Bias Reduction as Guidance for Developing Cumulus Parameterization in AM4

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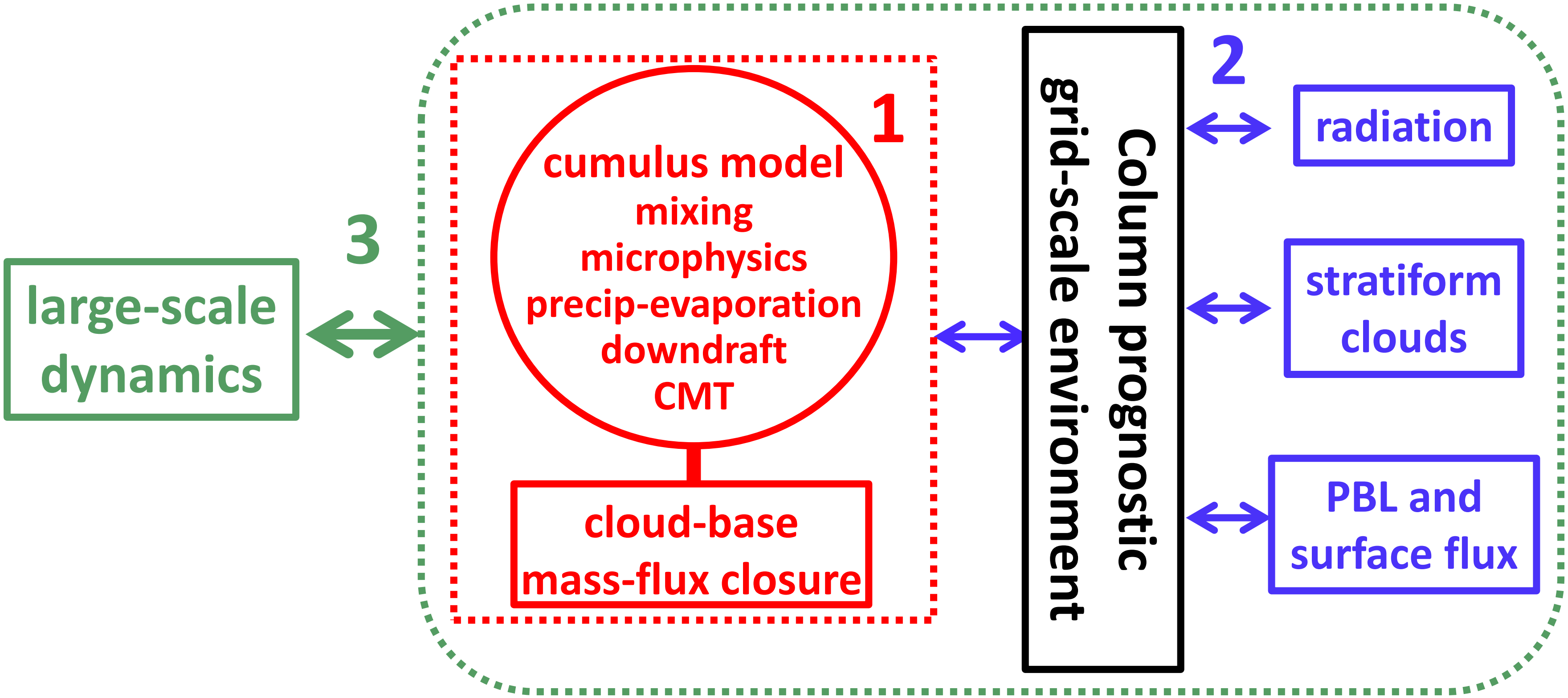
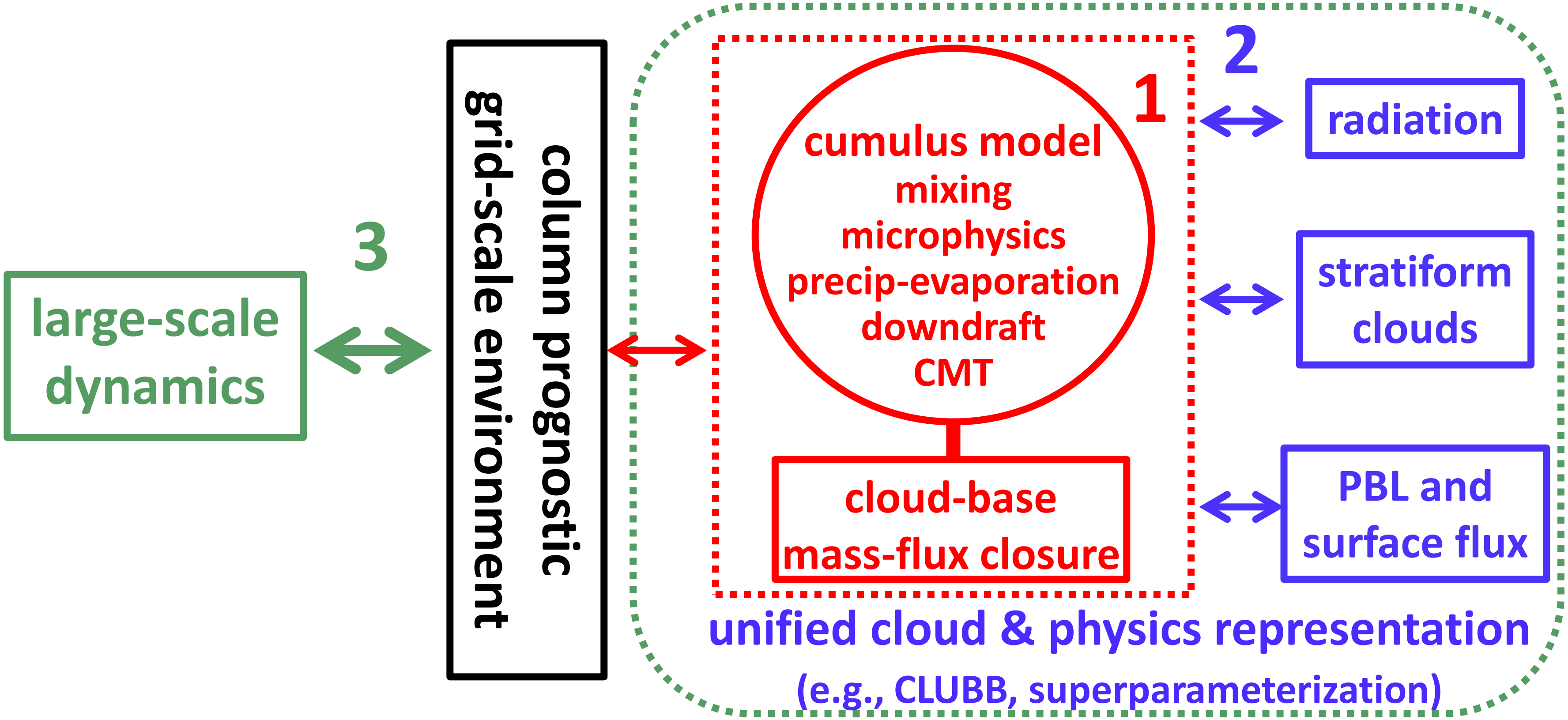
Fundamental problems in the traditional GCM's cumulus parameterization

