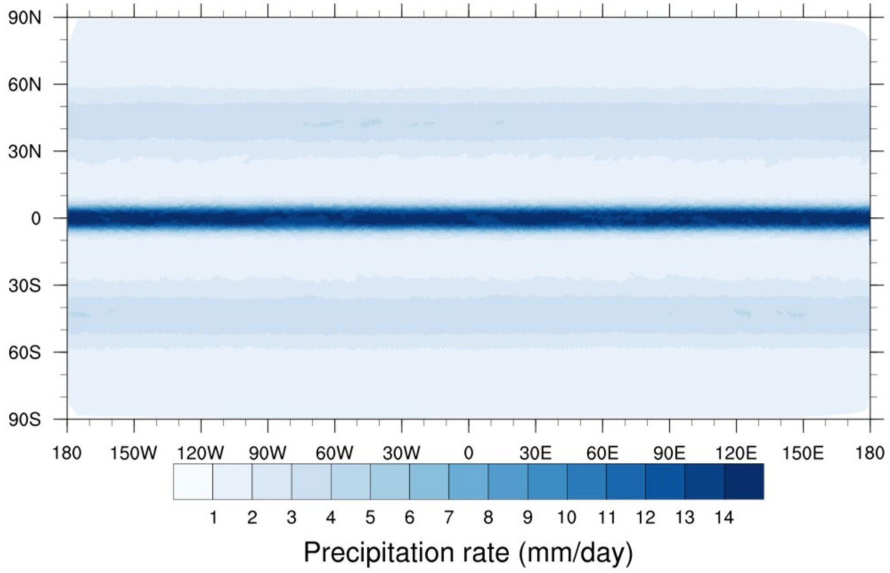

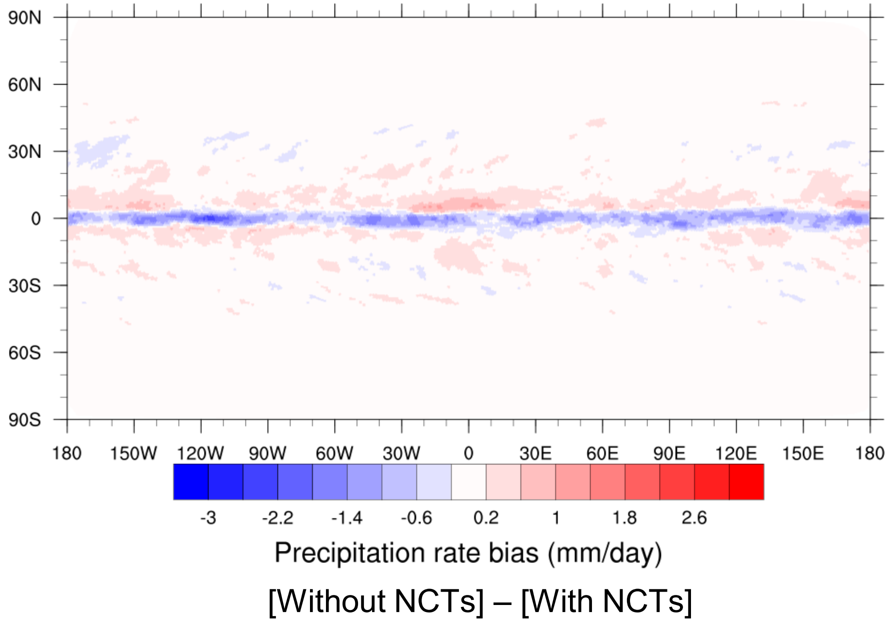

The ITCZ and the nontraditional Coriolis terms

Hing Ong

Unaffiliated

Thanks to NCAR CGD for the travel support

Collaborators:

Adam Herrington

National Center for Atmospheric Research

Da Yang

University of Chicago

The double-ITCZ (intertropical convergence zone) bias

has been a problem in generations of Earth system models and has been studied for decades

The Seasonal Cycle over the Tropical Pacific in Coupled Ocean–Atmosphere General Circulation Models

C. R. MECHOSO,* A. W. ROBERTSON,* N. BARTH,† M. K. DAVEY,# P. DELECLUSE,@ P. R. GENT,& S. INESON,#
B. KIRTMAN,** M. LATIF,†† H. LE TREUT,## T. NAGAI,@@ J. D. NEELIN,* S. G. H. PHILANDER,&&
J. POLCHER,## P. S. SCHOPF,*** T. STOCKDALE,††† M. J. SUAREZ,***
L. TERRAY,### O. THUAL,### AND J. J. TRIBBIA&

*Department of Atmospheric Sciences, University of California, Los Angeles, Los Angeles, California
†Scripps Institution of Oceanography, La Jolla, California
#Hadley Centre for Climate Prediction and Research, Meteorological Office, Bracknell, United Kingdom
@LODYC, Universite de Pierre et Marie Curie, Paris, France
&National Center for Atmospheric Research, Boulder, Colorado
**Center for Ocean–Land–Atmosphere Studies, Calverton, Maryland
††Max Planck Institut für Meteorologie, Hamburg, Germany
##Laboratoire de Meteorologie Dynamique du CNRS, Paris, France
@@Tokyo Institute of Technology, Ookayama, Meguro, Tokyo, Japan
&&Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey
***NASA/Goddard Space Flight Center, Greenbelt, Maryland
†††European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom
###CERFACS, Toulouse, France

(Manuscript received 26 September 1994, in final form 26 January 1995)

ABSTRACT

The seasonal cycle over the tropical Pacific simulated by 11 coupled ocean–atmosphere general circulation models (GCMs) is examined. Each model consists of a high-resolution ocean GCM of either the tropical Pacific or near-global oceans coupled to a moderate- or high-resolution atmospheric GCM, without the use of flux correction. The seasonal behavior of sea surface temperature (SST) and eastern Pacific rainfall is presented for each model.

The results show that current state-of-the-art coupled GCMs share important successes and troublesome systematic errors. All 11 models are able to simulate the mean zonal gradient in SST at the equator over the central Pacific. The simulated equatorial cold tongue generally tends to be too strong, too narrow, and extend too far west. SSTs are generally too warm in a broad region west of Peru and in a band near 10°S. This is accompanied in some models by a double intertropical convergence zone (ITCZ) straddling the equator over the eastern Pacific, and in others by an ITCZ that migrates across the equator with the seasons; neither behavior is realistic. There is considerable spread in the simulated seasonal cycles of equatorial SST in the eastern Pacific. Some

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Toward Improving the Simulation of Tropical Precipitation in E3SM

FUNDING PROGRAM AREA(S)	PROJECT TYPE	PROJECT TERM
ESMD	University Grant	2021-09 to 2025-08

PROJECT TEAM

Biases in tropical precipitation such as the double Intertropical Convergence Zone (ITCZ) are a long-standing problem in many global climate and Earth system models, including DOE's Exascale Energy Earth System Model (E3SM). The E3SM has large positive precipitation biases across the tropical Pacific south of the equator and an excessive equatorial cold tongue compared to observations. In this project, the team aims to improve the simulation of tropical precipitation and associated sea surface temperature (SST) in E3SM by addressing the following questions: (1) How and to what extent does convective parameterization contribute to tropical precipitation biases? (2) How do coupled atmosphere-ocean feedback processes affect the double ITCZ developed in E3SM? (3) How can tropical precipitation and SST simulations in E3SM be improved?

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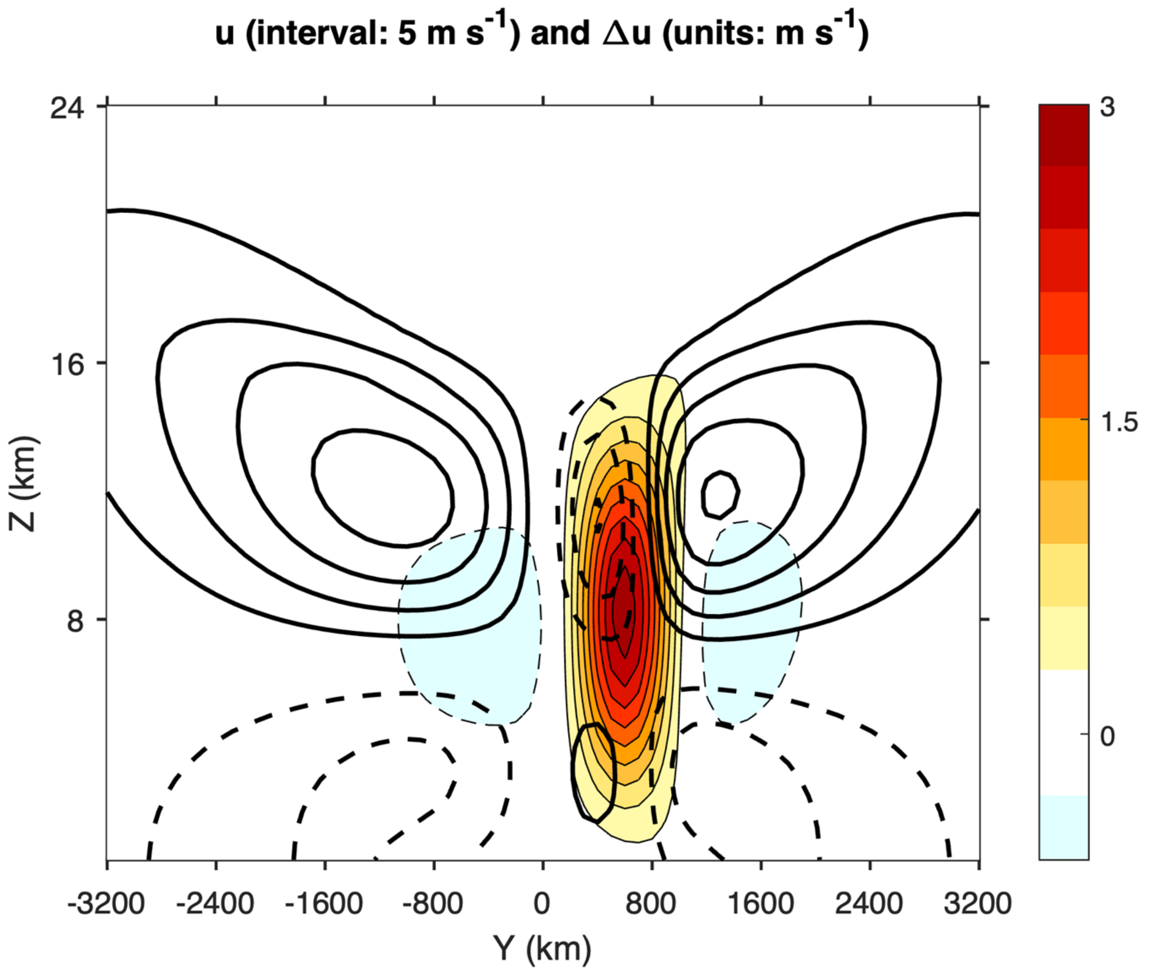
Most global atmospheric models* share a common approximation: the traditional shallow-atmosphere approximation, which neglects the NCTs.

NCTs arise from planetary rotation. NCTs turn eastward motion upward and upward motion westward, and vice versa.

*A notable exception lies in UK Met Office. The dynamical core of HadGEM relaxes this approximation.

