Influence of Subgrid Variability on Soil Moisture and Latent Heat Flux

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Introduction

Soil hydrology is highly nonlinear. As surface soil becomes saturated with water, excess water runs off in streams. If the parameters that influence surface soil water vary widely within a general circulation model (GCM) grid cell, the grid cell mean soil moisture and latent heat flux could be very sensitive to the treatment of subgrid variability.

The parameters that control surface hydrology include meteorology (primarily precipitation, but also wind speed, temperature, and humidity), downward radiation (solar and longwave), soil characteristics (porosity, hydraulic conductivity, thermal conductivity, albedo), and vegetation characteristics (leaf area index, fractional vegetation cover, stomatal resistance, and root zone depth).

The Atmospheric Radiation Measurement Program (ARM) Southern Great Plains (SGP) site was chosen by the ARM program partly on the basis of its surface homogeneity. Even so, the soil and vegetation characteristics may be heterogeneous enough to require a treatment of their subgrid variability.

A more likely candidate for driving subgrid variations in surface hydrology is precipitation, which in the summertime can be highly heterogeneous. One might expect to find much more runoff and, hence, less soil moisture and latent heat flux if subgrid variations in precipitation are accounted for.

However, because soil moisture is an integrator of temporal variability on time scales of up to one month, it is not necessarily the instantaneous distribution of the precipitation that is important for surface hydrology. Because precipitation systems typically propagate across the SGP site, the monthly mean precipitation is likely to be much more homogeneous than the instantaneous precipitation. Thus, it is not at all obvious that even the highly convective summertime precipitation over the SGP site can produce enough subgrid variability in surface hydrology that such variability must be treated when estimating the grid cell mean latent heat flux.

Approach

To characterize the subgrid variability in surface hydrology at the SGP site, we drive a land surface model (the Biosphere-Atmosphere Transfer Scheme [BATS]; Dickinson et al. 1993) with meteorology, radiation, soil characteristics, and vegetation characteristics observed at 111 Oklahoma MESONET stations for the period from June to August 1995. Summertime conditions were chosen because precipitation is most likely to be convective, and hence heterogeneous, during summertime.

The MESONET stations sample a region about the size of one GCM grid cell, and provide measurements of surface meteorology and downward solar radiation at 5-minute intervals. Some data gaps exist; these have been filled by using values from nearest neighbors (for surface pressure, insolation, temperature, wind speed, and relative humidity), from previous values (for accumulated precipitation and, if nearest neighbors are also missing data, for surface pressure, temperature, wind speed, and relative humidity), or from a model (for insolation if data at nearest neighbors is also missing). Downward longwave radiation is estimated from the measured surface air temperature and vapor pressure using Brunt's equation (Monteith 1973).

The soil characteristics are determined from the BATS representation of 12 different soil types ranging from sand to loam to clay. For each soil type, BATS assigns values of soil porosity, hydraulic conductivity, thermal conductivity, albedo, and other parameters. The soil types are assigned from the State Soil Geographic Data Base (Soil Conservation Service 1993) database, which has a spatial resolution of 8 km. Of the 111 MESONET stations, 44 were found to be sandy loam, 31 silt loam, 14 loam, 7 clay, 6 clay loam, 5 silty clay loam, 3 sand, and 1 loamy sand.

The vegetation characteristics are determined from the BATS representation of 18 different vegetation types. The vegetation type at each station was determined from the U.S. Geological Survey land cover characteristics data set cd-rom, which uses an advanced very high resolution radiometer (AVHRR) normalized-difference vegative index (NDVI) to estimate vegetation class at 1-km resolution. The 28 vegetation classes were folded into the 18 BATS vegetation classes. The class at each MESONET station was determined from the class at the nearest 1-km pixel. Of the 111 MESONET stations, 72 were found to be crops/mixed farming, 15 short grass, 10 tall grass, 8 deciduous broadleaf tree, 4 evergreen shrub, 1 mixed woodland, and 1 inland water. For each vegetation class, the BATS scheme assigns values for leaf area index, stem area index, fractional vegetation cover, minimum stomatal resistance, root zone depth, albedo, and other parameters.

These parameters were assumed to be constant during the time period of this study. Although actual parameters varied in time, such a simplification is still useful for the sensitivity tests described below.

To assess the importance of accounting for subgrid variability, we drive BATS at each station once accounting for the full subgrid variability of all parameters, and again with various parameters averaged over all stations. By averaging each parameter separately, we can isolate the importance of accounting for the subgrid variability in each parameter.

