Relationships Between Model Tropical Oceanic Precipitation Biases, PBL Convergence, and Energy Fluxes

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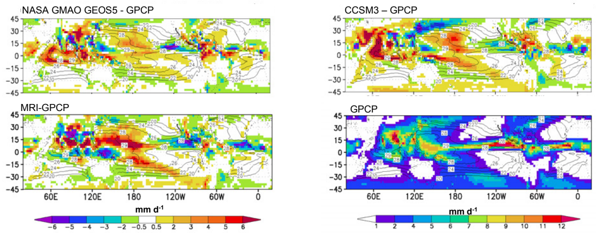
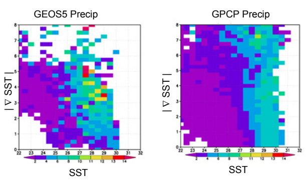
Representative JJA Climatological Model Precipitation Biases

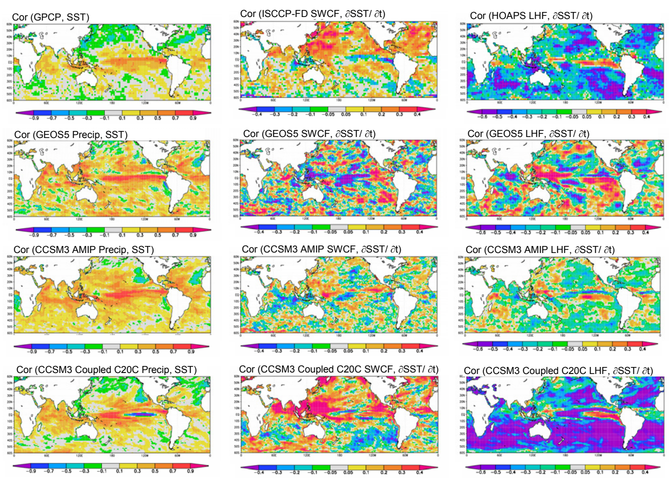
Systematic departures of various AMIP configured model integrations from the JJA climatology of the Global Precipitation Climatology Project (GPCP) illustrate problems in structure and amplitude of tropical rainfall—especially over the western Pacific and Indian Oceans. GEOS5 and CCSM3 have excessive rainfall on southern periphery of warm pool.





Precipitation phase diagrams of mean precipitation rate as a function of SST, |∇SST|. GEOS5 c0301 (left) JJA precipitation over the Warm Pool tends to locate preferentially in cooler SST, higher SST gradient regions compared to GPCP observations (right). (Color bar indicates mean precip rate, mm /h, for SST, |∇SST| space).

Precip vs SST **SWCF vs ∂SST/ ∂t** **LHF vs ∂SST/ ∂t**



Background / Objectve:

Feedback processes involving radiative fluxes, turbulent energy exchange between the surface and atmosphere, and convective dynamics remain weak links in coupled climate modeling. The propensity for "double ITCZ" configurations over the Pacific and poor rainfall simulations over the Indian Ocean and Asian Monsoon region are typical manifestations of these problems.

Here we use AR4 model integrations, recent NASA/GMAO GEOS5 model integrations, and satellite retrievals of surface and top-of-atmosphere (TOA) energy fluxes and winds to quantify these problems in JJA rainfall climatologies.

Conclusions:

- Model convective parameterizations tend to over-amplify low-level convergence both in eastern ocean basis where transient activity is significant as well as in SST-gradient regions at the periphery of the western Pacific / Indian Ocean Warm Pool.
- Outside of the eastern equatorial Pacific where ocean dynamical forcing of SST dominates, most AMIP experiments have too strong a coupling between SST and precipitation and fail to capture the correct phasing between ∂SST/ ∂t and SWCF and ocean surface latent heat flux (see also Wu et al., 2006 *JClim*). This may partially explain the problems with AMIP experiment precipitation structure. However, since coupled models can also retain this same error, convective parameterization (and other) flaws are still important contributors to unrealistic precipitation structure.
- The overly strong linkage between grid-scale surface convergence and precipitation evident in GEOS5 when re-evaporation is suppressed suggests dilution by entrainment and/or too high a precipitation efficiency. Precipitation re-evaporation in models such as GEOS5 is a strong "tuning constraint or mechanism" that partially ameliorates more fundamental shortcomings in the convective parameterization. Moist Static Energy budgets suggest an inability to get precip structure and cloud radiative feedbacks to agree simultaneously with observations.

