Evaluation of Regional Climate Models

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Background

- Regional Climate Models are used for examining future regional climate changes at relatively higher resolution.

- However, it is necessary to examine the uncertainties and biases associated with the RCM simulations so that uncertainty levels can be attributed to the future climate projections, that will benefit the policy decision makers.

What we need to evaluate

- Model's externally "forced" responses on a range of time scales:
  - Diurnal cycle
  - Annual cycle
- Model's "unforced" behaviour
  - ENSO, NAO
  - Weather statistics (extreme weather)
- Model representation of individual process and associated covariability relationships

The basic parameters

- Precipitation
  - Annual cycle
  - Diurnal cycle
  - Intraseasonal variations
  - Interannual variations
  - Teleconnections
- Temperatures
- Extreme weather events
  - Extreme temperatures
  - Extreme rainfall events

Precipitation

- We need to evaluate the skill and uncertainties of the hydrological cycle to understand the biases of precipitation simulations:

$$MFD + \frac{\partial PW}{\partial t} = E - P$$

P is cumulated precipitation, E is evapo-transpiration, MFD is vertically integrated moisture divergence from surface to the top of the atmosphere and the second term on LHS is time variation of precipitable water content. On seasonal time scale, this term can be assumed as zero.

Hydrological Cycle

- Moisture divergence
- Water budget over major river basins
- Energy Budget and Cloud distributions
  - Vertical cloud distribution ?

Metrics for evaluation

- Differences- how large is the error
- Variability between simulated and observed fields
- How the patterns between simulated and observed?

- How large is the error, i.e., the **difference** between a simulated and observed field?

"Bias"

$$\overline{E} = \overline{M} - \overline{O}$$

E = Error
M = Model
O = Observations

- Do the observed and simulated fields have similar **variability**?

Standard Deviation

$$\sigma_M = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(M_n - \overline{M}\right)^2} \qquad \sigma_O = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(O_n - \overline{O}\right)^2}$$

- How well do the **patterns** agree between a climate simulation and an observed field?

Correlation Coefficient

$$R = \frac{\frac{1}{N}\sum_{n=1}^{N}\left(M_n - \overline{M}\right)\left(O_n - \overline{O}\right)}{\sigma_M \sigma_O}$$

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RMS error components: "Bias" and "pattern"

The statistic most often used to quantify differences in two fields is the root mean square (RMS) error, E, which is defined by:

$$RMSE = E = \left[\frac{1}{N} \sum_{n=1}^{N} (M_n - O_n)^2 \right]^{1/2}$$

In order to isolate the differences in the patters from the differences in the means, *E* can be resolved into a "bias"

$$\overline{E} = \overline{M} - \overline{O}$$

And the "pattern error" or "centered RMS" error which can be defined as:

$$E' = \sqrt{\frac{1}{N} \sum_{n=1}^{N} \left[(M_n - \overline{M}) - (O_n - \overline{O}) \right]^2}$$

The two add quadradically to yield

$$E^2 = \overline{E}^2 + E'^2$$

total bias pattern

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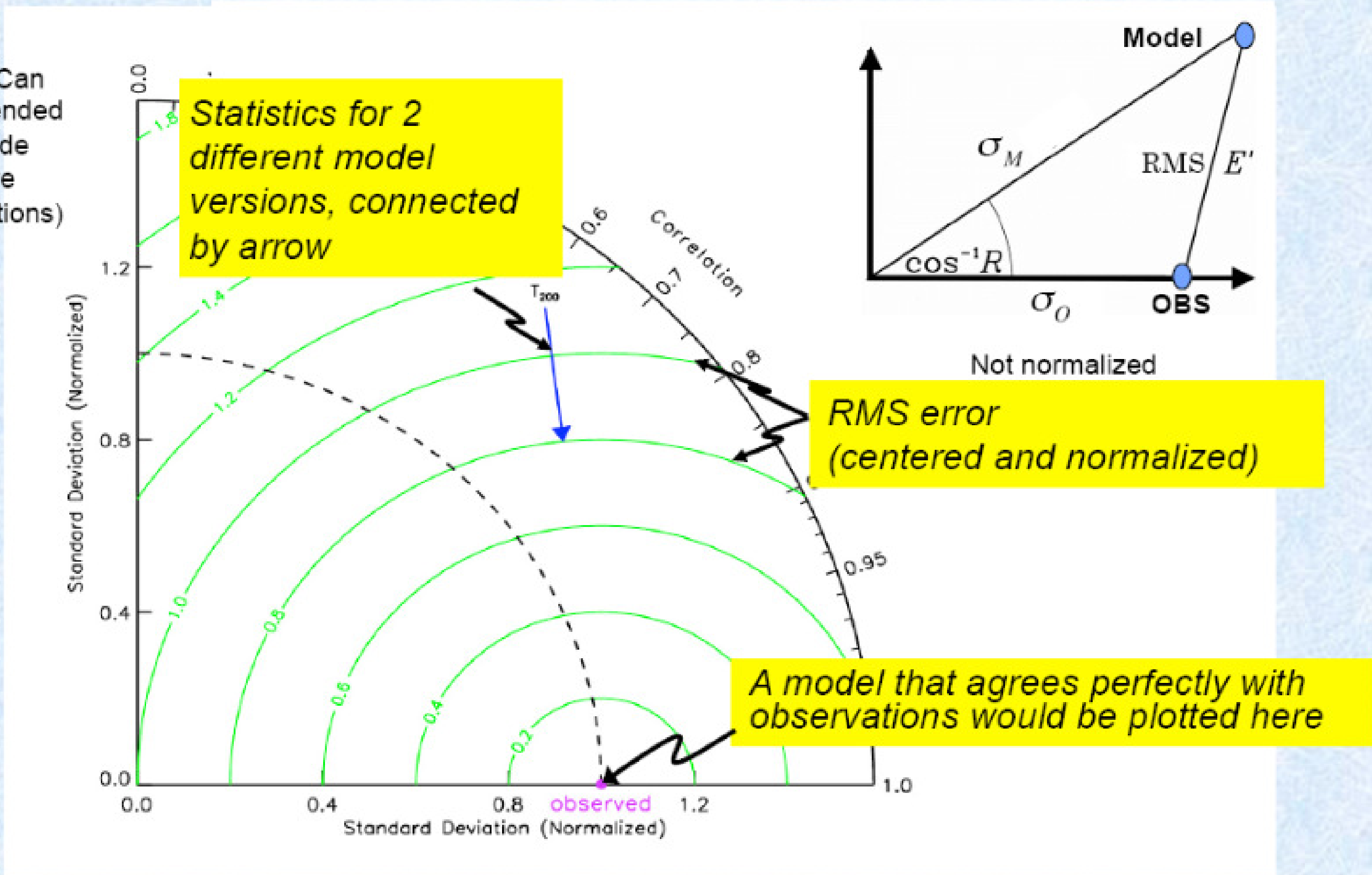
Three statistics characterizing agreement between simulated and observed fields can be shown: Taylor Diagram

(Note: Can be extended to include negative correlations)



Taylor, *J. Geophys. Res.* (2001)

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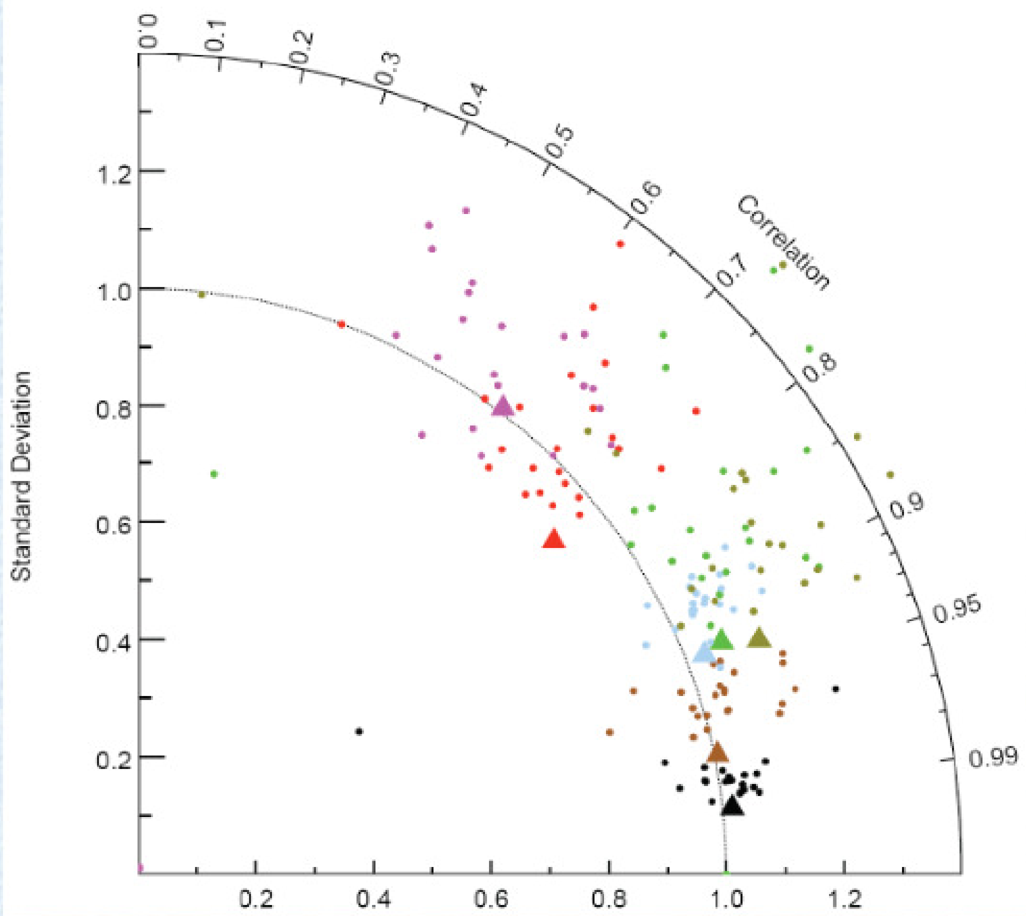
Taylor diagram for CMIP3 annual cycle global climatology (1980-1999)



