Using a Mesoscale Model Coupled to a Land-Surface Model to Simulate Surface Fluxes at High Resolution

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Overview

One goal of the Atmospheric Radiation Measurement (ARM) Program is to improve general circulation models (GCMs) by obtaining detailed meteorological information in limited areas of order 200 km square and comparing GCM parameterizations with the mean radiative and convective properties in such areas. Typical GCM grid boxes are 100 to 200 km square, but there is in reality much structure at smaller scales that is represented by their parameterizations. Meteorological observations alone cannot represent this structure, so we use a full-physics mesoscale model forced by large scale tendencies to give as complete a picture of the sub-200 km scale structures as possible. This allows us to produce a full four-dimensional characterization of the atmosphere that, given sufficiently complete physics in the model and sufficiently good data, will provide a representation of the actual state of the atmosphere.

Mesoscale models are also valuable testbeds for certain parameterizations in GCMs such as land-surface processes and radiation schemes. This is because of their high resolution that makes direct validation against ARM observations possible even in heterogeneous environments.

Introduction

The National Center for Atmospheric Research/Perm State Mesoscale Model (NCAR/MM5) has recently been coupled to the land-surface model (LSM) used by the National Centers for Environmental Prediction (NCEP) in its Eta forecast model. This is a sophisticated model with four soil layers and predictive equations for soil temperature, soil moisture, snow cover, and canopy water. It makes use of high-resolution vegetation and soil data, available on a 1-km grid from the United States Geological Survey (USGS), and climatological time-varying vegetation fraction derived from satellite.

A goal of this work is to use a high resolution of land-surface variability in the mesoscale model to determine how this relates to the ARM surface flux observations, and to allow an estimate of the mean fluxes over the ARM Southern Great Plains site. Factors such as cloudiness will also impact the mean, and may vary greatly across the ARM site, or a GCM grid box. A mesoscale model has a chance of capturing this heterogeneity better than the observations alone.

Methodology

We are taking seven summer cases, four from the First ISLSCP (International Satellite Land Surface Climatology Project) Field Experiment (FIFE) in 1987, and three from ARM in 1997. These range from clear to rainy conditions, and have good surface flux data sets for verification. Simulations are conducted of 48-hour periods with a finest mesh size of 10 km.

The soil moisture and temperature are initialized either from gridded fields provided by the NCEP/NCAR Reanalysis Project (2.5-degree grid), or from the Eta analysis system (40-km grid) if the case is recent enough.

To date we have implemented the land-surface model, incorporated the additional required data to specify the land-surface variations and properties (e.g., see Figure 1 where vegetation categories are displayed), and run preliminary tests on these seven cases that give promising results. The diurnal behavior is well captured in clear-sky conditions, and the fluxes are improved over the previous MM5 simple slab model. Circulations driven by surface heterogeneity are evident in quiet periods, and an impact is noticeable in rainfall. Sensitivity to initial soil moisture has been tested and shows that in drier regions small errors have much larger impacts on the fluxes than in near-saturated conditions.

For ARM we envisage generating longer period data sets to complement observations and for use in single-column modeling, where there is some need of adequately representative boundary conditions, including the lower boundary where there may be significant variation over the few weeks of an intensive observation period (IOP).

The MM5 Model

The model features and options used in this study are as follows. Equations are for nonhydrostatic, compressible motion, in terrain-following coordinates with a Lambert conformal map projection. Prognostic equations exist for wind components, vertical velocity, pressure perturbation, temperature, water vapor, ground temperature, and microphysical water and ice content variables. It has an upper radiative boundary condition, relaxation lateral boundary conditions, and interactive two-way nesting. The model includes microphysics with cloud, rain, snow/graupel, and ice processes on all domains' resolved scales. The Grell cumulus parameterization scheme is adopted on all domains. The Medium-Range Forecast Model (MRF) (Hong and Pan 1996), planetary boundary layer, and a surface energy budget calculation are used. There is also an atmospheric longwave and shortwave radiation scheme interacting with model clouds and land surface.

