J4.4 THE EFFECTS OF IMPLEMENTING TOPMODEL CONCEPTS IN THE NOAH MODEL

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1. INTRODUCTION

Topographic effects on runoff generation have been documented observationally (e.g., Dunne and Black, 1970) and are the subject of the physically based rainfall-runoff model TOPMODEL (Beven and Kirkby, 1979; Beven, 1986a;b) and its extensions, which incorporate variable soil transmissivity effects (Sivapalan et al, 1987, Wood et al., 1988; 1990). These effects have been shown to exert significant control over the spatial distribution of runoff, soil moisture and evapotranspiration, and by extension, the latent and sensible heat fluxes (Famiglietti et al., 1992; Famiglietti and Wood, 1994a; b; Peters-Lidard et al, 1999).

The objective of this research is to investigate and demonstrate the impact of topographic control of runoff production and lateral soil water redistribution on the water and energy balance as simulated by the NCEP NOAH land surface model (Mahrt and Ek, 1984; Mahrt and Pan, 1984; Pan and Mahrt, 1987; Chen et al., 1996; Schaake et al, 1996; Chen et al., 1997; Mitchell, 1999). Currently, the NOAH model solves the Richards equation for 1-D vertical soil water transport in each land surface model grid, which corresponds to the atmospheric model horizontal grid. There is no provision for lateral soil water redistribution or for explicit subgrid soil moisture heterogeneity. Several modifications to NOAH have been incorporated which parameterize the effects of subgrid variability in topography and/or soil moisture, including:

- infiltration/runoff generation parameter “REFKDT” (Schaake et al., 1996). REFKDT is a tuneable parameter that significantly impacts surface infiltration and hence the partitioning of total runoff into surface and subsurface runoff. Increasing REFKDT decreases surface runoff.
- non-linear soil moisture stress function for stomatal resistance (Chen et al., 1996). The non-linearity in this function represents the ability of wetter portions of the grid to transpire even when the grid-averaged soil moisture is near the wilting point, as well as the dryer portions of the grid which may be stressed when the grid-averaged soil moisture is near field capacity.
- drainage parameter “SLOPE” (Schaake et al., 1996). SLOPE is a coefficient between 0.1-1.0 that modifies the drainage out the bottom of the bottom soil layer. A larger surface slope implies larger drainage.

TOPMODEL provides a physically-based approach to represent subgrid topography and soil effects on the runoff production, the soil moisture distribution and drainage, via a drainage index which can be estimated directly from digital topographic and soils data. In the current project, the three parameterizations above are being replaced with a subgrid distribution of the TOPMODEL drainage index to explicitly represent the subgrid distribution of water table depth and soil moisture. The effect of this subgrid distribution on lateral soil water redistribution, runoff generation and surface fluxes will be modeled statistically in the manner of Famiglietti and Wood (1994a) and Peters-Lidard et al. (1997). We are demonstrating the NOAH model in both its original and new forms in the Arkansas-Red River basin using all other input parameters as specified in the LDAS project. By incorporating topographic effects into the existing NOAH model while all other processes remain the same, the effects of this representation on runoff, soil moisture and energy fluxes can be isolated. All simulations are being run off-line and in a retrospective mode for this test period.

2. APPROACH

As discussed in the introduction, three parameterizations in NOAH have been formulated to indirectly represent the effects of lateral soil water redistribution and subgrid soil moisture heterogeneity. In this work described here, three phases of modifications to the NOAH model are being carried out in order to systematically explore the effects of these parameterizations.

In the first phase, the SLOPE parameter is being replaced with the TOPMODEL baseflow model. Thus, the baseflow Q_b is calculated as:

$$Q_b=Q_0 exp(-f z_{bar}) \tag{1}$$

where Q_0 and f are parameters of the catchment’s baseflow recession curve and z_{bar} is the catchment mean depth to the water table (Sivapalan et al, 1987). The TOPMODEL parameters Q_0 and f are functions of the individual catchment and must be calculated from known catchment data.