Sea Level Pressure: ERA40 reference
Total precipitation rate: CMAP reference
Total Cloud Cover: ISCCP reference
LW radiation TOA (OLR): CERES reference
Reflected TOA Shortwave: ERBE reference
Air Temperature (850 hPa): ERA40 reference
Zonal Wind (850 hPa): ERA40 reference

- Variable dependent skill
- Multi-model mean "superiority"

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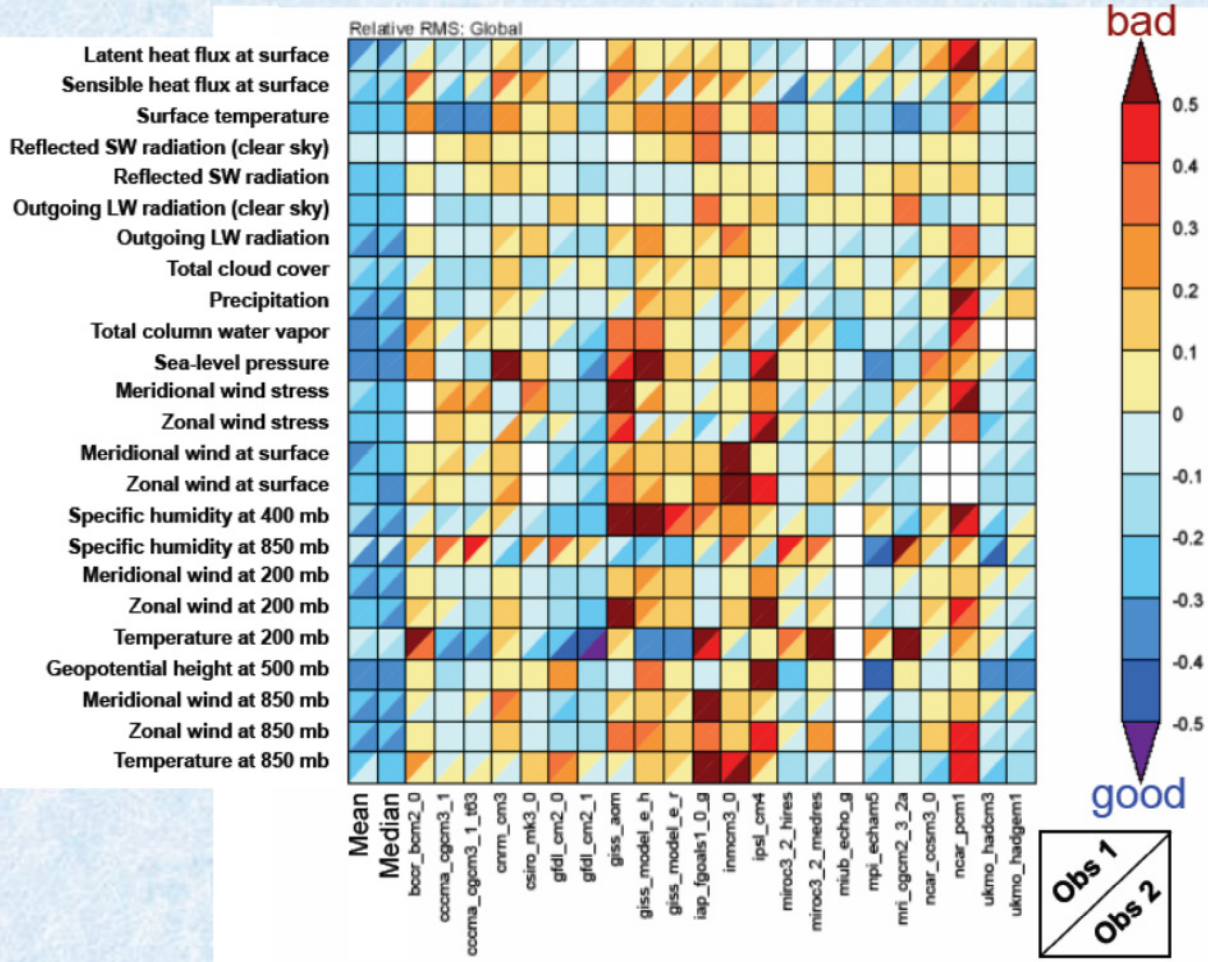
Annual cycle of global fields: Assessment of the relative skill (S) of individual CMIP3 models.

E_{vm} = RMS error in simulating the spatial pattern of the climatological annual cycle of variable *v* by model *m*

$$S_{vm} = \frac{E_{vm} - \hat{E}_v}{\hat{E}_v}$$

where $\hat{E}_v$ is the median of the individual error measures, E_{vm}



Gleckler, et al., J. Geophys.Res., 2008

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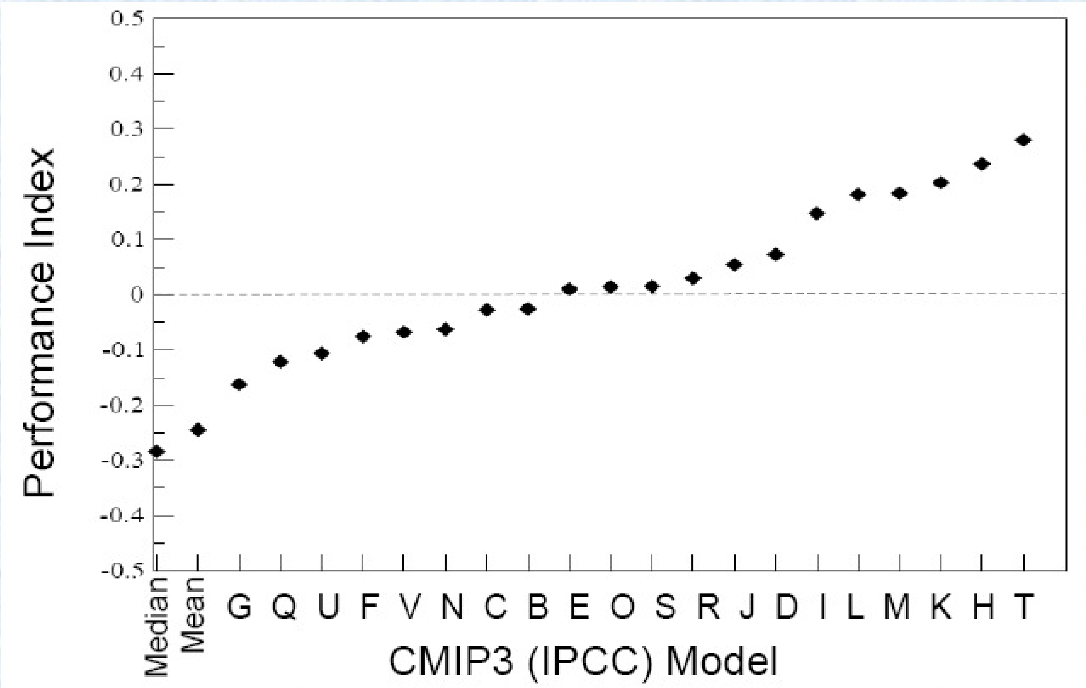
We are beginning to explore the value and limitations of a single "performance index"

- From performance portrait recall: $S_{vm} = \dfrac{E_{vm} - \hat{E}_v}{\hat{E}_v}$
- Let the "performance index" be the mean of S_{vm} over all the variables.



