Regional Tropical Precipitation Change Mechanisms in ECHAM4/OPYC3 under Global Warming

Abstract / Mechanisms of global warming impacts on regional tropical precipitation are examined in a coupled atmosphere-ocean general circulation model (ECHAM4/OPYC3). Evidence for two main mechanisms is found in this more comprehensive coupled general circulation model. The upped-ante mechanism signature of dry advection from non-convective regions is found on the margins of convection zones. The signature of the rich-get-richer mechanism enhances precipitation within strong convective regions. The pattern of the regional tropical precipitation changes, once established, tends to persist, growing in magnitude as greenhouse gases increase. The sulfate aerosol induces regional tropical precipitation anomalies similar to the greenhouse gases but with an opposite sign, thus reducing the early signal. Ocean dynamical feedbacks, the El Nino-like shift of the equatorial Pacific convection zone, are also found.

Impacts of global warming on regional tropical precipitation involve complex processes which are not well understood. Analyzing ECHAM4 AOGCM simulations with theory derived from an atmospheric model of intermediate complexity coupled with a mixed-layer ocean (Chou and Neelin 2004), we examine mechanisms of global warming impacts on regional tropical precipitation. Under global warming, two main mechanisms associated with atmospheric dynamical feedbacks via anomalous vertical motion which have been discussed in Chou and Neelin (2004) are the upped-ante mechanism and the rich-get-richer mechanisms.

In this study, we find evidence for the upped-ante mechanism in the ECHAM4 simulations, although with slight modification. To initiate the upped-ante mechanism, horizontal gradients of low-level moisture anomalies induced by QE (quasi-equilibrium)-mediation should occur. In the ECHAM4 simulations, stronger positive moisture anomalies are found in convective regions, while weaker positive moisture anomalies are found in non-convective regions (Fig. 1). For those regions where the mean flow is from non-convective regions to convective regions, evidence of the import of dry air is found. The regions with the dry air import coincide with negative tropical precipitation anomalies. This suggests that the dry air import associated with the upped-ante mechanism is responsible for the regional precipitation reductions (Fig. 2). In this study, we also find the dry air import occurs not only in the ABL, but also in the lower free tropospheric layer.

Another important mechanism for inducing positive regional tropical precipitation anomalies is the rich-get-richer (anomalous gross moist stability \( M' \)) mechanism. The gross moist stability \( M \) depends on low-level moisture and depth of convection. The increased low-level moisture reduces the stability of the atmosphere in convec-
tive regions and this enhances convection in strong convection regions (Fig. 1). In the ECHAM4 results here, the tropical precipitation anomalies do increase over most strong convective regions (Fig. 3) which provides evidence for the impact of the $M'$ or rich-get-richer mechanism in ECHAM4.

The aerosol effect reduces the regional precipitation anomalies in magnitude and cools the whole troposphere, so the aerosol impacts tend to reduce the greenhouse-gas (GHG) signal in early periods. The pattern of the tropical precipitation anomalies induced by the greenhouse effect tends to persist and grow over the century. In other words, the pattern of the regional precipitation anomalies in the latter stage, such as 2070-2099, has already been established in the earlier stage, and the main change is the amplitude of the precipitation anomalies.

The ocean heat transport produces large surface heat flux locally, which affects regional tropical precipitation via effects on the energy budget and the associated vertical motion. In the ECHAM4 AOGCM global warming simulations, positive surface heat flux anomalies are found over the eastern Pacific, associated with an El Nino-like SST anomaly pattern (Fig. 4). The positive surface heat flux anomalies enhance local upward motion and
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Fig 2. A schematic diagram for the upped-ante and rich-get-richer mechanisms.

Fig 3. Differences for the 2070-2099 averages minus the 1961-1990 climatology for the GHG experiment. Precipitation in (a) JJA and (b) DJF. The thick dashed line in (a) and (b) is the 6 mm day$^{-1}$ contour of the precipitation climatology in 1961-1990.

Convection over the eastern Pacific. Thus, strong positive precipitation anomalies are found over the eastern Pacific.

Progress in predicting tropical regional precipitation anomalies under global warming requires a clearer theory for mechanisms. In this
study, we provide evidence that two mechanisms are the leading players in producing tropical precipitation anomalies in a warmer climate. We also suggest a possible way to assess other GCM results for signatures of these two mechanisms: the upped-ante and rich-get-richer mechanisms.

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Reference: