Uncertainty Analysis of Simulated Hydrological Processes With Respect to Prescribed Model Parameters

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1. **Introduction**

The atmosphere and land-surface continuously interact for which the surface affects climate and current weather. The biosphere, which is a part of the system, plays an important role because it is the medium in those interactions. The existence of biosphere forces us to include its effect in atmospheric models. The processes that describe those interactions are heat, water and matter exchange. The water exchange is represented by latent heat fluxes; the heat exchange is associated with the sensible heat fluxes, and matter exchange is given through carbon transport. Different vegetation types will affect those transfers in variety of ways.

To include the biosphere effects into atmospheric models those processes have to be parameterized. By parameterizing we are compelled to produce some sort of errors. These errors are of different origin. One source of errors is averaging, required because of the lack of reliable data sets for initialization. Another source of errors results from the necessity to prescribe plant physiological and phenological as well as soil physical parameters for quantities that in nature vary even among the same plant or soil type (e.g. Avissar, 1991, Clapp and Hornberger 1978, Cosby et al., 1984). Whatever the origin of errors is, they have to be minimized in order to achieve an accuracy of the model prediction to the highest degree possible.

As Mölders (2001) pointed out, it is very difficult to get suitable data sets of soil parameters. Moreover, measurements of quantities that describe soil conditions, like soil moisture, are scarce and available only at certain points in short periods of time (Callies, et al., 1998). Due to the nature of different soil and vegetation types it is difficult to assign certain soil and vegetation parameters to a specific area because surface properties are time and space dependant. Furthermore, the area of integration can be covered with variety of different vegetation species and different soil types.

There were several attempts on determining the uncertainty of the fluxes and variables of state predicted by land surface models. Mölders (2001) changed values of prescribed soil physical and the plant physiological quantities in order to reveal to which degree the model was sensitive to the choice of parameters. Those changes were done one at the time. She found that another choice of soil and vegetation parameters can lead to a shift in the predicted amount of precipitation. Results from such kind of studies provided information on the range over which parameter values could be chosen and ingested in the model calculation.

The technique applied was able to describe the error that comes from one single parameter. It does not allow exploring effects that are consequence of the combination of several errors in the several different parameters within one calculation. It is the combination of these errors that is to be examined to understand the full uncertainty in the predicted fluxes or variables of state due to prescribing parameters. We will address this uncertainty by using error propagation method.

It is well known that if values of several quantities are averaged, initial errors will propagate through one single calculation amplifying each other finally producing high uncertainty in the model results. By applying the method of error propagation when calculating the fluxes, in addition to predicted values of fluxes, we also obtain a value for the error resulting from the necessity to prescribe parameters in the parameterizations. This additional knowledge provides a better insight into the reliability of the simulation.

When simulating water, energy and trace gas fluxes in coastal areas the parameterizations are different over water and land. Over water, usually only emissivity is prescribed. Albedo is parameterized as a function of solar zenith angle; and roughness length is calculated as a function of wind speed. While emissivity is the only prescribed and, hence, uncertain parameter over water whereas, over land, there are many more prescribed uncertain parameters (e.g. soil hydraulic conductivity, soil thermal conductivity, porosity, pore-size distribution index, leaf area index, albedo and emissivity of the foliage, emissivity of the soil, minimum stomatal resistance, canopy height, etc.). Therefore, it has to be expected that the error in predicted fluxes caused by the necessity to prescribe parameters will differ over land and water surfaces. It also has to be expected that the choice of the parameters can affect the strength of the predicted land-sea breeze and prediction of the weather in coastal areas. Therefore, it is of interest to know the uncertainty in predicted fluxes for more reliable weather prediction in coastal areas.

In this study, atmosphere and land-surface interaction is modeled through the OSU land surface (Oregon State University) model as described by Chen et al. (1996) and Chen and Dudhia (2001). In the calculations, the model uses prescribed parameters (see Table 1.) in the parameterizations to calculate the exchange of matter, water and heat between the surface and the atmosphere.

2. **Method**

The Gaussian Error Propagation method is based on derivation of the equations of the model. As mentioned above in this study, the OSU land surface model (referred to as OSULSM hereafter) is used and equations are derived with respect to the uncertain quantities listed in Table 1. The derivatives were incorporated into the equation for Gaussian Error Propagation along with individual errors (standard deviations) in the uncertain parameters. Standard deviations of the parameters were taken from the literature. These values are given in Table 2. To find the relation between the overall behavior of the error and certain parameters we varied the variables of state and fluxes (e.g., soil-, air-, and ground-surface-temperature, volumetric soil water content, precipitation, specific moisture, downward shortwave radiation) over the natural range of values, applying an offline version of OSULSM. This means these quantities, which are usually predicted either by OSULSM or the forcing model, were linearly varied over the range of typical values. The results show how uncertainty in the prescribed parameters could affect the calculation and give an estimate of the error made at certain atmospheric or soil condition. This investigation did not consider real synoptic situation, but gave an insight into the general behavior of the error of the parameters. In these offline studies forced by variables of state or fluxes within a typical range no feedback was allowed.

