

User's Guide for USACRREL

ONE-DIMENSIONAL SNOW TEMPERATURE MODEL (SNTHERM.89)

Revised 3/90

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To : Recipients of the SNTHERM.89 1-D mass and energy balance model
From: Rachel Jordan
Subject: Revisions to SNTHERM.89 code. Date: Oct 1992.

1. Revision to the code.

We are in the process of testing and validating the SNTHERM.89 code. While the major extensions and improvements will not be made available until the release of SNTHERM2, there is one revision we would like to bring to your attention at this time. In the current version, snow ablation occurring through melt and drainage of a node is modeled by allowing the snow matrix to lose in density. We felt that it would be more realistic to model nodal ablation through a loss in nodal thickness. This process has been implemented in the compaction routine, which now includes a factor so that melt loss to the snow matrix is compensated by compaction, thereby keeping the dry snow density unchanged. Changes to the code are indicated on the enclosed hard copies of the routines *sntherm.f*, *compact.f* and *old.f*.

2. Corrections to the Technical Report

a) Solar heating. As described on p 22 of the Technical Documentation (CRREL Special Report 91-16), the low-energy portion of the solar spectrum is assumed to be absorbed within the top node. The definition of β_{nir} as the bulk extinction coefficient for near-infrared radiation (eq 77) is misleading. The factor $\exp(-\beta_{nir} 0.002)$ should instead be interpreted as the fraction of net solar radiation at the surface which is *not* absorbed within the top node. For example, the model uses a default value of $\beta_{nir} = 400$, which results in 55% of the net solar radiation being totally absorbed in the top node.

b) Typographical errors. Typographical errors in subscript notation have been found within the section, 'Discretization and Numerical Implementation.' A complete errata list will be provided at a later date.

Description of files on SNTHERM89 directory
One Dimensional Mass and Energy Balance Model for a Snowcover
US Army Cold Regions Research and Engineering Lab
Hanover, NH 03755

sntherm.f MAIN
other.f files Subroutines

const Include file
arrays Include file

documentation Description of global variables

FILENAME Required file containing filenames

Makefile Creates executable code for UNIX System. Note that an
extension for long variable names (16 digits) is required

test.in or snow.in Input file for running test case
metrev.in Meteorological data for running test case
test.out or test.short Output from test case

SNTHERM89.rev4 upgrade. Further revisions made through November 20, 1996.
Note improvements to turbulent transfer routine (Item 6) and new print-out options (Item 7).

I am in the process of creating a Web-Site for the User's Guide to make it available over the internet along with the computer code. It should be completed by the end of the year.

.....
This directory contains code for SNTHERM89.rev4, released on Nov 10, 1995.
Questions about the code should be addressed to Ms. Rachel Jordan, USA-CRREL.
e-mail: rjordan@crrel.usace.army.mil.

A running list of changes made to the code since Nov 10, 1995 is recorded in the file README.CHANGES. IT IS THE RESPONSIBILITY OF THE USER TO CHECK THIS FTP SITE FROM TIME TO TIME AND TO KEEP UP WITH THESE CHANGES.

A. The major upgrades affecting this version are:

1) A variable albedo algorithm can be triggered by inputting a snow albedo greater than 1. The routine is an adaptation of that described in the dissertation of Danny Marks (1988), which in turn is based on the work of Marshall and Warren (1987). The main driver in the routine is grain size. The routine does not handle dirty or shallow snow (<10cm) and is limited to clear sky conditions, but does make an adjustment for slope and solar angle. Complete documentation can be had from R. Jordan.

The following new options require additional input to LINE READ 1 of the LAYER.IN file.

2) There are now three ways to specify the density of new snow, which was previously hard-wired to 100 kg/m³. A lower limit is set to 30 kg/m³.

a. A fixed density for new snow (bifallin) can be input.
b. SNTHERM can estimate the new density based on air temperature, using the Alta function described in Anderson (1976) or in LaChapelle (1961). This option is triggered by inputting a density greater than 950 kg/m³. There are of course variables other than temperature affecting the new snow density (wind speed, crystal type, etc.), so that estimates may be off by as much as 50%.
c. If 0.0 is input, new snow densities will be read from the MET.IN file. The column for this parameter should be inserted after that for new grain size. Establishing these values is tricky, since density measurements need to be corrected for settlement during the storm. Adjustments are best made using eq (26) in Jordan (1991), with T as an average temperature. By integrating (26) the average settlement is found as the rate times one-half the time elapsed since the beginning of snowfall. As discussed in item 5), the settling phase of compaction is now limited to either 15% over the initial density or by the "dmlimit" cutoff. Back correction for settlement should consider these limits. The overburden contribution to compaction is small by comparison and can be neglected in the correction.

3) THE PRECIPITATION RATE IS NOW ENTERED IN THE MET FILE IN M/HR OF SNOW WATER EQUIVALENT UNITS, instead of in m/hr of as snow accumulation. This change was necessary because of the variable new snow density, but also has the benefit that we can be taken directly from the precip gauge.

4) The upper limit on snowfall is set at +2.5C. This determination was based on data provided in Snow Hydrology (1956), p. 55. The percentage of liquid water by mass in falling snow is arbitrarily set to vary linearly with air temperature from 0% at 0C to a 40% maximum at + 2C.

5) Recent testing of the compaction algorithm, taken from Anderson (1976), indicated that adjustments were in order. The settling or destructive metamorphism component was found to significantly overpredict the compaction rate for new snow and the overburden component to compact the snow too slowly. More study is needed of the compaction rate of new snow, but as a 'Band-Aid' it is suggested that the upper snow density limit [dmlimit] for the settling process be lowered from the previously fixed value of 150 kg/m³ to around 100 kg/m³. Dmlimit is now entered in the LAYER.IN file, and the model takes as a cut-off the smaller of this value and the density of the snow at the start of the storm compacted by 15%. Limited testing of the overburden function suggests a lower value of 0.9d6kg-s/m² for the viscosity coefficient, slightly less than the value of 1.0d6kg-s/m² used by Brun et al. (1989). The viscosity coefficient [eta0] is now an input. In Jordan (1991), the units on eta0 were incorrectly stated as N-s/m² and the units on overburden as N/m² instead of kg/m². In accordance with Brun et al., I have also changed the exponential scaling factor on density in eq (29) from 0.021 to 0.023 m³/kg. The model had adjusted for mass losses due to melt by decreasing the thickness of nodes (rather than by decreasing snow density). In the heavier stages of melt this procedure contributed to over-densification of the pack, and with the exception of the top node has now been limited to snow less dense than 250 kg/m³. The compaction of wet snow and snow undergoing melt needs further study. In the later stages of the melt period, after the snow has undergone several freeze-thaw cycles, the model over-densifies the snowcover due to repeated freezing of the retained residual water.

6) Turbulent Transfer. SNTHERM was originally fit to measured data on cold snow, with the primary intent of predicting snow surface temperature. The parameters in the User's Guide are a best fit for these purposes and conditions. In addition,

the stability correction for stable atmospheric conditions was turned off, as it appeared to degrade the model's ability to predict surface temperatures. Subsequent testing of the model under melt conditions, at CRREL and elsewhere, have indicated that these default parameters cause the model to over-predict melt. The current recommendation (as of November, 1996) is to use the stability correction, but to set an upper limit on the Richardson number. This is done through a new input switch {istboff}, where the stability correction is turned off when istboff = 1, is on when istboff = 0 and is on with a limit of $R_b = 0.16$ when istboff = 2. The current hard-wired limit of 0.16 is conservative. It could be set as low as 0.12 and still be realistic.

