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AN INVESTIGATION OF SCALE AND SPATIAL VARIABILITY USING FULLY- AND SEMI-DISTRIBUTED TOPLATS AT THE WHITEWATER WATERSHED, KANSAS.

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1 INTRODUCTION

A primary aim of the DOE Water Cycle Pilot Study is to represent the water budget in a small watershed in the Southern Great Plains. An important consideration is how the spatial heterogeneity should be represented to give reasonable land surface hydrological fluxes. There is much discussion in the literature regarding under which conditions and at which scales spatial variability should be explicitly modeled, described by a distribution, or ignored (Wood, 1998). There are also problems of scaling that suggest that using small scale process descriptions at a large scale is inappropriate (Beven, 1995). The representation of spatial heterogeneity of soil moisture is essential for modeling processes that are nonlinearly related to soil moisture, such as the partitioning of sensible and latent heat fluxes. Remotely sensed soil moisture data is becoming increasingly available, however the variability within the remotely sensed footprint is spatially averaged. It is necessary to represent this variability, however it is not clear how, especially since the patterns of variability change under different conditions due to different controls.

In the absence of detailed spatially variable measurements, TOPLATS, a land surface model that has been shown to reproduce soil moisture patterns and hydrological fluxes in the Southern Great Plains (eg Famiglietti and Wood, 1994), is being used in fully distributed mode to generate small scale (30m) spatially variable data over the Whitewater catchment, a subcatchment of the Walnut River watershed, Kansas. The model has also been run in distributed mode at 1km scale, and with different representations of spatial variability of vegetation, topography, and precipitation. Comparison of the states and fluxes from the different representations can give insight into whether distributions of topography and vegetation, and spatially variable precipitation inputs will improve the representation of the hydrology. This study will focus on the effects on the soil moisture variability, average fluxes, and runoff, and whether this varies under different wetting and drying conditions.

This paper will give an initial comparison of the variation between outputs from the larger scale simulation, and simulations with varying representations of spatial variability. When the fully distributed data are available, a further analysis will be performed involving investigation of how the spatial variability could be represented to give reasonable average fluxes, without small scale fully distributed modeling which requires extensive computer resources. This will be presented in the final paper at AMS 2003.

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2 APPROACH

2.1 TOPLATS model

The TOPMODEL-based land-atmosphere transfer scheme, TOPLATS (Famiglietti and Wood, 1994) is a Soil-Vegetation-Atmosphere Transfer Scheme (SVATS) developed to be used as a land surface parameterisation in atmospheric models. As suggested by the title it is based on a TOPMODEL framework

(Beven and Kirkby, 1979), and therefore differs from other SVATS by allowing for topographic effects on water availability resulting from downslope flows.

The water balance is solved for a canopy (or bare soil) layer, a thin upper soil zone, and a lower soil zone, and the water table. The water and energy balance are coupled through the evaporation term. A detailed description of the original model is given by Famiglietti and Wood (1994), and modifications are described by Peters-Lidard et al. (1997).

There are two formulations of the model. The statistical version uses a distribution of the topographic index to describe the spatial variability of topography, and fractional representation of land cover types. The water and energy balance is solved for each combination of topographic index class and landcover class. The distributed version solves the water and energy balance for each pixel. This study focuses on the effects of running the model in different modes and at different scales. The finest scale at which spatially variable data are available is 30m, therefore the model is being run in fully distributed mode at 30m scale, and used as a baseline. In the absence of fine scale measurements, it will be assumed that the output data represent the spatial variability, though it should be acknowledged that it is scaling up from the point scale. The model has been run with different representations of spatial variability, and the outputs will be compared with the 30m simulation outputs, to examine to what extent spatial variability should be represented to give reasonable hydrological fluxes.

At present, the completed model simulations are in distributed mode at 1km, and in combined distributed/statistical mode, where the variability of topography and vegetation within each 1km pixel is described by distributions of the 30m variability. The combined mode has been run firstly with spatially variable precipitation, and secondly, with spatially uniform precipitation. A brief description of the variations in outputs for 1999 from these different representations is given here, and a more detailed analysis will be presented in the final paper when the data from the 30m scale model simulation are available.

2.2 Whitewater watershed data

The Whitewater river is a tributary of the Walnut river in Kansas. The topography is gently rolling, and the main land uses are cropland and grassland. It falls within the U.S. Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site, therefore there are measurements available that are pertinent to land surface modeling experiments. TOPLATS input data were prepared for the years 1999 and 2000.

