High resolution climate simulations with CESM: What does the high resolution buy us?

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National Center for Atmospheric Research, Boulder

CESM Tutorial, NCAR, Boulder, Aug 11-15 2014

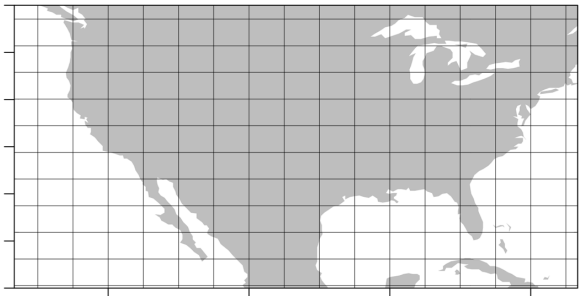
Motivation

Common wisdom

"The expectation is that increasing spatial resolution will generally cause the simulation to improve because of a more accurate topography, and a better large-scale circulation"

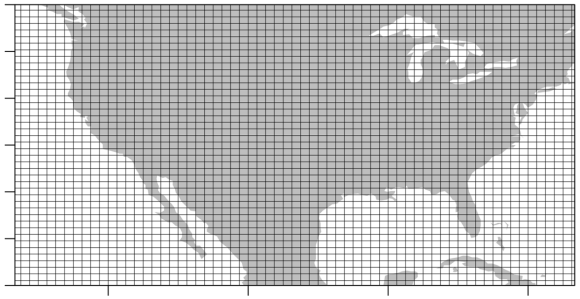
What does the high resolution buy us ?

1°



Current standard resolution

0.25°

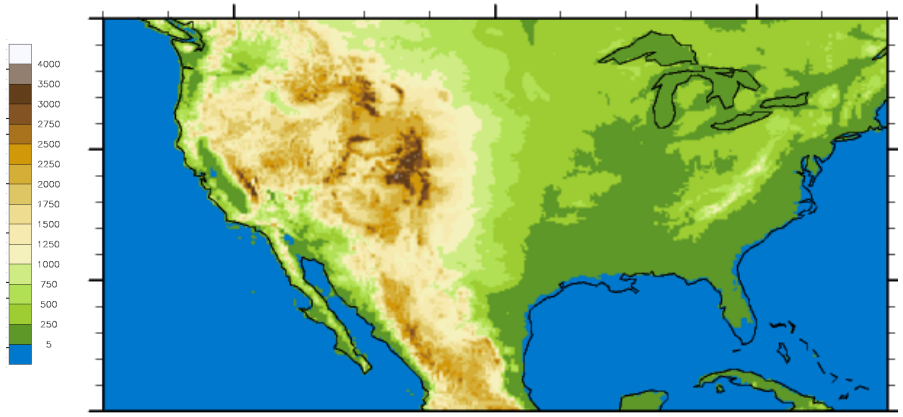


Future resolution (?) as computer power increases

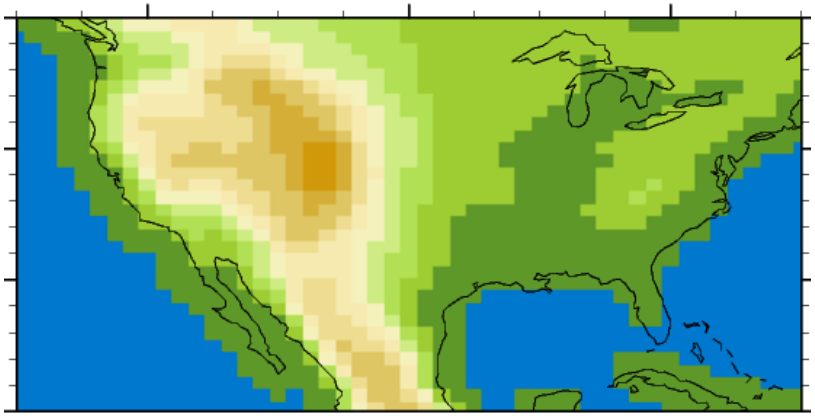
Analysis focuses on precipitation and tropical cyclones

United States Topography

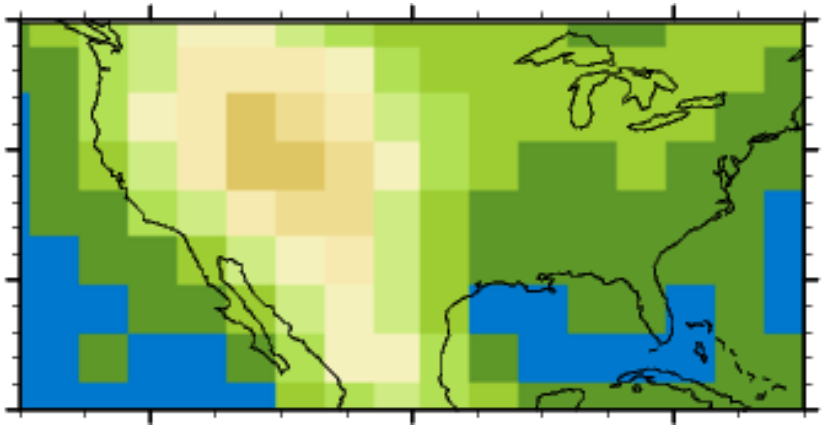
Observation



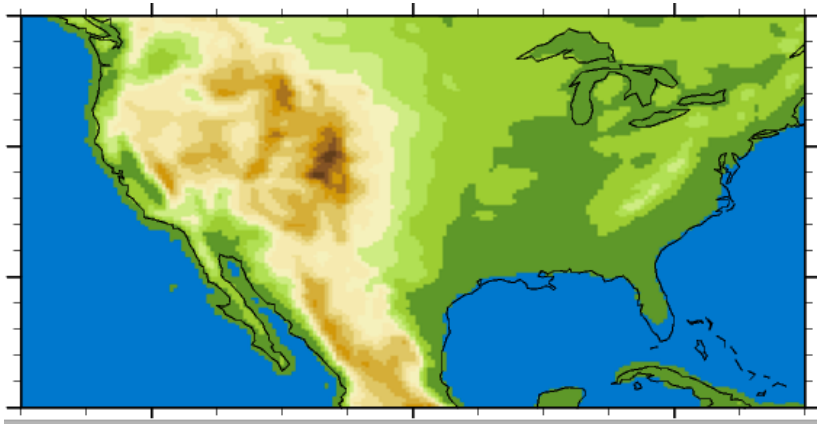
CAM at 1 degree (standard resolution)



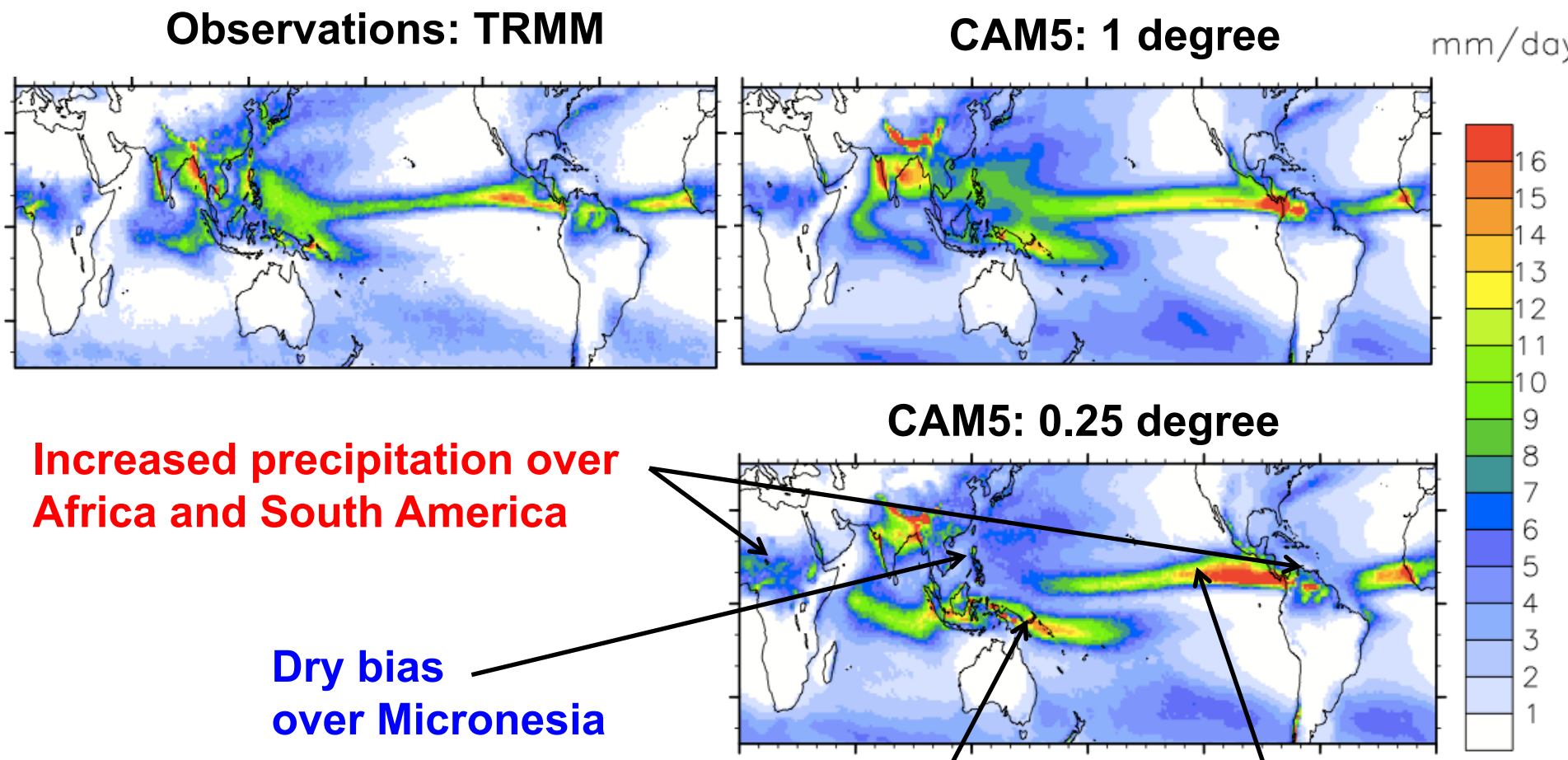
CAM at T31 (This tutorial)