AS OF NOVEMBER 1996, QTURB AND QTURB2 ARE REPLACED WITH QTURB3.

The main addition to this routine is the correct computation of the transfer functions when measurement heights for air temperature, wind speed and Rh are at different levels. To improve computation of the Richardson number, an estimation of the new surface temperature is used rather than the past temperature. The "iqurb" switch is no longer used, but is required as a "space holder."

7) Alternative output. CRREL added alternative output options as part of ongoing developments in distributed runs which may be of use to other SNTHERM users. Specific shell scripts used at CRREL rely on different output formats for both the standard output file ("snow.out") and the flux output file ("flux.out"). The ifluxout variable is now used as a generic output format variable. The values of ifluxout are the sum of the flux.out format code and the snow.out format code. The use of these format codes retains the original values of ifluxout for the default output formats, but also allows for new output formats to be developed and for any combination of output formats to be used.

snow.out format codes used in ifluxout variable:

```
0      default (original) output format (write.f)
10     no snow output
20     alternative output format 2 (write2.f)
30     alternative output format 3 (write2.f)
```

flux.out format codes used in ifluxout variable:

```
0      no flux output
1      default (original) flux output format
2      alternative output format
```

All alternative snow.out formats differ from the original format as follows:

- no header information
- swe(mm), depth(m), outflux(kg/m2) and cold content (j/m2) are printed after a "|" on time line
- time line printed before snow profile (instead of after)

Alternative snow.out format 2 also differs as follows:

- only top soil layer printed
- time line only printed when snow profile is printed

The alternative flux.out format differs from the original format as follows:

- no header information
- eliminated met data after flux columns
- time changed to decimal-day format
- order of remaining columns changed

8) Summary of LAYER.IN (generic name) file changes.

LINE READ 1: General Parameters.

Items which have been changed or added are noted by an asterisk.

```
-Number of layers (if >4, increase parameter ld in file const.) (2)
-Print-out interval for LAYER.OUT(every nth base-step or if code=99,at
  base-time interval) (12)
-*Optional print-out of surface heat flux file:1=yes 0=no (0)
  Other codes will generate alternative output files
  (see Section 7).
-Approximate average barometric pressure(mb)over period of run (990.)
-Estimated solar radiation: 2=estimate missing values only 1=yes 0=no (0)
-Estimated incident long wave radiation: 2=estimate missing values only (0)
  1=yes 0=no
-Sloped terrain: 1=yes 0=no (0)
-Snow compacted (tank tracks): Currently disabled, must be 0 (0)
-Near IR extinction coefficient for top snow node (400.)
-Optional input of measured temperature data 1=yes 0=no (0)
-Optional print-out of water infiltration estimates 1=yes 0=no (0)
  Note: This option may generate extensive output
-Basic time period in seconds (determined by time-step of MET data) (3600.)
-Estimate standard MET data from user-supplied routine: 1=yes 0=no (0)
-*Snow albedo >1 compute albedo <1 use constant input value (1.78)
-Irreducible water saturation for snow (0.04)
-*New snow density: 0=read from met file >950=compute from Alta algorithm
  Else use fixed input value. A minus sign in conjunction (80.)
  with options 2 and 3 will read a met file value but override it.
-*Density limit for settling compaction (100.)
```

```

-Correction for stable conditions  0=turn-off 1=turn-on          (2)
                                   2=set max Richardson number at 0.16
-Turbulent transfer routine Any number-No longer an option      (2)
-Viscosity coefficient                                (0.9d6)

```

LINE READ 2: Measurement heights above ground surface for MET data in meters.
 -Air temp height, wind speed height, dewpoint or RH height (2.,2.,2.)

LINE READ 3: Specification of characteristics for each layer type.

Since layers number in ascending order, BEGIN WITH THE LOWEST LAYER FIRST.
 For some stock material types, many of the characteristics are automatically supplied from a database within the model as shown in Table 1. Codes for materials currently catalogued in the model are:

1=snow 2=clay 3=sand (90..99)= user supplied material

Enter the following items, one line per layer type. User defined properties are read at Line 5).

```

-Number of nodes (if > 70, increase parameter nd in file const) (Integer)
-Material code (Integer)
-Quartz content (0.0-0.45)
-Roughness length or 999. (.001-.005 for snow)
-Bulk transfer coefficient for eddy diffusivity or 999. (999.)
-Cd/Ce (1.0)
-Cd/Ch (1.0)
-Windless convection coefficient for latent heat (0.0 for snow)
-Windless convection coefficient for sensible heat (1.0 - 2.0 for snow)
-Fractional humidity relative to saturated state (1.0 For snow, <1.0 for soil)

```

The remainder of this file is unchanged from the original User's Guide.

Following is an example of the revised LINE READ 1 of the LAYER.IN file.

```

2,6,1,990.,0,0,0,0,400.,0,0,3600.,0,1.78,0.04,999.,100.,2,2,0.9d6,ln,pinv,
ifluxout,bp,isolarcalc,ircalc,islope,itracks,bext,itm,ioutfiltrate,dtbase,
imetcalc,albsnow,ssisnow,bifallin,dmlimit,istboff,iqturb,eta0

```

Variable computation of albedo is indicated by albsnow = 1.78 (> 1.0).
 Computation of the new snow density is triggered by bifall = 999. (> 950.).
 The settling compaction limit dmlimit is 100 kg/m3.
 The stability correction for stable conditions has a minimum lower limit
 The viscosity coefficient is 0.9d6 kg-s/m2.

B. Other changes to the code.

The upper limit on the grain growth algorithm has been increased from 3mm to 5mm, and the lower limit on the algorithm for estimating the grain size of new snow has been decreased from 400 microns to 25 microns. Since grain size is critical when computing albedo, it is recommended that both the new snow density and grain size be estimated if the variable albedo option is selected and the data set contains multiple snow events. The new snow grain size algorithm is triggered by stating the grain size as 0.0 in the MET.IN file. Debugging changes have been made in the procedures for handling wet snow storms.

The routine for generating the SNOW.OUT file has been expanded to print out information on the new options, plus it echoes other input information not printed out before.

There have been minor debugging changes to the code, some of which corrected problems experienced by very strict compilers.

C. Changes to the User's Guide.

In addition to the three new parameters in LINE.READ 1 of the LAYER.IN file and the different default values for melting snow, there are the following changes.

The terminology of "Turbulent Schmidt number" and "Turbulent Prandtl number" is incorrect. More accurate descriptions are respectively: "ratio of neutral stability bulk turbulent transfer coefficients of momentum and latent heat (Cd/Ce)" and "ratio of neutral stability turbulent transfer coefficients of momentum and sensible heat (Cd/Ch)."

THE PRECIPITATION RATE IS NOW ENTERED IN THE MET FILE IN M/HR OF SNOW WATER EQUIVALENT UNITS, instead of in m/hr of snow accumulation

If 0.0 is input for bifallin, new snow densities will be read from the MET.IN file. The column for this parameter should be inserted after that for new grain size. If bifallin is <0.0, the new snow density will be read from the met file but overridden.

Cloud type 5 in the MET.IN file is disallowed.

