4B.2 A GLOBAL CLIMATE MODELING STUDY OF ANTARCTIC CLOUD RADIATIVE PROCESSES

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1. INTRODUCTION

Simulations with the National Center for Atmospheric Research (NCAR) Community Climate Model version 3 (CCM3) detail the impacts of Antarctic clouds and radiative processes on the global climate. Current global climate models (GCMs) contain little to account for the unique meteorology and atmospheric physics over Antarctica. Unfortunately, over the Southern Ocean and Antarctica, many GCM simulations of present day climate still contain large errors in the meteorological fields and the radiation balance. The model CCM3 contains a single set of parameterizations for liquid water and ice clouds that is applied globally. The Antarctic continent may be a place where these global parameterizations need to be refined at their cold and dry limits. Clouds are generally thinner over Antarctica due to the lower water vapor amounts. In addition, the Antarctic troposphere is the cleanest on earth, being far from continental aerosol sources. Lubin et al (1998) show that a change from liquid water clouds to ice clouds over Antarctica modifies the solar and longwave radiation resulting in dramatic changes in Southern Hemisphere climate and even changes in Northern Hemisphere climate.

2. THE MODEL

The model CCM3, with a standard horizontal resolution of T42 and 18 levels in the vertical, has highly significant improvements in the simulation of the modern climate compared to its predecessor CCM2. Kiehl et al. (1998) show that, based upon comparisons with observed data, dramatic improvements in global annual means are simulated for the radiation fields.

Briegleb and Bromwich (1998a,b) examine the polar climate and radiation balance simulated with a standard version of CCM3. A much improved pattern of sea level pressure near Antarctica is simulated than with the NCAR CCM2. In the CCM3 simulations, the intensity of the Antarctic circumpolar trough is reduced and much closer to observed values. Additionally, the positioning of troughs and ridges over the Southern Ocean is more realistic. Biases, however, still remain in the simulated polar radiation budget. Consequently the polar tropospheric temperatures are too cold and the middle-tropospheric circumpolar vortex is too strong. The semi-annual wave in high southern latitudes is still not properly simulated. The circumpolar trough has a sharp pressure maximum during January and a flat minimum during winter.

To seek improved climate simulations, both the prognostic cloud particulate scheme of Rasch and Kristjansson (1998) and the Rapid Radiative Transfer Model (RRTM, Iacono et al. 2000) developed by Atmospheric and Environmental Research (Inc.) have been implemented in a version of CCM3. A 6-year simulation with climatological boundary conditions is performed. We refer to this new simulation as RRTM+PCW. Results are compared to earlier CCM3 simulations including the following: (1) the last 10 years of a 15-year simulation with climatological boundary conditions performed with a standard version of CCM3 by James Rosinski of NCAR, (2) a 14-year simulation (1979-1992) with annually varying boundary conditions and the Rasch and Kristjansson (1998) prognostic cloud scheme performed by the third author, and (3) a 10-year simulation (1979-1988) with annually varying boundary conditions and RRTM performed by the second author. The earlier simulations will be referred to as CONTROL, PCW, and RRTM, respectively.

3. RESULTS

Figure 1 shows the average surface pressure for 60°-70°S for each month of the multi-year CCM3 simulations. The pressure in this band will fluctuate with semi-annual oscillation in the Antarctic circumpolar trough. The observed semi-annual oscillation has its highest maximum and lowest minimum during January and October, respectively, with a secondary maximum and minimum during June and March/April, respectively (Briegleb and Bromwich 1998b). For the standard version of CCM3 (CONTROL), the general amplitude of the semiannual oscillation is close to the observed amplitude of about 8 hPa, however, the austral autumn minimum is too

