Investigation of Shortwave Radiative Processes and Cloud Prediction in the Eta Forecast Model

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Introduction

In an earlier work (Hinkelman et al. 1999), time series of surface flux predictions from the National Centers for Environmental Prediction (NCEP) Eta forecast model were evaluated by comparison to measured values from the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) central facility. As expected, the Eta surface energy budget was nearly balanced over the first half of 1997. However, an average 50 Wm^{-2} excess in downwelling solar radiation was found. This excess shortwave flux was offset by a smaller negative bias in the downwelling infrared flux and the use of slightly high albedos, in addition to errors of lesser magnitude in the latent and sensible heat fluxes. In this study, we attempt to determine the source of the extra solar radiation. In addition, we examine the accuracy of cloud prediction in the model.

The Eta Model

The Eta forecast model is run operationally twice a day at the NCEP. Model output from January to June of 1997 was employed in this study. During that time, the model's horizontal domain covered most of North America with a grid spacing of 48 km. There were 38 vertical levels defined in pressure coordinates from the surface to about 22 km. The model had a dynamic time step of 2 min. and was run to provide hourly forecasts for a 48-hour period. An explicit cloud prediction scheme and a radiation package were included in the model. Changes to the model have been made since 1997, so that the exact version from which this output came is no longer in use.

For the ARM measurements, data from the central Cloud and Radiation Testbed (CART) facility in Lamont, Oklahoma, located at (36.62°N, 97.50°W), were used. Data for the Eta model grid point nearest Lamont were used for comparison. This grid point fell at (36.70°N, 97.55°W), or approximately 12 km northwest of the ARM facility.

Surface Shortwave Fluxes

Cloudy Versus Clear-Sky Error

To assess the effect of clouds on calculated incoming radiation, the difference between the measured and predicted downwelling solar fluxes was computed for the 32 clearest days and the 39 cloudiest days in the six-month period, as determined from the ARM radiation data. The mean difference between the ARM and Eta values was found to be 87 Wm^{-2} on the cloudy days but only 27 Wm^{-2} on the clearest days. This indicates that about half of the overall average excess downward shortwave flux results from mishandling of clouds by the model while the rest is due to errors in the treatment of radiative transfer through the clear sky.

Sources of Clear-Sky Error

Possible sources of the clear-sky incoming solar flux error were evaluated by comparing the downward solar fluxes predicted by the Eta model with ARM measurements and values from a radiative transfer calculation for several clear-sky days. The calculations accounted for measured water vapor but omitted aerosols; the model contained a crude correction for aerosol and water vapor effects; and the measured fluxes were affected by all atmospheric constituents. The results of this comparison are shown in Figure 1. These results indicate that most of the Eta excess in clear-sky downward solar radiation is due to insufficient absorption by water vapor but that the effect of aerosols is also underestimated.

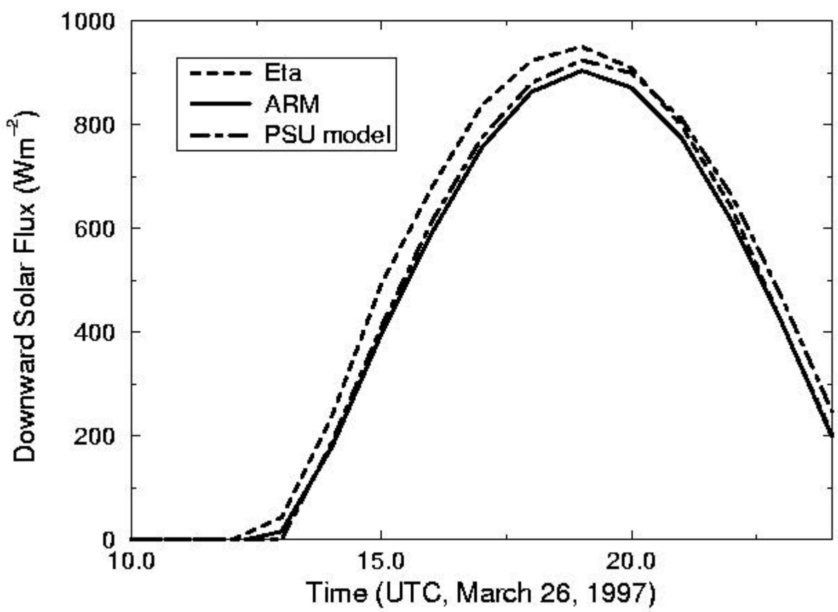

Figure 1. Comparison of downward solar fluxes predicted by the Eta model with values from our radiative transfer calculations and the ARM SGP site measurements. All data were averaged to one-hour increments.

