A MODEL FOR DOWNSCALING SPATIAL RAINFALL AT THE MESOSCALE

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The precipitation output of a mesoscale atmospheric numerical model is usually interpreted as the average rainfall intensity over the grid cell of the model (typically 30x30 km to 60x60 km). However, rainfall exhibits considerable heterogeneity over subgrid scales (i.e., scales smaller than the grid cell), so it is necessary for hydrologic applications to recreate or simulate the small-scale rainfall variability given its large-scale average. Rainfall disaggregation is usually done statistically. In this research, a model has been developed that has the ability to statistically reproduce rainfall variability at small (subgrid) scales. The model is conditioned on large-scale rainfall averages and thermodynamic parameters of the prestorm environment. It is intended to be coupled with a mesoscale numerical weather prediction model for subgrid-scale parameterization of rainfall.

The model development is based on two hypotheses: (a) multiscale standardized rainfall fluctuations (defined as rainfall wavelet coefficients divided by the corresponding scale rainfall averages) show scale invariance over the mesoscale (40 to 60 km in horizontal length), and (b) the statistical parameterization of these fluctuations relates to prestorm environmental conditions. These hypotheses were tested extensively using data from mid-latitude mesoscale convective systems observed during the PRE-STORM experiment (May and June of 1985) over Oklahoma and Kansas. It was found that, ignoring the directionality present in some systems, multiscale standardized rainfall fluctuations can be parameterized by a Gaussian distribution, a scale-invariant parameter, H, and a scale-dependent parameter σ_1, (scale index $m=1$, here at the scale 8x8 km). The parameter σ_1, relates to the variability of the standardized rainfall fluctuations at the specified scale. The parameter H dictates how the variability changes over scales, i.e., $\sigma_m = 2^{(m-1)H}\sigma_1, m>1$. If strong directionality is present, then one has at most six parameters $\{H_i, \sigma_{1,i}\}_{i=1,2,3}$, two for each direction (horizontal, vertical, and diagonal).

The parameters H and σ_1 were found to depend strongly on the convective instability of the prestorm environment as measured by the convective available potential energy (CAPE). The linear correlations of CAPE with H and σ_1 (based on 17 events for which adequate radar rainfall and rawinsonde observations were available) showed that CAPE explains almost 60 percent of the variability in H and σ_1 (R=0.82 and R=-0.73, respectively). These correlations were interpreted based on physical reasoning.

The implementation of the model for physically-based, statistical, subgrid-scale parameterization of rainfall involves several steps. First, the model is initialized with large-scale averages of rainfall (e.g., averages over 30x30 or 60x60 km) and representative soundings from which CAPE values can be estimated. Both input parameters may be obtained from the output of a mesoscale numerical weather prediction model. Second, based on the empirical relations between rainfall statistical parameterization and CAPE, the parameters H and σ_1 are predicted. Standardized rainfall fluctuations at the large scale are then generated from a Gaussian distribution with zero mean, and variance appropriately computed from the values of σ_1, m, and H. The generated fluctuations are rescaled by the corresponding averages at that scale and are "added," via the inverse wavelet transform, to these averages to get rainfall intensities at the next finer scale. This procedure is repeated at all intermediate scales up to the finest scale of interest.

The ability of the model to reproduce small-scale rainfall variability was validated by comparing summary statistics and spatial pattern measures of simulated and observed fields. Validation was done on four different mesoscale convective system types (e.g., squall line, mesoscale convective complex, chaotic system, and "leading-line/training-stratiform" system with transition region) observed during the PRE-STORM experiment. By the properties of the Haar wavelet transform, the unconditional first moment of rainfall is explicitly preserved at all scales. Other statistical measures, e.g., the conditional mean, conditional and unconditional variances and probabilities of exceedence, compared very well with the corresponding statistical properties of the original fields. However, there is a tendency for the autocorrelation of the simulated fields to decrease more rapidly with lag than is observed. One-run-simulation spatial patterns also compared relatively well with patterns of the observed rainfall fields in most simulations, although the model could not always reconstruct the transition region for "leading-line/training-stratiform" storm. One of the most notable features of this model is its ability to reconstruct the fraction of the rainy area at all subgrid scales.