Omitting NCTs yields a westerly wind bias in an ITCZ-like heating region

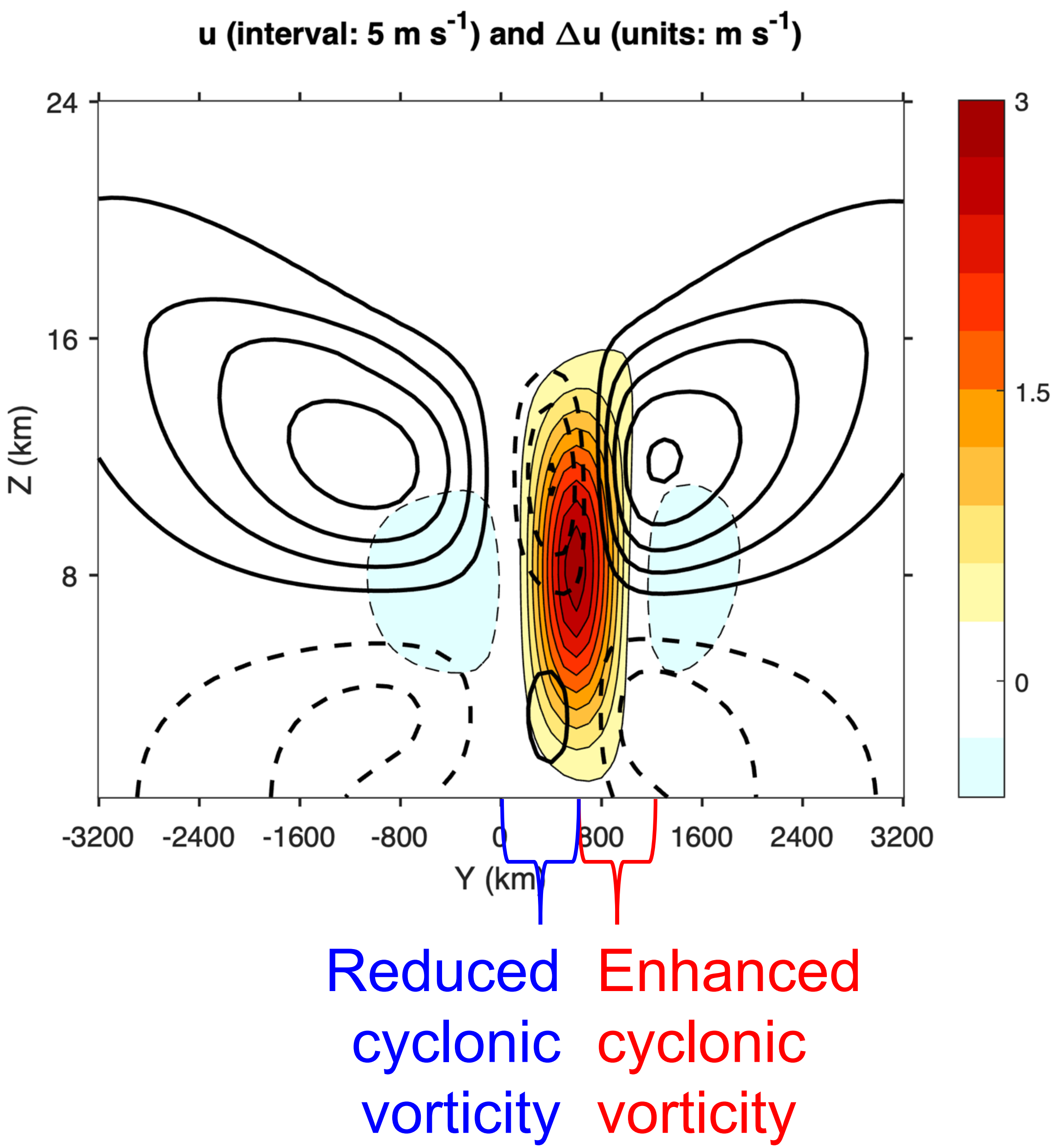


- Contour: u (w/ NCTs)
- Shading: Δu (w/o minus w/)
- Flow response to the following prescribed heat source:
  - ITCZ width = 1000 km
  - ITCZ location = 600 km

$$\frac{max.\, westerly\ bias}{max.\, westerly\ wind} = 12\%$$

Ong & Roundy (2019)

Hypothesis



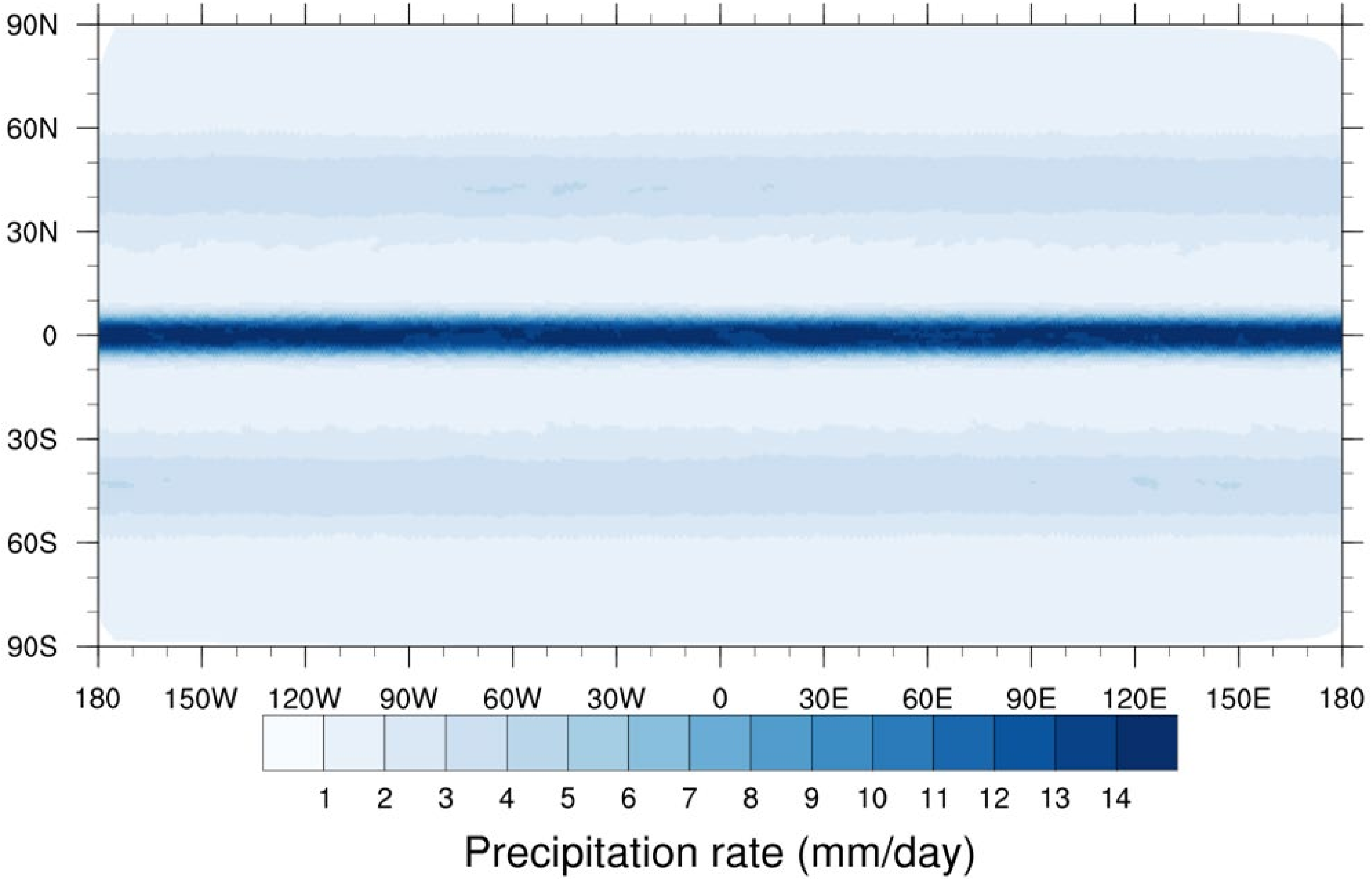
- On the poleward side of ITCZ:
  - Neglecting NCTs
  - ➡️ enhances cyclonic vorticity
  - ➡️ enhances Ekman pumping
  - ➡️ enhances precipitation
- On the equatorward side of ITCZ, the opposite is true.

We hypothesize neglecting NCTs

- reduces equatorial precipitation,
- enhances off-equatorial precipitation, and thus
- promotes a double-ITCZ pattern

Methods: Aquaplanet experiment

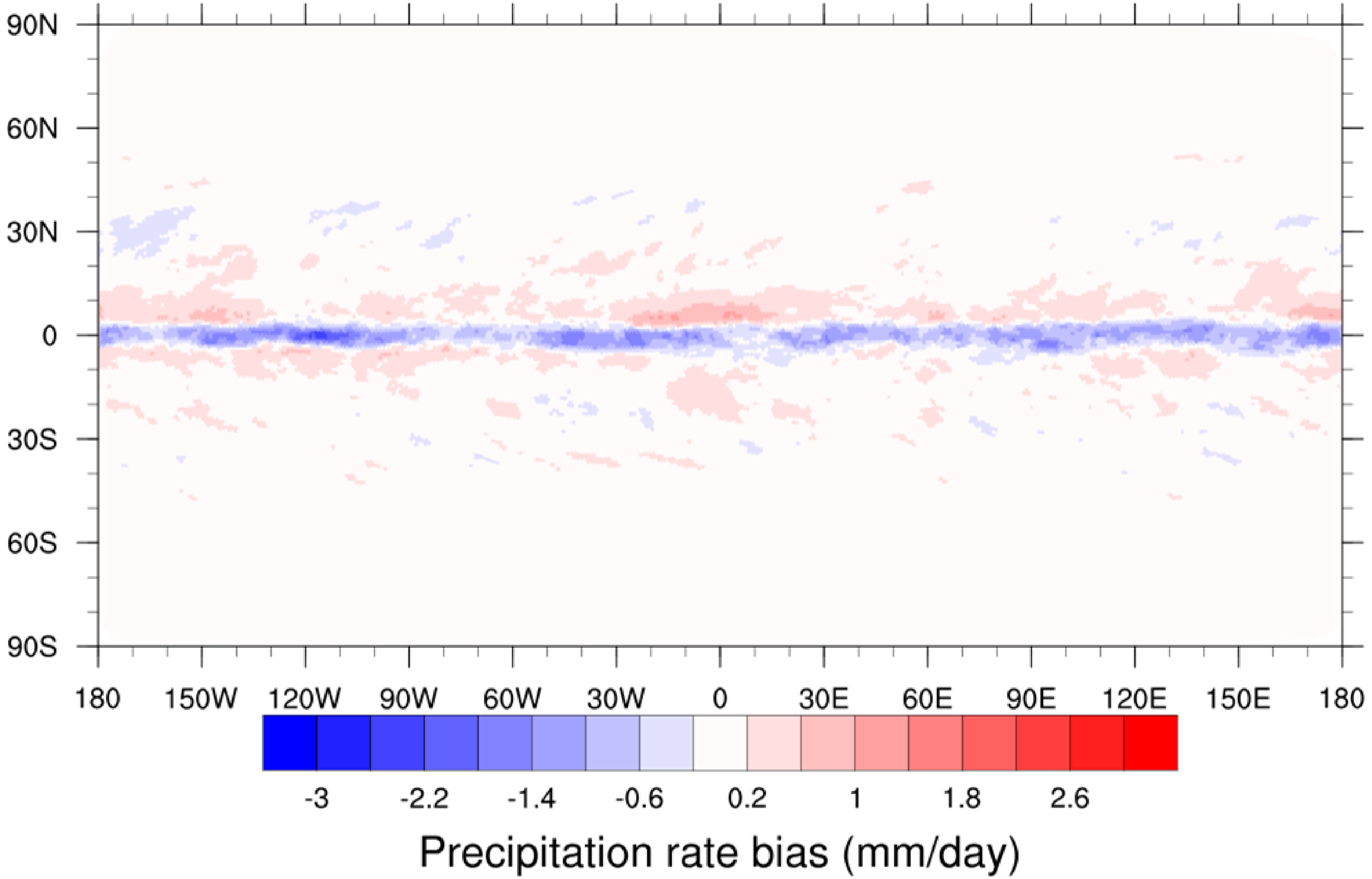
- Model used:
  - CAM (Community Atmosphere Model) development version (cam6_4_044) with the
  - deep-atmosphere MPAS (Model for Prediction Across Scales) dynamical core (Skamarock, Ong, & Klemp, 2021) with 120-km mesh.
- ‘QPC6’ Configuration:
  - Aquaplanet with fixed sea-surface temperature
  - Perpetual equinox forcing
- Simulation setup:
  - Spin up for one year from motionless US standard atmosphere state with the deep-atmosphere option, and then
  - Branch into two 16-year simulations:
    - continue to solve the deep-atmosphere equations (with NCTs)
    - switch to solve the shallow-atmosphere equations (without NCTs)



