Verification of June 1993 IOP Assimilation Dataset and its Use in Driving a Single-Column CCM3 Model

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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 km 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.

Introduction

An intensive observation period (IOP) of the ARM Program took place at the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site from June 16-26, 1993.

The National Center for Atmospheric Research (NCAR)/ The Pennsylvania State University Mesoscale Model (MM5) has been used to simulate this period on a 60-km domain with 20-km and 6.67-km nests centered on Lamont, Oklahoma. Figure la shows the outer two domains, and Figure lb shows the 20-km domain and the 6.67-km domain. The white square indicates the region extracted for the single-column model (SCM). 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. For the work reported here, the MAPS [Mesoscale Atmospheric Prediction System of the National Oceanic and Atmospheric Administration (NOAA)] 3-hourly analyses were used to drive the 60-km domain while the inner domains were either unforced or nudged with observations. A continuous 10-day period was simulated.

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 polar-stereographic 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, ice processes on all domains' resolved scales. The Grell cumulus parameterization scheme is adopted only on

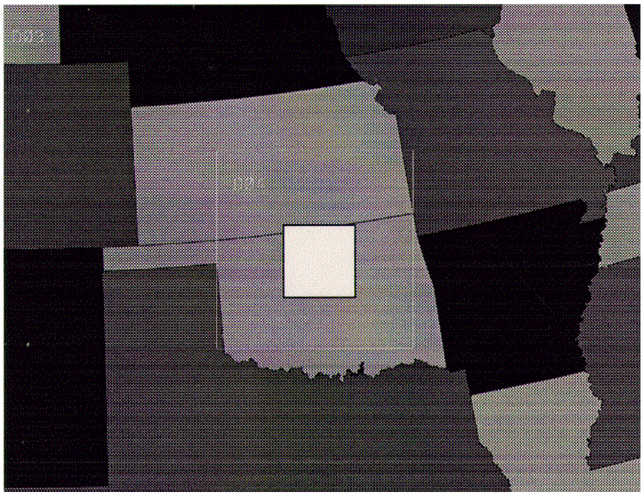


Figure 1a. 60-km domain showing 20-km domain in box.

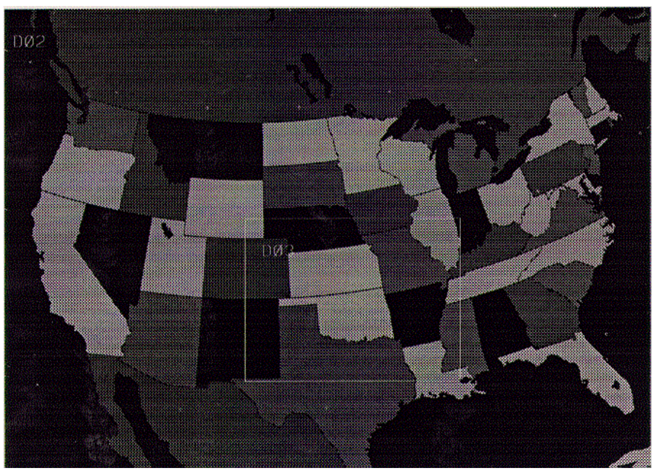


Figure 1b. 20-km domain showing 6.67-km domain outline and SCM area in white box.

the 20-km and coarser domains. The Blackadar high-resolution 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.

By resolving land-cover variations, the mesoscale model will be used to determine mean surface fluxes for areas relevant to climate models and the methods can be validated against ARM's comprehensive surface data at the SGP site.

The Assimilation Input Dataset

The following data were used to force the model by an "obs-nudging" method, whereby the observations are assigned a radius of influence and a time window, and all obs affecting a model grid point are weighted by distance (and time) similarly to objective analysis techniques. The weighted mean error at the ob positions within a radius of influence is used to determine the forcing term.

- Wind-Profiler Demonstration Network (WPDN)—sixteen 405-MHz profilers (Figure 2a) with hourly wind data.
- National Weather Service (NWS) upper-air soundings—fifteen sites at 00 Z and 12 Z.
- NWS surface observations—about 100 sites every 3 hours.
- Additional NWS Cross-Chain Loran Atmospheric Sounding System (CLASS) soundings at Dodge City, Norman, and Topeka (Figure 2b) at 06 Z and 18 Z.
- NCAR Integrated Sounding System 915-MHz profiler near central SGP site.

Validation of Assimilated Dataset

Two experiments were compared: one with all the observations described in panel 4 assimilated [four-dimensional data assimilation (FDDA)], one without (NOFDDA).