1. Deficiency in cumulus cloud models (mixing, microphysics,…)
2. Arbitrary separation of physical processes
3. Arbitrary separation of convective and large scale



Our long-term goal is to address the fundamental problems through community efforts

1. Fundamental changes of cumulus cloud model
2. Unified cloud and physics representation
3. Prognostic, non-deterministic, scale-adaptive closure



Long-term community efforts to achieve success

Our short-term goal focuses on model bias reduction

Despite the fundamental problems, significant progresses can still be made within the existing framework. They include simulations of both mean climate and transient variability.

AM4 development start from:

- **AM3-like (Donner deep + UWShCu)**
- **HIRAM-like (UWShCu only, a less intrusive scheme)**

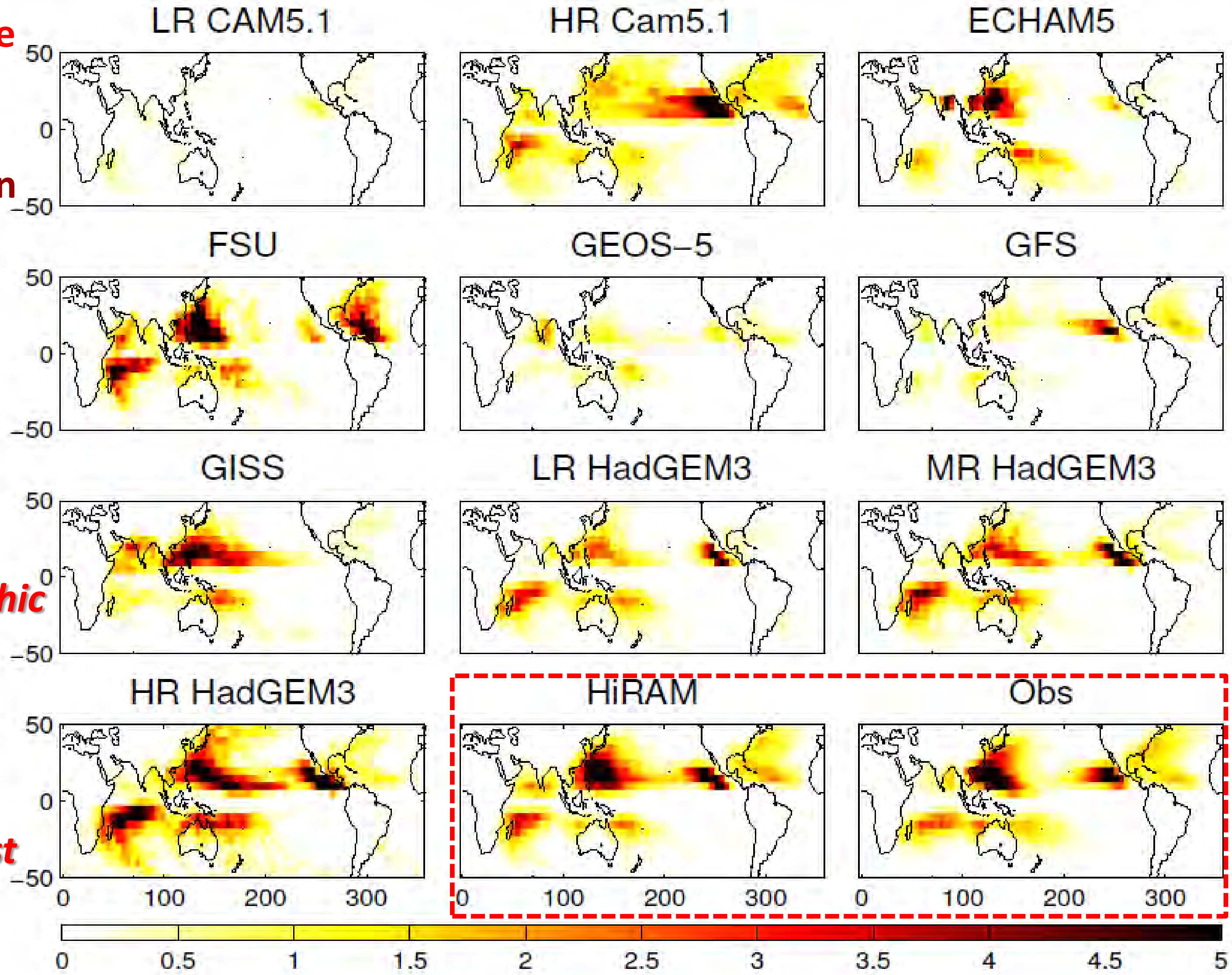
Each has strength and weakness. New development focus on reducing their biases without losing their strengths. Examples:

- **Tropical cyclones**
- **Equatorial Pacific SST and precipitation biases**
- **Precipitation and cloud response to ENSO**
- **Madden-Julian-Oscillation**

HIRAM performs outstandingly in the GCMs participating in US CLIVAR Hurricane Working Group (Fig: TC track density)

Model resolutions range from 28km to 130km
LR: Low Resolution
MR: Medium Resolution
HR: High Resolution

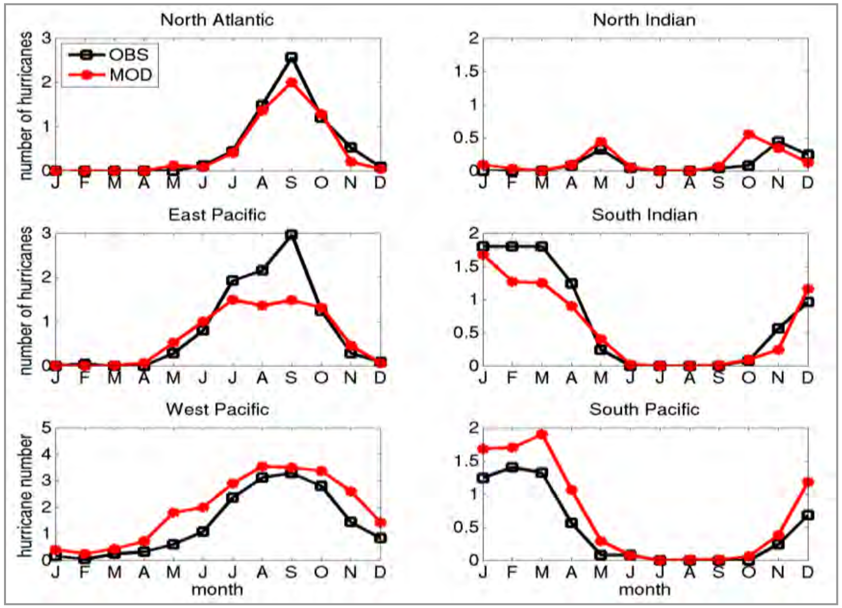
Shaevitz et. al (2014, J. Climate, in review) conclude: *"Overall the models were able to reproduce the geographic distribution of TC track density in the observations, with the HIRAM, in particular, demonstrating the most similarity to observations."*