Cloud Prediction

Data Description

Time series of cloud occurrence at the vertical levels defined by the model were assembled for both the model output and for measurements from the Millimeter Cloud Radar. For the model, clouds were defined to occur in areas of the atmosphere where the liquid/ice water content was predicted to be at least 0.01 gm^{-3} at a given forecast hour. For the radar, clouds were considered to be present in a grid box during the hour if significant returns were received for at least half of the interval. (See Clothiaux et al. 1999 and Marchand et al. 1998, for details of the algorithms used to detect clouds from radar and lidar measurements.) No attempt was made to eliminate radar returns from precipitation.

Cloud Profiles

Average cloud profiles predicted by the Eta model and measured by the ARM SGP cloud radar for January through March of 1997 are shown in Figure 2. During this time, cirrus clouds are substantially overpredicted by the Eta model. Low and middle clouds may be slightly underpredicted as well.

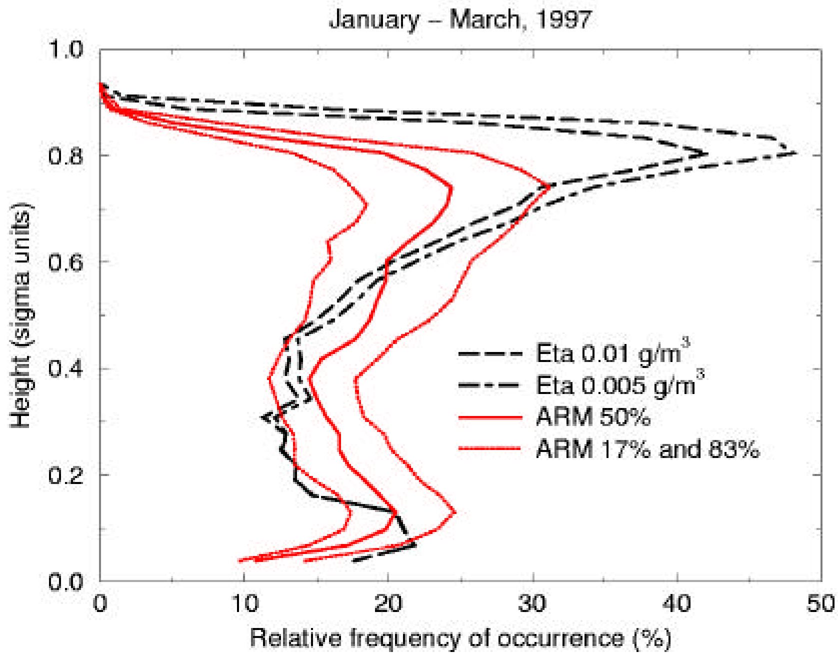

Figure 2. Averaged cloud profiles predicted by the Eta model and measured by the ARM SGP cloud radar for the first three months of 1997.

The average predicted and measured cloud profiles for April to June of 1997 appear in Figure 3. The model clearly underpredicts the occurrence of low and middle clouds during the spring. However, the frequency of occurrence of high clouds is approximately correct during this period.

Cloud Timing and Location

Eta model cloud predictions and ARM radar detections for January 1997 are compared in Figure 4. Overprediction of cirrus is clearly evident. However, most major cloud systems are correctly identified by model.

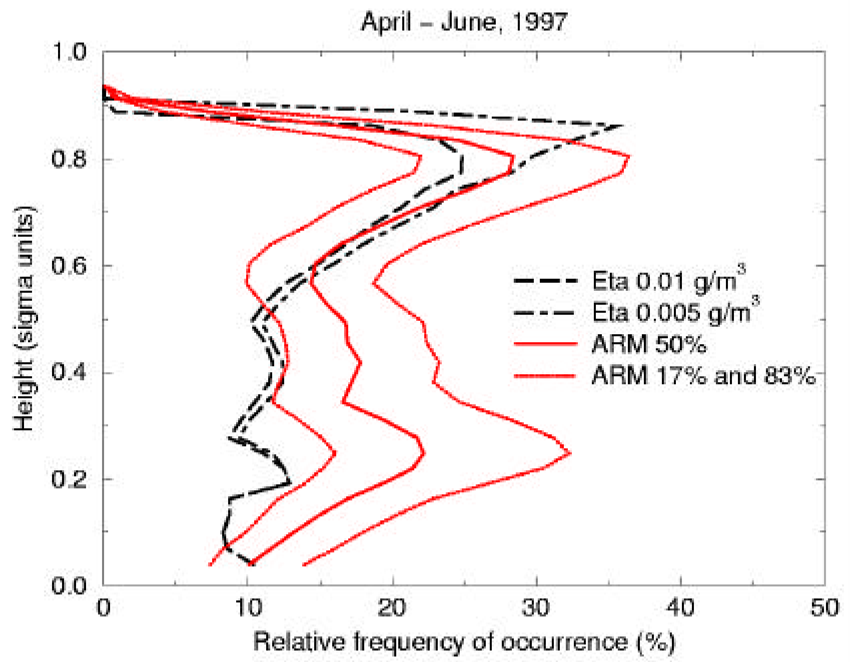

Figure 3. Averaged cloud profiles predicted by the Eta model and measured by the ARM SGP cloud radar for the next three months of 1997.

