Longwave Radiative Forcing in Global Climate Models[(a)]

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Introduction

Long wave radiation (LWR) forcing is determined in atmospheric global climate models (AGCMs) by a heating algorithm embedded in the model. These algorithms compute vertical heating rate (HR) profiles from profiles of temperature (T), moisture (Q), clouds, and minor atmospheric constituents; thus the HRs depend on the vertical structure of the input variables plus internal physics. The sensitivity of various algorithms (taken from AGCMs) to these input variables was tested; examples of their sensitivity can be found in Baer et al. (1996). It is particularly noteworthy that the algorithms are extremely sensitive to clouds.

LWR algorithms calculate vertical profiles of HRs periodically at each point in an AGCM, generating 3-dimensional fields. These HR fields represent the LWR forcing, which determines the temperature-tendencies in the model. The temperature field predicted from these tendencies, in turn, modifies the wind field tendencies by nonlinear interaction in space. The predicted wind field subsequently modifies the temperature tendencies by nonlinear advection. Thus the impact of the HRs is spread in time and space to all the model variables and, in particular, to the T, Q, and cloud fields. These modified variables are then used to recalculate new HRs. It is the response of the AGCMs to these effects and how they impinge on climate prediction that we seek to establish.

Previous Model Discoveries

We studied a number of archives of AGCM runs with reference to radiative forcing and found the following results:

- HRs depend strongly on model truncation; however, this variability depends on the particular AGCM considered.

- HRs are strongly dependent on model changes including changes to the incorporated LWR algorithm.

- HR dependence on surface forcing in the form of sea-surface temperature (SST) appears to have a significant effect on the evolution of the model variables.

Unfortunately, there are no direct observations of HRs to use for comparison to model output. As an approach to generating observations, we used a model (the Community Climate Model [CCM2]) to generate clouds from observed (T, Q) data, and used those clouds to generate HRs in the model. Specifically, we introduced observed data into the CCM2 as initial conditions for each day of an Atmospheric Model Intercomparison Project (AMIP) period (January - February 1987) and ran the model for 36 hours. The HR fields the model developed at that time we defined as "pseudo-observations" to compare with output of various AMIP model runs. Those comparisons showed significant differences in the HR patterns and indicated that the AMIP runs have sizable climate variability leading to their own model climate. Based on these results, we undertook controlled AGCM integrations.

GCM Control Experiments and Climate Validation

To test the effect of longwave radiative forcing with all other GCM features held fixed, we ran the CCM2 twice using a different longwave radiation column model (LWRM) algorithm each time—the National Center for Atmospheric Research (NCAR) native version and the European Centre for Medium Range Weather Forecasting (ECMWF) version; nothing else in the model was changed. Both integrations were for two months of the AMIP period, January - February 1987, with identical initial conditions. The results show differences on the order of 10%, a significant difference, with the ECMWF algorithm yielding stronger cooling. To determine if these differences are due to the algorithms or climate variability, we must establish the AGCM variability.

(a) Poster presented at the ARM Science Team Meeting, 3-7 March 1997. A complete version can be found on the web at the following address: http://metosrv2.umd/~baer/ARMpost_97/

Any one realization of climate statistics may not reflect the climate for that period. To determine climatic variability, we ran ten realizations of the CCM2 with only slight variations in initial states. All runs began 1 October 1986; two months were allowed for equilibrium, and model output statistics for the subsequent three months of December, January, and February were used to assess the model variability. All ten runs included the NCAR radiation algorithm. Means of HRs from the ten realizations and their standard deviations were viewed on 200 and 500 hPa maps as well as amplitudes of planetary wave number vs. height. The standard deviations frequently exceeded 10%. Similar results were found for clouds and temperature.

