Cloud-Resolving Model Simulations Conducted Over the Southern Great Plains Cloud and Radiation Testbed Site

J. Dudhia and D.B. Parsons
Mesoscale and Microscale Meteorology Division
National Center for Atmospheric Research
Boulder, Colorado

Introduction

An Intensive Observation Period (IOP) of the Atmospheric Radiation Measurement (ARM) Program took place at the Southern Great Plains Cloud and Radiation Testbed (CART) site from June 16-26, 1993.

The National Center for Atmospheric Research (NCAR)/Penn State Mesoscale Model (MM5) has been used to simulate this period on a 60-km domain with 20- and 6.67-km nests centered on Lamont, OK. Simulations are being run with data assimilation by the nudging technique (Kuo and Guo 1989; Stauffer and Seaman 1990) to incorporate upper-air and surface data from a variety of platforms. The model maintains dynamical consistency between the fields, while the data corrects for model biases that may occur during long-term simulations and provides boundary conditions.

This dataset provides a valuable starting point for detailed simulations that may resolve individual clouds, and that can be used to study meteorological events in more detail. The case chosen for study with a 2.22-km nested model is that of a cold front passing into the CART site on June 24, 1993.

Overview

One goal of the ARM program is to improve general circulation models (GCMs) by obtaining detailed meteorological information in limited areas on the order of 200 km square and comparing GCM parameterizations with the mean radiative and convective properties in such areas. Typical GCM grid boxes are 100-200 km square, but there is in reality much structure at smaller scales that is represented by their parameterizations. Meteorological observations alone cannot represent this, so we use a full-physics mesoscale model with four levels of nesting to give as complete a picture of the sub-100 km scale structures as possible.

In order to avoid the need for cumulus parameterization, a grid size of 2.22 km is used. The domain is centered on Lamont, OK, and covers a 160-km square. The model includes a fairly detailed microphysics package and a radiative scheme that interacts with the resolved clouds and surface.

Currently the land-use category is determined from 5-minute data archived at NCAR, but in principal a more detailed characterization of the CART site's surface properties (e.g., roughness length, soil moisture, albedo) could be used.

Domain and Simulations

Figure 1 shows the areas covered by the four MM5 domains. The 60-km domain coincides with the MAPS domain. The 6.67-km domain is centered on a profiler hexagon of the demonstration network around Lamont, OK, and covers a 480-km square, and the 2.22-km domain covers a 160-km square centered near Lamont.

Two fine-scale simulations have been run covering the 12-hour period starting 12Z 24th June 1993. They are based on the control and full data assimilation runs described in Dudhia (1996) which were run triple-nested down to 6.67 km for the full ten days, June 16-26. The full data assimilation run included observational nudging of additional available data in the 20-km and 6.67-km domains including rawinsonde, profiler, and surface observations. The 2.22-km simulation contains no nudging terms and, hence, the results can be used to determine realistic budgets and mean properties as well as to investigate physical processes and their interactions.

The Cold Front of June 24, 1993

Before the front entered the 6.67-km domain covering much of Oklahoma and southern Kansas, there was a well-represented nocturnal jet case (Dudhia and Guo 1995). This had been verified by an ISS profiler near the central CART

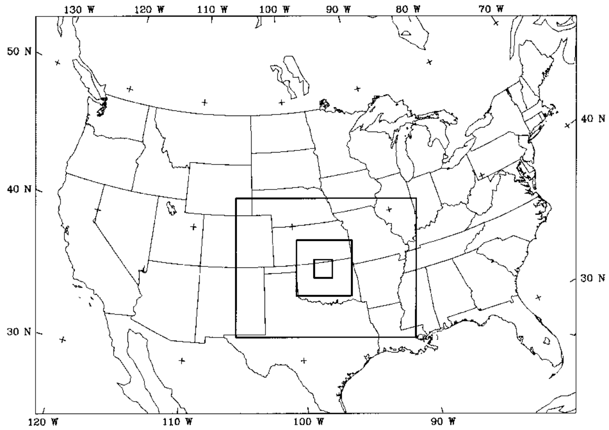

Figure 1. Areas covered by the four model domains with grid sizes of 60, 20, 6.67, and 2.22 km.

site between 00Z and 06Z 24th June. The model captured the strength and rotation of the jet through this period.