A similar comparison for June of 1997 is given in Figure 5. In this case, widespread underprediction of cloud occurrence is seen. Rising cumulus towers are especially likely to be missed. This may be due to the lack of explicit cloud formation in the model's convective adjustment scheme.

Conclusions

Solar Radiation

About half of the excess downwelling solar radiation calculated by the Eta model is attributed to insufficient absorption by water vapor and deficient absorption and scattering by aerosols. The other half of the excess is attributed to errors in predicting clouds and their radiative effect.

Cloud Prediction

Excess cirrus clouds are predicted in the winter, but low and middle clouds are missed during spring. While synoptic cloud systems are reproduced well, springtime convective towers are not explicitly predicted.

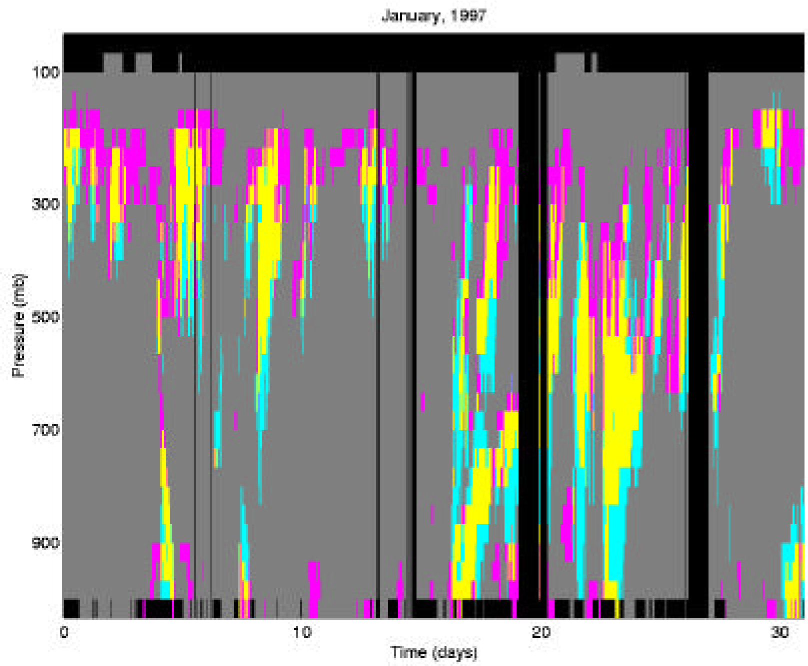

Figure 4. Comparison of Eta model cloud predictions and ARM radar detections for January 1997. Color scheme: gray = no cloud, both Eta and ARM; cyan = no cloud Eta, cloud ARM; yellow = cloud, both Eta and ARM; magenta = cloud Eta, no cloud ARM; black = no ARM data.

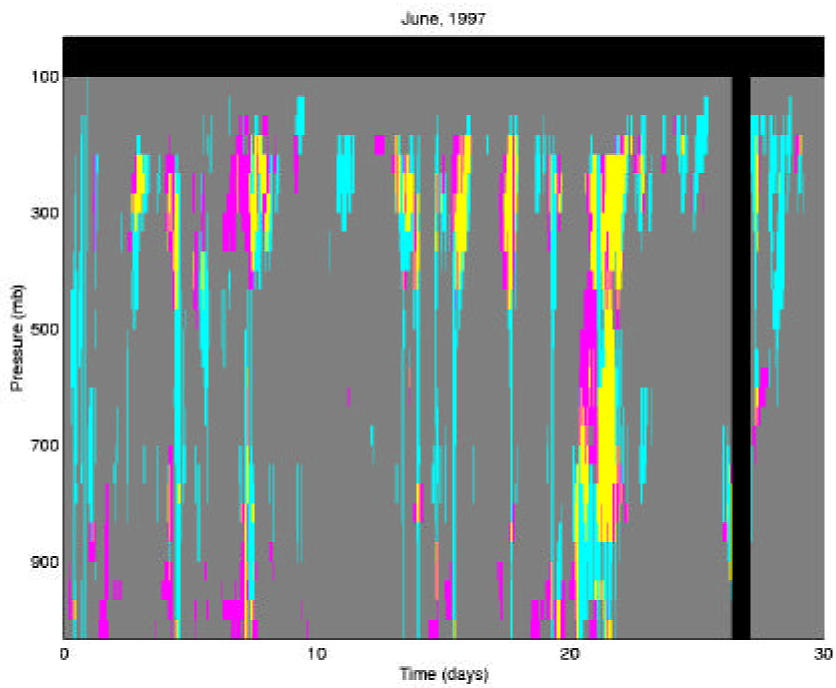

Figure 5. Comparison of Eta model cloud predictions and ARM radar detections for June 1997. Same color scheme as Figure 4.

References

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