in each of the primary categories are displayed together. One can access and move from category to category at any time during the simulation definition. This is

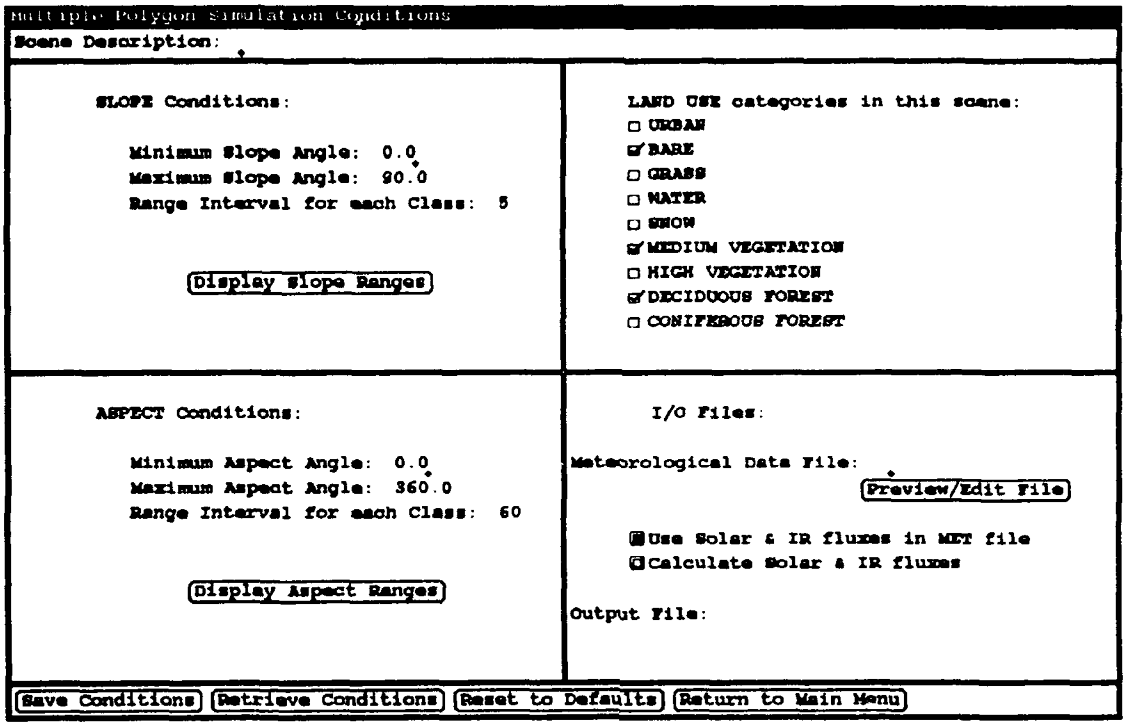

Figure 17. SWOE UIS Menu to Define Scene Simulation Conditions for a "Multiple Polygon Simulation"

contrasted to a menu-based system in which one must scroll through one menu, and any subsequent submenus, sequentially before moving to the next menu. In order to enter data for each category, the cursor arrow must be moved into the box containing that category. A triangular caret will blink at the current item to be entered.

5.2.2.1 Scene Description Header

The scene description header is entered at the top of the menu. This is a general comment line written by the user that will be used as a header in the output file. Move the cursor arrow with the "mouse" within this box until the blinking caret appears and type in the desired header description from the keyboard.

5.2.2.2 Slope and Aspect Angles

The slope and aspect angles are input in terms of a minimum, maximum and range interval for each class. That is, the user types in the minimum and maximum values and the range interval, all in degrees. The UIS will then determine the actual value to be used in the ITM calculations by taking the midpoint of each interval. The minimum, maximum, and range interval can be changed by pressing the delete key on the keyboard to delete the current value and typing in a new value. Hitting

RETURN moves the user to the next entry. Remember to move the cursor arrow with the "mouse" into the slope or aspect box before attempting to change any values. The blinking caret points to the current item to be changed; hit RETURN to move from item to item. At any time, the user can view the defined slope and/or aspect ranges by moving the "mouse" over the "display" button and pressing the leftmost button. A window will appear in the center of the screen displaying the ranges and the values used by the model in parentheses, as shown in Figure 18. To return to the menu, the user must click on the "continue" button. Slope angles must be between 0 and 90 degrees, and aspect angles must be between 0 and 360 degrees. The UIS performs error checking on these values and will not let the user return to the Main Menu until these angles are within range.

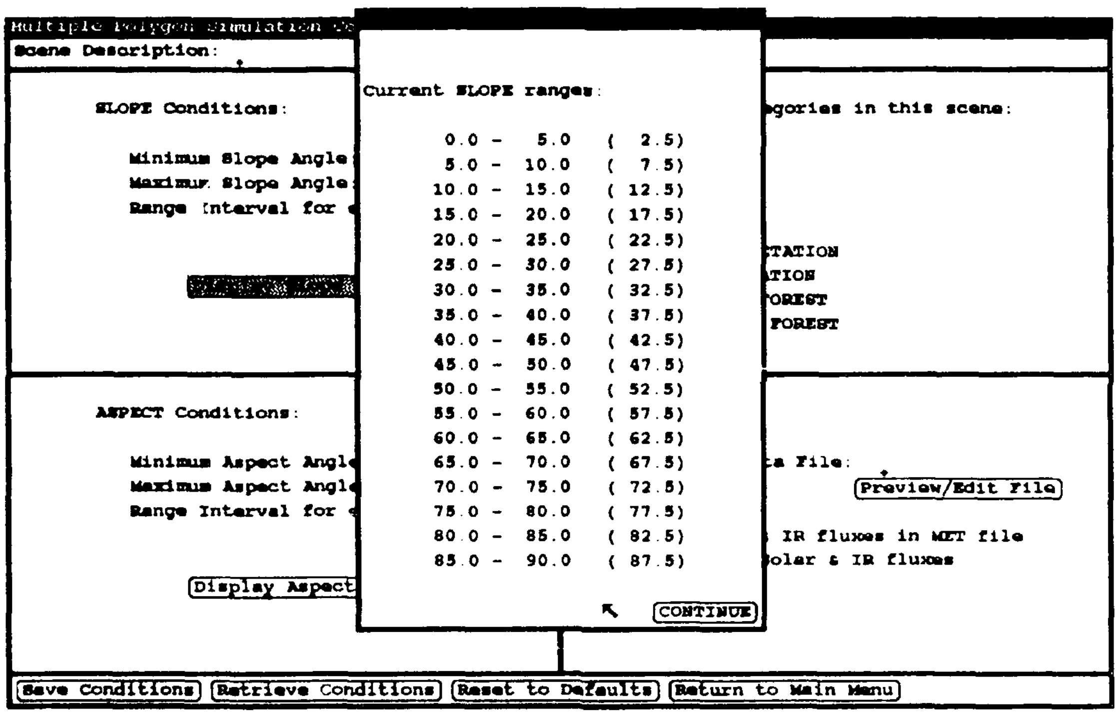

Figure 18. Display of Currently Defined Slope Ranges

5.2.2.3 Land Use Categories

The land use categories (see Figure 17) present in the scene are selected by checking the box next to each desired category. In order to choose a particular land use category, move the "mouse" over that category and press the leftmost button of the "mouse". A check mark should appear in the box next to the land use category chosen. To remove a selected category, position the cursor over the appropriate land use box, press the leftmost button of the "mouse" and the check mark should disappear. Note that although there is an option to select the URBAN land use category, a database of material properties does not yet exist and the ITM will simply skip over any entries using the URBAN land use. In addition, temperatures for the WATER land use category are calculated for slope and aspect angles of zero degrees only, not for the full range of slope and aspect angles defined in the menu.

5.2.2.4 Input and Output Files

The last category of the menu specifies the names of the necessary input and output files for the simulation. The name of the meteorological data file must be entered and must reside in the user's current directory. The user may preview/edit this file by "clicking on" the "Preview/Edit File" button. When this is done the file (if it exists) is displayed and can be edited similar to files in the Suntools TextEditor window. Buttons for saving changes and exiting the viewing window are provided at the top of the window (see Figure 19). Along with entering the name of the meteorological data file, the user must choose the source for the solar and infrared flux data. The source can be either from within the meteorological data file or can be calculated by the interim atmospheric radiation package. To choose the source of the flux data, the user must move the "mouse" over the desired option and press the leftmost button on the "mouse". The box indicating which option has been chosen will be filled in. Finally, the user must enter the name of the output file to which the results of the simulation will be written. The UIS will check if this file already exists when the user executes the perform simulation option from the Main Menu in order to avoid overwriting existing files. If the file exists, the UIS will warn the user, as shown in Figure 20 and ask the user to confirm that the file is to be used again.

5.2.2.5 Additional Features

Several buttons are provided at the bottom of the menu for extra features. Any of these buttons can be selected and executed at any time by moving the cursor arrow with the "mouse" over the particular button and again pressing the leftmost button of the "mouse". The "Save Conditions" button allows the user to save a scene simulation definition to a file so that it can be easily recalled at a later time. The UIS checks that all parameters have been entered correctly and otherwise warns the user before saving the defined conditions. Subsequently, saved conditions can be retrieved by selecting the "Retrieve Conditions" button. The original defaults can be retrieved by selecting the "Reset to Defaults" button. Finally, the user must return to the Main Menu by selecting the last button, "Return to Main Menu".

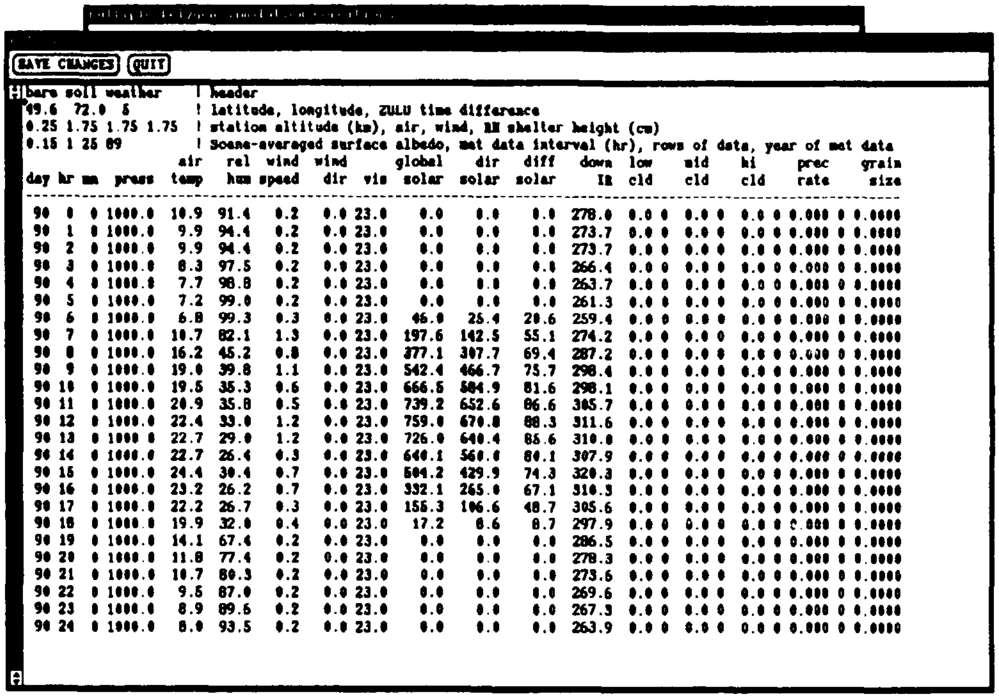

Figure 19. Example of the User Interface System's Preview/Edit Window

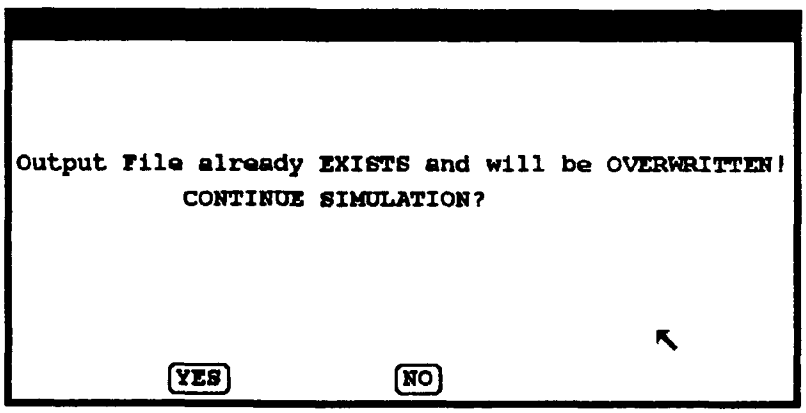

Figure 20. Warning Message Given Informing the User That a Selected Output File Already Exists