CAM at 0.25 degree (high resolution)

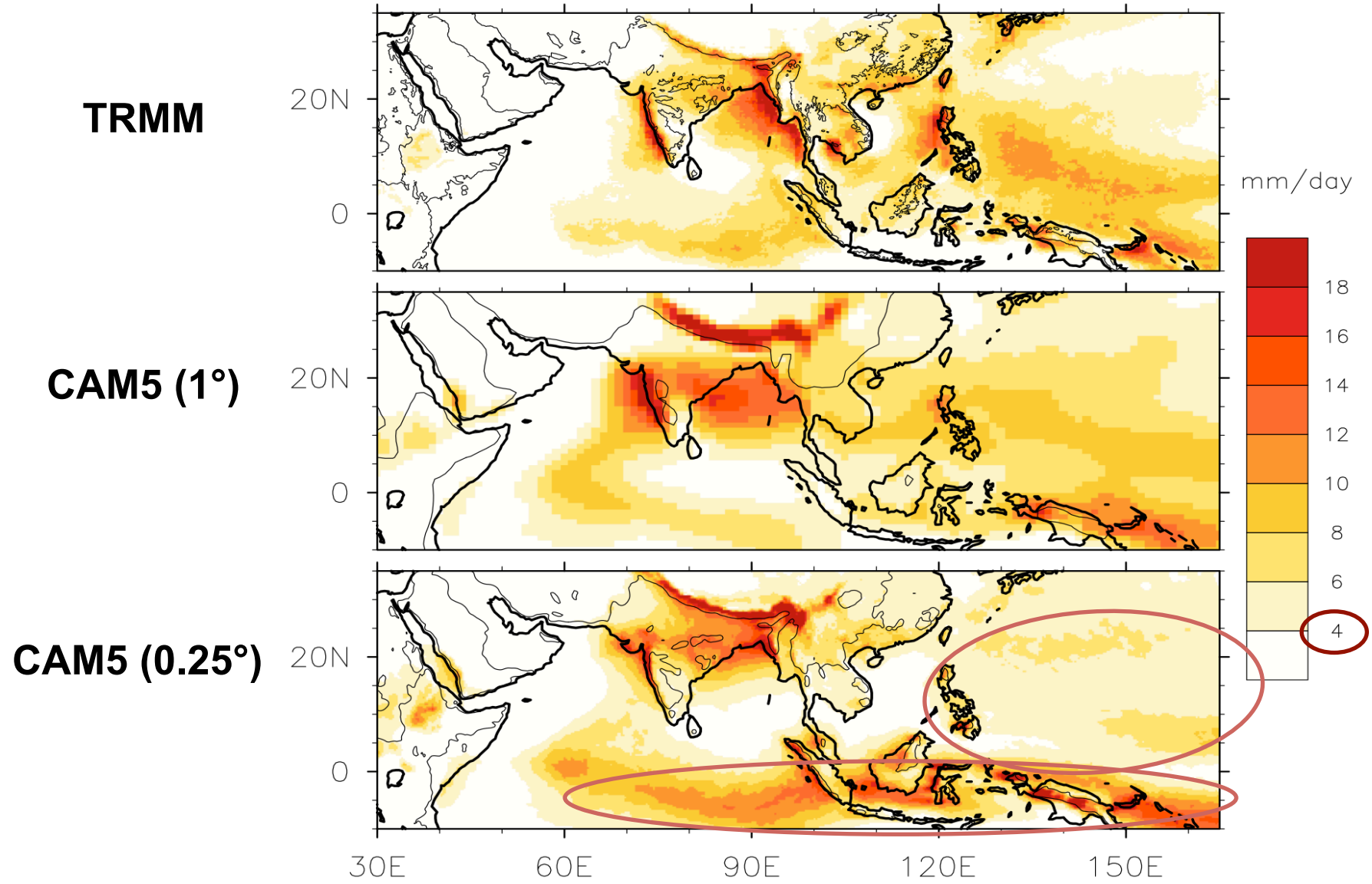


Precipitation, JJA



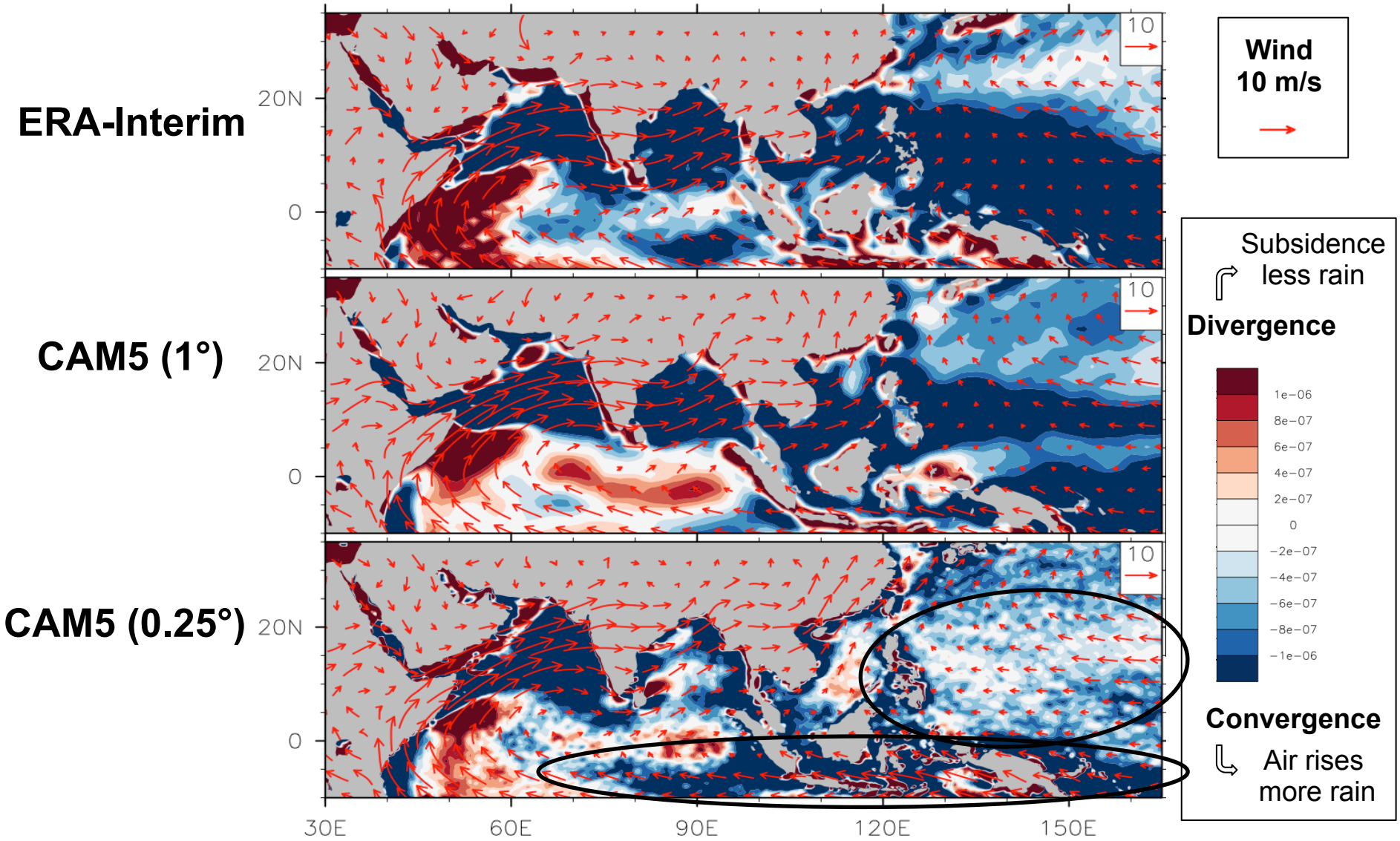
Asian Monsoon, JJA

Precipitation (color). Topography (contour line = 500m level)



