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Changes in tropical climate due to bifurcations of radiative-convective equilibrium

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Radiative-convective equilibrium (RCE), a simplified model of tropical climate, has been shown to be linearly unstable to moisture perturbations above a critical sea surface temperature (Emanuel et al., JAMES 2013). The mechanism of this instability relies on the temperature dependence of changes in the emissivities of the lower and upper troposphere due to changes in their moisture content, and hence is driven by the thermodynamics of radiation. A requirement for this instability is that the lower troposphere is sufficiently moist and hence opaque in the infrared, so that variations in its radiative cooling are determined primarily by variations in the moisture content of the upper troposphere. Emanuel et al. (2013) and Raymond and Zeng (2000) have shown that the instability migrates the ordinary RCE state to either a dry state with large-scale descent, or to a moist state with mean ascent.

Given that general circulation models (GCMs) describe the thermodynamics essential for this instability accurately, we examine their output to detect changes in the behavior of tropical deep convection due to global warming, as anticipated by the theoretical work described above. We do so by analyzing the dependence of convection, radiation and precipitation on SST in the warm pool region of the tropical west Pacific from the CMIP5 archive. We also examine outgoing long-wave radiation from the NASA CERES observational dataset. We find that both model output (from 6 GCMs) and observations show a consistent change in the behavior of radiation and convection, i.e. a bifurcation, across a critical SST. The critical SST is the same (to within 0.5 K) across all the models and variables examined thus far.

Deep convection becomes more vigorous and cloud fraction increases across this critical SST, whilst outgoing long-wave radiation decreases. Further, we find a significant change in the behavior of precipitation across this critical SST. In particular, intense rain events and long dry spells are more frequent above the critical temperature, and hence this bifurcation may have important implications for extreme climate events in the tropics and elsewhere, via teleconnections. Further, the warmest SSTs currently observed are close to the critical SST and tropical SSTs are more likely to cross the critical value in warmer climates. Therefore we propose that this bifurcation will be an increasingly frequent feature of tropical climate as the globe warms.