5.3 Perform Simulation

When this option is selected, a screen will appear displaying the output from the model as it is running. The model execution can be aborted at any time by selecting the "Exit Simulation" option at the top of the window. The user will then be asked to confirm the choice of exit as this will stop the execution of the model package if it is already in progress. As the model is running it displays the current polygon description - land use category, slope and aspect class - and the various temperatures as they are calculated. This screen display includes model results, without units, from the simulation timesteps. The results written to the selected output files contain more information than shown in this screen and with the appropriate headings and units. When the simulation is complete the normal prompt for your system will appear. The user must then select the "Exit Simulation" option and confirm the exit in order to return to the Main Menu. An example of the Simulation Window with model output is shown in Figure 21.

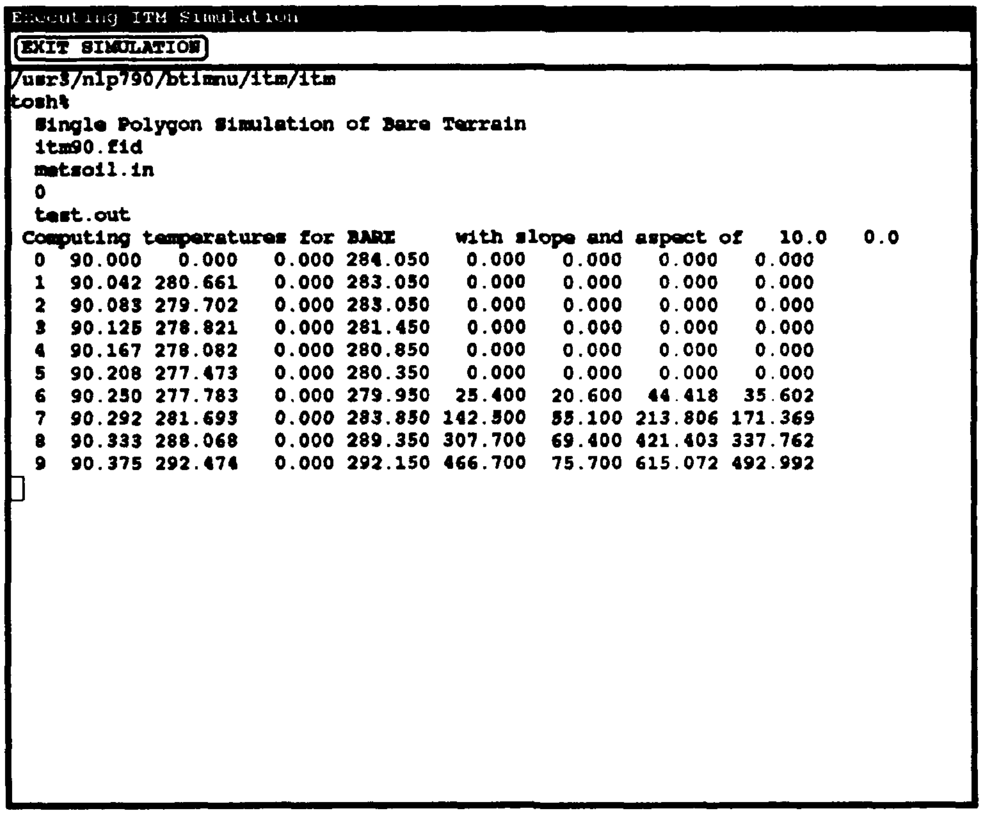

Figure 21. SWOE User Interface System Menu Displaying Results While a Simulation is Being Performed

5.4 Display Simulation Results

For the "Single Polygon Simulation" option, the calculated surface temperatures versus time can be graphically displayed by choosing this option from the Main Menu. The UIS displays the contents of the output file defined in the Single Polygon Simulation Definition Menu. This must be defined along with the correct terrain for that output file before any data will be plotted. The UIS then displays the temperatures in degrees C versus time. To exit the plot the user must select the "Exit Plot" button at the top of the plotting window. Examples of the display are shown in Figure 22 for a calculation made with a bare surface and in Figure 23 for a calculation made with a foreset surface.

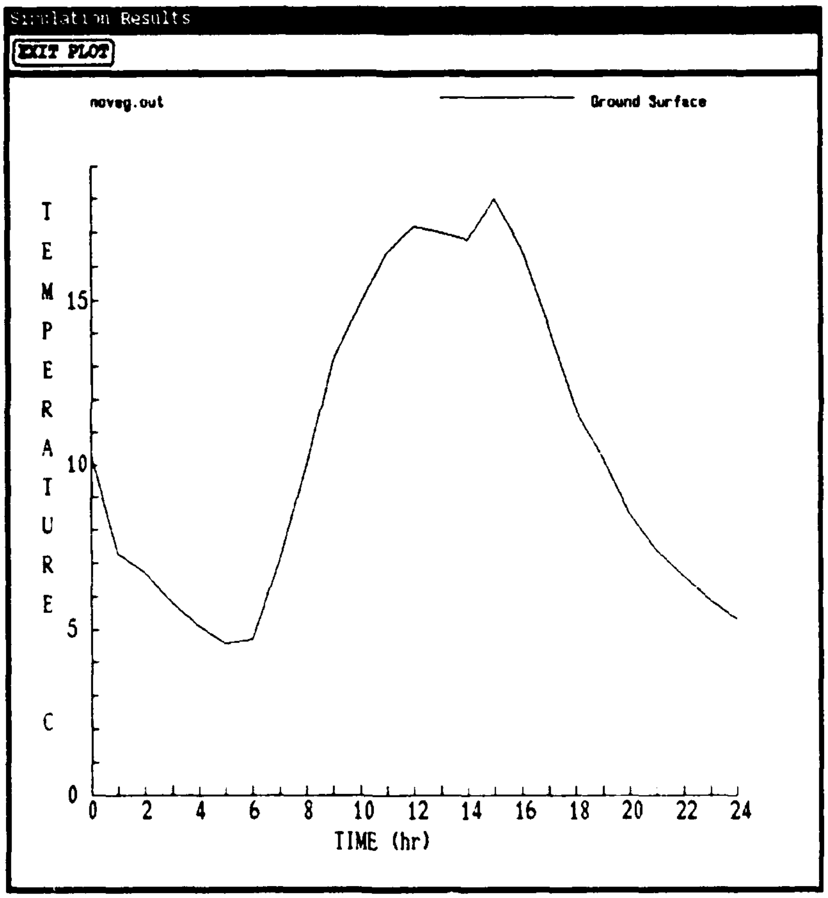

Figure 22. SWOE User Interface System Graphical Display of Results With a Simulated Bare Surface

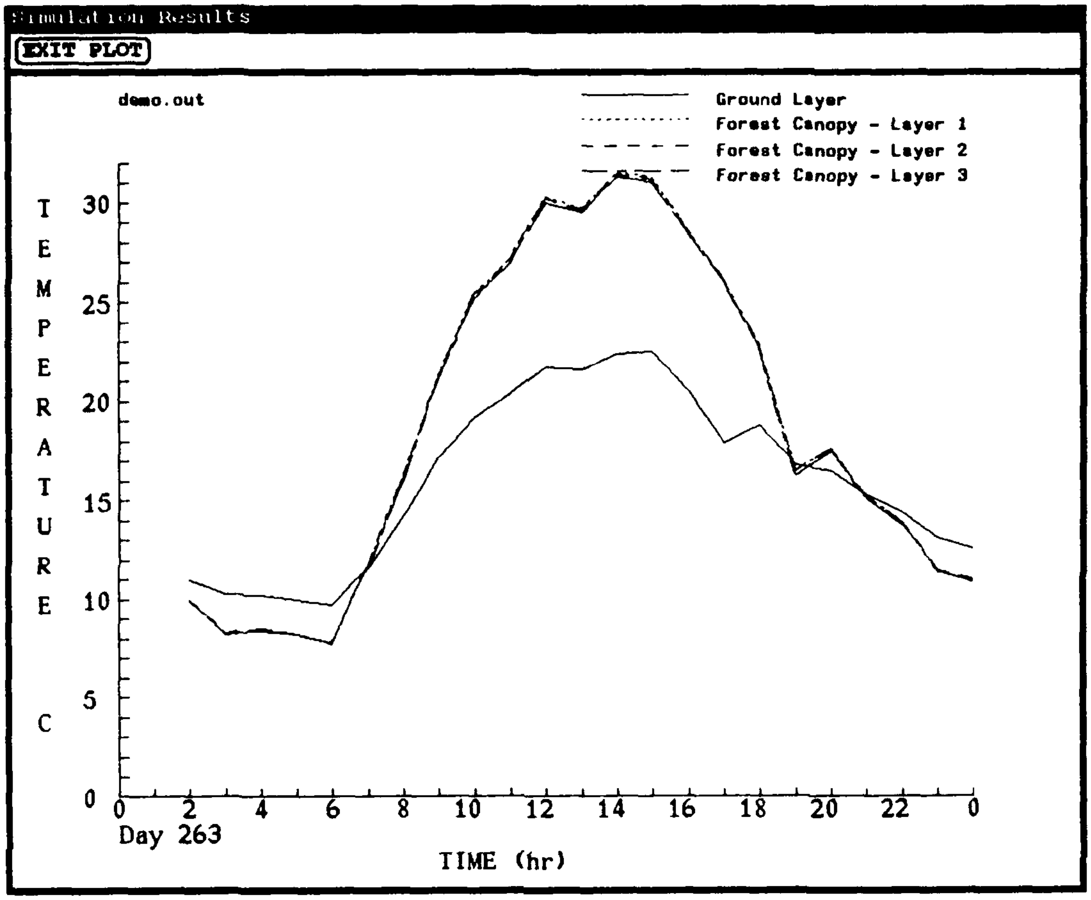

Figure 23. SWOE User Interface System Graphical Display of Results With a Simulated Forest Canopy

5.5 Viewing Simulation Output File

The user may view the tabulated simulation output file by selecting this option from the Main Menu. The output file displayed is the one that was defined by the user in the Single or Multiple Polygon Simulation Definitions Menu. The output file is displayed and can be edited similar to files in the Suntools TextEditor window. Options for saving changes and exiting the viewing window are provided at the top of the window.

