Uncertainty Analysis on Quantities Predicted by the Hydro - Thermodynamic Soil Vegetation Scheme (HTSVS)

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Abstract

This paper discusses an uncertainty analysis preformed on a soil vegetation atmosphere transfer scheme described in Kramm et al. (1996). The effects of using several uncertain but required parameters in the prediction equations were estimated using Gaussian Error Propagation. The analysis considered the effects on the model prediction with respect to certain soil and atmospheric conditions that were varied over typical value ranges. It is shown that the effects of the uncertainty in the parameters on the predicted quantities can vary strongly. However these effects change only slightly with respect to different soil and atmospheric conditions.

1. Introduction and Motivation

Land surface models are used to simulate processes such as the exchange of moisture, matter and heat that take place between the surface and the atmosphere. Ideally these models should be as accurate as possible in order to produce a useful prediction. Usually the more realistic the land surface models are at describing nature, the more they contain complicated equations and calculations that require parameters. Such parameters including porosity, maximum and minimum temperatures at which stomata are still open, root length and soil density etc. are uncertain. These uncertainties can either come from inaccurate measurements or from taking a mean value for a parameter that contains a lot of natural variance. For example the root length of a certain type of plant will be given just one value in the model when clearly not all plants of the same species will have exactly the same root length and roots can grow up to one centimeter a day depending on the soil and atmospheric conditions. Therefore such prescribed parameters are estimated average values with a standard deviation of error. Unfortunately having several uncertain parameters in each equation can lead to errors in the prediction.

Uncertainty analysis studies have been performed on several of these land surface models in order to estimate their accuracy. In a study done by Mölders (2001) for instance, parameter values were varied one at a time and the results of the changes were looked at individually. A parameter was changed by ten percent of its value for example, then the simulation was run and the effects of that parameter change on the predictive quantities were estimated. This method is extremely time consuming and only provides information on the impact of that one parameter change on the simulation results for the conditions present in the case study performed.

Our project involves the uncertainty analysis technique described later in this paper. We used this technique to analyze the HTSVS described by Kramm et al. (1996). Doing so involved looking at how these prescribed parameters and their uncertainties can affect the model prediction and how the accuracy of the model is affected by the uncertainty in these parameters over typical ranges for atmospheric and soil conditions. For example, varying soil temperature over a typical range of values and calculating the error in soil heat flux caused by the uncertainty in the parameters used in the soil heat diffusion equation can help to determine the accuracy of soil temperature and heat flux predictions. This type of information can be used to identify what time of day or even during which season the model will be the most accurate.

2. Method

We used the Gaussian Error Propagation method to determine the error of Equations (11), (20)-(24), (26)-(30) and the correction functions in Appendix A given in Kramm et al. (1996). First these equations were differentiated with respect to the following prescribed parameters: minimum stomatal resistance, minimum, maximum and optimal temperature for stomata, pore size distribution index, porosity, hydraulic conductivity at saturation, soil moisture potential at saturation, root length, permanent wilting point, and field capacity. Using a given set of values for theses parameters and their standard deviations (Tables 1, 2), the errors of various quantities were calculated.

Error analysis was performed for various ranges of soil and atmospheric conditions holding other quantities constant that in nature would also change with the varied quantities. This was done for five quantities, namely soil temperature, foliage temperature, relative humidity, volumetric water content and specific moisture.

3. Results

3.1 Behavior of Errors for Varying Relative Humidity

A change in relative humidity only affects the accuracy of the calculations for stomatal resistance and the correction function with respect to water vapor deficit. The error in both calculations decreases quickly at first and then levels off with respect to increasing relative humidity (Figure 1). The error of the correction function approaches zero while the error of stomatal resistance levels off at approximately 29.5%. This shows that under relatively humid conditions, HTSVS calculates stomatal resistance with less uncertainty than under dry conditions.