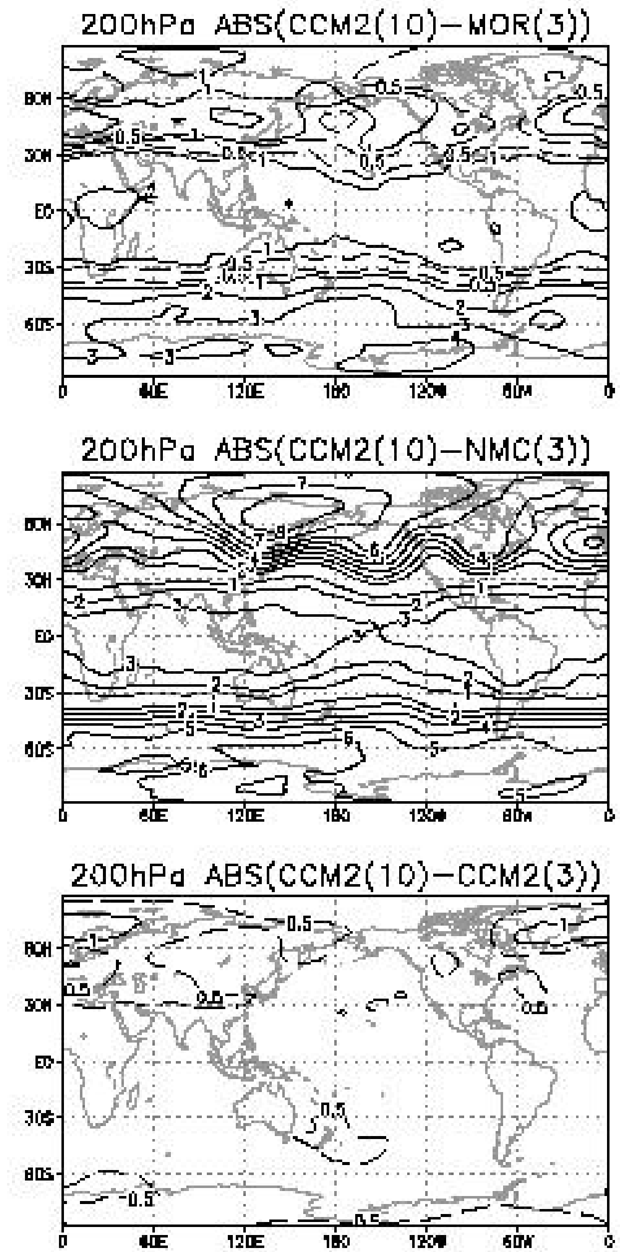

Figure 1. Maps of temperature differences on the 200 hPa surface from CCM2 integrations averaged over the period December-January-February 1986-87. The differences in the top two panels reflect the use of different LWR algorithms in the calculation. The bottom panel shows the climate variability of the CCM2 using the NCAR algorithm.

Climate versus Model Variability

Three realizations with the CCM2 using the ECMWF algorithm and three using the National Centers for Environmental Prediction (NCEP) algorithm were run in addition to the ten runs with the NCAR algorithm. Analysis of the model output suggested that testing for climate variability with three realizations appears realistic. Figure 1 shows difference maps of the average temperature at the 200 hPa level, comparing the ten CCM runs with the three runs (same initial conditions) each using the ECMWF, NCEP and NCAR algorithms. The bottom panel is based on the same algorithm; thus it reflects model climate variability. The other panels reflect variability dependent on the selected algorithm. The climate statistics for the runs with different algorithms show much larger variability from one another than is seen for the model climate variability itself (bottom panel).

Integrations using the NCAR, ECMWF and NCEP algorithms for the same three realizations were intercompared, considering the realization averaged fields of various model variables. The results indicate that the NCAR and ECMWF runs compare more favorably to one another than to the NCEP (National Meteorological Centre [NMC]) run, but differences on all maps exceed 10% in many places on the globe, differences which are far above the model climate variability. An extreme response is seen on Figure 2, which shows temperature at both 250 hPa and 100 hPa for two of the experiments, the ECMWF and NCEP runs. Note the reversal of temperature in the stratosphere on the NCEP (NMC) chart. The experiment with the NCAR algorithm is more like the ECMWF results.

