# Radiation Studies with a High-Resolution Mesoscale Model

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## Introduction

The parameterization of radiation in general circulation models (GCMs) relies strongly on correctly representing the mean radiative properties over a typical grid size (200 km). The quality of the model's feedback between clouds and radiation would depend on the accuracy of this representation; this feedback is a key factor in determining the climate's behavior under various future scenarios.

For GCMs, cloud-radiation effects are often parameterized simply in terms of cloud fractions at various levels and some specified degrees of overlap between clouds at different levels. These parameterizations are difficult to evaluate observationally unless a detailed knowledge of the three-dimensional radiative and cloud fields can be obtained over a wide area typical of a grid scale. A parallel approach to this massive observational effort would be to represent these fields in a mesoscale model.

The use of a mesoscale model allows both clouds and radiation to receive a high-resolution treatment that can be free of the assumptions of overlapping and cloud fraction. To this end, a version of MM5, making use of the fully compressible nonhydrostatic primitive equations, is being applied to determine typical radiative properties of the atmosphere.

Here the model will be introduced and preliminary results of tests with radiation will be shown. Of particular interest for this study are the domain-averaged properties of a cloud system as it evolves during one diurnal cycle. The case presented here is one of deep convection over Oklahoma on 10-11 April 1979 during the Severe Environmental Storms and Mesoscale Experiment (SESAME) program.

## The Model

The newest version of the Penn State/National Center for Atmospheric Research (NCAR) Mesoscale Model (MM5) is upgraded to include a radiation package. The model's physics is quite complete with respect to the requirements of mesoscale simulations, including representations of the boundary layer; a moisture scheme with cloud and ice processes; convective parameterizations for coarse (>10 km) grid scales; and a surface heat budget dependent on radiative, sensible and latent heat fluxes.

Preprocessing packages allow the model to be initialized with data analyzed from synoptic observations. Boundary conditions also may be provided by later analyses or a numerical weather prediction model run on a larger domain. This initialization allows a realistic re-creation of observed mesoscale systems that interact with larger-scale features, a critical requirement for a true four-dimensional representation of the meteorological parameters in general and the cloud fields in particular.

For the purposes of the Atmospheric Radiation Measurement (ARM) Program, a simple longwave and shortwave package based on broadband emissivity and a single-stream integration, respectively, (Dudhia 1989, Chen and Cotton 1983) has been implemented in this model. It is applied to three-dimensional simulations of an Oklahoma severe weather event (10-11 April 1979). The model is being run on 20- and 5-km grids for 24 and 18 hours, respectively, with the latter domain nested inside and taking hourly boundary conditions from the former.

The radiation scheme fully interacts with the clouds in the model (Stephens 1978) and the surface energy budget contributing to ground temperature tendencies. It also allows for ice, precipitation, and carbon dioxide effects in the longwave scheme.

Thus longwave cooling at cloud top, heating at cloud base, and shortwave cloud heating are all represented. The longwave fluxes are also influenced by water vapor in the atmosphere and ground emissivity. Shortwave cloud absorption and albedo and clear-air scattering and absorption caused by water vapor are considered with zenith angle dependencies. Typically radiative heating and surface flux calculations are updated every 30 minutes. Dudhia (1989) has shown tests of this scheme with idealized cloud layers to produce realistic heating rates.

# Results

The results for the 20-km simulation are described here. The model domain covers an area 960 x 1080 km. Simulations were run with and without the radiative scheme. For this case, atmospheric radiative heating was found to have little effect on the convective development and rainfall pattern. The case was one in which severe convection with high updrafts formed as a result of strong instability that developed when a capping inversion was removed. A widespread low stratiform cloud east of a sharp dry line persisted through much of the simulation.

Comparison of domain-averaged temperatures in simulations with and without the radiative scheme (Figure 1a) showed differences in the boundary layer as the new scheme produced more daytime surface heating than the old surface radiation scheme that allows for clouds in an integrated sense. Also an upper nighttime dipole of cooling above warming of about 0.5 K amplitude reveals the longwave radiative influence of widespread upper clouds, and low-level daytime warming above the boundary layer is shortwave heating of low stratiform clouds. As shown by the difference field in Figure 1b, cloud amounts were also affected by radiation, low-level clouds being decreased during the day and high clouds being increased at night.

