Data Assimilation of a Ten-Day Period During June 1993 Over the Southern Great Plains Site Using a Nested Mesoscale Model

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Introduction

A goal of the Atmospheric Radiation Measurement (ARM) Program has been to obtain a complete representation of physical processes on the scale of a general circulation model (GCM) grid box in order to better parameterize radiative processes in these models. Since an observational network of practical size cannot be used alone to characterize the Cloud and Radiation Testbed (CART) site's 3D structure and time development, data assimilation using the enhanced observations together with a mesoscale model is used to give a full 4D analysis at high resolution.

The National Center for Atmospheric Research (NCAR)/ Penn State Mesoscale Model (MM5) has been applied over a ten-day continuous period in a triple-nested mode with grid sizes of 60, 20 and 6.67 in. The outer domain covers the United States' 48 contiguous states; the innermost is a 480-km square centered on Lamont, Oklahoma. A simulation has been run with data assimilation using the Mesoscale Analysis and Prediction System (MAPS) 60-km analyses from the Forecast Systems Laboratory (FSL) of the National Ocean and Atmospheric Administration (NOAA). The nested domains take boundary conditions from and feed back continually to their parent meshes (i.e., they are two-way interactive). As reported last year, this provided a simulation of the basic features of mesoscale events over the CART site during the period 16-26 June 1993 when an Intensive Observation Period (IOP) was under way.

The MME Model

The MME Model has the following characteristics:

- nonhydrostatic, compressible, with terrain-following coordinates and polar-stereographic map projection
- prognostic equations for wind components, vertical velocity, pressure perturbation, temperature, water vapor, ground temperature, and microphysical water and ice content variables
- B-grid staggering, upper radiative boundary condition, relaxation lateral boundary conditions, second-order centered spatial and leapfrog temporal differencing with short step for sound-wave terms
- microphysics with cloud, rain, snow/graupel, and ice processes on all domains' resolved scales
- Grell single-cloud mass flux cumulus parameterization scheme on 60- and 20-km domains
- Blackadar high-resolution planetary boundary layer with four stability regimes, five layers in lowest kilometer. Implicit vertical diffusion above boundary layer
- atmospheric longwave and shortwave radiation scheme interacting with model clouds and land surface
- land surface energy budget calculation to predict ground temperature.

Overview of Results

Comparisons of model data with surface observational data have been made. This has pointed to some improvements in model physics that were required to adequately represent cloud cover and, hence, diurnal heating.

One area of scientific interest is a nocturnal jet on 24 June 1993 that was simulated. The model captured well the low-level wind maximum observed with NCAR's Integrated Sounding System (ISS) 915-MHZ profiler.

Further work has involved acquiring surface and upper-air standard observations and profiler data from NOAA's Demonstration Network and ARM's CART site, and preparing these data for input to the model. A second simulation will assimilate these data by the "station-nudging" technique on the inner two domains. Comparisons with observations will then be made to evaluate the impact of the added data.

Cloud Cover and Ice Sedimentation

From comparison of the model temperature 40 m above ground (short-dash line in Figure 1) at the center of the 6.67-km domain versus 3-hourly analyses based on surface observations at that point (long-dash line), it can be seen that the diurnal heating was severely underestimated, particularly on 16, l9, and 22 June.

This was traced to excessive cirrus cloud cover in the model. Clouds originating over the Rockies nearly every afternoon were advected over Oklahoma, reducing the surface diurnal heating there the next day through the model's cloud/radiation interaction.

The solution was to add sedimentation of ice particles (following Heymsfield and Donner 1990), thus allowing the cirrus clouds to dissipate more realistically. The temperature trace is improved (solid line) with this modification in a rerun of the ten-day simulation.

Also noted was the significant reduction in integrated cloud water over the domain. This is an improvement in areal coverage that is vital to making realistic simulations over

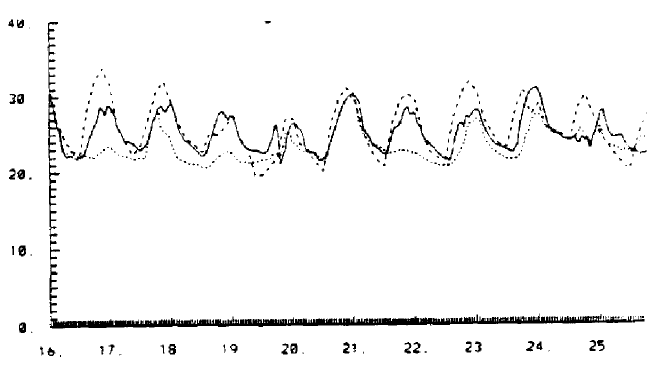

Figure 1. Temperature trace (degrees C versus June date), surface observation (long dash), model without (short dash) and with (solid) sedimentation.

cloud-cover forecasts in an independent wintertime study with MM5 where model output was compared in detail with satellite pictures (K. Manning and C. Davis, personal communication).

