Arctic Region Evaluation of the Hydro-Thermodynamic Soil Vegetation Scheme (HTSVS)

Pamela Spier
Department of Atmospheric Science, Cornell University, Ithaca, NY

Nicole Mölders
Geophysical Institute, University of Alaska, Fairbanks, AK

Abstract

This paper presents an evaluation of the Hydro-Thermodynamic Soil Vegetation Scheme (HTSVS). The model was analyzed with respect to its accuracy in predicting soil temperatures and the temporal change in soil volumetric water content. The methodology involves comparing the simulated data with the observed data to check for accuracy in quantities as well as seasonal and diurnal temporal trends. According to the tests presented in this study HTSVS performs well when the temperatures are moderated either by seasonal tendency or by temperature regulating precipitation. HTSVS tends to underestimate soil temperatures after the onset of a snow pack. HTSVS tends to slightly overestimate soil temperatures during the warm season. It also has a tendency to overestimate the diurnal maximum values.

1. Introduction and Motivation

The Hydro-Thermodynamic Soil Vegetation Scheme (HTSVS, Kramm et al. 1996, Mölders et al. 2003a) is a land-surface model designed for use in climate models to numerically examine the long-term changes of the water budget elements (water supply to the atmosphere, ground water recharge and change in storage.) HTSVS, as described by Mölders et al. (2003a), constructs a feedback mechanism between the land and atmospheric part of the water cycle in the climate model. In this study the stand-alone version of HTSVS is driven by meteorological data routinely observed at Blueberry Hill (Alaska).

Short term evaluation of HTSVS is based on the observation of mean values of wind speed, temperature, and humidity as well as the eddy flux densities of momentum, sensible heat, and water vapor performed during the Great Plains Turbulence Project, GREIV I-1974 (GREnzschicht Instrumentelle Vermessung phase I, i.e. first phase of probing the atmospheric boundary layer, e.g., Kramm 1995), SANA (Sanierung der Atmosphäre über den neuen Bundesländer, i.e. recovery of the atmosphere over the new federal countries, e.g., Spindler et al. 1996), CASES97 (Cooperative Atmosphere Surface Exchange Study 1997, e.g., LeMone et al. 2000), which showed that HTSVS is able to simulate the diurnal course of all these first and second moments well (Kramm 1995, Mölders 2000). Mölders et al. (2003a,b) evaluated the influence of soil frost, snow, and root water uptake of the long-term water budget quantities and soil temperature. Thus, on the short-term scale HTSVS performs well for mid-latitude conditions. Mölders et al.

(2003) showed that HTSVS is also able to capture the variability on the long-term and to guarantee a sufficient accuracy for the long-term accumulated sums of the water supply to the atmosphere and recharge. This ability is one pre-requisite for being a suitable tool for climate modeling.

Today numerical weather prediction (NWP) models are to be applied world-wide, which requires that their land-surface scheme be able to accurately simulate also extreme surface conditions as they occur, for instance, in sub-arctic and arctic regions. Thus, the aim of our study is to evaluate HTSVS as it is usually applied in mesoscale NWP models. In these models, no vertical resolution of the soil type distributions is considered due to the lack of 3D distributions of soil data at a resolution required by the NWP models. Therefore, we assumed no vertical resolution of the soils and no site specific soil parameters. Instead we used the values of soil porosity, pore-size distribution indexes, water potential at saturation, hydraulic conductivity, and soil volumetric heat capacity, as they are typically assigned for the 16 USDA soil types. Note that Mölders et al. (2003) used site specific parameters and a vertically varying soil type profile.

The present study evaluates the simulated accuracy of soil temperatures and change in soil volumetric water content by means of routine data from the ATLAS network. Routine data of less accuracy are compared to those gained in special field campaigns. Some data required in HTSVS were not recorded or were flawed. Therefore, an evaluation using routine data will never provide as good results as those that can be achieved when all needed data were measure under the special conditions of field campaigns (e.g., Spindler et al. 1996, Slater et al. 1998, Mölders et al. 2003). For the reasons discussed above, larger discrepancies between the simulated and observed values may occur than those typical for evaluations of calibrated site specific models or evaluations using data from special field campaigns designed to evaluate a certain model.

2. Data

2.1 *Available Data*

Meteorological data, from Council, Alaska, was used to force the HTSVS simulation. The data taken from the Council site C2 was prepared for the Arctic Transitions in the Land-Atmosphere System (ATLAS) project (Hinzman et. al 2002)

2.1.1 Location and Vegetation

The Council site, C2 (about 50 miles northeast of Nome), is located at a latitude of 64°53.47’ N and a longitude of 163° 38.61’W. The C2 site is 140 meters above sea level on the south slope of Blueberry Hill, about half a mile east of Council. The vegetation is tussock tundra and moss. For modeling purposes, it is assumed that the moss layer does not extend into the deeper soil layers. The soil type used in the model is silty clay loam as it would be in mesoscale NWP models. The USGS vegetation type used in the model is herbaceous tundra.