Figure 2 shows a surface analysis with a cold front across Oklahoma/Kansas at 18Z 24 June 1993. This front had moved into Oklahoma over the previous 6-12 hours and became stationary over the CART site. The radar summaries show that convergence ahead of the front was capable of triggering convection over northern Oklahoma and southern Kansas, but there was a period before 1830Z when the front had no radar echoes associated with it. Convection persisted through 0000Z 25th in north central Oklahoma, but did not become severe. In the later part of the period there was some development southwestward along the front into central Oklahoma.

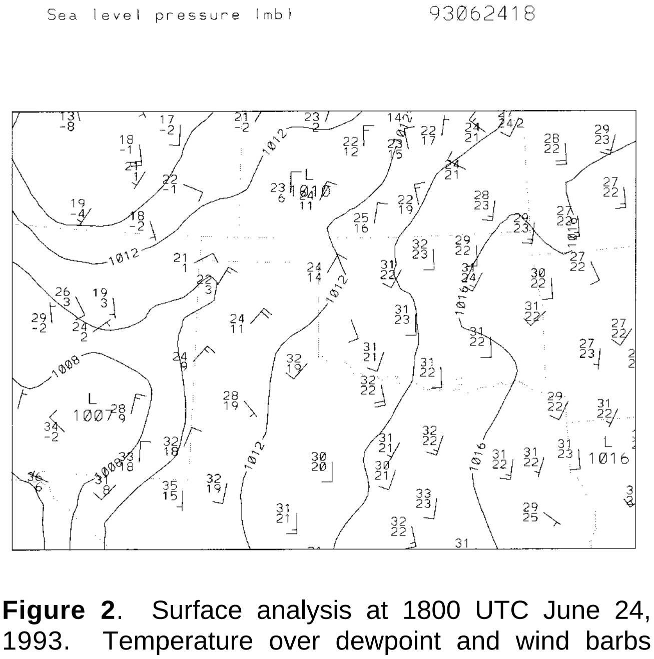

Figure 2. Surface analysis at 1800 UTC June 24, 1993. Temperature over dewpoint and wind barbs shown.

Simulated Front

Comparison of Figure 2 with Figure 3a shows that the simulated front was positioned well. The temperature gradient and wind shift in north central Oklahoma are comparable. Figure 3b shows how much complexity the simulated frontal structure has on the 2.22-km grid (inner box in Figure 1).

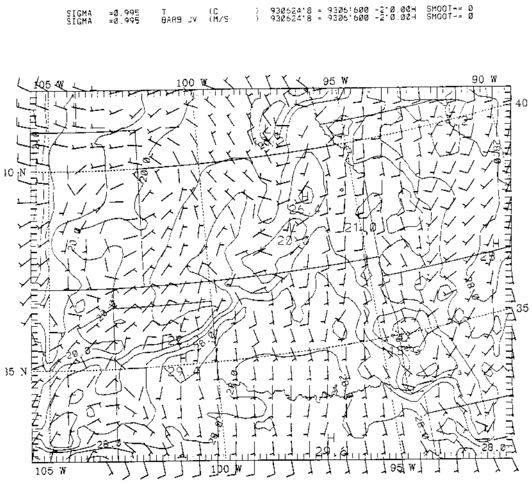

Figure 3a. 20-km simulation at 1800 UTC 24th June 1993, showing wind barbs and temperature (shading).

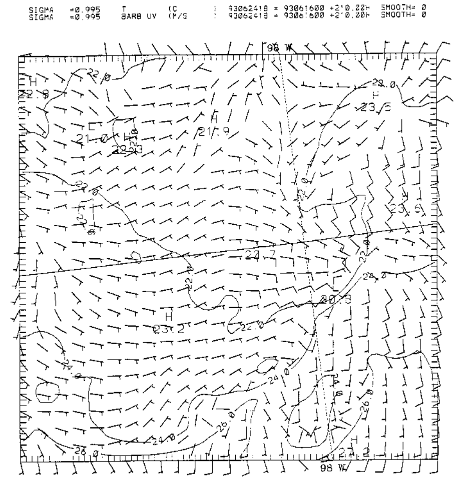

Figure 3b. As Figure 3a, but for 2.22 km domain.

Frontal Clouds

Particularly well represented was the change in the front's motion as it quickly moved into northern Oklahoma and became stationary. It eventually weakened and the model shows significant reduction in the temperature gradient with time, probably due to differential solar heating during the day of the pre-frontal cloudy region and the post-frontal clear region, which would contribute to a diabatic frontolysis in the boundary layer. Also contributing are the cool downdrafts associated with the pre-frontal convective cells of which some indication is seen in Figure 3b.