Results

Precipitation climatology

With NCTs



[Without NCTs] – [With NCTs]

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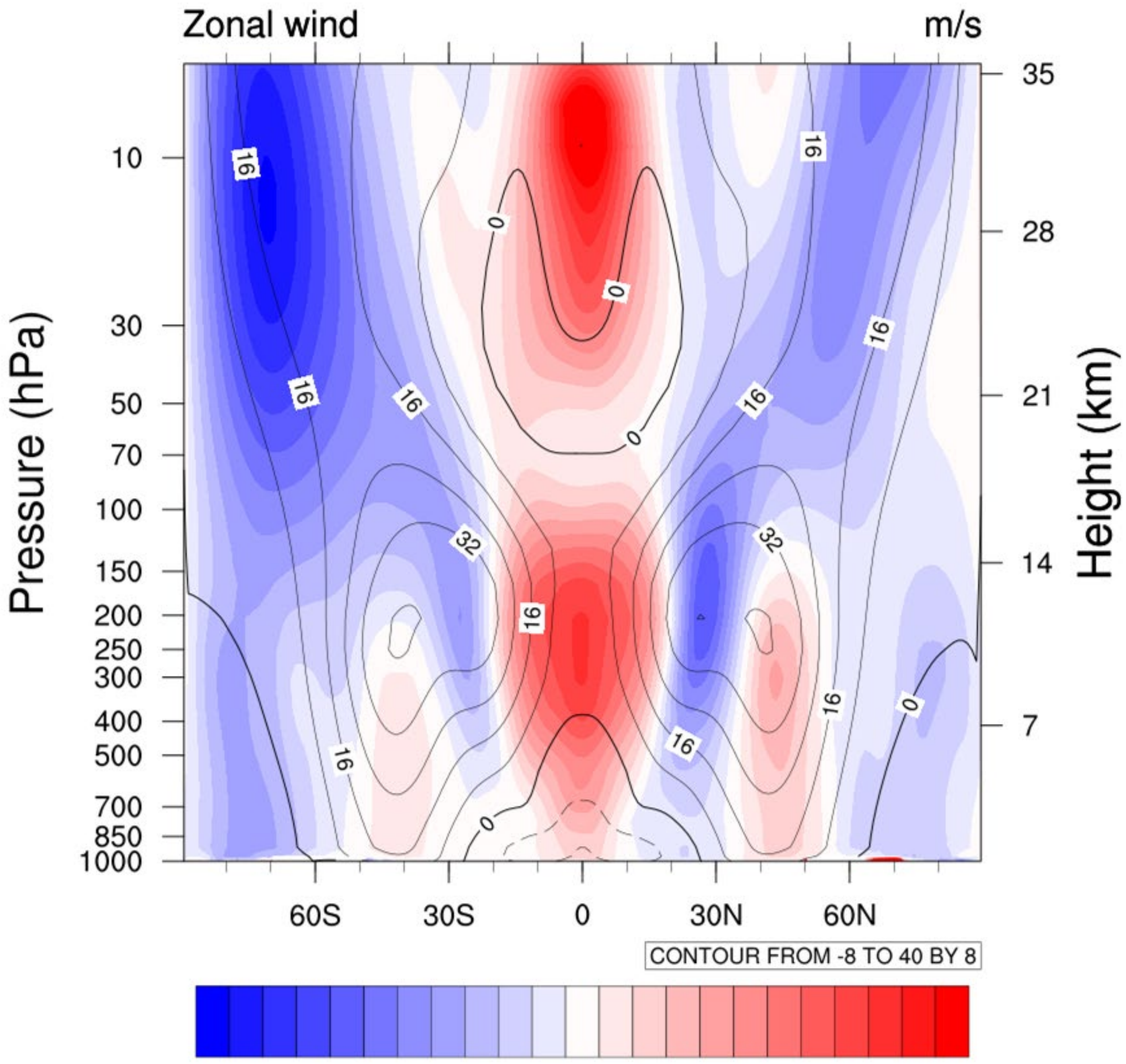
Bias of precipitation climatology due to the traditional approximation

Note:

- Reduced equatorial precipitation
- Enhanced off-equatorial precipitation



[Without NCTs] – [With NCTs]

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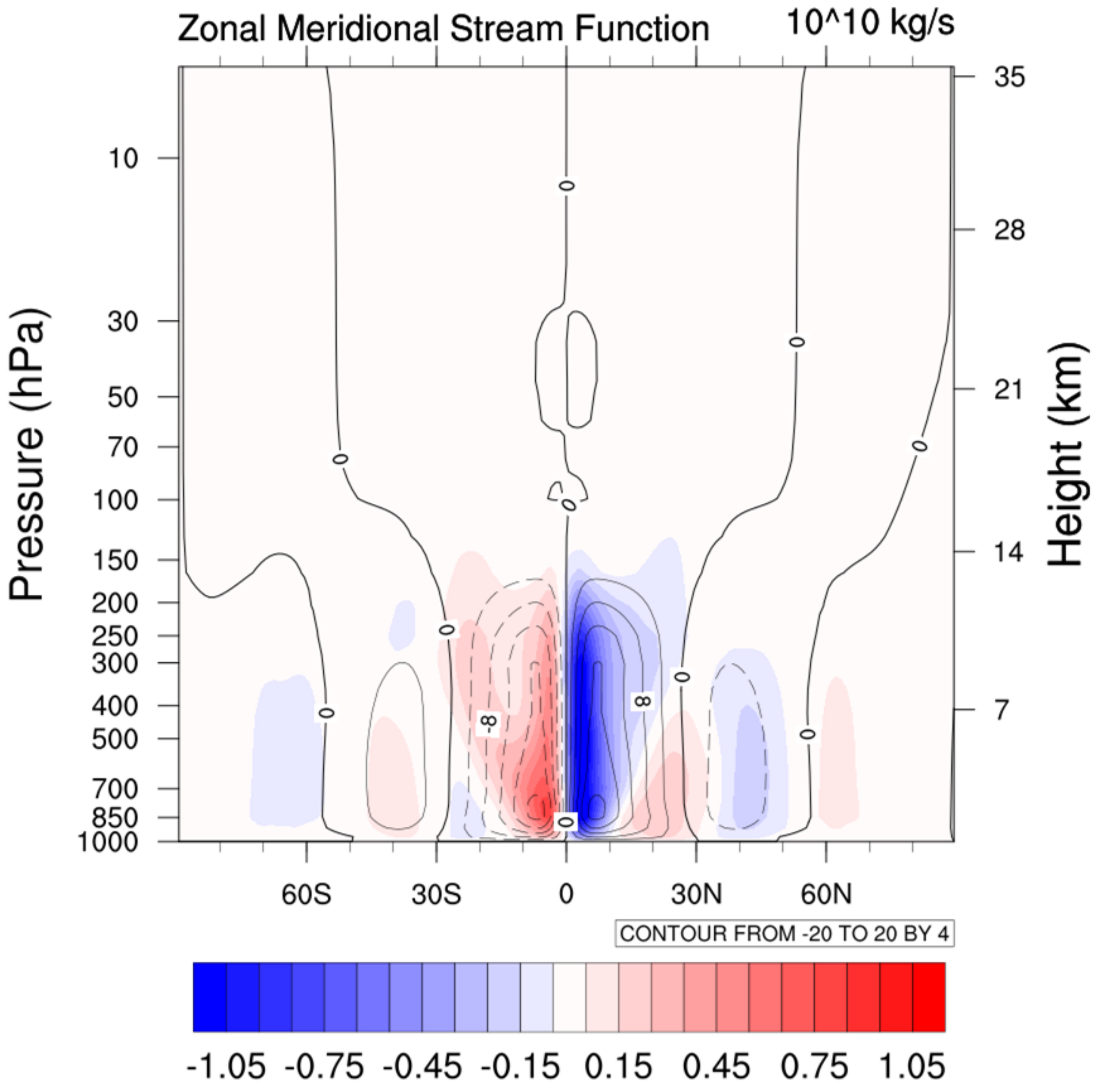
Zonal mean zonal wind climatology (contoured)

Its bias due to the traditional approximation (shaded)

Note:

- Enhanced cyclonic wind shear in 5° to 20° latitudes



[Without NCTs] – [With NCTs]

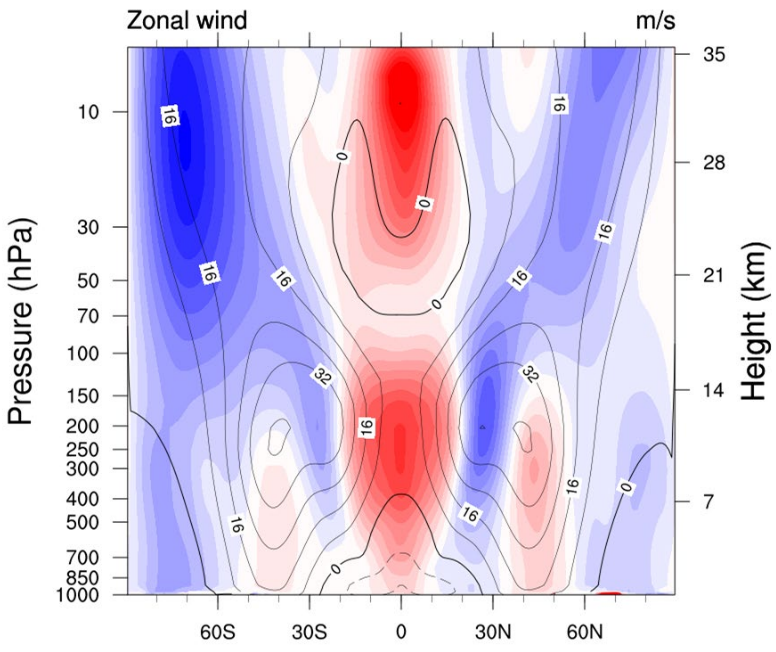
Results

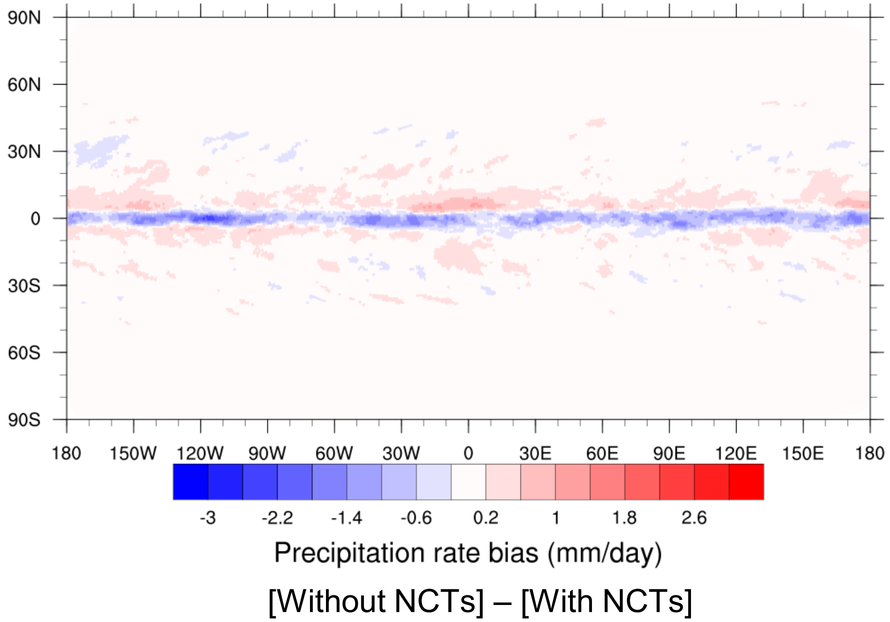
Zonal mean streamfunction climatology (contoured)