Asian Monsoon, JJA

Red vector: Winds at 850 mb; Contour: Wind divergence



Seasonal pattern ⇔ High frequency data (daily)

- Seasonal pattern of precipitation → Precipitation **frequency**
- Seasonal pattern of precipitation → Precipitation **intensity**

- **How often does it rain ?**

$$\text{Precipitation frequency (\%)} = \frac{\text{Number of rainy days (>1 mm/day)}}{\text{Total number of days}}$$

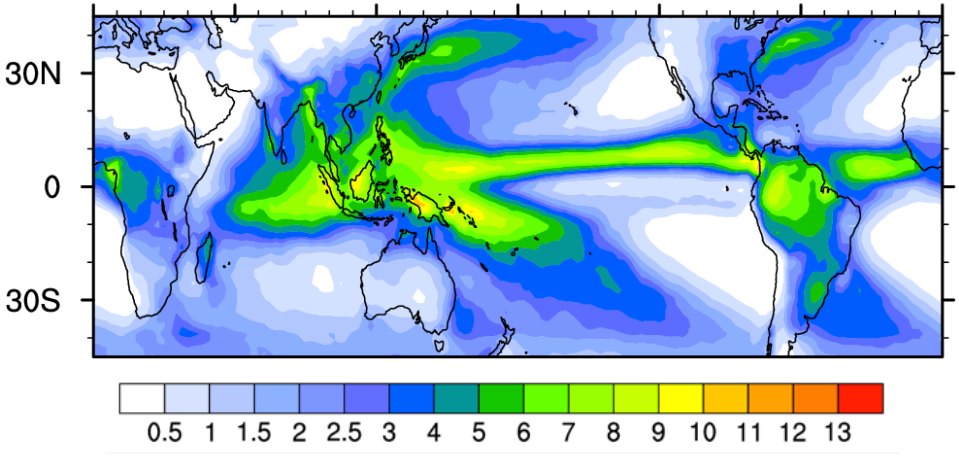
- **How hard does it rain?**

$$\text{Precipitation intensity (mm/day)} = \frac{\text{Total amount of precipitation}}{\text{Number of rainy days (>1 mm/day)}}$$

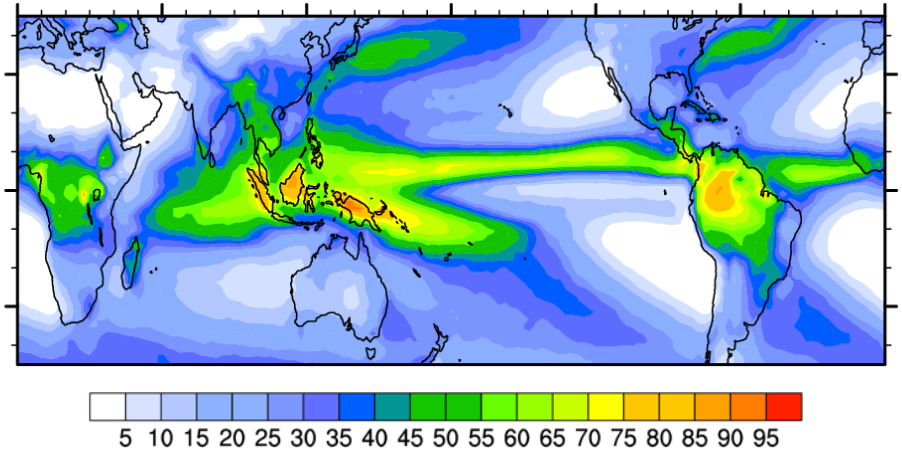
Dai et al. (2007)

TRMM: Precipitation intensity and frequency (ANN)

Precip amount (mm/day)

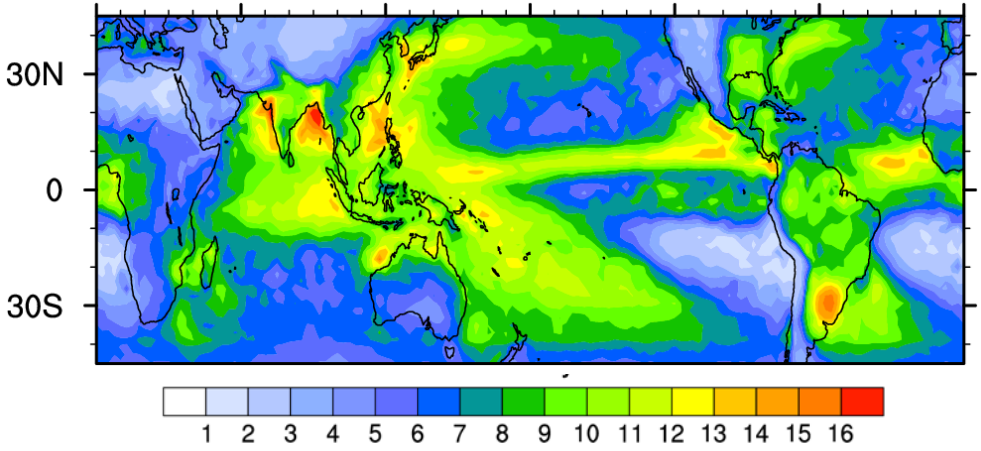


Precip frequency (%)



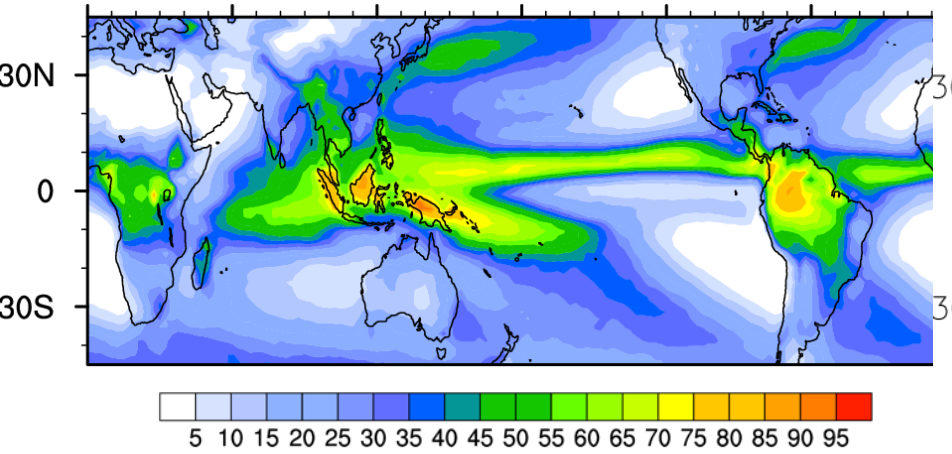
In observations, precipitation amount is mainly determined by the precipitation frequency

Precip intensity (mm/day)

