# The development of double-ITCZ biases in coupled hindcasts with SP-CESM and CESM

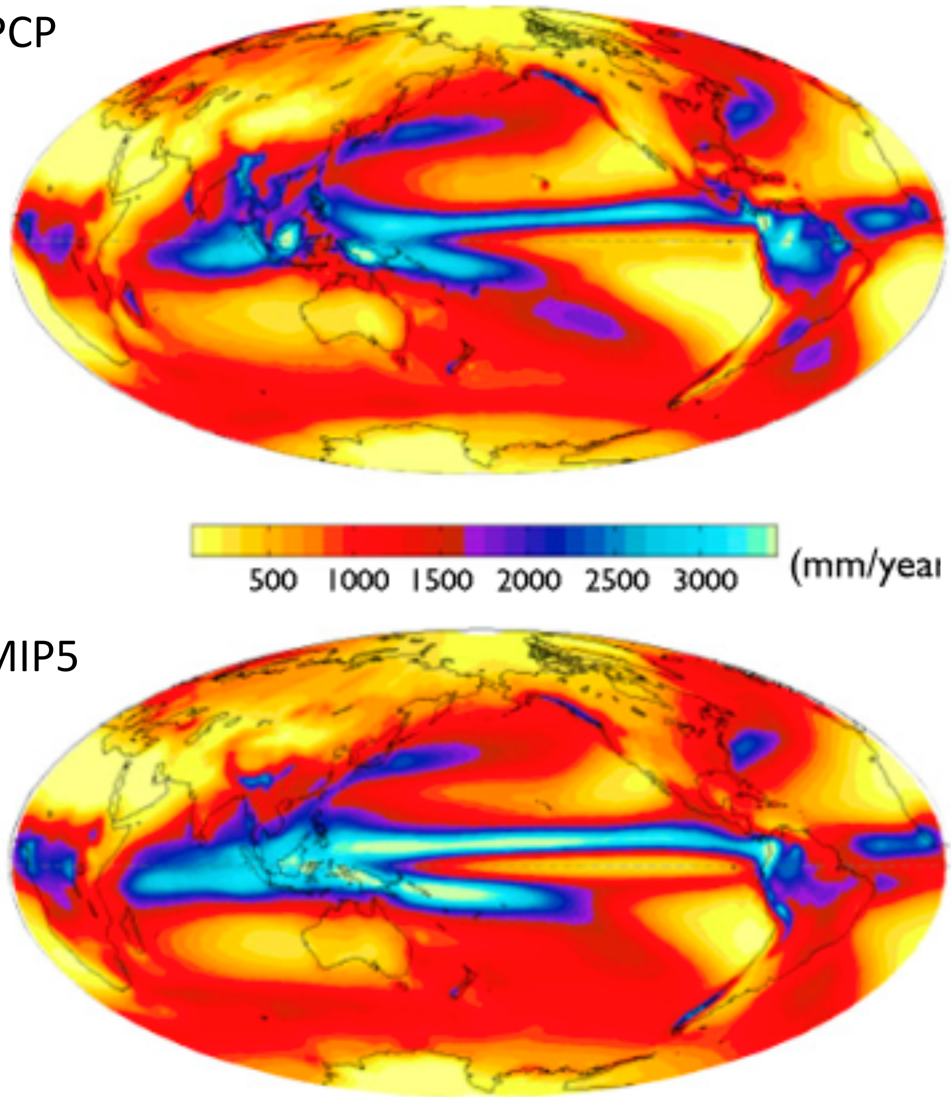
Matthew Woelfle and Chris Bretherton, U. Washington
Sungduk Yu and Mike Pritchard, UC Irvine

Funding: NSF EaSM
Computing: NSF (Yellowstone)

# Double ITCZ precipitation bias in CMIP5 GCMs

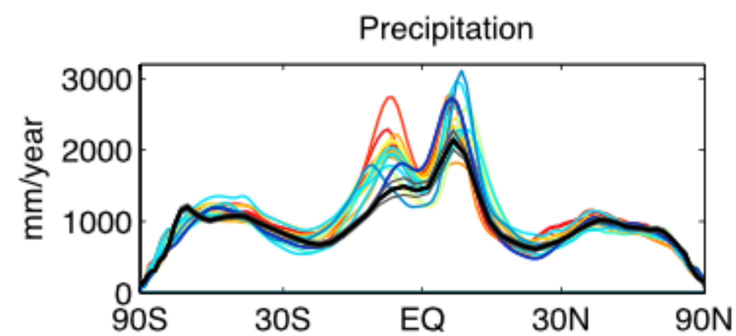
GPCP

CMIP5




Hwang and Frierson 2013

Highlighted over 20 years ago by Neelin et al. (1992) and Mechoso et al. (1995), but persists in most coupled GCMs.

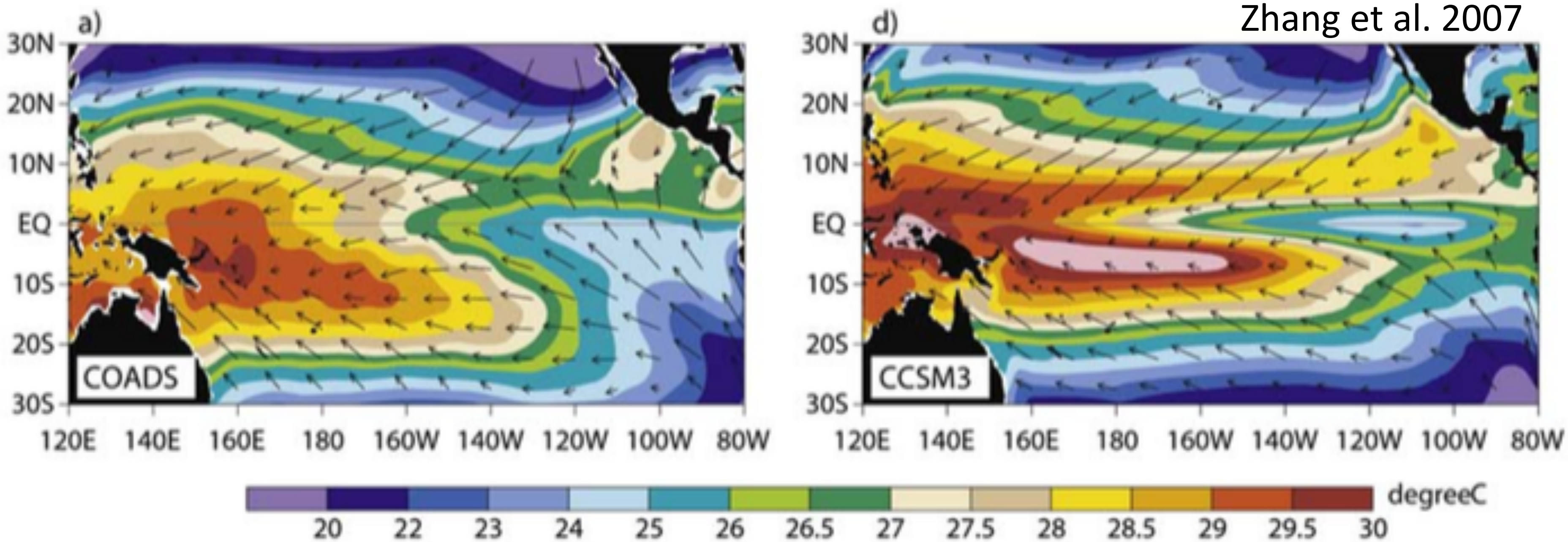



Three bias components:

1. Rain skewed to SH
2. Too wet over warm SST
3. Rain is off equator
   (cold tongue bias)

# Pacific 2xITCZ/cold tongue bias in annual-mean SST

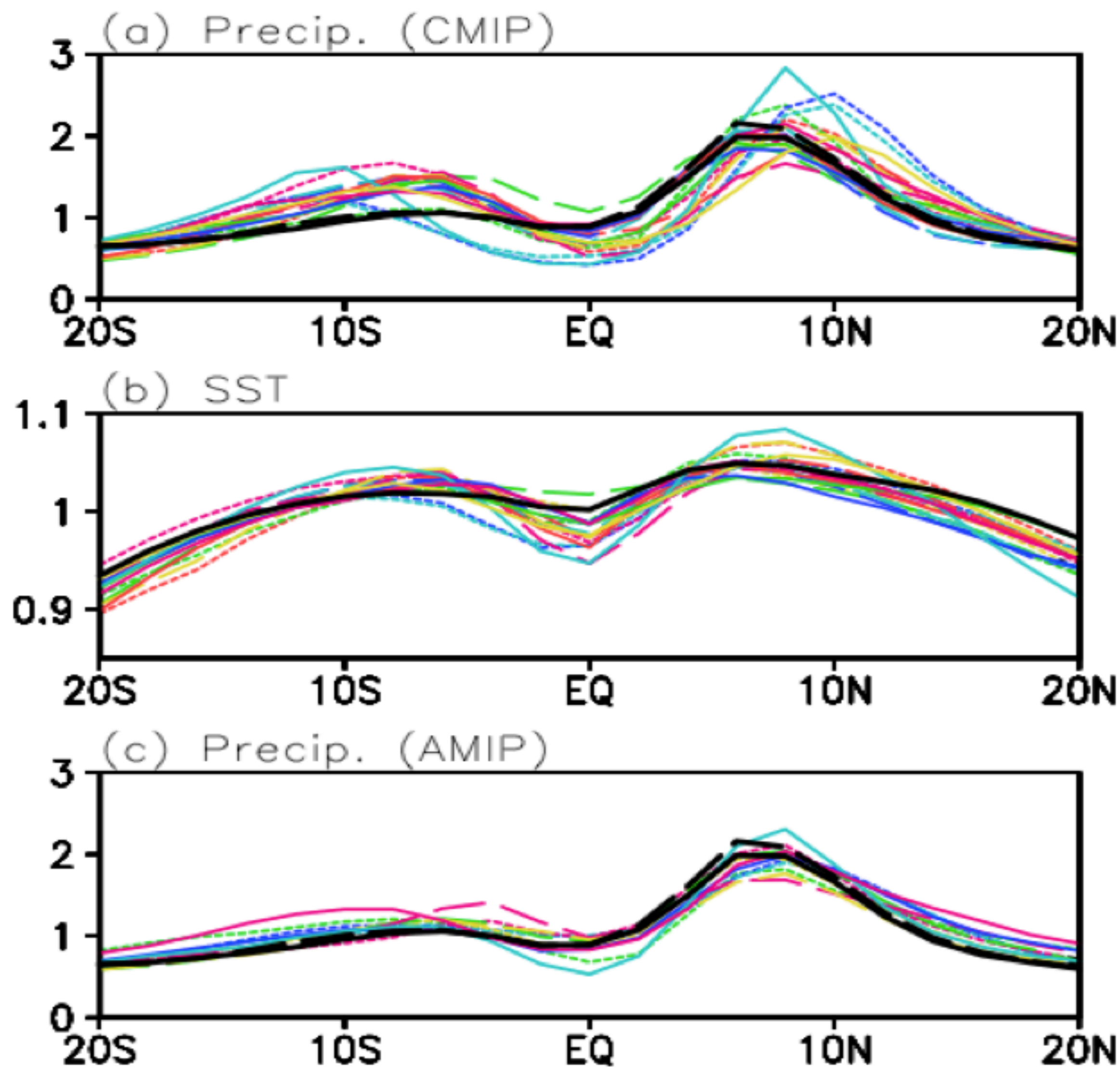
Zhang et al. 2007




Several hypotheses for its cause:

- Excessive equatorial upwelling or mixing
- Inadequate lateral eddy mixing of warmer water
- Premature triggering of deep cumulus parameterizations
- …amplified by strong coupled feedbacks between SST, winds, and convection

# The double-ITCZ bias is much stronger in coupled models




Li and Xie (2014) – note quantities are normalized by their tropical mean

# Mechanisms and feedbacks for 2xITCZ/cold tongue bias?

Atmosphere:

Inadequate cloud in SE Pacific
Premature triggering of deep cumulus parameterizations
Midlatitude forcing

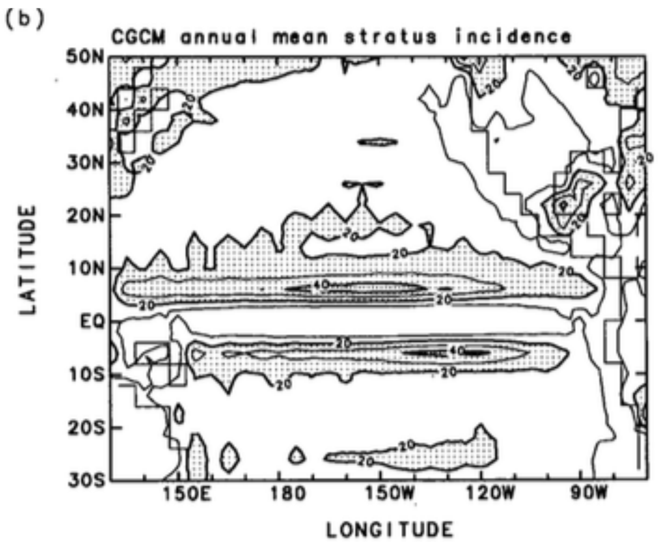
Ocean:

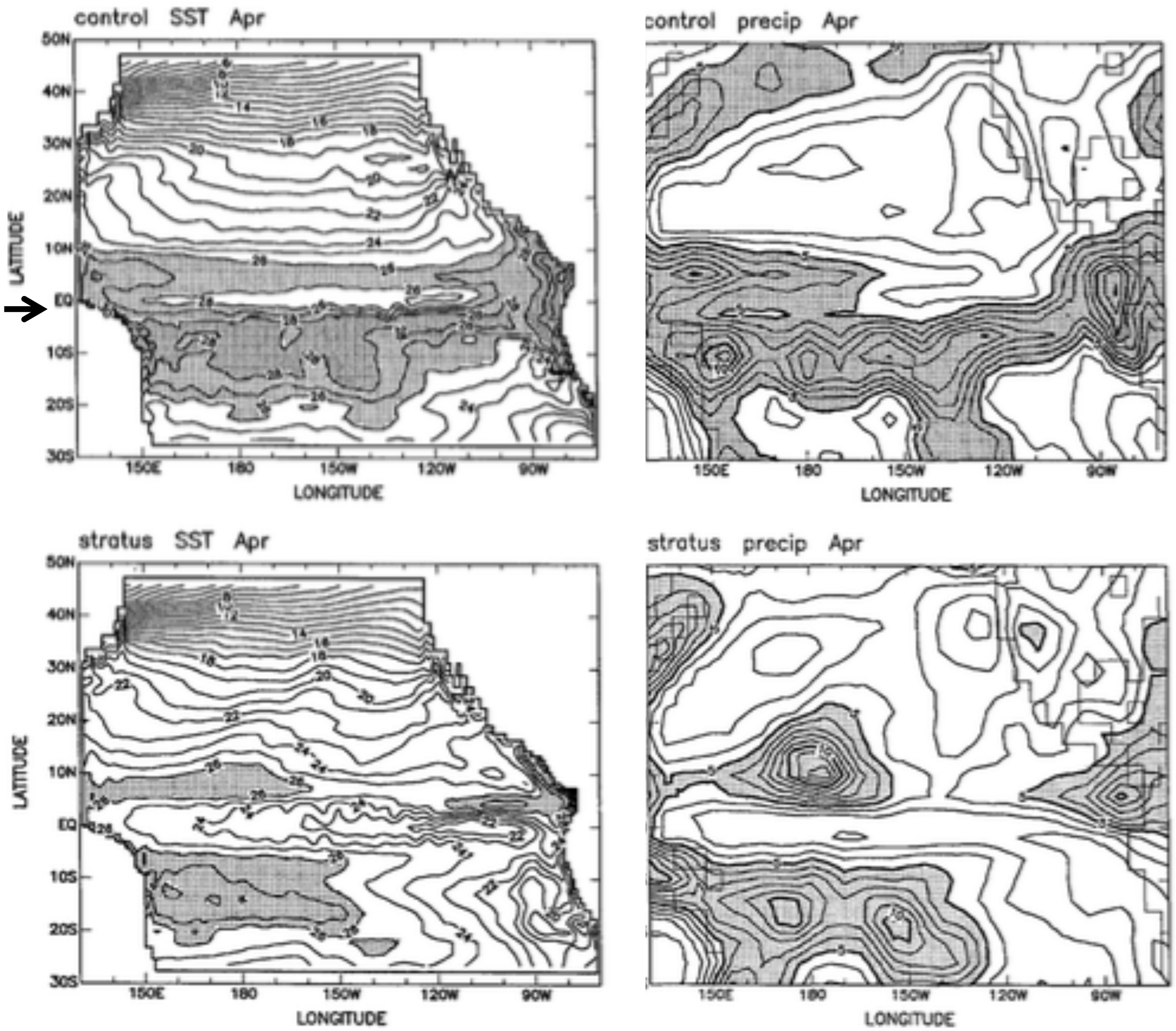
Excessive equatorial upwelling or mixing
Inadequate lateral eddy mixing of warmer water

…amplified by strong coupled feedbacks between SST, winds, and convection?

# More Pacific low clouds reduce 2xITCZ bias

Ma et al. (1996)




Fill Pacific with stratus cloud →

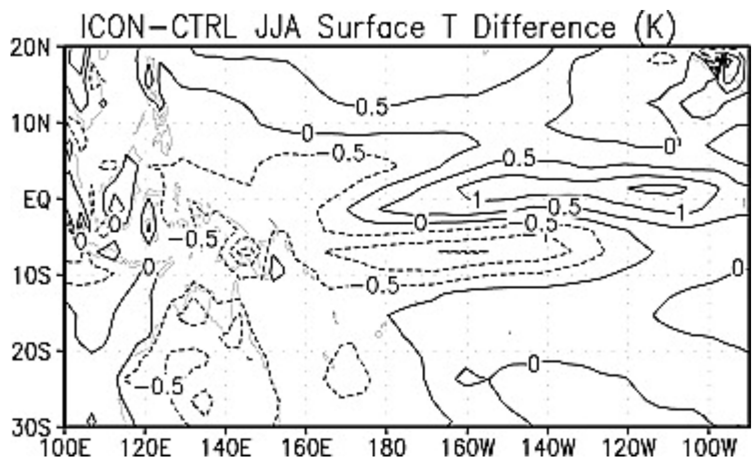
Cooler, esp. in SE Pacific

Much less SE Pacific rainfall

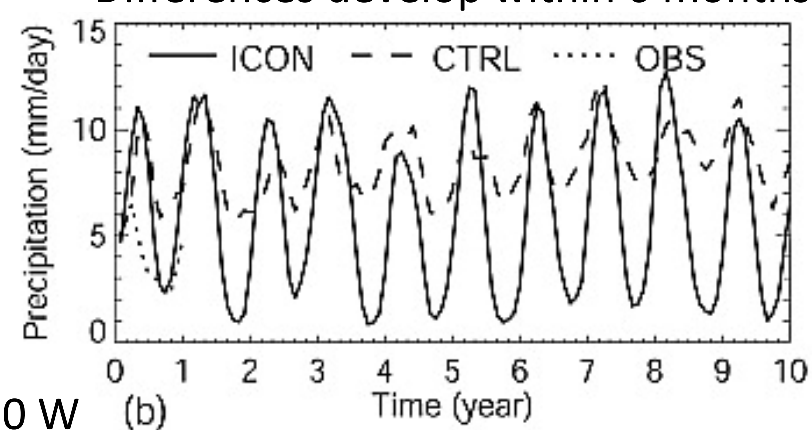
# Cold tongue and 2xITCZ biases sensitive to Cu param

G. Zhang et al. (2006): Base CAM Cu mass flux closure to use free trop destabilization instead of CAPE

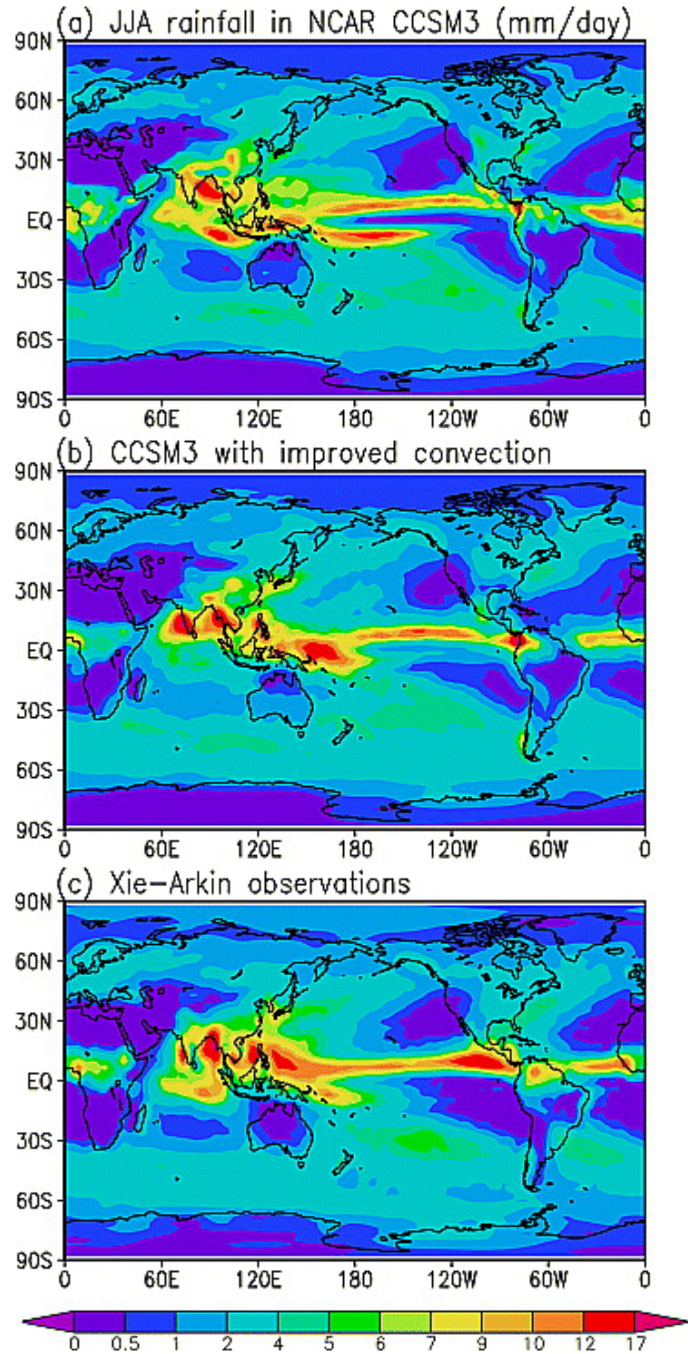
Central Pac SST warms along equator, cools to S