The Nocturnal Jet

A nocturnal jet is a low-level wind maximum that may reach 20–30 m s^{-1} within a kilometer of the ground. It is typically found over the SGP, making the CART site an ideal location for its study. It is likely to be important in the large-scale moisture transport of the region.

Its formation is believed to result from the collapse of the daytime boundary layer which decouples the ageostrophic wind from the frictional layer that was responsible for it. Upon decoupling, the ageostrophic component turns clockwise through Coriolis forces.

In situations favorable for the nocturnal jet, the geostrophic wind has a southerly component, and so the ageostrophic wind has an easterly component during the day that rotates to southerly at night, making the wind supergeostrophic, and hence the jet is formed. The role of the gradual westward terrain slope of the region in aiding the ageostrophic upslope flow is also probably important.

For the model to reproduce this sequence accurately requires 1) an adequate representation of the synoptic-scale flow, 2) proper boundary-layer formation during the day, 3) proper collapse of the boundary layer at night, and 4) a good representation of the terrain.

The ISS 915-MHZ profiler (Figure 2) showed a clear nocturnal jet development after 00Z 24 June. Winds reached 25 ms^{-1} in the lowest kilometer and turned slowly clockwise with time.

A time sequence of the model wind at about 1 km above ground also shows the nocturnal jet reaching a maximum of 25 ms^{-1} and turning clockwise as it accelerates and becomes more parallel to the isobars by 06Z (Figure 3) than earlier at 00Z. The level of the jet is slightly higher than observed, but the feature's time development is reproduced well.

Boundary Layer Development in MM5

The soundings taken at the center of the domain near Lamont, Oklahoma, every 6 hours from 00Z 24 June till 25 June, also show the jet's development and boundary

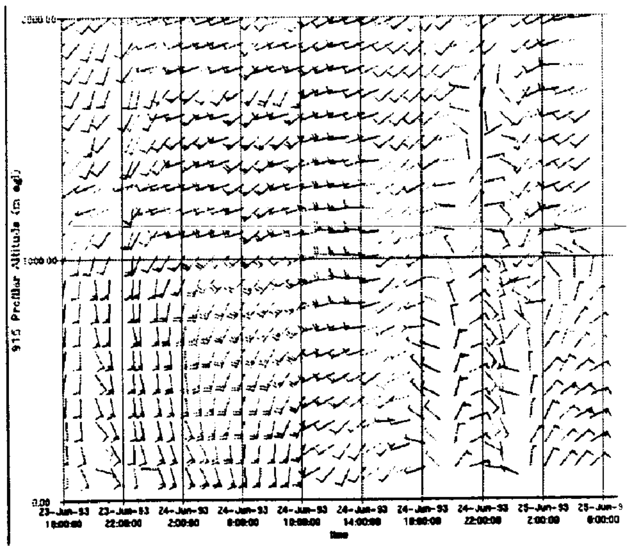

Figure 2. 915-MHZ ISS profiler height versus time plot for 0 to 2 km altitude between 18Z 23rd and 06Z 25th June 1993. Wind barbs in m/s.