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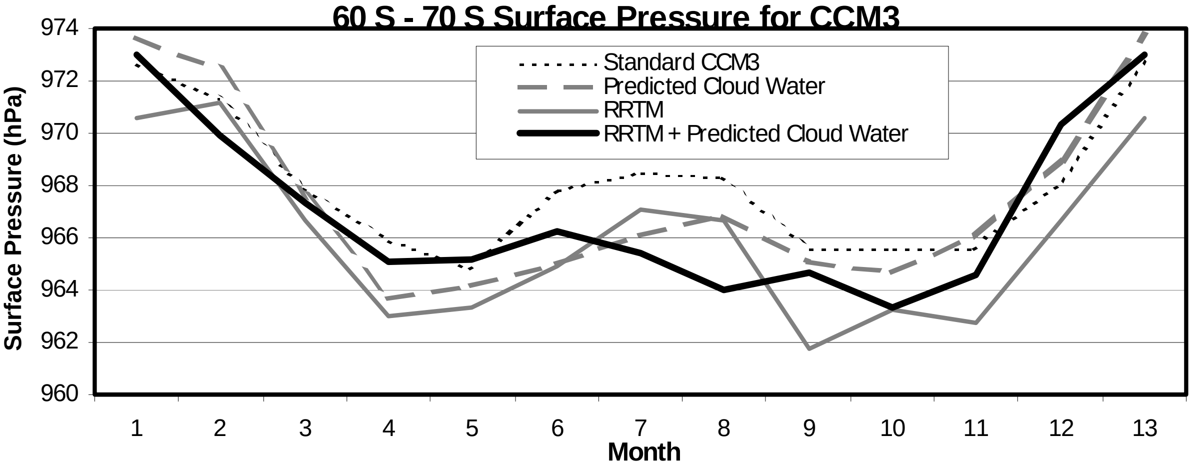

Figure 1. Seasonal cycle of average CCM3 surface pressure (hPa) between 60°-70°S.

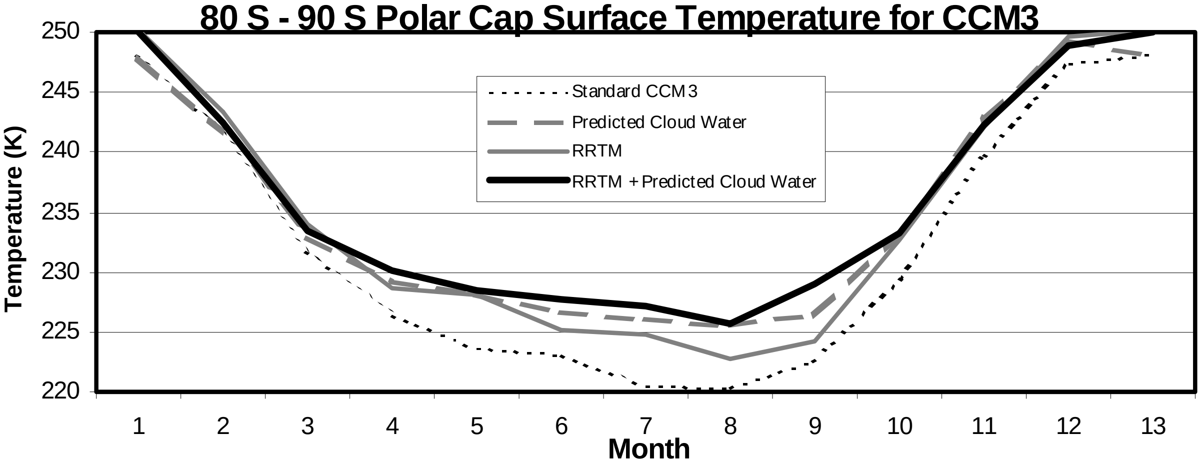

Figure 2. Seasonal cycle of average CCM3 surface temperature (K) between 80°-90°S.

intense and slightly delayed compared to observations. The radiation and cloud scheme additions to the new version of CCM3 (RRTM+PCW) produce an improved simulation of the seasonal cycle of the circumpolar trough, although the annual-average pressure in the trough is probably too low (see Briegleb and Bromwich 1998b). Figure 1 suggests that the deeper minimum during austral spring results from the RRTM radiation scheme. Furthermore, both the prognostic cloud scheme and RRTM work to intensify the circumpolar trough during austral winter.

Figure 2 shows the 80°-90°S polar cap surface temperature. The surface temperature over Antarctica has a continental-wide cold bias of 2-5 K for the standard version of CCM3, with a slightly larger bias over the high interior plateau (Briegleb and Bromwich 1998b). The additions to the new version of CCM3 increase the surface temperature by as much as 5-7 K in winter for PCW, RRTM and RRTM+PCW. An increase in the downward clear-sky longwave flux might be responsible for the increase in RRTM, while an increase in Antarctic clouds and corresponding downward radiation might be responsible for the temperature increase in PCW.