Differences develop within 6 months




5-10 S
130-180 W



# Kang-Frierson ITCZ shift mechanism

(Kang et al. 2008, Hwang and Frierson 2013)

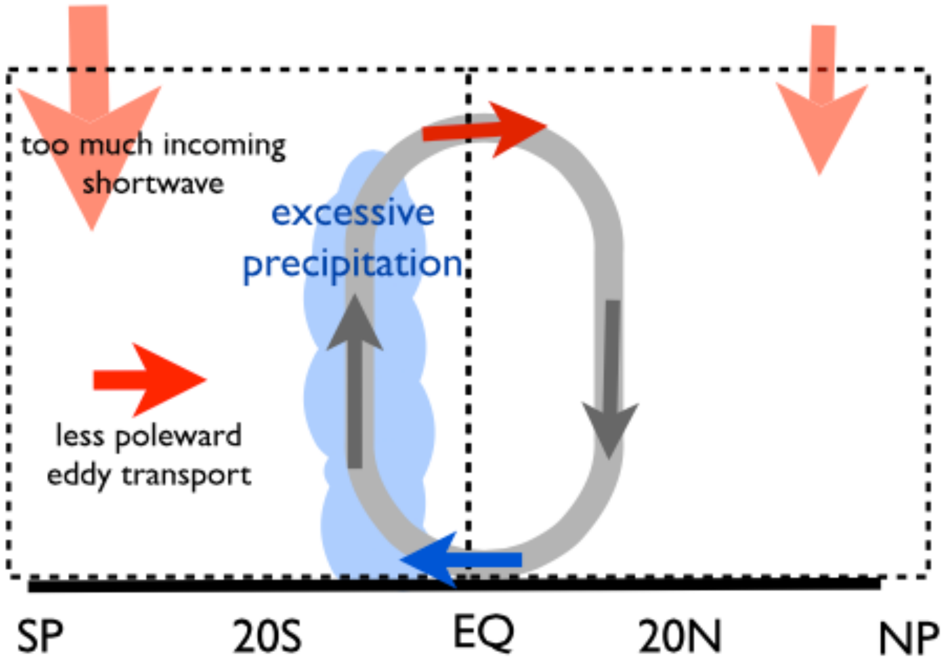
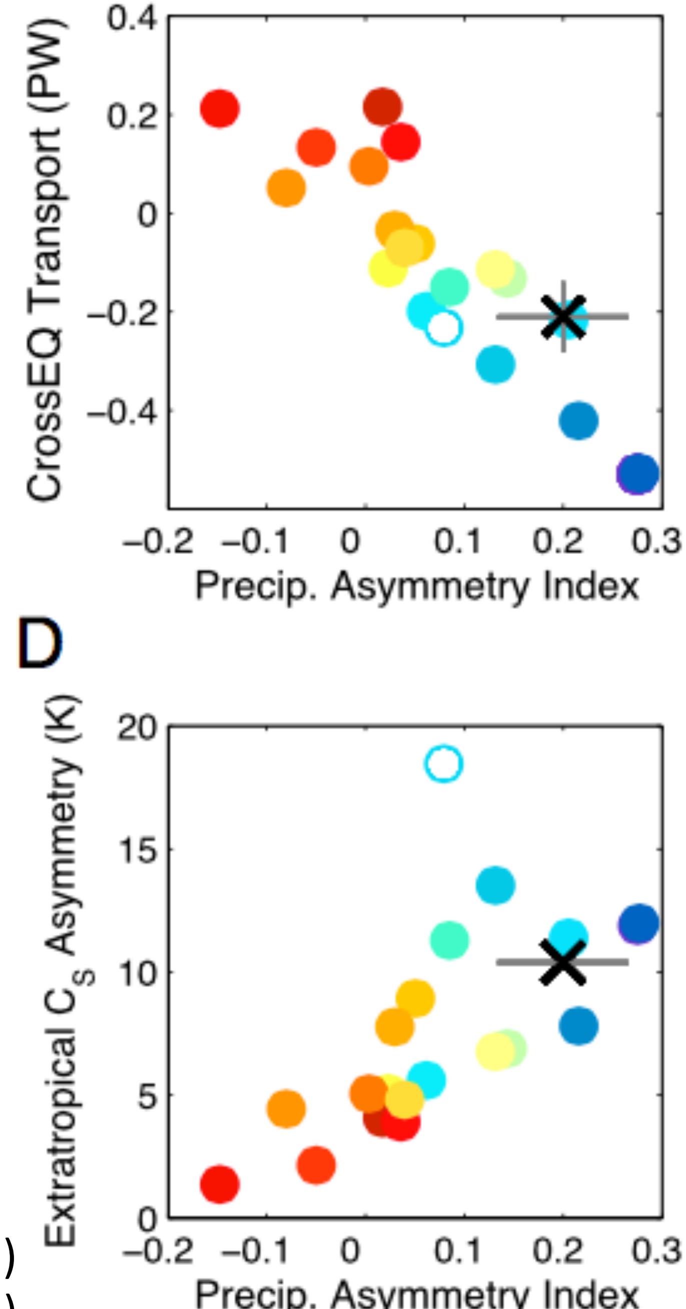



**Fig. 4.** Schematic of the proposed mechanism for the double-ITCZ bias.




ITCZ biases remotely forced by TOA radiation biases
ITCZ biased south if too little Southern Ocean low cloud

Caveat: Oceanic MOC affects needed atmos. transport
NH ITCZ though SH absorbs more radiation (Fuckar et al. 2013)
Fixing CESM SH cld bias changes MOC, not ITCZ (Kay etal 2015)

# Coupled feedback mechanism to amplify cold tongue bias

M. Zhang et al. (2007)

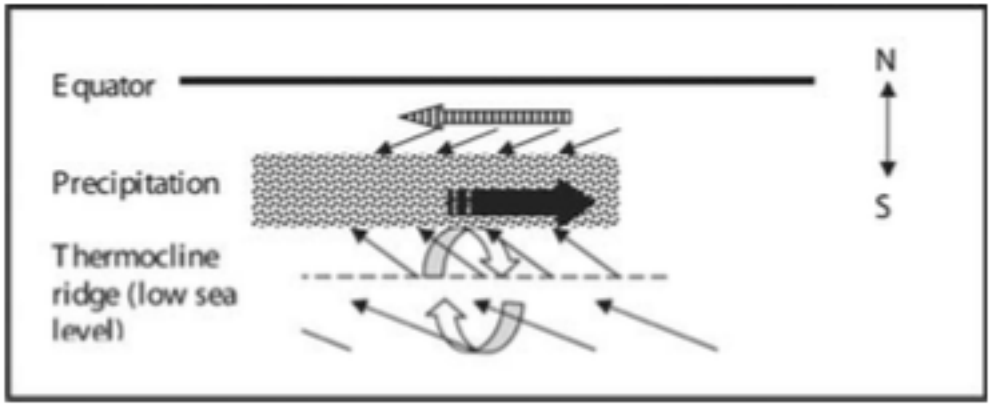



**Figure 6.** Schematic figure of key processes. Lightly shaded area represents region of initial precipitation. Thin arrows denote surface winds. Curved arrows denote negative curl. Dashed line is the latitude of thermocline ridging and thus low sea level height. The thick straight arrow represents the SECC forced by the meridional gradient of thermocline. The SECC advects warm water eastward.

Too much rain at 5-10°S

↓

Wind converges into rainy region

↓

Anticyclonic wind stress curl to S

↓

Low sea level height to S

↓

Warm E-ward current under rain

↓

Higher SSTs amplify rain, CT bias

# How to sort out processes contributing to ITCZ biases?

✓ Sensitivity studies (usually run to steady state)