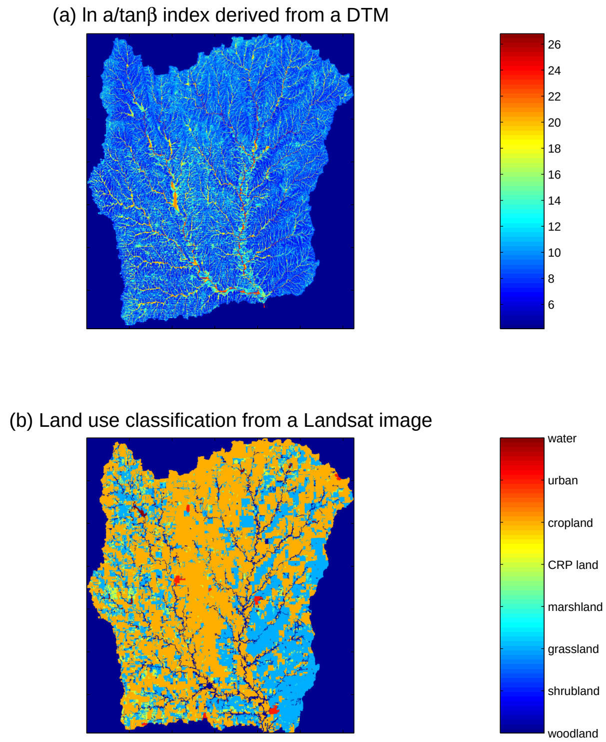

Figure 1: Topographic index and landcover classification at 30m resolution, Whitewater catchment, Kansas

The topographic index was prepared from a 30m DTM (figure 1), and 8 land use/cover types were derived by Kansas GAP based on a 30m scale Landsat-TM image (Gibbs, pers. comm., figure 1). TOPLATS input files were generated at 30m scale, and at 1km scale as distributions of 30m data within 1km pixels. They were also generated at the 1km scale from a downscaled version of the DTM, and by assigning the dominant vegetation class within the 1km pixels (figure 2). Land cover parameters were assigned to each land cover class, and the leaf area index data (Gibbs, pers. comm.) were changed every 2 weeks to represent the seasonal variations. The soil classes are based on 1km STATSGO data, and the parameters assigned according to the soil texture (Bashford et al., 2002).

For each pixel, the rainfall is calculated as a weighted average of the nearest 4 raingauges of the 24 that are within the Whitewater watershed. Meteorological data from the Towanda ARM site were used, and data from neighbouring Halstead ARM site were used for infilling missing data.

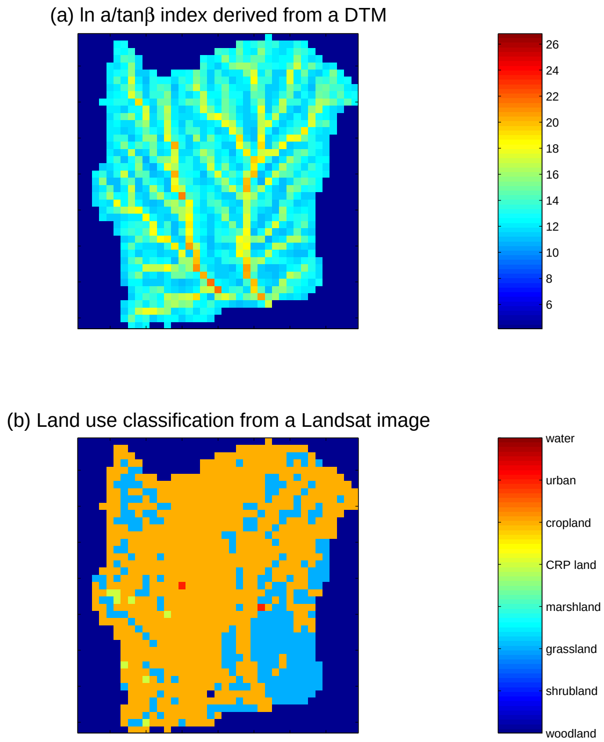

Figure 2: Topographic index and landcover classification at 1km resolution, Whitewater catchment, Kansas

3 RESULTS

Upon completion of the 30m distributed modeling, a detailed validation and comparison of outputs will be performed. At this time, the data from the combined distributed/statistical simulation with spatially variable precipitation have been used for comparison with measured data, as they best represent the spatial heterogeneity. Figures 3 and 4 show the measured fluxes at the Whitewater EBBR site, and the equivalent fluxes for the co-located 1km pixel. The modeled latent heat flux is close to the measured, but sensible heat tends to be overestimated.

The total runoff (baseflow and surface runoff) predicted by the combined statistical/distributed model run averages 0.0273 mmh^{-1} which is close to the measured 0.035 mmh^{-1}. The hourly data were not compared as there is no routing, but the weekly averages show a similar pattern (figure 5).

The mean values of variables from each run are given in table 1. One main effect of using uniform data over the 1km pixels as opposed to a distribution is higher evapotranspiration, and evapotranspiration occurring at or nearer to the potential rate for most of the period. This could indicate that the distributions lead to a range of soil moistures, some of which are low enough to lead to moisture controlled evapotranspiration, but without the distributions the 'average' soil moistures remain high enough to allow atmospherically controlled evapotranspiration. Saturated excess runoff is lower with the uniform data, probably again because the 'average' 1km soil moisture rarely reaches saturation, whereas with a distribution of topographic index values within the 1km area, the fractional area with a high topographic index is likely to reach saturation.

