12B.6 MOISTURE-CONVECTION FEEDBACK IN THE TROPICS

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This paper illustrates the large-scale moisture-convection feedback, a mechanism of the large-scale organization of tropical convection. In this feedback, spatial fluctuations of deep convection cause perturbations of free-tropospheric moisture, which, in turn, affect the spatial distribution of deep convection. Such feedback was postulated by Tompkins (2001) to explain organization of convection in his three-dimensional cloud-resolving simulations of convective-radiative quasi-equilibrium. Extended discussion of the moisture-convection feedback is given in Grabowski and Moncrieff (2004).

Free-tropospheric humidity affects convection in two distinct ways. First, the entrainment of humid environmental air into convective clouds slows the loss of positive buoyancy compared to the scenario whereby drier environmental air gets entrained. Consequently, a larger proportion of clouds can reach the upper troposphere when free-tropospheric humidity is high. Second, precipitation falling outside clouds evaporates less when the environmental humidity is enhanced. These two effects strengthen convective heating in more humid regions compared to regions that are drier. In addition, there are more subtle effects related to stronger precipitation-laden downdrafts when environmental humidity is low (this impacts surface fluxes and mesoscale convective organization).

In convective-radiative quasi-equilibrium, large-scale differences in convective heating must be balanced by the temperature tendency due to the large-scale circulation. Because of the weak horizontal temperature gradients in the Tropics, the large-scale temperature advection is dominated by the vertical motion. Therefore an enhanced large-scale subsidence develops in areas having suppressed convection. From the point of view of our discussion, it is irrelevant how the large-scale circulation is actually established; its presence is simply required to maintain the large-scale state of convective-radiative quasi-equilibrium. There is no doubt, however, that interactions between areas with enhanced and suppressed convection involve gravity waves that bring the large-scale winds and thermodynamic fields into balance. The key point is that the large-scale temperature homogenizes rapidly through the gravity-wave mechanism, whereas moisture detrained from convection relies on advection (both horizontal and vertical) to remove inhomogeneities, which is inefficient on large scales. Radiative processes strengthen the moisture-convection feedback through the effect of water vapor and clouds on radiative transfer (Grabowski and Moncrieff 2002). A simple heuristic argument using the time-scale of free-tropospheric humidity change due to large-scale subsidence demonstrates that the moisture-convection feedback is particularly relevant for tropical intraseasonal oscillations (Grabowski and Moncrieff 2004).

Grabowski (2003; hereafter G03) investigated Madden-Julian Oscillation (MJO)-like coherent structures on a rotating constant-SST aquaplanet using cloud-resolving convection parameterization (CRCP, or super-parameterization). Sensitivity simulations suggested that the large-scale moisture-convection feedback was essential for development and maintenance of MJO-like structures. When this feedback was suppressed by artificially smearing out large-scale free-tropospheric moisture fluctuations, MJO-like coherences did not develop and, if already present, disintegrated rapidly. However, the short time-scale over which the moisture fluctuations were removed in G03 (1-3 hrs) called for additional tests using more gradual relaxation. Such simulations, using 1-day relaxation, were recently performed and they yielded results consistent with the discussion in G03 (i.e., MJO-like structures were absent when the relaxation was applied; see Grabowski and Moncrieff 2004 for details).

Lack of sensitivity of traditional convective parameterizations to the free-tropospheric humidity was argued in G03 to explain the weak intraseasonal variability in traditional climate models. This is further supported by simulations similar to those discussed in G03, but with the super-parameterization replaced by a traditional convective parameterization, the Emanuel scheme (Emanuel 1991). Results from these simulations are illustrated in Figs. 1 and 2.

In its standard configuration (Fig. 1), the Emanuel scheme is only weakly sensitive to environmental humidity. In particular, the sensitivity of the surface precipitation rate (hence the net

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heating in a column) to environmental humidity is weak (cf. Derbyshire et al. 2004). Consequently, the MJO-like coherence in the simulation applying the standard Emanuel scheme is much weaker when compared to G03's simulations that applied super-parameterization.

The sensitivity of the Emanuel scheme can be artificially enhanced by increasing the amount of precipitation that falls outside clouds and is exposed to environmental humidity. In the modified Emanuel scheme applied in a simulation illustrated in Fig. 2, the amount of precipitation that falls outside clouds was increased from 0.12 to 0.30. This simple modification dramatically improves the simulated MJO-like coherence which develops after a mere 10 days and features surface precipitation and surface winds similar to the simulations applying the super-parameterization.

Idealized aquaplanet simulations discussed in G03 and in Grabowski and Moncrieff (2004), together with results applying Emanuel scheme discussed herein, illustrate the role of moisture-convection feedback in intraseasonal oscillations in the tropics. This aspect remains a major challenge for traditional convective parameterizations and it is likely the key for the MJO simulated by traditional climate models.

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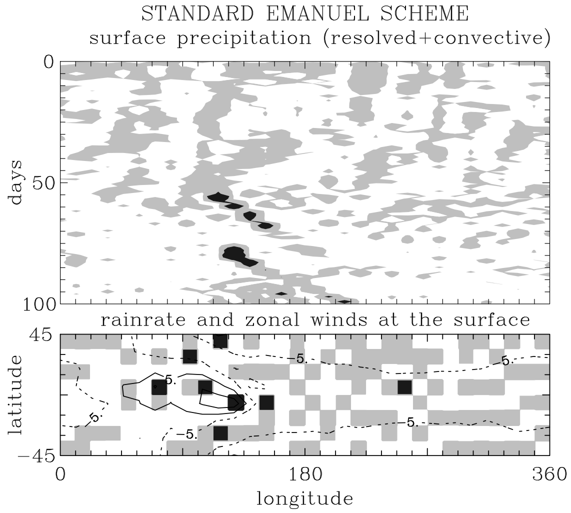

Figure 1: Results from the constant-SST aquaplanet simulation using Emanuel convective parameterization in its standard configuration. Upper panels show Hovmöller diagrams of the surface precipitation at the equator. Lower panels show spatial distributions of surface precipitation and surface zonal winds at day 60. Precipitation rate larger than 1.5 and 15 mm day^{-1} is shown using light and dark shading, respectively. Zonal winds are shown using solid and dashed contours for positive and negative values, respectively, with contour interval of 10 ms^{-1} starting from 5 ms^{-1}.

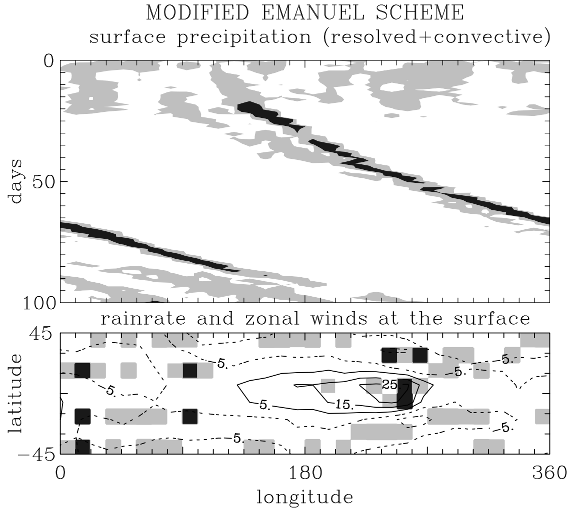

Figure 2: As fig. 1, but using modified Emanuel scheme. Spatial distributions of surface precipitation and surface zonal winds at day 50.