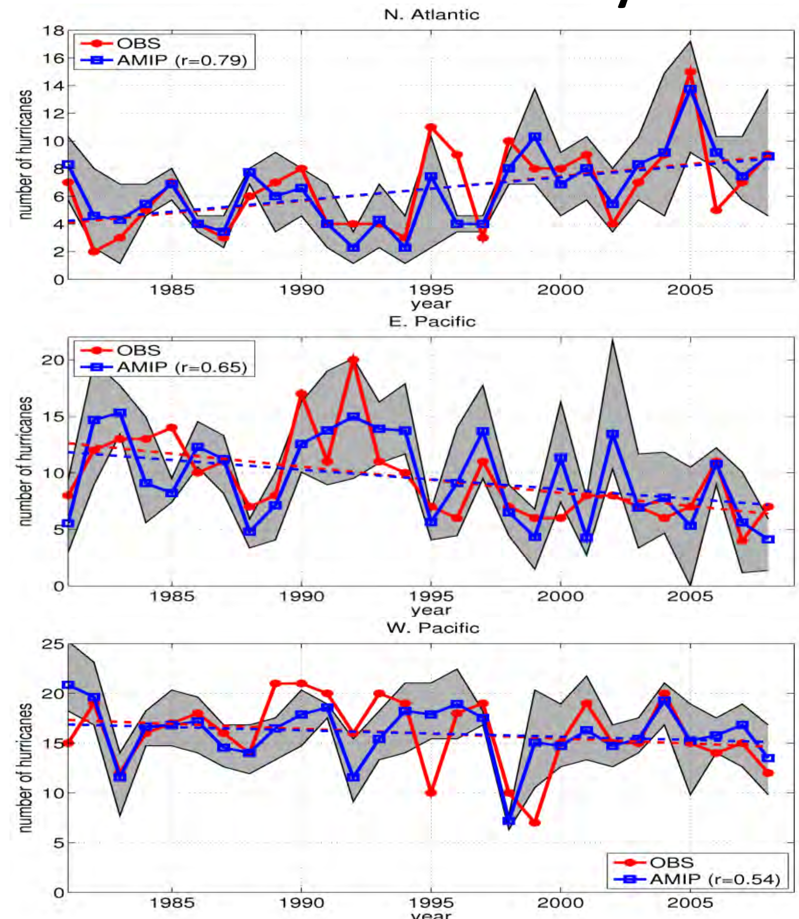
HiRAM captures the seasonal cycle, inter-annual variability and decadal trends of hurricanes over multiple ocean basins

Seasonal Cycle

Zhao et. al (2009)



Inter-annual variability



Red: observations

Blue: HiRAM ensemble mean

Shading: model spread

Shaevitz et. al (2014) conclude:

"In simulations forced with historical SSTs, the models were able to reproduce the inter-annual variability of TC frequency in the N. Pacific and Atlantic basins, with HiRAM and GEOS-5 models showing particularly high correlation with observations in those basins."

A new double plume convection scheme incorporates recent findings on key processes for modeling convection and MJO

HIRAM also well simulates mean climate including LW and SW CRF when forced by observed SSTs. However, when coupled with ocean, it produces significant cold/dry bias in the equatorial Pacific, negatively affecting ENSO simulation. To reduce the biases, we have developed a modified convection scheme:

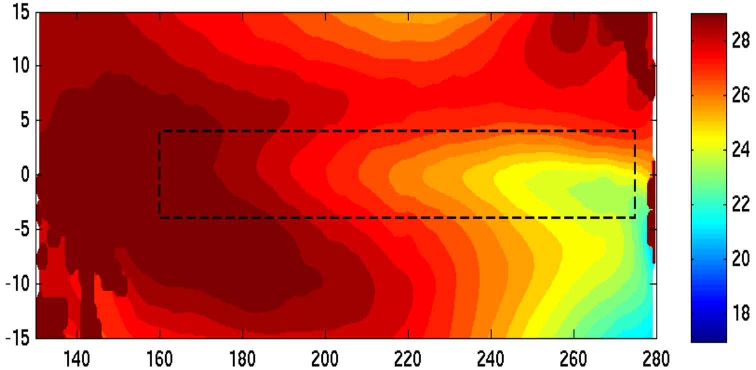
- **An additional plume is introduced to represent deep/organized convection with entrainment rate dependent on ambient RH**
- **Shallow cumulus moistening ahead of deep/organized convection**
- **Enhance LW and SW cloud radiative effect via convective microphysics**
- **Enhance the effect of cold pools through precipitation re-evaporation**

The modified scheme (called double plume scheme used in AM4a1)

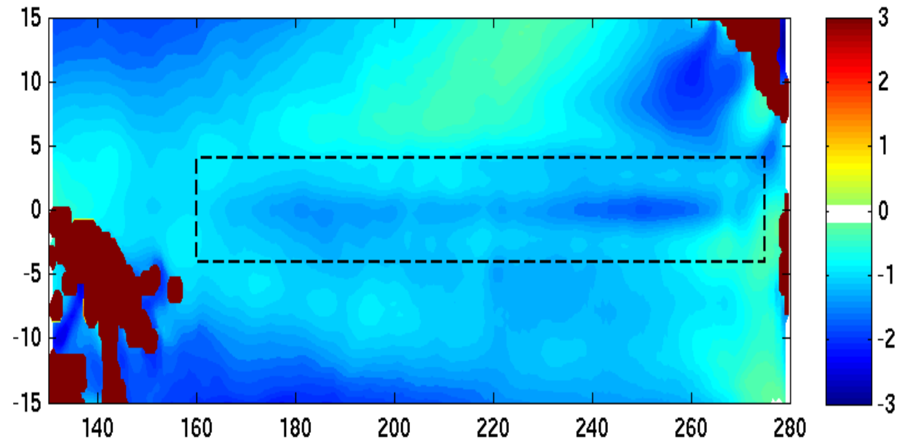
- ➢ **significantly reduces the equatorial Pacific cold/dry bias**
- ➢ **Improve simulated precipitation and cloud response to ENSO**
- ➢ **maintain competitive simulation of global TC statistics**
- ➢ **Improve MJO simulation**