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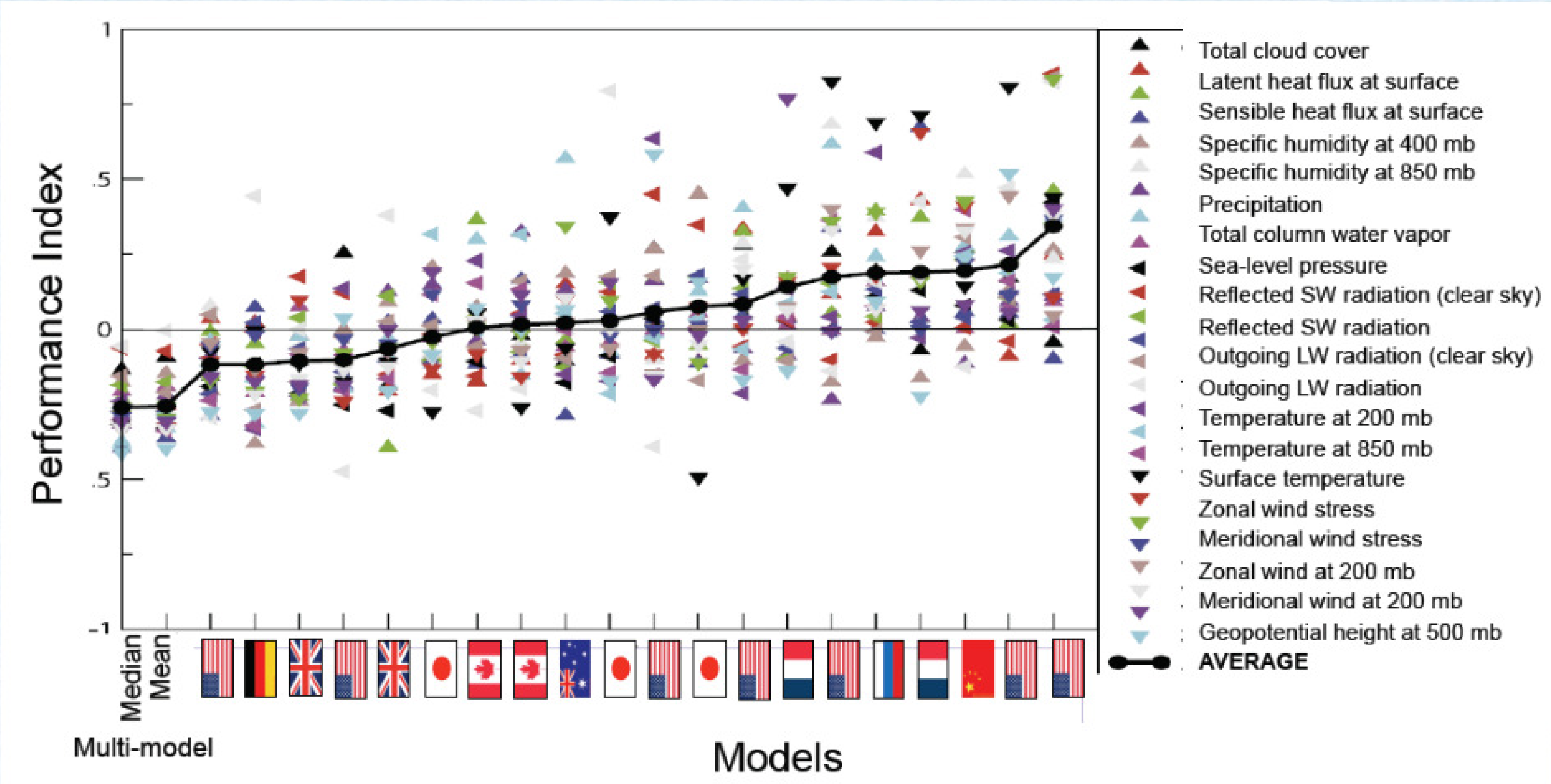
An arbitrary skill score: All variables treated equally. Is it meaningful?



Gleckler, P., et al., *J.Geophys.Res.* (2008)

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Annual Mean and Cycle

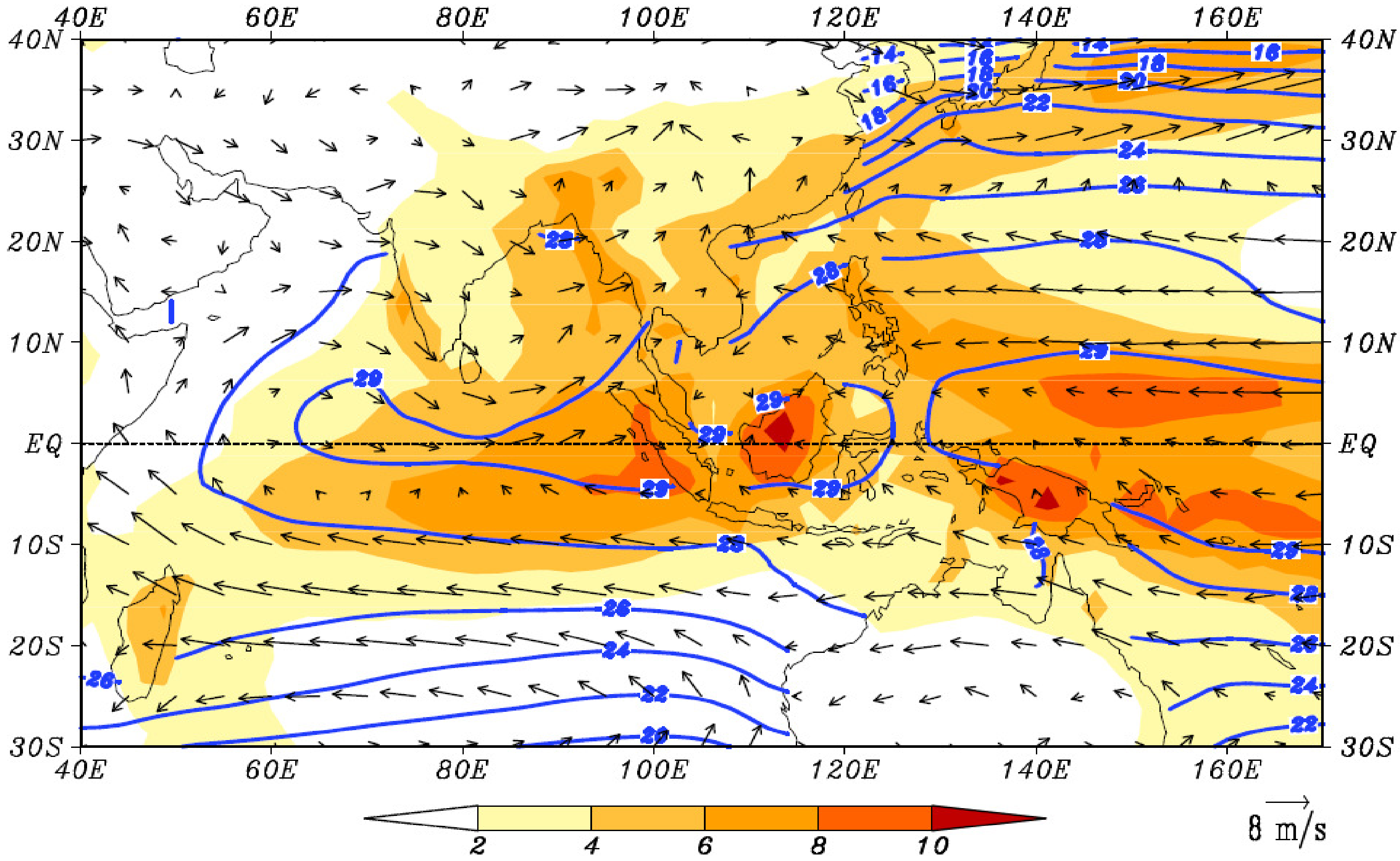


Fig. 1 Annual Mean (AM): Precipitation/SST/uv850 climatology (Precipitation: Color, SST contour).

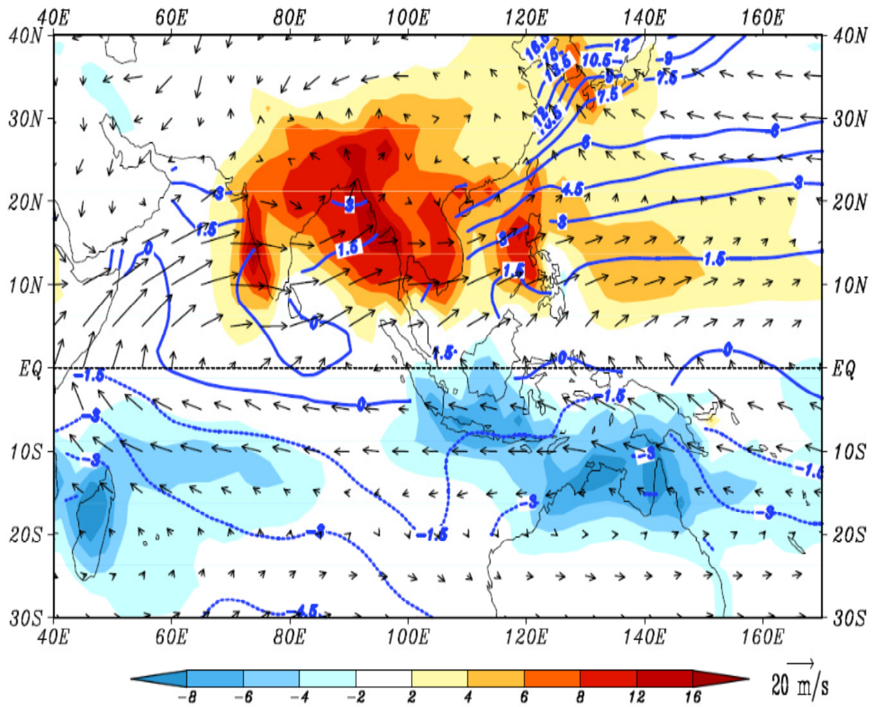


Fig. 2: Annual Cycle 1 (AC solstice mode): JJAS minus DJFM Precipitation/SST/uv850 climatology.

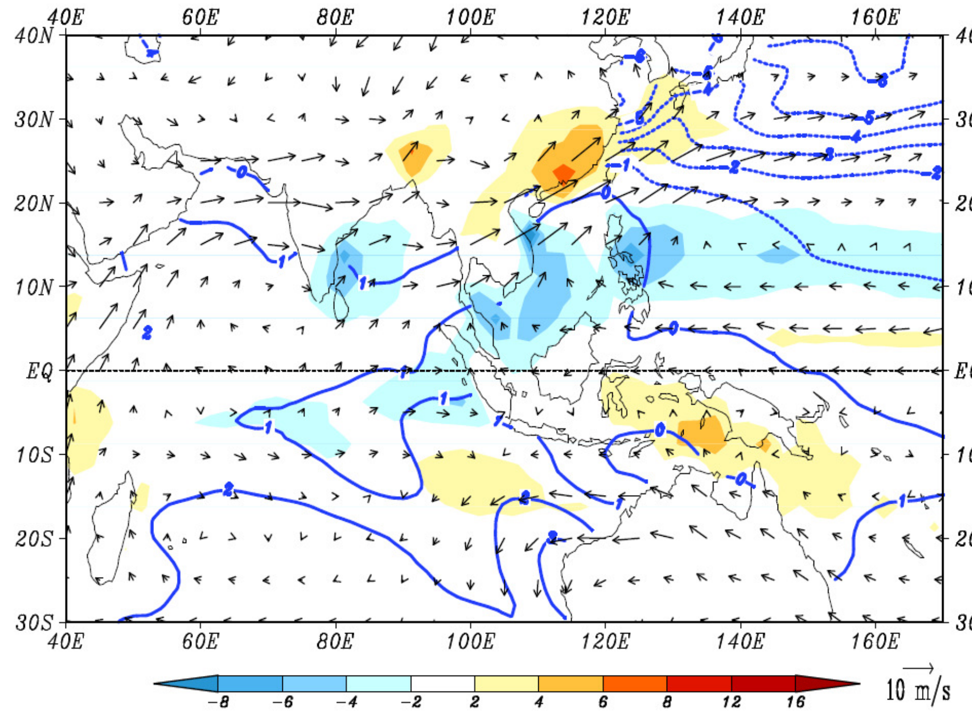
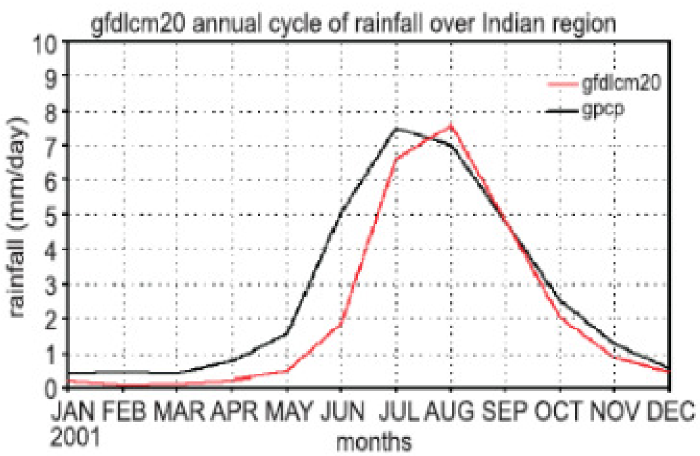
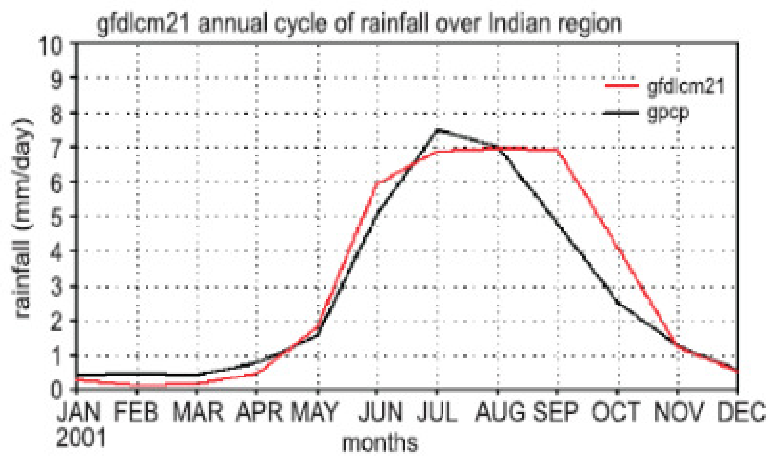


Fig. 3: AC2 (Equinoctial asymmetric mode): AM minus ON Precipitation/SST/uv850 climatology.

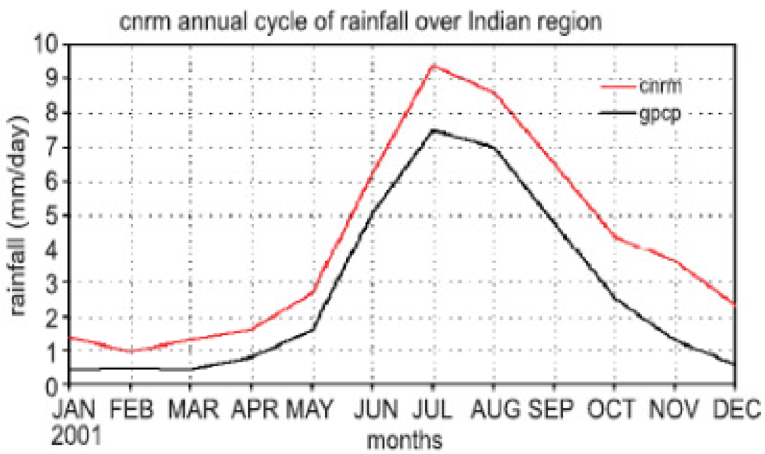
Annual Cycle of Rainfall



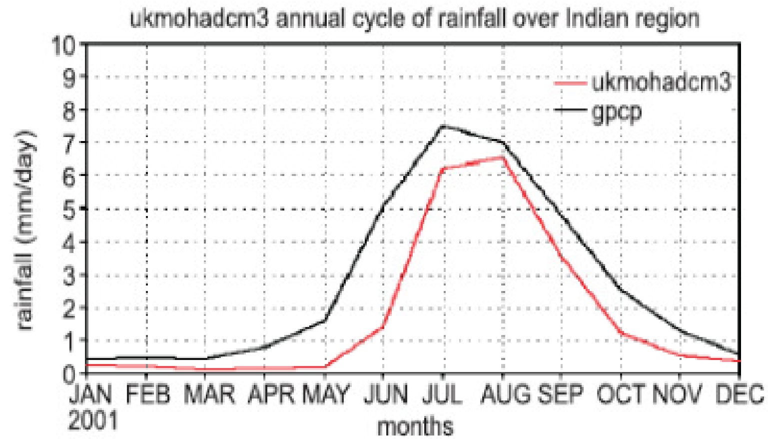
(a) GFDL 2.0



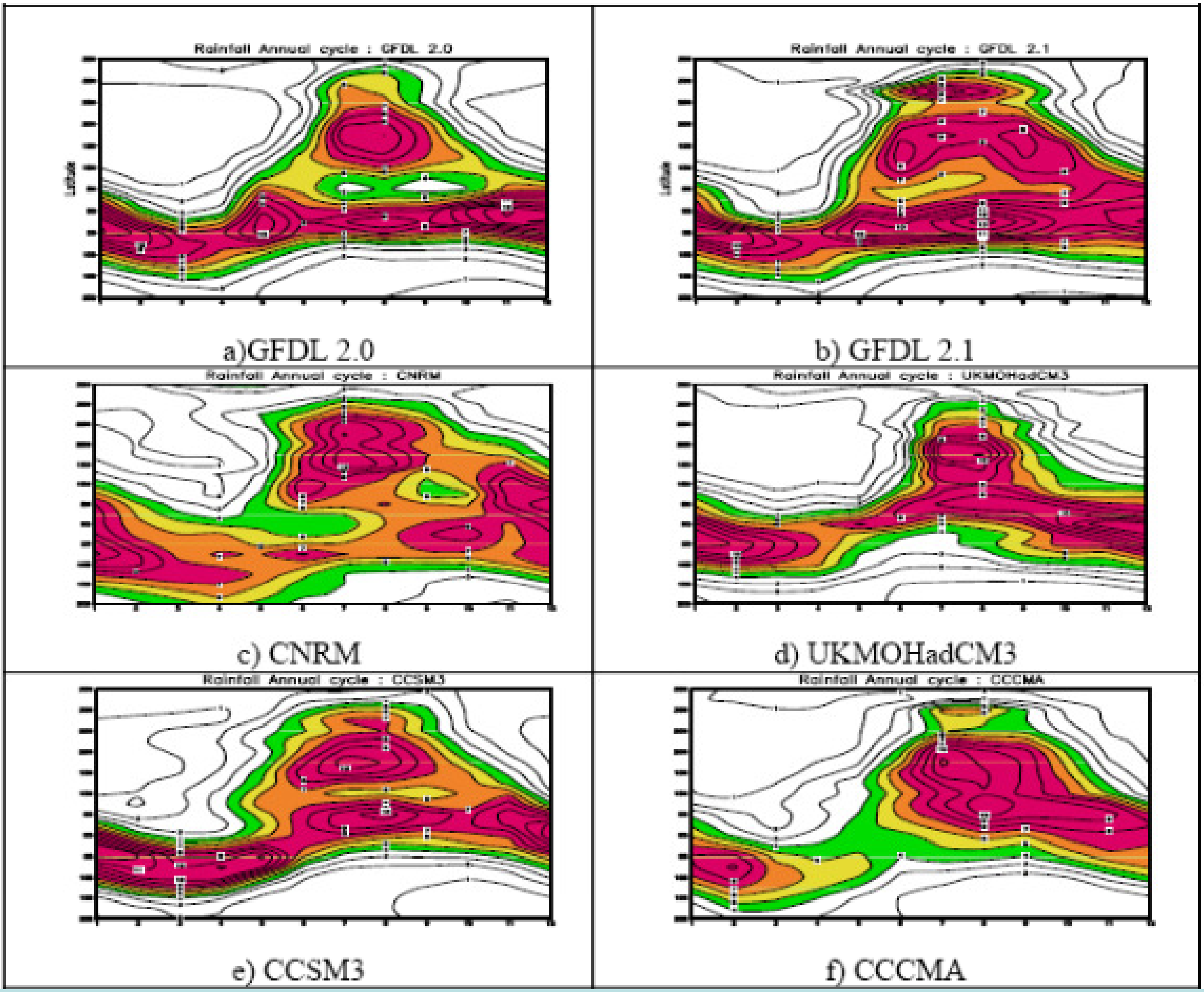
(b) GFDL 2.1

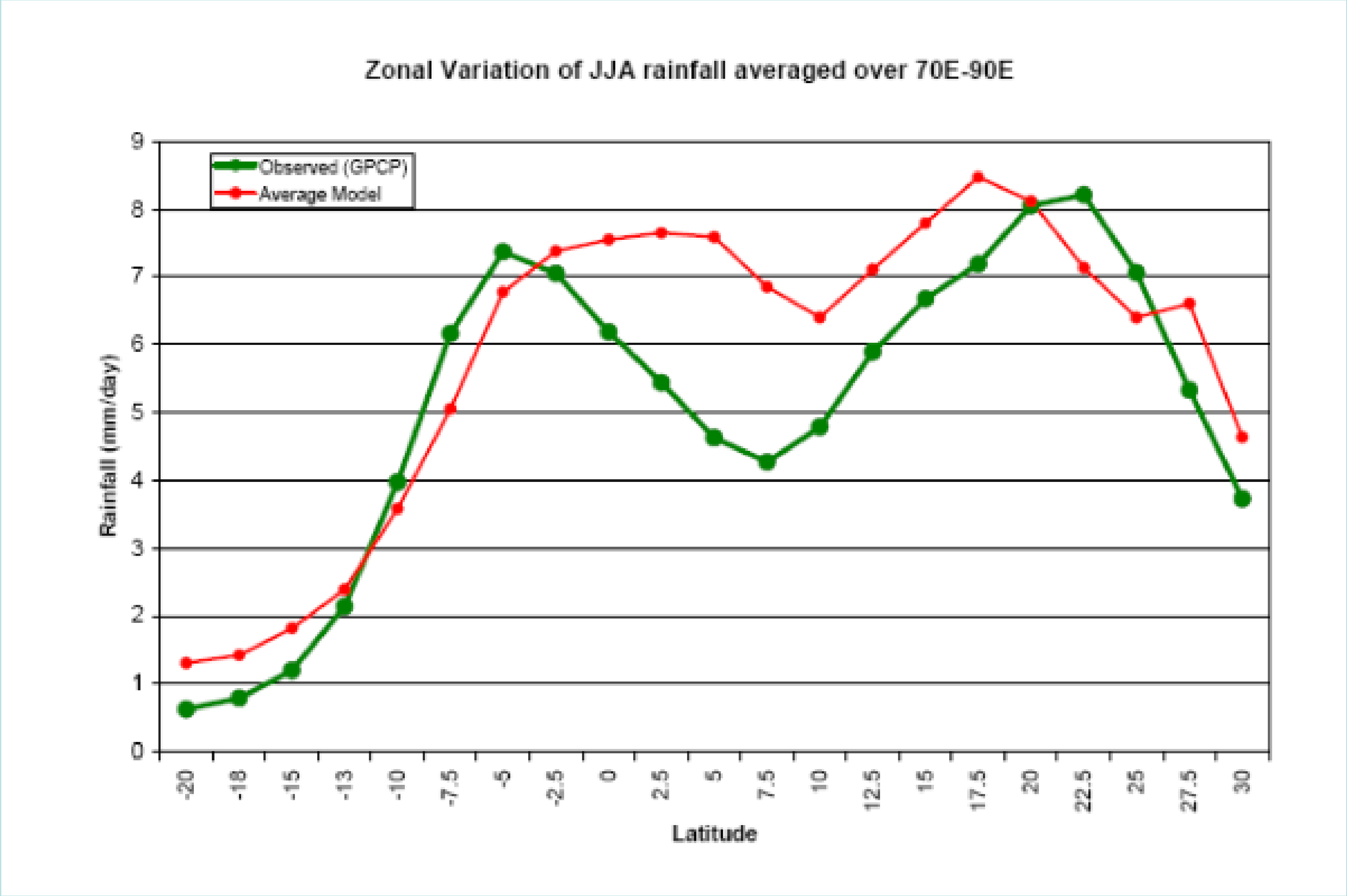


(c) CNRM



(d) UKMOHadCM3


Rainfall Annual cycle : GFDL 2.0
a)GFDL 2.0
Rainfall Annual cycle : GFDL 2.1
b) GFDL 2.1
Rainfall Annual cycle : CNRM
c) CNRM
Rainfall Annual cycle : UKMOHadCM3
d) UKMOHadCM3
Rainfall Annual cycle : CCSM3
e) CCSM3
Rainfall Annual cycle : CCCMA
f) CCCMA



Zonal Variation of JJA rainfall averaged over 70E-90E
Observed (GPCP)
Average Model
Rainfall (mm/day)
0
1
2
3
4
5
6
7
8
9
-20
-18
-15
-13
-10
-7.5
-5
-2.5
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
25
27.5
30
Latitude

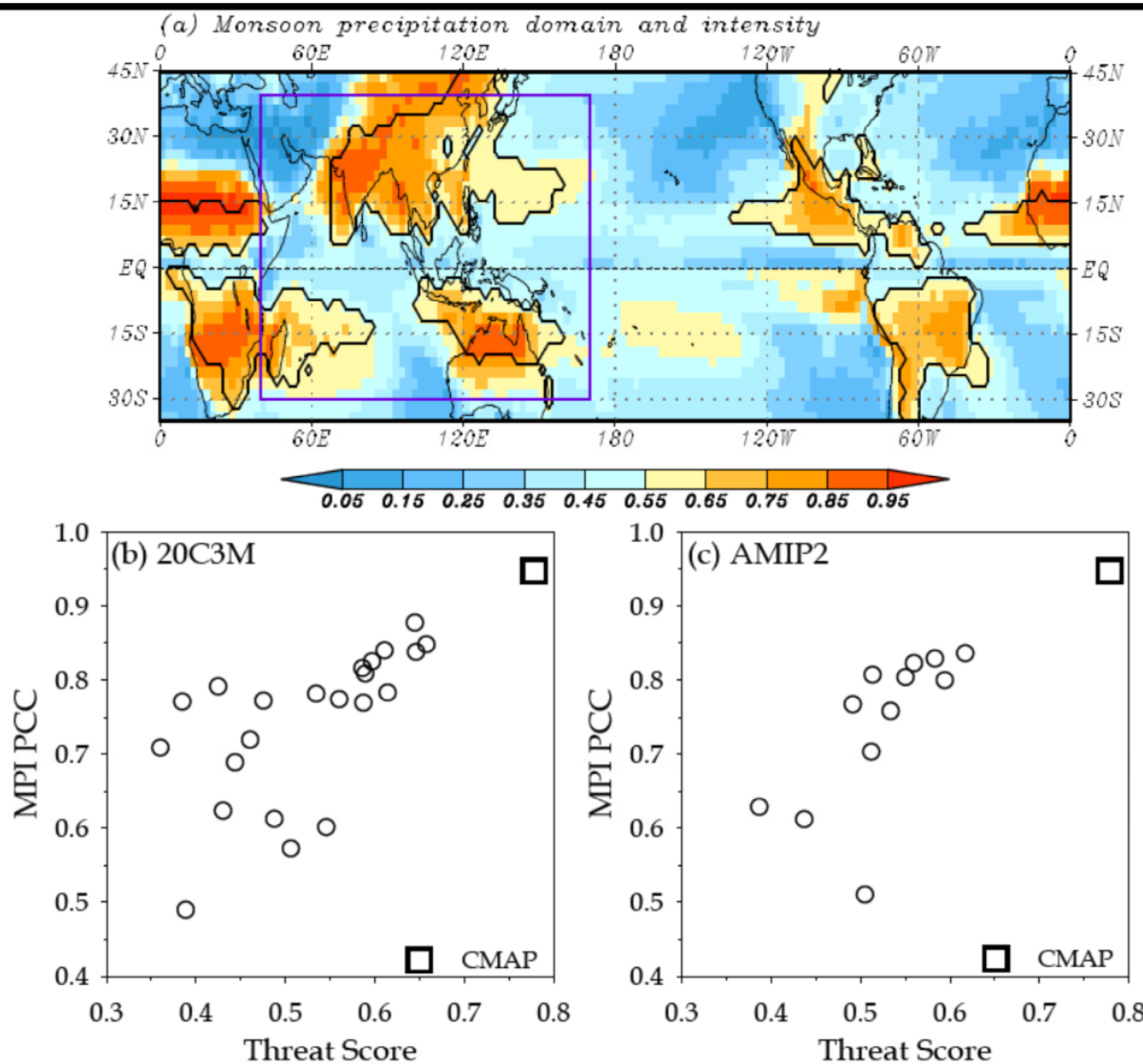
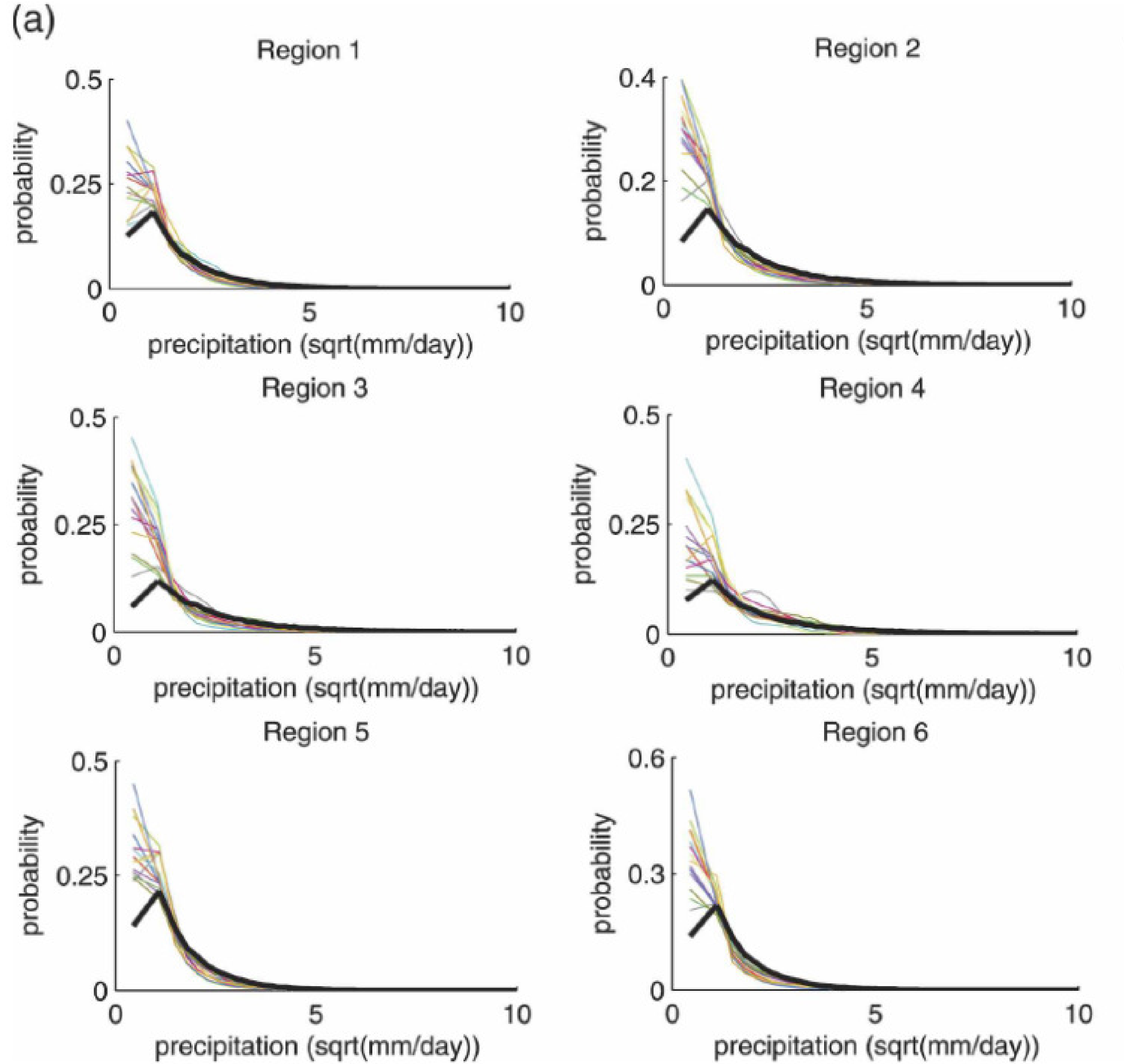