5.6 Running the ITM without the SWOE User Interface System

If the are not on a SUN™ computer, the ITM can still be run without the SWOE User Interface System. The user must first create the control parameters file, *itm90.inp*, whose contents were described in Section 3.3. The user must also create or modify a simulation file (see Appendix b) containing the land use categories and slope and aspect classes for each polygon in the scene. This simulation file can be created by running the *create_sumul_file* program or an existing file can be modified by using a standard text editor. Then, to execute the model, the user simply types *d-itm/itm* at the main prompt from the directory containing the UIS code and necessary input files. The model will display output as it is working and will write the results to the output file specified in the input file, *itm90.inp*.

The program *create_sumul_file* prompts the user for the necessary information, item by item, and then creates the file FIN. The initial prompt on the screen is shown in Figure 24.

```
% create_simul_file
***** DEFINE LAND USE CATEGORIES IN THIS SCENE *****
Include land use category: URBAN        [y/n]?
```

Figure 24. Initial Prompt for Creating the Simulation File When Using the Program *creat_sumul_file*

For each land use category currently implemented, the user is prompted to answer 'y' or 'n' indicating whether that land use is present in the scene or not. The program continues in this fashion until the user has been prompted for information on each of the possible land use categories (Figure 25). If the user is simulating conditions for one land use category only, answer 'y' for the desired category and 'n' for all others.

The user is then prompted for the slope and aspect ranges. The user enters the minimum and maximum angles, and the range interval for each class, for both slope and aspect. The prompts for this information are shown in Figure 26. If the user is simulating conditions for one slope and/or aspect class, enter a minimum and maximum value centered on the desired value and give a range interval equal to the difference between the maximum and minimum values.

Finally, the user is given a menu of options as shown in Figure 27. The user can either view the slope or aspect ranges on the screen, create the simulation file or abort the program.

Figures 28 and 29 show the screen output when options 1 and 2 are chosen, respectively. The slope/aspect ranges are displayed with the actual value for each

```
% create_simul_file
***** DEFINE LAND USE CATEGORIES IN THIS SCENE *****
Include land use category: URBAN      [y/n]? n
Include land use category: BARE       [y/n]? y
Include land use category: GRASS      [y/n]? n
Include land use category: WATER      [y/n]? y
Include land use category: SNOW       [y/n]? n
Include land use category: MEDVEG     [y/n]? n
Include land use category: HIVEG      [y/n]? n
Include land use category: DFOREST    [y/n]? y
Include land use category: CFOREST    [y/n]? n
```

Figure 25. Land Use Category Prompts From the Program *creat_sumul_file* for Creating the Simulation File

```
***** DEFINE SLOPE AND ASPECT CLASSES *****
Enter minimum slope angle: 0.0
Enter maximum slope angle: 50.0
Enter slope range interval for each class (integer): 10

Enter minimum aspect angle: 0.0
Enter maximum aspect angle: 10.0
Enter aspect range interval for each class (integer): 5
```

Figure 26. Slope and Aspect Angles Prompts for Creating the Simulation File

range used by the ITM code (the average) shown in parentheses. When option 3 is chosen to create the simulation file, the program prompts the user for the name of the simulation file to create, as shown in Figure 30. This file is then created and the program exits. Figure 31 shows the file that was created with parameters entered as shown in the preceding figure examples.

```
***********************************
            MENU
   1 = Display slope ranges
   2 = Display aspect ranges
   3 = Create simulation file
   0 = ABORT
***********************************
Enter option:
```

Figure 27. Menu Prompt for Options Available From *creat_sumul_file* for Creating the Simulation File

```
***********************************
            MENU
   1 = Display slope ranges
   2 = Display aspect ranges
   3 = Create simulation file
   0 = ABORT
***********************************
Enter option: 1
______________________
Current SLOPE ranges:
0.0 - 10.0 (5.0)
10.0 - 20.0 (15.0)
20.0 - 30.0 (25.0)
30.0 - 40.0 (35.0)
40.0 - 50.0 (45.0)
______________________
Hit RETURN to continue
```

Figure 28. Display of Slope Ranges Option When Creating the Simulation File

```
************************************
            MENU
  1 = Display slope ranges
  2 = Display aspect ranges
  3 = Create simulation file
  0 = ABORT
************************************
Enter option: 2
________________________
Current ASPECT ranges:
0.0 - 5.0 (2.5)
5.0 - 10.0 (7.5)
________________________
Hit RETURN to continue
```

Figure 29. *creat_sumul_file* Menu Displaying the Aspect Ranges While Creating the Simulation File

```
************************************
            MENU
  1 = Display slope ranges
  2 = Display aspect ranges
  3 = Create simulation file
  0 = ABORT
************************************
Enter option: 3
Enter name of simulation file to create: test.fid
```

Figure 30. Menu Displayed to Create the Simulation File

BARE	5.0	2.5
BARE	5.0	7.5
BARE	15.0	2.5
BARE	15.0	7.5
BARE	25.0	2.5
BARE	25.0	7.5
BARE	35.0	2.5
BARE	35.0	7.5
BARE	45.0	2.5
BARE	45.0	7.5
WATER	0.0	0.0
DFOREST	5.0	2.5
DFOREST	5.0	7.5
DFOREST	15.0	2.5
DFOREST	15.0	7.5
DFOREST	25.0	2.5
DFOREST	25.0	7.5
DFOREST	35.0	2.5
DFOREST	35.0	7.5
DFOREST	45.0	2.5
DFOREST	45.0	7.5

Figure 31. Example of a Simulation File Used With the SWOE ITM

5.7 Compiling Instructions for User Interface System

A makefile, *makeUIS*, has been provided to recompile the User Interface System code if necessary. The user simply types *make -f makeUIS* at the main prompt and the required routines for the interface menus are recompiled and linked. In addition, to recompile the code for plotting single polygon simulation results, the user types *make -f makeUIS display* at the main prompt. Note that the SunCore^{TM} graphics libraries are required to recompile the UIS code. Similarly, a makefile for the ITM code has been provided called *makeITM*, for which the user simply types *make -f makeITM* in order to recompile the model code. The code for creating simulation files outside of the UIS menus (*create_simul_file.c*) can be recompiled simply with a standard "C" compiler with no linking to other files or libraries necessary.

6 SUMMARY AND RECOMMENDATIONS FOR FUTURE WORK

6.1 Summary

The BTI/SWOE program has as a goal to provide to the smart weapons community a set of software tools that can make the job of designing and testing new weapons concepts easier and less costly. The Interim Thermal Model is one component of that software package.

The ITM will allow the user community to model the environmental conditions for a variety of land surfaces and weather conditions. The ITM calculates the thermal balance for:

- Land Surfaces Without Vegetation
- Land Surfaces With Vegetation
- Winter Surfaces
- Bodies of Water
- Individual Trees for Leaf or Leafless Conditions

The ITM programs were developed to operate under the UNIX operating system. The individual program elements have been developed using standard FORTRAN 77 or C.

A first generation SWOE User Interface System (UIS) has also been developed for use with the ITM. Developed to operate on SUN™ computers, the UIS allows the user to study in detail the thermal balance for a single set of land and environmental conditions or to set up and perform calculations for a series of land surface types. For users that do not have access to a SUN™ computer system, procedures for developing the required databases have been provided. Sample datafiles have also been provided.

6.2 Recommendations for Future Work

6.2.1 Incorporation of User Feedback

During the course of the ITM development effort, the SPARTA development team tried to anticipate the needs of the User Community. Feedback was solicited from within the SWOE community and obtained but a number of "executive decisions" concerning physics, computational, database, and procedural issues had to be made. It is hoped that these decisions correctly address the needs of the user community but it is recognized that some may not.

Therefore, it is recommended that the ITM be distributed to a small group of users for evaluation and feedback. In particular, feedback should be solicited on the need for additional or modified features in:

- The physics being modeled
- The land use categories included as defaults
- The User Interface System

In addition, the SPARTA development team, provides the following specific recommendations.

6.2.2 Integration With Atmospheric Package

The SWOE concept includes characterizing the atmosphere at the simulation location with a SWOE Atmospheric Package. This characterization includes modeling the three dimensional structure of the atmosphere and the solar and radiative fields from the atmosphere. At the time of the ITM development, the SWOE Atmospheric Package was not available. To provide the required solar and infrared fluxes, an interim package was utilized and delivered with the ITM.

The SWOE Atmospheric Package is to be completed in FY 91 and needs to be integrated with the ITM. This package will consist of a 3-D cloud model and 3-D radiative transfer model.

Integration of the Atmospheric Package with the ITM will involve possible changes in databases as well as calculation strategies. Once the package is available, it is recommended that it be made available to the ITM development team and representatives of the SWOE Database Task Area in order to determine that the data needs of the Atmospheric Package are properly met and accessible by the UIS.

6.2.3 Enhancements to the Treatment of Simple Vegetation

The simple vegetation module VEGIE was incorporated into SWOETHRM without modifications. The treatment should be modified based on recommendations made by researchers at WES. As recommended by WES, the model should contain a simple scheme for estimating shortwave and longwave penetration into the vegetation which is based on the vertical distribution of the vegetation. Also the solution scheme adopted by VEGIE should be examined more carefully. This recommendation is based on a series of SWOETHRM runs in which the VEGIE algorithm failed to converge to a meaningful simple vegetation temperature. A "patchwork" solution to this problem has been included in SWOETHRM that is "reasonable." However, further examination is warranted because the lack of convergence suggests the possibility of a more fundamental deficiency with the numerical or physical assumptions in VEGIE.

6.2.4 Enhancements to the Treatment of Forest Canopies

Because TVCM was incorporated into SWOETHRM without modifications, improvements to the model should be considered in future SWOE efforts. As noted by the developers of TVCM, the model should allow for a height dependency of air temperature and wind speed in (and above) the canopy. Currently, these values are assumed to be constant and equal to the surface meteorological values which is a gross simplification. Also, future versions of TVCM should access the atmospheric longwave fluxes that are common to the rest of the SWOETHRM code. Currently, TVCM internally calculates longwave fluxes from the atmosphere using a simple T^4 relationship. Finally, the SWOE ITM should utilize "effective" temperatures of a forest canopy instead of the top layer temperatures which are currently used. Clearly these effective temperatures, which represent weighted contributions from the three canopy layers according to their leaf density and orientations, will depend on the zenith angle at which the canopy is being viewed.

6.2.5 Enhancements to the User Interface System

6.2.5.1 <u>Development of Computer Independent User Interface System</u>

The first generation User Interface System delivered with the SWOE ITM was developed using software utilities specific to the SUN™ computer system. While the ITM physics computer codes can be run on any UNIX computer system, the current UIS can only be run on SUN™ computers. This restriction can be removed by redesigning the UIS using a portable software utility system such as X-Windows which will allow the development of an overall Command Interface System that is independent of computer systems.

6.2.5.2 <u>Addition of Tree Model to UIS</u>

The standalone 3-D tree thermal model is currently run as a standalone model. It is run in batch mode on UNIX computers. The tree model should be brought under the SWOE UIS umbrella. As discussed in the tree model report[8], a preliminary interface system that is consistent with the UIS was begun.