The effects on average fluxes of using spatially uniform precipitation are not severe in this case. The main effects are to reduce surface runoff and evapotranspiration. It is assumed that this is because less saturation occurs when the precipitation is spatially averaged as there are less intense precipitation occurrences.

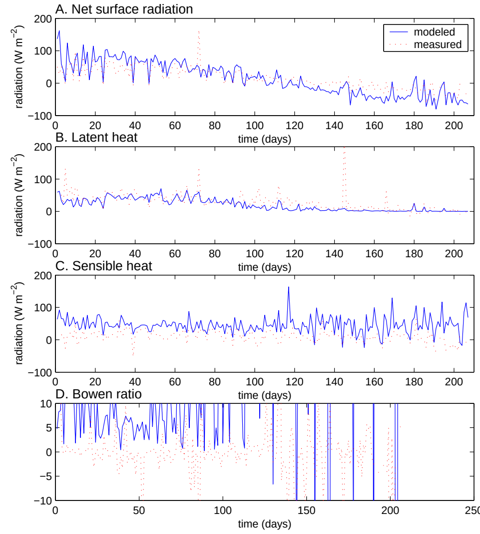

Figure 3: Comparison of modeled and measured energy fluxes at the Whitewater EBBR site, daily values are the average of hourly values 9.00-15.00

4 DISCUSSION

It is anticipated that this study will give insights into how spatial variability can be represented without using fully distributed modelling at a small scale. The preliminary results shown here confirm that different representations of spatial variability do lead to differences in averaged outputs. This will be examined further as more results become available.

It should be acknowledged that any findings could be specific to this model, parameter set, and domain. TOPLATS model has been shown to reproduce hydrological fluxes in the Southern Great Plains, however it does not represent all processes, and any conclusions

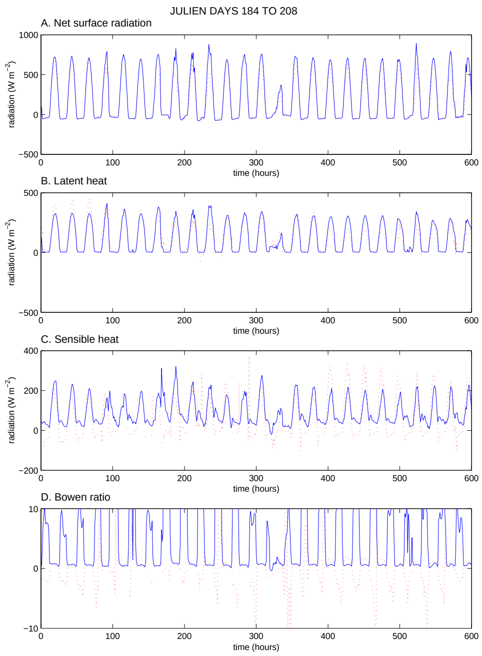

Figure 4: Comparison of modeled and measured hourly energy fluxes at the Whitewater EBBR site

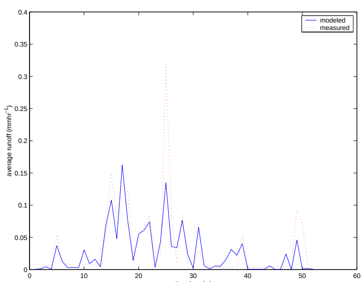

Figure 5: Comparison of modeled and measured weekly runoff at the Whitewater EBBR site

drawn from a study like this should be verified with other complex models, and other parameter sets. The dominant controls on hydrological fluxes have been shown to vary significantly at different locations, therefore it should also be assumed that the results are specific to the Whitewater subcatchment.

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	[a]	[b]	[c]
Surface runoff (mmh^{-1})	1.81E-2	2.30E-2	2.20E-2
Subsurface flow (mmh^{-1})	5.01E-3	4.25E-3	4.13E-3
Upper SM	3.77E-1	3.78E-1	3.78E-1
Lower SM	3.94E-1	4.04E-1	4.04E-1
Water table depth (mm)	1.36E+3	1.42E+3	1.42E+3
Evapotranspiration (mmh^{-1})	1.54E-2	1.88E-2	1.84E-2
Net radiation (Wm^{-2})	1.27E+2	1.25E+2	1.25E+2
Latent heat (Wm^{-2})	5.68E+1	5.37E+1	5.49E+1
Sensible heat (Wm^{-2})	9.23E+1	9.40E+1	9.27E+1
Ground heat (Wm^{-2})	-2.20E+1	-2.33E+1	-2.29E+1

Table 1: Average values of TOPLATS outputs 1999 for [a] 1km scale distributed run, [b] combined distributed/statistical run, and [c] combined distributed/statistical run, spatially averaged precipitation

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