2.1.2 Data Used

Three parameters of data were available: meteorological data, soil data, and radiation data. Data is available from 1999 – 2002, and was last updated March, 2003. The meteorological data provides hourly values of the air temperature (°C) (1m, 3m and10m), relative humidity (%) (1m, 3m and 10m), wind speed (m/s) (1m and 10m), wind direction at 10 m (degrees from true North), standard deviation of wind direction, precipitation, liquid or water equivalent of solid precipitation (mm), and cumulative liquid precipitation (mm). In this study, only the one meter values are used to force HTSVS. The soil data reports the soil temperature (°C) (0cm, 5cm, 10cm, 15cm, 25cm, 35cm, 60cm, 85cm and 110cm.) and soil moisture (%) (5cm, 10cm, 15cm, 20cm, 30cm and 40cm) and they are available every three hours. Note that in 2002 the observed soil temperature data (°C) (0cm, 5cm, 10cm, 15cm, 25cm and 40cm) and the observed soil moisture data (%) (5cm, 10cm, 15cm and 20cm) contain fewer soil depths. The radiation data provides hourly reports of the net radiation (W/m^2), outgoing and incoming short wave radiation (W/m^2), and outgoing and incoming long wave radiation (W/m^2). For the purpose of this study only the incoming short wave and long wave radiation data are used.

2.2 Data Treatment

The data to force HTSVS is a combination of meteorological data and radiation data.

2.2.1 Pressure Calculation

To calculate the pressure, p, use the equation,

$$p = 1013.25 \times e^{\frac{(-9.81\times h)}{(287.04\times(2\times(273.15+T)-h\times .0098)\times 5)}} \tag{1}$$

with the variable T representing the air temperature at the surface and h is terrain height (140m).

2.2.2 Specific Humidity Calculation

Specific humidity, q_v, is given by,

$$q_s = \frac{0.622\times(6.1078\times e^{(17.1\times T/(235.+T))})}{p - 0.378\times(6.1078\times e^{(17.1\times T/(235.+T))})}\ , \tag{2}$$

$$q_v = RH \times q_s \times .01\ , \tag{3}$$

where T, p, and RH are surface air temperature, pressure and relative humidity, respectively.

2.2.3 Precipitation Type

It is necessary to determine whether the precipitation is rain or snow. It is assumed that if the temperature is less than 2 °C then the precipitation is in the form of snow. If this is the case then the original precipitation amount is multiplied by 10 and the resulting value is centimeters of snow, i.e. a snow density of 100 kg/m^3 is assumed for freshly fallen snow.

2.3 Initialization

Prior to running the HTSVS model it is crucial to provide accurate initial values (Tables 1 – 4). The model simulates its data at depths of 0cm, 5cm, 12.6cm, 31.6cm, 79.5cm and 200cm. Therefore, it is essential that the initial values (Tables 1 – 4) be interpolated from the Council C2 data. The foliage temperature is calculated as being the average of the ground surface temperature and the air temperature.

2.4 HTSVS Output

The HTSVS model simulates among other quantities snow height (m), snow or soil albedo, emissivity of the snow or combined system vegetation soil, foliage temperature (K), surface temperature (K), soil temperature (K) at 5cm, 12.6cm, 31.6cm, 79.5cm, and 200cm, snow temperature (K) at three levels on an equidistant grid that depends on snow height, snow density at three levels, snow water content at three levels, water fluxes within the snow at three levels, volumetric liquid water content at 5cm, 12.6cm, 31.6cm, 79.5cm, and 200cm, and volumetric ice content at 5cm, 12.6cm, 31.6cm, 79.5cm, and 200cm. The data evaluated for this study includes the surface temperature, the soil temperatures and the volumetric liquid water content values.

2.4 Interpolation to Layers of Observation

If soil data is available every three hours we perform the evaluation on a three hour basis rather than every hour. The simulated data are interpolated to match the depths of the original soil data. Subsequently, the original soil data should be modified so that soil temperatures are in Kelvin rather than degrees Celsius.

3. Method

3.1 Full Data Set Assessment

The first method compares each simulated soil temperature data value with each observed soil temperature data value. A graph is made for each soil depth to compare the simulated and observed values. By using this method seasonal trends can be analyzed and diurnal maximum and minimum values can be identified. In addition, this method provides the means to observe how much the simulated soil temperature values differ from the observed soil temperature values.

3.2 Diurnal Temperature Patterns

The second method focuses on how well the simulated data follows the diurnal temperature pattern at each soil depth. As a result of incoming radiation, soil temperatures should vary throughout the day. The average temperature was calculated for each hour of observation in order to create data values to compare diurnal temperature patterns. The simulated data values were graphed against the observed data values to see how well the simulated values replicate the diurnal course and how much the hourly averages differ.

3.3 Daily Average Comparison

The third method involves calculating the daily average soil temperature at each soil depth. Graphing the simulated averages against the observed averages allows for the projection of seasonal trends. Furthermore, this comparison also shows whether the simulation picked up on daily and weekly temperature fluctuations.

3.4 Soil Volumetric Water Content Difference

A fourth approach has to be used to evaluate the soil volumetric water content (moisture) values. In organic soils, probes adjacent to each other can give different fractional (percent) soil moisture values, because they do not always have the same particle to probe contact. Therefore, a direct comparison of soil moisture measured in organic soil layers is not suitable for evaluation of soil models. However, the probes have been found to have the same rate of change values (pers. com. Hinzman 2003). Therefore, we compare the simulated rate of change in relative soil volumetric water content to the observed rate of change in soil moisture.

As for soil temperature, soil moisture data is available ever three hours. The simulated soil moisture values are interpolated to the same depths as the observed soil moisture values. The simulated data is converted from soil volumetric water content, η, to relative soil water content, RSWC, by multiplying each value by the porosity that relates to the soil type. The soil type used in our study was silty clay loam which has a porosity, η_s, of 0.464 m^3/m^3. The simplest approach to this conversion,

$$\mathrm{RSWC} = \frac{\eta_{\mathrm{sim}}}{\eta_{\mathrm{s}}} \times 100\,, \tag{4}$$

assembles the simulated data in a similar format as the observed data. The best way to compare the simulated and observed soil moisture data values is to calculate the rate of change between each consecutive RSWC value.

$$\frac{\frac{\eta_{obs}}{\eta_{\mathrm{s}}}(\mathrm{T}_{\mathrm{n+3}}) - \frac{\eta_{obs}}{\eta_{\mathrm{s}}}(\mathrm{T}_{\mathrm{n}})}{\Delta t} \cong \frac{\partial(\frac{\eta_{obs}}{\eta_{\mathrm{s}}})}{\partial t} \tag{5}$$

$$\frac{\frac{\eta_{sim}}{\eta_{\mathrm{s}}}(\mathrm{T}_{\mathrm{n+3}}) - \frac{\eta_{sim}}{\eta_{\mathrm{s}}}(\mathrm{T}_{\mathrm{n}})}{\Delta t} \cong \frac{\partial(\frac{\eta_{sim}}{\eta_{\mathrm{s}}})}{\partial t} \tag{6}$$

$$\frac{\partial(\frac{\eta_{obs}}{\eta_{s}})}{\partial t} \, vs. \frac{\partial(\frac{\eta_{sim}}{\eta_{s}})}{\partial t} \tag{7}$$

Here, n is the time step counter, and t is time; $\eta_{\mathrm{obs\ and}}\,\eta_{\mathrm{sim}}$ are the observed and simulated soil volumetric water content, respectively.

3.5 Root Mean Square

The fifth technique used to evaluate the model involved statistically checking the root mean square difference at each soil depth. This technique can be applied to the four previous methods of comparison. This method provides an average value of the difference between the simulated values and the observed values. The formula,

$$RMS = \sqrt{\frac{(T_{obs} - T_{sim})^2}{n}}\,, \tag{8}$$

calculates the root mean square difference. The observed data value, the simulated data value, and the number of observations are denoted as T_{obs}, T_{sim}, and n, respectively.

4. Results

4.1 General Findings

The simulated soil temperatures are almost always lower than the observed soil temperatures after the first snowfall. The exact method in which the surface temperature is observed (i.e. whether it is snow or surface temperature) is unknown at this time. Therefore, this discrepancy could possibly be resulting from measuring the snow surface temperature as opposed to the soil surface temperature. The HTSVS does a better job at predicting soil temperature when the temperatures are modest, rather than extreme. Therefore, the model seemingly works better when it precipitates during the summer months because the rain moderates the temperature. This finding agrees with Mölders et al. (2003a, b).

4.2 Full Data Assessment

It is illustrated in figure 1 that HTSVS well captures both seasonal and diurnal temperature trends in the shallowest soil layers.

4.2.1 0*7/28/99 – 09/30/99*

The simulated soil temperatures in the soil depths between 0cm and 35cm have a tendency to be between 2 to 6 K higher than the observed soil temperatures when precipitation is in liquid form. After the first snowfall the model underestimates soil temperatures by 2 to 5 K. At these depths the simulation also has greater diurnal extremes than observed. At the deeper depths, 60cm to 100cm, the model broadly agree with the general trends of the observed data. However, the simulated soil temperatures differ from the observed soil temperatures by no more than 3 K.

4.2.2 05/13/00 – 09/24/00

Similarly to 1999, the simulated soil temperatures in soil layers between 0cm to 35cm are highly overestimated in the warm and dry summer months. At the beginning of August, as observed temperatures begin to moderate, HTSVS well simulates the soil temperatures. Again, the model begins to underestimate the soil temperatures after the first snowfall in the shallowest soil depths. In the deeper soil layers, the simulated data fails to replicate the patterns and temperatures of the observed data, being off by at most 8 K.

