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Lessons about cumulus parameterization from tropical cyclogenesis studies

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Recent field programs studying tropical cyclogenesis are yielding information about the prerequisites for intense convection and significant rainfall over tropical oceans. Intensifying tropical disturbances provide an environment which differs from normal tropical conditions in two respects: (1) The disturbance-scale flow pattern protects convection from the injection of dry air, resulting in a moister environment. (2) The environment in the disturbance is significantly warmer at upper levels and cooler at lower levels than normal. The moister environment produces more intense rainfall, as one would expect from recent work showing a strong correlation between precipitation and saturation fraction or column relative humidity. More surprising is the altered character of convection resulting from the modification in the local temperature profile. Relatively modest cool anomalies at low levels and warm anomalies aloft cause the level of vertical mass flux in the convection to drop from typical values over warm oceans of 8-10 km to approximately 5 km. This result is seen in both observations and in cloud-resolving models subjected to weak temperature gradient lateral boundary conditions. The conversion from "top-heavy" to "bottom-heavy" mass flux profiles results in profound changes in the vertically integrated moist entropy budget, with less lateral entropy export or even entropy import under extreme circumstances. This greatly decreases the gross moist stability and increases the ratio of rainfall to surface evaporation. The conditions in the early stages of tropical cyclone development are not very different from other heavy rain situations in the tropics. The results of our observations can therefore be used as a benchmark for testing the behavior of cumulus parameterizations in large-scale weather and climate models.