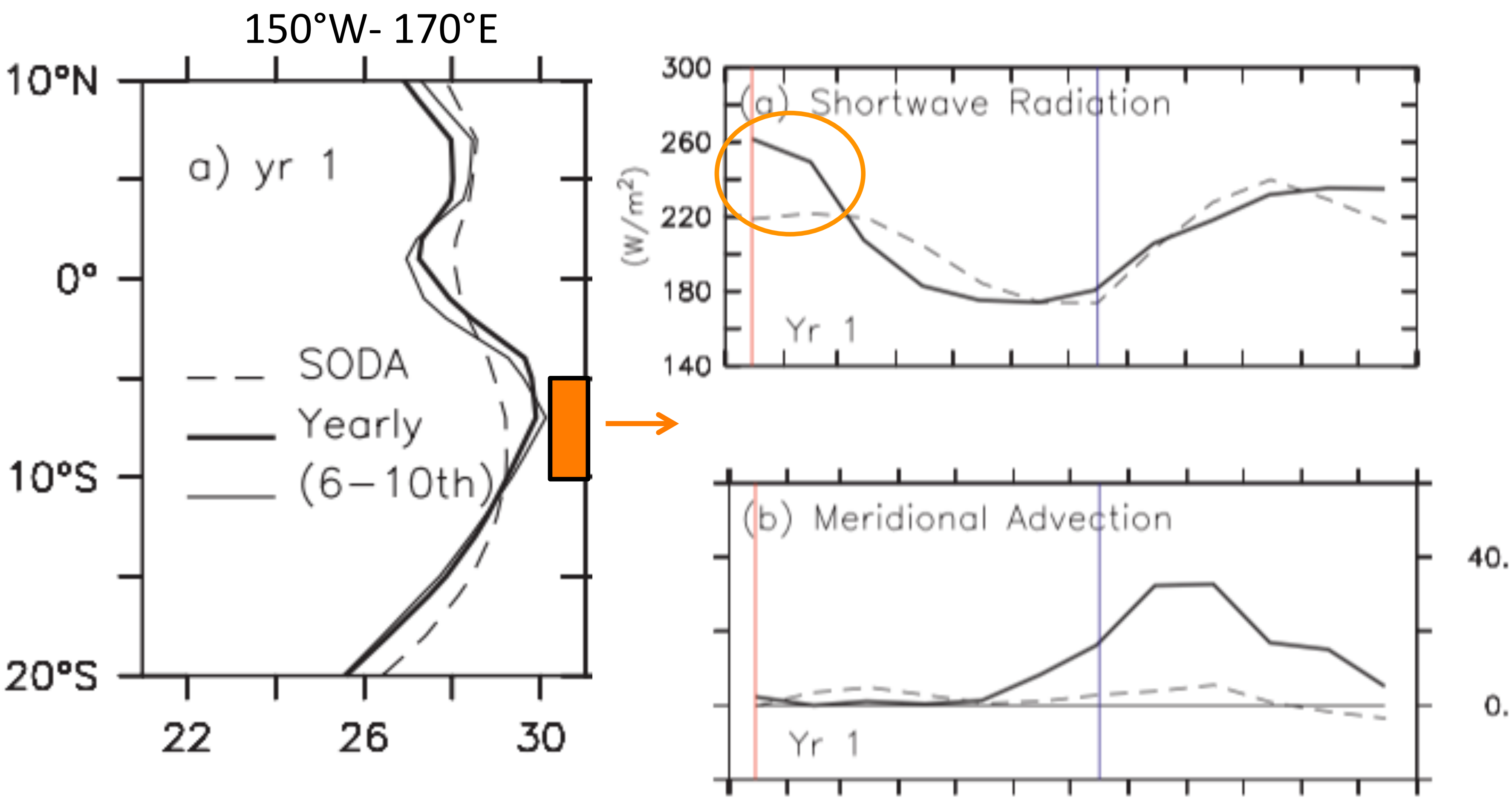
- Clear test of model response and improvement
- Can be run with coupled and/or specified-SST
- Process interactions can make interpretation challenging

Spin-up of biases

- Different biases develop on different time scales
- Clearer separation of physical mechanisms and causality

# CCSM3 biases vs. SODA climo spin up in 3 months

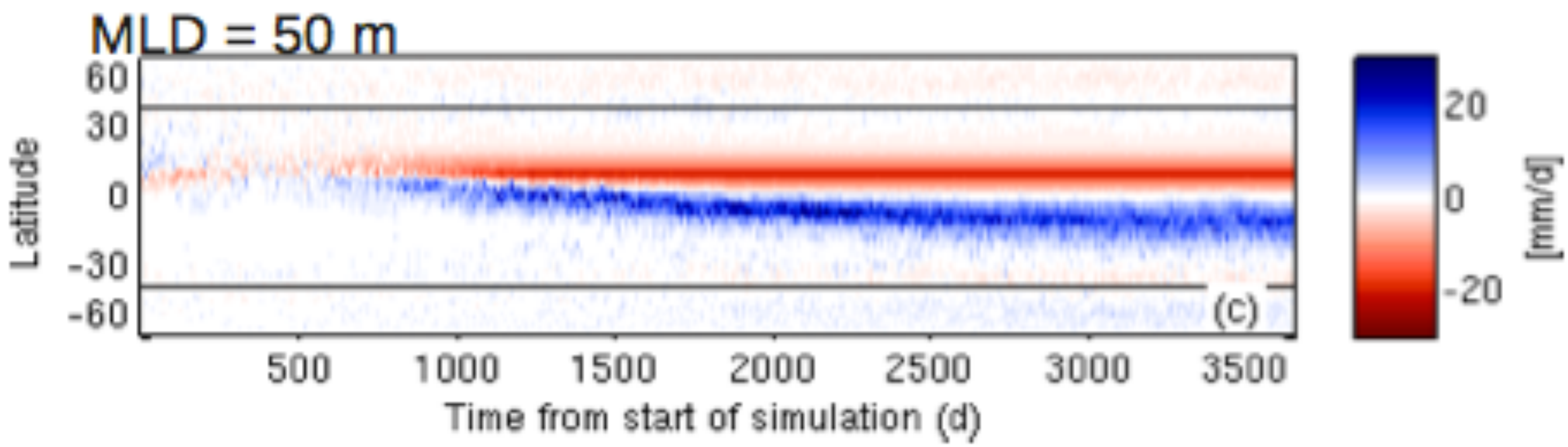
Liu et al. (2012)




- Warm SST bias at 5-10 S initiated mainly by too little cloud
- It is sustained by S-ward advection of warm SST in Austral spring
- Artificially increasing cloud albedo decreases the double-ITCZ bias

# Find spin-up time with slab-ocean aquaplanet simulations
(Woelfle et al. 2015)

- AM2, 2° x 2° resolution run to steady state over a slab ocean of depth D
- Impulsively turn on a steady 1 PW NH extratropical heat sink and SH heat source
- ITCZ precipitation shift takes 8 years to complete for D = 50 m.
- Extratropical forcing of ITCZ shifts has a time scale of several years



# UW-UCI EaSM 2xITCZ project

**Strategy:**

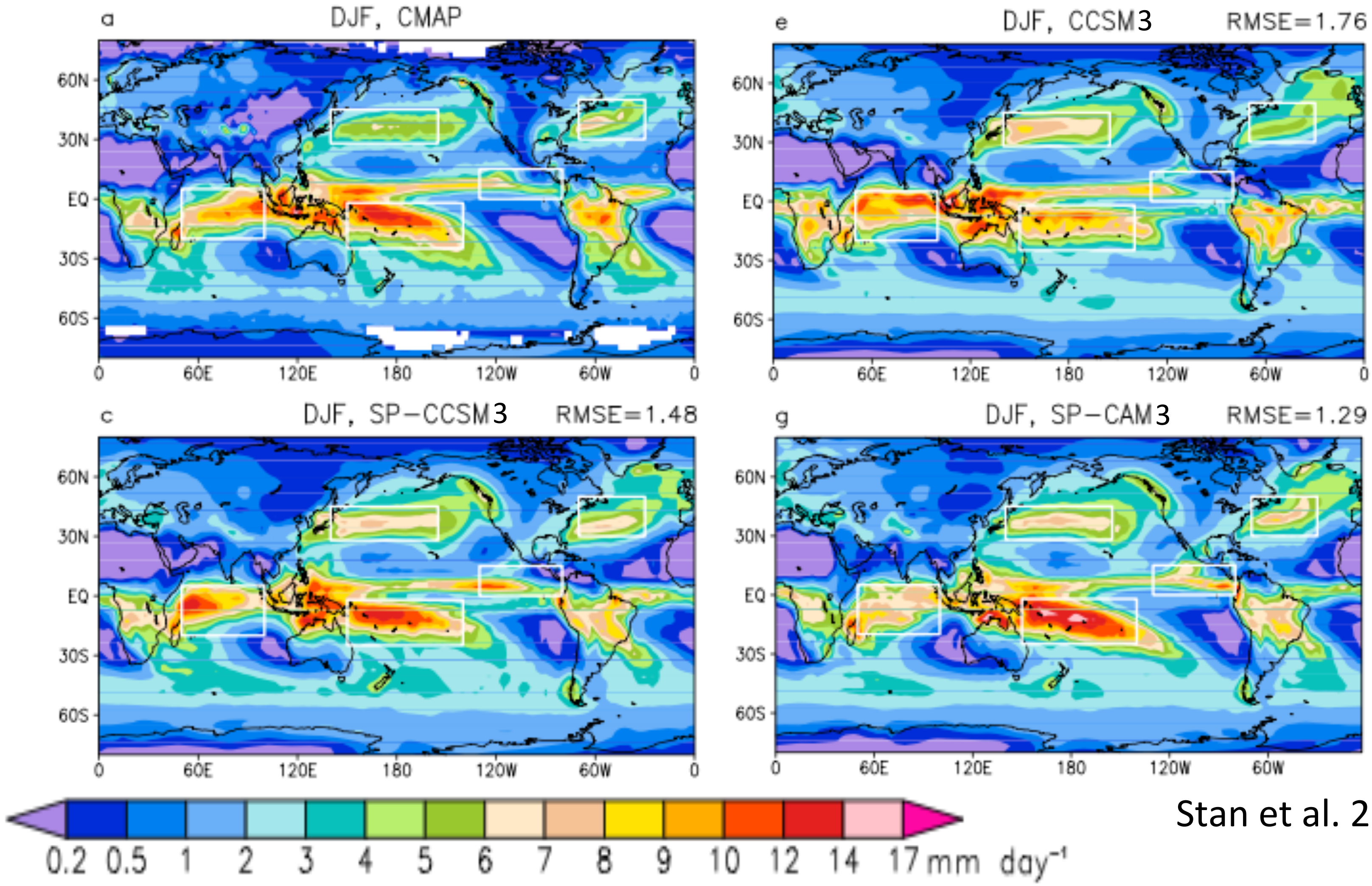
1. Study spin-up of ITCZ bias in realistically initialized CESM and SP-CESM (NWP)

2. Use this approach for process understanding and improvement of both models

**Context:**

- Use of SP logical to explore whether more realistic convection helps ITCZ biases
- Fits with operational use of CCSM3 as part of NOAA's North American Multi-Model Ensemble (NMME) seasonal forecasting system (B. Kirtner, U. Miami)
- Could exploit more accurate ocean reanalyses made possible by the ARGO array