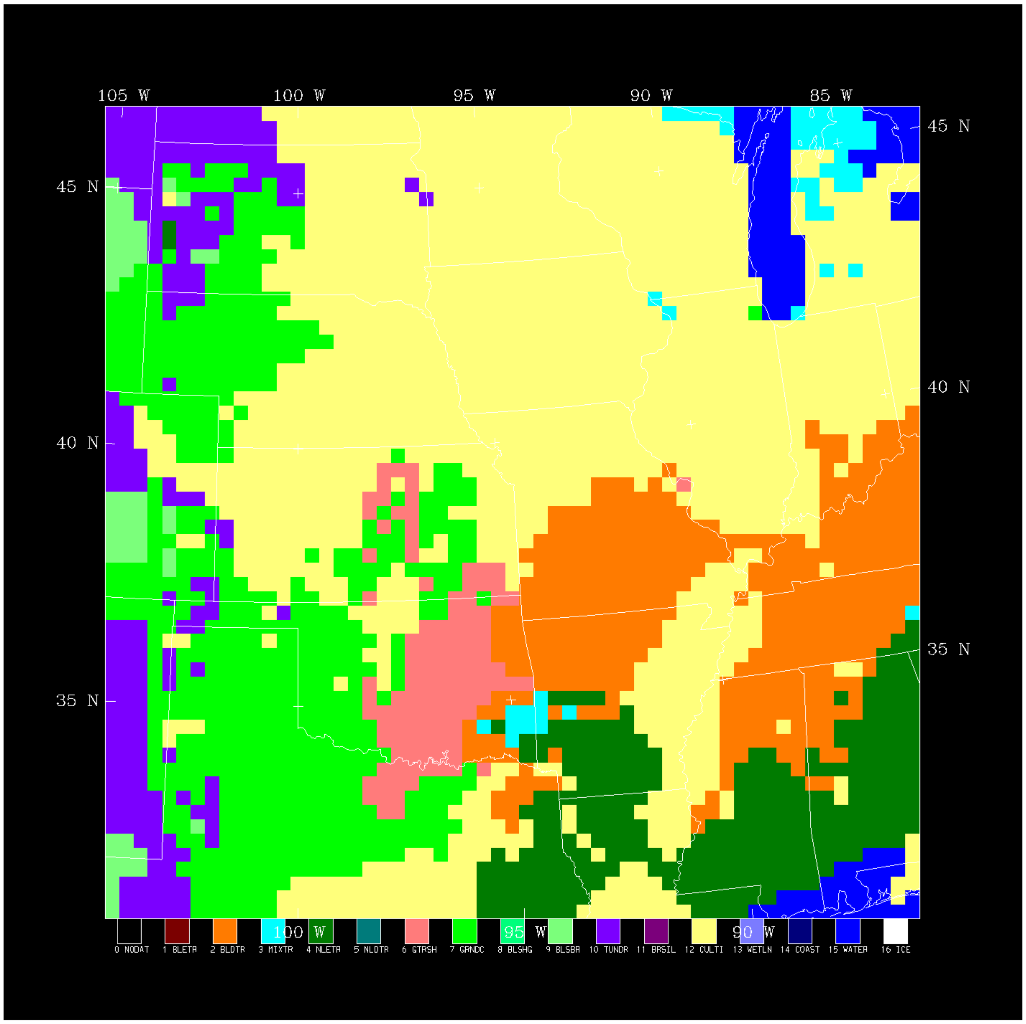

Figure 1. The 30-km vegetation category map used on domain 2 in the simulations (based on SiB categories).