The second phase of the NOAH modifications consists of modifications to the infiltration formulation to

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be consistent with TOPMODEL's saturation excess runoff model. Hence, all precipitation is transformed to runoff in any area that is deemed "saturated" (local water table depth z_i less than height of capillary fringe) according to the TOPMODEL water table depth distribution, viz:

$$z_i = z_{bar} - (1/f)\{ln(\alpha_d T_e/(T_0 tan\beta)) - \lambda\} \qquad (2)$$

where T_0 is the local transmissivity, T_e is the areal integral value of transmissivity, and α_d is the area that drains through a given location per unit contour length. The term $ln(\alpha_d/tan\beta)$ is known as the topographic index (Beven & Kirkby, 1979), and the term $ln(\alpha_d T_e/(T_0 tan\beta))$ as it is used in Equation 2 is the combined soil-topographic index because it includes the transmissivity terms (Sivapalan et al, 1987). The term λ represents the areal integral value of the topographic index. As illustrated above, the local water table depth governs the redistribution of subsurface water as well as the occurrence of contributing areas.

The third and final modification is to implement and calculate a subgrid soil moisture distribution to canopy resistance routine so that canopy resistance function F2(θ) and energy balance/fluxes are computed by local soil moisture profile, which varies by local topographic index.

3. RESULTS

Figure 1 shows topographic index derived from the USGS HYDRO1K dataset for the Arkansas Red River basin. As shown above, the distributions of topographic index are required by TOPMODEL for catchment in order to calculate runoff, baseflow and the subgrid soil moisture distribution. As shown in Figure 2, the vertical and hoirizontal resolution has a significant effect on the parameters.

Figure 3 shows the location for a single grid modeling study carried out to demonstrate the effects of the TOPMODEL baseflow parameterization on NOAH. As shown in Figure 4, the old and new baseflow patterns are significantly different. The topographic index value used in the baseflow calculations of Figure 4 is derived from the uncorrected HYDRO1K data. However, as shown in Figure 2, the combined effect of vertical and horizontal resolution can have a significant effect on the ability to estimate the "true" average topographic index value. In Figure 5, the effect of downscaling the HYDRO 1K data according to Figure 2 is demonstrated.

4. CONCLUSIONS

The work to date suggests the following three conclusions:

1. The baseflow predicted by the TOPMODEL equation seems to behave more smoothly and realistically than the original formulation, which has a peak in the summertime.
2. The baseflow predictions, as with other aspects of TOPMODEL, are highly sensitive to parameters related to the Topographic index distribution and the decay of saturated hydraulic conductivity with depth.
3. In order to be useful as an LDAS model, the TOPMODEL parameters must be available for the CONUS and beyond, and therefore, an understanding of the effects of DEM resolution on the parameter estimation is essential.

More results and detailed discussion will be presented at the conference.

5. ACKNOWLEDGEMENTS

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Topographic Index of the Central US

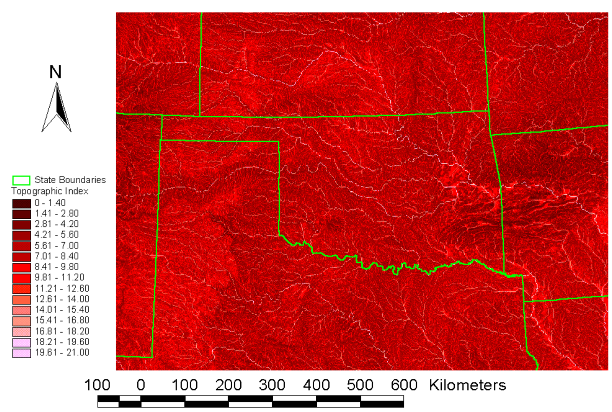

Figure 1: Topographic index from the USGS HYDRO1K dataset.. As implied by the name, the horizontal resolution is 1 km.