Its bias due to the traditional approximation (shaded)

Note:

- Enhanced cyclonic wind shear in 5° to 20° latitudes





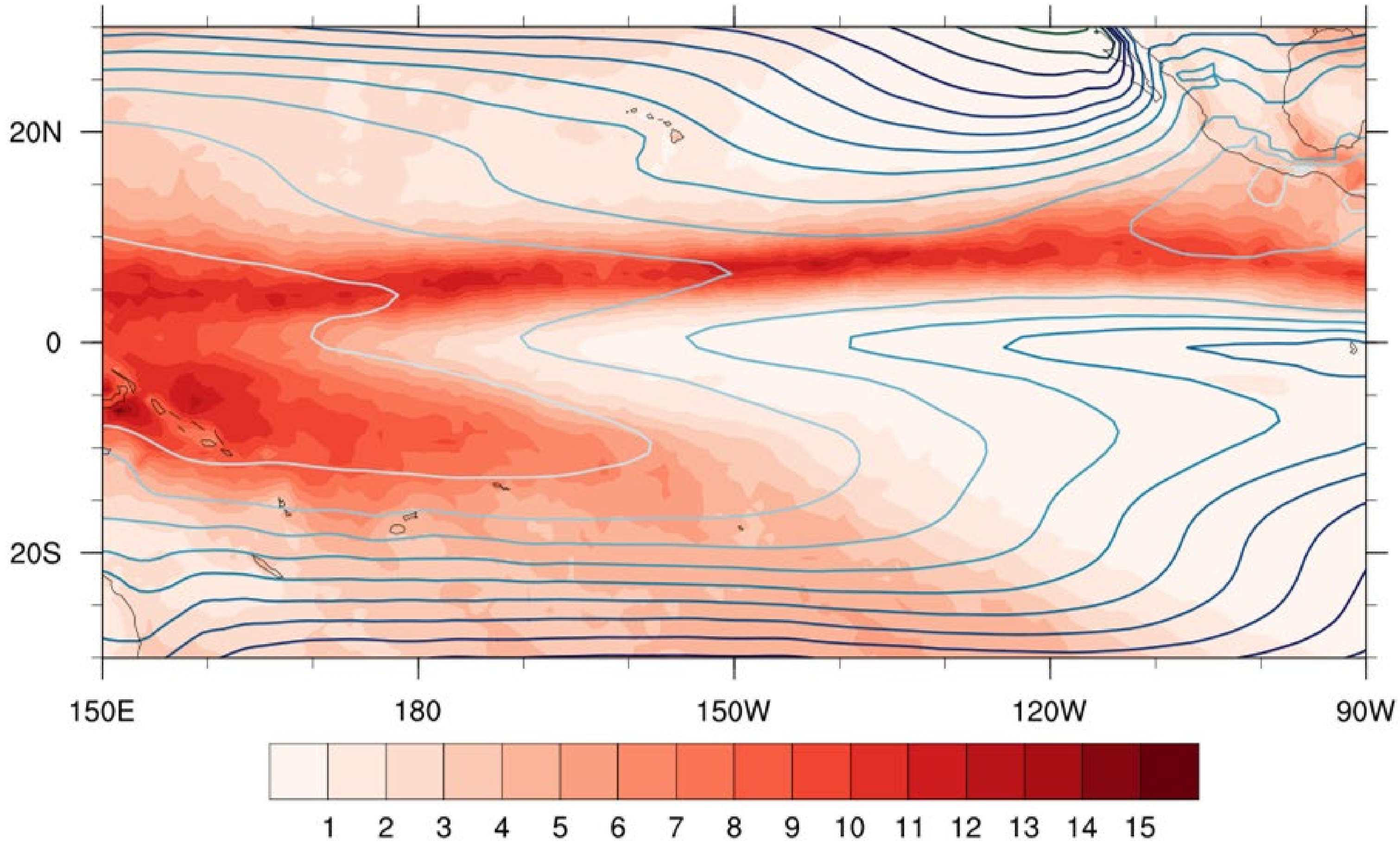
Aquaplanet Conclusion

- Neglecting NCTs promotes a double-ITCZ pattern through the following pathway:
  - On the poleward side of ITCZ:
    - Neglecting NCTs
      - ➡️ enhances cyclonic vorticity
      - ➡️ enhances Ekman pumping
      - ➡️ enhances precipitation
  - The opposite is true on the equatorward side of ITCZ

Methods: AMIP experiment

- Model used:
  - CAM (Community Atmosphere Model) development version (cam6_4_044) with the
  - deep-atmosphere MPAS (Model for Prediction Across Scales) dynamical core (Skamarock, Ong, & Klemp, 2021) with 120-km mesh.
- 'F2000climo' Configuration:
  - Climatological seasonal sea-surface temperature (1995-2005)
  - Climatological seasonal forcing around (1995-2005)
  - 32-year simulations with and without NCTs
- Evaluated against:
  - Precipitation: GPM IMERG V07 June 2000 to May 2005
  - Radiation: CERES EBAF Ed4.2 March 2000 to February 2005
  - Winds: ERA5 (to be done)

$$\text{Pacific equatorial precipitation index } (\textbf{PEPI}) \equiv \frac{\overline{\text{Precipitation}}_{[15°S,15°N]} - \overline{\text{Precipitation}}_{[5°S,5°N]}}{\overline{\text{Precipitation}}_{[15°S,15°N]}} \text{ in } [150°E, 90°W]$$



Results

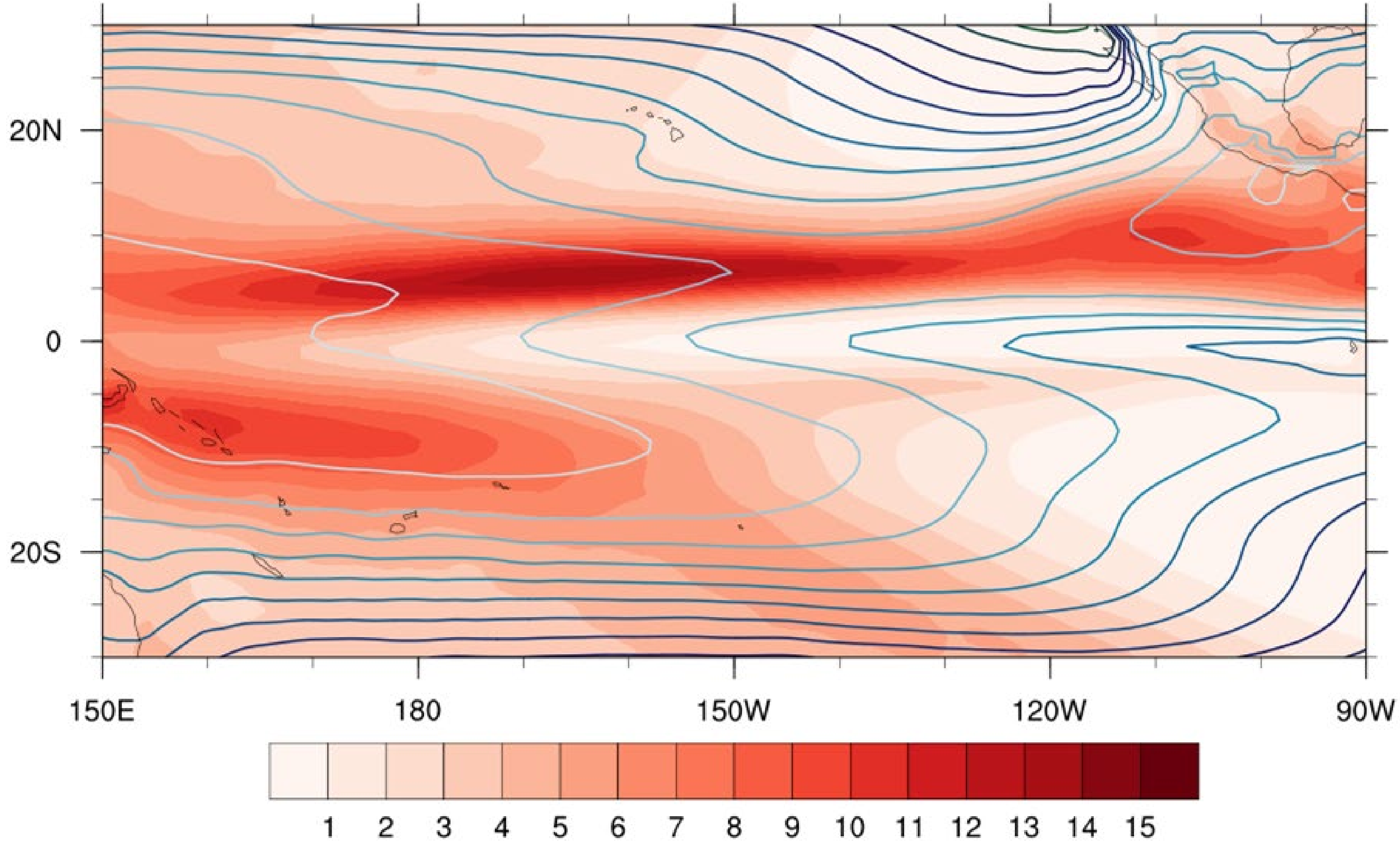
Precipitation climatology

Observation

PEPI = 0.24

Sea-surface temperature (contoured) and precipitation (mm/day, shaded)

Pacific equatorial precipitation index (**PEPI**) $\equiv \dfrac{\overline{\text{Precipitation}}_{[15°S,15°N]} - \overline{\text{Precipitation}}_{[5°S,5°N]}}{\overline{\text{Precipitation}}_{[15°S,15°N]}}$ in [150°E, 90°W]