To examine the error behavior in a more realistic environment the whole procedure is nudged within the PennState/NCAR mesoscale meteorological model MM5 (see Dudhia 1993 for a model description). Herein, feedbacks between the variables of state and fluxes are accounted for. Gaussian Error Propagation is now done within OSU land surface model for every grid point, which provides an ability to plot two-dimensional maps of the errors for each time step. The variables of state and fluxes are changing with time as the weather changes and uncertainty in predicted fluxes of water, energy and trace gases is investigated.

3. **Brief description of the model setup**

The test platform is the NCAR mesoscale meteorological model MM5 (e.g., Dudhia, 1993). Clouds are represented by a modified version of Schultz's (1995) explicit scheme at the resolvable scale. Convective cloudiness is modeled in accordance with Grell (1993). The planetary boundary layer physics is described by the MRF-scheme (Hong and Pan, 1996). The OSU land surface model (Chen and Dudhia, 2001) is used to describe the surface-atmosphere interaction.

The model domain covers the area that corresponds to the state of Alaska. There are two interacting domains. The outer one, centered on Fairbanks, AK, has 31x42 grid points with 90 km spacing, whereas the inner one domain has 49x52 grid points, with 30 km spacing. The simulation preformed covers the four day period, starting August 23, 1998 at 12 UTC, and ending on August 27, 1998 at 12 UTC.

The synoptic situation was driven by cyclonal activity developed in the Bering Sea, progressing, in the north-northeastward direction, and gradually weakening with time. The surface center of the cyclone for the most of the period was located somewhere along the west coast of the state with tendency to go up north and penetrate the mainland. Throughout the period, the frontal system was traversing the state from the west coast and Aleutian Islands ending up in the Yukon Territory in the mainly southerly and south-westerly mean flow at 500 HPa geopotential height. The simulated fields were in a good agreement with analyzed ones and substantial consistency was present throughout the whole period.

4. Preliminary results of the offline studies

The standard deviations for soil porosity, soil and water potential at saturation, and pore size distribution index are of the order of magnitude of the mean values themselves (e.g., Clapp and Hornberger, 1978; Cosby et al., 1984). Therefore, the errors obtained in the fluxes will be very high if the parameters used are averaged for all soil types within a soil class (e.g., clay) as it is the case when these parameters applied as it is custom in mesoscale modeling.

In mesoscale modeling usually only information on soil class exists. This means that in general the errors caused in predicted surface fluxes by prescribed values of porosity, pore-size distribution index, soil water potential, and soil hydraulic conductivity will be large. Prochaska and Mölders (2002) showed that the error in predicted surface fluxes can become much lower if more accurate site specific values are available (e.g., Fig.1). Here site specific parameters as given in Mölders et al. (2003) were used.

Preliminary results on the error in soil volumetric water content showed that the accuracy for simulation of canopy resistance is affected by a change in the volumetric soil water content (Fig. 2). Towards the wilting point, the accuracy in this calculation goes down. On the contrary, simulated vertical gradient of rate of soil heat flux and rate of change in volumetric water content are unaffected by the change in the volumetric soil water content. These results mean that the same standard deviation in the soil physical parameters can lead to greater or smaller errors depending on the moisture regime of the soil.

5. **Summary, conclusion and outlook**

The Gaussian Propagation Error is a successful way to investigate on the accuracy of a model simulation with respect to the prescribed parameters used. It is shown that a proper choice of the prescribed parameters is of importance. Errors in prescribed soil physical parameters propagate throughout the calculation making the overall error in predicted soil fluxes large.

The tool for analyzing the errors by Gaussian Error Propagation is currently incorporated in MM5 to provide error bars for the fluxes resulting from the uncertainty in the prescribed parameters. Knowing more about the model's accuracy, behavior and sensitivity to the parameter can provide better understanding of the atmosphere and improve model forecasts as well.