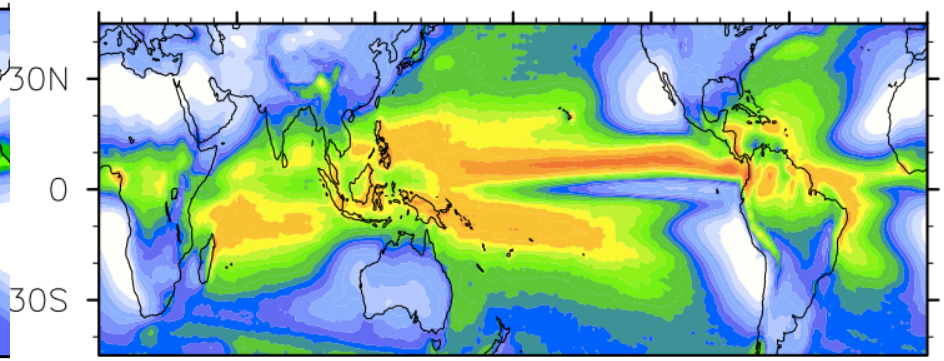


Intensity and frequency: CAM (1°) versus obs

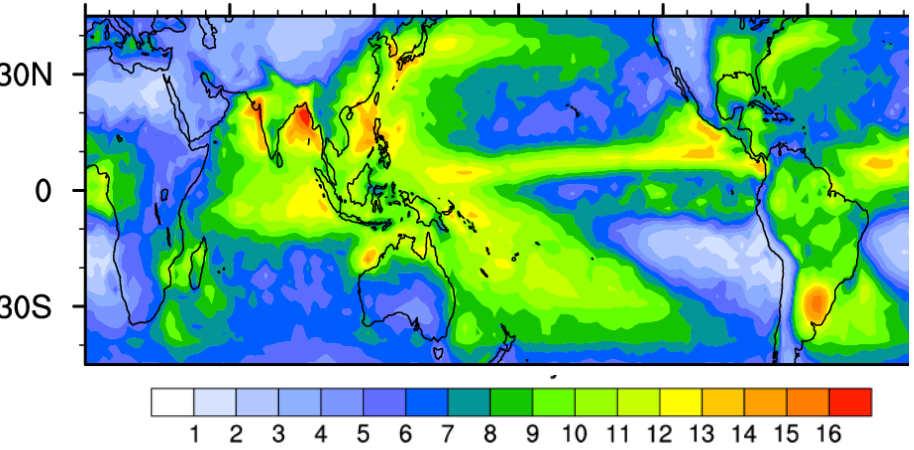
TRMM: Precip frequency (%)



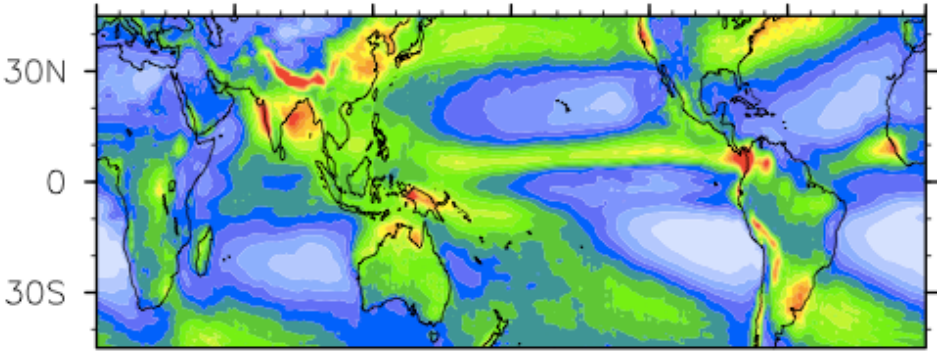
CAM (1°) => rains too often



TRMM: Precip intensity (mm/day)

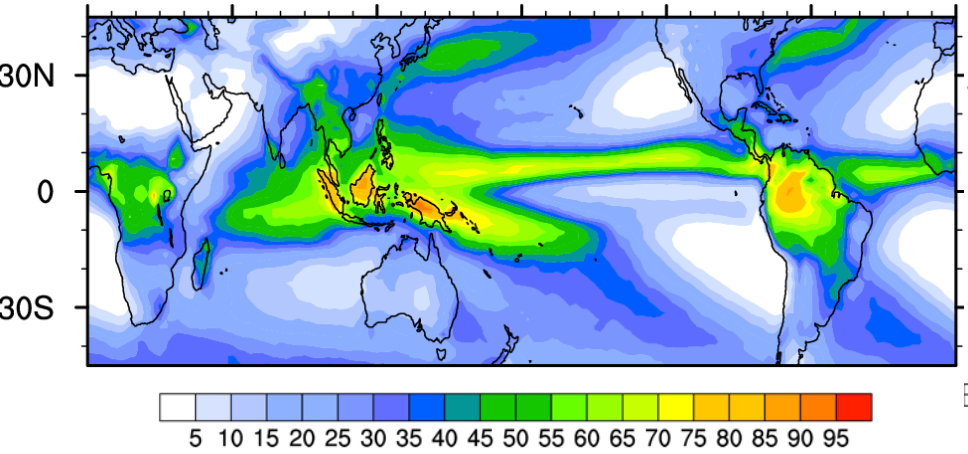


CAM (1°) but not hard enough

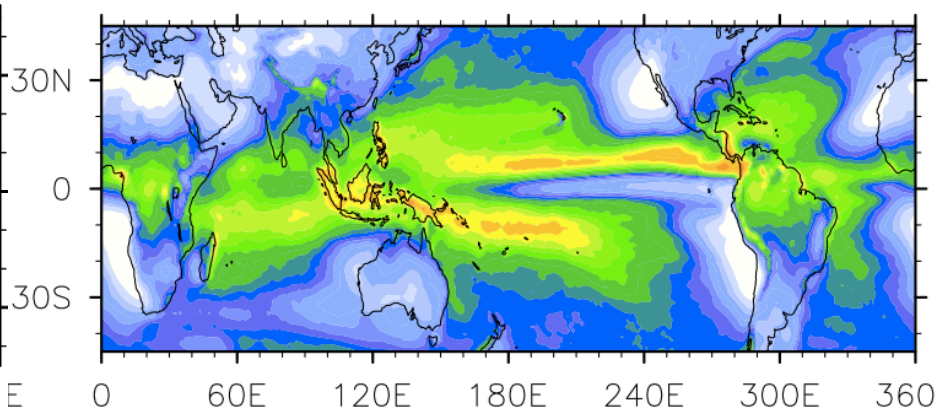


Intensity and frequency: CAM (025°) vs obs

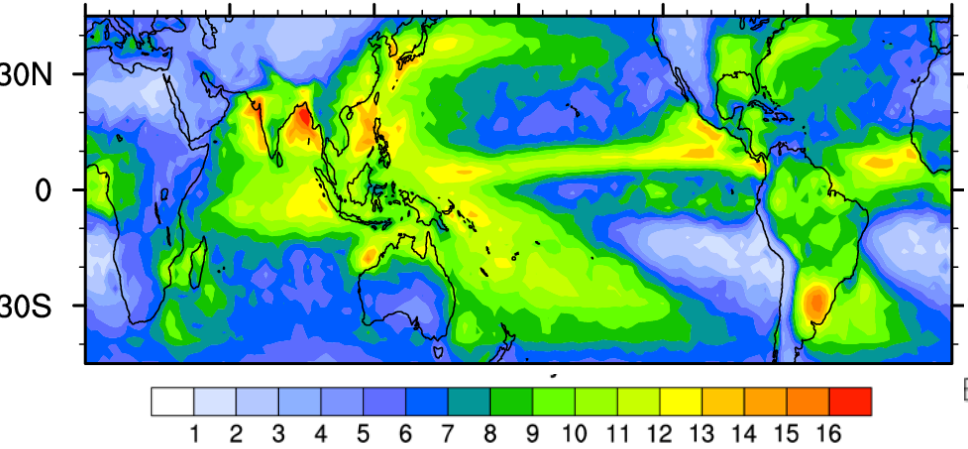
TRMM: Precip frequency (%)



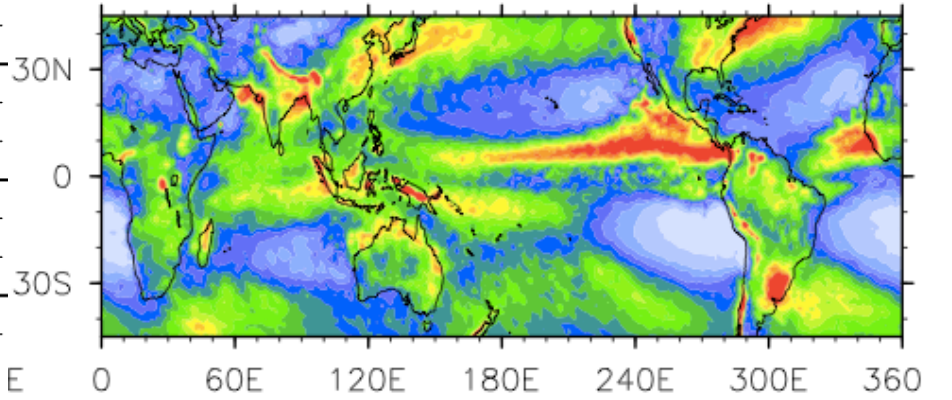
CAM (0.25°) => improved frequency



TRMM: Precip intensity (mm/day)