Figure 3 shows the net longwave and the net clear-sky longwave radiation at the earth's surface. The difference between net and clear-sky radiation is due to the effects of clouds. Many radiation schemes, including the one used by CCM3, underestimate the downward longwave clear-sky radiation at the surface in the polar regions. In CCM3, the error may be as large as 25 Wm^{-2} (Briegleb and Bromwich 1998a). Thus net clear-sky longwave radiation (upward - downward) should be too large for polar surfaces. The RRTM code should reduce this deficiency (Iacono et al. 2000). Correspondingly, Fig. 3 shows that net clear-sky radiation is reduced by about 5 Wm^{-2} for RRTM compared to CONTROL.

The large difference between clear-sky and net

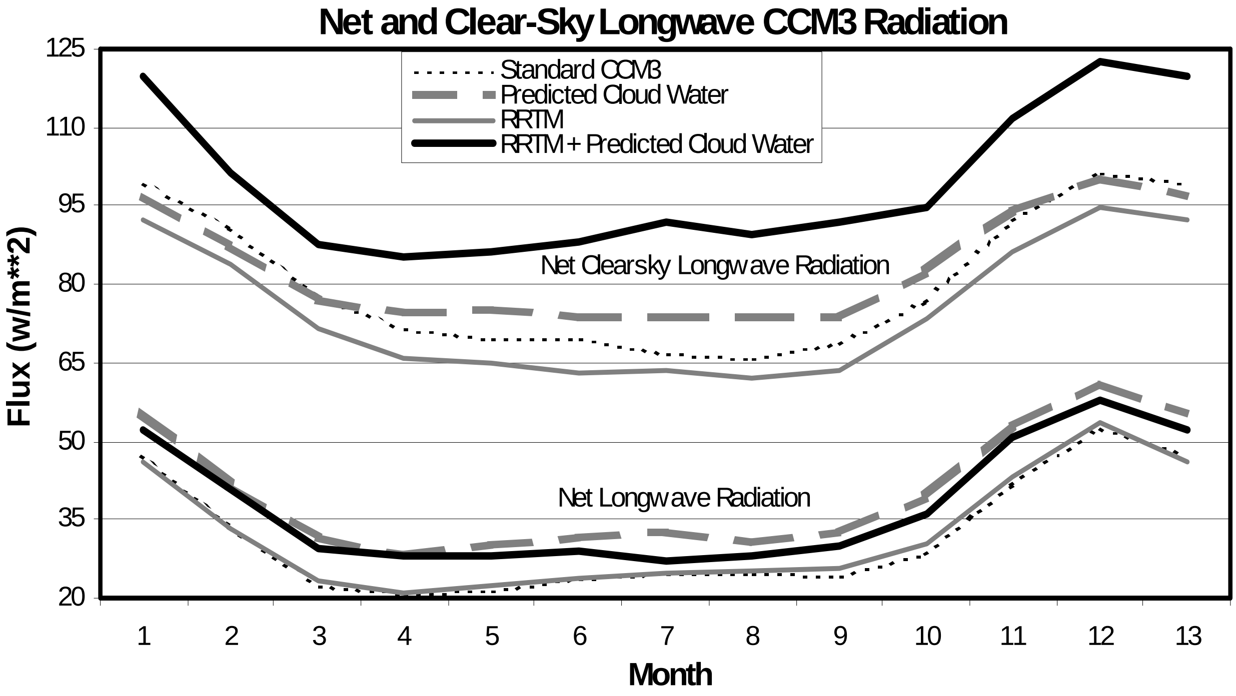

Figure 3. Seasonal cycle of average net longwave radiation and net clear-sky longwave radiation (Wm^{-2}) at the surface between 80°-90°S.

longwave radiation in Fig. 3 indicates the critical effect of clouds on the polar simulations. Briegleb and Bromwich (1998a) find that the longwave cloud forcing for CCM3 is much too large for the South Pole. Apparently, our additions to CCM3 have increased this as the difference between clear-sky and net longwave radiation have increased from 45-50 Wm^{-2} for the standard version of CCM3 to 60-65 Wm^{-2} for RRTM+PCW. The increased net longwave radiation for PCW and RRTM+PCW is probably a result of increased upward flux from warmed surface temperatures.

4. CONCLUSIONS

Numerical simulations of the NCAR CCM3 examine the impact of advanced global cloud and radiation parameterizations on model climate for Antarctica. The changes result in a warmer simulated climate for Antarctica. While the RRTM scheme, by itself, reduces a deficiency in clear-sky longwave radiation, the prognostic cloud scheme apparently exacerbates errors in the longwave radiation due to clouds. The changes improve the simulation of the annual change in circumpolar trough surface pressure.

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