AM4 reduces equatorial Pacific SST cold biases
(Each coupled to identical 1˚ ocean & tuned to TOA radiative balance)

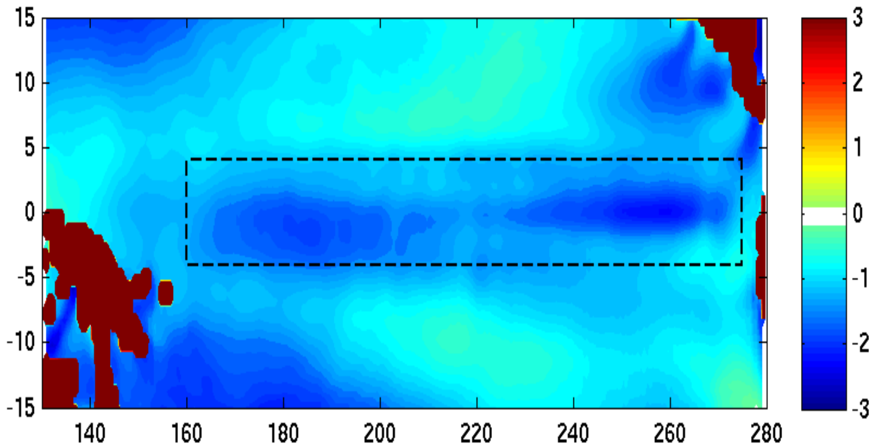
HADISST (ANN)



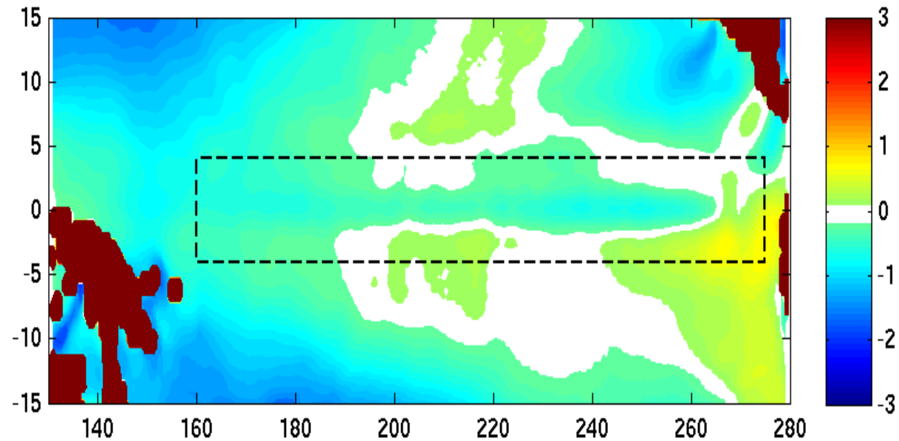
AM3-like minus HADISST (C)



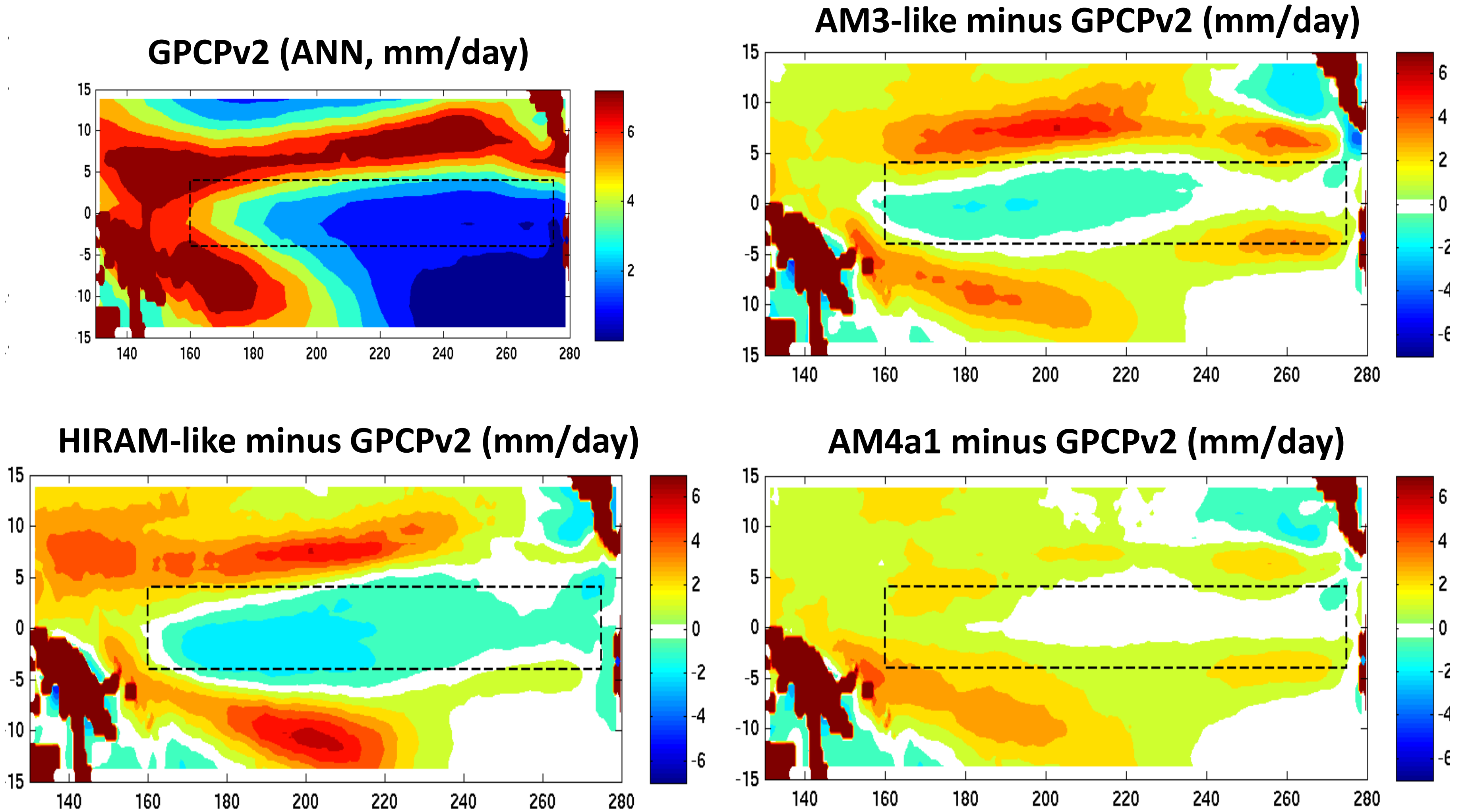
HIRAM-like minus HADISST (C)