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Precipitation climatology

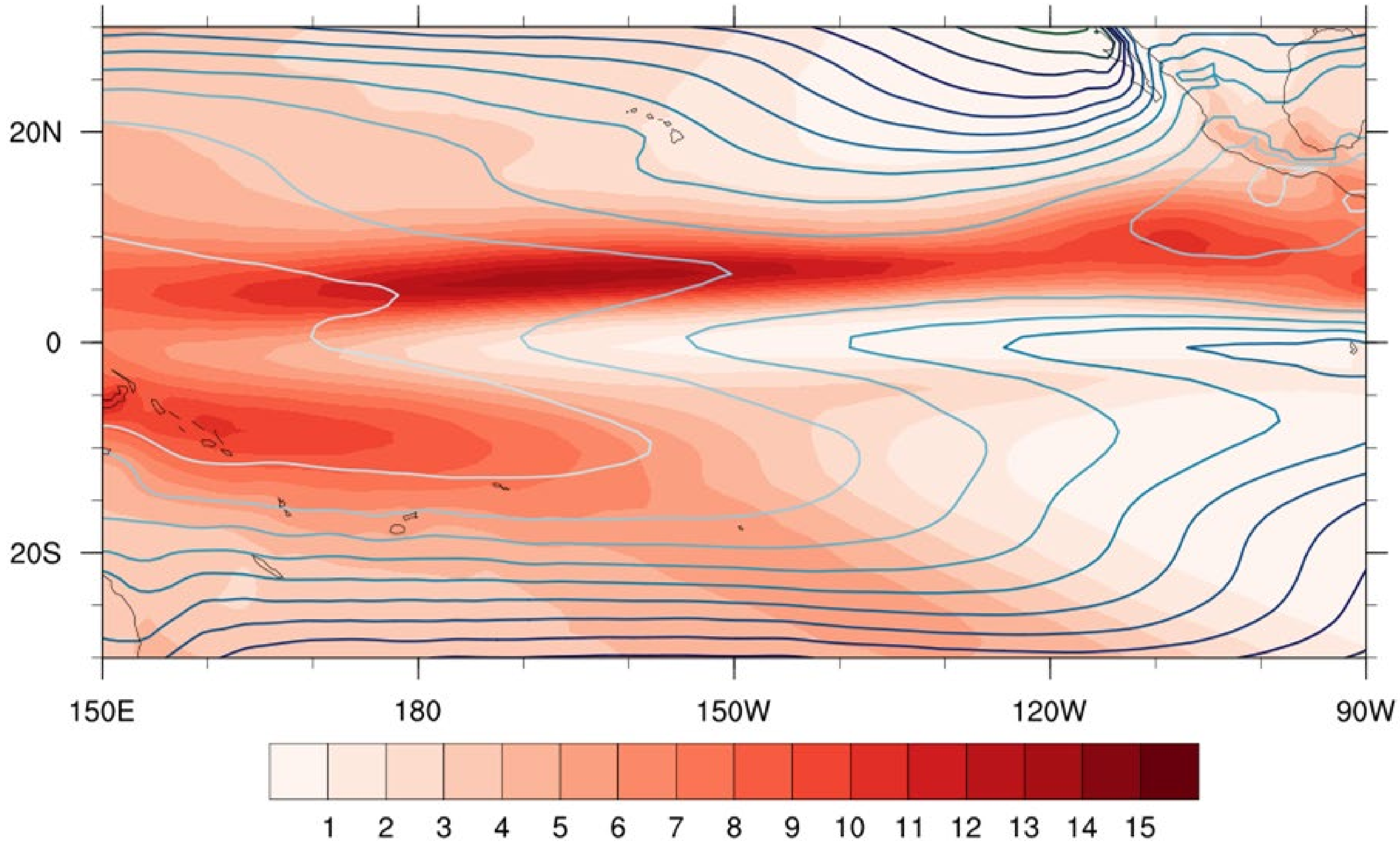
Simulation without NCTs

PEPI = 0.29

PEPI is higher than observed, meaning that precipitation is more distributed to the off-equatorial tropics.

Sea-surface temperature (contoured) and precipitation (mm/day, shaded)

$$\text{Pacific equatorial precipitation index } (\textbf{PEPI}) \equiv \frac{\overline{\text{Precipitation}}_{[15°S,15°N]} - \overline{\text{Precipitation}}_{[5°S,5°N]}}{\overline{\text{Precipitation}}_{[15°S,15°N]}} \text{ in } [150°E, 90°W]$$



Sea-surface temperature (contoured) and precipitation (mm/day, shaded)

Results

Precipitation climatology

Simulation with NCTs

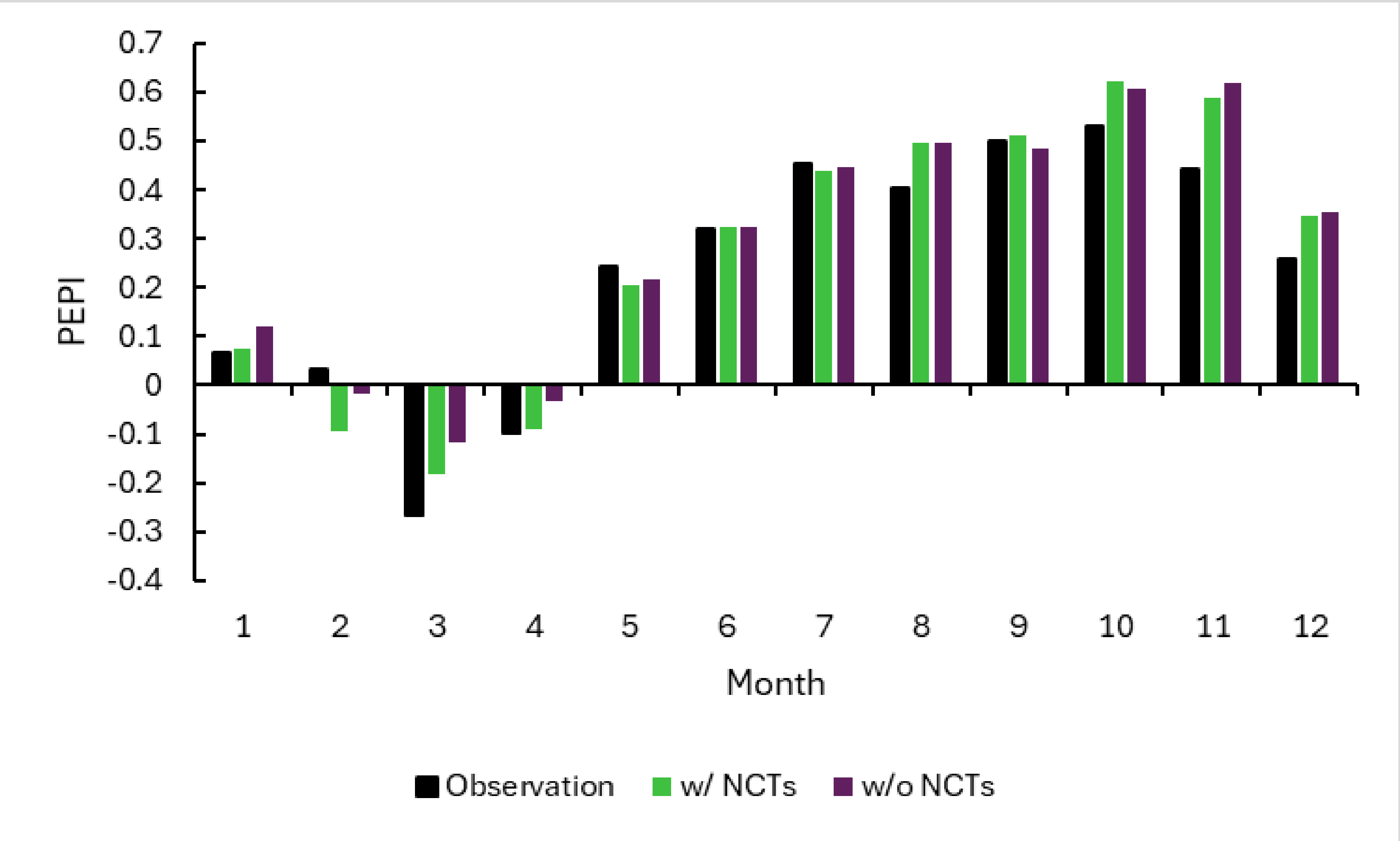
PEPI (with NCTs) = 0.26

PEPI (without NCTs)= 0.29

PEPI (observed) = 0.24

The inclusion of NCTs leads to substantial improvement in PEPI.

$$\text{Pacific equatorial precipitation index } (\textbf{PEPI}) \equiv \frac{\overline{\text{Precipitation}}_{[15°S,15°N]} - \overline{\text{Precipitation}}_{[5°S,5°N]}}{\overline{\text{Precipitation}}_{[15°S,15°N]}} \text{ in } [150°E, 90°W]$$



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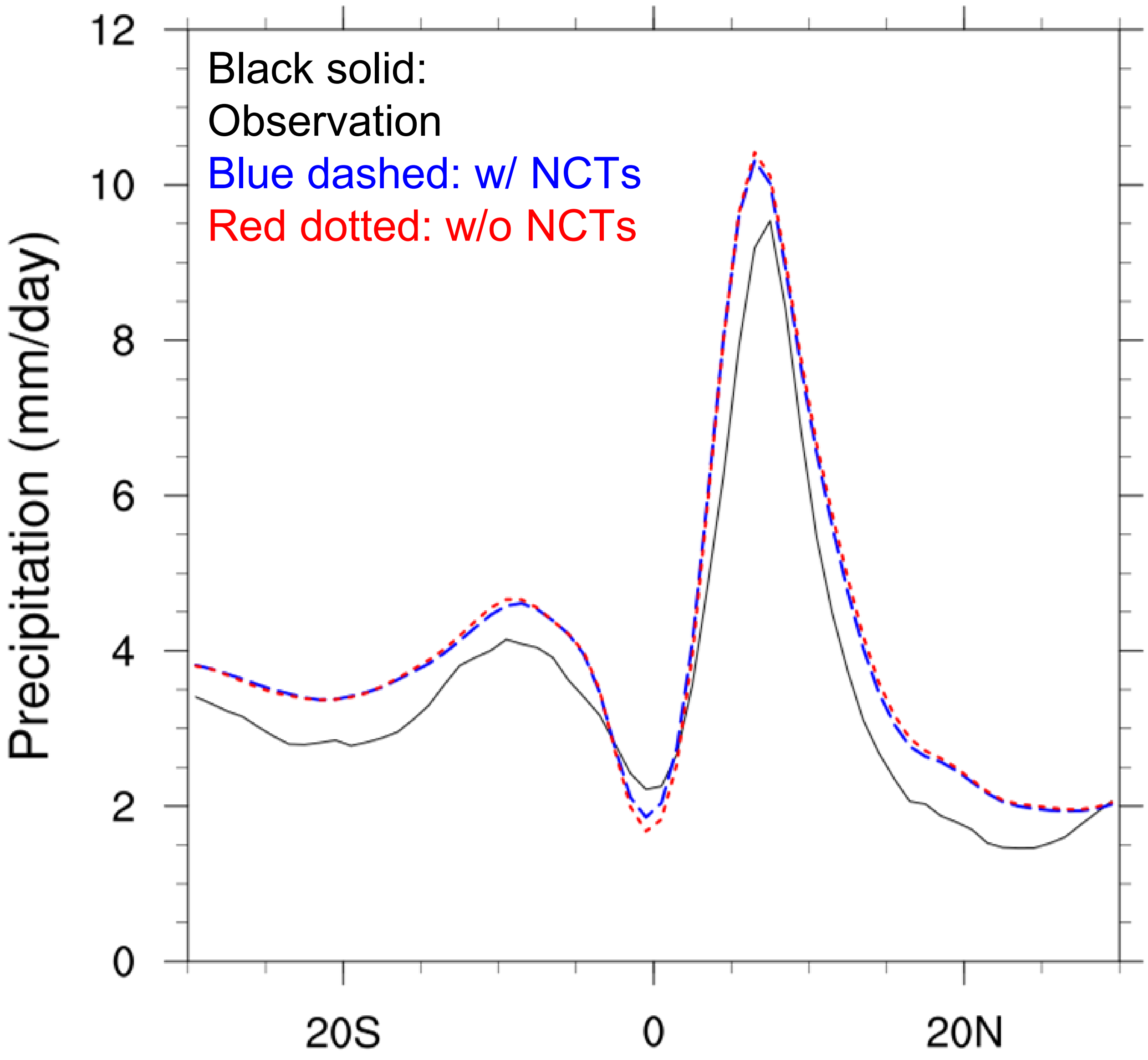
PEPI seasonality

The inclusion of NCTs improves monthly mean PEPI in many but not all months.