4.2.3 08/17/01 – 10/07/01

For the forced meteorological data from 2001, the HTSVS generates simulated soil temperatures that follow the seasonal temporal trends extremely well. At the surface the simulated data slightly overestimates the soil temperature by at most 4 K. This may result from the assumption used in the model that albedo and emissivity of the vegetation are constant. In nature, these parameters change as the vegetation change with the seasons. At the 60cm soil depth the model simulates soil temperatures that are 4 to 6 K higher than those observed. The simulation also creates a diurnal temperature pattern that has extreme high and low temperatures. At the deepest soil level, 110cm, the simulated data does not compare well to the observed data

4.2.4 08/05/02 – 01/01/03

As seen in the previous simulations, the model overestimates the diurnal soil temperature boundaries. Around the equinox the simulated temperatures at all soil levels, 0cm through 40cm, begin to match up with the observed data extremely well. When the snow pack builds up in November, the simulated soil temperatures at the surface are about 10 K above the observed soil temperatures. Again, it is unclear whether the reported value is soil surface or snow surface temperature. The simulated data at the other soil depths differ from the observed data on average by 3 K.

4.3 Diurnal Temporal Patterns

It is illustrated in figure 2 that the HTSVS simulates diurnal temperature trends well. The largest diurnal course can be seen at the surface. In deeper soil depths, the simulation picks up on the decrease in overall diurnal variation. The simulation stops creating a diurnal pattern at a depth of 60cm, which agrees with the observations.

4.3.1 0*7/28/99 – 09/30/99*

Simulated diurnal temporal patterns match observed patterns almost perfectly. The simulation is closest to the observed data between 900 and 1200 hours. At the later hours the simulated temperatures are between 0.5 and 3 K greater than the observed temperatures.

4.3.2 05/13/00 – 09/24/00

Much like the previous year, when graphed the simulated data matches up well with the observed data. At the surface the simulated diurnal temperatures are 2 to 6 K greater than the observed temperatures. Deeper into the soil the simulation is off by no more than 2.5 K.

4.3.3 08/17/01 – 10/07/01

At the shallowest soil depths the HTSVS simulates the diurnal temporal trends very accurately. Between 15cm and 35cm the simulation creates a diurnal curve that is more extreme than the observed curve. Overall, the simulated temperatures are no more than 3 K greater or less than the observed temperatures.

4.3.4 08/05/02 – 01/01/03

At the surface the simulated diurnal temporal curve has a shape that is slightly different than the observed curve. The model tends to overestimate temperature around noon by 2 – 3 K, as well. Below the surface the simulated temperatures are about 1 K above or below the observed temperatures. At 25cm, the simulation does not pick up on the diurnal patterns in the observed data.

4.4 Daily Average Comparison

The simulated daily averages of soil temperatures follow the observed daily averages (Fig. 3) except for mid-November, when the snow pack begins to form. Furthermore, the simulated temperatures match the observed temperatures, by usually differing by less than 4 K.

4.4.1 0*7/28/99 – 09/30/99*

The simulated data follows the observed data trends very well. Early August, it precipitates a lot, and the model performs better than in the early summer months. Later in the season the simulation underestimates the daily average temperatures which could be related to the first few snowfalls of the year.

4.4.2 05/13/00 – 09/24/00

This years HTSVS simulation of the daily average temperature is not as precise as the previous years. The simulated data follows the general seasonal temporal trend. However, during the warmest and driest part of the summer the simulation fails to accurately predict the daily average temperature. During May and after August the model performs well in simulating the daily average temperatures.

4.4.3 08/17/01 – 10/07/01

During this time period the simulated data matched up well to the observed data. The simulation picked up on seasonal temporal trends as well as accurately predicting the daily average temperature within about 3 K.

4.4.4 08/05/02 – 01/01/03

Until the snow pack forms in November, the simulated data is very similar to the observed data. Until this time, the simulated daily average temperatures differ from the observed daily average temperatures by about 2 K. After the snow pack forms the simulation is on average 3 to 6 K off from the observed data. Here differences in simulated snow height and its natural equivalent can be the reason.

4.5 Soil Volumetric Water Content Difference

The simulated change in volumetric water content data follow the trends presented in the observed data (Figure 4.) Furthermore, the comparison values of the simulated and observed data are off by no more than 0.04 s^{-1}.

4.5.1 07/28/99 – 09/30/99

At a soil depth of 5cm the simulated values are 0.02 s^{-1} greater than the observed values. Deeper than 5cm, the simulated values are less than 0.01 s^{-1} off from the observed values.

4.5.2 05/13/00 – 09/24/00

For the data from 2000, the simulated values are less than 0.02 s^{-1} off from the observed values. The simulation recognizes the maxima and minima that are present in the observed data.

4.5.3 08/17/01 – 10/07/01

At the shallow soil depths the simulated values are about 0.04 s^{-1} greater than the observed values. At deeper soil depths the simulated and observed values differ by no more than 0.015 s^{-1}. At the end of the episode, when the snow pack is beginning to form, there are fluctuations that probably have to do with the freezing and thawing the soil.

4.5.4 08/05/02 – 01/01/03

Simulation captures observed trends and is consistently 0.02 - 0.04 s^{-1} greater than observed values.

4.6 Root Mean Square

By analyzing the resulting values it can be seen that almost all of the quantities are less than 3 K, thus proving that the HTSVS creates accurate simulations (Tables 5 – 8).

