2.4 CLOUD MICROPHYSICS AND THE TROPICAL CLIMATE: IDEALIZED AQUAPLANET SIMULATIONS USING THE CLOUD-RESOLVING CONVECTION PARAMETERIZATION (CRCP)

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This paper presents results from idealized simulations using a nonhydrostatic general circulation model with Cloud-Resolving Convection Parameterization (CRCP, the "super parameterization"; Grabowski 2001, hereafter G01). The cornerstone of CRCP is to use a 2D cloud-resolving model to represent the impact of cloud-scale processes — such as convective motions, precipitation formation and fallout, interaction of clouds with radiative and surface processes — in every column of a large-scale or global model. We consider an idealized problem of convective-radiative equilibrium on a rotating constant-SST (30°C) aquaplanet with the size and rate of rotation of the Earth (as in section 4 of

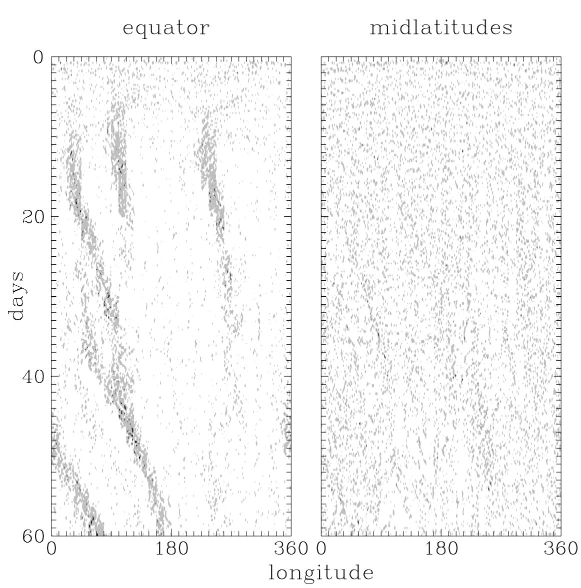

Figure 1: Hovmöller diagrams of the surface precipitation rate at the equator (left panel) and in the southern hemisphere midlatitudes (right panel) for the simulation SP. Precipitation intensities larger than 0.2 and 5 mm hr^{-1} are shown using light and dark shading, respectively.

G01). The current paper extends the simulations reported in G01 and in Grabowski 2002 (hereinafter G02) by applying an interactive radiation transfer model (Kiehl et al. 1994) inside CRCP domains. This replaces the prescribed radiative cooling applied in G01 and G02. Equinox conditions, no diurnal cycle, and a zero zenith angle are assumed over the entire aquaplanet. We stress that the radiative transfer applies cloud-scale fields supplied by CRCP and it does not involve any subgridscale representation of cloud structure and overlap.

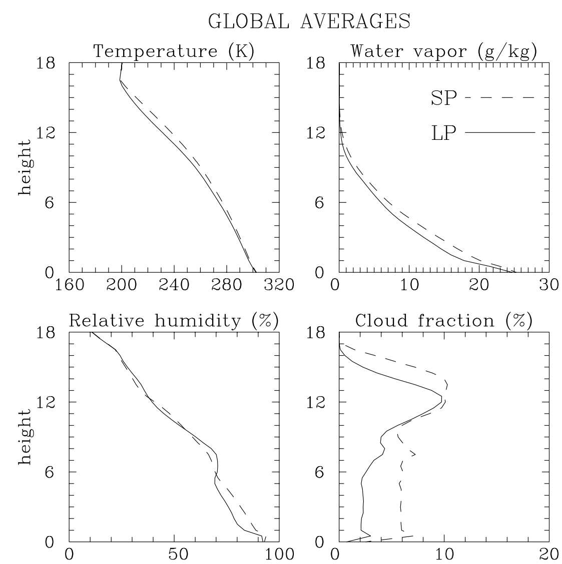

Figure 2: Globally-averaged profiles of the temperature, water vapor mixing ratio, relative humidity, and cloud fraction for the last 5 days of simulation SP (dashed lines) and LP (solid lines).

