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## Surface Temperature Assimilation in Land Surface Models

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**Abstract** – This paper examines the utilization of surface temperature as a variable to be assimilated in offline land surface hydrological models. Comparisons between the model computed and satellite observed surface temperatures have been carried out. The assimilation of surface temperature is carried out twice a day (corresponding to the AM and PM overpass of the NOAA10) over the Red-Arkansas basin in the Southwestern United States ( $31^{\circ}50'N-36^{\circ}N, 94^{\circ}30'W-104^{\circ}30'W$ ) for a period of one year (August 1987 to July 1988). The effect of assimilation is to reduce the difference between the surface soil moisture computed for the precipitation and/or shortwave radiation perturbed case and the unperturbed case compared to no assimilation.

### BACKGROUND

Land surface modeling has faced limitations in the past due to the lack of spatially distributed data on land surface characteristics as well as variables in water and energy budgets, namely surface temperature and soil moisture. Soil moisture is a crucial component of both the water and energy budget. The absence of spatially distributed observations of soil moisture makes it very difficult for hydrological model validation. Comparison of model streamflows at the catchment outlet with the observed streamflow does not ensure energy and water budget validation. Satellite observed surface temperatures satisfies our requirements of being spatially distributed and having connections to both the water and the energy budgets. Surface temperature

has seen observed by NOAA polar orbiting satellites using the AVHRR (Advanced Very High Resolution Radiometer) and TOVS (Tiros Operational Vertical Sounder) since 1978. The subject of assimilation of soil moisture data or assimilation of meteorological data in order to estimate soil moisture more accurately is relatively a new area of study (McLaughlin, 1995). Recent advances in inverse methods (Entekhabi et. al. 1994, Lakshmi et. al. 1997) have demonstrated the use of microwave satellite data in estimating soil moisture. The assimilation of soil moisture from low-level atmospheric variables using a mesoscale model (Bouttier et. al. 1993a,b) have shown that the assimilated soil moisture estimates help in the initialization of atmospheric models. Another class of methods use satellite estimates of surface skin temperature to adjust for the soil moisture (McNider et. al. 1994, Oettle et. al., 1994) and estimate with greater accuracy the surface fluxes and surface temperature. Van de Hurk et. Al. (1997) carry out assimilation by nudging the forecast model evaporation fraction using the satellite data and hydrological model computed evaporative fraction.

### THEORY

The land surface hydrology can be represented by a two-layer model as shown in Figure 1 (Mahrt and Pan, 1984; Lakshmi et. al., 1997). The water balance for the model can be written as

$$z_1 \frac{\partial \theta_1}{\partial t} = P - E - R - q_{1,2}$$

$$z_2 \frac{\partial \theta_2}{\partial t} = q_{1,2} - q_{2,wt} - T \quad (1)$$

where  $\theta_1$  and  $\theta_2$  are the volumetric soil moistures of the top layer (with thickness  $z_1$ ) and the bottom layer (with thickness  $z_2$ ),  $P$  is the precipitation,  $E$  is the bare soil evaporation,  $R$  is the surface runoff,  $T$  is the transpiration,  $q_{1,2}$  is the moisture flow from layer 1 to layer 2 and  $q_{2,wt}$  is the moisture flow from layer 2 to the water table. In this model, the the transpiration is assumed to occur from the bottom layer only. The moisture flow from layer 1 to layer 2 ( $q_{1,2}$ ) and the flow from layer 2 to the water table ( $q_{2,wt}$ ) are modeled using the Philips equation accounting for the gravity advection and the moisture gradient. The difference between the model computed and the new evapotranspiration flux  $ET'$  (that satisfies the satellite observed surface temperature) is given by

$$ET' - ET = \delta ET = -4\epsilon\sigma T_s^3 \delta T_s - H_1 \delta T_s - G_1 \delta T_s \quad (2)$$

where  $\delta T_s = T'_s - T_s$ , the difference between the assimilated surface temperature and the model computed surface temperature. The partition of this difference in evapotranspiration  $\delta ET$  into the difference for bare soil evaporation  $\delta E$  and the vegetation transpiration  $\delta T$  is given by,

$$\begin{aligned} \delta E &= \delta ET \frac{W_1}{W_1 + W_2} \\ \delta T &= \delta ET \frac{W_2}{W_1 + W_2} \end{aligned} \quad (3)$$

The soil moisture of layer 1 and layer 2 has to be modified by  $\delta\theta_1$  and  $\delta\theta_2$  respectively so that this new bare soil evaporation and vegetation transpiration hold good.

$$\begin{aligned} \delta\theta_1 &= \frac{\delta E}{\rho_w L} \frac{\Delta t}{z_1} \\ \delta\theta_2 &= \frac{\delta T}{\rho_w L} \frac{\Delta t}{z_2} \end{aligned} \quad (4)$$

where  $\Delta t$  is the time step in our land surface model.