D. References

- Anderson, E.A. (1976) A point energy and mass balance model of a snow cover, Office of Hydrology, National Weather Service, Silver Springs, Maryland, NOAA Technical Report NWS 19.
- Brun, E., et al. (1989) An energy and mass model of snow cover suitable for operational avalanche forecasting, Journal of Glaciology, p. 333-342, 35,21.
- Jordan, R. (1992) Estimating turbulent transfer functions for use in energy balance modeling, Internal Report 1107, U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, N. H.
- Jordan, R. (1991) A one-dimensional temperature model for a snow cover: Technical documentation for SNTHERM.89, Special Report 91-16,, U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, N. H.
- La. Chapelle, E. (1961) Alta Avalanche Study Center, Project F, Progress Report No. 1, Snow Layer Densification, U.S. Department of Agriculture Forest Service, Wasatch National Forest.
- Marks, D. (1988) Climate, energy exchange, and snowmelt in Emerald Lake Watershed, Sierra Nevada. PhD Dissertation, University of California at Santa Barbara.
- Marshall, S. and S. Warren (1987) Parameterization of snow albedo for climate models, in Large Scale Effects of Seasonal Snow Cover, ed. by B. E. Goodison, R. G. Barry and J. Dozier, IAHS Publication No. 166, pp. 43-50, International Association of Hydrological Sciences, Wallingford, UK.
- North Pacific Division, U.S. Army Corps of Engineers (1956) Snow Hydrology, Summary Report of the Snow Investigations.

Jun 5 11:22

rev4release

1

TO: SNTHERM users
FROM: Ms Rachel Jordan
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Tel: (603) 646-4298 Email: rjordan@crrel.usace.army.mil

A new upgrade of SNTHERM89 is now available (SNTHERM89.rev4). The main revisions are new algorithms to compute snow albedo and the density of newly fallen snow, and improvements to the routines on compaction, grain growth and computation of the turbulent transfer function. In this version precipitation is input as meters of swe/hr rather than as snow depth accumulation/hr. Some bugs associated with the handling of falling wet snow have been corrected, and other minor bugs have been eliminated. The new capillary code (SNTHERM2) is not available yet.

The revised code and a README file explaining the changes are available through anonymous ftp. The procedure for accessing the code is:

```
ftp to crrel41.crrel.usace.army.mil
(CRREL users should ftp to cdc4000)
login with the username of anonymous
use any password with at least 3 characters
cd sntherm89
dir
get or mget all the files in the directory
```

I am attempting to compile an e-mail listing of all SNTHERM users, in order to easily keep everyone updated on changes and any new suggestions for running the model. I will be following up with letters to users for whom I have no e-mail addresses. If you are aware of any users who have received the code second-hand, rather than directly from me, and who would like to be added to the mailing list, please have them e-mail me. Thanks!

I have included a file README.CHANGES which is a running list of changes made to the code, which you should check from time to time or if you are having difficulties. I am letting it be the responsibility of the user to keep up with revisions and to upgrade their own model version.

SNTHERM89.rev4 upgrade.

NOTE NEW OPTIONS FOR STABILITY CORRECTION (April 7, 1996)

This directory contains code for SNTHERM89.rev4, released on Nov 10, 1995. Questions about the code should be addressed to Ms. Rachel Jordan, USA-CRREL. e-mail: rjordan@crrel.usace.army.mil.

A. The major upgrades affecting this version are:

1) A variable albedo algorithm can be triggered by inputting a snow albedo greater than 1. The routine is an adaptation of that described in the dissertation of Danny Marks (1988), which in turn is based on the work of Marshall and Warren (1987). The main driver in the routine is grain size. The routine does not handle dirty or shallow snow (<10cm) and is limited to clear sky conditions, but does make an adjustment for slope and solar angle. Complete documentation can be had from R. Jordan.

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c. If 0.0 is input, new snow densities will be read from the MET.IN file. The column for this parameter should be inserted after that for new grain size. Establishing these values is tricky, since density measurements need to be corrected for settlement during the storm. Adjustments are best made using eq (26) in Jordan (1991), with T as an average temperature. By integrating (26) the average settlement is found as the rate times one-half the time elapsed since the beginning of snowfall. As discussed in item 5), the settling phase of compaction is now limited to either 15% over the initial density or by the "dmlimit" cutoff. Back correction for settlement should consider these limits. The overburden contribution to compaction is small by comparison and can be neglected in the correction.

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5) Recent testing of the compaction algorithm, taken from Anderson (1976), indicated that adjustments were in order. The settling or destructive metamorphism component was found to significantly overpredict the compaction rate for new snow and the overburden component to compact the snow too slowly. More study is needed of the compaction rate of new snow, but as a 'Band-Aid' it is suggested that the upper snow density limit [dmlimit] for the settling process be lowered from the previously fixed value of 150 kg/m³ to around 100 kg/m³. Dmlimit is now entered in the LAYER.IN file, and the model takes as a cut-off the smaller of this value and the density of the snow at the start of the storm compacted by 15%. Limited testing of the overburden function suggests a lower value of 0.9d6kg-s/m² for the viscosity coefficient, slightly less than the value of 1.0d6kg-s/m² used by Brun et al. (1989). The viscosity coefficient [eta0] is now an input. In Jordan (1991), the units on eta0 were incorrectly stated as N-s/m² and the units on overburden as N/m² instead of kg/m². In accordance with Brun et al., I have also changed the exponential scaling factor on density in eq (29) from 0.021 to 0.023 m³/kg. The model had adjusted for mass losses due to melt by decreasing the thickness of nodes (rather than by decreasing snow density).

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1 General Description

For purposes of remote sensing it is often necessary to know the radiometric temperature of a background snow cover. CRREL has developed a research grade one-dimensional mass and energy balance model (SNTHERM.89) for predicting temperature profiles within snow and frozen soil. It is comprehensive in scope, being adaptable to a full range of winter meteorological conditions, such as snowfall, sleet, rainfall, 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 an accurate representation of water flow in soil. The underlying theory of the model is presented in USACRREL Report 495 (Jordan, currently available in draft form).

The model currently handles five different material types or layers. A numerical solution is obtained by subdividing snow and soil layers into horizontally infinite control volumes (Figure 1), each of which is then subject to the governing equations for heat and mass balance. As a spatial discretization procedure the control-volume approach of Patankar (1980) is adopted, which is similar in implementation to a finite-difference scheme. Within the time domain a Crank-Nicolson method is used which gives equal weighting to past and current time periods. The respective diffusive and convective components of the heat and mass fluxes are numerically approximated by central-difference and upwind schemes, weighted by the power-law methodology of Patankar (1980). Governing sets of equations are linearized with respect to unknown variables and solved by the powerful tridiagonal-matrix algorithms. In conjunction with this linearization procedure, an adaptive time-step is used that automatically adjusts between maximum and minimum values (typically between 900 sec and 5 sec) to achieve the desired accuracy of the solution. The time-step limits and solution accuracy are specified as user-inputs to the model. This approach is efficient in terms of computer time, since in most instances quarter-hourly time steps are sufficient, and smaller steps, associated primarily with melt and water flow, are implemented only as needed. The overall structure of the model is very flexible, permitting an unlimited number of nodal subdivisions and material types or layers. For solution accuracy, mesh thickness is constrained to a minimum of 2 mm and to maxima of 1.67 and 3.33 cm for the top two nodes, but is otherwise unspecified.

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; and, if available, measured values of solar and incoming infrared radiation. In lieu of radiation measurements, the model provides estimations through routines that take into account location, solar aspect, cloud conditions, and the albedo and inclination of the surface (Shapiro, 1982 and 1987). In addition, any of the

meteorological values can be estimated by user-supplied algebraic functions. The model is initialized with profiles of temperature and water content for the various strata, the accuracy of which determines the time required for the simulation to equilibrate after inception of the computer run. Physical characteristics for the selected strata are either entered by the user, or optionally supplied from internal databases currently provided for snow, sand and clay.