Independent data were used to carry out the comparison. These were special balloon launches every 3 hours during the IOP at Kingfisher, Kingman, and Pawhuska shown in Figure 2b.

These sites form a triangle about 100 km from the SGP central site, and also are away from the profilers that are used in the data assimilation.

Comparison with Observations (Nocturnal jet)

In Figure 3, the observed and simulated southerly wind component is compared in simulations FDDA and NOFDDA with the observed wind. These represent mean winds at the three independent ARM balloon sites. The lower troposphere shows distinct southerly jets near 06 Z (local midnight) on 6 of the 10 days. This is the nocturnal jet, and there was a particularly strong event early on June 24 with southerly winds exceeding 20 m/s about 1 km above ground level.

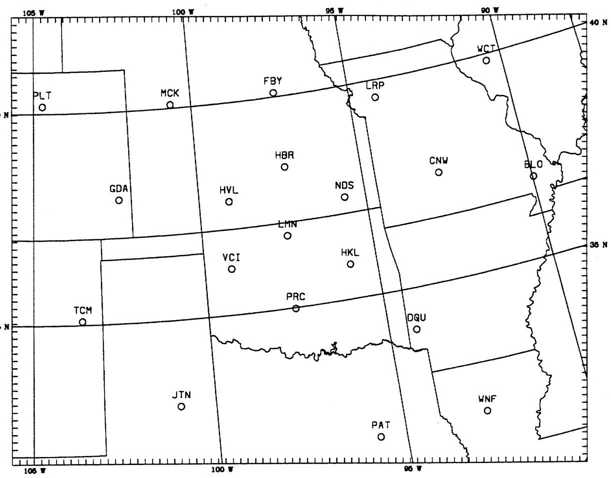


Figure 2a. 20-km domain showing WPDN profiler sites.

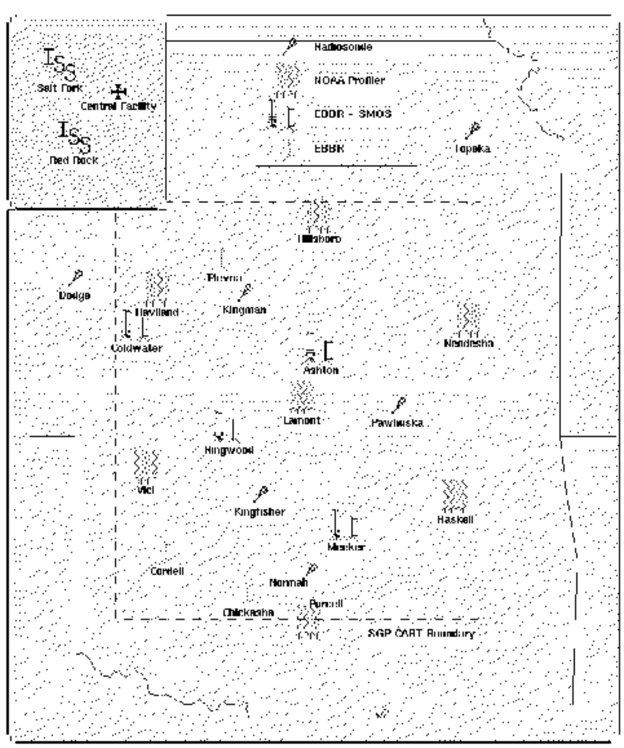


Figure 2b. Site map showing inner hexagon of profilers, NWS upper-air stations, and ARM balloon sites.

It can be seen that the model simulated this behavior well but with slightly improved accuracy in the FDDA experiment.

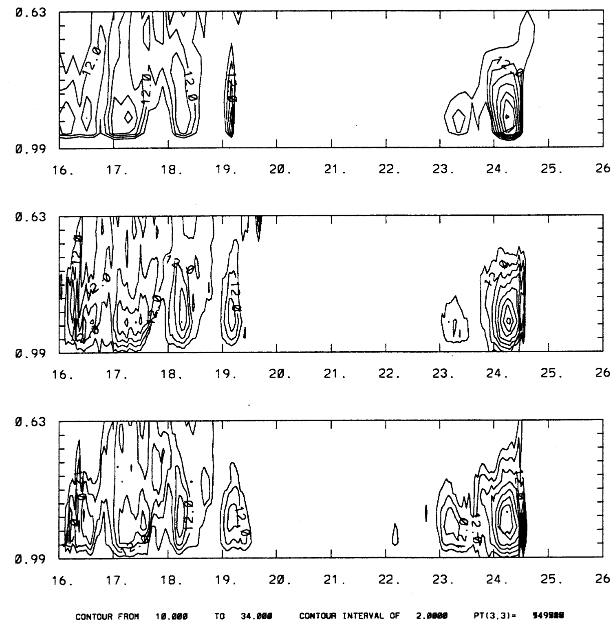
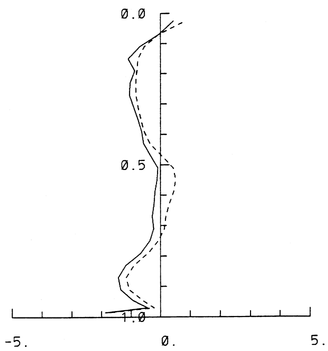