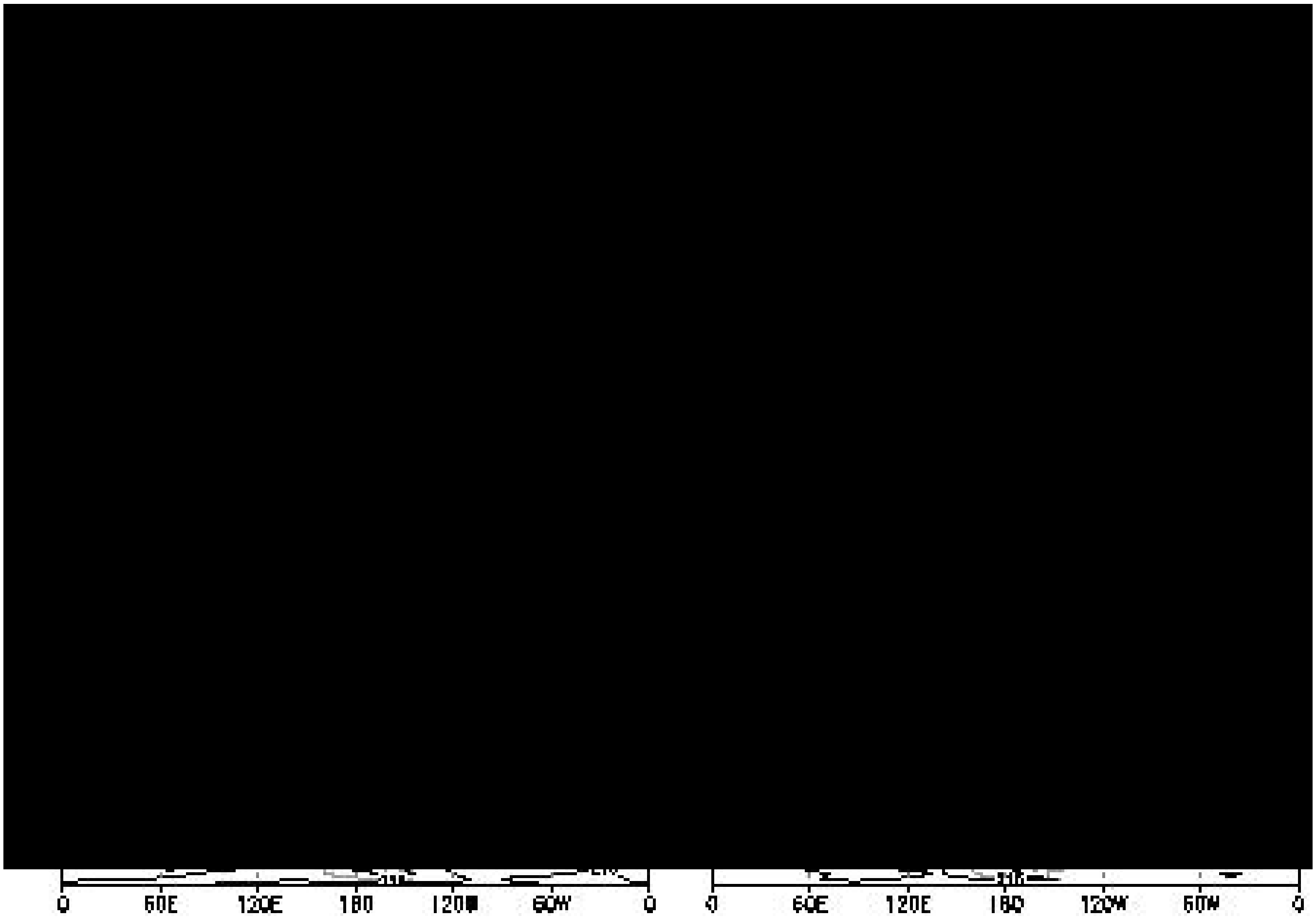

Figure 2. CCM2-predicted average temperature patterns at 250 and 100 hPa resulting from using two different algorithms (ECMWF and NCEP [NMC]) in the calculations. The model output data are averaged over the period December-January-February 1986-87.