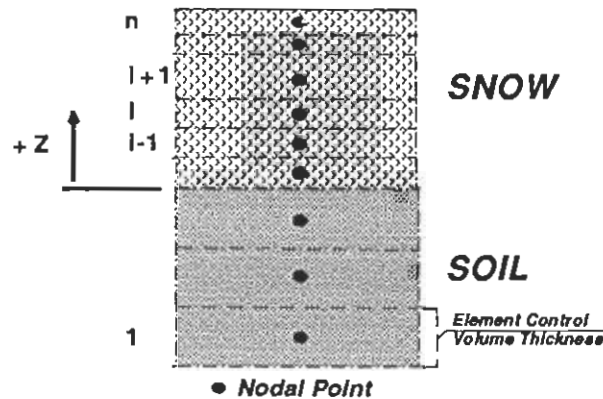


FIGURE 1. *SNTHERM.89 Model Spatial Scheme*

The model is coded in standard FORTRAN-77 and has been implemented on several machines, including an IBM-PC with a math coprocessor. An extension for long variable names (16 digits) is required. The INCLUDE (or INSERT) statement is generally compiler dependent, and may need to be globally changed.

2 Data Input Requirements

Unless otherwise specified all entries should be in free format, separated by a standard delimiter (blank, comma, etc.). Suggested values are in parenthesis. All units are in the MKS system. Except for "FILENAME," file names may be any combination of legal FORTRAN strings of twelve characters or less. Note that the file name syntax must also comply with the requirements of the operating system on which the code is installed.

2.1 File FILENAME (specific name)

Contains filenames in free format, one name (in quotes, 12 characters or less) per line. If run under UNIX, the filenames are case sensitive. Files are as follows:

Layer.in (required input)

Met.in (required input)

Tc.in (optional input)

Snow.out (general output file)

Flux.out (optional surface flux output)

Filt.out (optional water infiltration output)

All filenames must be specified, even if the files are not used. The user can fill in with a fictitious or dummy file name as long as no file name is repeated. A sample version of FILENAME (upper case) in which none of the optional files are used is shown in Figure 2b.

```
'Layer.in'  
'Met.in'  
'Tc.in'  
'Snow.out'  
'Flux.out'  
'Filt.out'
```

Figure 2a. Sample Input File FILENAME

```
'Layer.in'  
'Met.in'  
'Dum1'  
'Snow.out'  
'Dum2'  
'Dum3'
```

Figure 2b. Sample Input File FILENAME Without Optional I/O Files

2.2 File LAYER.IN (generic name)

This file contains general parameters and initial nodal values of temperature and water content. A sample LAYER.IN file is shown in Figure 3.

LINE READ 1: General Parameters

- Number of layers (If > 4, increase parameter *ld* in file *const.*) (2)
- Print-out interval for LAYER.OUT (every *n*th base-step or if code = 99, at base-time interval) (12)
- Optional hourly print-out of incident heat fluxes: 1=yes 0=no (0)
- Approximate average barometric pressure (mb) over period of run (990.)
- Estimated solar radiation: 2=estimate missing values only 1=yes 0=no (0)
- Estimated incident longwave radiation: 1=yes 0=no (0)
- Sloped terrain: 1=yes 0=no (0)
- Snow compacted (tank tracks): 1=yes 0=no Currently disabled (0)
- Near IR extinction coefficient for top snow node (400.)
- Optional input of measured temperature data 1=yes 0=no (0)
- Optional print-out of water infiltration estimates 1=yes 0=no (0)
- Note: This option may generate extensive output
- Basic time period in seconds (determined by time-step of MET data) (3600.)
- Estimate standard MET data from user-supplied routine: 1=yes 0=no (0)
- Snow albedo (0.78)
- Irreducible water saturation for snow (0.04)

LINE READ 2: Measurement heights above ground surface for MET data in meters.

- Air temp height, wind speed height, dewpoint or RH height (2.,2.,2.)

LINE READ 3: Specification of characteristics for each layer type. Since layers number in ascending order, BEGIN WITH THE LOWEST LAYER FIRST. For some stock material types, many of the characteristics are automatically supplied from a database within the model as shown in Table 1. Codes for materials currently catalogued in the model are:

1 = snow 2 = clay 3 = sand [90..99] = user supplied material

Enter the following items, one line per layer type: [Note: The model will soon be revised to include all but the first three items within the internal database. User defined properties are read at Line 5].

- Number of nodes (integer)
- Material code (integer)
- Quartz content .001-.002 (0.0-0.45)
- Roughness length or 999. $L \rightarrow 1005$ m for snow
- Bulk transfer coefficient for eddy diffusivity or 999. 1.0
- Turbulent Schmidt number C_D/C_E (0.7 for snow)
- Turbulent Prandtl number C_D/C_H (1.0 for snow)
- Windless convection coefficient for latent heat 0.0 (2.0 for snow)
- Windless convection coefficient for sensible heat 1.0 or (2.0 for snow)
- Fractional humidity relative to saturated state (1.0 for snow, ≤ 1.0 for soil)

Layer.in cont.

LINE READ 4. Convergence related input.

- Number of successive good calculations before increasing-time step (2)
- Minimum allowable time step in seconds (5.0)
- Minimum allowable time step when water flow is present
 Cannot exceed 10 (1.0)
- Maximum allowable time step in seconds
 Cannot exceed 900 (900.0)
- Maximum allowable time step when water flow is present
 Cannot exceed 900 (900.0)
- Maximum allowable change in saturation per time step (.01)
- Maximum allowable temperature estimation error per time step (°C) (.05)

LINE READ 5 (optional) If you desire to supply your own material characteristics for a layer, use a material code from 90-99 (see Line 1 above) and the model will then expect to read the following items. This read will be repeated for each layer whose type is in the user defined range of 90-99. Example values below are for clay.

- Density of dry minerals in material (kg/m^3) (2700.0)
- Bulk density of dry material (kg/m^3) (1000.0)
- Heat capacity of dry material (J/kg-K) (800.0)
- Thermal conductivity for dry bulk material (W/m-K) (0.113)
 [If unavailable, this can be estimated as $(0.135\gamma_d + 64.7)/(2700 - 0.947\gamma_d)$,
 where γ_d is the dry bulk density in kg/m^3 .]
- Coarseness code (1=coarse, 0=fine) (1.0)
- Plasticity index (0.0 - 0.30) (0.20)
- Albedo (at normal incidence) (0.40)
- Emissivity (0.90)

LINE READ 6 (Optional): Required data if solar insolation is to be calculated or the terrain is sloped.

- Degrees latitude
- Degrees longitude
- Elevation angle of slope in degrees, measured from horizontal
- Azimuthal angle in degrees of fall-line,
 measured clockwise from absolute north (180° for a north facing slope)
- Hours difference of local time from Greenwich mean time

LINE READ 7 (Optional): Required data for tank tracks (Note: This option is currently disabled.).

- Time-hack when track is laid: Year (last two digits only), Julian day, 24-hour time, Minute
- Compaction ratio (compacted snow depth/undisturbed snow depth)
- Track width

Layer.in cont.

- Compacted snow depth
- Track orientation (in degrees, relative to due north)

LINE READ 8: Initial nodal/control volume values. One line for each node. START WITH THE BOTTOM NODE AS NODE NUMBER 1 (See Figure 1).

-Temperature (K). Comment: The model uses a freezing curve to determine what portion, f_1 , of the nodal water content is unfrozen. In the case of snow, it has arbitrarily been set to begin melting near 272.83°K according to the relationship.

$$f_1 = 1./[1. + (100T_d)^2]$$

where T_d is the depression temperature, 273.15- T° K. It is preferable to initialize the model at a time when the snow is dry. If it is necessary to start with wet snow cover, the curve in Figure 4 can be used to estimate the temperature for a given water content (volume per volume). Note that for $T = 273.15^\circ$ K the node is totally melted and will automatically combine with its lower neighbor.