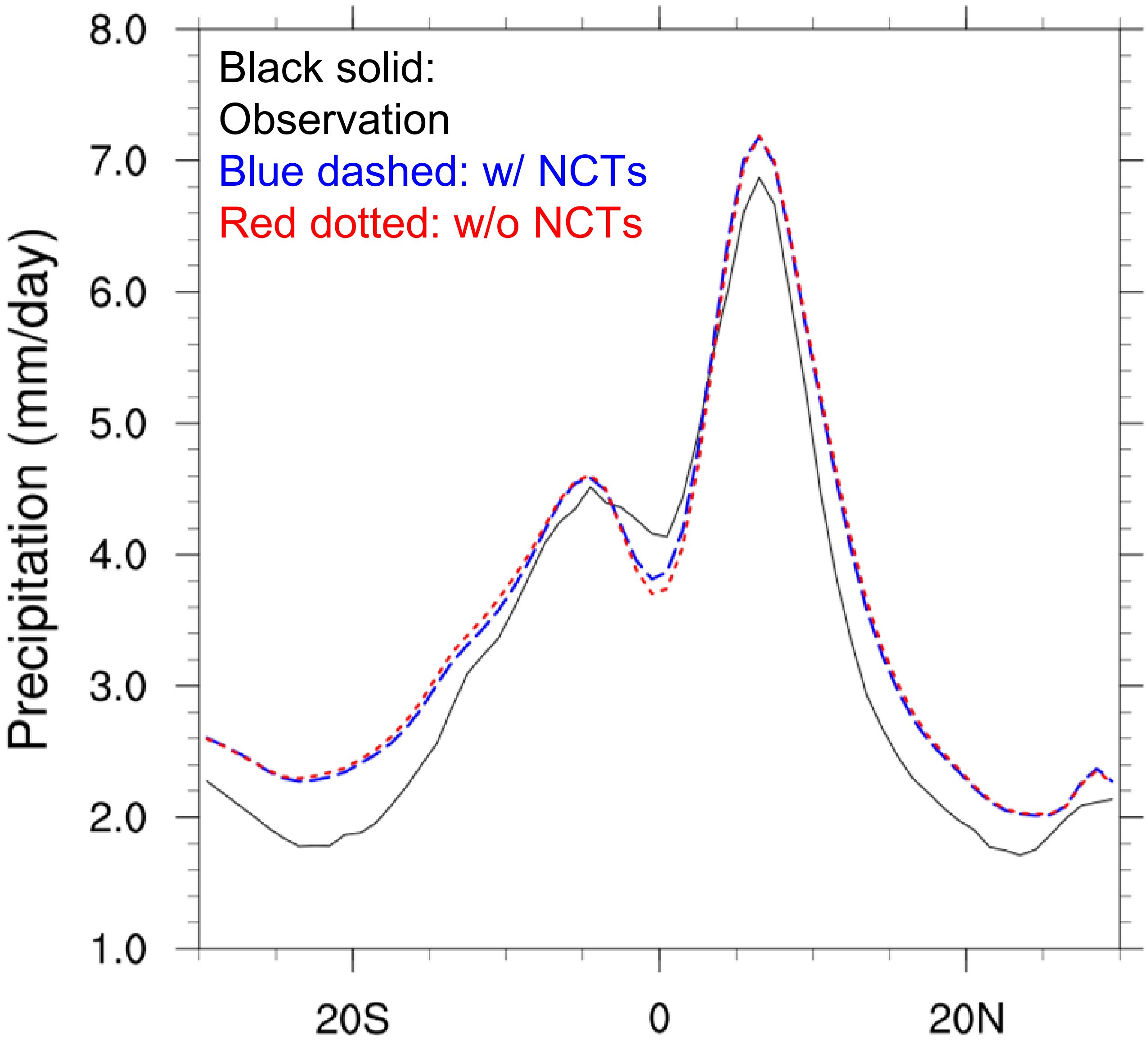
Results

Precipitation climatology

Zonal annual mean over the Pacific [150°E, 90°W]

Neglecting NCTs tends to distribute precipitation to the off-equatorial tropics

The inclusion of NCTs improves precipitation distribution.



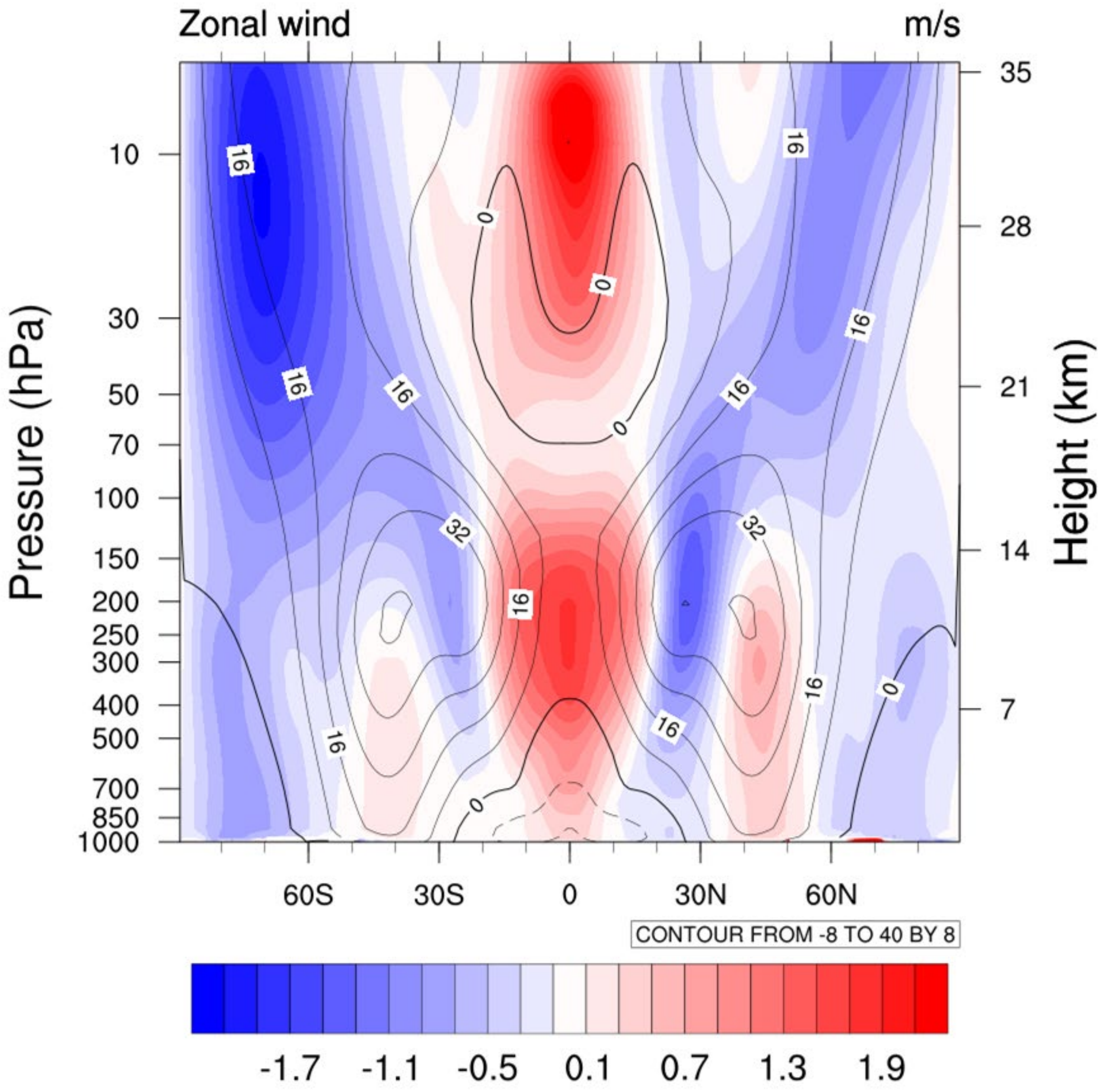
Results

Precipitation climatology

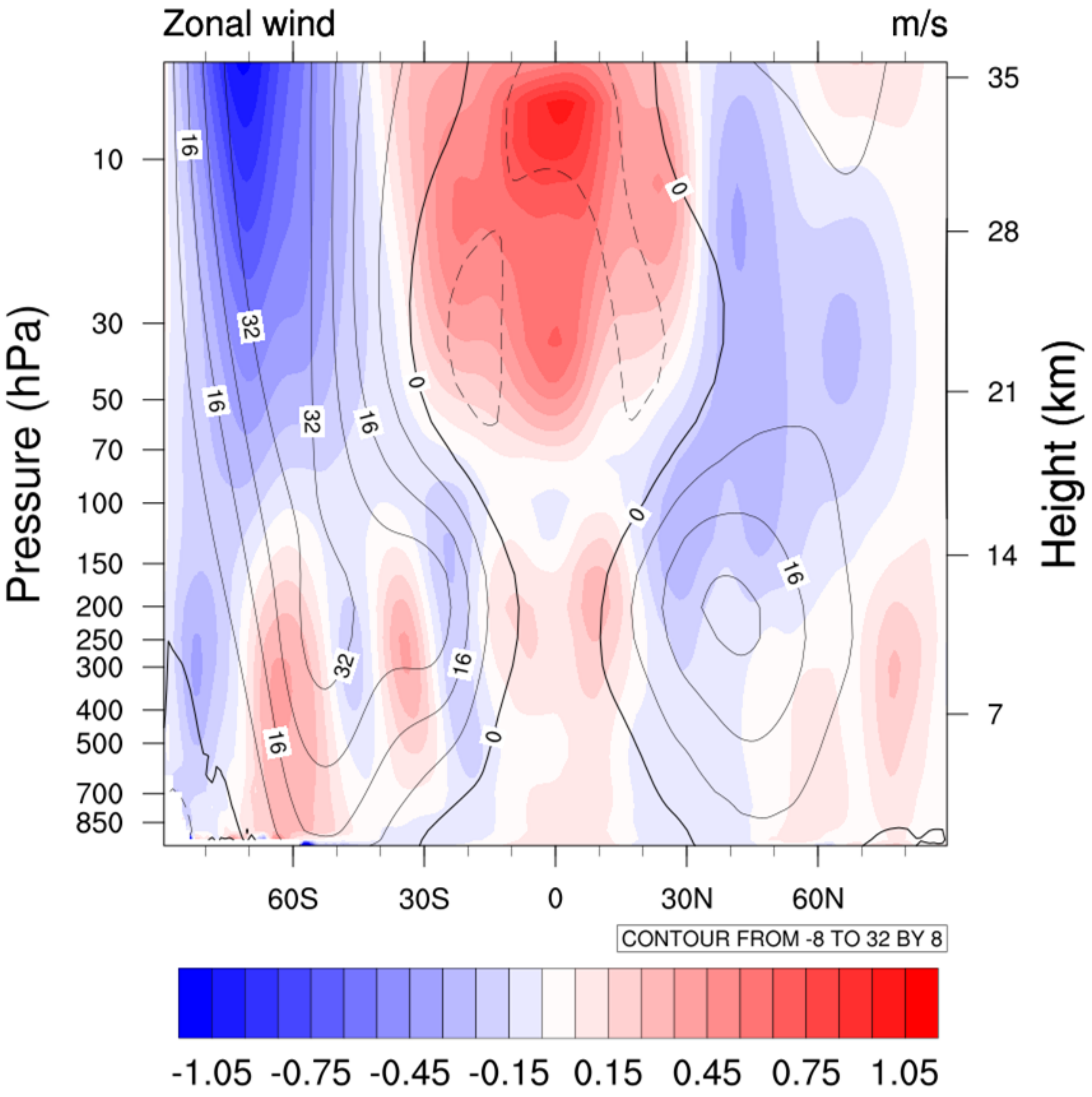
Zonal annual mean over the entire tropics

Southern Hemisphere shows similar improvement while Northern Hemisphere does not (maybe due to land).