6.2.5.3 <u>Expansion to Full SWOE Command Interface System</u>

The SWOE UIS is currently configured to control the production of thermal balance calculations. All other SWOE operations are performed "off-line" seeing that the models required for the radiance calculations and scene simulation are still under development. As they become available, they need to be integrated with the SWOE ITM and the UIS expanded to incorporate the new program features. This evolutionary growth in the UIS will result in the development of a SWOE Command Interface System that can control the production of a complete SWOE simulation.

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Appendix A

Additional Information About SWOETHRM

A-1. General Modifications to SNTHERM.89

SWOETHRM is an extension of the SNTHERM.89 program developed by CRREL. The "science" of the code has not been changed and, therefore, it produces the same results as SNTHERM.89 whenever bare or snow-covered surfaces are specified. Furthermore, the simple vegetation and canopy models have been merged into SWOETHRM without altering the framework of the original SNTHERM.89 code.

In addition to the new vegetation models, SWOETHRM and SNTHERM.89 differ only in how they input data. All of the SNTHERM.89 input/output files have been retained; however, some of the input parameters are internally hard-wired to conform with SWOE ITM applications. Also, the current version of SWOETHRM uses fixed input/output filenames instead of the FILENAME file option from SNTHERM.89. For reference, Table A-1 lists the file naming convention adopted by SWOETHRM.

Table A-1. Filenames Used by SWOETHRM. Files dealing with simple vegetation and a forest canopy are not included in this listing

FILENAME	FILE TYPE	REQUIRED/ OPTIONAL	CONTENTS
surface.in	Input	Required	Main surface input file for SWOETHRM. This file is created internally from *bare.inp* or *snow.inp*
METFIL	Input	Required	Character string defining the meteorological file. *METFIL* is an argument passed into SWOETHRM
undist2.in	Input	Optional	Measured temperature data. Read whenever a flag is set in *surface.in*
surface.out	Output	Required	Standard SWOETHRM output file
flux	Output	Optional	SWOETHRM file containing incident heat fluxes. Created whenever a flag is set in *surface.in*
filtout	Output	Optional	SWOETHRM file containing water infiltration estimates. Created whenever a flag is set in *surface.in*
noveg.out	Output	Required	Calculated surface temperatures.

One additional feature was added to SWOETHRM so it could satisfy SWOE ITM applications. Specifically, SWOETHRM internally calculates "best guesses" for the direct and diffuse components of solar flux whenever users only specify the total global flux. Effectively, the best guesses are based on ratios of direct-to-global solar flux as calculated by the solar routines in SWOETHRM. These ratios are then applied to the total global fluxes in the meteorological file.

A-2. Treatment of an Extended Forest Canopy

For each time period, the canopy and underlying surface temperatures are computed independently from each other. This approach differs from that used by CTSTM in which canopy and underlying surface temperatures are coupled in an iterative manner. The coupling between canopy and underlying surface was not made in this version of SWOETHRM because it would have required major modifications to SWOETHRM that could not be accomplished at this time. It is being recommended that this coupling be added in a follow-on effort. However, its omission is not considered to have a significant impact on resultant temperature fields.

The canopy model routines from the original TVCM code were not modified when added to the SWOETHRM package. Instead, a series of routines were developed to access the canopy model and then reformat the output data for use by SWOETHRM. For reference, Table A-2 describes the routines linking TVCM to SWOETHRM.

Table A-2. Routines Linking TVCM to SWOETHRM

ROUTINE NAME	PURPOSE
incan	Inputs canopy specific parameters. If necessary, TVCM routines are called to compute canopy matrix parameters
echocan	Prints out canopy input parameters
vctm	Obtains canopy temperatures by calling TVCM. Also, surface solar and IR fluxes are computed allowing for the canopy's presence
outcan	Prints canopy temperatures and flux data to output file

The canopy model TVCM is called just before SWOETHRM calculates a new surface temperature. As part of this formulation, the previous surface temperature from SWOETHRM is used in the canopy energy balance. Also, additional coding has been developed to determine surface shortwave and longwave fluxes after interacting with a canopy. These fluxes are then used by SWOETHRM when computing the next surface temperature. Additionally, based on physical reasoning, the bottom canopy layer temperature replaces the "open air" temperature from the meteorological file for the surface calculations. In simple, the canopy's effect on fluxes and air temperature have been addressed, but "open air" values of relative humidity and wind speed are used in the SWOETHRM surface calculations. Future SWOE work should determine the best way to modify these parameters when a canopy is present.

As discussed in the main text, forest canopy parameters are contained in files called *dforest.inp* and *cforest.inp*. When an extended forest is selected as the land use category, the ITM copies either input file to a temporary file called *canopy.inp* which is then accessed by SWOETHRM. TVCM will be included only if *canopy.inp* exists; otherwise, SWOETHRM executes in a bare/snow mode. Output from the canopy model is written to a file called *canopy.out*. This file contains a listing of the canopy input parameters followed by the temperatures calculated by TVCM. In *canopy.out*, the surface solar and longwave fluxes represent fluxes incident on the underlying surface.

A-3. Treatment of Simple Vegetation

The simple vegetation model VEGIE has been linked to SWOETHRM in the same way it was linked to the CTSTM program. For consistency and programming ease, the VEGIE routines, which were written in C, were converted to Fortran. The "science" of the model was not modified in any way, however. For reference, Table A-3 describes the routines that implement the VEGIE model.

Table A-3. Routines to Calculate Simple Vegetation Temperatures

ROUTINE NAME	PURPOSE
inveg	Inputs vegetation parameters
echoveg	Prints out vegetation input parameters
tempveg	Calculates vegetation temperatures. Also, surface solar and IR fluxes are computed allowing for vegetation
budgveg	Calculates vegetation energy budget. This routine is called by tempveg in an iterative manner
outveg	Prints vegetation temperatures and flux data to output file

Like the canopy model TVCM, VEGIE is called just before SWOETHRM calculates a new surface temperature. As part of this formulation, the previous surface temperature from SWOETHRM is used in the energy budget calculations for simple vegetation.

Besides simple vegetation temperatures, VEGIE also determines surface short-wave and longwave fluxes after interacting with the vegetation. These expressions have been included at the end of the *tempveg* routine for use by SWOETHRM when computing the next surface temperature. Additionally for the SWOETHRM calculations, the "open air" temperature and wind speed from the meteorological file have been replaced with values representative of the environment within the vegetation. (Expressions for these values can be found in the TSTM report[2] and in Deardorff.[9]) The "open air" relative humidity is still used in the SWOETHRM surface calculations.

As discussed in the main text, simple vegetation parameters are contained in files called *grass.inp*, *medveg.inp*, or *hiveg.inp*. When one of these land use categories is selected, the SWOE ITM copies either input file to a temporary file called *veggie.inp* which is then accessed by SWOETHRM. The VEGIE model will be included only if this file exists; otherwise, SWOETHRM executes in a bare/snow mode. (If both *canopy.inp* and *veggie.inp* exist, then the selected vegetation model is implemented.)

Output from VEGIE is written to a file called *veggie.out*. This file contains a listing of the vegetation input parameters followed by the temperatures calculated by VEGIE. In *veggie.out*, the coverage-weighted temperatures are computed differently from those in the CTSTM program. Specifically, coverage-weighted radiances are now converted to temperatures using an emissivity that is based on the ground emissivity, the foilage emissivity and the fractional foilage cover. Previously, CTSTM assumed an effective emissivity of 1 which, in some instances, could cause the coverage-weighted temperatures to be physically unrealistic. This deficiency is exemplified in Figure A-1 which shows coverage-weighted temperatures as obtained from the CTSTM and SWOETHRM schemes. For demonstrative purposes, the ground and grass emissivities have been set to 0.90. Clearly, the CTSTM temperatures are not plausible based on the ground and grass temperatures. On the other hand, the SWOETHRM scheme leads to reasonable coverage-weighted temperatures.

A-4. Modifications to CE-THERM-R1

The CE-THERM-R1 module has been modified for use in the SWOE ITM. Most of the modifications pertain to the way CE-THERM-R1 reads its input data. Specifically, CE-THERM-R1 now reads input data from two files:

- *water.inp* containing physical attributes of the water reservoir being modeled
- A data file containing the meteorological data for the time period being modeled, including solar and infrared fluxes

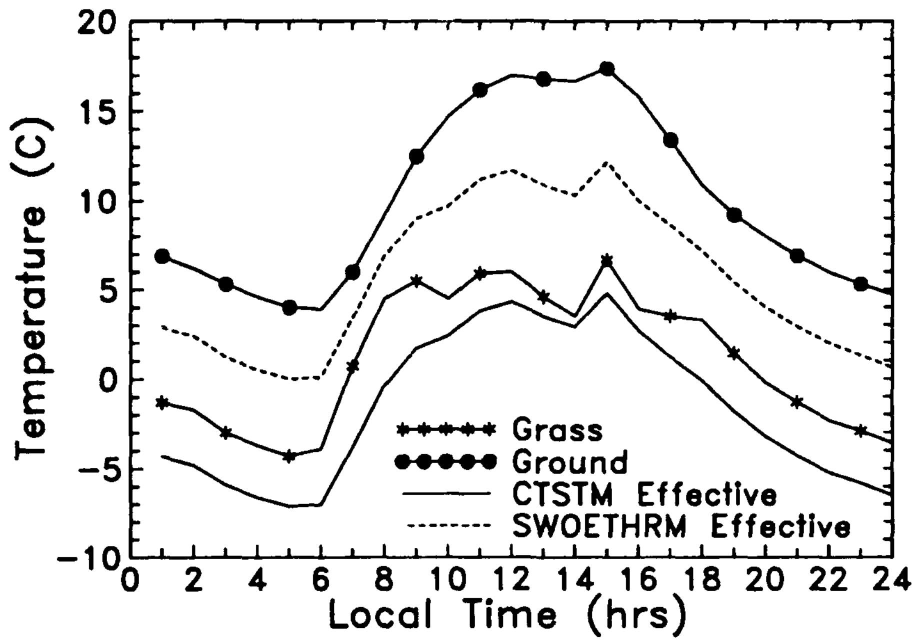


Figure A-1. Comparison of Coverage-Weighted (Effective) Temperatures As Predicted by CTSTM Against Those Predicted by SWOETHRM. The temperatures represent soil partially covered by grass (fractional coverage of 0.50.) The emissivities of the soil and grass are 0.90. The meteorological conditions represent mid-March with clear skies. For reference, the ground and grass temperatures are also shown

The file *water.inp* describes physical attributes for a default body of water. The default case was taken directly from the sample case provided with CE-QUAL-R1 and is for DeGray Lake, Arkansas for 1979. Appendix B lists the default data contained in *water.inp*.

The code was modified to read in solar and infrared fluxes, rather than calculating them internally as in the version provided by WES. In the version provided by WES, diurnal changes in solar and infrared flux were accounted for by the code. In the version included in the ITM, the diurnal variability must be accounted for in the environmental data. Therefore, the meteorological grid and simulation interval should be fine enough to reflect diurnal changes in solar and infrared flux. It is therefore recommended that the meteorological data be specified hourly and the simulation interval be hourly.