5. Conclusion

The hydro-thermodynamic soil vegetation scheme (HTSVS) is able to simulate soil temperature and temporal changes in relative soil volumetric water content, with accurate simulated values being those within 3 K and 0.04 s^{-1} of the observed values. The model performs the best when the temperature is moderated. Rain during the warm summer months is an important temperature moderator, thus making the model function better during periods of notable precipitation. The simulation correctly picks up on both diurnal and seasonal temperature trends. Furthermore, the HTSVS is able to numerically calculate the movement of water throughout the soil layers.

The results show that there are some deficits in the models performance. During extreme temperature periods the model either overestimates or underestimates the soil temperature. The simulation also tends to exaggerate the diurnal temperature patterns in deeper soil layers. After the first snowfall the model fails to accurately predict the soil temperatures at the shallowest layers. Some of this inconsistent data can be due to measurement uncertainties. The model simulates the surface soil temperature, whereas the observed surface soil temperature may actually be the snow surface temperature.

The organic soil type can also be blamed for the limitations of the model that assumes mineral soil as it is in NWP. Soil moisture measurements in the organic layer are not very reliable (Hinzman 2003, pers. com.). Tussock tundra tends to pool water in the spring and summer months and freeze up when the temperature drops, preventing water flow into deeper soil layers. Therefore, this is a plausible reason that the model has difficulties in predicting soil temperature and volumetric water content in the deepest soil layers.

There are various ways in which the hydro-thermodynamic soil vegetation scheme can be improved. Initialization can be improved by use of data assimilation. It has to be examined whether changing the mineral soil type to organic soil will improve the results. Additionally, when the model runs it assumes constant vegetation characteristics (vegetation height, albedo, emissivity, minimal stomatal resistance, root length, etc.) However, in nature the vegetation characteristics changes seasonally. To fix this problem the HTSVS could incorporate a mechanism that would have the vegetation parameters change with respect to the time of year. Furthermore, NWP models should use vertically varying soil types as soon as such data sets are available at the resolution required by NWP, as deep soil cannot be simulated well when assuming that the uppermost mineral soil type is representative for the entire soil column. Taking into account the coarse resolution of mesoscale NWP models, the coarse vertical resolution that they allow for modeling soil processes, and the lack of suitable parameters needed, it seems that discrepancies in the order of magnitude found in our study are a general uncertainty as the result of NWP at the biosphere-soil atmosphere interface.

Acknowledgements

We would like to thank the National Science Foundation for fiscally supporting the REU program. Further appreciated funding came from BMBF under contract 01LD0036.

References

Bhattacharyya, G., Johnson, R., 1977. Statistical Concepts and Methods. John Wiley and Sons, Inc. pp. 27-42

Hinzman, L.D., 2003, Climate data for the Arctic Transitions in the Land-Atmosphere System (ATLAS) project. URL:http://www.uaf.edu/water/projects/atlas. Fairbanks, Alaska, variously paged. June 4.

Kramm, G., 1995. *Zum Austausch von Ozon und reaktiven Stickstoffverbindungen zwischen Atmosphäre und Biosphäre*. Maraun-Verlag, Frankfurt, p. 268.

Kramm, G., Beier, N., Foken, T., Müller, H., Schröder, P., and Seiler, W., 1996. A SVAT scheme for NO, NO_2, and O_3 - model description. *Meteorol. Atmos. Phys*., **61**, 89-106.

Mölders, N., 2000. HTSVS - A new land-surface scheme for MM5. In*: The tenth PSU/NCAR Mesoscale model users' workshop,* 33-35 (available from NCAR, P.O. Box 3000, Boulder, CO 80307, USA or http://www.mmm.ucar.edu/mm5/mm5-home.html).

Mölders, N., Haferkorn, U., Döring, J., and Kramm, G., 2003a. Long-term numerical investigations on the water budget quantities predicted by the hydro-thermodynamic soil vegetation scheme (HTSVS) - Part I: Description of the model and impact of long-wave radiation, roots, snow, and soil-frost. *Meteorol. Atmos. Phys*. DOI 10.1007/s00703-002-0578-2

Mölders, Haferkorn, U., Döring, J., and Kramm, G., 2003b. Long-term numerical investigations on the water budget quantities predicted by the hydro-thermodynamic soil vegetation scheme (HTSVS) - Part II: Evaluation, sensitivity, and uncertainty. *Meteorol. Atmos. Phys*. DOI 10.1007/s00703-002-0596-0

Slater, A.G., Pitman, A.J., and Desborough, C.E., 1998. Simulation of freez-thaw cycles in a general circulation model land surface scheme. *J. Geophys. Res*. **103D**, 11303-11312.

Spindler, G., Mölders, N., Hansz, J., Beier, N., and Kramm, G., 1996. Determining the dry deposition of SO_2, O_3, NO, and NO_2 at the SANA core station Melpitz. *Meteorol. Zeitschr.* **5**, 205-220.

Table 1. Initial values for 1999 data.