Results: June 4 to 5, 1987, Clear-Sky Case

Figures 2 and 3 show some comparisons against observations and the current simple slab model in MM5 for a clear-sky case (June 4 to 5, 1987) during FIFE (First ISLSCP [International Satellite Land Surface Climatology Program] Field Experiment). The results show good agreement with boundary-layer and surface flux evolution with an improvement in the surface fluxes using the land-surface scheme.

The improvement is likely due to the use of a soil moisture based on the NCEP/NCAR reanalysis rather than the fixed value used in the standard MM5 surface scheme.

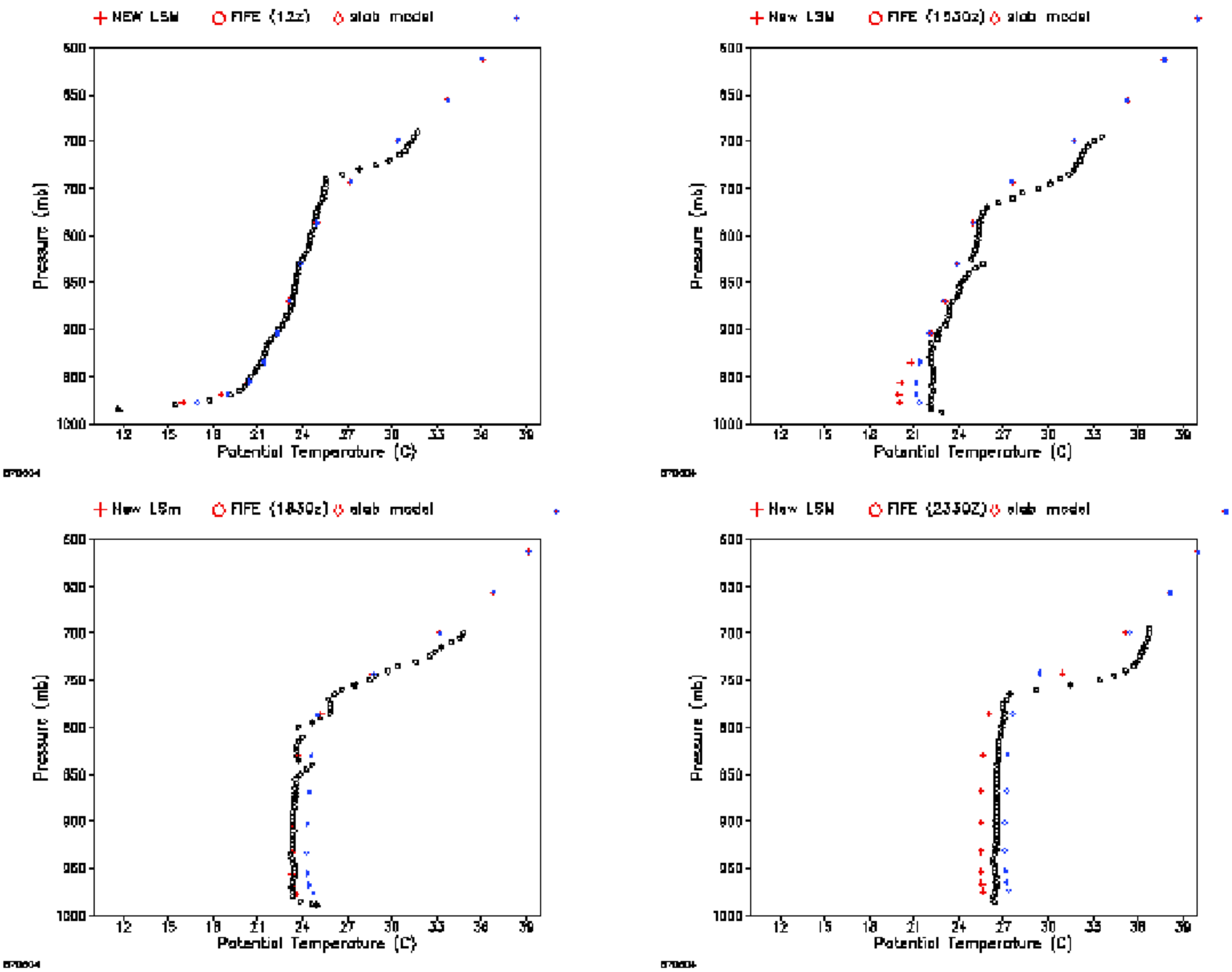

Figure 2. Boundary-layer evolution for FIFE June 4 to 5, 1987, case showing potential temperature profile at (a) 1200 Universal Time Coordinates (UTC), (b) 1530 UTC, (c) 1930 UTC, and (d) 2330 UTC, showing the old and new surface parameterizations and the observed profile.

Results: August 12 to 13, 1987, Rainfall Case

This test demonstrates the effects of rainfall on the soil moisture and surface run-off fields. As can be seen from the panels in Figure 4, heavy precipitation produced an area of run-off and soil moisture increase that followed the rainfall pattern. In Figure 5, the green line compared to the blue line shows the response of the deep soil moisture (10 cm to 40 cm below ground) compared to the topsoil layer (0 cm to 10 cm). This demonstrates the internal flux of moisture, which depends on soil properties. The point chosen is that nearest to the FIFE site.