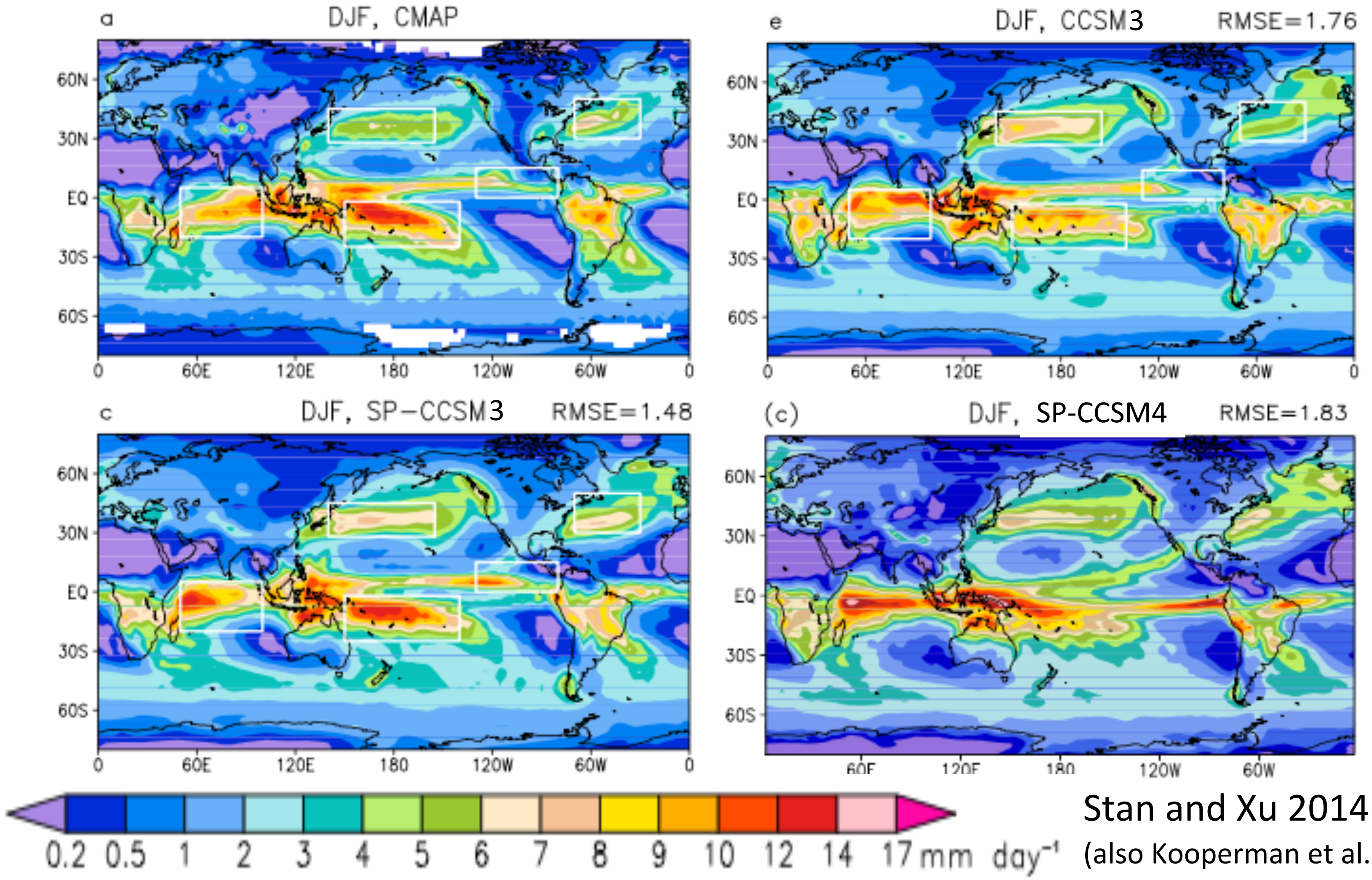
# Double-ITCZ bias is large in CCSM3 but small in SP-CCSM3




Stan et al. 2010

Double ITCZ biases are much weaker in SP-CCSM3 than in CCSM3
They are even weaker in SP-CAM3

# Double-ITCZ bias is large in CCSM3 but small in SP-CCSM3




Stan and Xu 2014
(also Kooperman et al. 2015)

However, they worsen in SP-CCSM4, especially in DJF
This may be due to the FV dycore but that hasn't been proven

# Sensitivity of ITCZ biases to SP configuration

## Strategy

i. Run nine of 1-year SP-CESM (res: 1.9x2.5, L30) simulations with different explicit convection subdomain configuration, i.e. CRM (cloud resolving model) configuration

ii. Assess internal variability of dITCZ from 7-year simulation of a standard SP-CESM

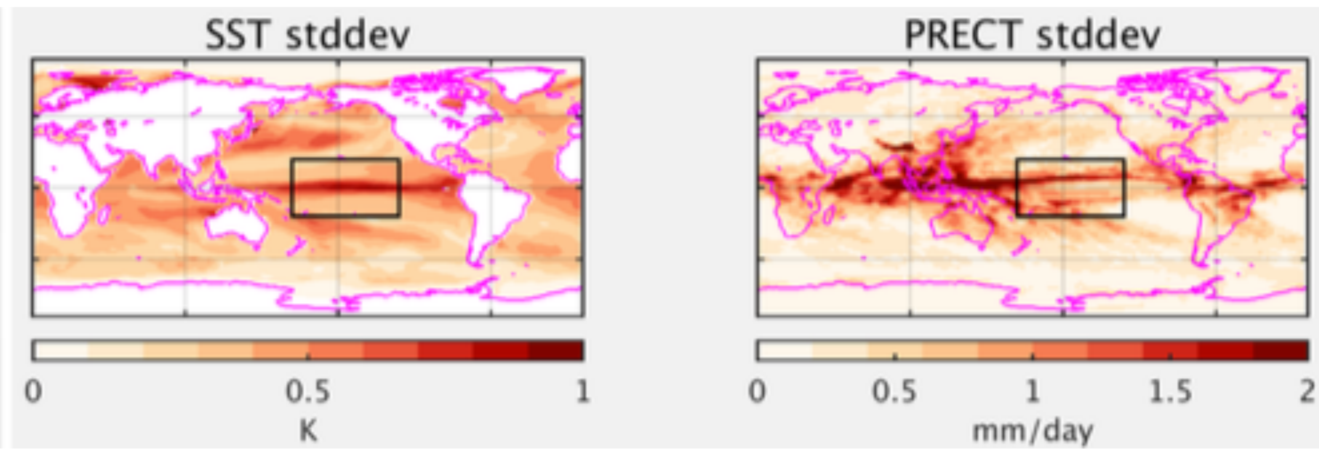
iii. Identify statistically detectable sensitivities of the dITCZ bias in SP-CESM

iv. Identify configuration of SPCESM that produces the most valid analog to observed ITCZ, for use in future hindcast work on transient bias dynamics.

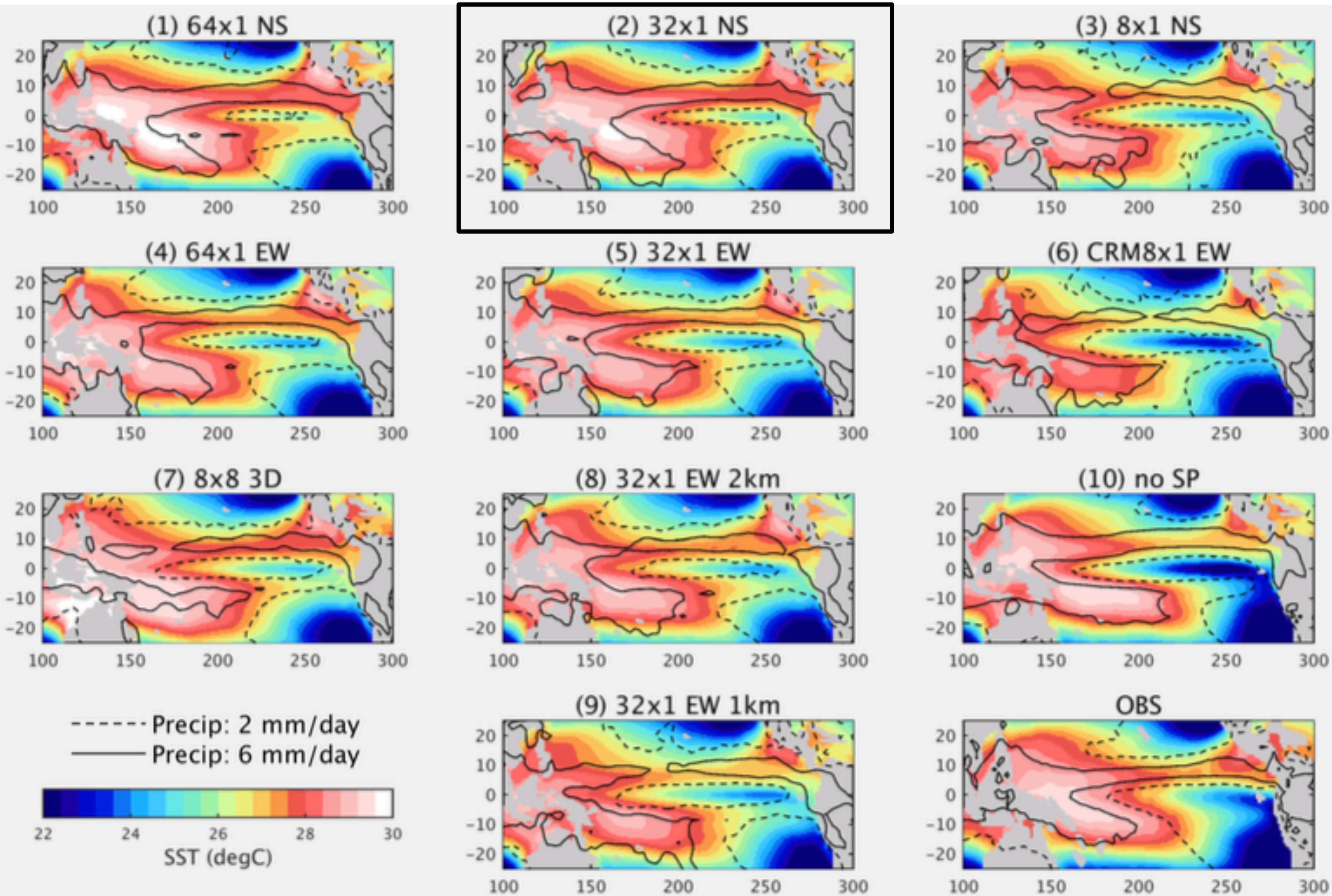
< Simulation list >

| | CRM orientation | CRM columns | CRM Δx |
|---|---|---|---|
| 1 | N-S | 64x1 | 4km |
| 2 | N-S | 32x1 | 4km |
| 3 | N-S | 8x1 | 4km |
| 4 | E-W | 64x1 | 4km |
| 5 | E-W | 32x1 | 4km |
| 6 | E-W | 8x1 | 4km |
| 7 | 3D | 8x8 | 4km |
| 8 | E-W | 32x1 | 2km |
| 9 | E-W | 32x1 | 1km |
| 10 | No superparameterization | | |