-Elemental control volume thickness (m). For the top 2 elements, thicknesses are usually initialized at .01 and .02m. The minimum allowable thickness for any element is .002m and the maximum allowable thicknesses for the top two elements are respectively .0163 and .0333m.

-Bulk water density (frozen plus liquid water) (Kg/m^3). Initial bulk water density for soil should be between the minimum drainable and saturation levels or:

$$0.75J_p\rho_{m,b} \leq \rho_w \leq 917.0(1. - \rho_{m,b}/\rho_{m,i})$$

where $\rho_{m,i}$ and $\rho_{m,b}$ represent the intrinsic and bulk densities of the dry soil, and ρ_w represents the bulk density of water (all units kg/m^3). The plasticity index J_p ranges from 0.00 for coarse sand to 0.30 for clay. For the stock sand and clay layers, the respective water density limits are:

	minimum (kg/m^3)	maximum (kg/m^3)
sand	60	374
clay	150	577

-Grain diameter (m) or 0.0. If 0.0 is used, the model estimates the grain diameter.

2,12,1,990.,0,0,0,0,500.,1,1,3600.,0,0.78,0.04

ln,pinv,ifluxout,bp,isolarcalc,ircalc,islope,itracks,bext,itm,ioutfiltrate,dtbase,imetcalc,albsnow,ssisnow

1.85,3.9,1.85, height[1..3]

9,3,0.40,.001,999,1.0,1.0,1.0,1.0,0.8,

14,1,0,0.005,999,0.7,1.0,2.0,2.0,1.0 (nn(i),ltype(i),qtz(i),znaught(i),cd(i),rce(i),rch(i),ck(i),csk(i),frh(i),i=1,ln)

1,5.0,1.0,900.,900.,.01,.05, ngood,dtmin,dtssmin,dtmax,dtssmax,dssallowed,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 3. Sample Input File Layer.in

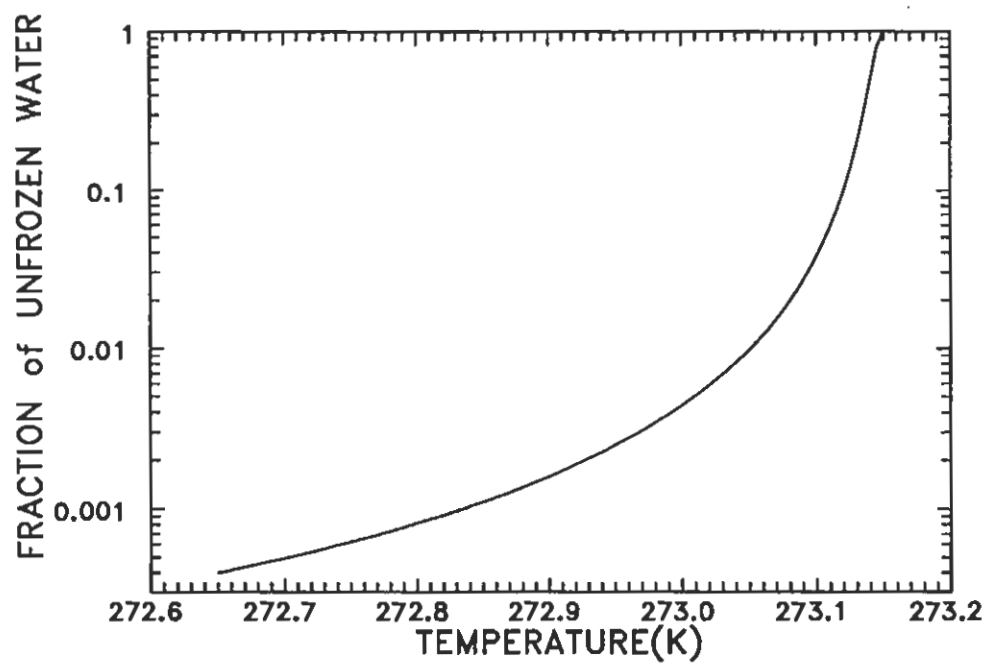


FIGURE 4. *Freezing Curve to Aid Wet Snow Temperature Initialization*

2.3 File MET.IN (generic name)

This file contains meteorological values, usually in the form of hourly averages (time-step indicated in LINE READ 1). (Time hacks should correspond to the midpoint of the averaged period.) Optionally, values may generated by theoretical functions (repeated constants, sine-waves, etc.). A sample MET.IN file is shown in Figure 5.

- Year (Last 2 digits only)
 - Julian day
 - Hour
 - Minute
 - Ambient air temperature ($^{\circ}\text{K}$)
 - Relative humidity (%)
 - Windspeed (m/sec)
 - Incident solar radiation (watts/m^2) or 9999.
 - Reflected solar radiation (watts/m^2) or 9999.
 - Incident longwave radiation (watts/m^2) or 9999. *(snow water equivalent)*
 - Precipitation accumulation in m/hour ~~(snow is actual amount, not water equivalent)~~
 - Precipitation type code: 0=none 1=rain 2=snow or sleet
 - Effective diameter of precipitation particle (m) or 0. *(model will estimate)*
- Optional: Include cloud conditions if solar or longwave radiation need to be calculated, otherwise leave blank
- Fractional cloud coverage (0.0-1.0) and...
 - Type code for low cloud layer: 0=None 4=Sc or ~~St 5=Ci or Cb~~
 - Fractional cloud coverage (0.0-1.0) and...
 - Type code for middle cloud layer: 0=None 3=As, Ac or any other
 - Fractional cloud coverage (0.0-1.0) and...
 - Type code for high cloud layer: 0=None 1=Ci 2=Cs

Y	J	H	M	Air T	Rh	Wn	Spd	Solar↓	Solar↑	IR↓	Precip	Data	Cloud	Coverage
87	36	14	0	267.600	28.523	2.400	348.000	273.000	176.000	0.000	0	0.0000	0.00	0 0.00 0 0.00 0
87	36	15	0	267.400	27.967	2.100	239.000	189.000	173.000	0.000	0	0.0000	0.00	0 0.00 0 0.00 0
87	36	16	0	267.000	29.860	1.200	103.000	76.000	178.000	0.000	0	0.0000	0.00	0 0.00 0 0.00 0
87	36	17	0	264.600	47.724	0.800	-3.000	-1.000	174.000	0.000	0	0.0000	0.00	0 0.00 0 0.00 0
87	36	18	0	261.300	55.970	0.400	-6.000	-5.000	176.000	0.000	0	0.0000	0.00	0 0.00 0 0.00 0
87	36	19	0	259.900	67.673	1.600	-5.000	-3.000	190.000	0.000	0	0.0000	0.00	0 0.00 0 0.00 0
87	36	20	0	259.600	66.462	1.000	-4.000	-3.000	196.000	0.000	0	0.0000	0.00	0 0.00 0 0.00 0
87	36	21	0	257.900	65.478	1.400	-4.000	-3.000	179.000	0.000	0	0.0000	0.00	0 0.00 0 0.00 0
87	36	22	0	257.000	74.320	0.300	-4.000	-3.000	190.000	0.000	0	0.0000	0.00	0 0.00 0 0.00 0

FIGURE 5. Sample Input File Met.in

2.4 Optional file TC.IN (generic name)

Contains measured values of surface and snow/ground interface temperatures from which to calculate a RMS error. Data should be at the basic time-step rate (usually hourly). Each line should contain a time-hack and the two measured temperatures ($^{\circ}\text{K}$) in free format as:

- Year (Last 2 digits only)
- Julian day
- Hour
- Minute
- Snow/ground interface temperature (K)
- Surface temperature (K)

If this option is selected, there must be measured values for each time-hack, or the model will give the error message "MET data and thermocouple data are out of sync.". If data is unavailable, input the dummy value 999.0, and the model will ignore the datapoint.