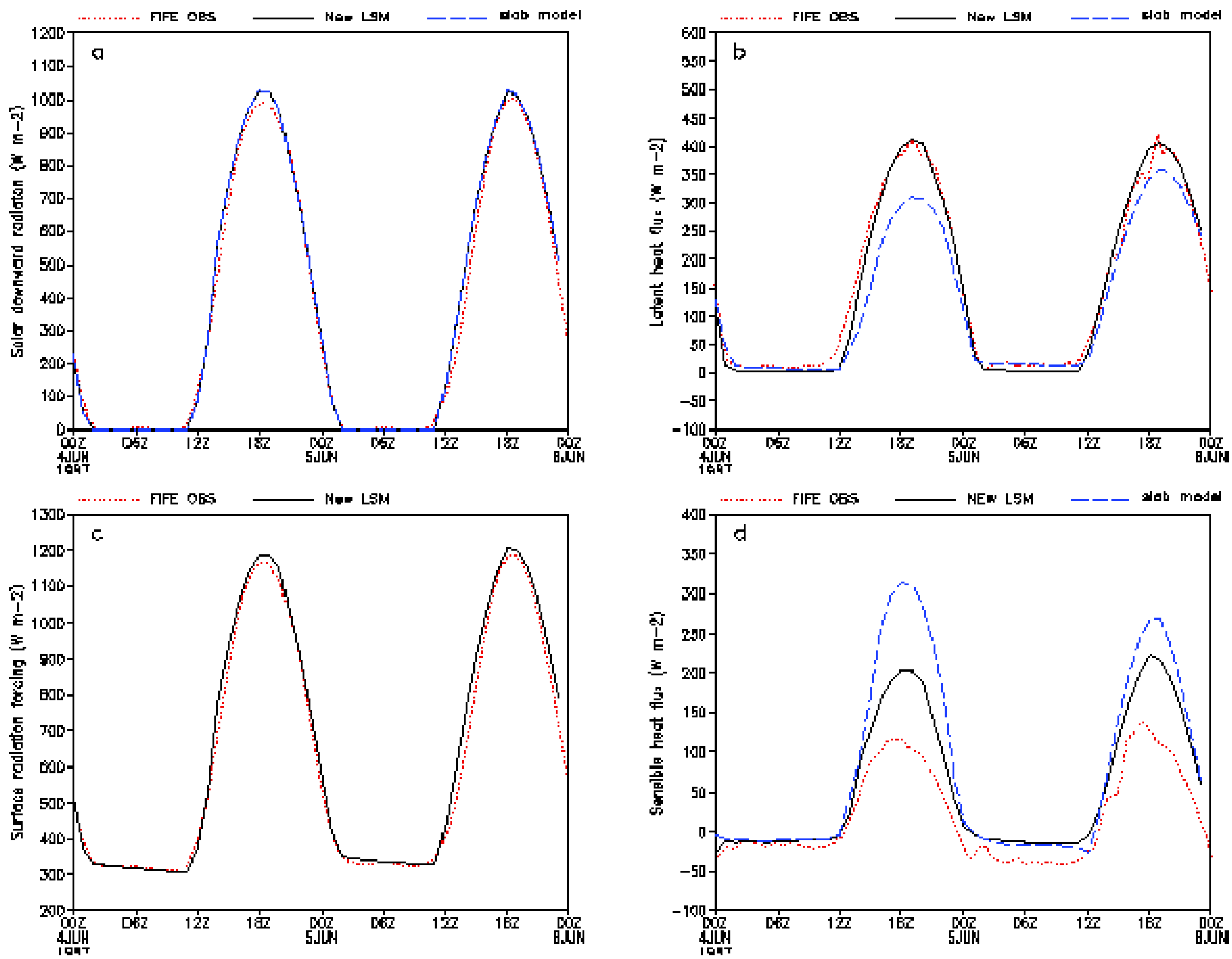

Figure 3. 48-hour evolution of (a) downward solar radiative flux, (b) surface latent heat flux, (c) total downward surface flux, and (d) surface sensible heat flux, in model runs comparing observations in FIFE with the new and old MM5 surface models, for the clear-sky June 4 and 5, 1987, case.

Sensitivity to Soil Moisture

The above results demonstrate one of the tests of model sensitivity. The soil moisture was reduced everywhere by 0.1 in its volumetric content, corresponding to drought conditions. It can be seen from Figure 6, that the sensible heat flux becomes greater than the latent heat flux in most areas. The nonuniformity of the flux is a function of both the land-use type and solar forcing (cloud cover) at the time shown, which is around local noon. Grasslands (green areas in Figure 1) such as in Texas, southwest of Oklahoma, and forests (orange areas in Figure 1), such as in southeast Missouri, seem to show a much greater response to the soil moisture change than Croplands (yellow areas in Figure 1), such as in most of Illinois.