For soil and vegetation properties, averaging was performed two different ways. In one the soil and vegetation parameters were averaged, weighting with respect to frequency of each soil and vegetation type (Noilhan and Lacarrere 1995). In the second mode, we simply adopted the parameters associated with the dominant soil and vegetation types (sandy loam and crops/mixed farming).

Results

Table 1 lists the station and 3-month mean runoff, evaporation, surface soil moisture, latent heat flux, and sensible heat flux for the simulations. As might be expected, averaging precipitation has the largest impact of any parameters on the surface energy and moisture balance, with runoff R reduced from 1.81 mm day^{-1} to 1.44 mm day^{-1}, surface soil moisture increased from 0.451 to 0.466, and evaporation E increased from 4.61 to 4.97 mm day^{-1}. The fractional increase in runoff is larger than that of evaporation because runoff depends directly on precipitation, which is more heterogeneous than soil moisture or temperature, which drive evaporation. The increase in soil moisture is rather small, as the increase in evaporation largely balances the reduction in runoff.

Averaging radiation, soil parameters, and vegetation parameters changes the mean fluxes by only a few W m^{-2}. Using the dominant vegetation type rather than averaging the vegetation parameters has little impact on the mean runoff but produces a latent heat flux bias greater than 10 W m^{-2}, because the dominant vegetation type (crops/mixed farming) evidently yields a larger latent heat flux and smaller sensible heat flux than other vegetation types under the same conditions. Because averaging the vegetation parameters yields much closer agreement with the heterogeneous case than does using the parameters of the dominant vegetation class, averaging the parameters is clearly preferable.

To illustrate how systematic the averaging biases can be, Figure 1 shows time series of the daily and station mean

Table 1. Simulation results.

Simulation	Runoff mm day^{-1}	Evap. mm day^{-1}	Soil Moisture	LH Flux W m^{-2}	SH Flux W m^{-2}
Full spatial variability	1.81	4.61	0.451	134.0	36.8
Average precipitation	1.44	4.97	0.466	144.3	27.9
Average radiation	1.78	4.65	0.453	135.0	33.4
Average forcing	1.41	5.06	0.465	147.1	23.2
Average soil parameters	1.69	4.67	0.462	135.6	35.7
Dominant soil type	1.83	4.49	0.382	130.6	38.9
Average vegatation parameters	1.77	4.69	0.425	136.5	33.9
Dominant vegetation type	1.82	5.01	0.477	145.7	25.3
Average surface & forcing	1.31	5.16	0.466	150.0	20.6