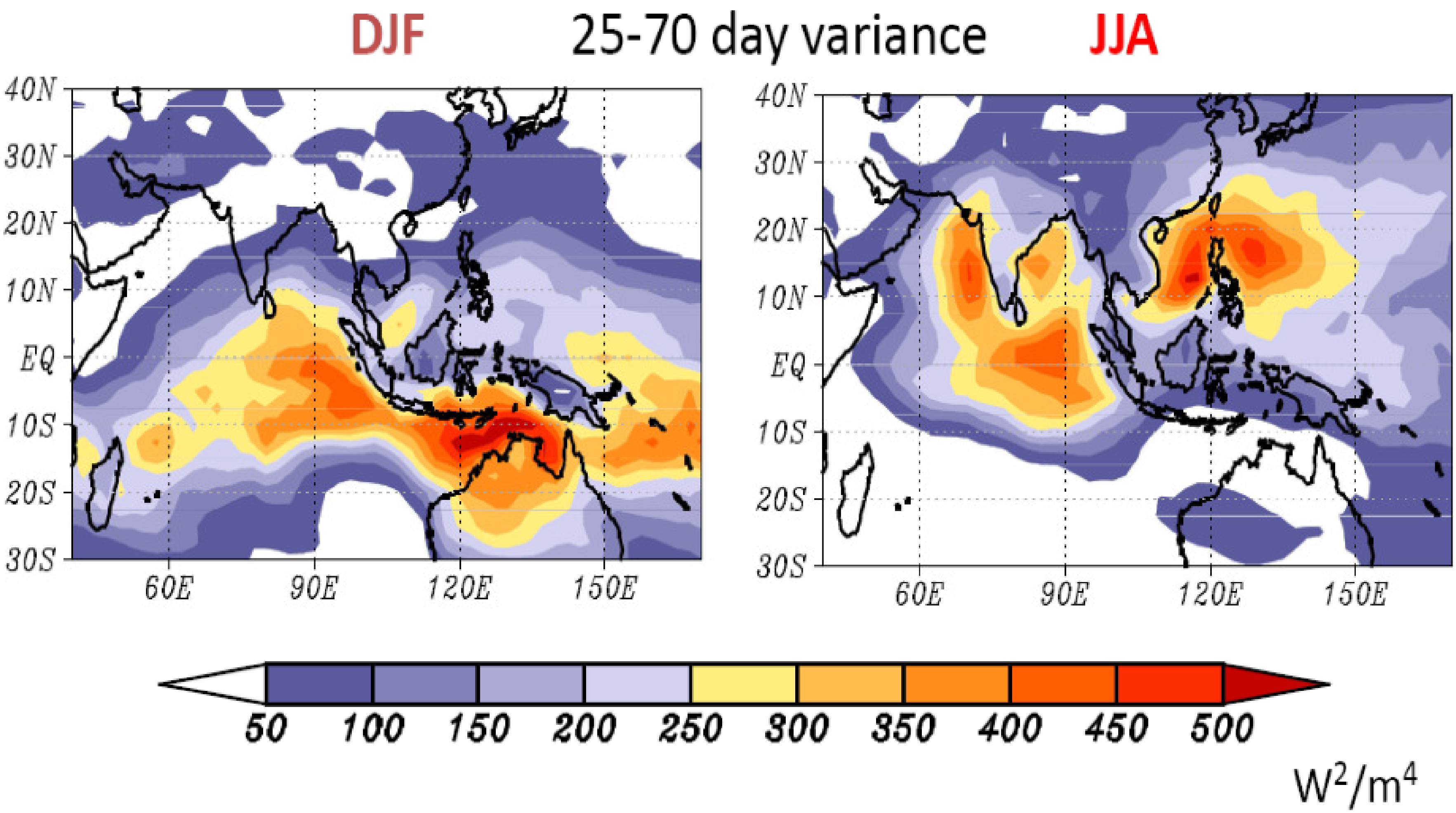
Fig. 4. (a) Monsoon precipitation domain (MPD) and intensity (MPI). The MPD was defined by the local summer minus winter precipitation rate exceeding 2.0 mm day^{-1} and the local summer precipitation exceeding 55% of the annual total. Here the local summer denotes May through September (MJJAS) for NH and November through March (NDJFM) for SH. (b)-(c) pattern correlation coefficients (PCC) for MPI and threat score (TS) for MPD over Asia-Australia monsoon regions [box in Fig. 4(a)] for 20C3M and AMIP2, respectively.