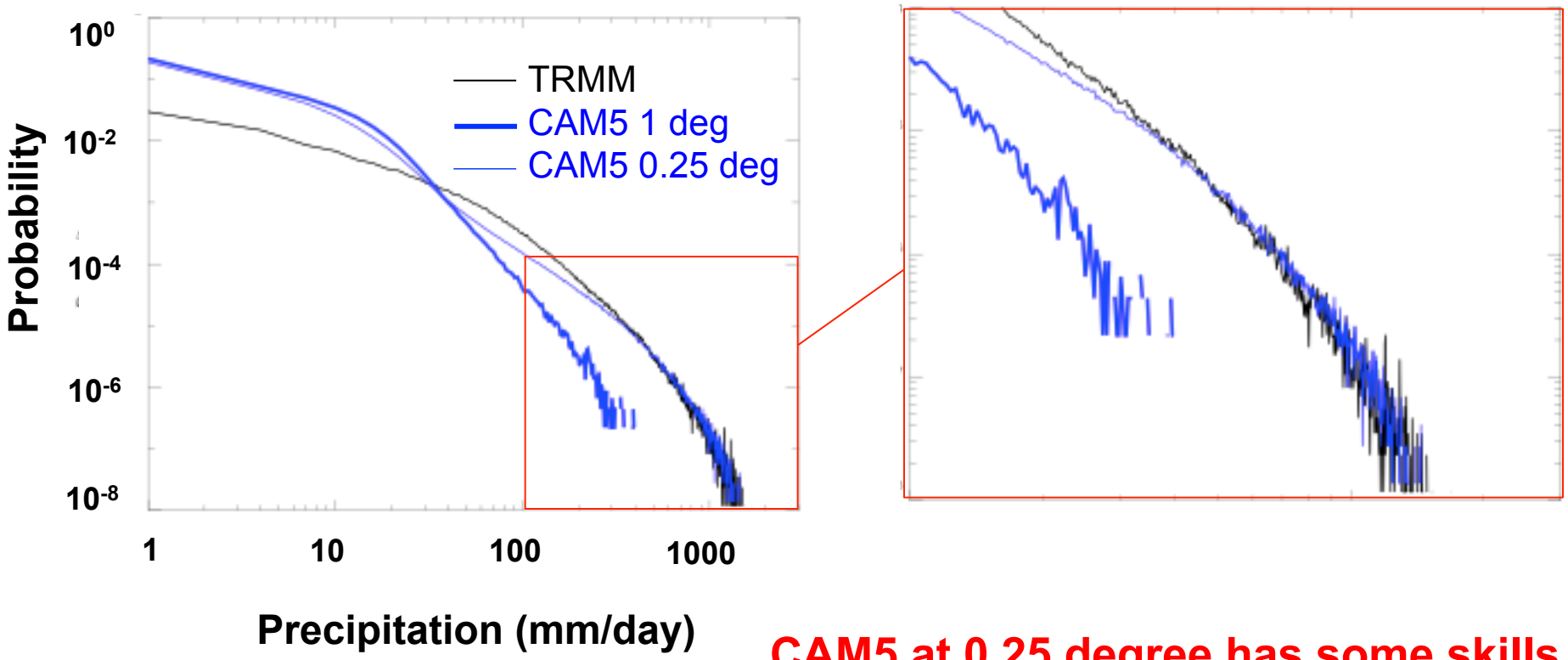
CAM (0.25°) => mixed result



Problem persists at higher resolution (despite some improvements) !

Extreme precipitation

PDFs of precipitation (August 2005)

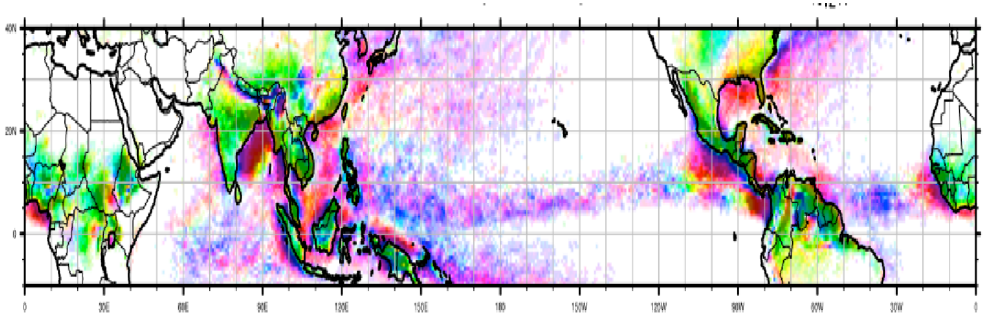


CAM5 at 0.25 degree has some skills to simulate extreme precipitation

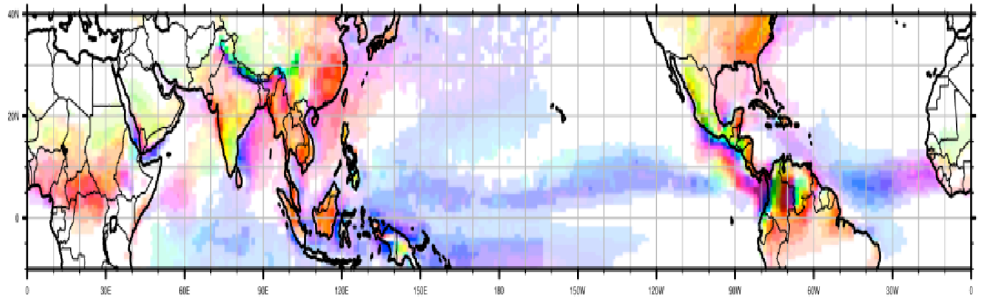
Courtesy Julio Bacmeister

Diurnal cycle of rainfall (JJA)

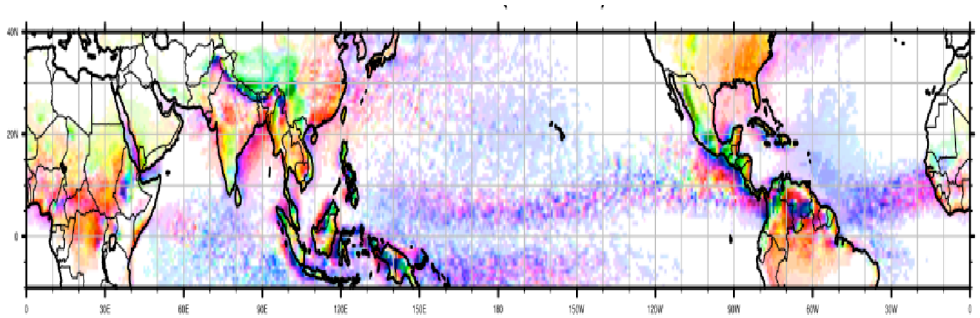
TRMM



1 deg



0.25 deg



In observations:
Land: evening max
Ocean: early morning max

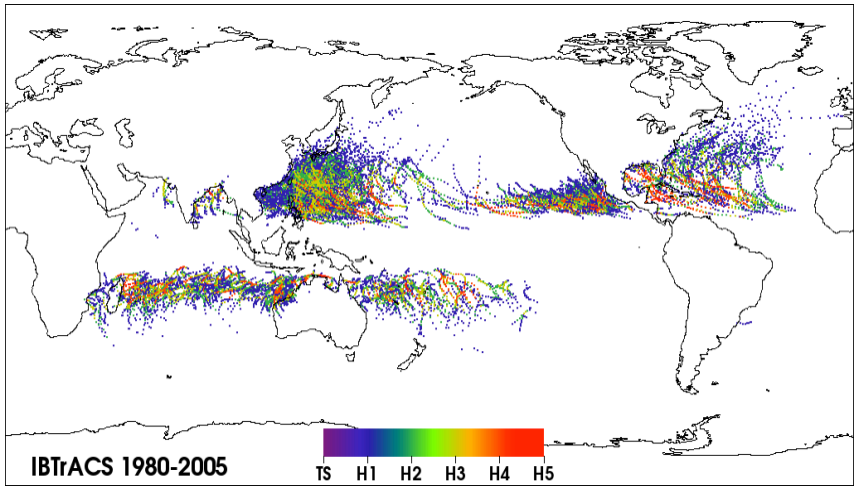
At coarse resolution,
- **Rains too early especially over land**
- **Diurnal cycle amplitude too weak**