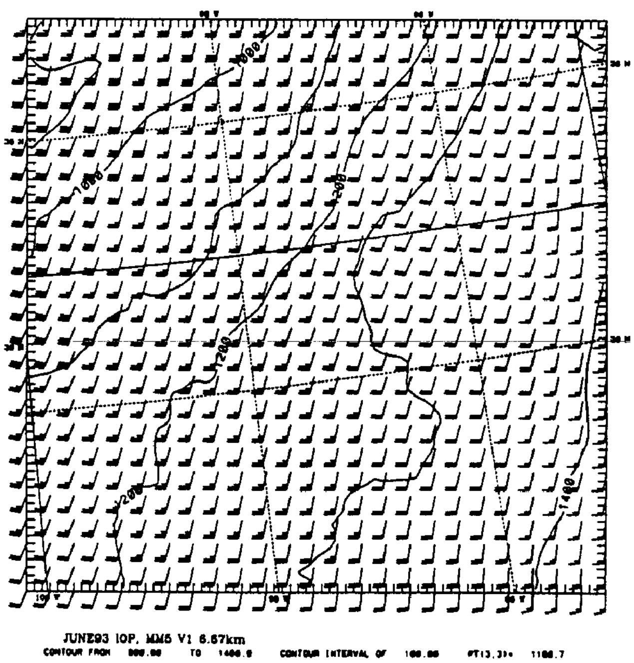

Figure 3. Wind at about 1 km above ground for model 6.67-km domain at 06Z 24th June 1993. Wind barbs in m/s. Pressure contoured with 1 hPa interval.

layer's collapse in the model, followed by the influence of convection at the cold front that moved into the region.

The daytime boundary layer is seen at 00Z 24 June (Figure 4a), but is gone by 06Z (Figure 4b) because of surface night-time cooling, and the jet becomes evident. By 12Z there is an inversion and the jet continues to rotate. The convection causes a near moist-adiabatic structure by 18Z (Figure 4c), followed by a drying by 00Z 25 June as a result of convective downdrafts. An accompanying paper (see Dudhia and Parsons in this volume) shows the rainfall associated with this front and the radar summary.

The realistic model soundings are encouraging particularly since this period represents the ninth of the ten days assimilated. It is clear that MM5 is capable of maintaining a reasonable simulated atmospheric state without exhibiting a “climate drift” despite being only controlled by information beyond the boundaries of the 20-km domain, 600 km from the northern Oklahoma ARM site.

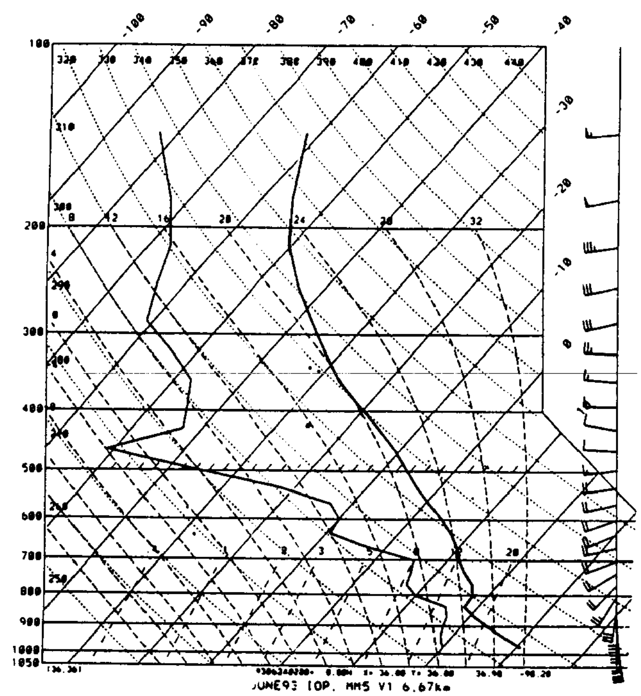

Figure 4a. Sounding in center of 6.67-km domain at 00Z 24 June 1993.

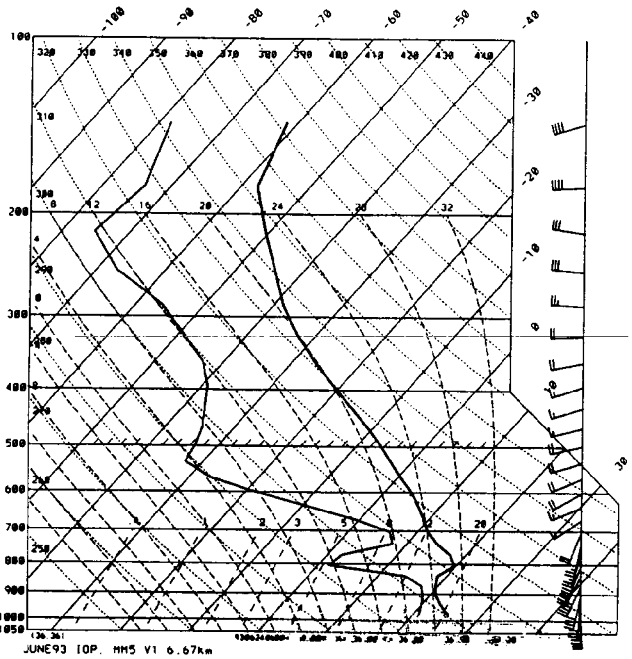

Figure 4b. As Figure 4a but for 06Z.