Condition	Value
Hours	1546
Month	8
Time Since Last Snow Event	0.00 s
Snow Height	0.00 m
Mean Soil Temperature At 2m Depth	265.00 K
Ground Surface Temperature	287.66 K
Foliage Surface Temperature	288.10 K
Air Temperature At Reference Height	288.54 K
Soil Temperature at 5cm	280.84 K
Soil Temperature at 12.6cm	279.34 K
Soil Temperature at 31.6cm	274.90 K
Soil Temperature at 79.5cm	273.02 K
Soil Temperature at 200cm	272.75 K
Soil Volumetric Water Content at 5cm	14.25 m^3m^{-3}
Soil Volumetric Water Content at 12.6cm	71.40 m^3m^{-3}
Soil Volumetric Water Content at 31.6cm	61.12 m^3m^{-3}
Soil Volumetric Water Content at 79.5cm	65.00 m^3m^{-3}
Soil Volumetric Water Content at 200cm	82.00 m^3m^{-3}

Table 2. Initial values for the 2000 data.

Condition	Value
Hours	3217
Month	6
Time Since Last Snow Event	0.00 s
Snow Height	0.00 m
Mean Soil Temperature At 2m Depth	273.00 K
Ground Surface Temperature	272.98 K
Foliage Surface Temperature	274.40 K
Air Temperature At Reference Height	275.82 K
Soil Temperature at 5cm	272.89 K
Soil Temperature at 12.6cm	272.89 K
Soil Temperature at 31.6cm	272.47 K
Soil Temperature at 79.5cm	271.64 K
Soil Temperature at 200cm	270.92 K
Soil Volumetric Water Content at 5cm	18.85 m^3m^{-3}
Soil Volumetric Water Content at 12.6cm	15.40 m^3m^{-3}
Soil Volumetric Water Content at 31.6cm	15.00 m^3m^{-3}
Soil Volumetric Water Content at 79.5cm	35.00 m^3m^{-3}
Soil Volumetric Water Content at 200cm	60.00 m^3m^{-3}

Table 3. Initial values for the 2001 data.

Condition	Value
Hours	1224
Month	9
Time Since Last Snow Event	0.00 s
Snow Height	0.00 m
Mean Soil Temperature At 2m Depth	262.00 K
Ground Surface Temperature	282.24 K
Foliage Surface Temperature	282.40 K
Air Temperature At Reference Height	282.55 K
Soil Temperature at 5cm	278.75 K
Soil Temperature at 12.6cm	276.80 K
Soil Temperature at 31.6cm	275.30 K
Soil Temperature at 79.5cm	273.53 K
Soil Temperature at 200cm	270.92 K
Soil Volumetric Water Content at 5cm	12.28 m^3m^{-3}
Soil Volumetric Water Content at 12.6cm	63.37 m^3m^{-3}
Soil Volumetric Water Content at 31.6cm	60.46 m^3m^{-3}
Soil Volumetric Water Content at 79.5cm	75.00 m^3m^{-3}
Soil Volumetric Water Content at 200cm	90.00 m^3m^{-3}

Table 4. Initial values for the 2002 data.

Condition	Value
Hours	3556
Month	9
Time Since Last Snow Event	0.00 s
Snow Height	0.00 m
Mean Soil Temperature At 2m Depth	268.15 K
Ground Surface Temperature	288.95 K
Foliage Surface Temperature	290.05 K
Air Temperature At Reference Height	291.15 K
Soil Temperature at 5cm	283.13 K
Soil Temperature at 12.6cm	281.26 K
Soil Temperature at 31.6cm	282.37 K
Soil Temperature at 79.5cm	275.15 K
Soil Temperature at 200cm	270.15 K
Soil Volumetric Water Content at 5cm	8.00 m^3m^{-3}
Soil Volumetric Water Content at 12.6cm	55.88 m^3m^{-3}
Soil Volumetric Water Content at 31.6cm	65.00 m^3m^{-3}
Soil Volumetric Water Content at 79.5cm	70.00 m^3m^{-3}
Soil Volumetric Water Content at 200cm	90.00 m^3m^{-3}

Table 5. Root mean square data for the values used in the Full Data Assessment method.

Depth	0cm	5cm	10cm	15cm	25cm	35cm	60cm	85cm	110cm
1999	2.117	2.117	1.866	2.449	2.416	2.035	1.002	0.834	2.62
2000	3.052	3.052	2.491	2.949	2.719	2.377	2.28	2.861	3.768
2001	1.94	2.37	2.18	2.49	2.51	1.75	1.26	1.15	2.81
2002	5.67	1.81	2.72	2.28	1.87	1.94	---	---	---

Table 6. Root mean square data for the values used in the Diurnal Temporal Patterns method.

Depth	0cm	5cm	10cm	15cm	25cm	35cm	60cm	85cm	110cm
1999	1.527	1.527	1.34	1.896	1.883	1.549	0.151	0.659	2.538
2000	2.258	2.258	1.661	1.931	1.404	0.676	0.596	1.764	2.736
2001	1.18	1.73	1.55	1.76	1.77	0.61	0.45	0.32	2.48
2002	3.22	0.85	2.15	0.97	1.13	1.17	---	---	---

Table 7. Root mean square data for the values used in the Daily Average Comparison method.