Figure 3a (top). Southerly wind component, v, mean at Kingfisher, Kingman and Pawhuska, where it exceeds 10 m/s. Sigma-level versus June day. Contour interval 2 m/s.
Figure 3b (middle). As Figure 3a for FDDA simulation.
Figure 3c (lower). As Figure 3a for NOFDDA simulation.

Comparison with Observations (Mean and Root Mean Square Errors)

In Figures 4 and 5, the errors are shown in the model simulation covering the 10-day period and the whole troposphere. From these it can be seen that while there is a marked improvement of about 1 m/s in the wind accuracy, the temperature accuracy shows no improvement with data assimilation. In Figure 4a there is a southerly bias, which is somewhat reduced by FDDA. Figure 5a shows a cool temperature bias, in the lower and upper troposphere of about 1° C.

The fact that assimilation helps the wind more than temperature can be explained by the dominance of hourly wind-profiler data in the assimilation input. However, even though past observation system simulation experiments have shown a potential benefit to the mass (thermal) field from wind assimilation on large scales, such an effect was not evident in the root mean square (rms) errors here (Figure 5b).



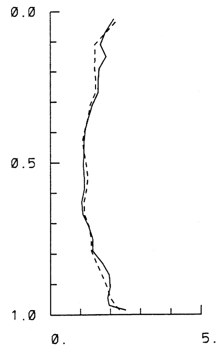
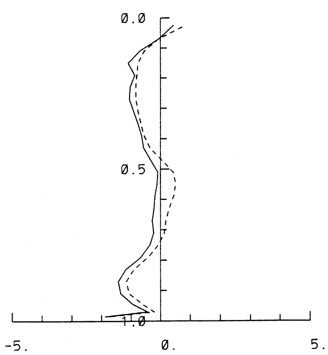


Figure 4a (left). Southerly wind component, v, mean error through 10 days at Kingfisher, Kingman, and Pawhuska. Sigma level versus error (m/s). FDDA (solid), NOFDDA (dashed).
Figure 4b (right). As Figure 4a, but rms error.



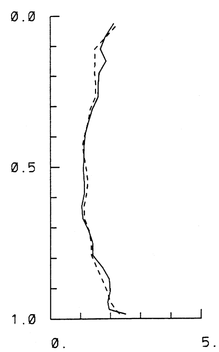


Figure 5a (left). Temperature, mean error through 10 days at Kingfisher, Kingman, and Pawhuska. Sigma level versus error (K). FDDA (solid), NOFDDA (dashed).
Figure 5b (right). As Figure 5a, but rms error.

Single-Column Model

The CCM3 SCM was run forced by the MM5 data described earlier. Of particular interest here is the effect of the imposed hydrometeor flux on the SCM results. The fluxes were imposed as part of the lateral boundary forcing for the SCM, and were derived from hourly MM5 output.

Figure 6a shows the hydrometeor averaged in the area of the white box (Figure lb) for the mesoscale model, and Figure 6b and Figure 6c show the same for the SCM without and with hydrometeor forcing through the boundaries.