Boundary Effects

We calculated the net upward flux at the surface and the top of the model from the statistics of the three model runs discussed above. To establish the relative effects in the different runs, we determined the flux differences produced by the runs. An example can be seen on Figure 3, which indicates differences on the order of 10 watts per m^2 over most of the globe. Particularly in the tropics, some of these flux differences are very large indeed. These sizable differences among the models could easily lead to a different climate scenario for each model.

Conclusions

- Using different LWRM algorithms in the CCM2 results in notable differences of model output when the integration proceeds for 60 days or more.

- From the climate validation studies we undertook, the impact of HR algorithms in a GCM shows significant climate variability.

- When intercompared, the climate statistics developed using three different LWR algorithms in a GCM (CCM2) show much greater variability than the climate variability of the GCM itself.

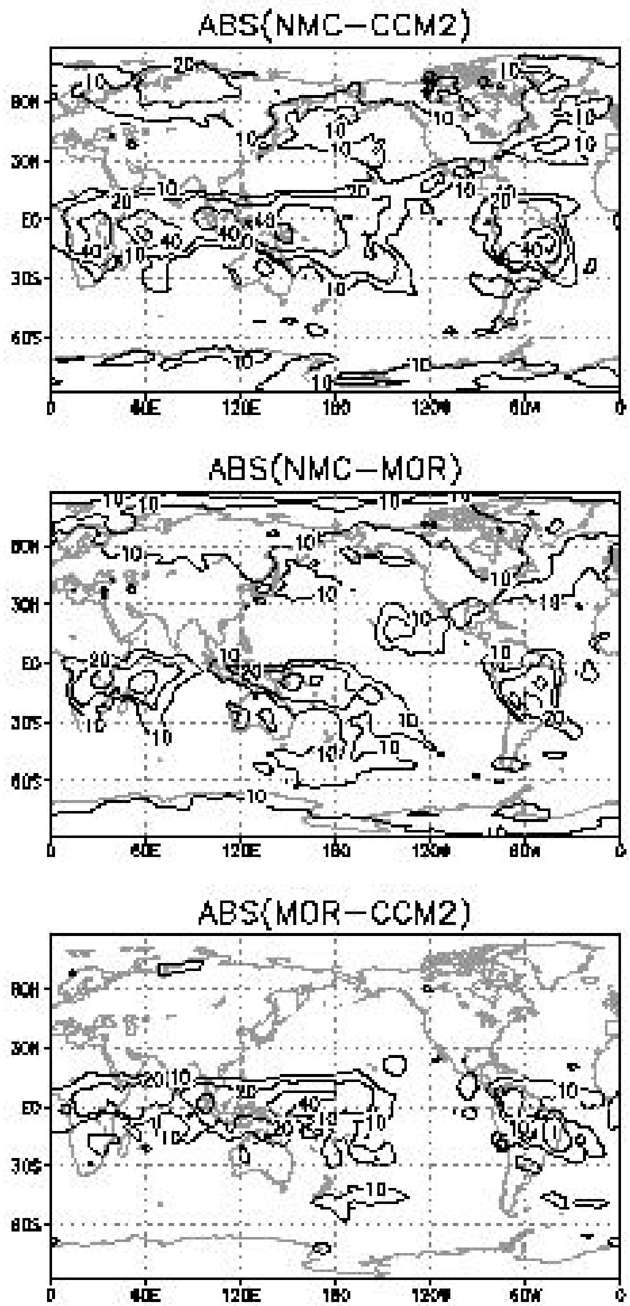

Figure 3. Differences in the net upward flux at the top of the CCM2 for the experiments using the three algorithms (NCAR, ECMWF, NCEP). The model output data are averaged over the period December-January-February 1986-87.

- Of the three algorithms tested, the NCEP algorithm showed greater differences in model response from the other two, the NCAR and ECMWF algorithms.

Further studies are needed to test AGCM effects. We are in the process of undertaking the same experiments described herein with the CCM3, NCEP and National Space and Aeronautics Administration AGCM models.

Reference

Baer, F., N. Arsky, J. J. Charney, and R. G. Ellingson, 1996: Sensitivity of heating rates from global climate model radiation codes. *J. Geoph. Res*., **101**, D21, 26589-26603.