Depth	0cm	5cm	10cm	15cm	25cm	35cm	60cm	85cm	110cm
1999	1.753	1.753	1.686	2.336	2.391	2.032	1	0.836	2.623
2000	2.557	2.557	2.32	2.888	2.706	2.37	2.257	2.833	3.743
2001	1.23	1.66	1.73	2.25	2.45	1.72	1.25	1.15	2.81
2002	4.97	1.59	2.63	2.19	1.44	1.92	---	---	---

Table 8. Root mean square data for the values used in the Soil Volumetric Water Content Difference method.

Depth	5cm	10cm	15cm	20cm	30cm
1999	0.026	0.006	0.004	0.008	0.006
2000	0.085	0.085	0.084	0.083	0.084
2001	0.04	0.01	0.02	0.02	0.01
2002	0.03	0.01	0.02	0.02	---

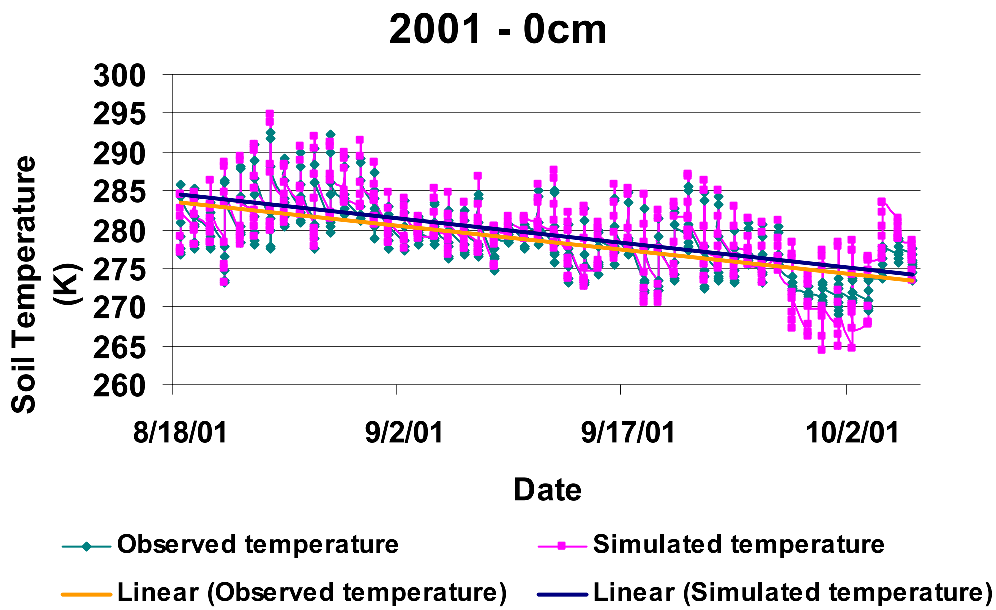

Figure 1. Example of observed data at 0cm graphed against simulated data at 0cm using the Full Data Assessment method. The top trend line is a linear representation of the simulated temperatures. The lower line is a linear representation of the observed temperatures.

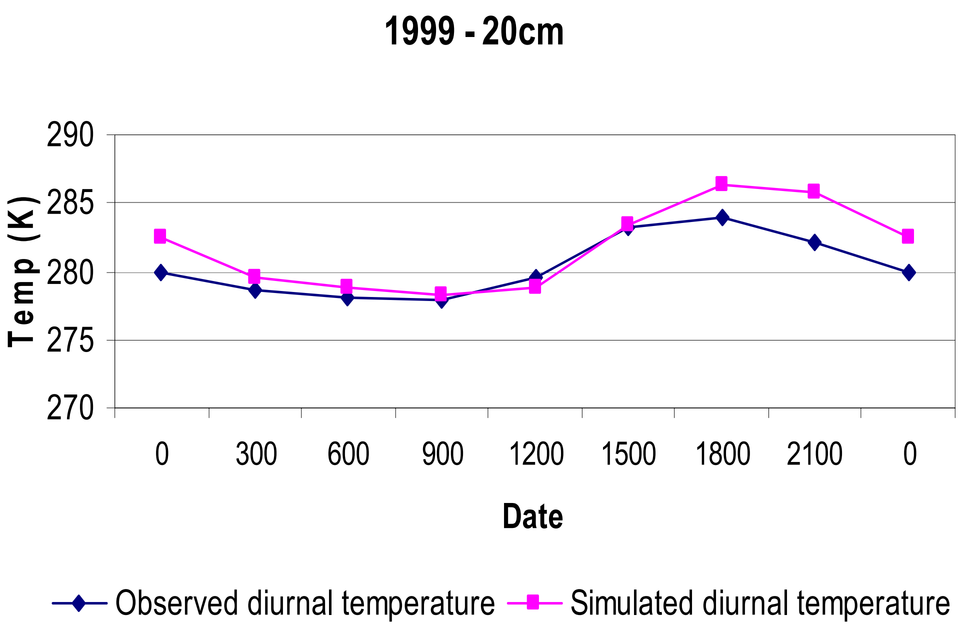

Figure 2. Example of observed data at 20cm graphed against simulated data at 20cm using the Diurnal Temperature Patterns method.