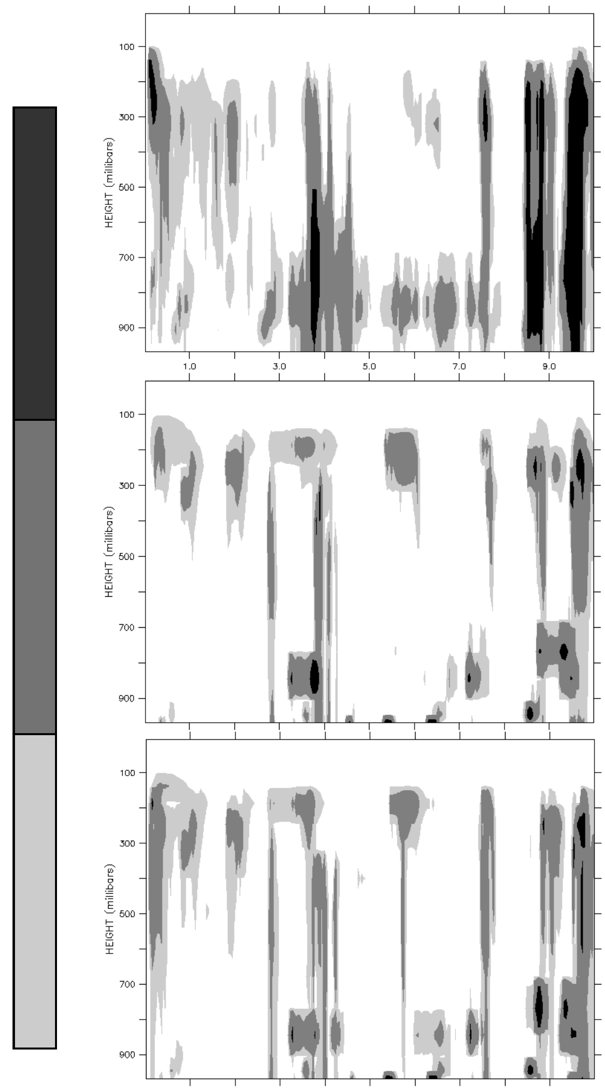


Figure 6a (top). Hydrometeor mixing ratio in mesoscale model SCM area (g/kg). Pressure (mb) versus time (days.
Figure 6b (middle). As Figure 3a for SCM without hydrometeor forcing.
Figure 6c (bottom). As Figure 3a for SCM with hydrometeor forcing.

SCM Results

Figures 6b and 6c show that introducing hydrometeors through the lateral boundaries has an impact on the resolved cloud prediction, and hence, on radiation, precipitation, and other SCM-predicted fields. Applying the hydrometeor forcing to the water vapor forcing instead of directly to hydrometeors has a similar impact. The effect is particularly seen around day 1 and day 8. The hydrometeor distribution in the mesoscale model is somewhat more extensive vertically because whereas the mesoscale model resolves all clouds, the SCM parameterizes deep convection, so that, particularly in the lower troposphere, significant differences appear in mean hydrometeor content.

Future Work

We are developing a land-surface parameterization for MM5 that is based on the OSU scheme in the Eta model from work by L. Mahrt, Fei Chen and others. This will make use of high-resolution datasets for soil [State Soil Geographic (STATSGO)] and vegetation [U.S. Geological Survey (USGS)/Earth Resources Observation Systems (EROS)] types. Figure 7 is an example of these data on a 10-km grid, but the actual data resolution is 1 km.

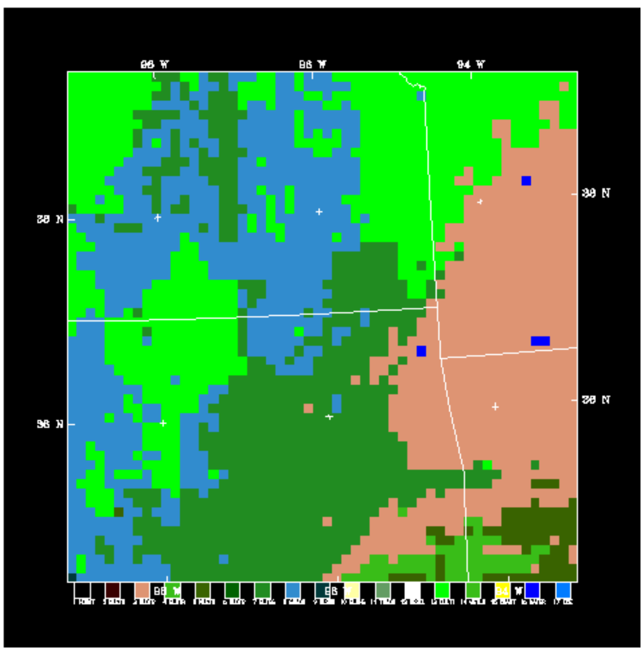


Figure 7. Example of 16-category vegetation dataset to be used on a 10-km grid as part of a test of a new land-surface scheme in MM5. Domain shown includes Kansas, Missouri, Oklahoma, and Arkansas. For a color version of this figure, please see *http://www.arm.gov/docs/documents/Technical/conf_9803/dudhia-98.pdf*.

The primary benefit of this compared to MM5's current surface scheme is the treatment of a soil-moisture budget and of evapotranspiration, which would lead to a more accurate sensible/latent heat flux partition.

References

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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.