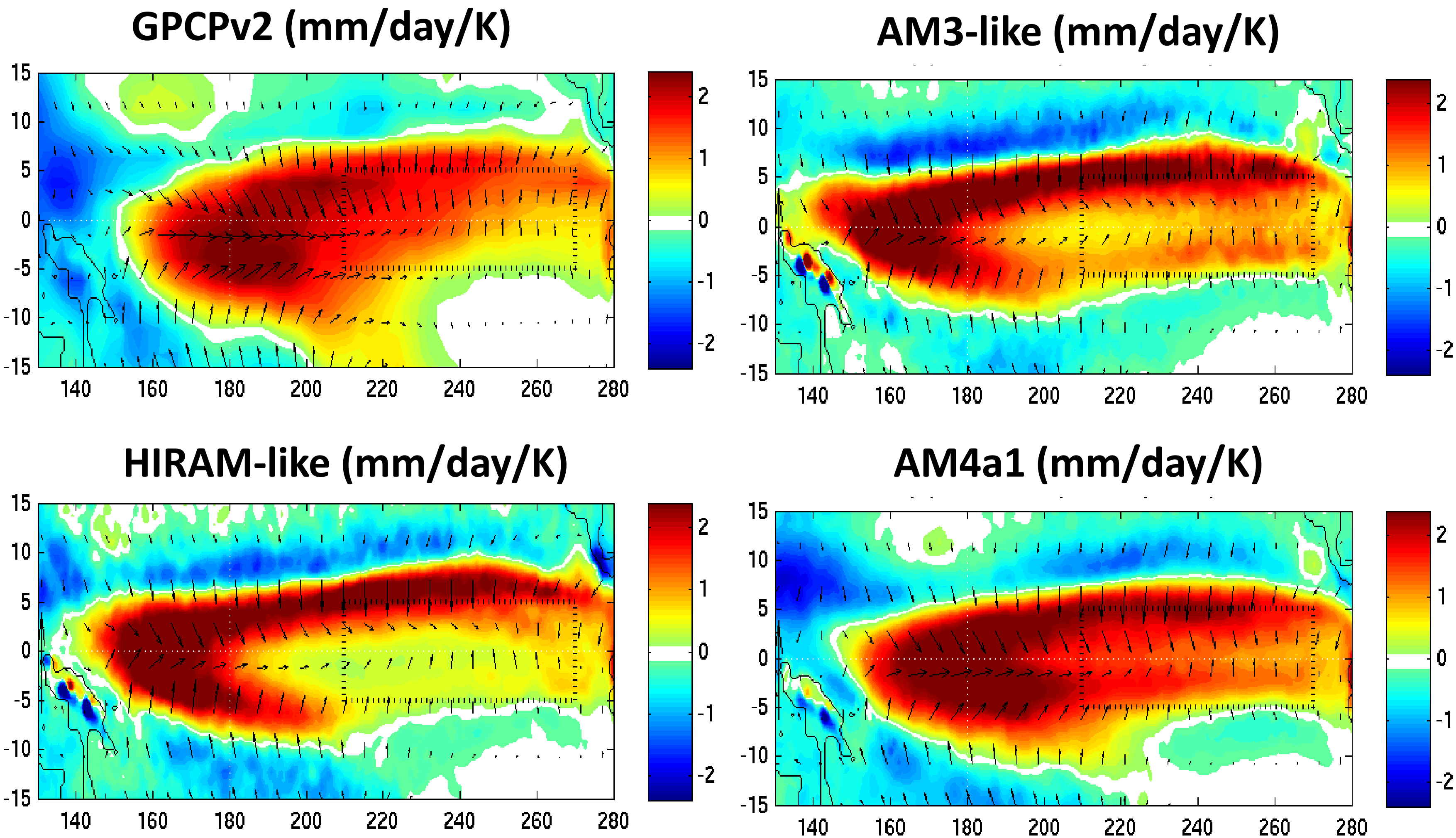
AM4a1 minus HADISST (C)



AM4 reduces equatorial Pacific precipitation dry bias
(Each coupled to identical 1˚ ocean & tuned to TOA radiative balance)

