Treatment of Cloud Radiative Effects in General Circulation Models

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We participate in the Atmospheric Radiation Measurement (ARM) program with two objectives: 1) to improve the general circulation model (GCM) cloud/radiation treatment with focus on cloud overlapping and the cloud optical properties and 2) to study the effects of cloud/radiation-climate interaction on climate simulations. The project includes three tasks: 1) GCM radiation model-to-observation comparison, 2) GCM radiation model development, and 3) GCM climate simulations.

Task 1: Radiation Model-To-Observation Comparison

Ground Measurements

We used the observed vertical distribution of temperature, humidity, and cloud cover at Albany, New York, as inputs to the National Center for Atmospheric Research (NCAR) Community Climate Model version one (CCM1) radiative code to calculate the solar radiation reaching the surface for both clear and cloudy sky conditions. The data include the surface solar radiation collected by the Atmospheric Sciences Research Center (ASRC) for 10/86, 4/87, 5/87, 7/87 and 10/87 and the meteorological data at the surface and in the upper air collected by the National Weather Service. Most of the data, however, were for cloudy sky conditions.

For the few clear sky cases, the calculated fluxes are in reasonable agreement with the observations. However, these fluxes are sensitive to the total amount of O_3 in the column, and to a lesser extent, to surface reflectivity. We plan to replace the O_3 with the satellite TOMS data. Large differences are found in the comparison for the case of cloudy sky. These differences can be attributed to the model's internally assigned cloud albedo (the lack of interactive cloud optical properties) and to the missing information of the cloud vertical layering from ground measurements.

Satellite Measurements

The satellite effort concentrates on developing 1) an interactive cloud analysis procedure which uses advanced, very-high resolution radiometer (AVHRR) channel radiance data to provide cloud field properties including cover, type, layers, and height, and 2) an interactive satellite imagery manipulation capability to delineate and prepare data for input into cloud analysis algorithms. Two procedures, single channel and bispectral, have been developed to extract the cloud field properties from AVHRR data. We also are exploring the method of extracting cloud vertical overlapping information. Preliminary results suggest that it is possible to extract two overlapping clouds. However, more detailed analyses are required. This effort is a collaborative work with D. Johnson and R. Issacs of Atmospheric and Environmental Research, Inc.

Task 2: Radiation Model Development

We continue the development of the radiation code used in CCM1. The effort so far involves the further refinement of the total band absorptance and k-distribution function (Wang et al. 1991a). Note that the k-distribution function method can treat multiple scattering in the presence of gaseous absorption. The total band parameters for H_2O,

CO_2 and O_3, and trace gases CH_4, N_2O, and CFCs were revised using the 1991 HITRAN absorption line data[a]. In addition, we are incorporating the H_2O continuum data recently updated by Clough et al. (1989).

Task 3: General Circulation Model Simulations of the Greenhouse Effect

As a follow-up of our previous study of the greenhouse effect (see Wang et al. 1991b), we carried out additional CCM1 experiments to study the radiation-climate interaction due to increasing CO_2 and trace gases CH_4, N_2O and CFCs. Specifically, the Business-as-Usual scenario of Houghton et al. (1990) for the period 1990-2050 was adopted to examine the global warming. We have also run an experiment with increases of CO_2 alone. Changes in the global and annual mean key climate statistics are summarized in Table 1. The model simulations suggest that the global and annual mean surface air temperature can be warmed by 4°C during the period 1990-2050. Accompanying this surface warming, the global averaged cloud cover decreases while total precipitation and atmospheric moisture increase. The contribution of CO_2 alone is calculated to be 2.7°C, which implies that the effect of trace gases accounts for one-third of the total warming.

(a) L. S. Rothman, Air Force Geophysics Laboratory, 1991 personal communication.