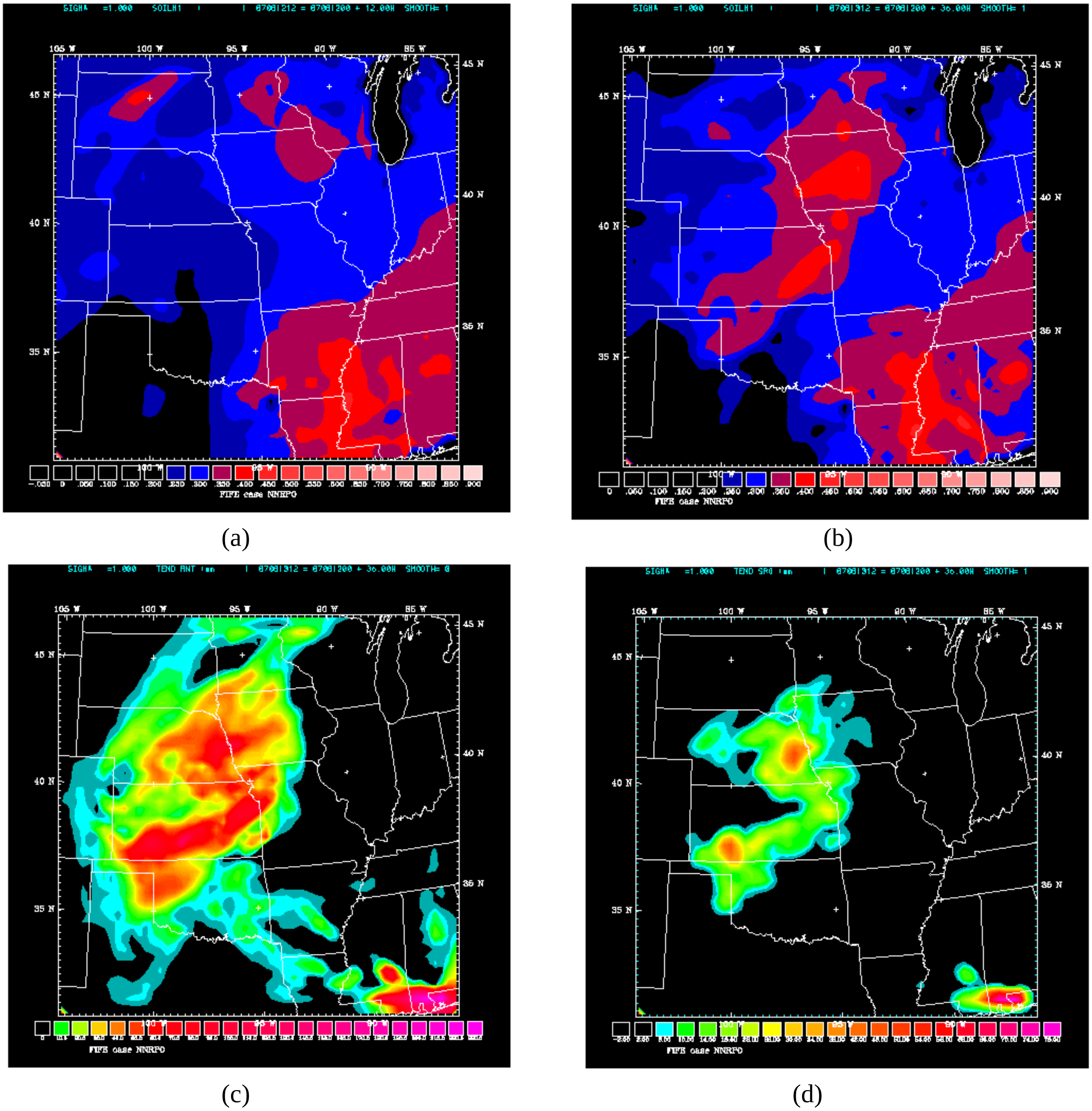

Figure 4. (a) Top-layer soil moisture at 12Z August 12, 1987, (b) top-layer soil moisture at 12Z August 13, (c) rainfall total between 12Z August 12, and 12Z August 13, and (d) runoff total in same period for MM5 simulation with LSM.