Figure 4 shows the clouds in the 2.22-km domain viewed from the southwest at 500 mb, demonstrating the marked difference in cloudiness across the front.

Frontal Rainfall

The convection in the simulation started earlier than observed, but by 1830Z radar echoes were located in a position very similar to the model's convection at that time. The convection at the front shows no organization as individual short-lived cells move along the front from southwest to northeast. Figure 5a shows the radar picture at 1900 UTC and Figure 5b shows the modeled rainwater at the lowest level at around the same time (6.67 km domain).

The model even captured the strengthening and south westward development of the convection later in the period as indicated in Figures 6a and 6b.

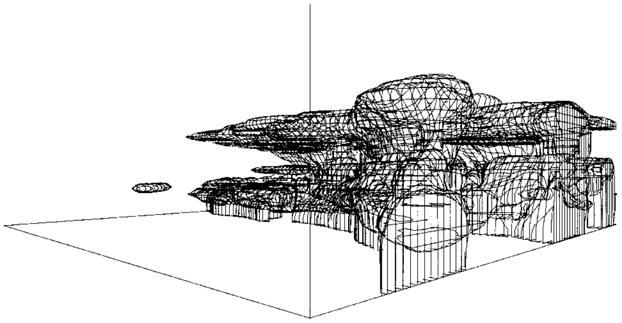

Figure 4. Three-dimensional depiction of cloud/rain outline as viewed from SW at 1800 UTC in the 2.22-km domain.

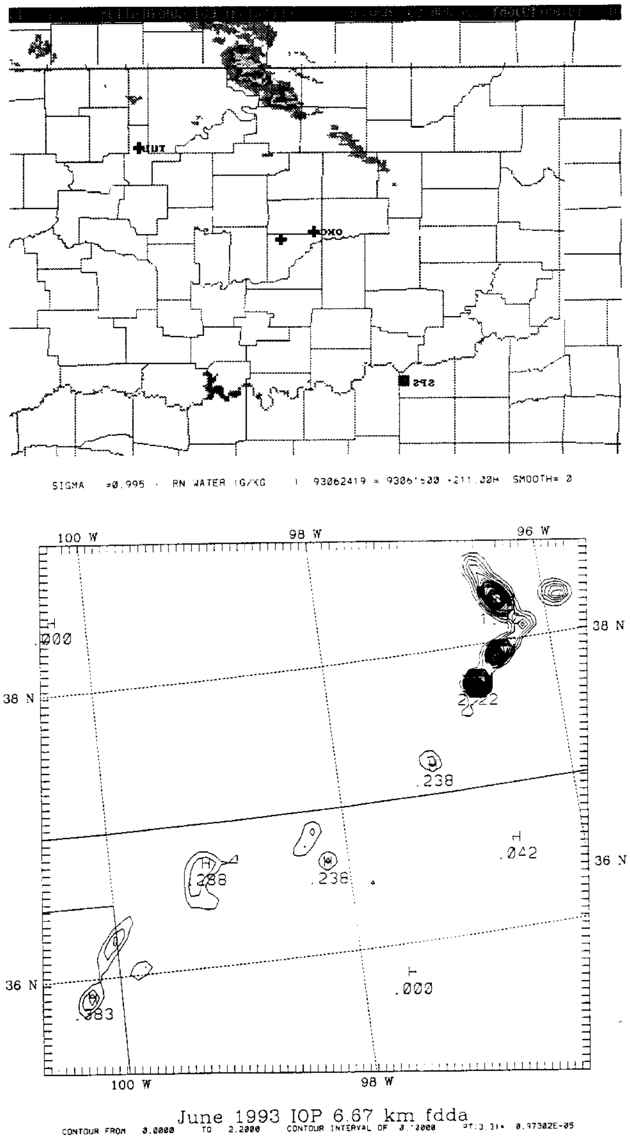

Figure 5. Radar picture (top) and model-simulated rain (bottom) at 1900 UTC June 24, 1993.