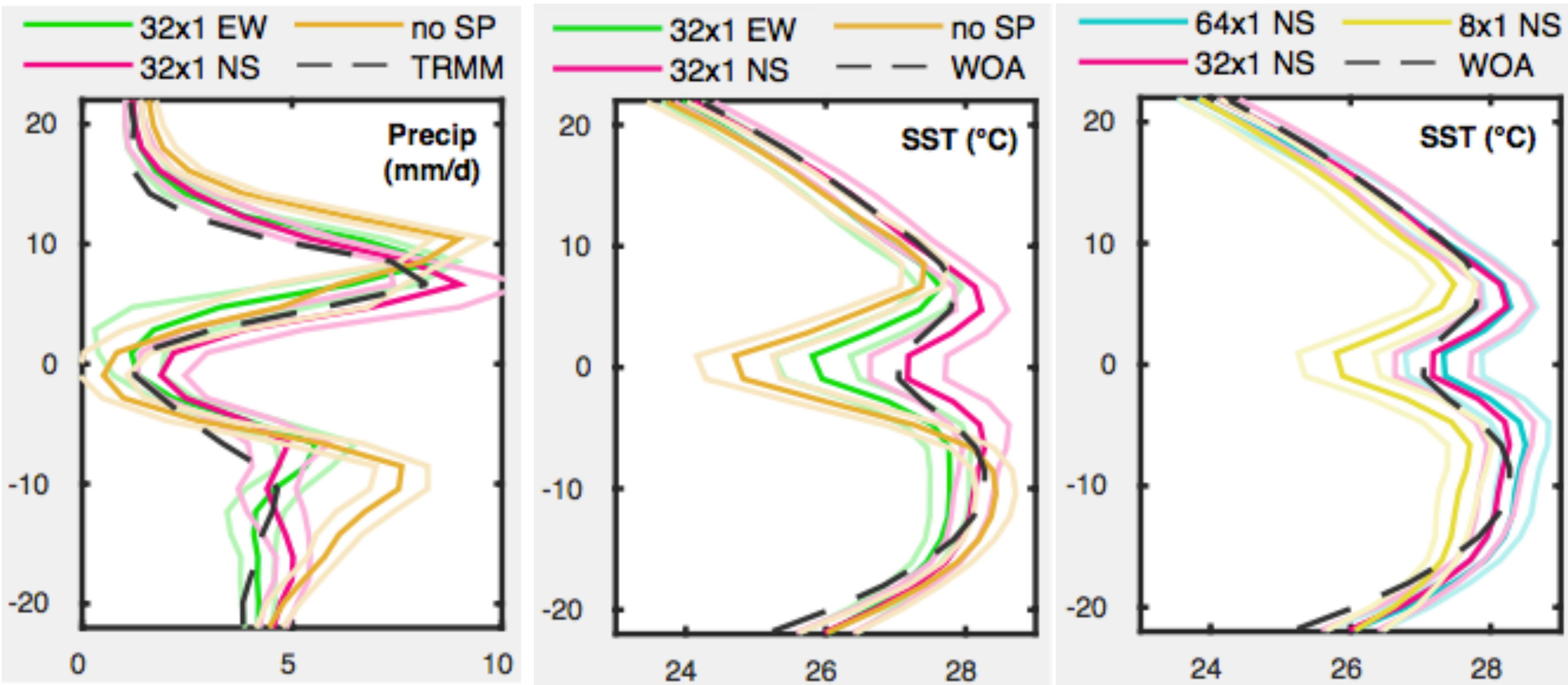
Assess bias from zonal means over 170°E- 120°W.



# SP CRM configuration affects ITCZ bias



# Default 32x1 N-S CRM wins the ITCZ beauty contest



# CESM initialization procedure

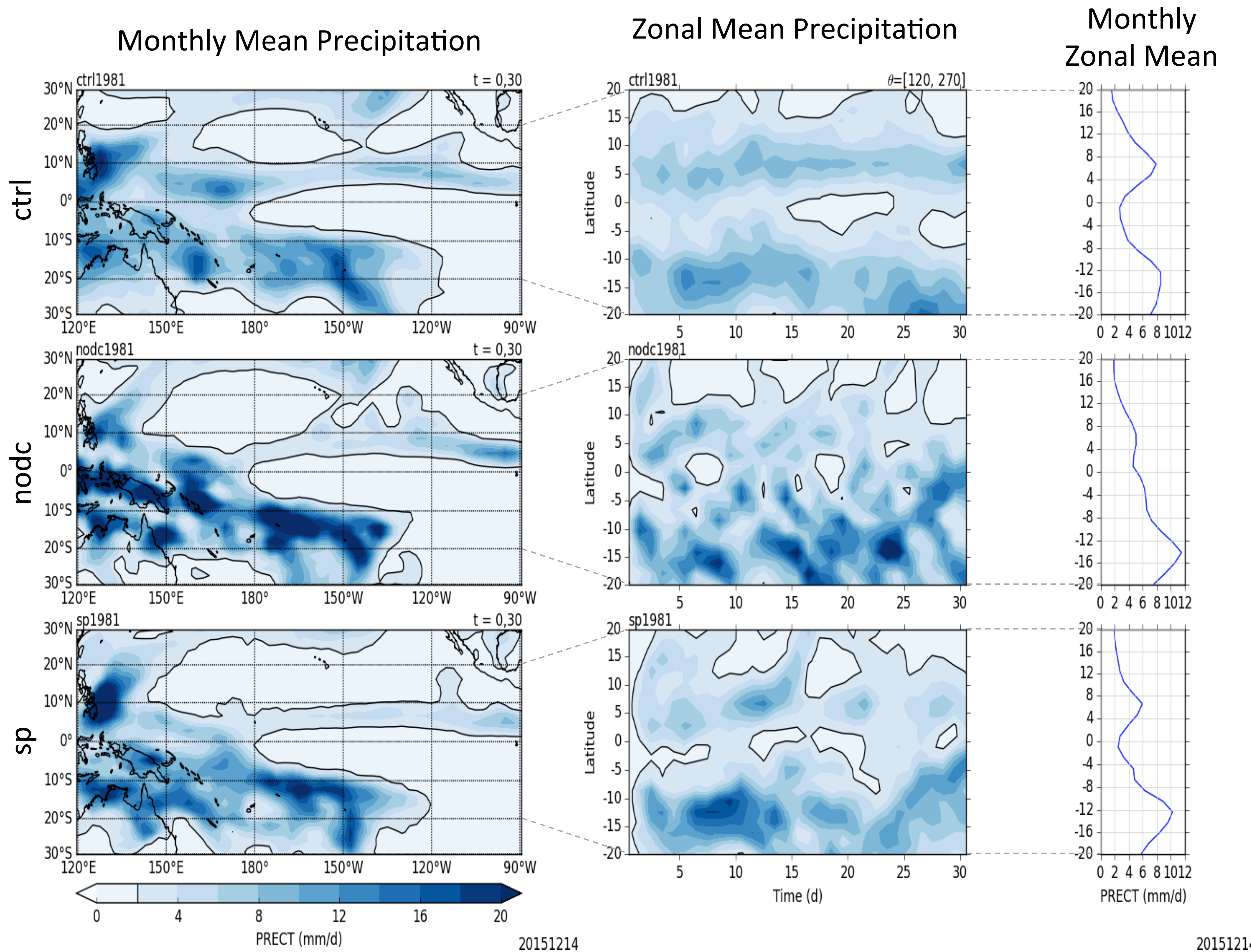
Use stand-alone POP ocean run forced by CORE reanalysis/obs surface meteorology, precip and radiative fluxes.

Separately spin up CLM land component using hybrid reanalysis/observational datasets for surface meteorology, precipitation and radiative fluxes.

Start CAM atmosphere from reanalysis

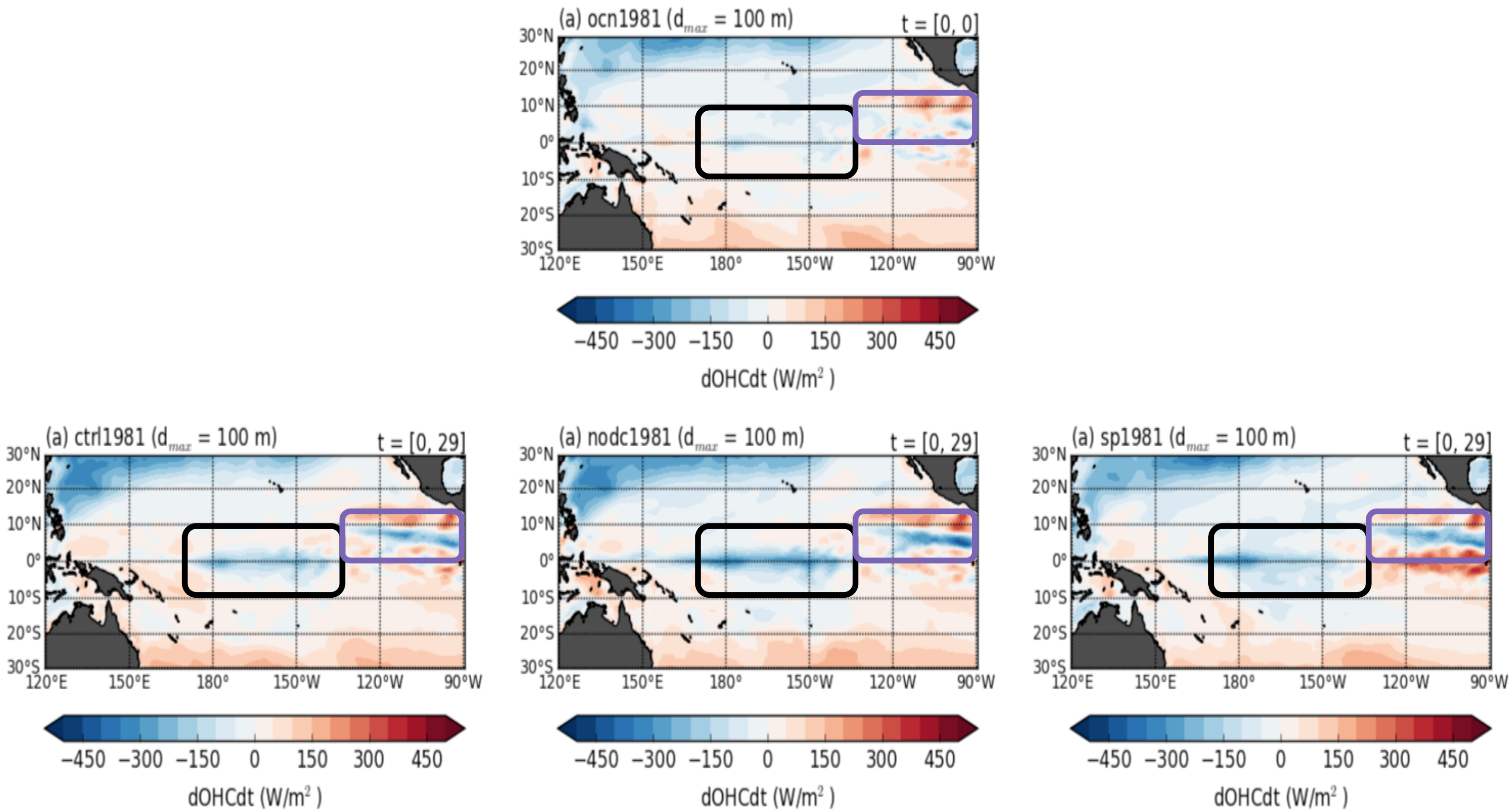
1-month (5-year to come) simulations use CESM1.2 (CAM5@ 2°x2.5°,POP2@ ~1°)
Enhanced upper-ocean diagnostics sufficient to close regional heat budgets
Results shown for 1/1/1981 initialization, a few for 1/1/1986, 1/1/1991
Compare bias development for control, NoDC (no ZM deep convection) and SP.