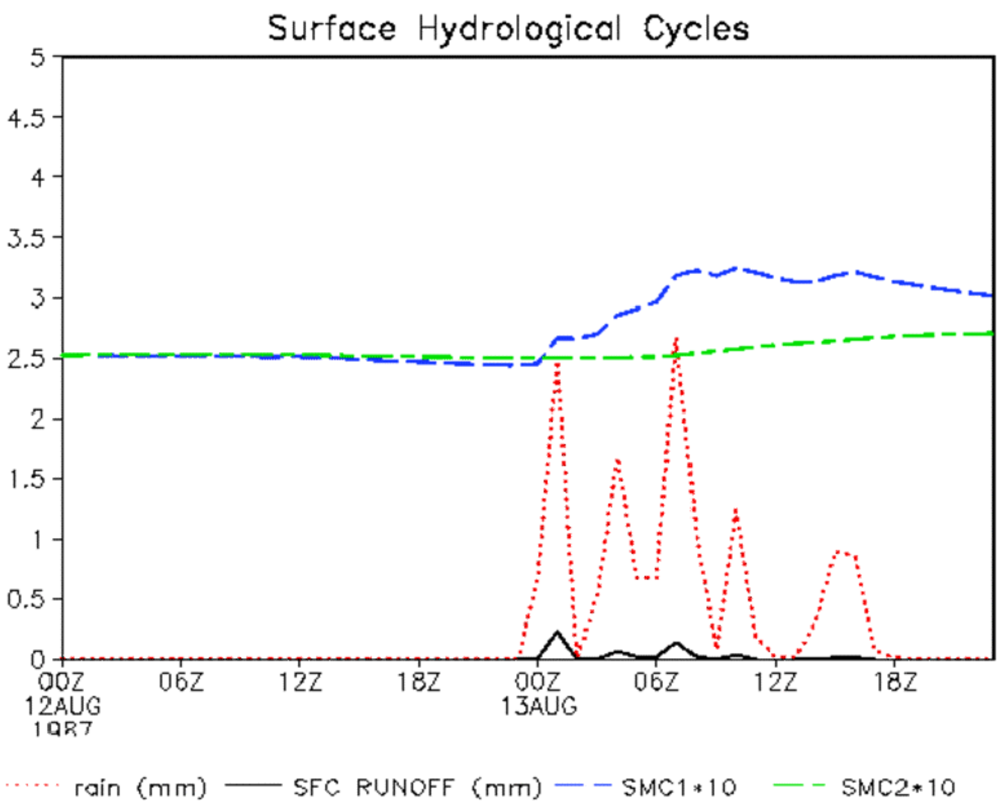

Figure 5. Time series of rainfall rate (red), run-off (black), top-level soil moisture (blue), deeper soil moisture (green).

Conclusion

By representing a full set of interactions between the ground and the atmosphere, a mesoscale model can be used to provide a realistic picture of heterogeneous behaviors on scales less than 200 km. This heterogeneity is a natural consequence