The mean rate of radiative heating shown in Figure 2 varies from a few degrees of cooling at night to no net cooling during the day in clear air. The cloud effects

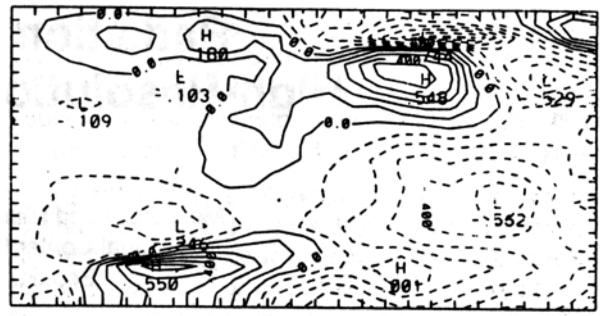

**Figure 1a.** Domain-averaged temperature with radiation minus without radiation. Vertical axis is model level, horizontal is time (24 h starting at 0600 CST). Contour interval 0.1 K.

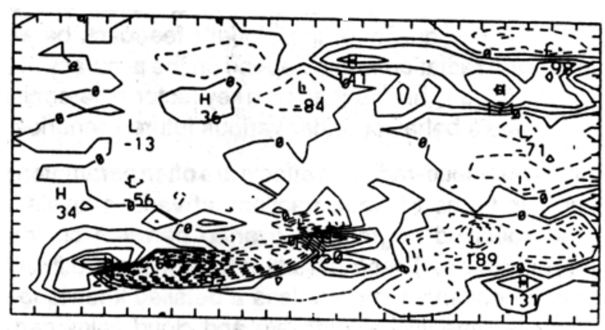

**Figure 1b.** Domain-averaged cloud with radiation minus without radiation. Axes as in Figure 1a. Contour interval 0.004 g/kg.

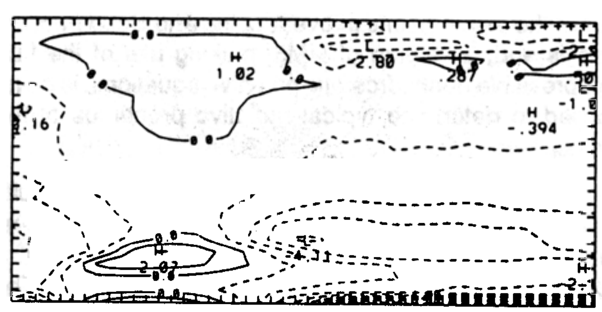

**Figure 2.** Domain-averaged radiative heating rate. Axes as in Figure 1a. Contour interval 1 K/day.

mentioned earlier and additional cooling of low-level cloud tops at night all contribute to the domain-scale average. In this case, the degree of overlap of low-level and high-level clouds would affect the amount of low-level cloud-top cooling. Less overlap would result in more cooling.

The model results at a selected time, 00Z (1800 CST), both at cloud levels (e.g., 300 mb) and at the surface, show mesoscale variability in radiative cooling/heating particularly caused by clouds (Figure 3). The figure shows local cloud-top cooling rates of 10-20 K day$^{-1}$ and similar cloud-base warming rates in contrast to the 2-3 K day$^{-1}$ in clear air. The heating maxima occur where the cloud base intersects the 300-mb surface.

The influence of low cloud cover upon surface longwave radiative fluxes is 70-100 W m$^{-2}$, while clear drier air gives 50 W m$^{-2}$ less downward IR than neighboring clear moister air east of the dry line (bold dashed line) as seen in Figure 4a. Shortwave heating (Figure 4b) below cloud cover is negligible at the low solar angle near sunset, but in the clear air the effect of changing solar elevation with longitude is seen.

# Conclusions and Further Work

An atmospheric radiative scheme has been incorporated into a mesoscale model. The above results are part of the testing for this new scheme and demonstrate that it gives results in keeping with generally accepted radiative influences.