The two simulations presented herein explore the impact of cloud microphysics on the convective-radiative quasi-equilibrium, in the spirit of the discussion in Grabowski (2000, hereafter G00). As in G00, the sensitivity simulations concentrate on sizes of precipitation particles, although the role of the conversion from cloud water to rain in a representation of warm rain microphysics is considered as well. The first simulation assumes small cloud droplets (concentration of 2000 cm^{-3}) and small precipitation particles ($N_o = 10^9$ m^{-4} for both rain

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and snow, where N_o is the intercept parameter of the exponential distribution of precipitation particles). This simulation is referred to as SP (small particles). The simulation assuming large cloud droplets (concentration of 50 cm^{-3}) and large precipitation particles ($N_o = 10^5$ m^{-4} for both rain and snow) is referred to as LP (large particles). The information about the sizes of cloud and precipitation particles is also incorporated into the radiation transfer model (see section 4 in G00).

Large-scale organization of convection is similar to that in the simulations of G01 and G02. Figure 1 illustrates the organization for the simulation SP (LP features a similar pattern and it is not shown). As Fig. 1 illustrates, convection outside the equatorial waveguide lacks large-scale organization throughout the entire simulation. Inside the waveguide, on the other hand, large-scale organization spontaneously develops. As discussed in G01 and G02, the large-scale organization within the equatorial waveguide resembles the Madden-Julian Oscillations (MJO; Madden and Julian 1994 and references therein), the spectacular example of tropical climate variability on intraseasonal time scales.

Figure 2 compares globally-averaged temperature, moisture, relative humidity, and cloud fraction profiles for the two simulations. The cloud fraction is calculated from the CRCP cloud-scale data assuming that a given gridbox is cloudy if the total condensate (cloud and precipitation) exceeds 0.01 g kg^{-1}. The cloud fraction profiles differ significantly between SP and LP, with higher cloud fractions in the lower and upper troposphere in SP. SP also features a warmer upper troposphere and higher water vapor content across the troposphere. Moreover, SP features weaker radiative cooling across the troposphere (not shown).

Simulation	Net Radiative Flux Divergence (Wm^{-2})	Surface Heat Fluxes (Wm^{-2})		Surface Net Radiative Flux (Wm^{-2})
		Sensible	Latent	
SP	-84	6	72	195
LP	-97	9	83	245

Table 1: Vertical energy fluxes averaged over the entire aquaplanet and over last 5 days of the simulations SP and LP. The first column identifies the simulation; the second column shows the net radiative flux divergence across the troposphere; the third and fourth column show surface sensible and latent heat fluxes, and the last column shows the net radiative flux into the ocean.

Table 1 summarizes the differences between SP and LP in terms of the vertical energy fluxes, averaged over the entire planet for the last 5 days of both simulations. The difference between net radiative fluxes at $z = 18$ km and at the surface (referred to as the net radiative flux divergence in Table 1) illustrates the magnitude of radiative cooling averaged over the entire troposphere. In quasi-equilibrium, this energy loss has to be balanced by the sum of surface sensible and latent heat fluxes. Note that this is not exactly true in Table 1 and the vertical transport across the tropopause is the most likely culprit. However, the changes in the flux divergence and the total surface heat flux between SP and LP is about the same, i.e., 13 W m^{-2} for the change of the flux divergence (from -84 to -97) and 14 W m^{-2} for the change of the total surface flux (from 78 to 92). The most significant difference between SP and LP is in the net radiative flux into the ocean, which changes from 195 W m^{-2} for SP to 245 W m^{-2} for LP. The fact that the net surface energy flux (i.e., the net radiative flux minus the total surface heat flux) is strongly positive implies that the ocean surface should warm, as illustrated in the idealized swamp ocean simulations discussed in section 4 of G00.

In conclusion, the simulations presented herein suggest that the main impact of cloud microphysics is not on atmospheric processes and dynamics, but rather on the ocean surface. This is in agreement with the results presented in G00.

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