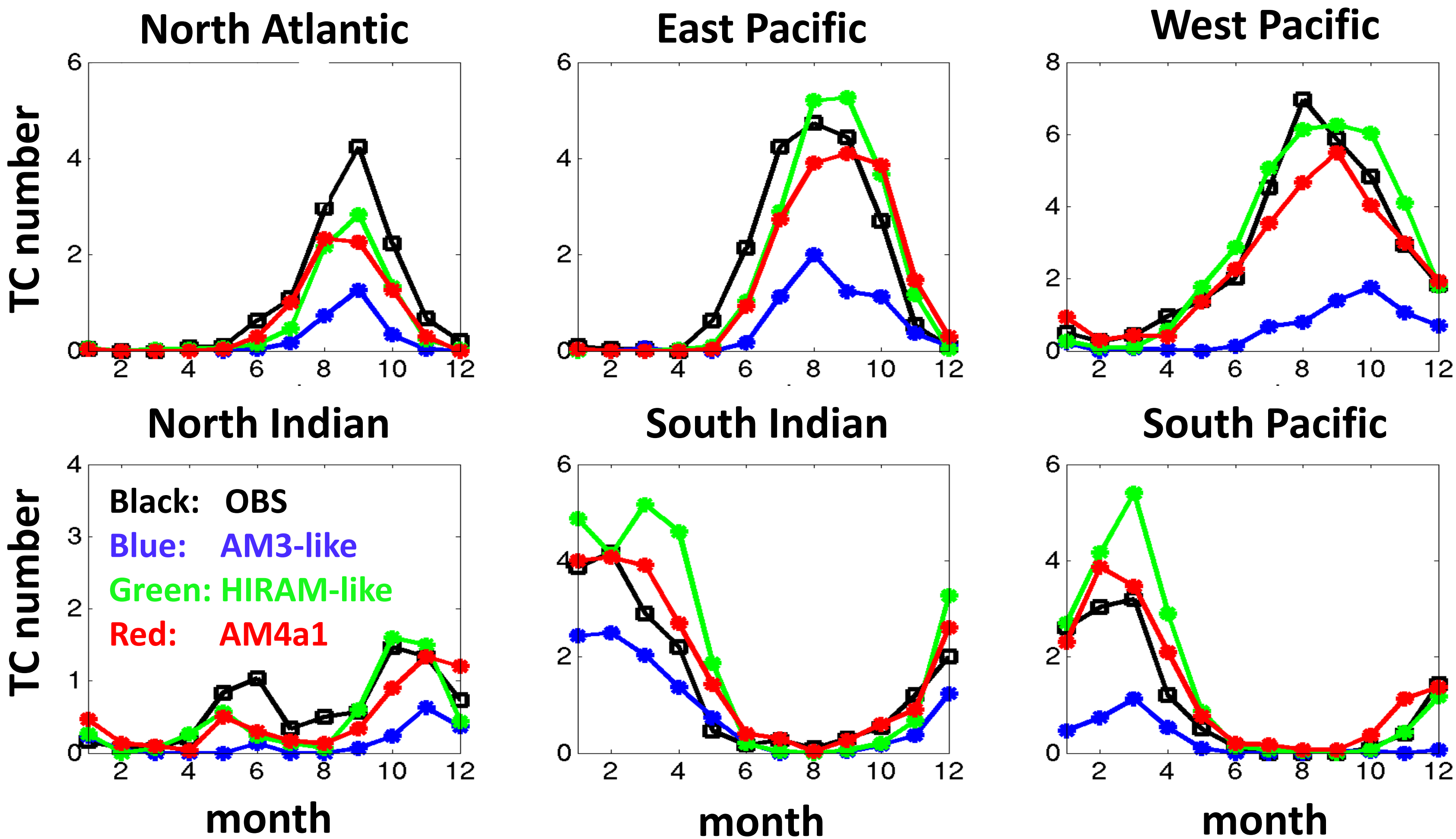


AM4 improves simulated precipitation response to ENSO
(Each coupled to identical 1˚ ocean & tuned to TOA radiative balance)

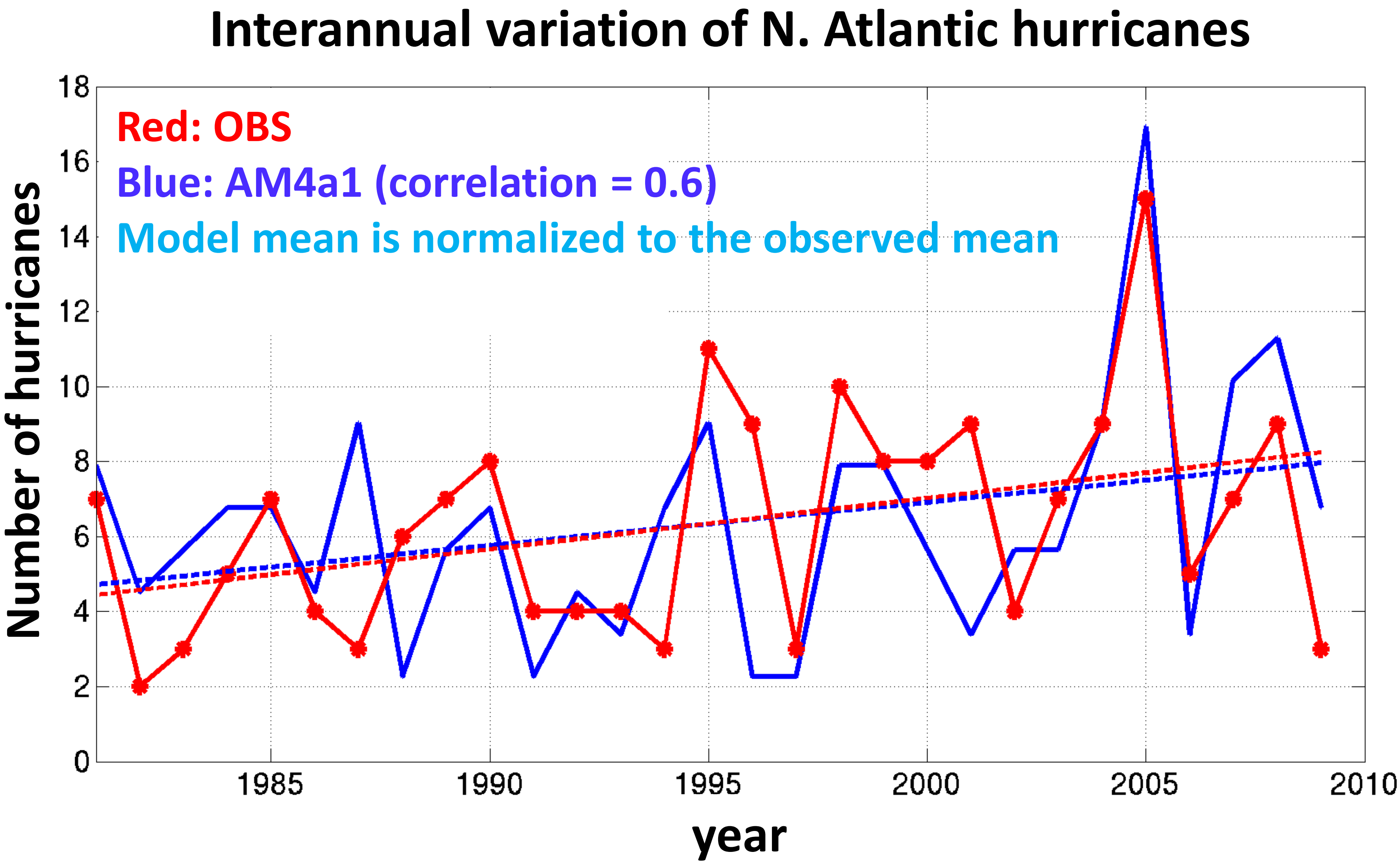


AM4 maintains competitive simulation of TC statistics
(Each coupled to identical 1˚ ocean & tuned to TOA radiative balance)

Seasonal cycle of annual TC frequency

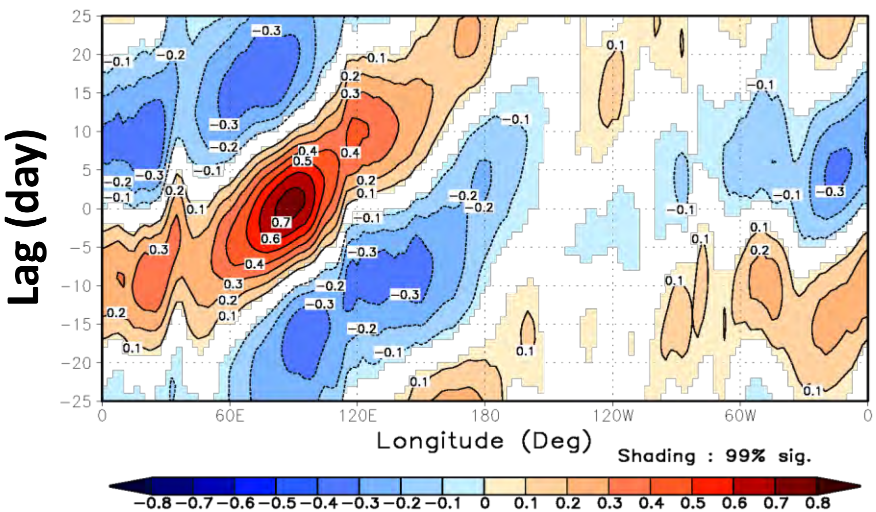


AM4 maintains competitive simulation of TC statistics when forced by observed SSTs