3.2 Behavior of Errors for Varying Volumetric Water Content

Varying volumetric water content affects the accuracy of several predicted quantities and it can be seen that the errors caused by the same parameter lead to different percentage errors for these quantities. The errors in hydraulic conductivity, thermal conductivity and volumetric heat capacity decrease with increasing water content (Figures 2, 3) The error for hydraulic conductivity approaches 35% with increasing volumetric water content while the error for thermal conductivity is lower at 17.7% and heat capacity even lower varying between approximately 5% and 2.5%.

The errors in total heat flux, total water flux and the vertical gradient of water flux increase with increasing water content (Figures 3, 4). The error for total heat flux ranges from approximately 12% to 18% while water flux and the vertical gradient of water flux increase from 40% to level off at 43.3%.

The errors in the soil transfer coefficients stay relatively constant at around 45% until the water content nears field capacity (Figure 5a). The error in the calculations of these transfer coefficients is very high at field capacity and can be explained by the fact that once the soil moisture reaches field capacity, the pore volume that can be filled by water vapor is very small. This causes the values of the transfer coefficients with respect to water vapor to also be small and small values can lead to higher calculated errors.

A similar situation occurs with the error of stomatal resistance with respect to water content (Figure 5b). At the wilting point, the error in the calculation for stomatal resistance is very high and can be explained by the fact that at that soil condition the plant permanently wilts and dies. Once the volumetric water content increases, the error of stomatal resistance with respect to water content stays approximately constant at 23%.

3.3 Behavior of Errors for Varying Foliage Temperature and Soil Temperature

When varying soil temperature, the error in calculating total heat flux and heat flux with respect to depth increases linearly with increasing soil temperature (Figure 6). However this error has little variance and falls between sixteen and seventeen percent for the entire range of varying soil temperature. Thus, this increase is negligibly small.

When varying foliage temperature, the errors for stomatal resistance and the correction function with respect to foliage temperature have no error before the minimum temperature at which stomata open and high errors at that value (Figure 7). When stomata are closed the value of the correction function becomes zero and the stomatal resistance becomes infinitely high, i.e. the plant does not transpirate. As foliage temperature passes this minimum value, the error in the correction function decreases quickly until the optimal temperature for photosynthesis and then increases steadily past this point ultimately falling in a range between 15% and 0.03%. The error in the stomatal resistance also decreases quickly after this minimum temperature, steadies at approximately 30% and then increases as the temperature approaches the maximum temperature at which stomata are still open.

3.4 Behavior of Errors When Varying Specific Moisture

Varying specific moisture only affects the error for stomatal resistance and the correction function for water vapor deficit. The error for stomatal resistance decreases with increasing specific moisture and levels off slightly below 30%. The error for the correction function also decreases with increasing specific moisture until it reaches a minimum at specific moisture at saturation and then increases again. The error for the correction function ranges from 27.7% to 0.05% (Figure 8).

4. Conclusion and Outlook

Changing just one condition at a time is not an accurate description of real world situations. For instance, as soil temperature increases, it would be expected that foliage temperature would also increase however these interactions were not considered in our project. Our focus was on how the error in prediction quantities caused by the uncertainty of their parameters change over typical ranges of atmospheric and soil conditions. This is a first step to better understanding the effect these uncertainties have on the model prediction.

Our results show that the effects of the uncertainty in the parameters on the predicted quantities can vary strongly. For instance the errors for total water flux and heat flux increase while the errors for heat capacity and hydraulic conductivity decrease with respect to the same soil or atmospheric condition. These effects change only slightly with respect to different soil and atmospheric conditions. The errors in stomatal resistance and total heat flux seem to be the least effected by different soil and atmospheric conditions. The percentage error of stomatal resistance stays between 20% and 30% while the percentage error of total heat flux stays between 16% and 18% regardless of which condition is being varied.

Based on these first results we can conclude that more land-use and soil types should be considered in land surface models. However, doing so requires higher resolved land use and soil data sets for use in atmospheric models that also give the distribution of these new added land-use and soil types.

Since our project was not focused on the interactions of multiple soil and atmospheric conditions, the next step would be to integrate our method into the framework of an atmospheric model coupled with HTSVS and analyze the error when varying several atmospheric and soil conditions at a time. This would give an estimate on the accuracy of the predictions for the exchange of heat, water and matter at the surface atmosphere interface made by atmospheric models.