Diurnal cycle improves at higher resolution

Courtesy Rich Neale

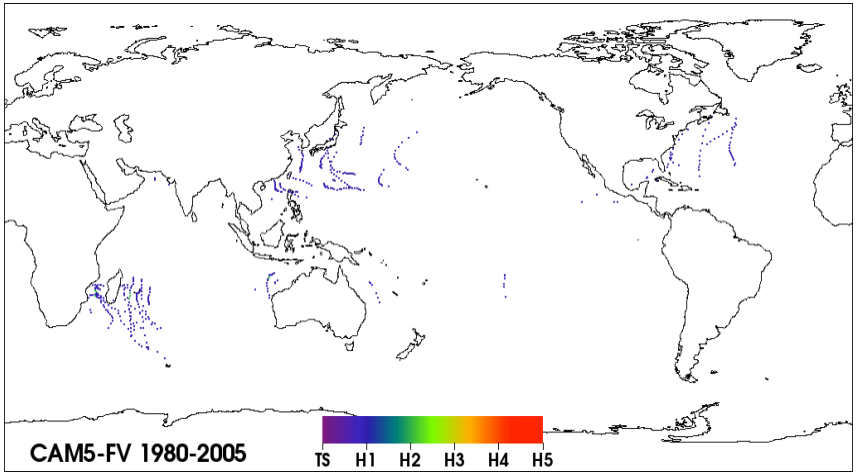
Tropical Cyclone Tracks

Observations: IBTrACS

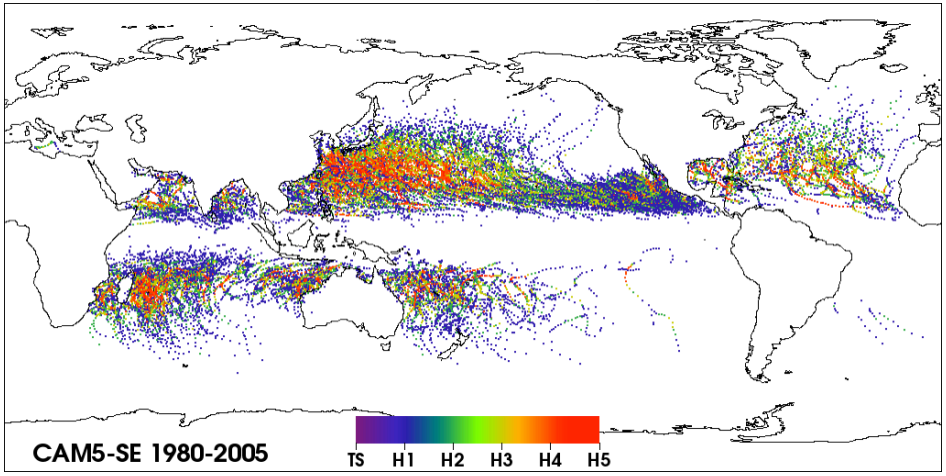


- Tropical cyclone tracks identified by GFDL tracking algorithm
- CAM5 at 0.25 degree has some skills to simulate tropical cyclones

CAM5: 1 degree



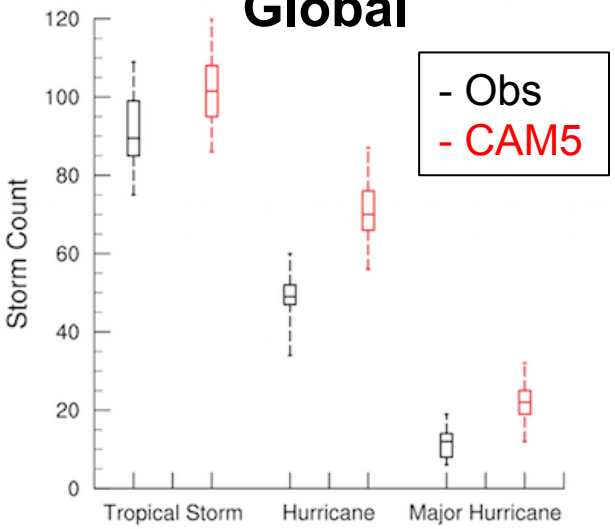
CAM5: 0.25 degree



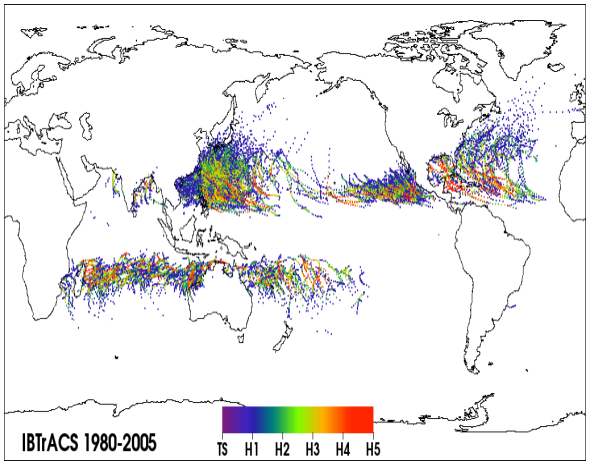
Courtesy: Kevin Reed [See also: Wehner et al. 2014, JAMES]

Storm Count: Tropical Storm, Hurricane, Major Hurricane.

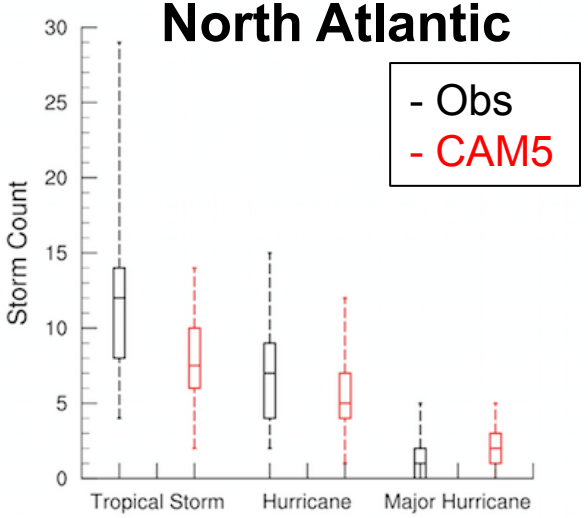
Global



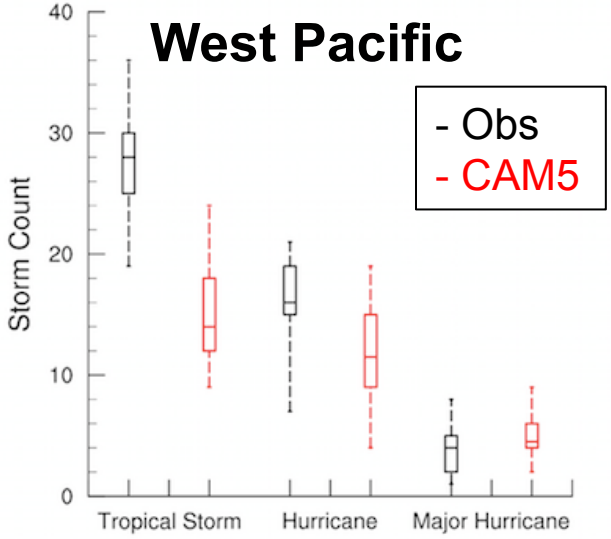
Observations: IBTrACS



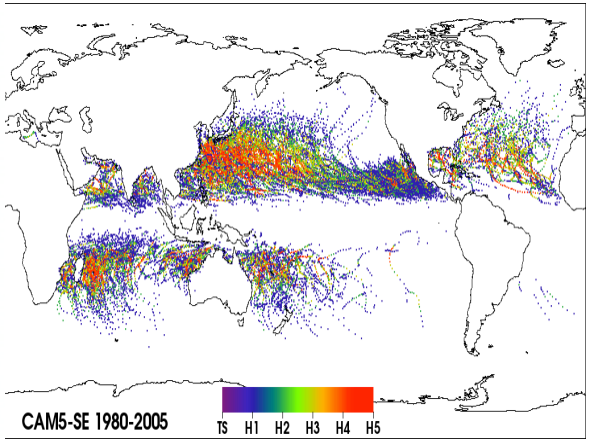
North Atlantic



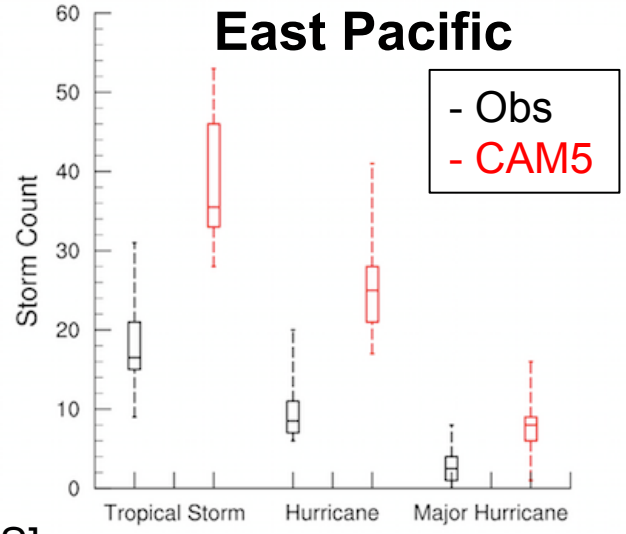
West Pacific



CAM5: 0.25 degree



East Pacific



Courtesy: Kevin Reed [See also: Wehner et al. 2014, JAMES]

Conclusions

Mean climate:

- Mean precipitation bias is not much improved at higher resolution.
- Some biases even get worse (dry Micronesia bias, double ITCZ…)

Daily data:

- In CAM5: rains too often but not hard enough.
  Despite some improvements, the problem persists at higher resolution.