Precip differences emerge within a day or two, and a central Pacific cold tongue bias appears in all three simulations within the first month.



Monthly Mean Precipitation
Zonal Mean Precipitation
Monthly Zonal Mean
ctrl
nodc
sp
ctrl1981
nodc1981
sp1981
t = 0,30
θ=[120, 270]
Latitude
Time (d)
PRECT (mm/d)
120°E 150°E 180° 150°W 120°W 90°W
30°N 20°N 10°N 0° 10°S 20°S 30°S
20151214
20151214

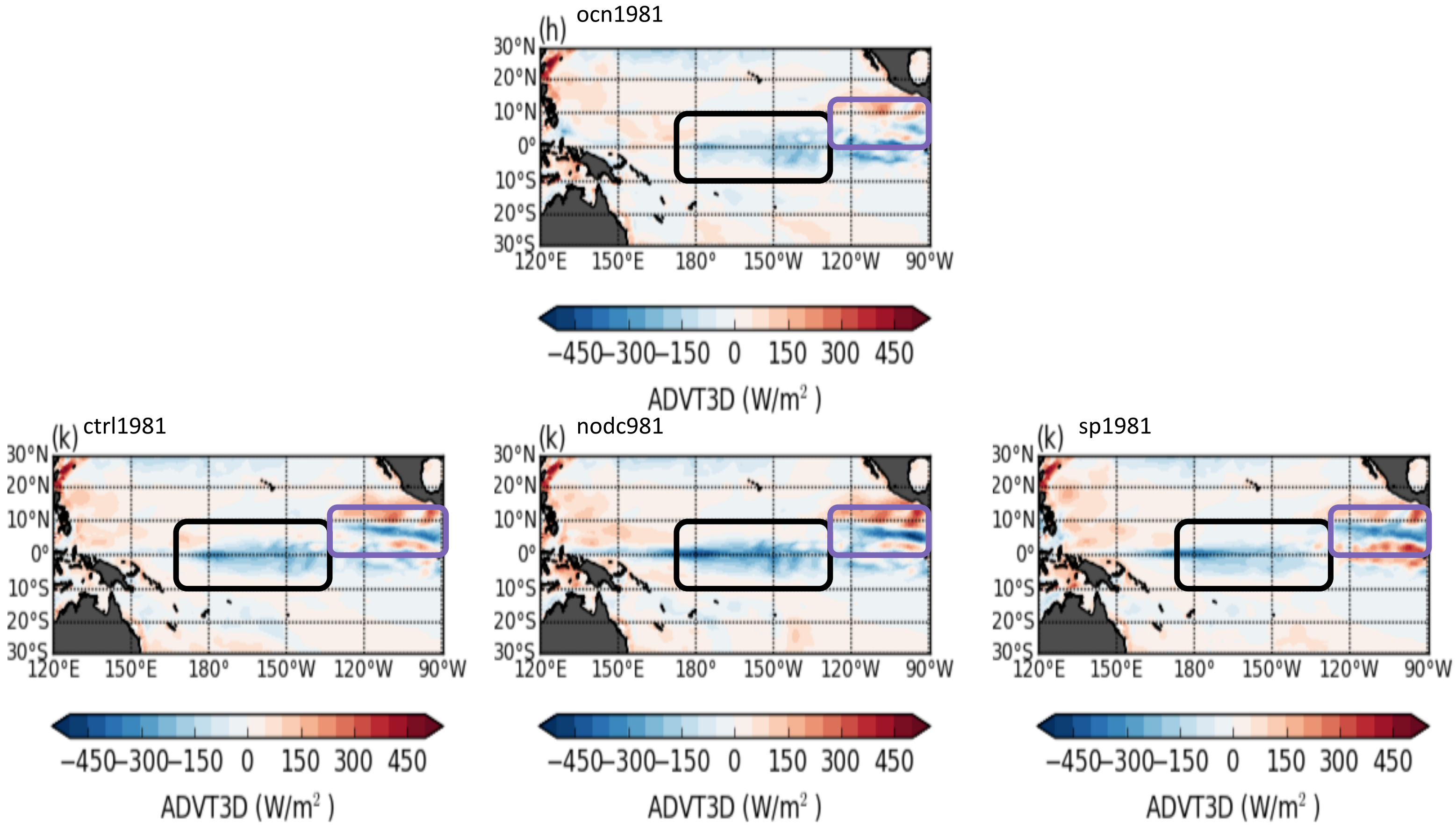
# Comparison to Ocean Only Simulation: ΔOHC (0-100 m)




Consistent features in fully coupled simulations:

- SST drifts look like OHC drifts
- Enhanced cooling along the equator (cold tongue bias)
  - approx. 170°E-140°W (170°E-220°E)
- Cooling north of the equator in far east pacific
  - centered around 5°N, 90°-120°W (240°E-270°E)

# Comparison to Ocean Only Simulation: ΔAdvection

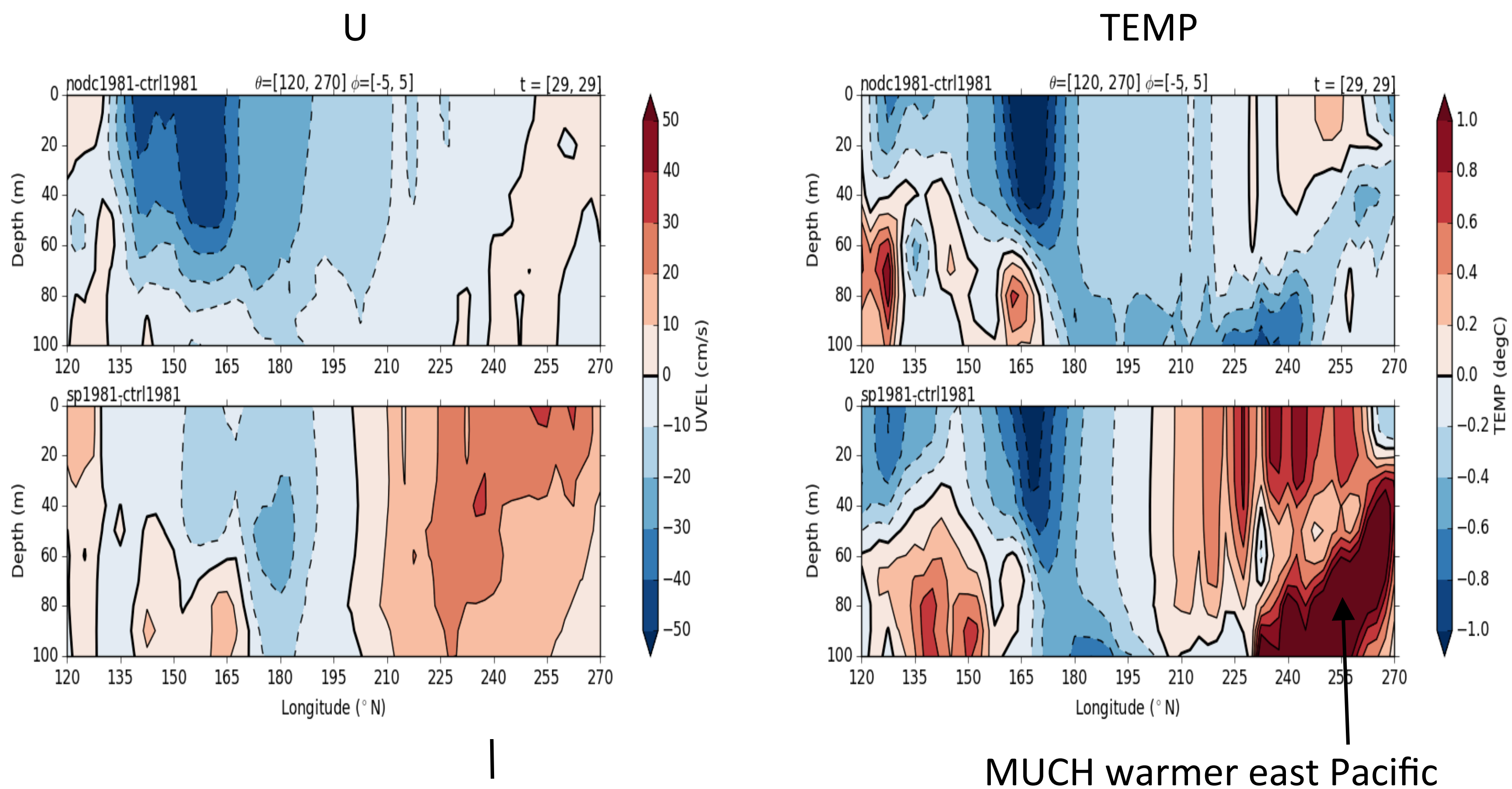



Most ΔOHC differences between simulations are due to advection
(contrast to Liu et al. 2012)