CE-THERM-R1 has also been modified so that meteorological data can begin on a Julian day different from that for updates in the *water.inp* file. That is, one can do the simulation calculations for a time period that is a subset of that included in the environmental data. (Previously CE-THERM-R1 required meteorological data and update data, such as daily inflow and outflow rates, to begin on the same day.)

During a given simulation, CE-THERM-R1 requires the use of various I/O units. The I/O unit numbers accessed by CE-THERM-R1 have been changed from that in the version provided by WES so they do not interfere with others used by other modules in the SWOE ITM. For reference, the units accessed by CE-THERM-R1 are listed in Table A-4. The data in *water.out* contain detailed research grade output that can be useful for standalone operations of the ITM or for debugging purposes.

Table A-4. I/O Units and Files Accessed by CE-THERM-R1

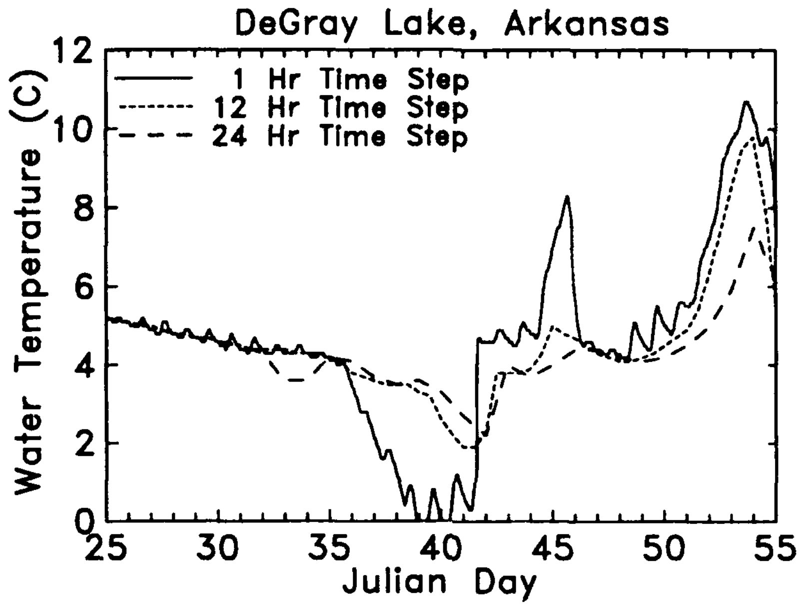
UNIT NO.	FILENAME	FILE ATTRIBUTES	CONTENTS
50	-	Internal Scratch	Inflow Rates for Tributary 1
51	-	Internal Scratch	Temperature for Tributary 1
52	-	Internal Scratch	Total Dissolved Solids for Tributary 1
53	-	Internal Scratch	Suspended Solids for Tributary 1
54	-	Internal Scratch	Inflow Rates for Tributary 2
55	-	Internal Scratch	Temperature for Tributary 2
56	-	Internal Scratch	Total Dissolved Solids for Tributary 2
57	-	Internal Scratch	Suspended Solids for Tributary 2
71	-	Internal Scratch	Meteorological Data
73	-	Internal Scratch	Operation Schedule (if schedule mode)
74	-	Internal Scratch	Verification Data (if used)
75	water.inp	Input File	Physical Attributes of Water Reservior
76	METFIL	Input File	Meteorological Data
77	water.out	Output File	Standard CE-THERM Output-R1
78	water.tem	Output File	Surface Temperature and Air Temperature Versus Time
89	FILNAM(1)	Output Plot File*	Water Column Data (unformatted)
90	FILNAM(2)	Output Plot File*	Predicted Outflow Data (unformatted)
91	FILNAM(3)	Output Plot File*	Inflow Tributary 1 (unformatted)
92	FILNAM(4)	Output Plot File*	Inflow Tributary 2 (unformatted)

* Currently deleted upon exiting CE-THERM-R1

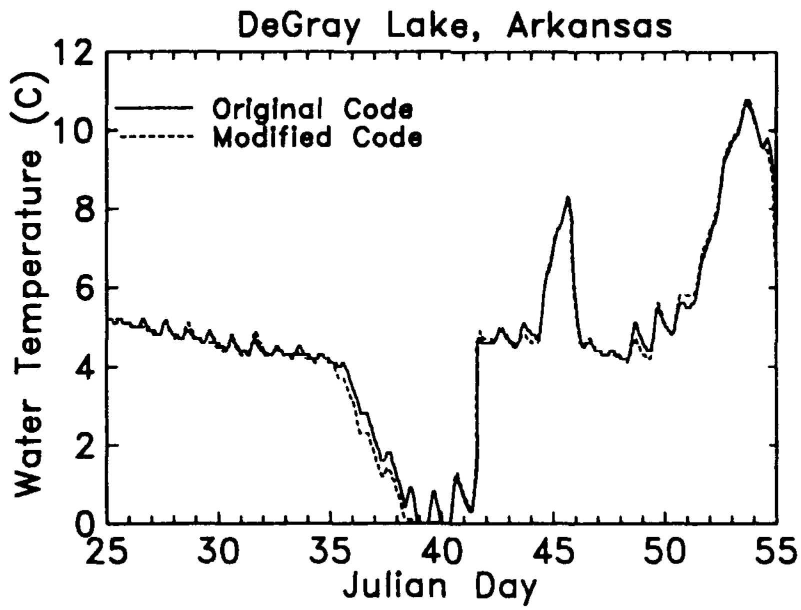
Figure A-2 examines the impact of the modifications made on CE-THERM-R1. Sample water surface temperatures are shown in Figure A-2 (a.) for simulation steps of 1, 12 and 24 hours. The water temperatures are for the default water body, DeGray Lake, Arkansas, from late January through February. The meteorological data were provided with the original CE-THERM-R1 code, however the solar and infrared data were calculated within the code. The Figure demonstrates that the simulation step can strongly affect the resulting temperature of the water surface.

The small scale oscillations for the 1 hour simulation step are diurnal in nature.

When the solar and infrared fluxes are included in the meteorological data rather than calculated within the code, there is little impact on the calculated temperatures as shown in Figure A-2 (b.). The small differences in the two curves are due to the truncation of the solar fluxes in the input file.



(a.)



(b.)

Figure A-2. (a.) Impact of Varying the Simulation Time Step in CE-THERM-R1 and (b.) Comparison of CE-THERM-R1 Output From the Original Code and That With the Modified Input Structure

Appendix B

Sample Input Files for the SWOE ITM

As discussed in Section 3, a number of input data files are required to perform a calculation with SWOE ITM. This appendix describes the input parameters that are required by the ITM, their units (if any), possible ranges, and lists the sample input files that are supplied with the ITM. The sample files are intended to provide the user with a set of input conditions that can be used for representative calculations but are not intended to be an all inclusive set of data.

Table B-1 lists the various input files used by the ITM. These files are used to control the execution of a calculation, describe the surfaces being modeled, and the environmental conditions.

Table B-1. Files Containing Input Parameters for the SWOE ITM

FILENAME	CONTENTS
itm90.inp	Control Parameters for ITM
bare.inp	SWOETHRM Input Parameters for Bare Soil
snow.inp	SWOETHRM Input Parameters for Snow Field
grass.inp	VEGIE Input Parameters for Grasslands
medveg.inp	VEGIE Input Parameters for Medium Vegetation
hiveg.inp	VEGIE Input Parameters for High Vegetation
dforest.inp	TVCM Input Parameters for Deciduous Forest (Oak/Hickory)
cforest.inp	TVCM Input Parameters for Coniferous Forest (Douglas Fir)
water.inp	CETHERM Input Parameters for Water Body

B-1. Sample Control Parameters

The execution of a given SWOE simulation is controlled by a file named *itm90.inp*. Table B-2 lists the input records that are contained in the file. The variable names listed represent the names used internally by the code.

The first record in the control file is a descriptive header supplied by the user to characterize the calculation. This header must be 72 characters or less. The second

Table B-2. (a.) Description of the Input Records in the Control File *itm90.inp* and (b.) Sample File Delivered With the ITM

(a.)

RECORD	VARIABLE	DESCRIPTION
1	HEAD	Descriptive Header (72 characters or less)
2	FIN	Name of the file containing the land use categories and slope and aspect classes
3	METFIL	Name of the file containing the environmental data to be used for the SWOE ITM simulation
4	FLUXFLAG	Flag indicating source of solar and IR flux data 0 = Flux Data Provided in METFIL by User 1 = Fluxes Calculated by Atmospheric Package
5	FOUT	Name of Output File for SWOE ITM Temperatures

(b.)

```
Test Header for ITM
hunter.fid
hunt263.met
0
hunter.tem
```

record is the name of the input file that contains the land use categories and slope and aspect values. The third record contains the name of the input file containing the environmental data. The fourth record is an integer flag that determines if the solar and infrared flux are being provided by the user and contained in the environmental file or if they must be calculated by the Atmospheric Package. The fifth and final record contains the name of the output file where the SWOETHRM surface temperatures will be written to.

A sample of the control file *itm90.inp* has been supplied with the ITM and is listed in Table B-2 (b.). The information listed in Table B-2 (b.) was used to produce surface temperatures for conditions at Hunter-Liggett, California using environmental conditions on Julian day 263.

B-2. Land Use Categories and Slope/Aspect Data

The data describing the land use categories and slope and aspect classes are contained in the file FIN. FIN contains a group of data records that represents the different land use, slope, and aspect combinations for a given scene simulation. Each record consists of one land use category, slope, and aspect value. Table B-3 (a.) describes the variables contained in the file FIN and Figure B-3 (b.) lists the sample file that is supplied with the ITM. The land use categories are given as character strings of upper case letters using one of the choices given in Table B-3. The slope and aspect values are given in degrees as real numbers. The format of each data record is A8,2F8.1.

B-3. Environmental Data

Table B-4 describes the structure of the environmental file. This data file is the same as that required for the 3-D tree model. Table B-5 describes the required cloud cover information. It is noted that once the complete SWOE atmospheric package is added to the ITM that the structure of the required cloud data may change.

Three types of precipitation can currently be accounted for in the ITM. They are no precipitation present (IPREC = 0), rain (IPREC = 1), or snow or sleet (IPREC = 2).

The sample environmental file supplied with the ITM, *hunt263.met*, is environmental data for 20 September 1989 at Hunter-Liggett, California. The data are listed in Figure B-1.

B-4. Non-Vegetated Surface Data

SWOETHRM requires a number of parameters to describe the properties of the underlying materials. The reader is referred to the technical documentation on the original code,[5] SN-THERM, for a detailed explanation of the parameters. These parameters are input from a datafile containing the parameters described in Table B-6. The parameters required by the code are grouped together by type.

The first line of data, Record 1 in Table B-6, provides summary information about the simulation to be performed. Included in this line is the total number of layers of different materials, parameters detailing when results are printed out, flags to establish if the code will include the effects of tank tracks (an option currently available for winter simulations), and information about surface conditions.

Next comes data which describes the materials making up the different material layers. There is one line of data for each different material type, starting with the bottom layer. (Recall that the SWOETHRM numerical grid starts at the bottom and goes up.) Each line of data included the number of calculation nodes in each

Table B-3. (a.) Description of the Variables Contained in the File FIN Used to Input the Land Use, Slope, and Aspect Data for a SWOE ITM Calculation (b.) Sample Input Parameters for the FIN File

(a.)