Evaluation of climate models using PDFs

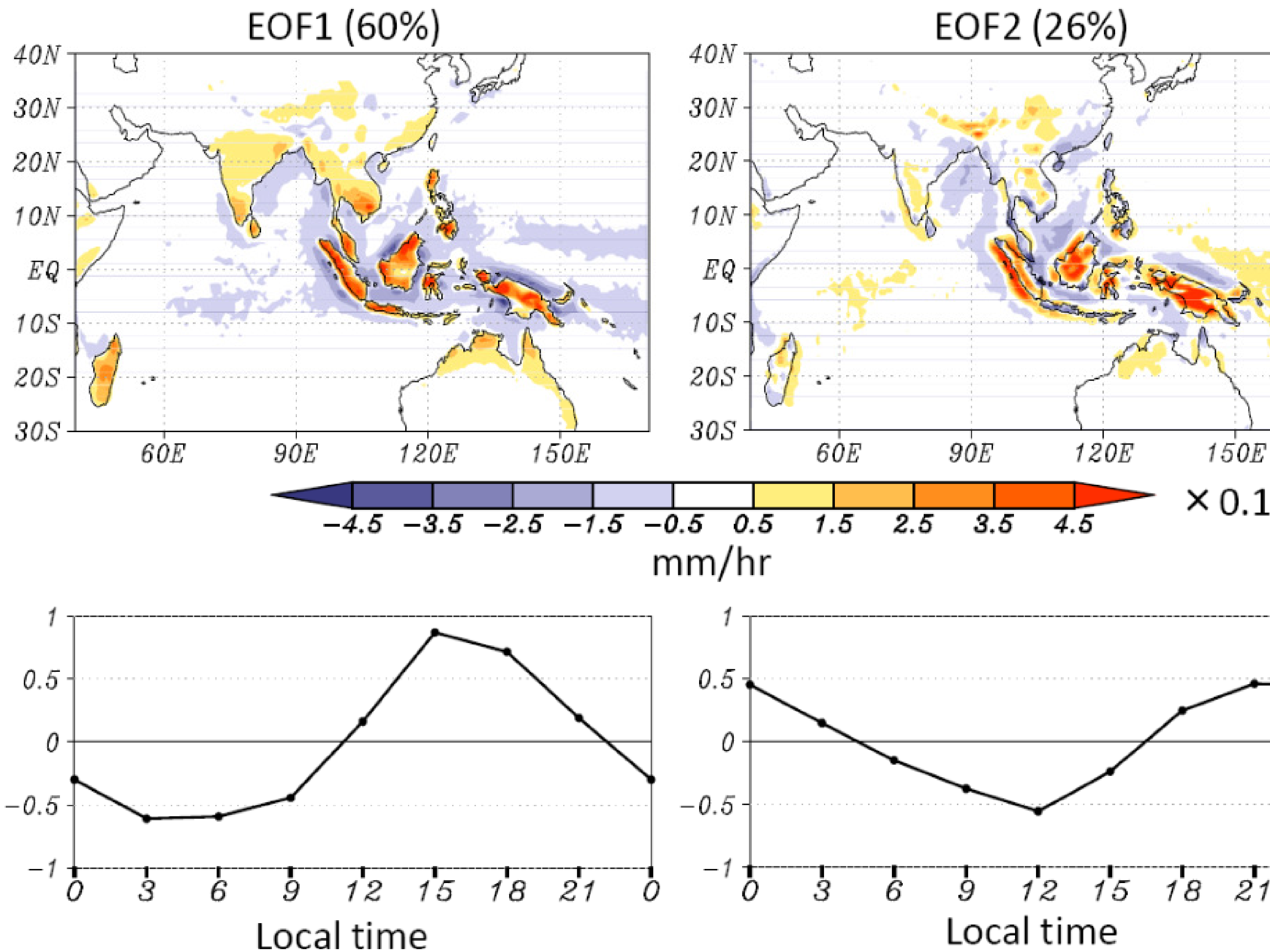


Perkins et al, 2007, J Climate

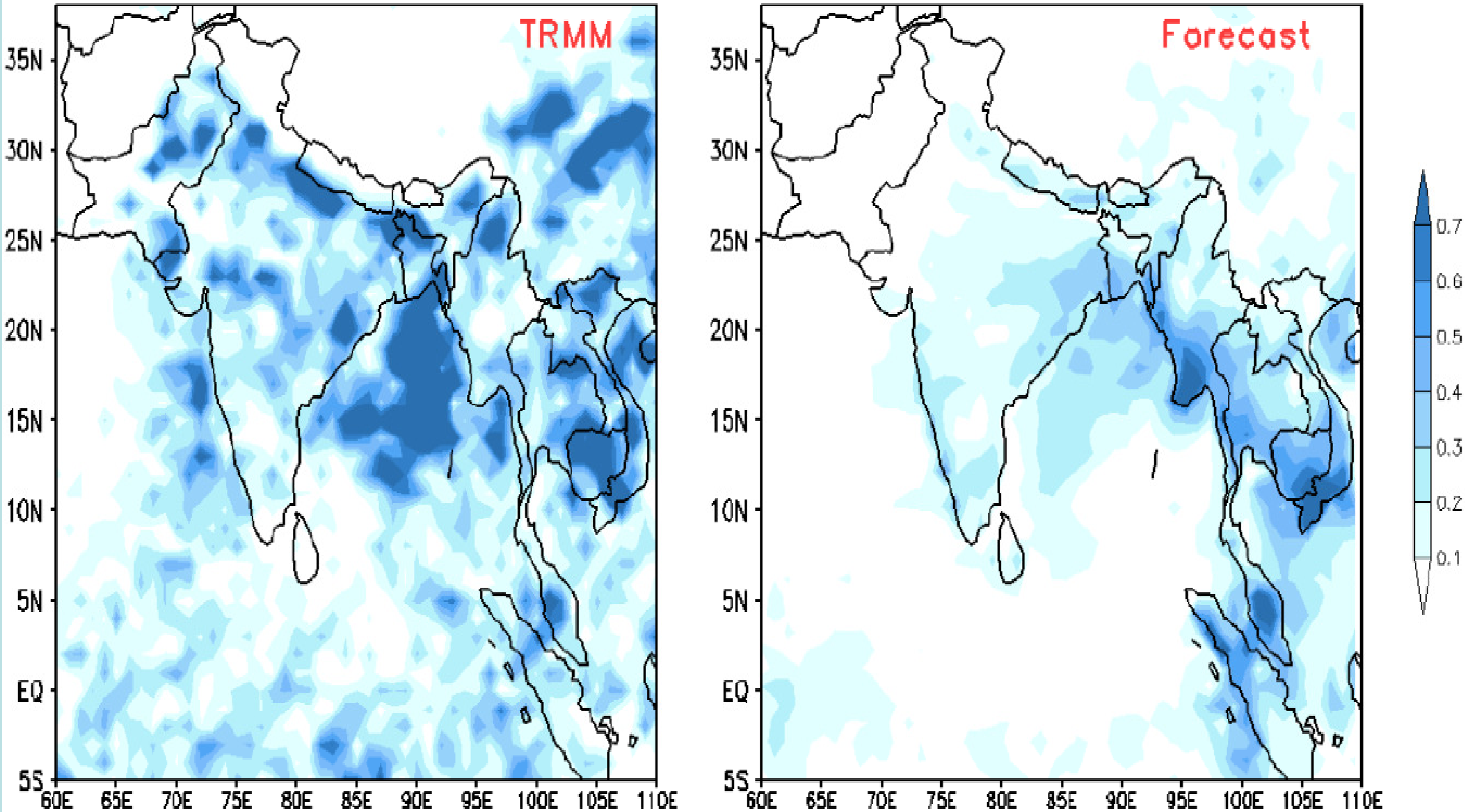
ISO variance



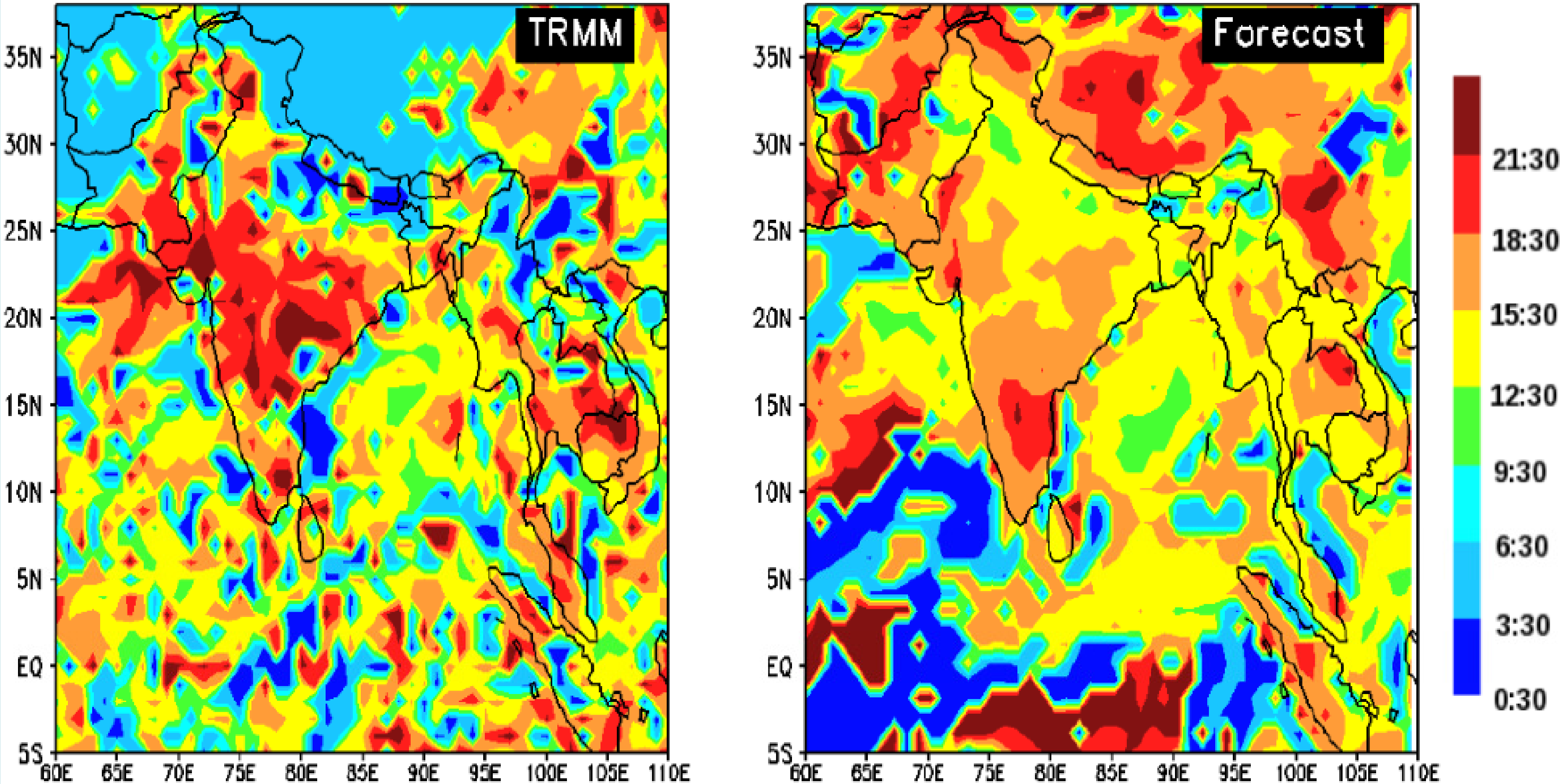
Diurnal Cycle



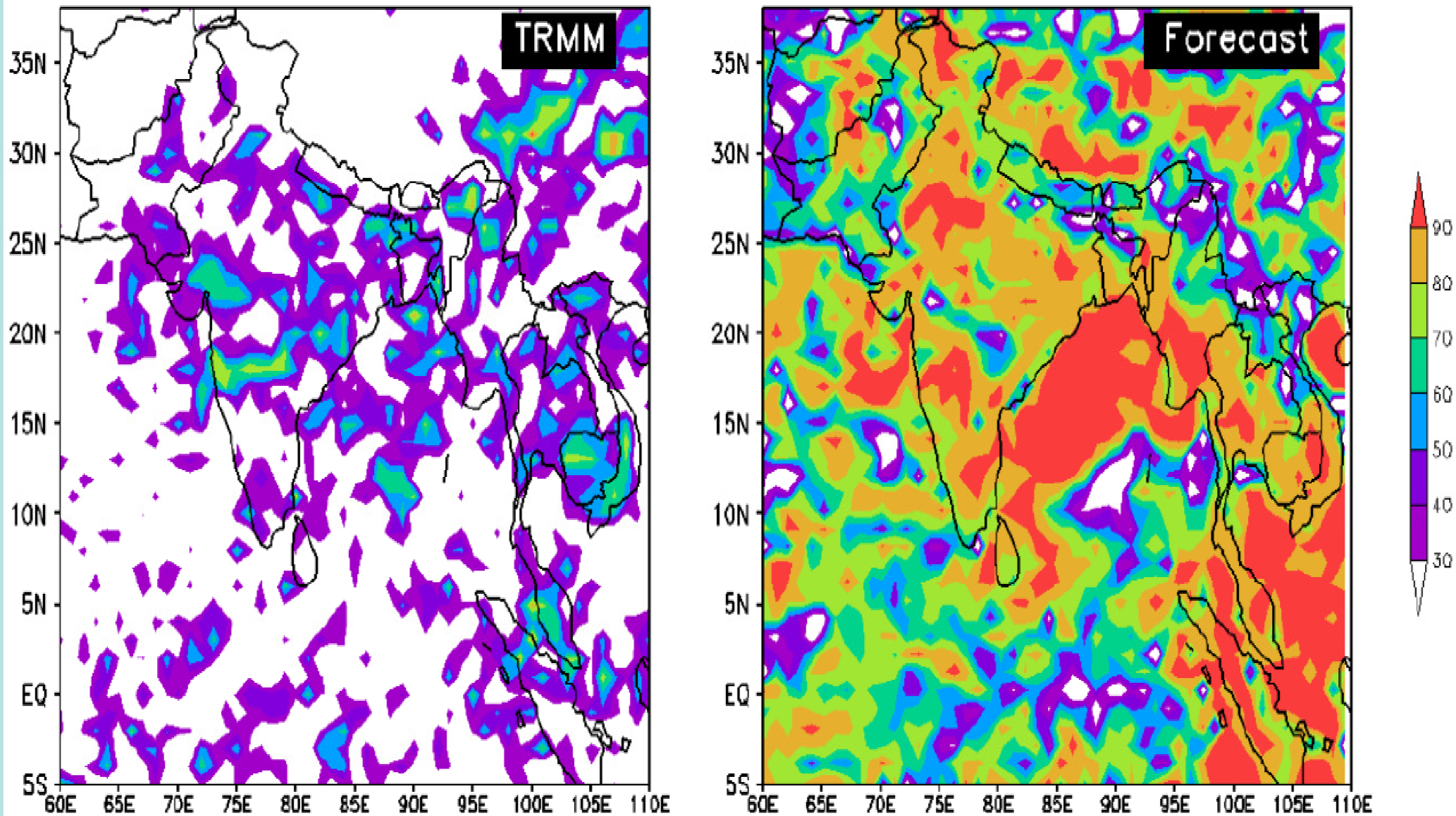
June-Sept 2009 : Amplitude of Diurnal Cycle(mm)



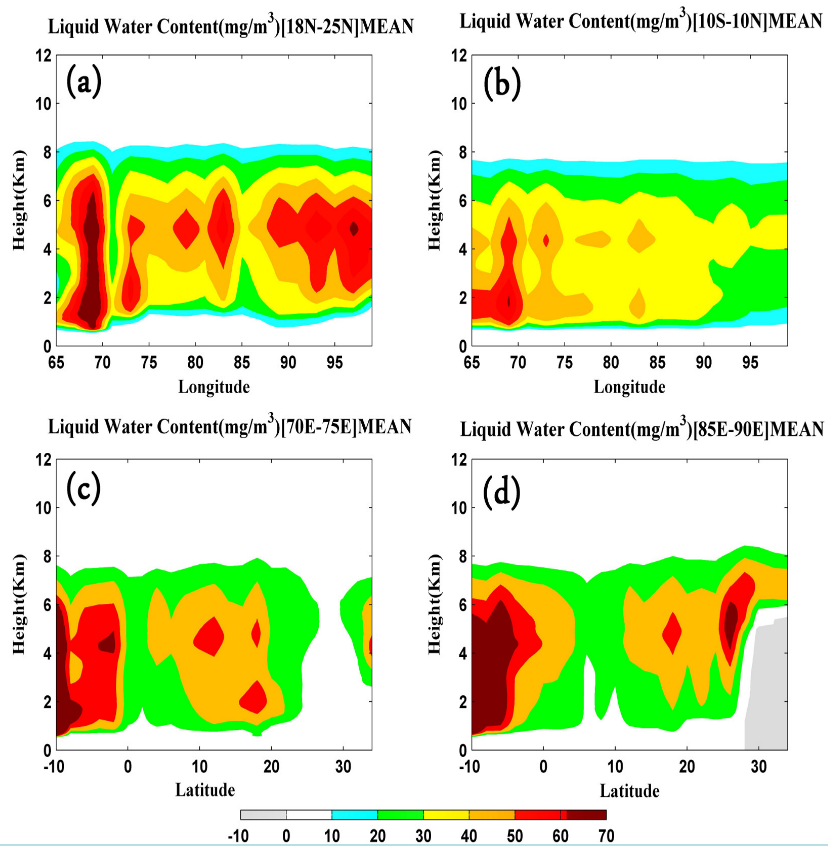