3 Sample Data Output

Figure 6 presents a partial listing of a *SNTHERM.89* output file. Output is obtained at the meteorological data point times (base time period increments (usually 3600 seconds)). Information available here is the predicted surface nodal temperature and phase as well as the current number of nodes and the air temperature. Optional output includes the measured and predicted temperature at the snow/ground (S/G) interface. Other optional output is the difference between measured and predicted surface temperature with the corresponding running RMS error.

A more detailed output is available at hourly intervals. (see *Layer.in*). The example in Figure 6 is for twelve (12) hour intervals. Temperature, phase, and effective specific heat and conductivity are shown for each node. In addition, nodal total bulk, bulk water, and bulk liquid densities are output. Other information listed is current nodal thickness, grain size, and distance from the S/G interface.

Figures 7 and 8 are a comparison of predicted surface temperatures from *SNTHERM.89* to snow surface thermocouple data from CRREL during February 5-18, 1987 at Hanover, NH. Also plotted is the measured air temperature.

date-time	tm	t(n)	tmsg	t(sg)	tkair	t(n)-tm	rms error	nodes	calc-iter	
87 36 15 0	264.450	262.330	273.150	272.453	267.400	-2.120	1.499	23 F	114	
87 36 16 0	263.750	260.703	273.250	272.490	267.000	-3.047	2.143	23 F	227	
87 36 17 0	259.250	257.557	273.150	272.513	264.600	-1.693	2.040	23 F	294	
87 36 18 0	256.550	254.488	273.250	272.530	261.300	-2.062	2.045	23 F	410	
87 36 19 0	255.250	256.415	273.250	272.546	259.900	1.165	1.926	23 F	533	
87 36 20 0	254.950	255.994	273.050	272.559	259.600	1.044	1.826	23 F	659	
87 36 21 0	253.150	254.482	273.250	272.572	257.900	1.332	1.772	23 F	726	
87 36 22 0	252.150	252.954	273.250	272.584	257.000	0.804	1.692	23 F	848	
87 36 23 0	251.550	252.605	273.150	272.593	256.100	1.055	1.640	23 F	915	

i	P	dz(i) (m)	z(i) (m)	t(i) (K)	bt(i) (kg/m ³)	bw(i) (kg/m ³)	bl(i) (kg/m ³)	ct(i) (J/kg-K)	thk(i) (W/m-K)	d(i) (m)	layer
23 F	0.00933	0.54105	254.729	167.5680	167.5680	0.0000	1973.4	0.13866	0.001438		Snow
22 F	0.01909	0.52679	255.425	167.4013	167.4013	0.0000	1978.9	0.13972	0.000584		Snow
21 F	0.01907	0.50762	256.825	167.4138	167.4138	0.0000	1989.9	0.14246	0.000569		Snow
20 F	0.04981	0.47313	259.061	220.6364	220.6364	0.0000	2007.4	0.20876	0.000615		Snow
19 F	0.04989	0.42326	261.626	240.4578	240.4578	0.0000	2027.4	0.24264	0.000560		Snow
18 F	0.04976	0.37342	263.627	221.0658	221.0658	0.0002	2043.0	0.22406	0.000573		Snow
17 F	0.04981	0.32361	265.285	230.9223	230.9223	0.0004	2055.9	0.24406	0.000573		Snow
16 F	0.04983	0.27377	266.644	240.8756	240.8756	0.0006	2066.5	0.26426	0.000573		Snow
15 F	0.04985	0.22392	267.860	250.8650	250.8650	0.0009	2076.0	0.28504	0.000573		Snow
14 F	0.04974	0.17410	269.074	241.2404	241.2404	0.0015	2085.5	0.27897	0.000573		Snow
13 F	0.04997	0.12423	270.110	350.2754	350.2754	0.0038	2093.6	0.46674	0.000573		Snow
12 F	0.03951	0.07946	271.107	222.8034	222.8034	0.0053	2101.4	0.26879	0.000573		Snow
11 F	0.02000	0.04969	271.745	799.9984	799.9984	0.0405	2106.4	1.85416	0.000573		Snow
10 F	0.03965	0.01984	272.312	251.5380	251.5380	0.0358	2111.0	0.31787	0.000573		Snow
9 M	0.05000	-0.02500	272.967	1950.0000	350.0000	271.2416	1254.0	1.66675	0.000020		Sand
8 M	0.05000	-0.07500	272.998	1950.0000	350.0000	290.7003	1274.9	1.60875	0.000020		Sand
7 M	0.05000	-0.12500	273.000	1800.0000	200.0000	171.8402	1066.4	0.98153	0.000020		Sand
6 M	0.05000	-0.17500	273.000	1800.0000	200.0000	171.8977	1066.5	0.98137	0.000020		Sand
5 M	0.10000	-0.25000	273.002	1800.0000	200.0000	172.5119	1067.2	0.97961	0.000020		Sand
4 M	0.20000	-0.40000	273.101	1800.0000	200.0000	196.3535	1094.9	0.91383	0.000020		Sand
3 T	0.20000	-0.60000	273.348	1800.0000	200.0000	200.0000	1099.2	1.33357	0.000020		Sand
2 T	0.20000	-0.80000	273.777	1800.0000	200.0000	200.0000	1099.2	1.33357	0.000020		Sand
1 T	0.20000	-1.00000	274.500	1800.0000	200.0000	200.0000	1099.2	1.33357	0.000020		Sand

FIGURE 6. Sample Output File *Snow.out*

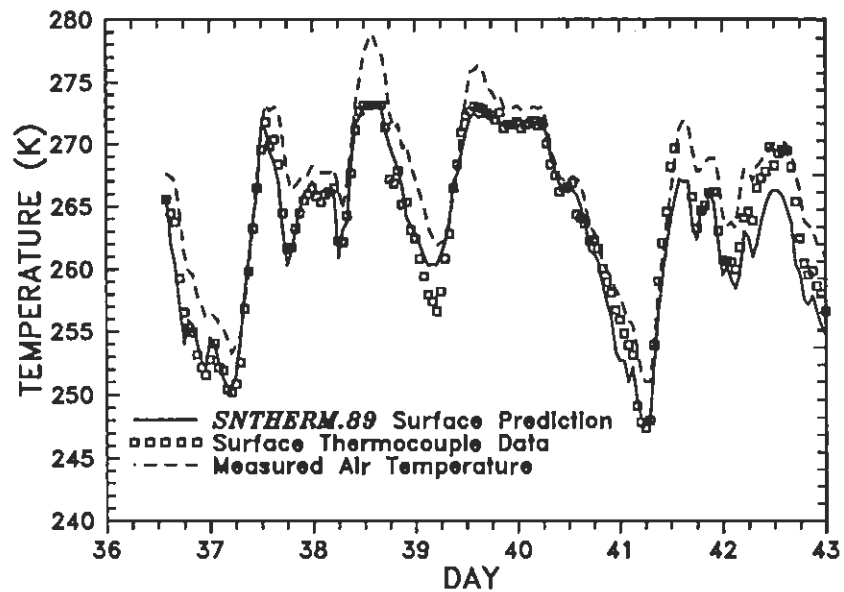


FIGURE 7. Predictions vs. Data. Surface Temperature Comparison.
CRREL Data, Hanover, NH, Feb. 5-11, 1987