## DATA AND METHODS

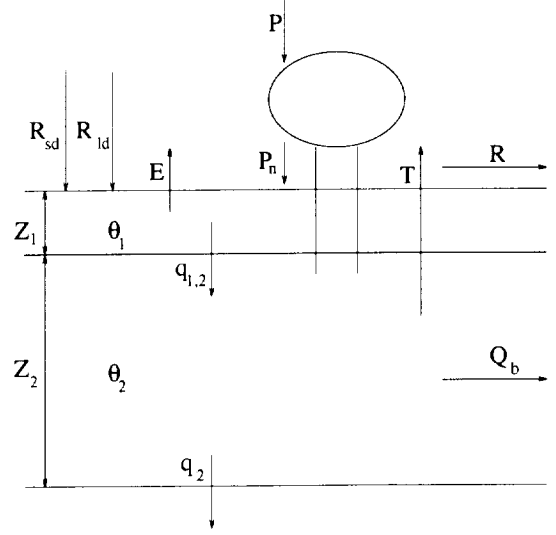


Figure 1: Representation of land surface hydrology

This study was carried out over an areal extent of  $4.75^\circ$  in latitude and  $10.5^\circ$  in longitude in the southwestern plains of United States. The meteorological data were obtained from the surface airways data (17 stations on a hourly basis) from EarthInfo's NCDC (National Climate Data Center) data product. The TOVS data of surface air temperature and surface vapor pressure serve as input to the land surface model and the surface skin temperature is assimilated. The NOAA 10 satellite with nominal overpass time at the equator of 730am/pm is used. The assimilation is carried out for a period of 1 year (August 1987 - July 1988). The land surface hydrological model is basically run in two modes, viz without assimilation of satellite surface temperature data and with the assimilation of satellite surface temperature for the values of input precipitation biased 20% higher and lower.

## RESULTS

Figure 2 shows the comparisons between the volumetric upper layer soil moisture averaged over the Red-Arkansas grid box between August 1, 1987 and July 31, 1988 for the control case with and without assimilation (top panel) and the difference between the control with assimilation and rainfall input decreased and increased by 20% with and without the

surface temperature assimilation.

## REFERENCES

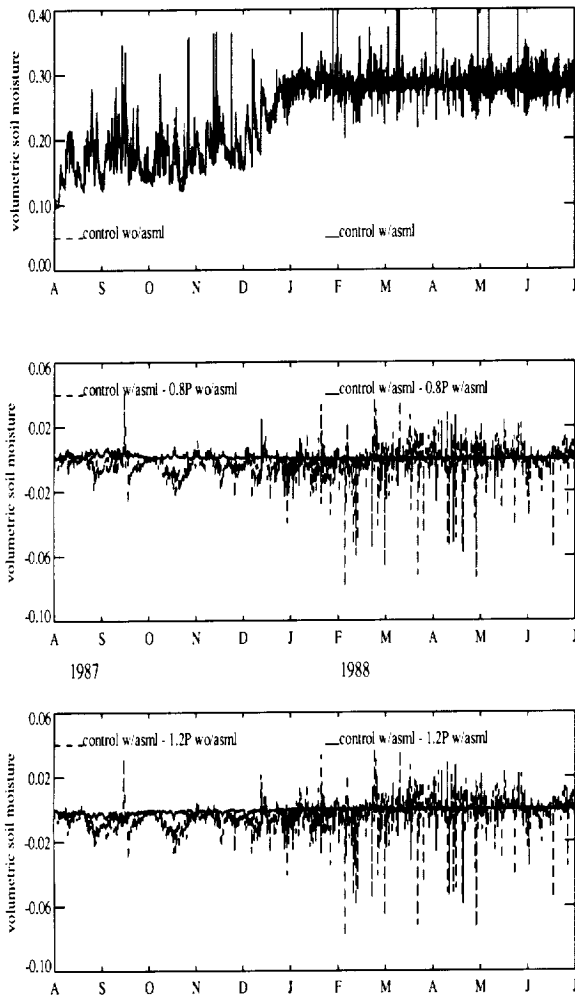


Figure 2: Surface air temperature measured in FIFE versus derived from NOAA 10

It can be seen from Figure 2 that the assimilation of surface temperature from the NOAA 10 TOVS data leads to reduction in the volumetric soil moisture of the upper layer caused by incorrect rainfall input. In fact, the assimilation brings the soil moisture closer to the control case for both - reduction in rainfall and increase in rainfall. The ability for the surface temperature assimilation to serve as a reset is most important for global hydrological data assimilation.

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