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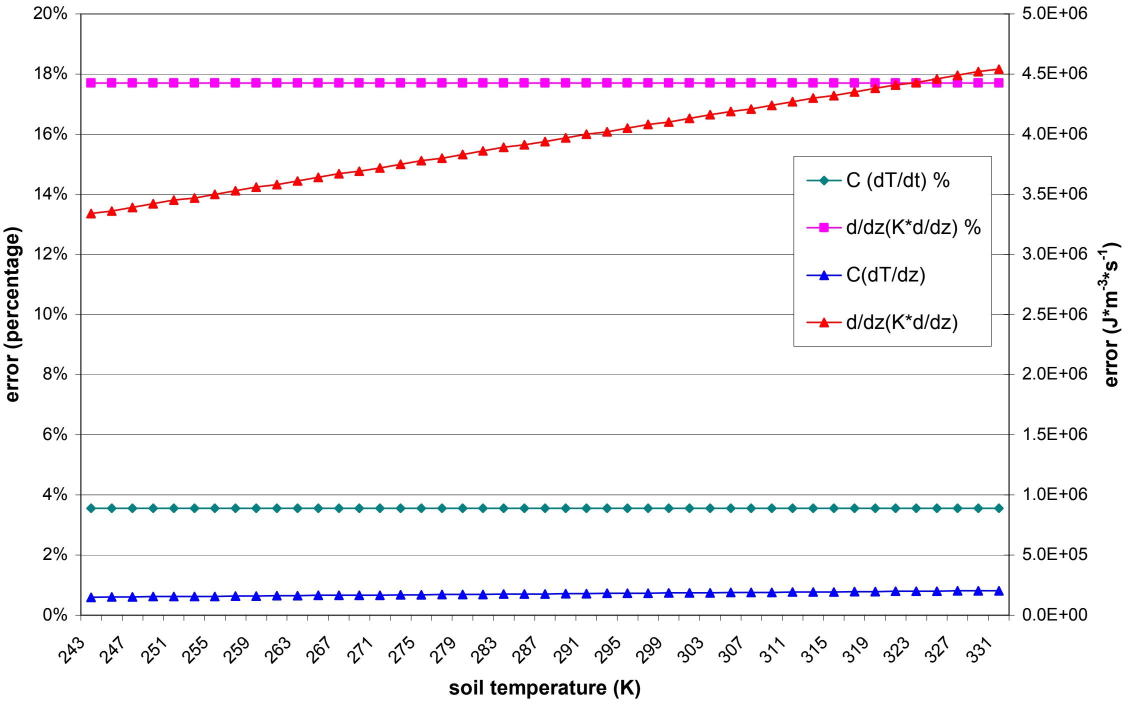

Fig. 1. Errors due to soil physical parameters as a function of soil temperature. All other quantities were fixed. C(∂T/∂t)% - percentage of error of volumetric heat capacity times rate of temperature change to actual value, C(∂T/∂t) – error; ∂/∂z(K*∂/∂z)% - percentage of error of vertical gradient of rate of soil heat flux to actual value, ∂/∂z(K*∂/∂z) – error. After Prochaska and Mölders (2002).