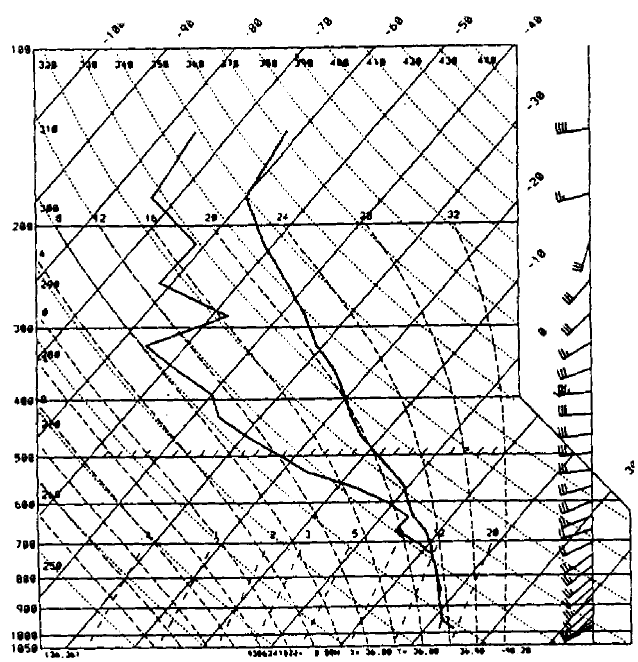

Figure 4c. As Figure 4a but for 18Z.

Further Work: Full Data Assimilation Run

With the recent availability of processed profiler data from the two 915-MHZ profilers at the CART site, there is now a complete dataset ready for assimilation into MM5 in a full Data Assimilation mode. The inner two meshes contain much data that are directly assimilatable into MM5, including enhanced NWS CLASS soundings taken 6-hourly at Topeka, Kansas; Dodge City, Kansas; and Norman, Oklahoma, around the CART site during this IOP. The balloon data is modified to allow for an estimated balloon drift and time lag, which are important considerations in the fine grid.

The NOAA Demonstration Network of 405-MHZ wind profilers (Figure 5) provided data that will be input to MM5. These data were quality controlled during this past year, and some effort has gone into determining an objective algorithm for this large quantity of data. The applied algorithm checks the data against neighboring levels and nearby stations (within 400 km). It provides hourly averaged wind profiles through the troposphere. Previous studies including Kuo and Guo (1989) and Dudhia (1993) have shown the value of a broad coverage of wind data in allowing retrieval of the thermal field.

Additionally, dense standard surface observations are used to provide an analysis towards which the model will be nudged.

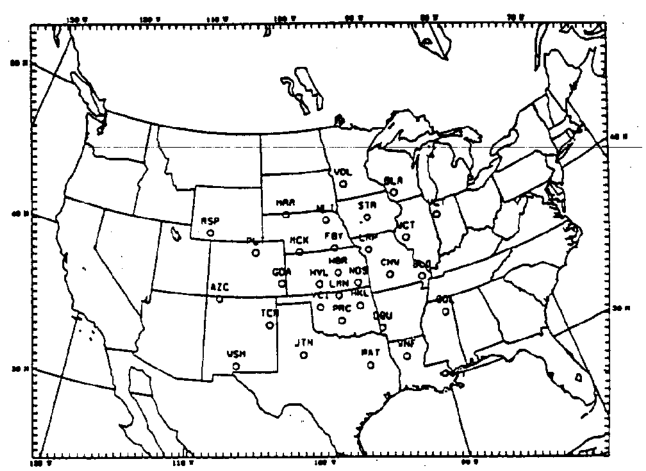

Figure 5. NOAA Demonstration Network of 405-MHZ profilers.

Supplemental balloons were launched from three locations in the CART site during this IOP that can be used as independent verification of the model's assimilation effectiveness since these data are not being assimilated.

References

Dudhia, J. 1993. The effect of network resolution on data assimilation in a mesoscale model. In *Proceedings of the Third Atmospheric Radiation Measurement (ARM) Science Team Meeting*, March 1993, Norman, Oklahoma, pp. 359-362. CONF-9303112, U.S. Department of Energy, Washington, D.C.

Heymsfield, A. J., and L. J. Donner. 1990. A scheme for parameterizing ice-cloud water content in general circulation models, *J. Atmos. Sci.*, **47**, 1865-1877.

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