Acknowledgements

We would like to thank the Nation Science Foundation for financially supporting this study within the REU program. We also thank BMBF for funding this work under contract 07ATF30.

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Table 1. The initial set of values for the soil and atmospheric conditions that were entered into the program. Most of these values remained constant throughout the project. All values are in SI units.

Condition	Value	Condition	Value
Air Temperature	289	Volumetric Water Content	0.3
Relative Humidity	60	Soil Temperature	285
Short Wave Downward Radiation	200	Empirical Constant b_e	66.6
Correction Function for Ambient CO_2	1	Minimum Stomatal Resistance	40
Foliage Temperature	288	T_{Min}	278.15
T_{Max}	318.15	T_{Opt}	298.15
b_{st}	20	Porosity	0.415
Specific Heat Capacity of Soil	890	Specific Heat Capacity of Water	4186
Soil Density	1600	Torsion Factor	0.65
Pore Size Distribution Index	2.86	Ideal Gas Constant of Dry Air	287
Hydraulic Conductivity At Saturation	$1.27 \cdot 10^{-4}$	Soil Moisture Potential At Saturation	-0.32
Change in Soil Layer	0.02	Latent Heat of Vaporization	$2.5 \cdot 10^{6}$
Change in Time	120	Permanent Wilting Point	0.242
Root Length	0.32	Field Capacity	0.406
Pressure	1013.25		

Table 2. The set of standard deviations for the initial set of soil and atmospheric condition values used in this study.

Standard Deviation	Value
T_{max}, T_{min}, T_{opt}	0.5
Wilting Point Field Capacity and Porosity	0.017
Root Length	Root Length*0.2
Pore Size Distribution Index	0.082
Soil Moisture Potential at Saturation	0.125
Hydraulic Conductivity at Saturation	$1.15 \cdot 10^{-14}$
Specific Heat Capacity of the Soil	63.63961
Minimum Stomatal Resistance	0.2213594
Empirical Constant b_e	b_e * 0.1
Soil Density	70.711