June-Sept 2009 Phase angle of Diurnal Cycle (in IST)

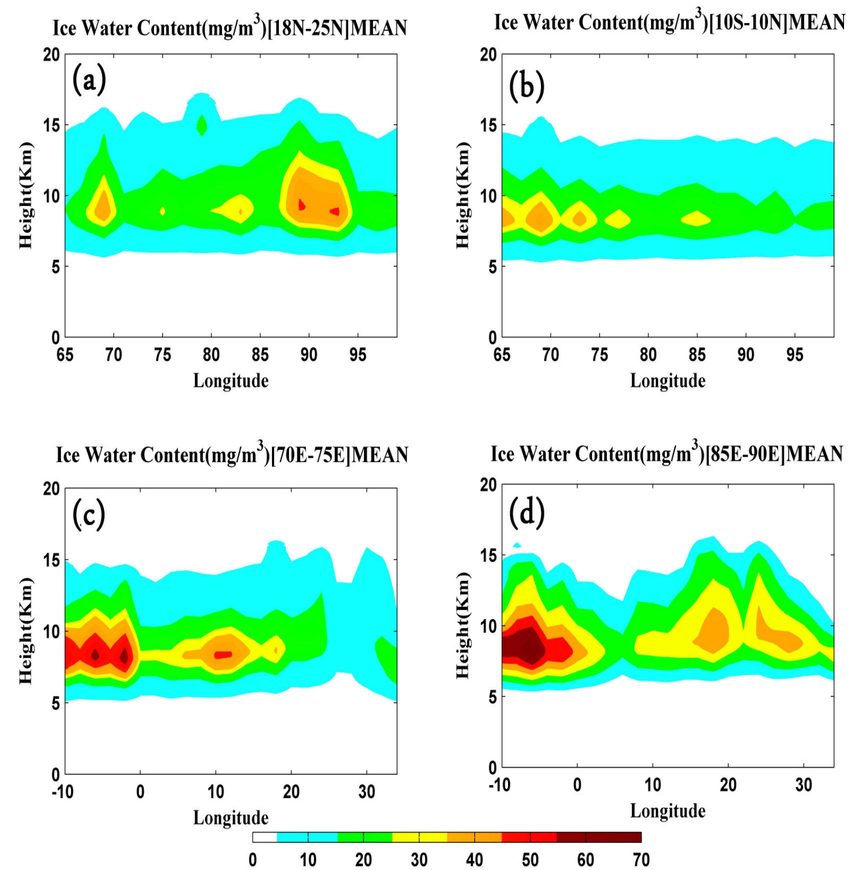


June-Sept 2009 Variance explained by Diurnal Cycle(%)



Vertical distribution of clouds: CloudSat data





Rajeevan et al. 2012, Climate Dynamics

Accurate simulation of observables does NOT guarantee reliable projections of future climate!

Thank you