not only of atmospheric phenomena, such as individual convective cells, but also of surface variability, whether in soil or vegetation type. To understand mean behaviors on the scales of GCMs it is first necessary to properly characterize and model such details.

Acknowledgments

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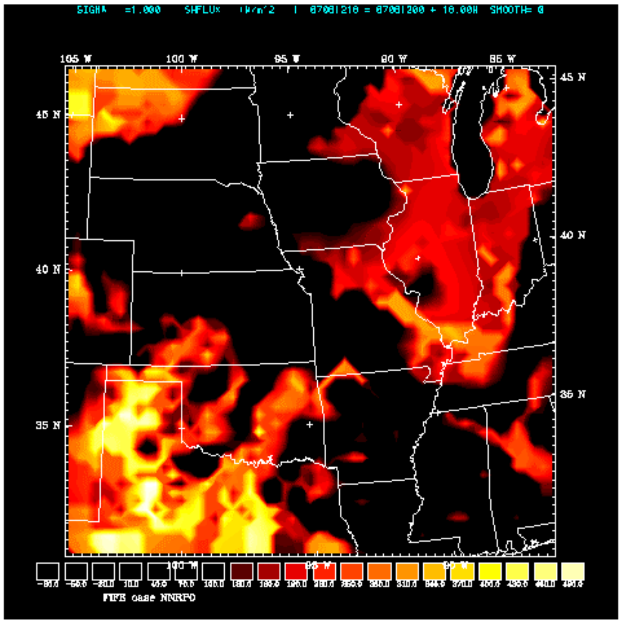
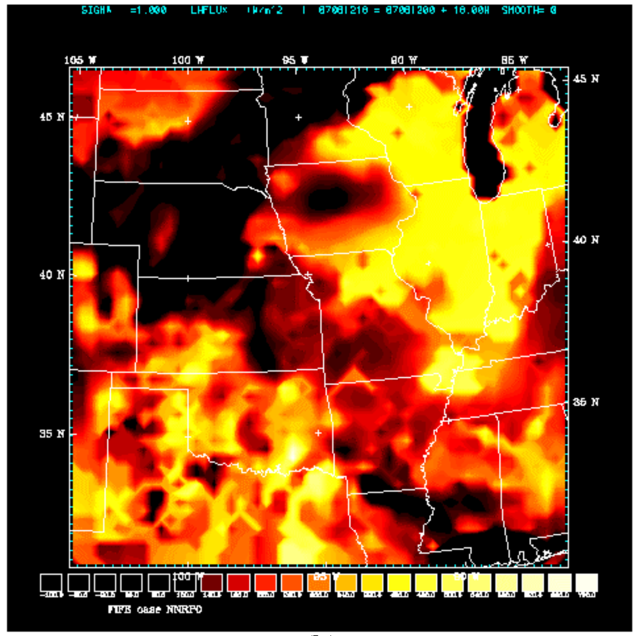