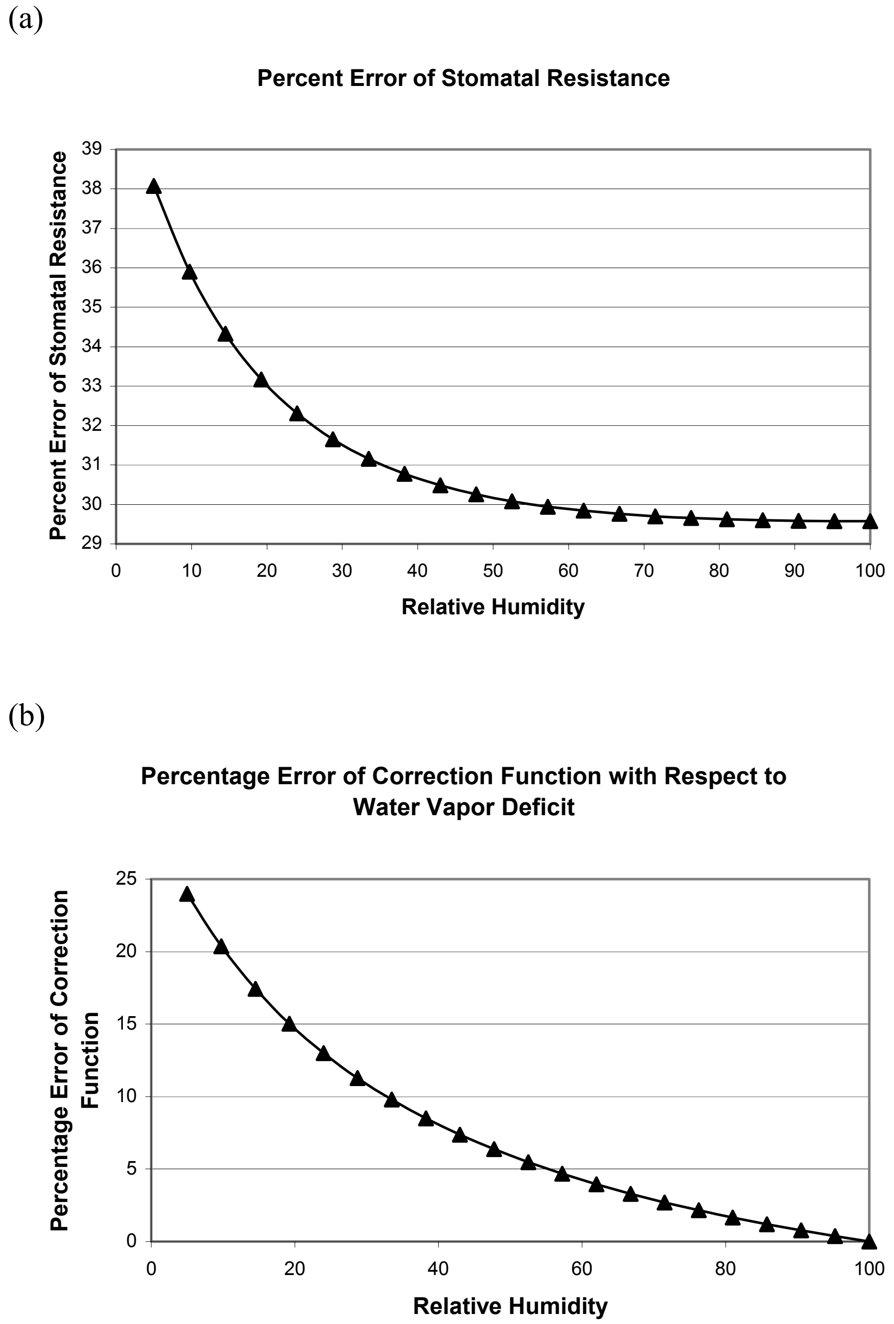

Figure 1. Percentage error with respect to varying relative humidity for (a) stomatal resistance and (b) the correction function with respect to water vapor deficit.