Conclusions

These initial results with and without assimilation of local observations around the CART site have demonstrated the advantages and limitations of 4D data assimilation by the nudging technique. Gross features of the flow including the

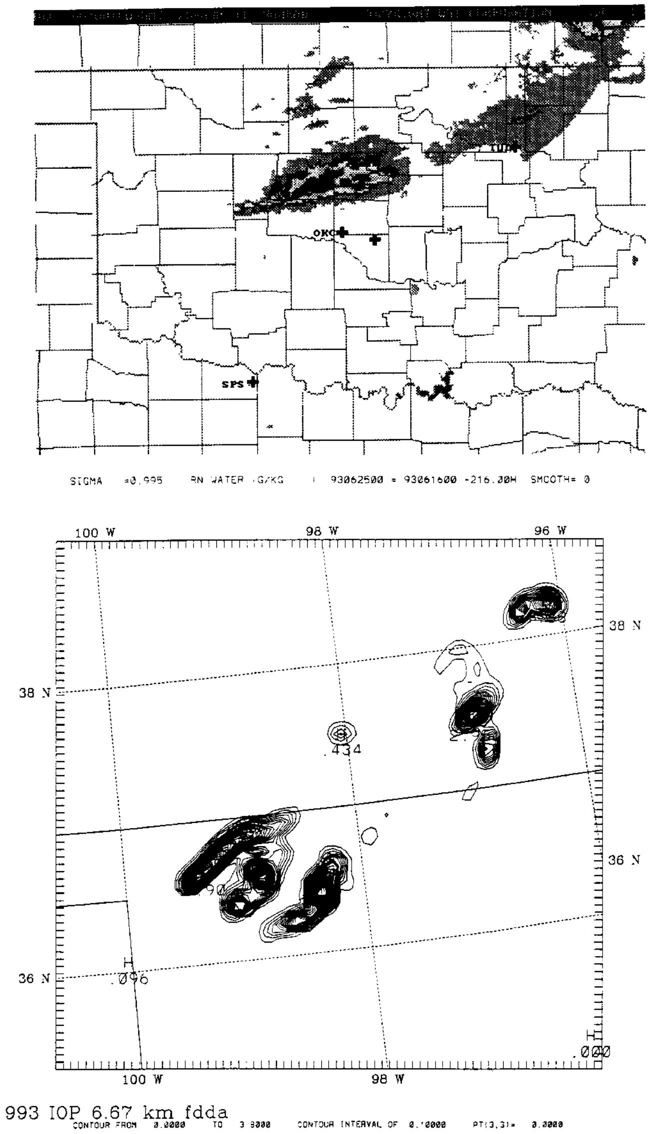

Figure 6. Radar picture (top) and model-simulated rain (bottom) at 0000 UTC on June 25, 1993.

front itself were well simulated, and the mean properties over the domain are likely to be realistic, and realizable by the real atmosphere, if not entirely correct in detail for this case. It is unrealistic to expect to simulate individual convective cells accurately given conditions that are marginal for development such as those associated with the weak cold front of June 24th 1993. This dataset represents a proxy for the real atmosphere about which, in principal, every thing is known. By continually improving the model based on comparisons with real cases, this dataset becomes more realistic. At high resolution the major uncertainties in GCMs of representing subgrid-scale radiative and convective effects are circumvented, leaving much more tractable parameterization problems associated with microphysics, the planetary boundary layer, and surface fluxes.

Further Work

To further this work, we need to

- improve the data assimilation technique. An alternative data assimilation strategy using the adjoint model is becoming more practical with the increase in computer power (Guo et al. 1996). This 4DVAR approach has the potential for more accurately fitting the model solution to the observations.
- evaluate cloud fractional coverage versus that predicted in GCMs' radiation schemes
- determine mean radiative properties of resolved cloud fields
- evaluate mean boundary-layer fluxes in high-resolution model and compare with GCMs
- improve cumulus parameterization such that it can reproduce a cloud-resolving model's rainfall/mass flux, possibly by modifying the scheme's initiation conditions, or by trying a variety of schemes.

References

Dudhia, J., 1996: Data assimilation for the June 1993 IOP at the Southern Great Plains site, this volume.

Dudhia, J., and Y.-R. Guo, 1995: Data assimilation of a ten-day period during June 1993 over the Southern Great Plains site using a nested mesoscale model. In *Proceedings of the Fifth Annual ARM Science Team Meeting*, San Diego CA, March 1995, 77-81.

Guo, Y.-R., X. Zou, and Y.-H. Kuo, 1996: Development of MM5 4DVAR system and its preliminary, this volume.

Kuo, Y.-H., and Y.-R. Guo, 1989: Dynamic initialization using observations from a hypothetical network of profiles. *Mon. Wea. Rev.*, 117, 1975-1998.

Stauffer, D.R., and N.L. Seaman, 1990: Use of four-dimensional data assimilation in a limited-area mesoscale model. Part I: Experiments with synoptic-scale data. *Mon. Wea. Rev.*, 118, 1250-1277.