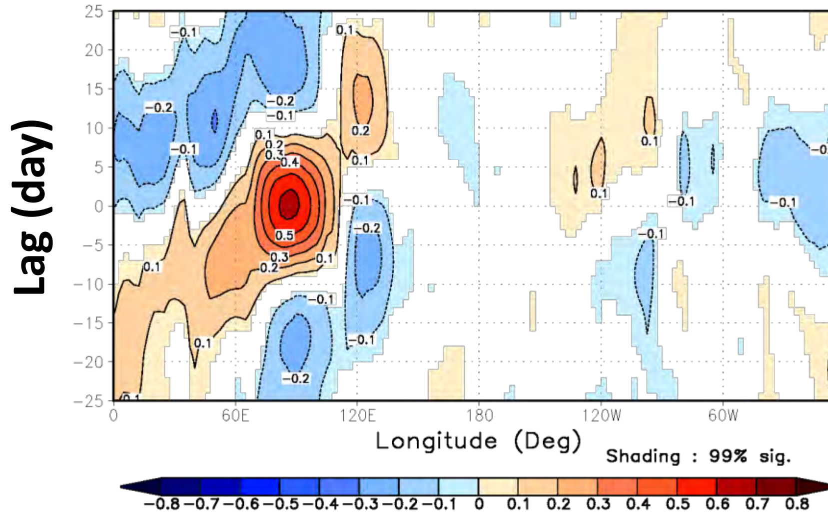


AM4 improves MJO simulation, Lag-Longitude diagram
(figures generated using US CLIVAR MJO standard diagnostic package)

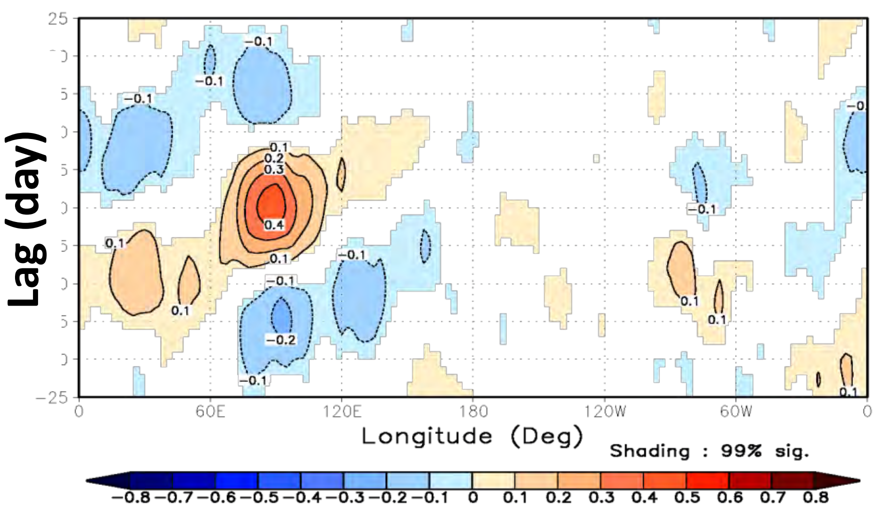
OLR (AVHRR, Nov-Apr)



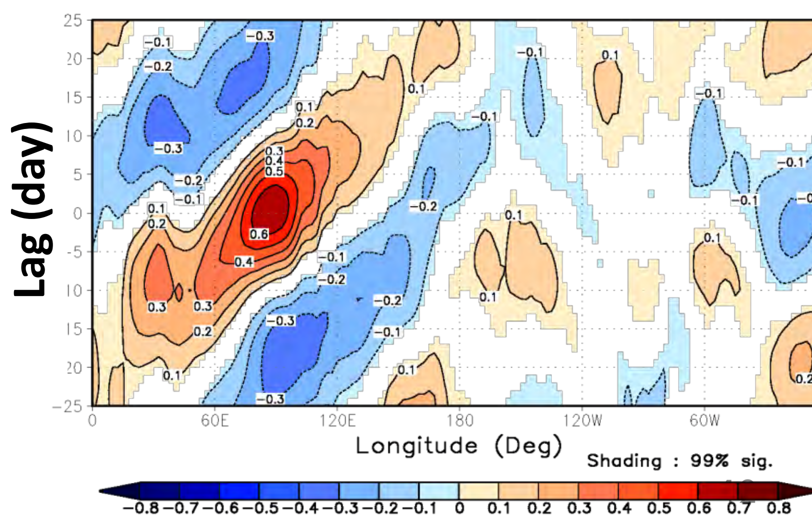
OLR (AM3-Like, Nov-Apr)



OLR (HIRAM-Like, Nov-Apr)