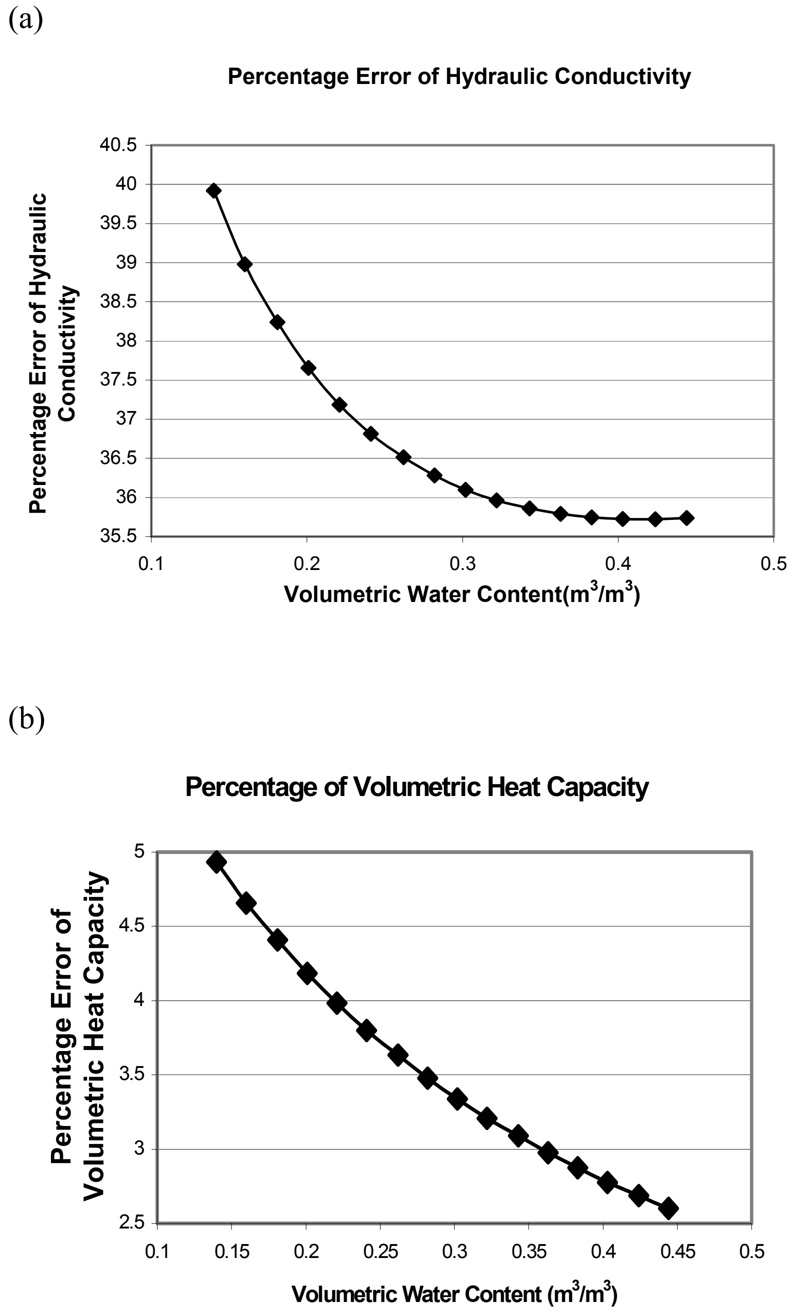

Figure 2. Percentage error with respect to volumetric water content for (a) hydraulic conductivity and (b) volumetric heat capacity.

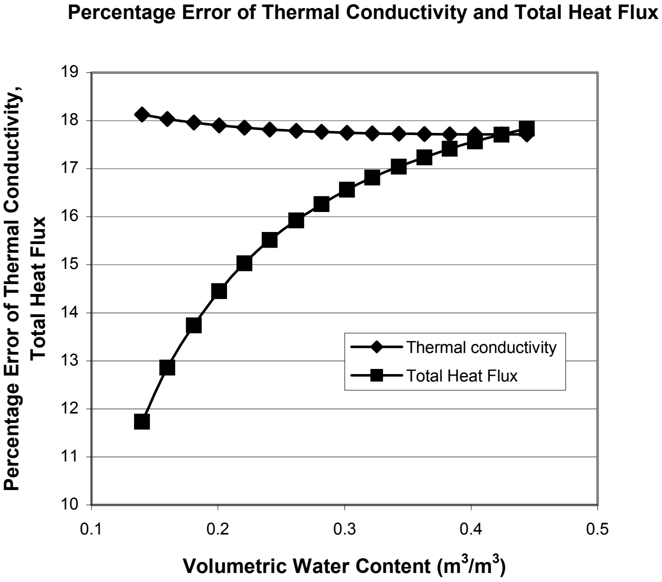

Figure 3. Percentage errors for thermal conductivity and total heat flux with respect to varying volumetric water content.

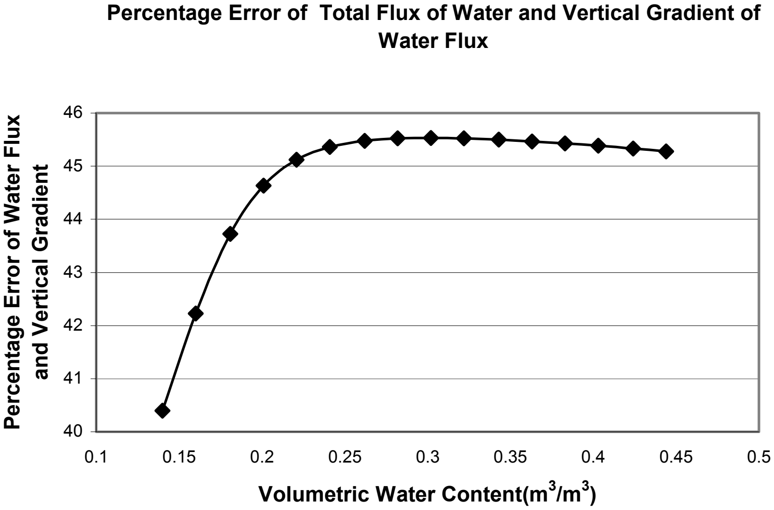

Figure 4. Percentage error of total water flux and the vertical gradient of water flux with respect to varying volumetric water content. Note that the two equations have the same percentage error graph because the vertical gradient is just the total water flux with a constant multiplier when looking at it with respect to volumetric water content.