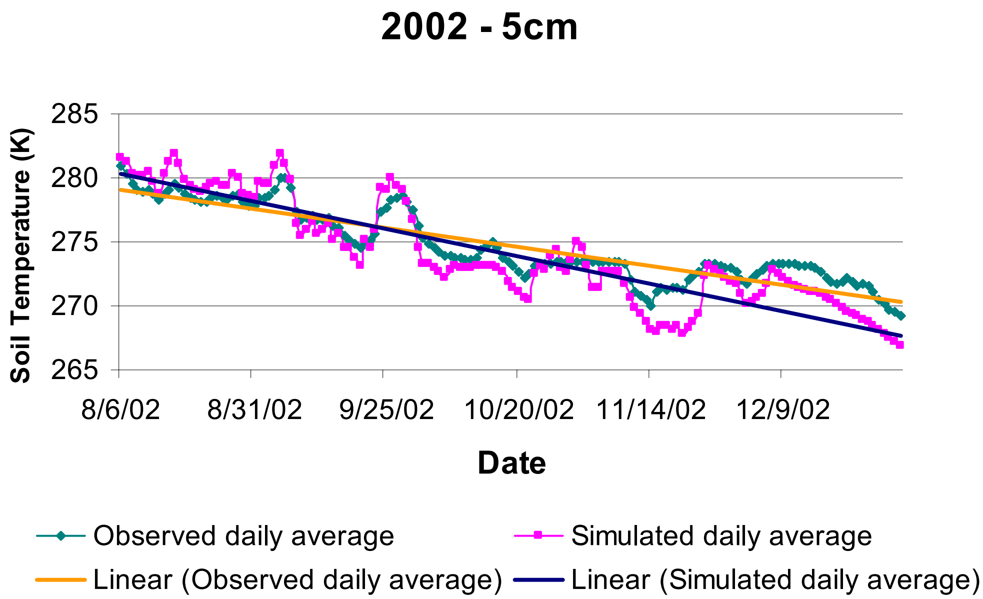

Figure 3. Example of observed data at 5cm graphed against simulated data at 5cm using the Daily Average Comparison method. The large variance seen in mid-November is likely due to the formation of the snow pack.

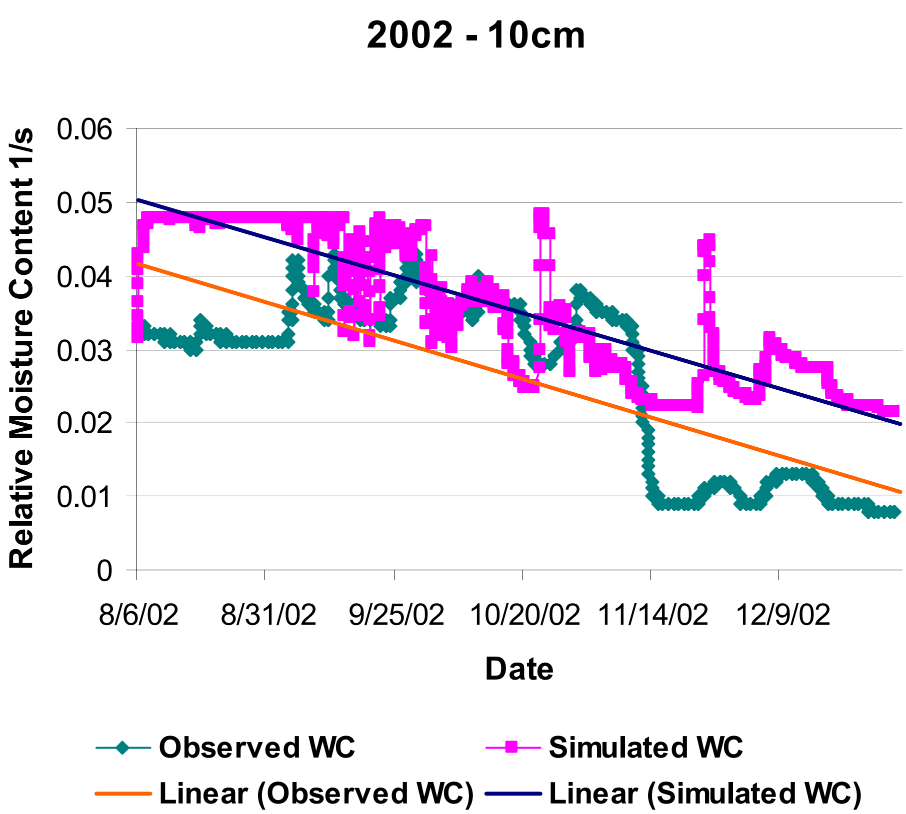

Figure 4. Example of observed data at 10cm graphed against simulated data at 10cm using the Soil Volumetric Water Content Difference method. The top trend line represents the simulated data, while the lower trend line represents the observed data.