VARIABLE	DESCRIPTION	POSSIBLE VALUES
CLASS	Character Descriptor for SWOE ITM Category	BARE, no vegetation SNOW, snow field CFOREST, coniferous forest DFOREST, deciduous forest GRASS, grasslands MEDVEG, medium vegetation HIVEG, high vegetation URBAN, urban area (Currently not implemented)
SLOP	Terrain Slope Angle (deg) Relative to Horizontal Surface	0 - 90 degrees
ASP	Terrain Aspect Angle (deg) Relative to North	0 - 360 degrees (Clockwise)

(b.)

BARE	5.0	2.5
BARE	5.0	7.5
BARE	15.0	2.5
BARE	15.0	7.5
BARE	25.0	2.5
BARE	25.0	7.5
BARE	35.0	2.5
BARE	35.0	7.5
BARE	45.0	2.5
BARE	45.0	7.5
WATER	0.0	0.0
DFOREST	5.0	2.5
DFOREST	5.0	7.5
DFOREST	15.0	2.5
DFOREST	15.0	7.5
DFOREST	25.0	2.5
DFOREST	25.0	7.5
DFOREST	35.0	2.5
DFOREST	35.0	7.5
DFOREST	45.0	2.5
DFOREST	45.0	7.5

Table B-4. Parameters Contained in a Meteorological Data. These parameters are read in free format. Note that Record 8 is repeated NCARDS times

RECORD	VARIABLE	BRIEF DESCRIPTION	UNITS
1	-	Descriptive Title	-
2	XLAT	Latitude	decimal deg
	XLON	Longitude	decimal deg
3	GNDALT	Station Altitude	km
	SHLTR1	Temperature Shelter Height	m
	SHLTR2	Wind Shelter Height	m
	SHLTR3	Relative Humidity Shelter Height	m
4	ALB	Scene-Averaged Surface Albedo	-
	INTMET	Meteorological Data Interval	hr
	NCARDS	# of Lines of Meteorological Data	-
	IY	Year of Meteorological Data	-
5-7	-	Header Material for Meteorological Data	-
8	DAY	Julian Day of Meteorological Data	-
	TIME	Hour Of Meteorological Data	-
	MIN	Minute Of Meteorological Data	-
	PRESS	Surface Pressure	mb
	T	Surface Temperature	C
	RH	Surface Relative Humidity	%
	WINDSP	Surface Wind Speed	m/s
	WINDDR	Surface Wind Direction	deg
	VIS	Surface Visibility	km
	GLOBS	Global Solar Flux	Watts/m^2
	DIRS	Direct Solar Flux	Watts/m^2
	DIFS	Diffuse Solar Flux	Watts/m^2
	IRFLX	Downwelling Infrared Flux	Watts/m^2
	COVER(1)	Fractional Cloud Cover for Low Clouds	-
	ICL(1)	Cloud Type for Low Clouds	-
	COVER(2)	Fractional Cloud Cover for Mid Clouds	-
	ICL(2)	Cloud Type for Mid Clouds	-
	COVER(3)	Fractional Cloud Cover for High Clouds	-
	ICL(3)	Cloud Type for High Clouds	-
	PRECR	Precipitation Rate	m/hr
	IPREC	Precipitation Type	-
	GRAIN	Precipitation Grain Size	m

Table B-5. Description of the Required Cloud Cover Information in the Environmental File (see Table B-4)

CLOUD TYPE CODE	LAYER	CLOUD TYPE
1	High	Thin Cirrus
2	High	Thick Cirrus
3	Middle	Middle Cloud
4	Low	Stratus
5	Low	Cumulus or Cumulonimbus

```
Hunter-Liggett weathe! header
36.0  121.3  8        ! latitude, longitude, ZULU time difference
0.1 2.0 2.0 2.0       ! station altitude (km), air, wind, RH shelter height (cm)
0.40 1.0 24 89        ! Scene-averaged surface albedo, met data interval (hr), rows of data, year of data
                  air   rel  wind  wind       global   dir   diff   down low    mid    hi     prec    grain
day hr mn  press  temp   hum speed   dir  vis  solar  solar  solar    IR cld    cld    cld    rate     size
-----------------------------------------------------------------------------------------------------------
 263  1  0 968.8 10.6   89.0  0.31 128.0  23.0   0.0    0.0    0.0  275.8  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263  2  0 969.2 10.5   90.0  0.67  76.0  23.0   0.0    0.0    0.0  275.5  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263  3  0 969.2  9.4   90.0  0.05  76.0  23.0   0.0    0.0    0.0  269.9  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263  4  0 969.4  9.5   91.0  0.21  91.0  23.0   0.0    0.0    0.0  270.7  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263  5  0 969.6  8.7   91.0  0.62  56.0  23.0   0.0    0.0    0.0  264.2  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263  6  0 969.9  8.2   91.0  0.57  65.0   1.0   2.9    0.0    2.9  339.2  1.0 4  0.0 0  0.0 0 0.0000 0 0.0000
 263  7  0 970.6 10.8   91.0  0.10  65.0   0.0  53.2    0.0   53.2  352.4  1.0 4  0.0 0  0.0 0 0.0000 0 0.0000
 263  8  0 970.8 13.0   87.0  0.26 246.0   0.0 128.9    0.0  128.9  362.7  1.0 4  0.0 0  0.0 0 0.0000 0 0.0000
 263  9  0 971.1 15.2   77.0  0.98  17.0   1.0 545.2  383.6  161.6  333.6  0.5 4  0.0 0  0.0 0 0.0000 0 0.0000
 263 10  0 971.1 19.1   55.0  1.34  93.0  23.0 777.1  687.4   89.7  307.8  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263 11  0 970.6 21.3   43.0  1.59  67.0  23.0 866.4  766.9   99.4  312.8  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263 12  0 970.1 23.7   34.0  1.39  31.0  23.0 894.4  '91.3  103.1  319.4  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263 13  0 969.6 25.2   21.0  1.95  89.0  23.0 863.2  764.2   99.1  315.7  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263 14  0 969.0 26.7   21.0  1.49 351.0  23.0 770.6  681.5   89.1  323.5  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263 15  0 968.5 27.6   18.0  1.39  59.0  23.0 613.4  535.1   78.3  324.9  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263 16  0 968.1 27.4   17.0  2.36  57.0  23.0 401.6  331.6   70.0  322.7  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263 17  0 968.3 26.1   20.0  3.03  49.0  23.0 175.8  124.0   51.8  319.3  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263 18  0 968.3 24.3   23.0  1.18  60.0  23.0   5.2    2.5    2.8  313.1  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263 19  0 968.5 19.6   41.0  0.26 220.0  23.0   0.0    0.0    0.0  302.3  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263 20  0 969.0 18.5   45.0  1.13 137.0  23.0   0.0    0.0    0.0  299.0  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263 21  0 969.3 16.3   54.0  0.72 162.0  23.0   0.0    0.0    0.0  292.2  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263 22  0 969.5 15.2   59.0  0.51 105.0  23.0   0.0    0.0    0.0  288.8  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 263 23  0 970.0 12.7   75.0  0.36  36.0  23.0   0.0    0.0    0.0  282.1  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
 264  0  0 970.0 12.3   81.0  0.21  36.0  23.0   0.0    0.0    0.0  282.1  0.0 0  0.0 0  0.0 0 0.0000 0 0.0000
```

Figure B-1. Sample Input Parameters for the Meteorological File layer (see Figure 4), a code number describing the material, the quartz content in each layer, and parameters required for the convective calculations. SWOETHRM currently has three materials, along with material properties, includes in a built-in generic database. These materials are snow (LTYPE = 1), clay (LTYPE = 2), and sand (LTYPE = 3). If the user intends to supply his/her own set of material properties, a material type code number between 90 - 99 should be supplied.

Record type 3 includes information used to control the numerical solution. These parameters are related to the various convergence criteria used.

Record type 4 is used only if the user supplies customized material properties. One line is required for each of the user-defined layers specified by lines of record type 2. The user is referred to references on soil material properties for specific data on various materials (*e.g.*[10].)

Record type 5 is used only the tank track option is set in record 1. Again, in the current version of SWOETHRM this option is only available for snow surfaces.

Finally, record type 6 provides initialization data for the calculation nodes. The data provided are the initial temperature at the node, the node thickness, the total bulk water density of the node, and the mean snow grain diameter for the node. The last paramater is obviously only required if snow is one of the specified layers.

Two sample files are included. One is for a non-winter surface and one for a winter surface. Figure B-2 (a.) lists the sample data supplied with the file *bare.inp*. These data are for a bare surface consisting of silt over clay. Figure B-2 (b.) lists the sample data supplied with the file *snow.inp*. These data are for a snow covered surface.

B-5. Sample Data for Simple Vegetation

The SWOE ITM can model the surface energy budget for a surface containing simple vegetation. Data for simple vegetation are contained in the input file *veggie.inp* and Table B-7 (a.) describes the parameters contained in the file *veggie.inp*. The reader is referred to the VEGIE documentation for specific details about each parameter.[3] Three sample data files are included for representative "high vegetation", "medium vegetation", and "grasslands." Table B-7 (b.) - (d.) lists the sample data supplied in the files *hiveg.inp*, *medveg.inp*, and *grass.inp*.

B-6. Data for Extended Forests

Data for extended forests are contained in the input file *canopy.inp*. Table B-8 lists the parameters contained in *canopy.inp* and their meaning. Note that two streams of input are possible:

Table B-6. Description of Input Records Required for SWOETHRM. Parameters without units listed are dimensionless

Record 1: LN,PINV,IFLUXOUT,ITRACKS,BEXT,ITM,IOUTFILTRATE,ALBSNOW
LN - Number of Layers
PINV - Print Out Interval
IFLUXOUT - Optional Hourly Print-out of Incident Heat Fluxes (1 = Yes, 0 = No)
ITRACKS - Includes Compaction by Tank Tracks (1 = Yes, 0 = No)
BEXT - Near IR Extinction Within the Top Material for Top Node
ITM - (Optional) Input of Measured Temperature Data (1 = Yes, 0 = No)
IOUTFILTRATE - (Optional) Print-out of Water Infiltration Estimates (1 = Yes, 0 = No)
ALBSNOW - Albedo of Snow

Record 2: NN(i),LTYPE(i),QTZ(i),ZNAUGHT(i),CD(i),RCE(i),RCH(i),RCH(i), CK(i) (Repeated LN Times)
NN(i) - Number of Nodes in Layer
LTYPE(i) - Material Code for Layer
QTZ(i) - Quartz Content of Soil
ZNAUGHT(i) - Roughness Length (Enter 999 if None is Given)
CD(i) - Bulk Transfer Coefficient for Eddy Diffusivity (Enter 999 if None is Given)
RCE(i) - Turbulent Prandtl Number
RCH(i) - Turbulent Schmidt Number
CK(i) - Windless Convection Coefficient

Record 3: NGOOD,DTMIN,DTSMIN,DTMAX,DTSSMAX,DSSALLOWED, ERRTALLOWD
NGOOD- Number of Successive Good Calculations Before Increasing Time Step
DTMIN - Minimum Allowable Time Step (sec)
DTSMIN- Minimum Allowable Time Step (sec) When Water Flow is Present
DTMAX - Maximum Allowable Time Step (sec)
DTSSMAX - Maximum Allowable Time Step (sec) When Water Flow is Present
DSSALLOWED - Maximum Allowable Change in Saturation Per Time Step
ERRTALLOWD - Maximum Allowable Temperature (C) Estimation Error Per Time Step