Diurnal cycle

At coarse resolution, CAM fails to reproduce observed diurnal cycle

- Rains too early especially over land
- Diurnal cycle amplitude too weak
- Diurnal cycle improves at higher resolution but some bias remains

Extreme events

CAM at 0.25 degree has some skills to reproduce extreme precipitation and tropical cyclones

Thanks !

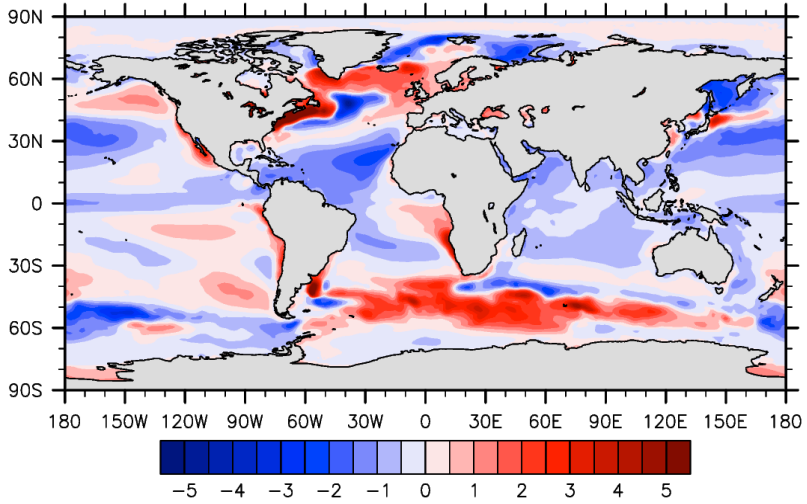
What is the impact of resolution for future projections ?

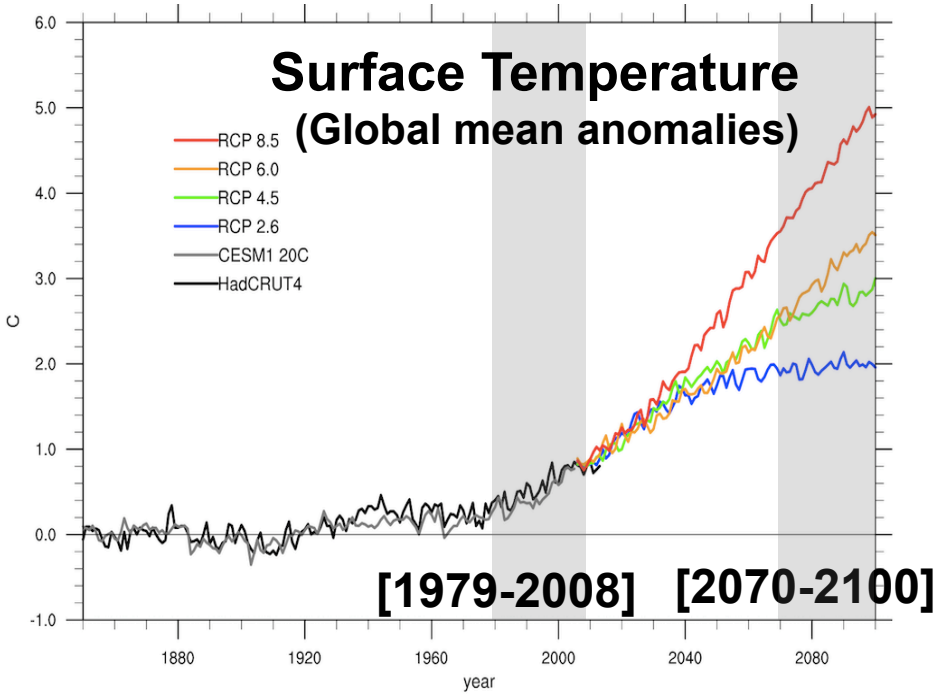
Time-slice experiments

- **Present-day conditions**
  Observed SSTs: Merged Hadley-OI

- **Future conditions**
  CESM SSTs: RCP4.5 & RCP8.5

+ bias correction

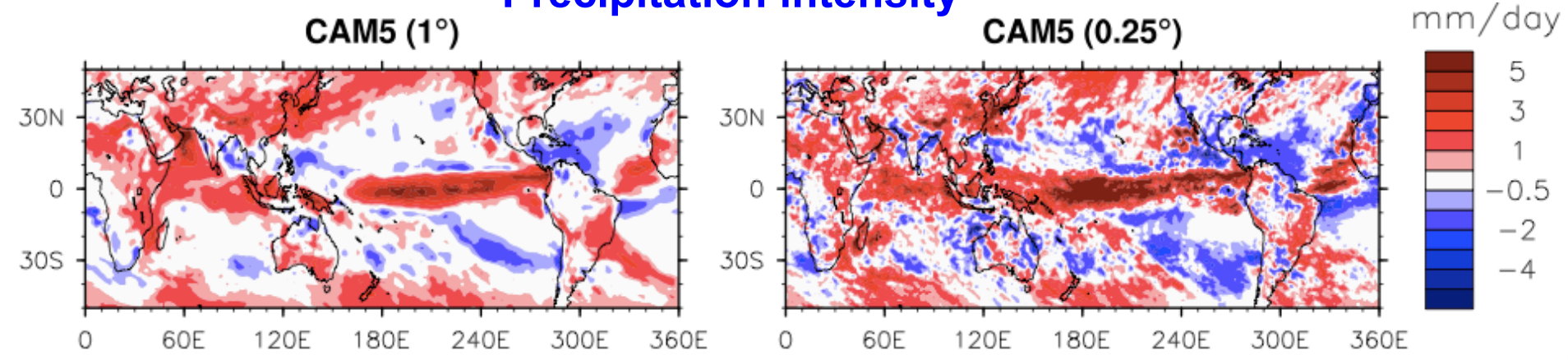




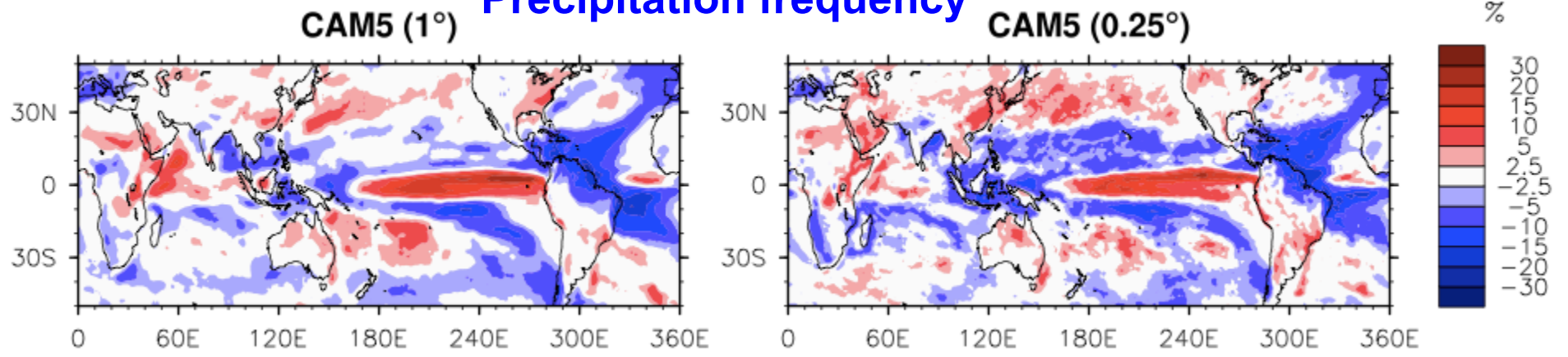
We use the present-day SSTs bias as a correction for RCP SSTs (Use 12-month cycle correction).