# Ocean Differences - Equatorial (±5°) after 1 month

nodc - ctrl

sp - ctrl



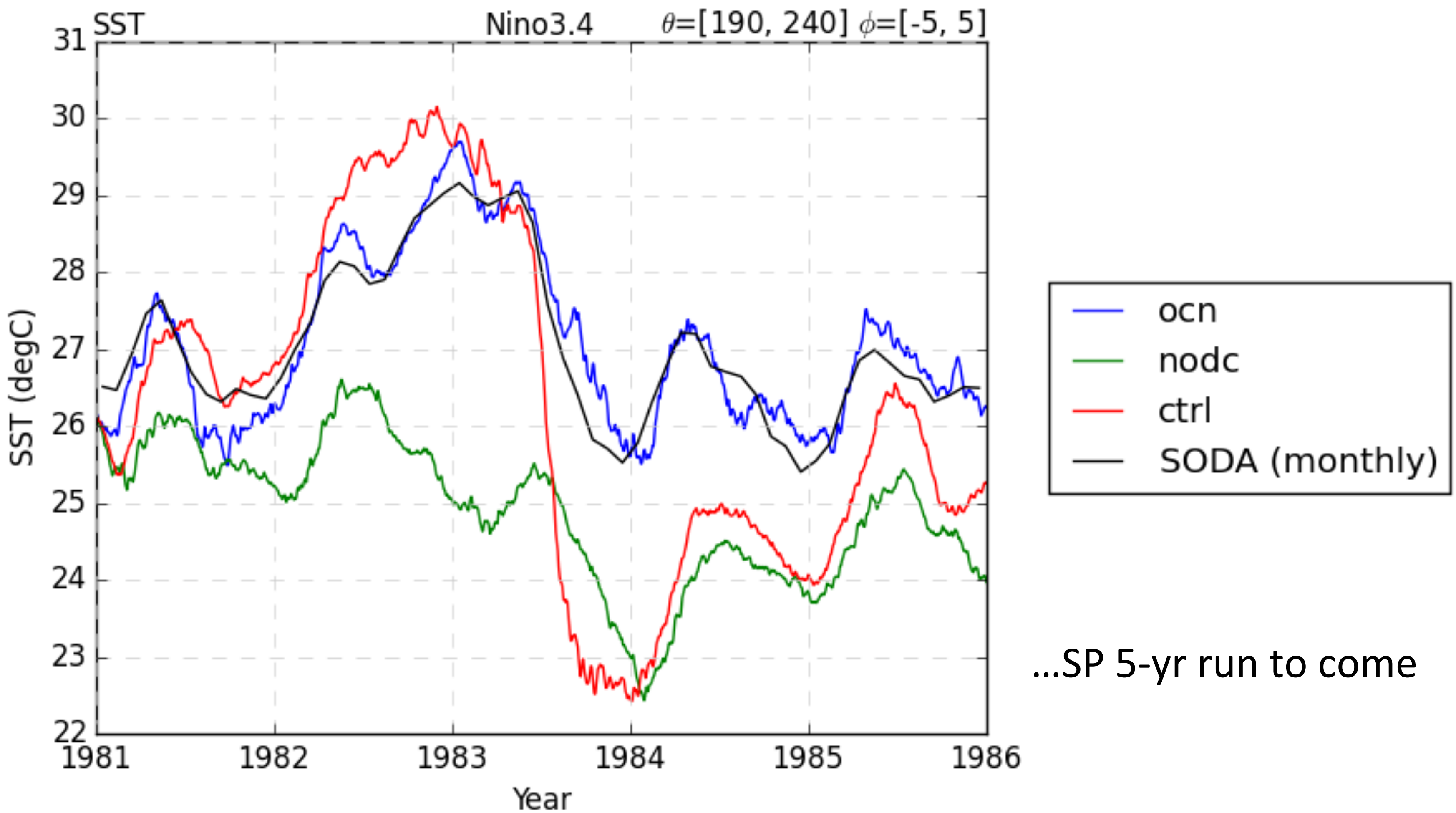

Weaker westward current across E. Pacific

MUCH warmer east Pacific consistent with heat budget analysis

- Simulated differences in cold tongue appear mainly due to oceanic zonal advection

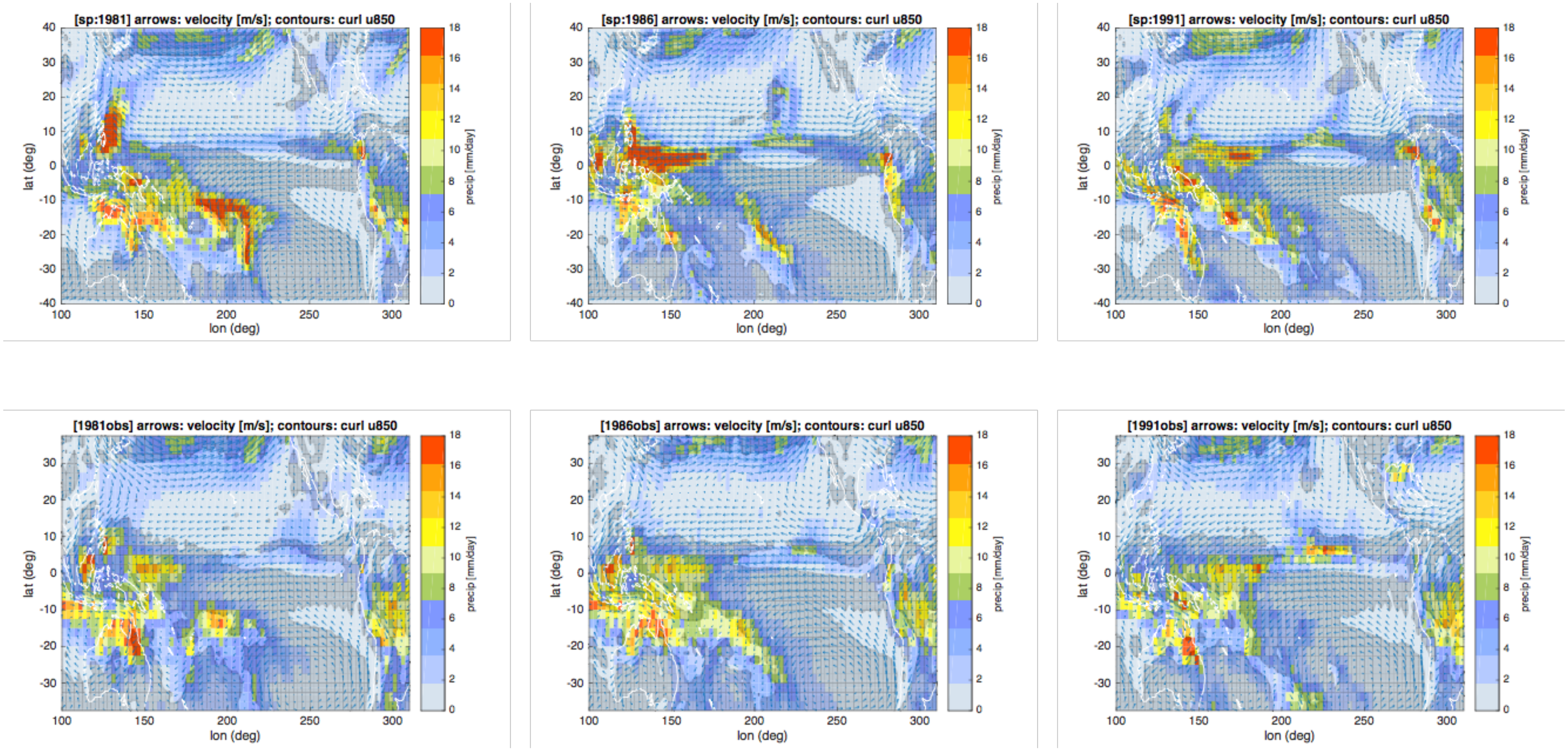
# 5-year CESM runs initialized 1/1/1981

- Large 1982/1983 El Nino well-forecast by CTRL but not NoDC, but both end up with a cold tongue bias by 1984.




…SP 5-yr run to come

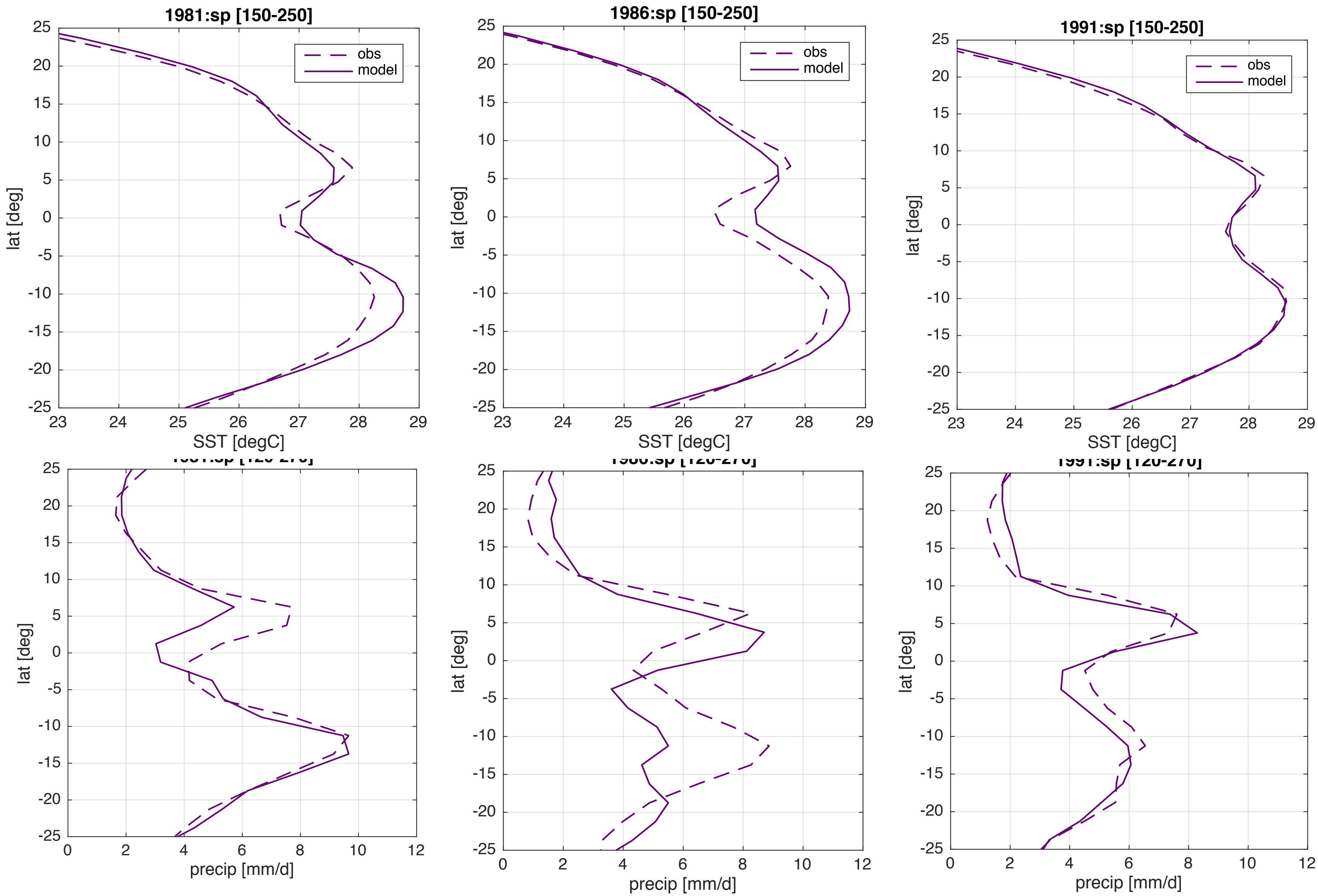
# Month 1 prec variability in SP and sat obs (1/81,86,91)




Mix of SST variability and low-frequency atmospheric variability (e. g. MJO)
Lots of differences in details between SP and obs.

# Mon-1 SP SST (but not prec) bias ‘similar’ at other init times

(results still in process for conventional CESM)



# Conclusions

- Realistically initialized CESM simulations allow tropical SST and precipitation bias assessment vs. obs. in a configuration directly applicable to seasonal forecasting as well as climate simulation.
- A locally-forced cold tongue/2xITCZ bias forms rapidly in CESM simulations with two cumulus parameterizations and with SP.
- Midlatitude radiation biases may shift ITCZ, but only after years.
- We think it is driven by excessive rainfall over warm SSTs, driving strong equatorial easterly winds and currents that advect cold water westward along the equator.
- The bias worsens if the ZM deep Cu scheme is turned off.
- With SP, the bias is sensitive to CRM configuration and GCM version. The N-S 32-column default CRM does best of the tested cases. SP-CCSM3 outperforms SP-CCSM4.