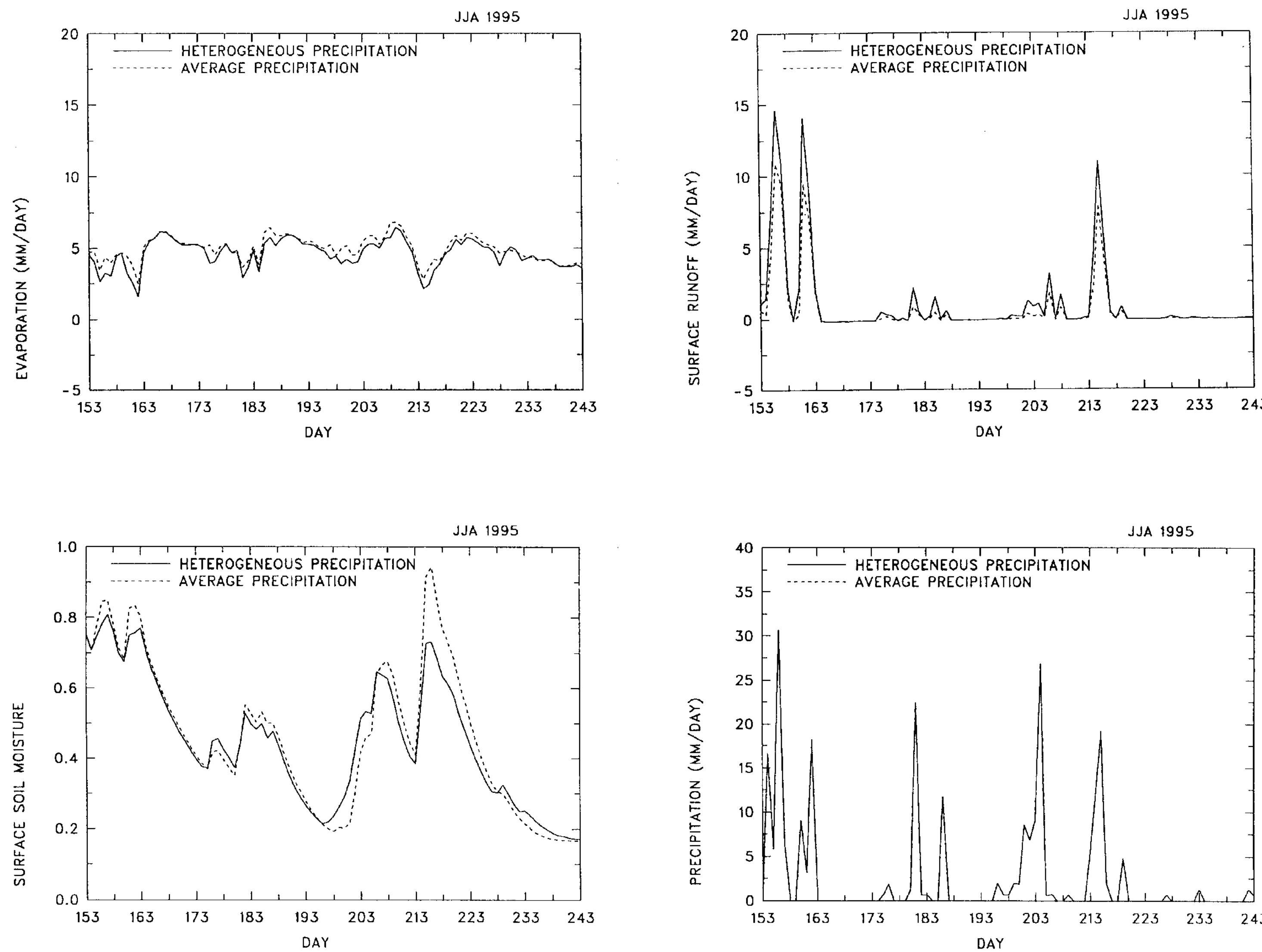

Figure 1. Daily and station mean simulated evaporation rate, surface runoff rate, and surface soil moisture simulated with station averaged precipitation (dashed line) and local station precipitation (solid line).

surface runoff, evaporation, precipitation, and surface soil moisture for the simulations with heterogeneous and average precipitation. The station mean precipitation, which is of course the same in each experiment, exhibits variability on times scales of just a few days. Surface runoff, which depends on both soil moisture and precipitation, also varies on time scales of days and is systematically smaller when precipitation is averaged over all stations. Surface soil moisture, on the other had, varies on time scales of weeks and is sometimes greater with average precipitation and other times less. Surface soil moisture is sometimes less with average precipitation than with heterogeneous precipitation because evaporation is almost always greater with average precipitation, even when there is no surface runoff. Because evaporation depends on the soil moisture of the root zone as well as the surface layer, evaporation with average precipitation can exceed that with heterogeneous precipitation even when the surface soil moisture would suggest otherwise.

Conclusions

In our application of the BATS model with MESONET data, we have found that neglecting subgrid variations in precipitation reduces the simulated summertime runoff by 20% and enhances summertime evaporation by about 8%. Neglecting subgrid variations in all meteorological forcing reduces the simulated summertime runoff by 22% and enhances summertime evaporation by about 10%. Neglecting subgrid variations in surface properties as well as meteorological forcing reduces the simulated summertime runoff by 28% and enhances summertime evaporation by about 12%. Thus for summertime in Oklahoma, most of the sensitivity of grid cell mean runoff and latent heat flux to subgrid variability can be attributed to spatial variability in precipitation.

We have also found that, for Oklahoma, averaging surface properties yields somewhat better agreement with the heterogeneous case than using the dominant soil and vegetation types.

In all cases the biases in evaporation, latent heat flux, and sensible heat flux are rather small. The biases in simulated runoff, on the other hand, are much larger and cannot be neglected if surface hydrology is the concern.

It is important to keep in mind that the vegetation characteristics were not allowed to change with time during the simulations. In reality, considerable variations are known to occur as crops grow and are harvested. In the future we will test the generality of these initial conclusions by including the effects of such variations explicitly. We will also compare the simulated fluxes with measured flux values at the ARM extended facilities.

References

Dickinson, R.E., A. Henderson-Sellers, and P.J. Kennedy, 1993: *Biosphere-Atmosphere Transfer Scheme (BATS) Version 1e as Coupled to the NCAR Community Climate Model*. NCAR Tech. Note, NCAR/TN-387+STR. National Center for Atmospheric Research, Boulder, Colorado.

Monteith, J.L., 1973: *Principles of Environmental Physics*. Edward Arnold Ltd, 242 pp.

Noilhan, J., and P. Lacarrere, 1995: GCM grid-scale evaporation from mesoscale modeling. *J. Climate* **8**:206-223.

Soil Conservation Service, 1993: The State Soil Geographic Data Base (STATSGO) Data Users Guide, pp. 88, Misc. Pub. Num 1492.