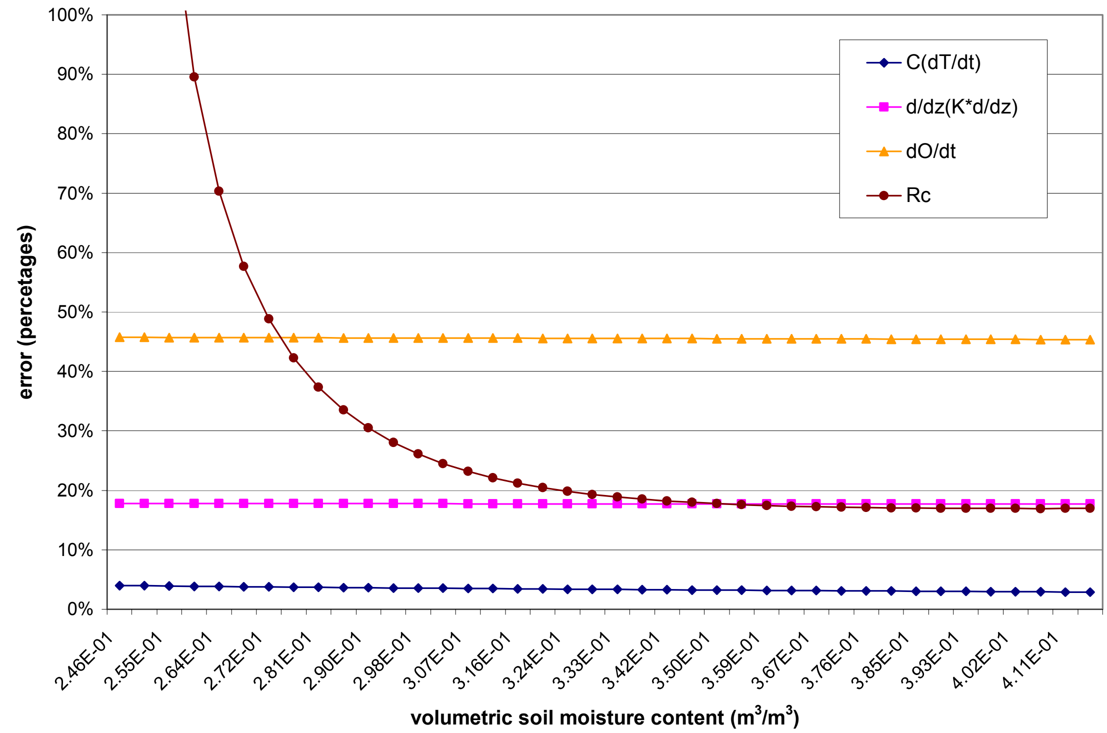

Fig. 2: Error relations for volumetric soil water content change. C(∂T/∂t) is the percentage of error of volumetric heat capacity times rate of temperature change per actual value, ∂/∂z(K*∂/∂z) is percentage of error of vertical gradient of rate of soil heat flux per actual value, ∂O/∂t is percentage of error of rate of volumetric soil moisture content per actual value, Rc is percentage of error of canopy resistance per actual value; volumetric soil moisture content range between wilting point and soil porosity. All other quantities were held constant. After Prochaska and Mölders (2002).

Table 1: List of calculations from the OSU Land Surface Model and prescribed parameters containing error. Error analysis performed on the calculations below. Refer to Chen et al. (1996) for equations used.

CALCULATIONS ANALYZED	*PARAMETERS CONTAINING ERRORS*
Volumetric heat capacity times rate of temperature change	Maximum intercepted canopy water content
Vertical gradient of rate of soil heat flux	Density of the soil
Rate of change in volumetric water content	Saturation hydraulic conductivity
Direct evaporation from the ground surface	Saturation soil suction
Wet canopy evaporation	Pore size distribution index
Intercepted water canopy budget	Soil porosity
Canopy evapotrasnpiration	Green vegetation fraction
Canopy resistance	Heat capacity of the soil
	Minimum stomatal resistance
	Maximum stomatal resistance
	Leaf area index
	Wilting point
	Field capcity
	Some empirical parameters

Table 2: Values used in OSU error analysis. T soil temperature, ∂t- time step, S_a-density of air, θ-volumetric water content, E_p-potential rate of evaporation, W_c- intercepted water canopy content, P-precipitation, R_g-short wave downward radiation, T_a-temperature of the air, q_a-specific moisture, T_g-temperature of the ground, T_{ref}-reference temperature, θ_1-volumetric soil moisture at first layer, θ_2-volumetric soil moisture at second soil layer, d_1-thickness of first soil layer, d_2-thickness of second soil layer, ∂z-depth, C_h-surface exchange, C_s-specific heat of soil, ρ_s-density of soil, K_s-saturation hydraulic conductivity, ψ_s-saturation soil suction, b-pore size distribution index, θ_s-soil porosity, σ_f-green vegetation fraction, S-maximum allowed W_c capacity, R_{cmin}-minimum stomatal resistance, LAI-leaf area index, R_{cmax}-maximum stomatal resistance, θ_w-wilting point, θ_{ref}-field capacity, empirical constants-B1, β, R_{gl}. SI units are used; some values derived from data given by Mölders et al. (2003) and Chen et al. (1996).

FORCING VALUES	
T	283
∂t	120
S_a	1.29
θ	0.15
E_p	0.001
W_c	0.0005
P	0.0001
R_g	220
T_a	283
q_a	0.005
T_g	285
T_{ref}	298
θ_1	0.15
θ_2	0.17
d_1	0.02
d_2	0.04
∂z	0.02
C_h	0.015

PRESCRIBED PARAMETERS		
	VALUE USED	ST. DEVIATION
C_s	890	63.63961
ρ_s	1600	70.711
K_s	7.00E-07	1.00E-07
ψ_s	-0.62	0.143
b	8.72	1.78
θ_s	0.464	0.056
σ_f	0.5	0.2
S	0.006	0.001
R_{cmin}	40	0.221359
LAI	2	0.2
R_{gl}	100	10
R_{cmax}	5000	8.856
β	36.25	3.625
θ_w	0.11	0.056
θ_{ref}	0.38	0.056
B1	0.0016	0.00016