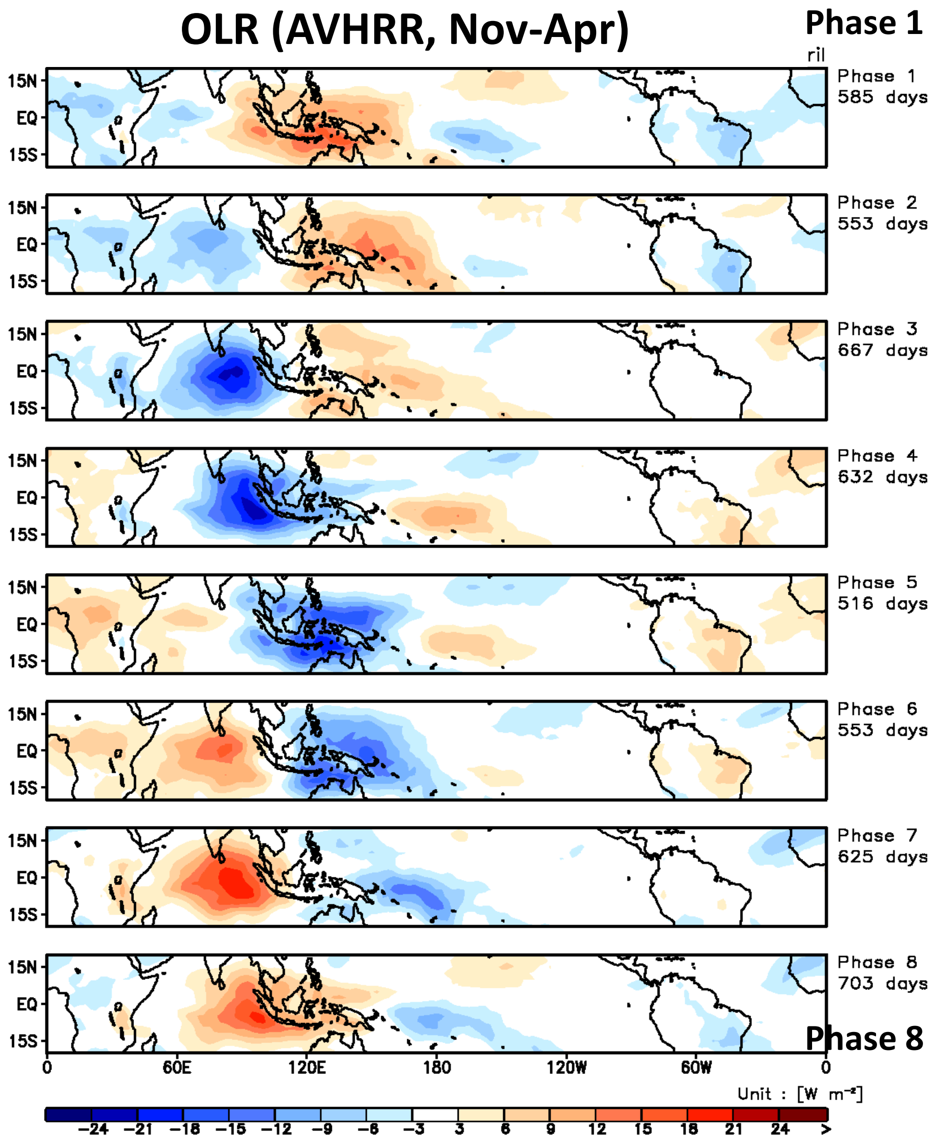


OLR (AM4a1, Nov-Apr)

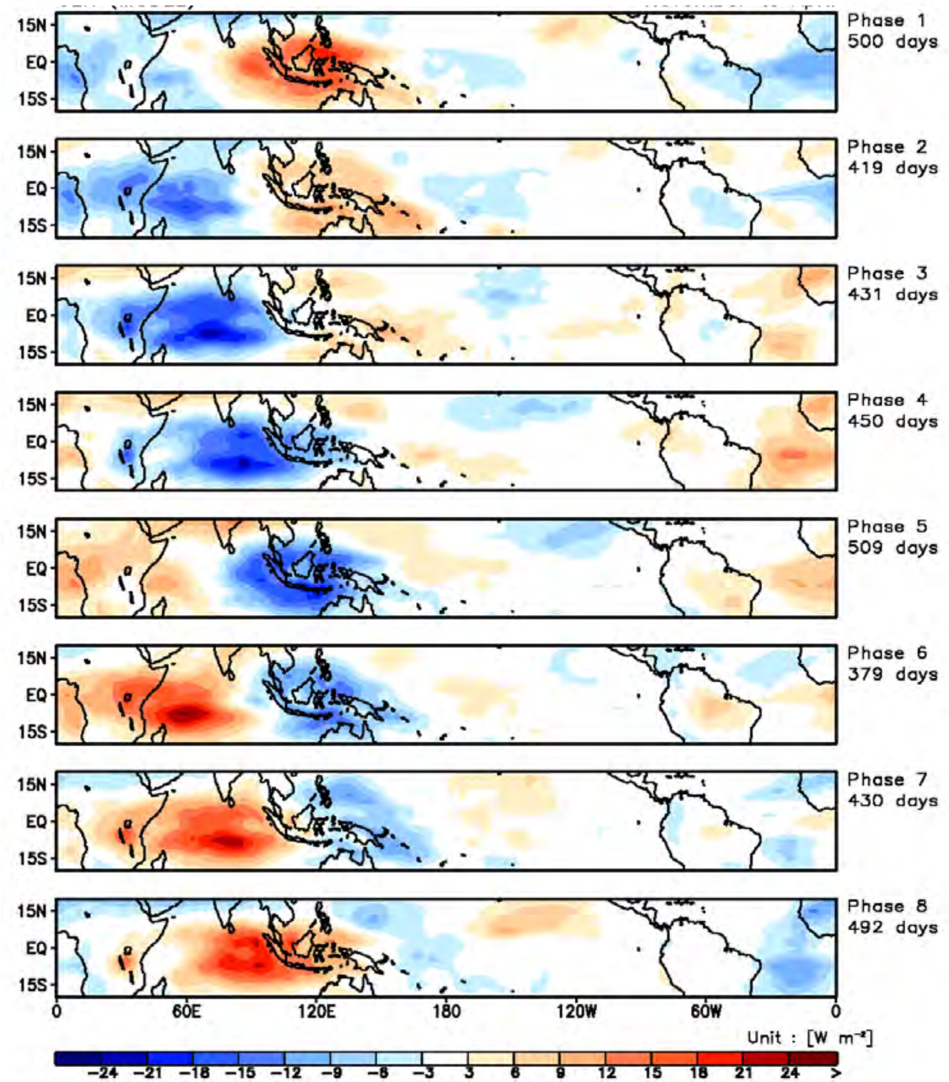


Observed and AM4 simulated MJO life-cycle composite
(figures generated using US CLIVAR MJO standard diagnostic package)

OLR (AVHRR, Nov-Apr)



OLR (AM4a1, Nov-Apr)



Summary

- HIRAM forced by observed SSTs provides outstanding simulations of TC statistics and mean climate, yet it produces significant cold and dry bias in equatorial Pacific when coupled with ocean. This negatively affects ENSO simulations.

- To reduce the biases, we develop a new double plume convection scheme which incorporates recent findings on key processes for modeling convection and MJO.

- Using the new scheme, AM4 significantly reduces the equatorial Pacific cold and dry bias and improves the simulated precipitation and cloud response to ENSO while maintaining a competitive simulation of TC statistics. Moreover, it dramatically improves model simulations of MJO.

Ongoing and future work

Model development:

- Improve diurnal cycle of precipitation over land
- Explicit representation of downdrafts and cold pools
- Convective microphysics, coupling with droplet/ice number concentration and aerosols

Understanding models and simulations:

- Simulated MJO mechanisms in AM4 and CM4
- Explore the causes of equatorial Pacific cold/dry bias in HiRAM- and AM3-like models and understand the AM4 improvement

GFDL Cloud Climate Initiative (CCI) to address our long-term goal for unified convection and cloud representation