Aquaplanet

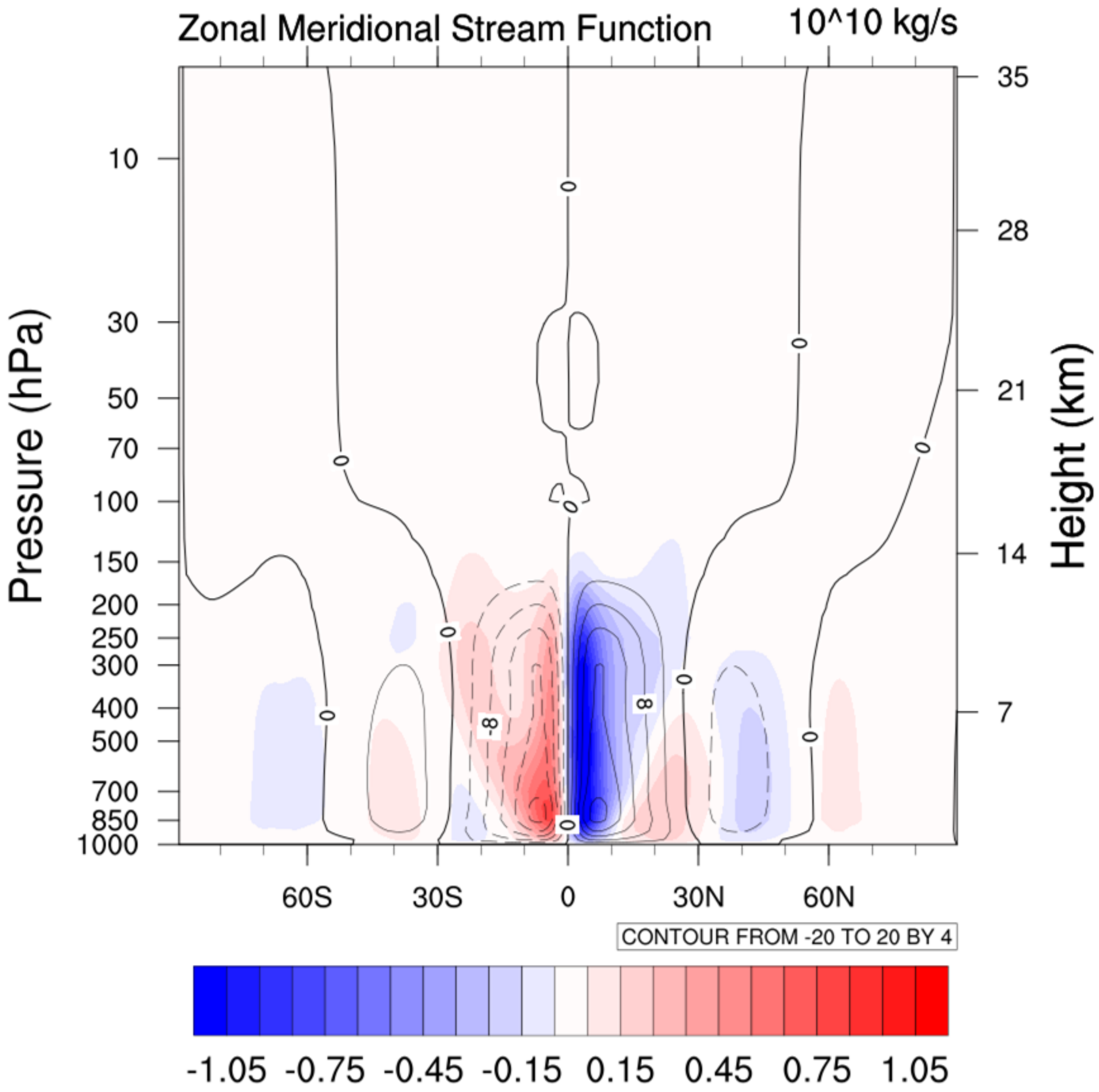


AMIP

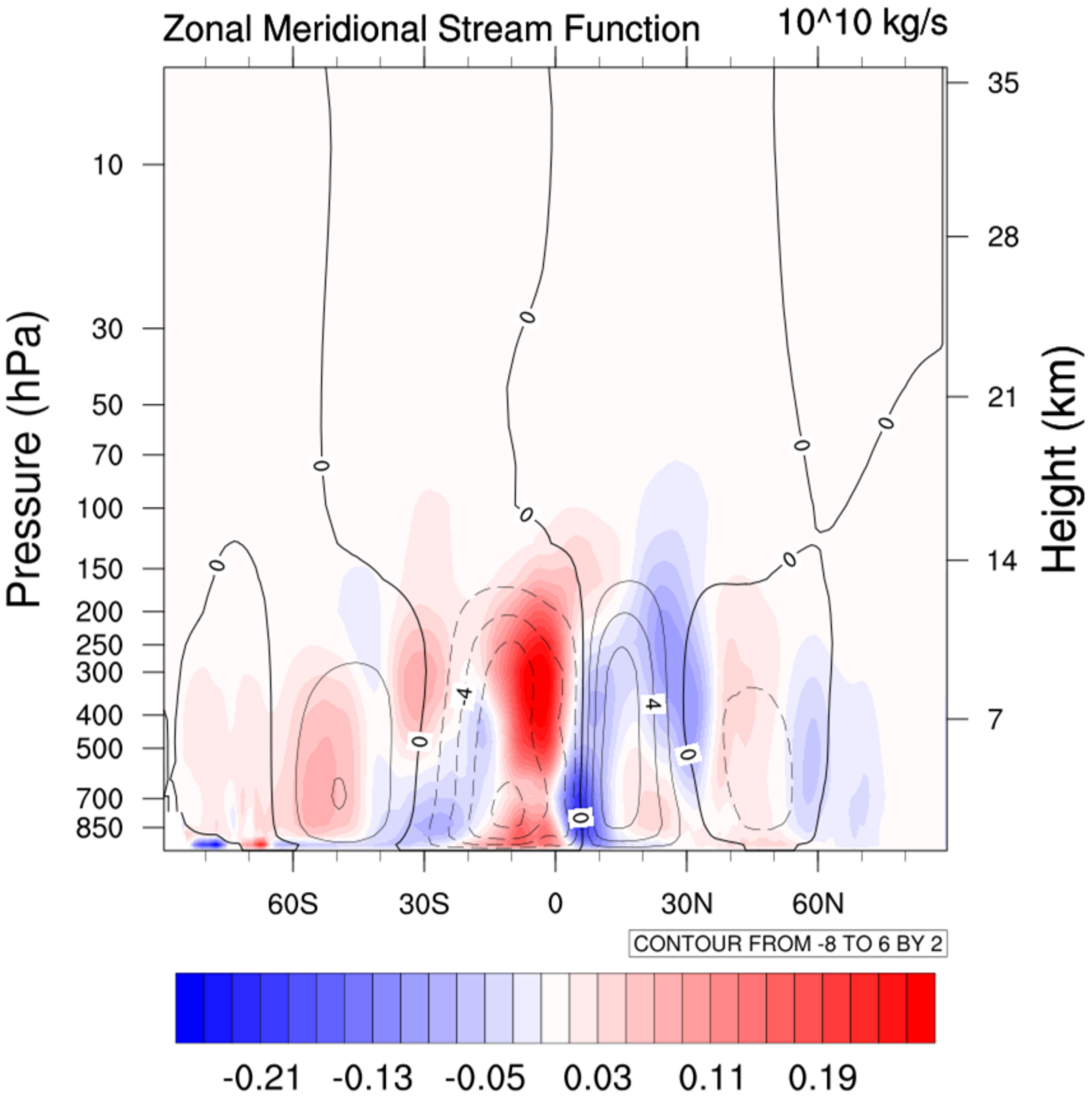


[Without NCTs] – [With NCTs]

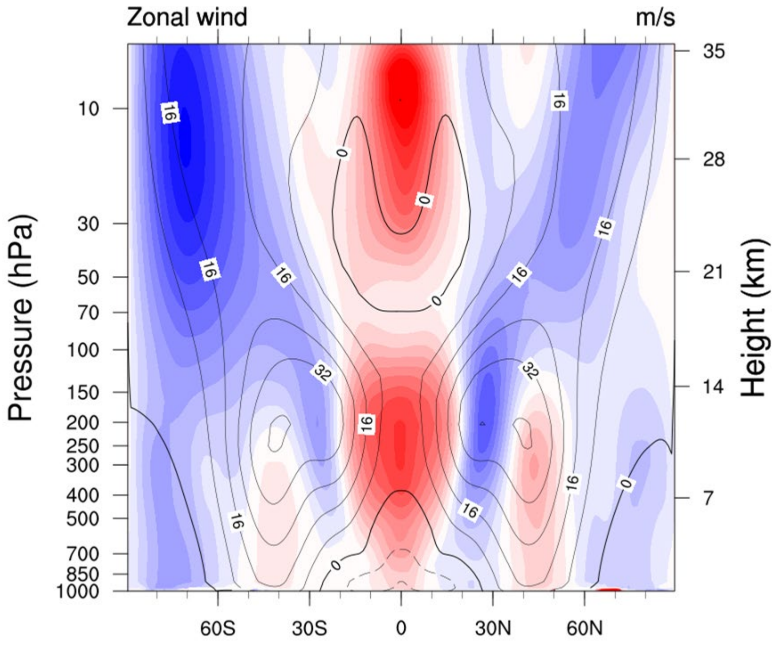
Aquaplanet

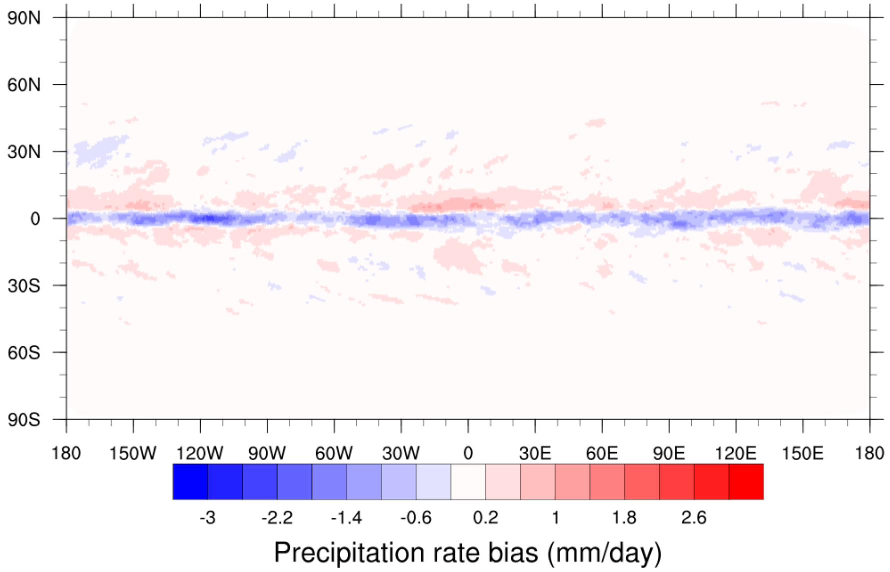


AMIP



[Without NCTs] – [With NCTs]





[Without NCTs] – [With NCTs]

