SENSITIVITY OF LUMPED PARAMETER HYDROLOGICAL MODELS TO SPACE-TIME VARIABILITY OF RAINFALL

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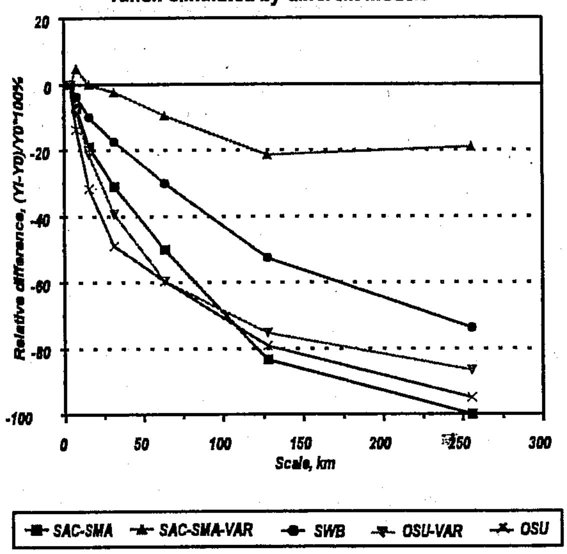
Introduction. Scale dependency of hydrological models is the critical issue in coupling of land surface-atmospheric parameterizations. The problem is not only that model outputs may depend on the space-time variability of input data and model states, but that widely used lumped models depend very much on aggregation scale used in tunning (calibrating) their parameters. The main issues of this study were: how outputs of hydrological models are sensitive to space-time variability of rainfall, how different formulations of infiltration processes account for the spatial variabilityof rainfall, and if there is a scale dependency of calibrated model parameters.

Models used. Three lumped hydrological models were used in the study; the Sacramento Soil Moisture Accounting (SAC-SMA) model, the Oregon State University (OSU) model, and a Simple Water Balance (SWB) model. The SAC-SMA model [Burnash et al.,1973] is a conceptually based rainfall-runoff model with spatially lumped parameters and there are strong physical arguments to support the model. It is an operational hydrologic model in the National Weather Service river forecast system, and it is applied to river basins ranging from 250 km^2 up to 4000 km^2, with exceptions outside of this range. The model has 6 soil moisture states and 16 parameters, not counting the 12 parameters used for adjusting potential evaporation values. Most of the model parameters have to be calibrated using historical data. The OSU model [Pan and Mahrt, 1987] was used as the land surface hydrologic parameterization in the Oregon State University one-dimensional planetary boundary layer model. The OSU model is based on the finite difference solution to the one-dimensional Richards equation. The two soil layer version was used in this study, with a thin upper layer of 5 cm and a thick lower layer of 1-1.5 m. The OSU model explicitly accounts for the effect of vegetation on evapotranspiration by inclusion of the canopy resistance scheme. However, it does not account for the effect of spatial variability in hydrologic variables. Most of the parameters in the OSU model are usually derived using the soil and vegetation classification information. The SWB model [Schaake et al., 1996] has a two-layer structure with both a physical and statistical basis for the model parameters. The model was developed based on probabilistic averaging of the point infiltration equation and implicitly accounts for the spatial variability in input data. This approach considers the frequency of occurrence of variables of certain ranges over an area without regard to the location of a particular occurrence within the area. The model has 5 parameters which should be calibrated using historical data. Reformulated version of the SAC-SMA (SAC-SMA-VAR) model and a version of the OSU model (OSU-VAR) with the infiltration formulation replaced by the infiltration formulation in the SWB were used in addition to the three basic models. The surface-runoff generation component of the SAC-SMA model was reformulated to account for the spatial variability of rainfall. Assuming that hourly rainfall is approximately gamma-distributed in space, areal surface runoff of the SAC-SMA can be calculated as the expectation of point surface runoff. Distribution function parameters were estimated continuously for each aggregation area at each time step using 4x4 km resolution radar data.

Method and Input Data. Hourly high-resolution rainfall estimates from the Next Generation Weather Radar (NEXRAD) were used to assess sensitivities of the models to the grid (i. e., sub-basin) scale of the models and aggregation scale of the model outputs. The NEXRAD data set covers the eastern portion of the Tulsa, Oklahoma, river forecasting region and spans a 9-month period from May 7, 1993 through January 31, 1994. This period records the very wet summer which resulted in the "Great Flood of '93" in the Midwest. The test area in the Red River Basin over the Oklahoma-Arkansas border was gridded into 64x64 rectilinear cells of approximately 4x4 km in size, which match those of radar rainfall data. The models were run at grid scales of 4x4, 8x8, 16x16, 32x32, 64x64, 128x128, and 256x256 km. Each component of the model output was then averaged over aggregation scales of 8x8, 16x16, 32x32, 64x64, 128x128, and 256x256 km. The SAC-SMA model was also run in semi-distributed mode using natural basin boundaries. A selected basin (1600 km^2) in the 64x64 grid test area was broken down into a number of sub-basins with a predefined average area. By changing the average sub-basin areas it is possible to create different spatial resolution. Model parameter calibrated on the entire basin were distributed spatially to all sub-basins. The average sub-basin area was changed from 60 km^2 to 800 km^2.

Results. The results show that faster responding components, such as surface runoff, interflow, and total channel inflow, are very sensitive to grid scale, particularly at larger aggregation scales. Figure shows the relative change in the surface runoff volume simulated by different models versus the scale for the 1-hour time step. The runoff volumes have been scaled relative to their value generated at the 4x4 km^2 scale. The point type models (SAC-SMA and OSU) are most sensitive to the spatial scale. Surface runoff estimated by those models was decreased to zero as the spatial scale increased to 256x256 km^2. The OSU-VAR version decreased scale dependency of the OSU. However, the SWB was less scale dependent than OSU-VAR. The reformulated SAC-SMA, SAC-SMA-VAR, reduced scale dependency very much, especially at the larger scales. These results indicate also that models calibrated at one sub-basin scale can produce biases in the water balance if applied at different scales. Use of 3-hourly and 6-hourly rainfall resulted in similar reductions in scale dependency.

Scale dependency of the surface runoff simulated by different models



Summary. Point type models (OSU, SAC-SMA) are very sensitive to the spatial scale at which they are applied. Probabilistic averaging of the point infiltration can reduce scale dependency, e.g. OSU-VAR and SAC-SMA-VAR. Continuous ingesting of a distribution function of rainfall significantly improved model performance at all scales. This analysis underscores the relationship between rainfall variability and transferability of the model parameters. It points out that a physically based land surface parameterizations derived from local water and energy balance equations, when coupled with a low resolution atmospheric model, can not guarantee a high accuracy in the areal water balance without adjustment of model parameters.

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