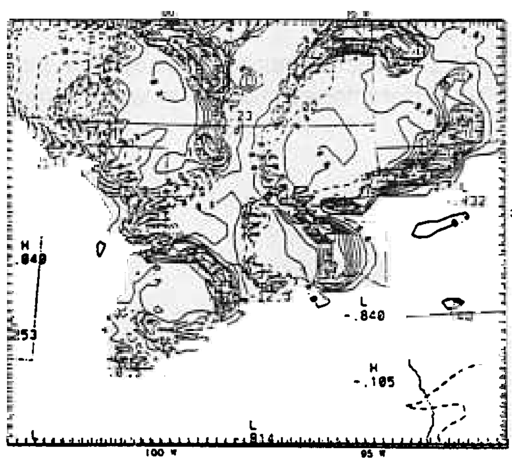

**Figure 3.** Net radiative heating at 300 mb, 12-h forecast time. Contour interval 1 K/day.

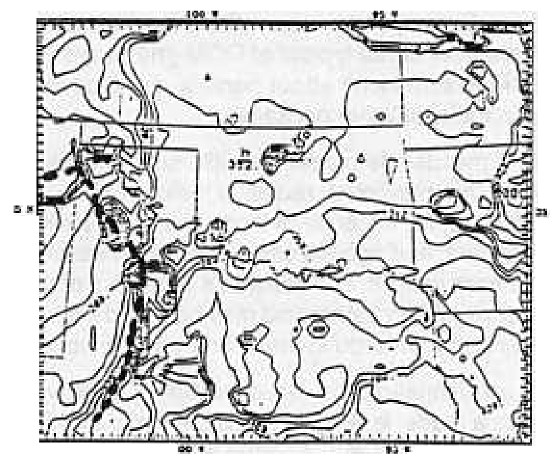

**Figure 4a.** Downward IR flux at surface, 12-h forecast time. Contour interval 10 W m$^{-2}$.

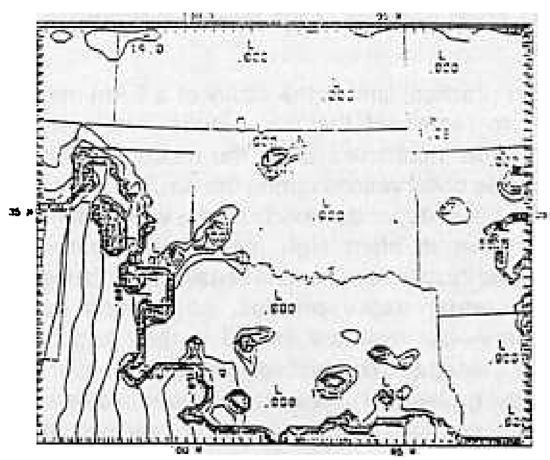

**Figure 4b.** Downward solar flux at surface, 12-h forecast time. Contour interval 10 W m$^{-2}$.

The domain-averaged radiative heating is distinctly for the 20-km grid influenced by two cloud layers, one of high cirrus and one of low stratus, and the diurnal cycle of heating in these layers.

By resolving cloudy and clear columns and cloud layers, the model can give some indication of the true atmospheric radiative fluxes. These may then be compared with averages over areas typical of GCM grid boxes to check the GCM assumptions about partially cloud-covered grid boxes in their radiative packages.

Use of a mesoscale model also affords the possibility of verifying the predicted radiative fields against in situ observations, for instance of long- and short-wave fluxes at the ground, and against other available measurements such as from aircraft. The scheme's treatment of clouds is based currently on theory and may be tuned if systematic errors are encountered in these intercomparisons.

There are limitations to be considered, however. The mesoscale model is likely to use a 5-km grid size in future applications related to the Cloud and Radiation Testbed (CART) sites, where there are still sub-grid scale fluctuations in the cloud fields, particularly in the case of small cumulus. This limitation can be overcome with selected very-high-resolution runs, but at these scales, the radiation scheme breaks down because of the three-dimensionality of the fluxes.

Another practical limit is the ability of a 5-km mesoscale model to represent the true clouds accurately. Data assimilation techniques allow the model to incorporate mesoscale observations during the run, but it is clear that the cloud field depends heavily on the water vapor field in which there is often high mesoscale variability. To compound this problem, remote sensing techniques cannot provide water vapor profiles, so balloon data are necessary—but they are limited in their temporal and spatial coverage. In convectively unstable situations, there is also the problem of unpredictability where differences in the location of, for instance, the first convective tower may lead to widely different results.

Thus, in general, the data assimilation model output cannot be compared cloud-by-cloud with observations. The model's cloud/radiative interaction may sometimes have to be verified by comparing similar clouds in the model with observations requiring aircraft measurements of cloud properties. The improvements made to the model's radiation scheme and also possibly to the cloud scheme through such comparisons will lead to a model simulation that can closely resemble realistic meteorological environments. The output would be a full dataset sufficient for representing GCM grid areas and could therefore be used as a testbed for GCM parameterizations. This dataset complements the CART observations that are limited in coverage.

# Acknowledgments

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