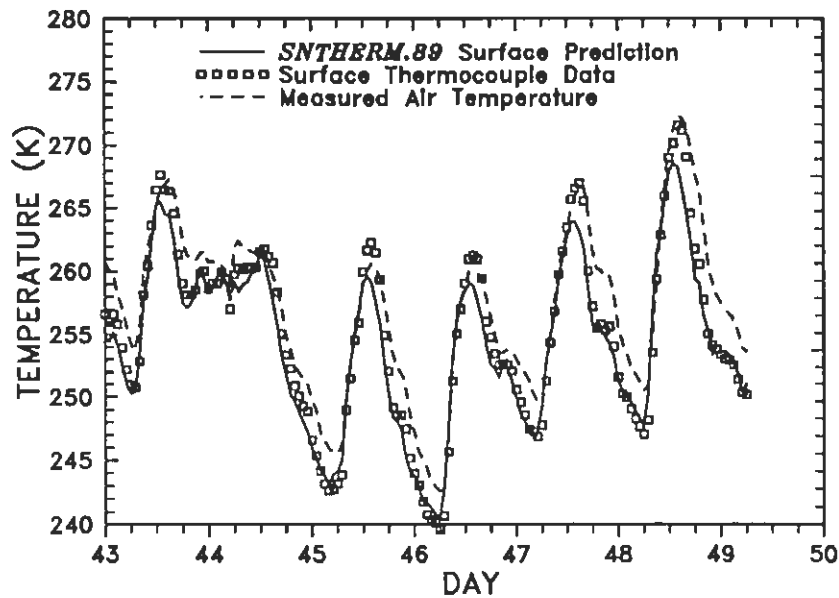


FIGURE 8. Predictions vs. Data. Surface Temperature Comparison.
CRREL Data, Hanover, NH, Feb. 12-18, 1987

4 Model Validation

In addition to the development of a snow temperature model, CRREL has conducted an ongoing program to measure the surface temperature of natural and compacted snow. Comparison of field test measurements with model predictions for both snow types have yielded standard deviations in the range of ± 1.0 to $\pm 1.5^\circ\text{C}$. These experimental results, along with earlier, less complex versions of the snow temperature model are discussed in the papers (Jordan, et.al., 1986) and (Jordan, et.al. 1989). The water flow algorithm gives results within $\pm 2\%$ of Colbeck's test cases for dry and wet snow.

5 References

Jordan, R.H., O'Brien and R.E. Bates (1986) Thermal measurements in snow. Proceedings of SNOW Symposium V, USA Cold Regions Research and Engineering Laboratory, Special Report 86-15.

Jordan, R., H. O'Brien and M.R. Albert (1989) Snow as a Thermal Background: Preliminary Results from the 1987 Field Test, Proceedings of SNOW Symposium VII, USA Cold Regions Research and Engineering Laboratory, Special Report 89

Jordan, R. (in press) A one-dimensional temperature model for a snow cover : Technical Documentation for SNTHERM.89 ; USA Cold Regions Research and Engineering Laboratory, Special Report 657.

Patanker, S.V. (1980) Numerical heat transfer and fluid flow. New York: Hemisphere Publishing.

Shapiro, R. (1982) Solar Radiative flux calculations from standard surface meteorological observations. Systems and Applied Sciences Corporation, Scientific Report No. 1, Riverdale, MD. Under contract to Air Force Geophysics Laboratory, Report AFGL-TR-82-0039.

Shapiro, R. (1987) A simple model for the calculation of the flux of direct and diffuse solar radiation through the atmosphere. ST Systems Corporation, Lexington, MA. Scientific Report No. 35. Under contract to Air Force Geophysics Laboratory, Report AFGL-TR-87-0200.

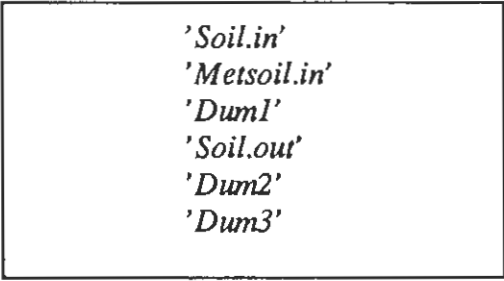
6 APPENDIX

6.1 Example: Bare Soil Case

This section deals with the input for a bare soil case. As noted previously, *SNTHERM.89* does not consider capillary action in soil yet, so the effects of the fluid flow are not accurately represented.

An arbitrary set of meteorological data and soil properties were used. This example was also used to demonstrate the solar estimation and user defined material options. In addition, the IR calculation option was used in this example. Figures 9, 10, and 11 show the contents of the input files *FILENAME*, *Soil.in*, and *Metsoil.in*, respectively, that were used in modeling this example.

Predictions for the bare soil case were obtained for a twenty-four hour period (midnight to midnight). Figure 12 partially lists the output file *Soil.out* while Figure 13 graphically depicts the predicted surface temperature history as well as the ambient air temperature.



```
'Soil.in'  
'Metsoil.in'  
'Dum1'  
'Soil.out'  
'Dum2'  
'Dum3'
```

FIGURE 9. *Input File FILENAME for Example Bare Soil Case*

```

2,13,1,1000,1,1,0,0,1000.,0,0,3600.,0,
      ln,pinv,ifluxout,bp,isolarcalc,ircalc,islope,itracks,bext,itm,ioutfiltrate,dtbase,imetcalc
3*1.75, height(1..3)
12,91,0.40,.001,999.,1.,1.,3.45
10,92,0.40,.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
' user91',2700,1600,710, .184, 1.,.05, 0.4,0.9, soilname, rhod,bd,cds,dkdry,icoarse,djp,alb,em
' user92',2800,1700,710, .184, 1.,.05, 0.4,0.9, soilname, rhod,bd,cds,dkdry,icoarse,djp,alb,em
49,6,72.0,0.,0.,5, dlatt,dlongt,elev,azslope,itimezone
288.20      0.02500      65.0      0.0000
288.20      0.02500      65.0      0.0000
288.20      0.02500      65.0      0.0000
287.95      0.02500      65.0      0.0000
287.70      0.02500      65.0      0.0000
287.45      0.02500      65.0      0.0000
287.20      0.02500      65.0      0.0000
286.95      0.02500      65.0      0.0000
286.70      0.02500      65.0      0.0000
286.45      0.02500      65.0      0.0000
286.20      0.02500      65.0      0.0000
285.95      0.02500      65.0      0.0000
285.70      0.02500      65.0      0.0000
285.45      0.02500      65.0      0.0000
285.20      0.02500      65.0      0.0000
284.95      0.02500      65.0      0.0000
284.70      0.02500      65.0      0.0000
284.45      0.02500      65.0      0.0000
284.20      0.02500      65.0      0.0000
283.95      0.02500      65.0      0.0000
283.70      0.01000      65.0      0.0000
283.45      0.01000      65.0      0.0000