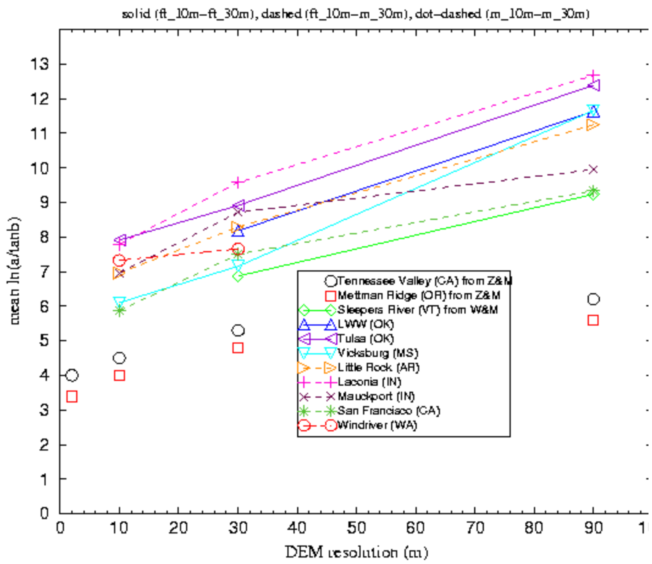

Figure 2: Effect of DEM horizontal and vertical resolution on TOPMODEL parameter topographic index. Dashed lines indicate a change in vertical resolution.

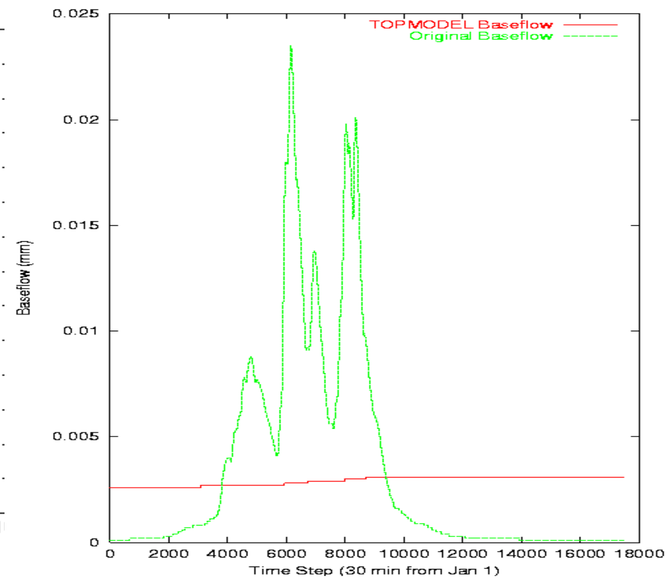

Figure 4: Baseflow (RUNOFF2) predicted by Original NOAH model and NOAH model with TOPMODEL-derived baseflow using TOPMODEL parameters derived directly from HYDRO1K data.

Figure 3: NOAH Test location near Champaign, IL

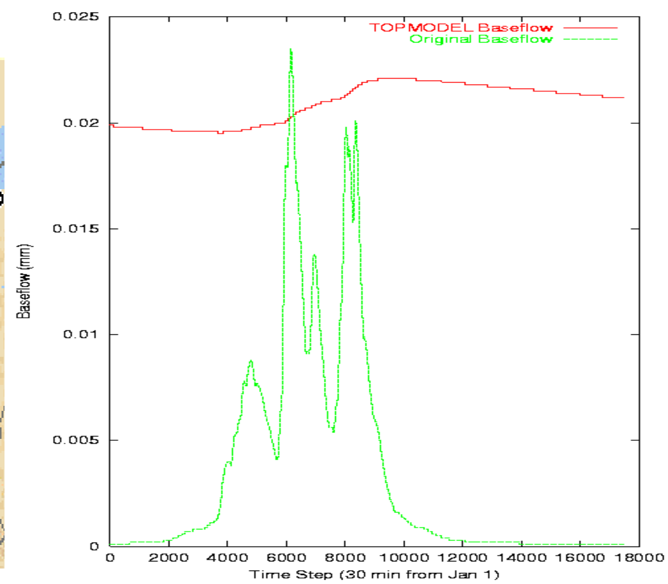

Figure 5: Same as Figure 4, but using TOPMODEL parameters estimated via downscaling relationships in Figure 2.