Record 4: SOILNAME,RHOM,BD,CM,DKDRY,ICOARSE,DJP,ALB,EM
(Included Only for User-Defined Materials) SOILNAME - Name of Soil Material
RHOM - Density of Dry Materials (kg m^{-3})
BD - Bulk Density of Dry Materials (kg m^{-3})
CM - Heat Capacity of Dry Material (J kg^{-1} K^{-1})
DKDRY - Thermal Conductivity of Dry Material (W m^{-1} K^{-1})
ICOARSE - Coarseness Code (2 = Coarse, 1 = Fine)
DJP - Plasticity Index (0.0 - 0.3)
ALB - Surface Albedo at Normal Incidence
EM - Emissivity

Table B-6. (Continued)

Record 5: IY2,JDAY2,IHOUR2,CTRACK,TRWIDTH,TRDEPTH,ORIENTATION
(Included Only if ITRACKS = 1.)
IY2 - Last Two Digits of Year When Tank Track Data Were Taken
JDAY2 - Julian Day When Tank Track Data Were Taken
IHOUR2 - 24 Hour Time When Tank Track Data Were Taken
CTRACK - Compaction Ratio (Compacted Snow Depth/Undisturbed Snow Depth)
TRWIDTH - Track Width
TRDEPTH - Compacted Snow Depth
ORIENTATION - Track Orientation Relative to North (deg)

Record 6: TO(j),DZO(j),BWO(j),DO(j)
TO - Temperature of Node (K)
DZO - Nodal Thickness (m)
BWO - Total Bulk Water Density (kg m^{-3})
DO - Snow Grain Diameter (m)

```
2,12,0,0,1000.,0,0,0, ln,pinv,ifluxout,itracks,bext,itm,ioutfiltrate,albsnow
9 ,91,0.40,.001,999.,1.,1.,3.45,
13,92,0 40,.001,999.,1.,1.,3.45,  (nn(i),ltype(i),qtz(i),znaught(i),cd(i),rce(i),rch(i),ck(i),i=1,ln)
1,10.,10.,900.,900.,.05, 1, ngood,dtmin,dtsmin,dtmax,dtssmax,dssallowed,errtallowd
  '   clay',2700,1000,800, 1.256, 2, .2, 0.6,0.95, soilname, rhom,bd,cm,dkdry,icoarse,djp,alb,em
  '   silt',2700,1000,800, 1.396, 1, .2, 0.2,0.90, soilname, rhom,bd,cm,dkdry,icoarse,djp,alb,em
    283.75      0.02500     200.0      0.0000
    283.75      0.02500     200.0      0.0000
    283.75      0.02500     200.0      0.0000
    283.75      0.02500     200.0      0.0000
    283.75      0.02500     200.0      0.0000
    283.75      0.02500     200.0      0.0000
    283.75      0.02500     200.0      0.0000
    283.75      0.02500     200.0      0.0000
    283.75      0.02500     200.0      0.0000
    283.75      0.02500     300.0      0.0000
    283.75      0.02500     300.0      0.0000
    283.75      0.02500     300.0      0.0000
    283.75      0.02500     300.0      0.0000
    283.75      0.02500     300.0      0.0000
    283.75      0.02500     300.0      0.0000
    283.75      0.02500     300.0      0.0000
    283.75      0.02500     300.0      0.0000
    283.75      0.02500     300.0      0.0000
    283.75      0.02500     300.0      0.0000
    283.75      0.02500     300.0      0.0000
    283.75      0.01000     300.0      0.0000
    283.75      0.01000     300.0      0.0000
```

Figure B-2. Sample Input Parameters in (a.) *bare.inp* for Bare Surfaces

```
2,12,0,0,500.,0,0,0.78, ln,pinv,ifluxout,itracks,bext,itm,ioutfiltrate,albsnow
9,3,0.40,.001,999,1.,1.,3.45,
14,1,0.0,0.005,999,1.0,1.0,3.45, (nn(i),ltype(i),qtz(i),znaught(i),cd(i),rce(i),rch(i),ck(i),i=1,ln)
1,1.,10.,900.,900.,.05,.05, ngood,dtmin,dtsmin,dtmax,dtssmax,dsallowed,errtallowd
    274.5      0.2000        200.0      0.0000
    273.5      0.2000        200.0      0.0000
    273.2      0.2000        200.0      0.0000
    273.1      0.2000        200.0      0.0000
    273.0      0.1000        200.0      0.0000
    273.0      0.5000E-01    200.0      0.0000
    273.0      0.5000E-01    200.0      0.0000
    273.0      0.5000E-01    350.0      0.0000
    273.0      0.5000E-01    350.0      0.0000
    272.0      0.4000E-01    250.0      0.5000E-03
    271.0      0.2000E-01    800.0      0.5000E-03
    270.0      0.4000E-01    220.0      0.5000E-03
    269.0      0.5000E-01    350.0      0.5000E-03
    268.0      0.5000E-01    240.0      0.5000E-03
    266.0      0.5000E-01    250.0      0.5000E-03
    265.3      0.5000E-01    240.0      0.5000E-03
    264.0      0.5000E-01    230.0      0.5000E-03
    264.0      0.5000E-01    220.0      0.5000E-03
    265.0      0.5000E-01    240.0      0.5000E-03
    265.0      0.5000E-01    220.0      0.5000E-03
    265.2      0.2000E-01    160.0      0.5000E-03
    265.2      0.2000E-01    160.0      0.5000E-03
    265.2      0.1000E-01    160.0      0.5000E-03   to(i),dzo(i),bwo(i),do(i)
```

Figure B-2. Sample Input Parameters in (b.) *snow.inp* for Snow Covered Surfaces

- When the variable IVEG equals 2, leaf parameters are specified where, in turn, the canopy matrices are calculated internally by the TVCM routines named *gdist* and *scalc*
- When the variable IVEG equals 3, the canopy matrices are directly specified.

Two sample data files are included for extended forests, one for a deciduous and one for a coniferous forest. The deciduous forest data file is based on data for an oak/hickory forest and the coniferous data is based on a Douglas fir forest. Figures B-3 (a.) and (b.) list the sample data supplied in the files *dforest.inp* and *cforest.inp*, respectively. These data files assume that the forest canopy matrices are calculated internally (see Table B-7.)

B-7. Sample Data for Water Surfaces

The sample data included for water surfaces is based on conditions for DeGray Lake. Figure B-4 lists the sample data contained in *water.inp*. These data are required by CE-THERM-R1 for calculations involving bodies of water. The reader is referred to the CE-QUAL-R1 manual[6] for specifics about the individual parameters.

Table B-7. (a.) Description of the Input Records Con· ned in *veggie.inp* and Sample Data Files Supplied With the ITM for (b.) High vegetation, (c.) Medium Vegetation, and (d.) Grasslands

(a.)

RECORD	VARIABLE	DESCRIPTION
1	HEAD	Descriptive Header
2	SIGF	Fraction of Surface Covered by Vegetation
	STATE	State of the Vegetation
	EPF	Longwave Emissivity
	FOLA	Shortwave Absorptivity
	HFOL	Vegetation Height (cm)

(b.) *hiveg.inp*

```
High Vegetation Parameters for VEGGIE
0.70 1.0 0.85 0.96 50.00
```

(c.) *medveg.inp*

```
Medium Vegetation Parameters for VEGGIE
0.40 1.0 0.85 0.96 100.00
```

(d.) *grass.inp*

```
Grassland Parameters for VEGGIE
0.50 1.0 0.98 0.80 50.00
```

Table B-8. Input Records in *canopy.inp*

RECORD	VARIABLE	DESCRIPTION
1	HEAD	Descriptive header
2	IVEG	Flag describes how canopy matrices are obtained 2 = matrices calculated internally 3 = user specified matrices
	TLAY(1)	Initial temperature of top canopy layer (C)
	TLAY(2)	Initial temperature of middle canopy layer (C)
	TLAY(3)	Initial temperature of bottom canopy layer (C)
	>>>> Specify the following records if IVEG = 2 <<<<	
3	LAYERF(1)	Leaf frequency distribution type for top layer
	S(1)	Leaf clumpness factor for top layer
	PLAI(1)	Leaf area index for top layer
4,5		Repeat record 3 for middle and bottom layers
	>>>> Specify the following records if IVEG = 3 <<<<	
3	WMAT(1,J) J=1,9	Shortwave view matrix for top layer for zenith angles 5,15,..85 (measured from horizontal)
4,5,6		Repeat record 3 for middle and bottom layers and the ground
7	SMAT(1,J) J=1,5	Longwave matrix for top layer
8,9,10		Repeat record 7 for middle and bottom layers and the ground
	>>>> Specify the following records for IVEG = 2,3 <<<<	
11	EMS(1)	Longwave emissivity for top layer
	EMS(2)	Longwave emissivity for middle layer
	EMS(3)	Longwave emissivity for bottom layer
12	SWABS(1)	Shortwave absorption coefficient for top layer
13	SWABS(2)	Shortwave absorption coefficient for middle layer
14	SWABS(3)	Shortwave absorption coefficient for bottom layer
13	RSTOMA	Leaf stomatic resistance to water vapor diffusion

```
Deciduous Forest Parameters for TVCM (Oak/Hickory)
2 9.0 9.0 9.0
1 0.1 3.4
1 0.1 0.8
1 0.1 0.4
0.98 0.98 0.98
0.75 0.75 0.75
0.07
```

(a.) *dforest.inp*

```
Coniferous Forest Parameters for TVCM (Douglas-fir)
2 9.0 9.0 9.0
1 0.1 1.5
1 0.1 5.3
1 0.1 1.0
0.98 0.98 0.98
0.75 0.75 0.75
0.66
```

(b.) *cforest.inp*

Figure B-3. Sample Input Parameters for (a.) Deciduous Forests and (b.) Coniferous Forests

```
TITLE             1979 DEGRAY THERMAL SIMULATION
TITLE           FOR USER MANUAL VERSION JULY 1986
TITLE
TITLE                      SEP  8 1986
TITLE
MODE       NORMAL    PORT SPECIFY      YES       1
PHYS1           2      60     .06  1.0-09  1.2-09      74.
PHYS2       13000      .5     2.0
PHYS2+ 1     1.25    1.25      1.      1.      1.      1.      1.      1. 1.
PHYS2+ 2      1.      1.       1.      1.      1.      1.      1.      1. 1.
PHYS2+ 3      1.      1.       1.      1.      1.      1.      1.      1. 1.
PHYS2+ 4      1.      1.       1.      1.      1.      1.      1.      1. 1.
PHYS2+ 5      1.      1.       1.      1.      1.      1.      1.      1. 1.
PHYS2+ 6      1.      1.       1.      1.      1.      1.      1.      1. 1.
PHYS2+ 7      1.      1.       1.      1.      1.      1.
OUTLET          3
PHYS3        56.4     6.4    4.87
PHYS3        51.8     6.4    4.87
PHYS3        44.4     6.4    4.87
CURVE       POWER
AREAC      561.81    2.79
WIDTHC      47.70    0.55
MIXING        1.0    0.30 3.6-05  9.0-07       .1
LIGHT        0.65    0.40     .01
SSETL         1.0
INITO          45
INIT2          0.     5.2     49.     6.3
INIT2        16.5     5.2     49.     6.3
INIT2        17.5     5.2    51.7     3.5
INIT2        18.5     5.3    54.3      .1
INIT2        19.5     5.3     57.      0.
INIT2        20.5     5.3     61.      0.
INIT2        21.5     5.3    60.6      0.
INIT2        22.5     5.3    60.2      0.
INIT2        23.5     5.3    59.8      .5
INIT2        24.5     5.3    59.4     1.1
INIT2        25.5     5.3     59.     1.7
INIT2        26.5     5.3     59.      .6
INIT2        27.5     5.2     59.      0.
INIT2        28.5     5.3     58.      0.
INIT2        30.5     5.3     58.      0.
INIT2        31.5     5.3    58.6      0.
INIT2        32.5     5.3    59.2      0.
INIT2        33.5     5.3    59.8      0.
INIT2        34.5     5.3    60.4      .2
INIT2        35.5     5.3     61.      .9
INIT2        36.5     5.3    61.2      0.
INIT2        37.5     5.3    61.4      0.
INIT2        38.5     5.3    61.6      0.
INIT2        39.5     5.3    61.8      0.
```