Conclusion

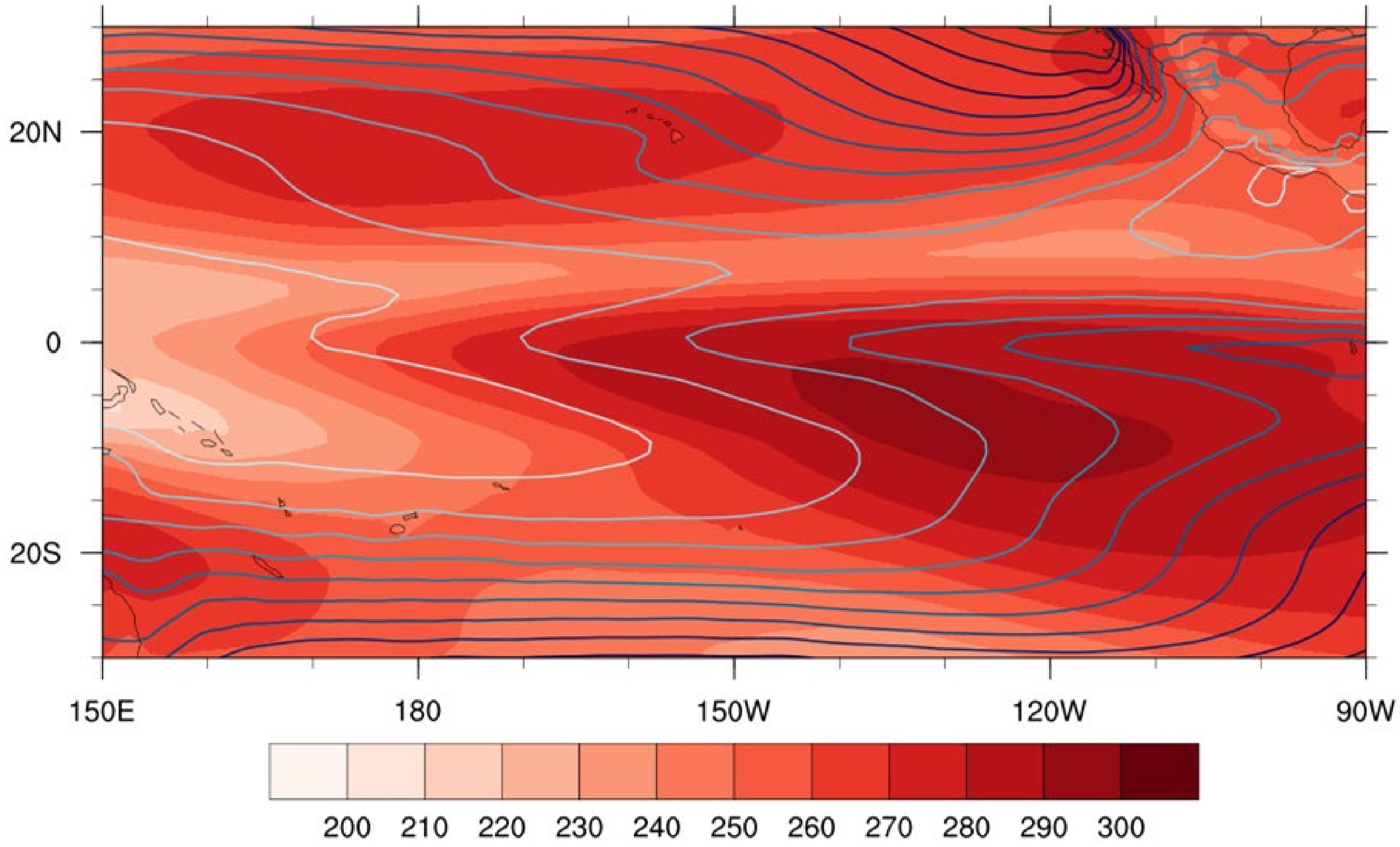
- Climate models have suffered from the double-ITCZ bias for decades.
- Climate models have neglected NCTs for decades with only few exceptions
- This study suggests that neglecting NCTs tends to distribute precipitation to the off-equatorial tropics in Aquaplanet and AMIP simulations through enhanced Ekman pumping on the poleward side of an ITCZ.

Supplementary

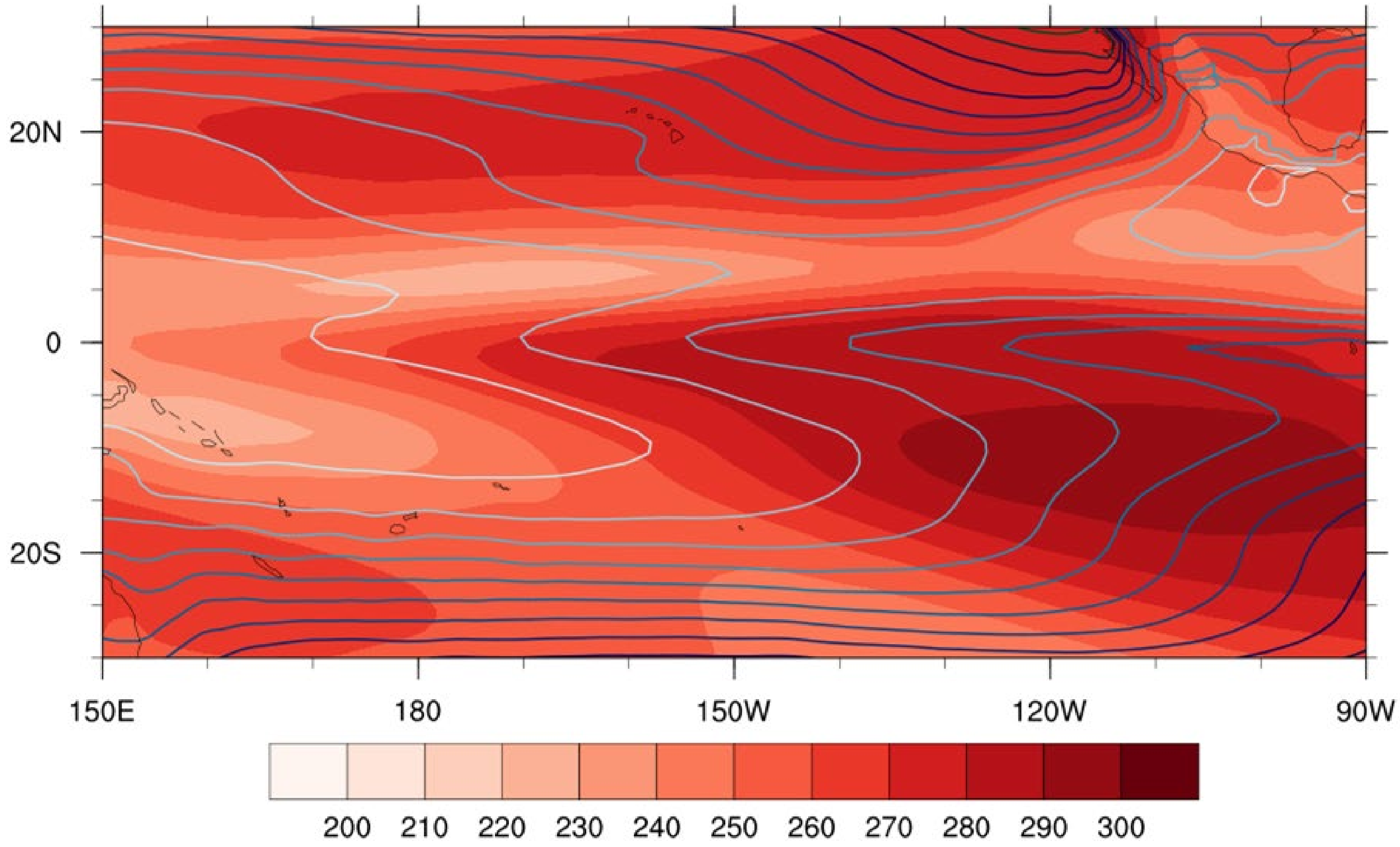
Results

OLR climatology

Observation



Sea-surface temperature (contoured) and outgoing longwave radiation (OLR, W/m^2, shaded)



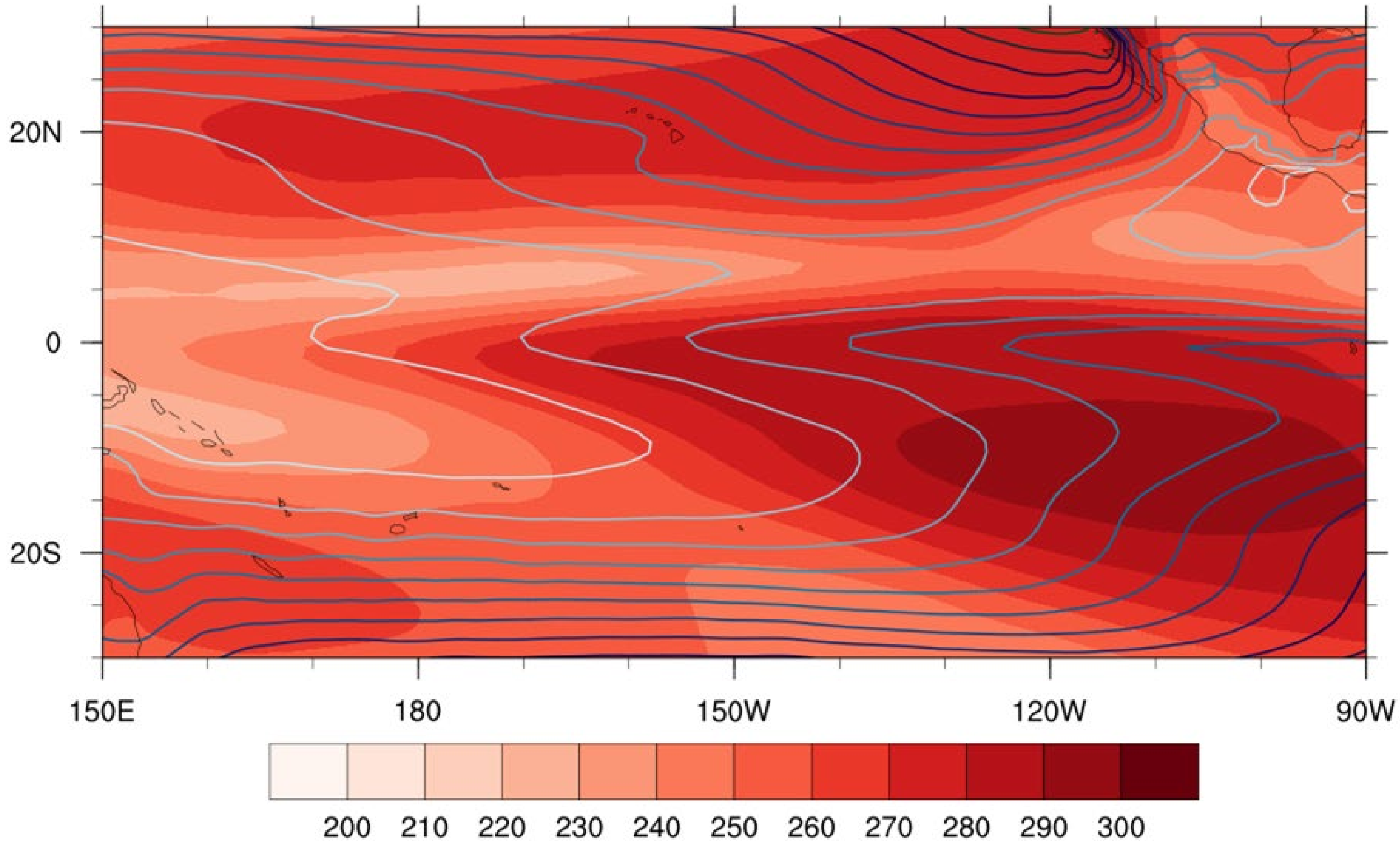
Results

OLR climatology

Simulation without NCTs

RMSE = 5.40 W/m^2

Sea-surface temperature (contoured) and outgoing longwave radiation (OLR, W/m^2, shaded)



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OLR climatology

Simulation with NCTs

RMSE = 5.25 W/m^2

The inclusion of NCTs marginally improves RMSE of OLR

Sea-surface temperature (contoured) and outgoing longwave radiation (OLR, W/m^2, shaded)