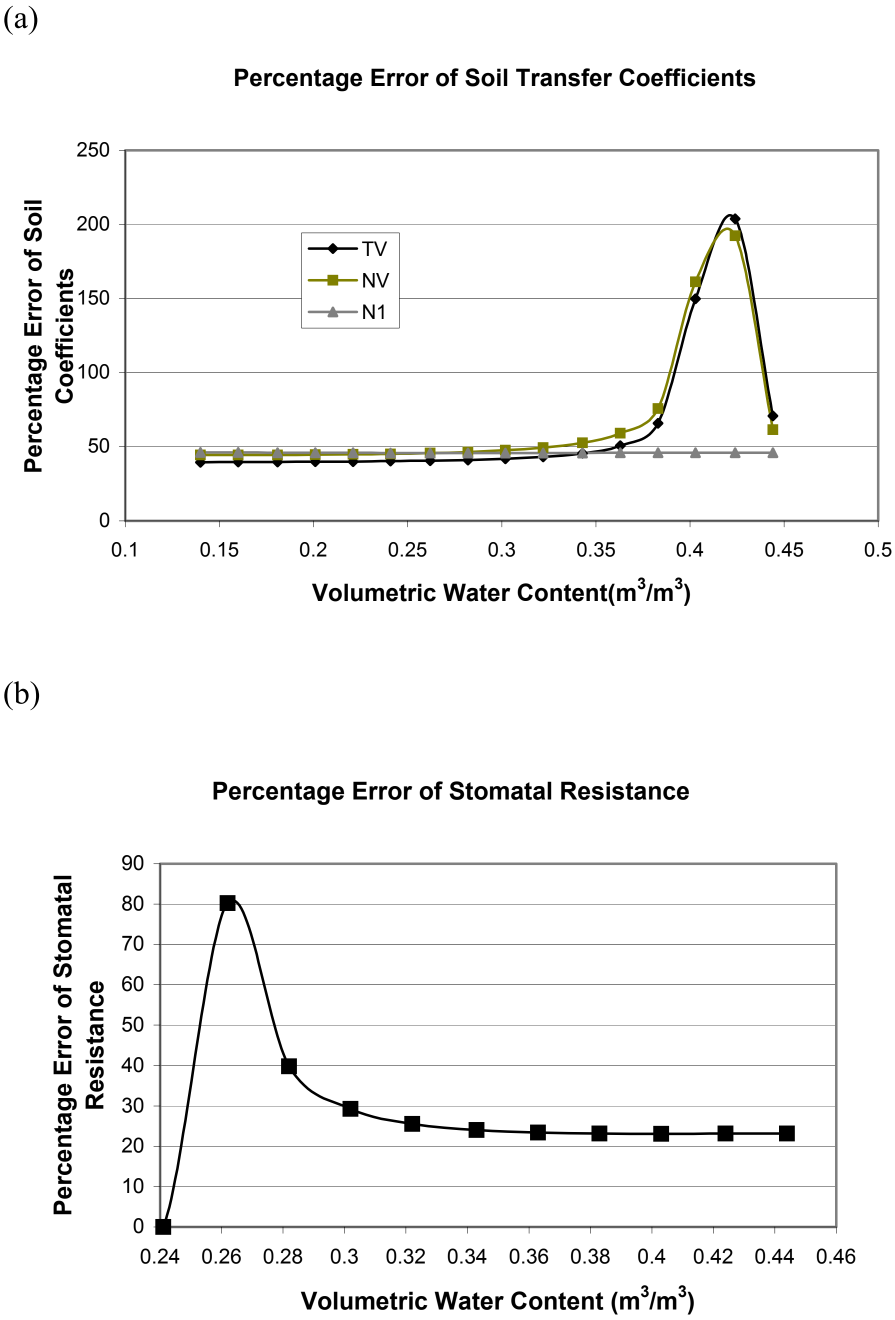

Figure 5. Percentage error for (a) the soil transfer coefficients and (b) stomatal resistance both with respect to varying volumetric water content.