(a)



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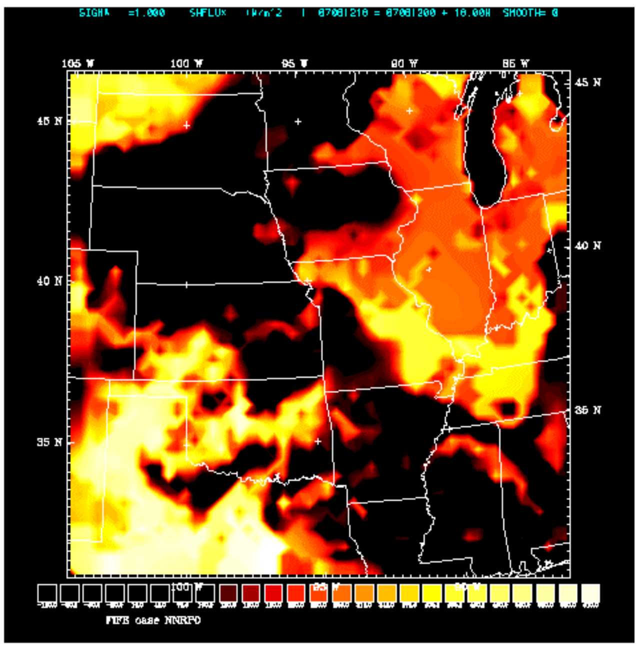

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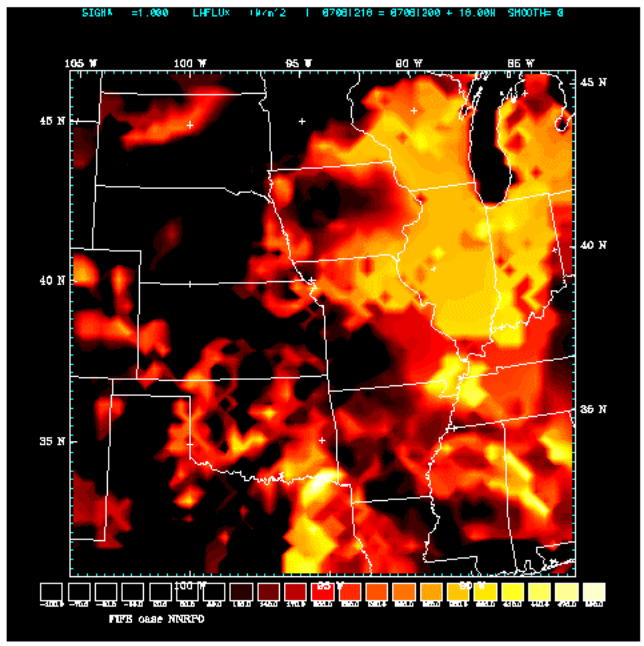

(d)

Figure 6. (a) Sensible heat flux at 18Z August 12, 1987, (b) latent heat flux, (c) dry sensitivity run sensible heat flux, and (d) dry sensitivity run latent heat flux.

Reference

Hong, S.-Y., and H.-L. Pan, 1996: Nonlocal boundary layer vertical diffusion in a medium-range forecast model. *Mon. Wea. Rev.*, **124**, 2322-2339.