Changes in precipitation intensity/frequency

Precipitation intensity



Precipitation frequency

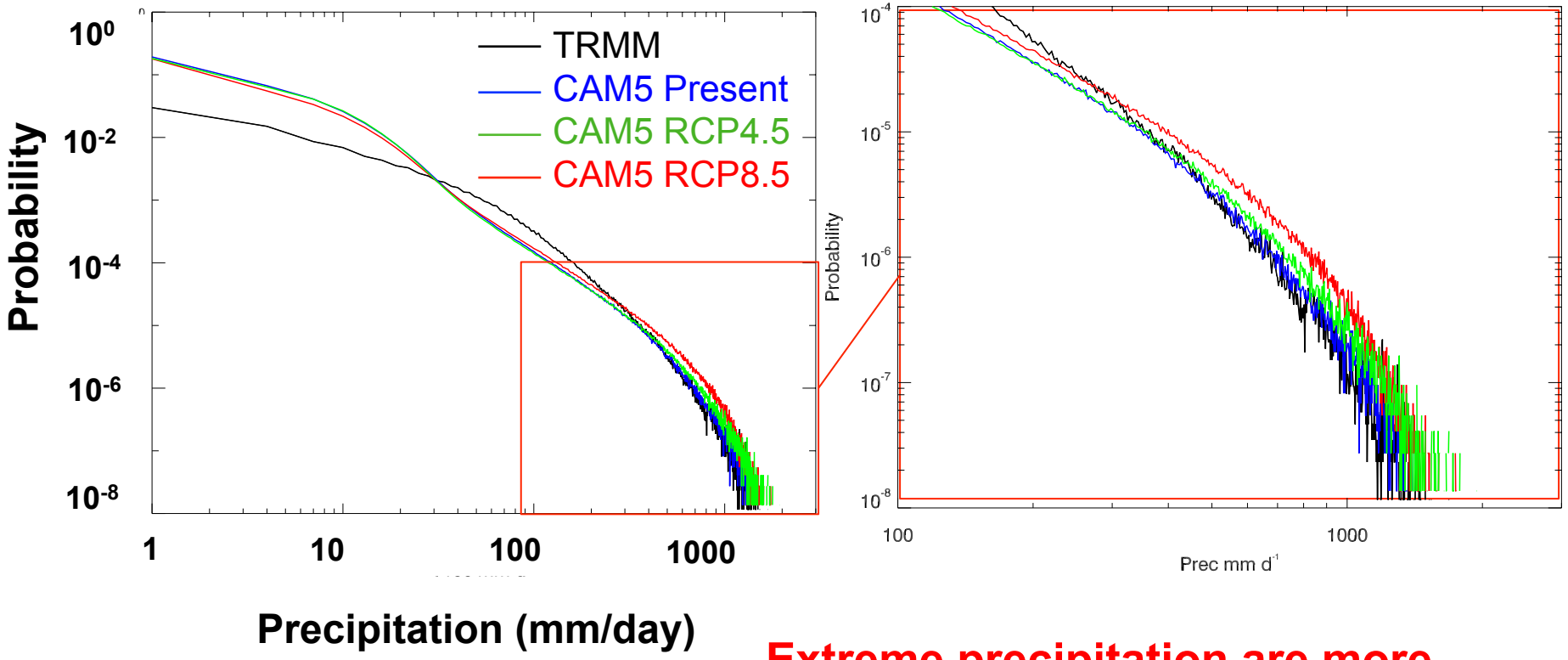


In warmer climate: it rains harder but less frequently

(Consistent with Trenberth et al. 2003)

Extreme precipitation in warmer climate

PDFs of precipitation at 0.25 degree (August)

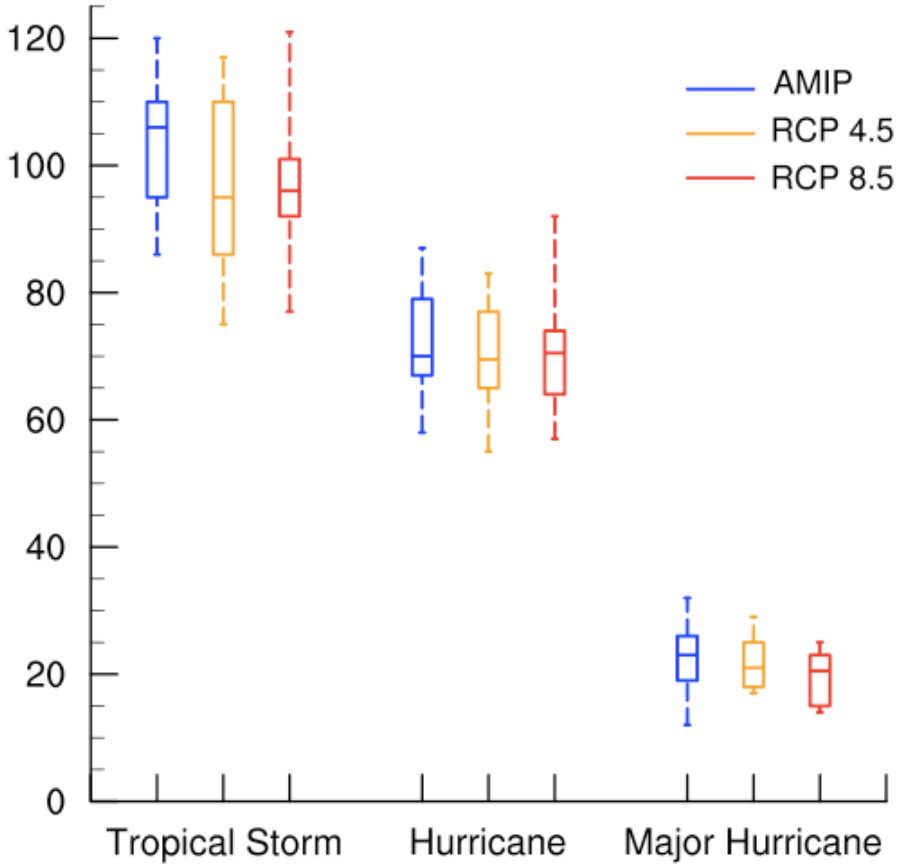


Extreme precipitation are more intense in a warmer climate

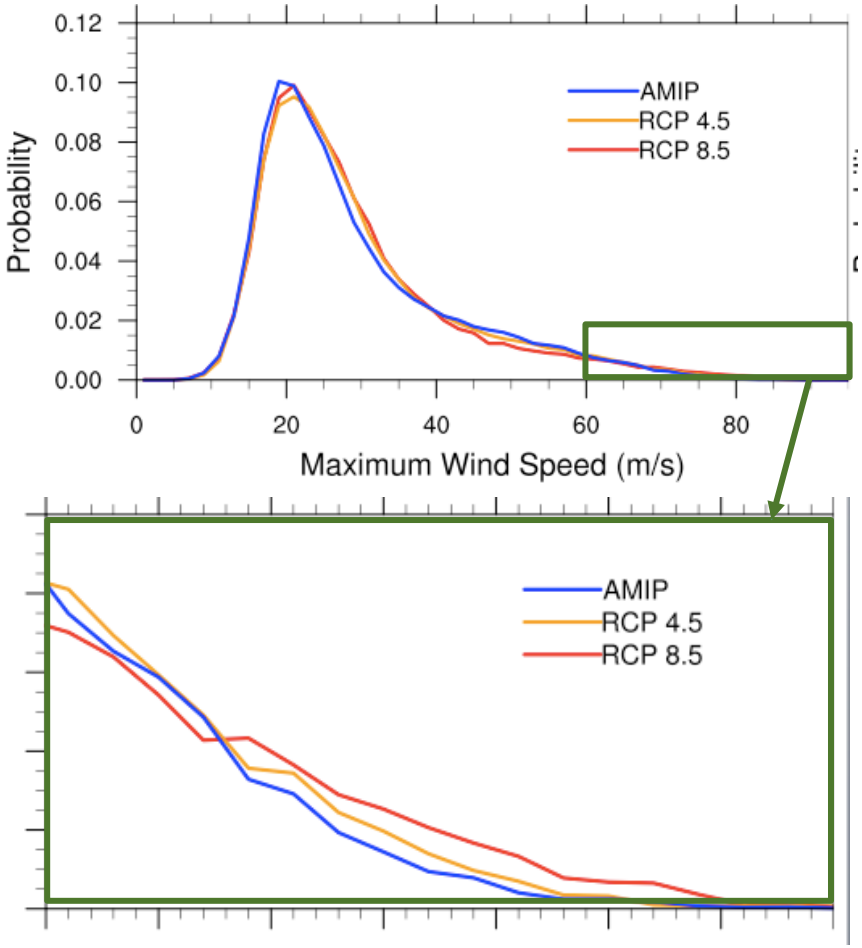
Courtesy Julio Bacmeister

Tropical Cyclone count and intensity in warmer climate

Storm Count



Maximum Wind Speed



In warmer climate:

number of tropical cyclones decreases

But the most intense storms become more intense.

Courtesy: Kevin Reed

Conclusions

In a warmer climate:

- It rains harder but less frequently
- Extreme precipitation are more intense
- The number of tropical cyclones decreases
  but the most intense storms become more intense.

Future work:

- Prediction depends on the SSTs.
- Impact of the SST bias and bias correction in the RCP runs.