Figure B-4. Sample Input Parameters in *water.inp* for Water Bodies. For brevity, some of the redundant inputs are not printed here (*Cont'd on next page*)

```
INIT2        40.5      5.3     62.       0.
INIT2        41.5      5.3     61.2      0.
INIT2        42.5      5.3     60.4      0.
INIT2        43.5      5.2     59.6      0.
INIT2        44.5      5.3     58.8      0.
INIT2        45.5      5.3     58.       0.
INIT2        46.5      5.3     60.7      0.
INIT2        47.5      5.3     63.3      0.
INIT2        48.5      5.3     66.       0.
INIT2        49.5      5.3     66.5      0.
INIT2        50.5      5.3     67.       0.
INIT2        51.5      5.3     66.       0.
INIT2        52.5      5.3     65.       0.
INIT2        53.5      5.3     65.5      0.
INIT2        54.5      5.3     66.0      0.
INIT2        55.5      5.3     64.       0.
INIT2        56.5      5.3     62.     5.44
INIT2        57.5      5.4     65.5      0.
INIT2        58.5      5.4     69.       0.
INIT2        59.5      5.4     63.       0.
INIT2        59.7      5.5     57.       0.
FILES    PLTWC    R1PLT04 R1PLT11 R1PLT12
FILID     DEGRAY 79 SEPT 8 1986
SOUTL1          24      365
SOUTL2DGRA 79001         1     10.0
SOUTL2DGRA 79002         1     10.0
SOUTL2DGRA 79003         1     41.1
SOUTL2DGRA 79004         1     63.8
SOUTL2DGRA 79005         1     51.5
SOUTL2DGRA 79006         1     36.9
SOUTL2DGRA 79007         1     36.9
SOUTL2DGRA 79008         1     36.9
SOUTL2DGRA 79009         1     20.1
SOUTL2DGRA 79010         1     10.0
.
.
.
SOUTL2DGRA 79355         1                2                3     8.2
SOUTL2DGRA 79356         1                2                3    14.2
SOUTL2DGRA 79357         1                2                3    20.6
SOUTL2DGRA 79358         1                2                3    81.4
SOUTL2DGRA 79359         1                2                3    31.6
SOUTL2DGRA 79360         1                2                3    21.1
SOUTL2DGRA 79361         1                2                3    29.6
SOUTL2DGRA 79362         1                2                3    60.7
SOUTL2DGRA 79363         1                2                3     0.4
SOUTL2DGRA 79364         1                2                3     2.3
SOUTL2DGRA 79365         1                2                3     2.2
TEMP 352      3.8      4.0      5.5      7.7      9.8     11.6     10.8      9.2  8.7
TEMP 361      8.9      9.1      8.6      7.8      7.5
```

Figure B-4. (Cont'd)

WQ TDS	168	6							
TDS	47.	47.	47.	47.	31.	15.	18.	21.	29.
TDS	36.	51.	65.	62.	59.	54.	49.	47.	45.
TDS	58.	71.	68.	65.	62.	59.	75.	91.	82.
TDS	73.	64.	55.	52.	49.	41.	32.	43.	53.
TDS	62.	71.	46.	21.	51.	51.	67.	91.	60.
TDS	29.	49.	92.	87.	67.	79.	23.	23.	
WQ SSOL	168	6							
SSOL	7.	7.	7.	7.	7.	6.	13.	20.	13.
SSOL	6.	74.	153.	65.	24.	15.	6.	6.	6.
SSOL	6.	6.	6.	6.	6.	6.	6.	6.	12.
SSOL	19.	12.	6.	8.	11.	22.	33.	20.	8.
SSOL	7.	6.	6.	7.	8.	7.	6.	6.	6.
SSOL	6.	6.	8.	13.	8.	6.	6.	6.	6.
Q1	24	41							
Q2 79 1	49.4	18.3	10.8	8.0	6.6	6.1	5.6	5.6	5.2
Q2 79 10	4.7	4.4	4.1	3.8	3.5	3.2	3.0	3.0	3.1
Q2 79 19	5.5	11.2	11.0	8.4	7.8	6.5	5.5	5.6	5.6
.									
.									
.									
Q2 79343	1.7	1.7	1.7	3.8	10.8	6.8	5.0	4.2	3.6
Q2 79352	3.1	2.8	2.6	2.5	4.0	45.7	75.4	19.2	10.2
Q2 79361	7.5	5.8	4.9	4.3	3.8	0.	0.	0.	0.
WQ TEMP	24	41							
TEMP 001	6.5	3.8	3.0	3.0	3.5	3.9	3.7	2.9	1.8
TEMP 010	2.1	2.4	2.4	2.7	1.3	1.2	2.0	3.8	4.2
TEMP 019	5.6	6.0	4.3	4.3	3.4	2.4	2.3	2.5	3.1
.									
.									
.									
TEMP 343	6.3	6.4	7.6	8.1	7.7	7.3	7.1	6.7	5.1
Q1 QIN	24	41							
Q2 79 1	105.0	39.0	23.0	17.0	14.0	13.0	12.0	12.0	11.0
Q2 79 10	10.0	9.3	8.7	8.0	7.4	6.8	6.4	6.4	6.5
Q2 79 19	11.8	23.9	23.3	17.9	16.7	13.8	11.7	11.9	11.9
.									
.									
.									
Q2 79343	3.7	3.6	3.6	8.1	22.9	14.4	10.6	9.0	7.7
Q2 79352	6.6	6.0	5.6	5.3	8.5	97.2	160.4	40.8	21.7
Q2 79361	16.0	12.4	10.4	9.2	8.1	0.	0.	0.	0.
WQ TEMP	24	41							
TEMP 001	6.5	3.8	3.0	3.0	3.5	3.9	3.7	2.9	1.8
TEMP 010	2.1	2.4	2.4	2.7	1.3	1.2	2.0	3.8	4.2
TEMP 019	5.6	6.0	4.3	4.3	3.4	2.4	2.3	2.5	3.1
.									
.									
.									
TEMP 343	6.3	6.4	7.6	8.1	7.7	7.3	7.1	6.7	5.1
TEMP 352	3.8	4.0	5.5	7.7	9.8	11.6	10.8	9.2	8.7
TEMP 361	8.9	9.1	8.6	7.8	7.5				

Figure B-4. (Cont'd)

```
WQ TDS        168       6
TDS           47.       47.       47.       47.       31.       15.       18.       21. 29.
TDS           36.       51.       65.       62.       59.       54.       49.       47. 45.
TDS           58.       71.       68.       65.       62.       59.       75.       91. 82.
TDS           73.       64.       55.       52.       49.       41.       32.       43. 53.
TDS           62.       71.       46.       21.       51.       51.       67.       91. 60.
TDS           29.       49.       92.       87.       67.       79.       23.       23.
WQ SSOL       168       6
SSOL          7.        7.        7.        7.        7.        6.        13.       20.       13.
SSOL          6.        74.       153.      65.       24.       15.       6.        6.        6.
SSOL          6.        6.        6.        6.        6.        6.        6.        6.        12.
SSOL          19.       12.       6.        8.        11.       22.       33.       20.       8.
SSOL          7.        6.        6.        7.        8.        7.        6.        6.        6.
SSOL          6.        6.        8.        13.       8.        6.        6.        6.        6.
VERIFY1       YES
VERIFY2       3
 4  1    65   49 48.0       4.500 47.0      4.500 46.0      4.600 45.0      4.600
                 44.0       4.600 43.0      4.600 42.0      4.600 41.0      4.600
                 40.0       4.600 39.0      4.600 38.0      4.600 37.0      4.700
                 36.0       4.700 35.0      4.700 34.0      4.800 33.0      4.800
                 32.0       4.900 31.0      5.000 30.0      5.100 29.0      5.200
                 28.0       5.300 27.0      5.300 26.0      5.400 25.0      5.400
                 24.0       5.400 23.0      5.400 22.0      5.400 21.0      5.500
                 20.0       5.500 19.0      5.500 18.0      5.600 17.0      5.600
                 16.0       5.700 15.0      5.700 14.0      5.800 13.0      5.900
                 12.0       5.800 11.0      5.900 10.0      5.900  9.0      6.100
                  8.0       6.100  7.0      6.200  6.0      6.200  5.0      6.300
                  4.0       6.400  3.0      6.400  2.0      6.600  1.0      6.600
                  0.0       6.700
 4  1   275   41 40.0       6.200 39.0      6.200 38.0      6.200 37.0      6.200
                 36.0       6.200 35.0      6.300 34.0      6.300 33.0      6.300
                 32.0       6.400 31.0      6.400 30.0      6.500 29.0      6.500
                 28.0       6.600 27.0      6.700 26.0      6.800 25.0      7.000
                 24.0       7.400 23.0      7.400 22.0      7.700 21.0      8.200
                 20.0       8.600 19.0      9.400 18.0     10.300 17.0     11.300
                 16.0      12.500 15.0     14.500 14.0     16.400 13.0     17.400
                 12.0      18.900 11.0     21.000 10.0     23.300  9.0     23.500
                  8.0      24.200  7.0     24.400  6.0     24.600  5.0     24.600
                  4.0      24.800  3.0     25.000  2.0     25.000  1.0     25.000
                  0.0      25.000
 4  1   361   44 45.0       6.400 44.0      6.400 41.0      6.400 40.0      6.500
                 39.0       6.500 38.0      6.500 37.0      6.500 36.0      6.500
                 35.0       6.500 34.0      6.600 33.0      6.600 32.0      6.600
                 31.0       6.600 30.0      6.700 29.0      6.800 28.0      6.900
                 27.0       7.000 26.0      7.300 25.0      7.300 24.0      7.500
                 23.0       8.000 22.0      8.300 21.0      9.000 20.0      9.800
                 19.0       9.900 18.0     10.000 17.0     10.000 16.0     10.000
                 15.0      10.000 14.0     10.000 13.0     10.000 12.0     10.100
                 11.0      10.100 10.0     10.100  9.0     10.100  8.0     10.100
                  7.0      10.100  6.0     10.100  5.0     10.100  4.0     10.300
                  3.0      10.300  2.0     10.500  1.0     10.900  0.0     11.100
```

Figure B-4. (Cont'd)