Local Correlation Analysis

Because surface fluxes strongly control the PBL thermodynamics and convective buoyancy we examine local correlations between fluxes, SST and ∂SST/ ∂t. Monthly mean data from GPCP precipitation, HOAPS (Hamburg Ocean-Atmosphere Parameters and Fluxes from Satellites) latent heat flux, and ISCCP-FD (International Satellite Cloud Climatology Project) shortwave cloud forcing are as abasis for the calculations.

Precip vs SST Outside of the eastern equatorial Pacific where ocean dynamical forcing of SST dominates, most model experiments have too strong a coupling between SST and precipitation, especially over the western Pacific. The CCSM Coupled C20C integration is much better in this regard.

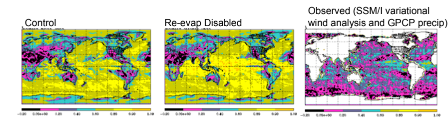
SWCF vs ∂SST/ ∂t Observations and coupled runs show SWCF is associated with SST decreases over in tropical western Pacific (increased cloudiness leads to SST decreases). This effect is much more muted in AMIP runs indicating that SWCF variations are not phased properly since SST is specified. Precip - ∂SST/ ∂t correlations (not shown) look very similar with opposite polarity indicating that SST cooling and SWCF is associated with precipitation.

LHF vs ∂SST/ ∂t AMIP experiments have too strong coupling over western tropical Pacific (especially GEOS5) and lack strong negative correlations observed at higher latitudes and in eastern ocean basis.

In summary, correlation results are similar to findings by Wu et al., (2006 JClim). In contrast to the eastern Equatorial Pacific, SST in the W Pac / IO tends to be more a *result* of forcing by surface energy fluxes; thus, PBL moist entropy is not coupled as directly to SST variations as in the eastern Pacific and specifying SST does not necessarily lead to a better simulation of convection.

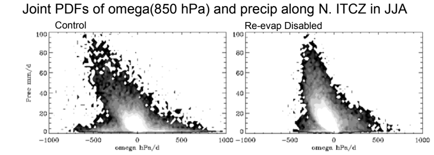
Daily Precipitation / Surface Divergence Relationships

In addition to the thermodynamic properties of tropical PBL air, the coupling between grid-scale divergence and precipitation seems to be inadequately represented, at least in the GEOS5 model. To understand mechanisms governing precipitation structure on synoptic time scales we examine daily data during JJA from two experiments using the GEOS5 model. The control experiment contains re-evaporation of precipitating condensate while the second has all re-evaporation disabled.



When precipitation re-evaporation is reduced, correlations between precipitation and PBL convergence are much stronger than observed. Note that even in the control model correlations remain too strong over the western Pacific / IO Warm Pool region.

Joint PDFs of omega(850 hPa) and precip along N. ITCZ in JJA



Joint PDFs of omega(850 hPa) and precipitation along N. ITCZ in JJA indicate that precipitation is more weakly correlated with omega (more scatter) in the control case, although the slope is larger (precipitation of a given intensity is associated with a larger amplitude vertical motion). Re-evaporation creates a larger "threshold" for the dynamics in order to produce precipitation

Feedback to the Moist Static Energy Flux Divergence

The vertically integrated atmospheric moist static energy budget (MSE) is written as

$$\langle \nabla \cdot hV \rangle = LE_o + S_o + R_n^{TOA} - R_n^{Sfc}$$

where h**V** is MSE horizontal flux, LE_o and S_o are surface latent and sensible heat fluxes, R_n^{TOA} and R_n^{Sfc} are net radiative fluxes at TOA and the surface, and ⟨ ⟩ indicates the mass-weighted vertical integral. It offers the advantage of eliminating the near-canceling processes of latent heat release and associated vertical motion and focuses on the radiative and turbulent fluxes that are ultimately responsible for maintaining tropical circulations. The *left hand panel below shows vertically integrated flux divergence of MSE* for the no re-evap and control experiments as well as observational estimates constructed from HOAPS LE_o and S_o and ISCCP-FD radiative fluxes. Compared to observations, the required MSE export from the Warm Pool region is excessive in the control case. For the no re-evap experiment the magnitude of energy export is closer to observations but the structure is distorted with disagreement particularly over the western tropical Pacific. Signatures of these problems are found primarily in the *net radiative cooling (right-hand panel)* and are consistent with TOA cloud forcing produced by convection. Surface turbulent fluxes (not shown) indicate less disagreement. These results suggest that even though the precipitation re-evaporation present in the control experiment enables a somewhat more realistic precipitation distribution, the longwave radiative effects of convectively generated clouds are too strong. The radiative forcing by clouds represents a feedback from the convective precipitation and acts to enhance upward motion in proportion to re-evaporation.