```

FIGURE 10. *Input File Soil.in for Bare Soil Case*

```

90 249 0 0 284.100 50.000 0.200 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 1 0 283.100 50.000 0.200 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 2 0 283.100 50.000 0.200 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 3 0 281.400 50.000 0.200 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 4 0 280.900 50.000 0.200 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 5 0 280.300 50.000 0.200 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 6 0 280.000 50.000 0.200 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 7 0 283.900 50.000 0.300 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 8 0 289.300 50.000 1.300 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 9 0 292.100 50.000 0.800 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 10 0 292.700 50.000 1.100 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 11 0 294.100 50.000 0.600 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 12 0 293.500 50.000 0.500 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 13 0 291.800 50.000 1.200 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 14 0 290.900 50.000 1.200 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 15 0 289.500 50.000 0.300 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 16 0 289.500 50.000 0.700 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 17 0 288.400 50.000 0.700 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 18 0 288.100 50.000 0.300 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 19 0 287.300 50.000 0.400 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 20 0 284.900 50.000 0.200 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 21 0 283.800 50.000 0.200 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 22 0 282.700 50.000 0.200 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 23 0 282.100 50.000 0.200 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0
90 249 24 0 281.200 50.000 0.200 0.000 0.000 0.000 0.000 0 0.0000 0.00 0 0.00 0 0.00 0

```

FIGURE 11. *Input File Metsoil.in for Bare Soil Case*

date-time			t(n)	t(sg)	tkair	nodes calc-iter	
90249	1	0	279.714	285.818	283.100	22 T	41
90249	2	0	278.595	285.764	283.100	22 T	90
90249	3	0	277.567	285.621	281.400	22 T	124
90249	4	0	276.753	285.409	280.900	22 T	155
90249	5	0	276.083	285.154	280.300	22 T	186
90249	6	0	277.137	284.872	280.000	22 T	218
90249	7	0	281.410	284.588	283.900	22 T	280
90249	8	0	287.442	284.369	289.300	22 T	330
90249	9	0	292.183	284.321	292.100	22 T	360
90249	10	0	293.809	284.509	292.700	22 T	415
90249	11	0	295.772	284.902	294.100	22 T	466
90249	12	0	295.915	285.413	293.500	22 T	521

i	P	dz(i)	z(i)	t(i)	bt(i)	bw(i)	bl(i)	ct(i)	thk(i)	d(i)	layer
		(m)	(m)	(K)	(kg/m ³)	(kg/m ³)	(kg/m ³)	(J/kg-K)	(W/m-K)	(m)	
22	T	0.01000	-0.00500	294.424	1763.7051	63.7051	63.7051	836.5	0.84286	0.000020	user92
21	T	0.01000	-0.01500	294.014	1765.0000	65.0000	65.0000	839.0	0.85168	0.000020	user92
20	T	0.02500	-0.03250	293.184	1765.0000	65.0000	65.0000	839.0	0.85168	0.000020	user92
19	T	0.02500	-0.05750	291.767	1765.0000	65.0000	65.0000	839.0	0.85168	0.000020	user92
18	T	0.02500	-0.08250	290.332	1765.0000	65.0000	65.0000	839.0	0.85168	0.000020	user92
17	T	0.02500	-0.10750	289.026	1765.0000	65.0000	65.0000	839.0	0.85168	0.000020	user92
16	T	0.02500	-0.13250	287.929	1765.0000	65.0000	65.0000	839.0	0.85168	0.000020	user92
15	T	0.02500	-0.15750	287.076	1765.0000	65.0000	65.0000	839.0	0.85168	0.000020	user92
14	T	0.02500	-0.18250	286.467	1765.0000	65.0000	65.0000	839.0	0.85168	0.000020	user92
13	T	0.02500	-0.20750	286.079	1765.0000	65.0000	65.0000	839.0	0.85168	0.000020	user92
12	T	0.02500	-0.23250	285.879	1665.0000	65.0000	65.0000	846.7	0.83237	0.000020	user91
11	T	0.02500	-0.25750	285.827	1665.0000	65.0000	65.0000	846.7	0.83237	0.000020	user91
10	T	0.02500	-0.28250	285.891	1665.0000	65.0000	65.0000	846.7	0.83237	0.000020	user91
9	T	0.02500	-0.30750	286.041	1665.0000	65.0000	65.0000	846.7	0.83237	0.000020	user91
8	T	0.02500	-0.33250	286.249	1665.0000	65.0000	65.0000	846.7	0.83237	0.000020	user91
7	T	0.02500	-0.35750	286.496	1665.0000	65.0000	65.0000	846.7	0.83237	0.000020	user91
6	T	0.02500	-0.38250	286.766	1665.0000	65.0000	65.0000	846.7	0.83237	0.000020	user91
5	T	0.02500	-0.40750	287.049	1665.0000	65.0000	65.0000	846.7	0.83237	0.000020	user91
4	T	0.02500	-0.43250	287.336	1665.0000	65.0000	65.0000	846.7	0.83237	0.000020	user91
3	T	0.02500	-0.45750	287.624	1665.0000	65.0000	65.0000	846.7	0.83237	0.000020	user91
2	T	0.02500	-0.48250	287.912	1665.0000	65.0000	65.0000	846.7	0.83237	0.000020	user91
1	T	0.02500	-0.50750	288.200	1665.0000	65.0000	65.0000	846.7	0.83237	0.000020	user91

FIGURE 12. *Output File Soil.out for Bare Soil Case*

date-time	t(n)	t(sg)	tkair	nodes	calc-iter
90249 13 0	294.424	285.979	291.800	22 T	594
90249 14 0	293.231	286.529	290.900	22 T	633
90249 15 0	291.918	287.004	289.500	22 T	702
90249 16 0	290.375	287.382	289.500	22 T	771
90249 17 0	288.180	287.659	288.400	22 T	842
90249 18 0	285.885	287.831	288.100	22 T	880
90249 19 0	283.531	287.893	287.300	22 T	919
90249 20 0	281.739	287.839	284.900	22 T	954
90249 21 0	280.407	287.677	283.800	22 T	987
90249 22 0	279.316	287.432	282.700	22 T	1019
90249 23 0	278.438	287.133	282.100	22 T	1051
90249 24 0	277.629	286.799	281.200	22 T	1083

FIGURE 12a. *Output File Soilout.in for Bare Soil Case(cont)*

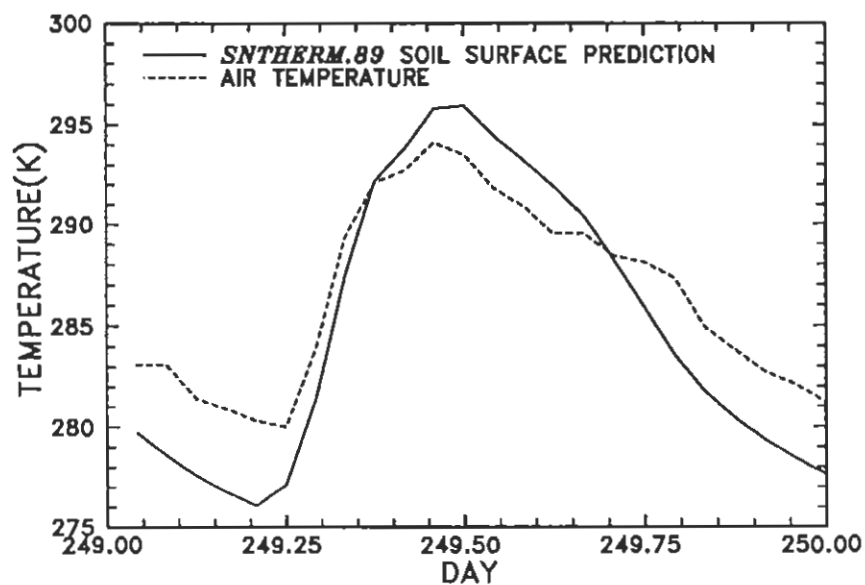


FIGURE 13. *Predicted Soil Surface Temperature History and Air Temperature from Meteorological Data for Example Bare Soil Case*