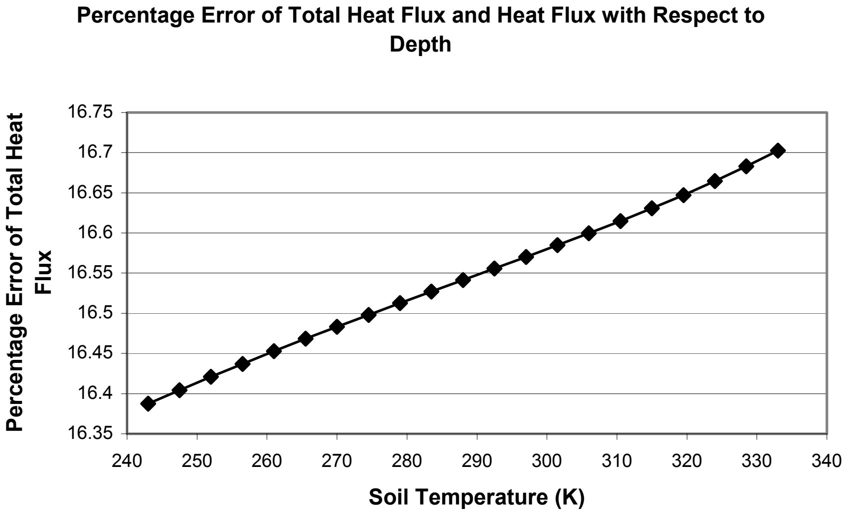

Figure 6. Percentage error for total heat flux and total heat flux with respect to depth for varying soil temperature.

(a)

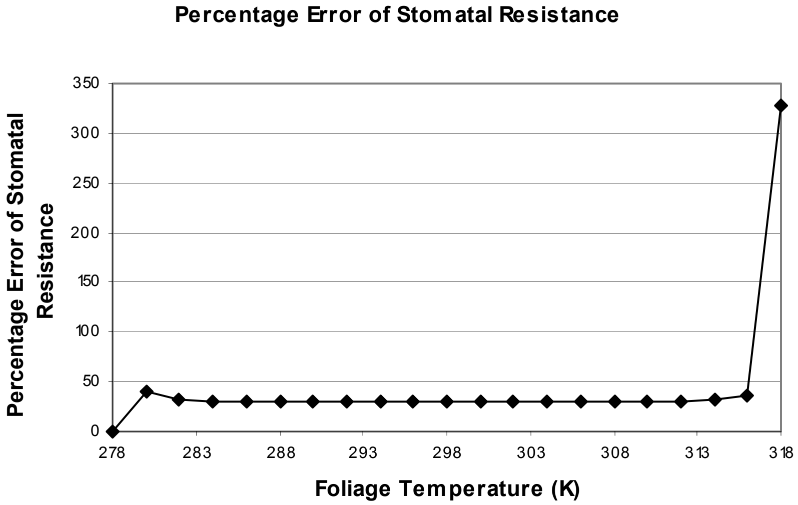

Figure 7. Percentage error for (a) stomatal resistance and (b) the correction function with respect to foliage temperature, both for varying foliage temperature.

(b)

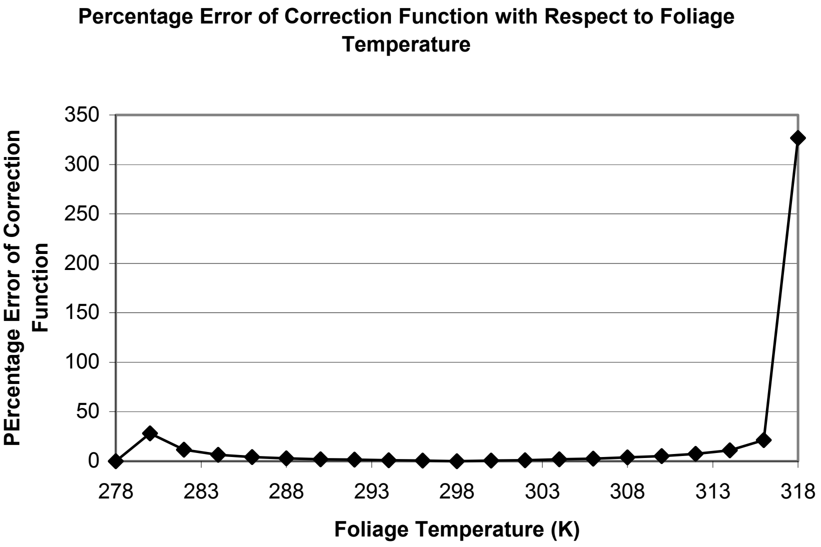

Figure 7. Continued.

(a)

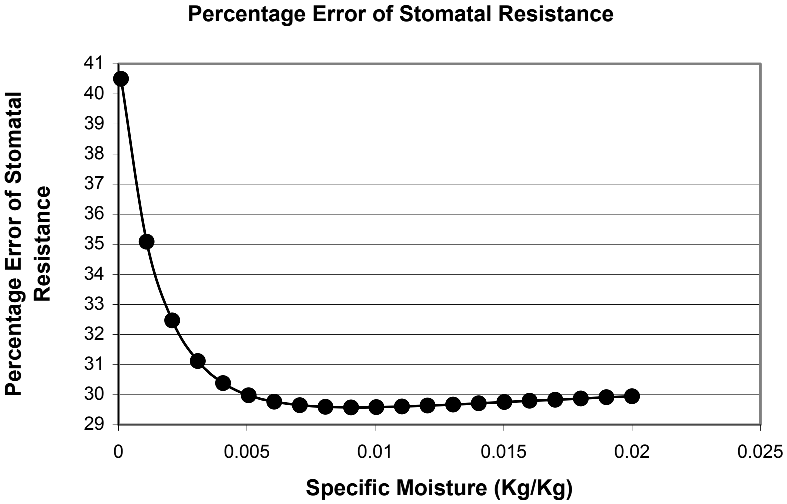

Figure 8. Percentage error for (a) stomatal resistance and (b) the correction function for water vapor deficit both shown with respect to varying specific moisture.

(b)

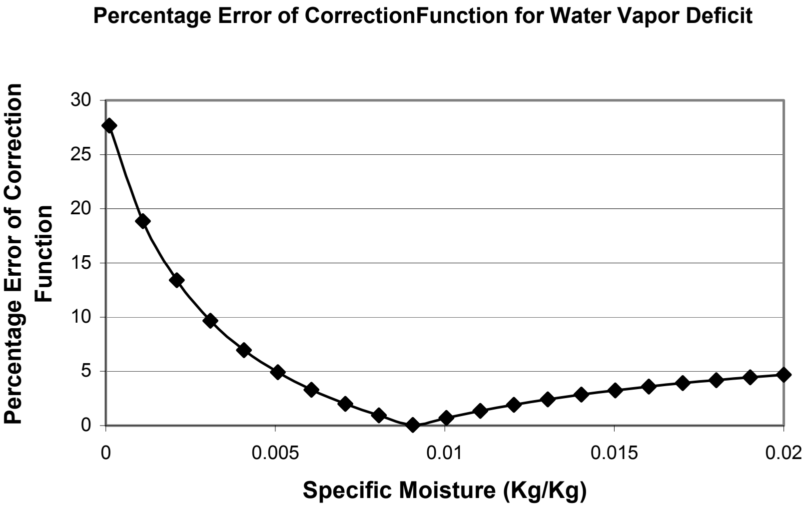

Figure 8. Continued