Climatology at Oklahoma Site

To get a sense of how well the GCM simulated local climate, we have compared the model simulations with observations at the Oklahoma site. The comparison was carried out simply by comparing the grid point simulated 1990 climatology (10 years of statistics) with observations averaged over 17 nearby stations. The comparison of surface air temperature in Figure 1 indicates that, although the annual mean value is different, the calculated seasonal cycles agree very well with observation. Figure 2 shows the precipitation comparison. Again, the seasonal cycle is in much better agreement than the annual mean values. In any case, it is interesting to note that the GCM does catch some of the observed local climate characteristics (see Karl et al. [1990] for further discussion).

Future Plan

We plan to continue the tasks discussed above with emphasis on Tasks 1 and 3. For Task 1, we will focus on the optical properties of clouds and their incorporation into the radiation code, which, as discussed above, can cause large differences in the solar radiation reaching surface. We plan to use both the satellite and ARM measurements. For Task 3, we plan to set up the 1-D column model to use the ARM data at the Southern Great Plains. In addition, we

Table 1. CCM1 simulated changes of surface air temperatures Ts (K), precipitation P (mm/day), cloud cover C (%) and column water vapor Q (mm). The Business-as-Usual scenario of Houghton et al. (1990) was used for the concentration increase.

Case	Ts	ΔTs	P	ΔP	C	ΔC	Q	ΔQ
1990	288.8		3.38		46.0		25.3	
2050	292.8	4.0	3.64	0.26	44.6	-1.37	32.4	7.1
2050[a]	291.5	2.7	3.55	0.17	45.2	-0.78	31.7	6.5

(a) CO_2 increase only.

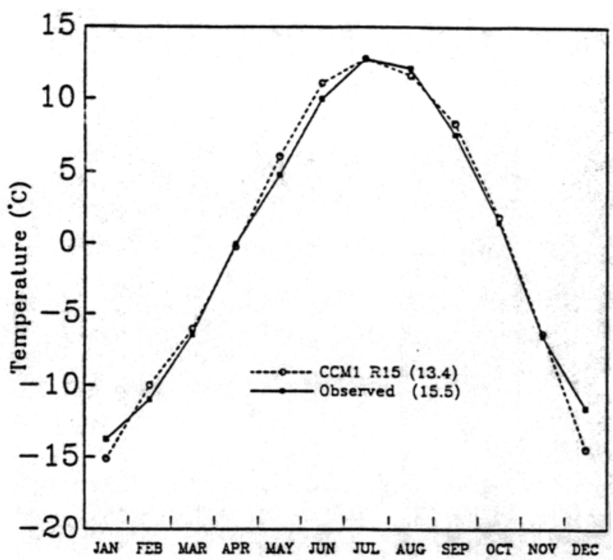

Figure 1. Comparison of the surface air temperature at Oklahoma site between CCMI single grid point and observations, which are the averaged values over seventeen stations. Note that the numbers within the parentheses are the annual mean values.

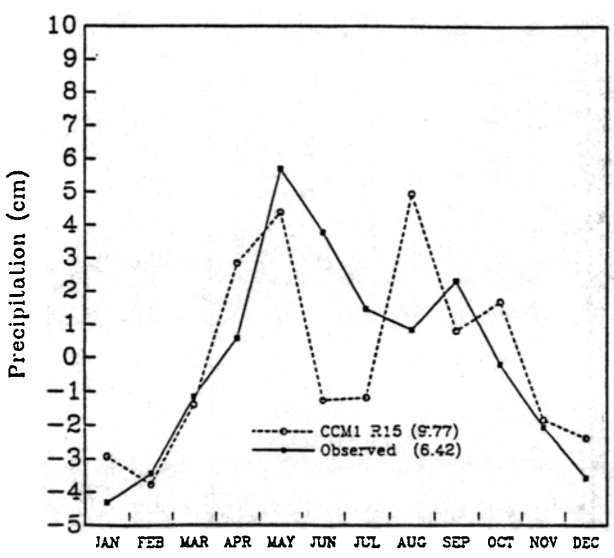

Figure 2. Same as in Figure 1 except for precipitation.

will study the impact of the cloud optical property on the climate model simulations.

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