INDIAN SUMMER MONSOON REGIONAL CLIMATE MODELLING CHALLENGES: DEPENDENCE ON THE CONVECTION REPRESENTATION OR GRID RESOLUTION?

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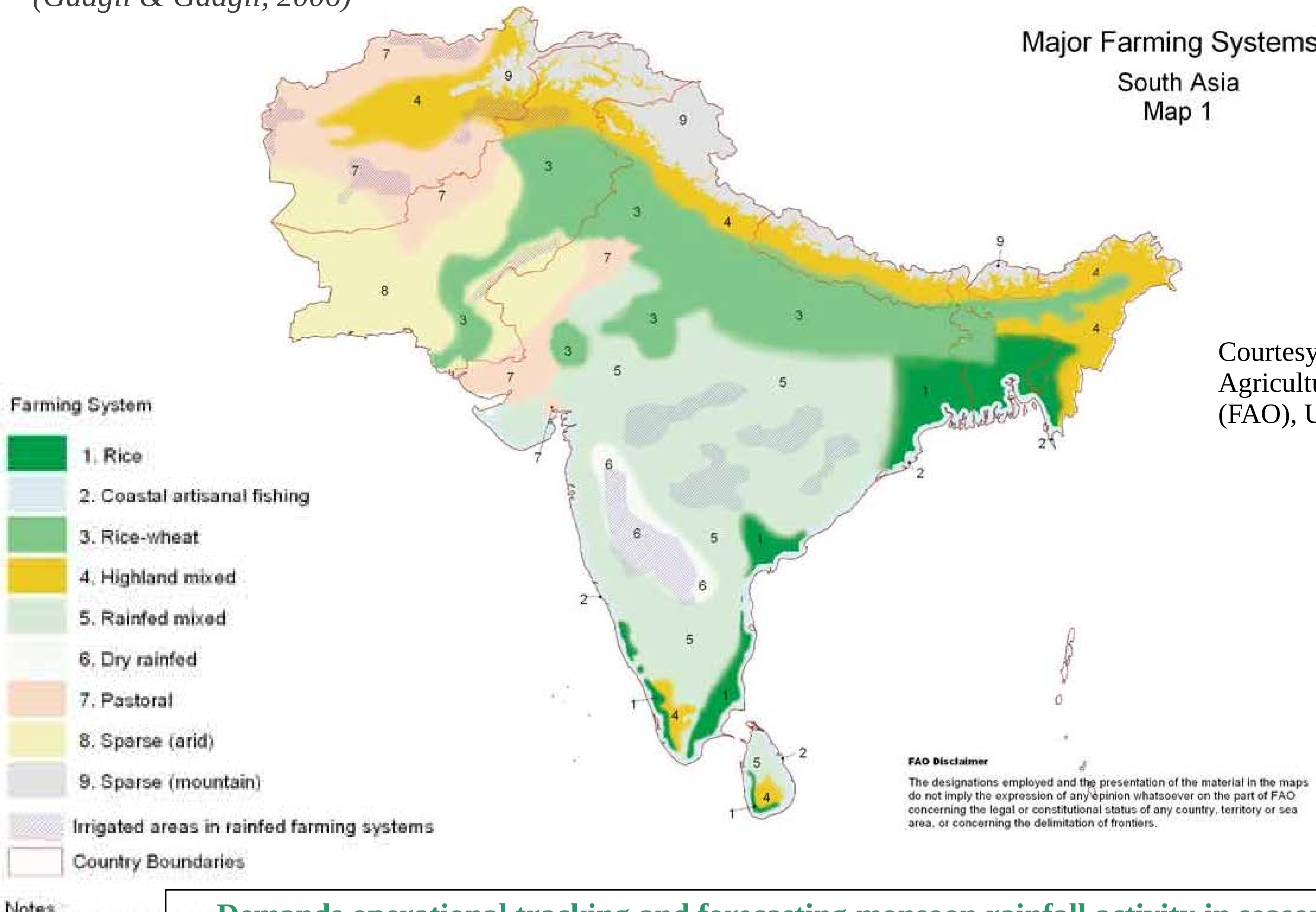
Introduction

❑ 1.7 billion South Asian population food basket and GDP totally depends upon monsoon season rainfall. *(Gadgil & Gadgil, 2006)*



Courtesy:- Food and Agriculture Organization (FAO), United Nations.

Demands operational tracking and forecasting monsoon rainfall activity in seasonal scale.

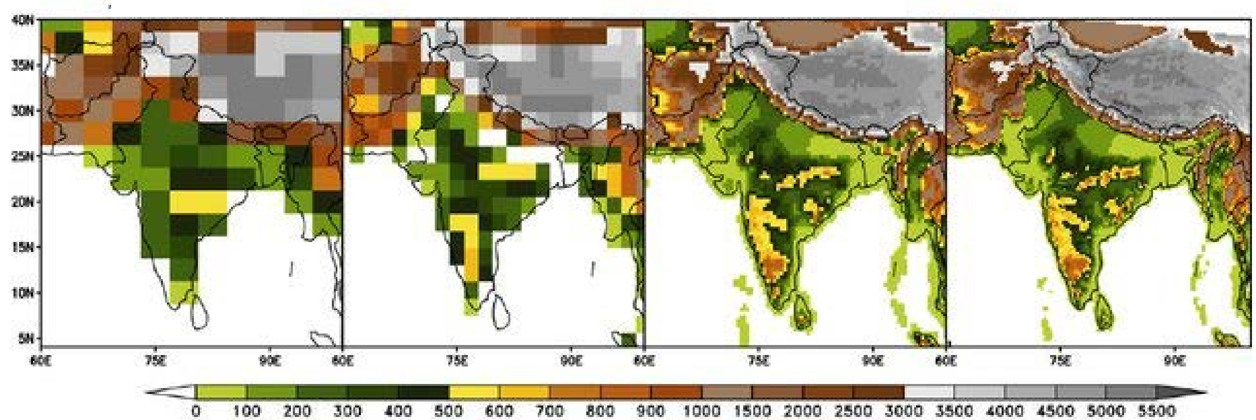
Introduction

- Efforts are underway to improve simulation and predictions using dynamical models that may have the ability to capture the monsoon seasonal rainfall and interactions.

- Discrepancies in the GCMS and RCMS in simulating regional precipitation *(Kripalani et al., 2007)*

Discrepancies

1) Representation of the orography
(Arun Kumar et al. 2005; Takahashi et al. 2016)

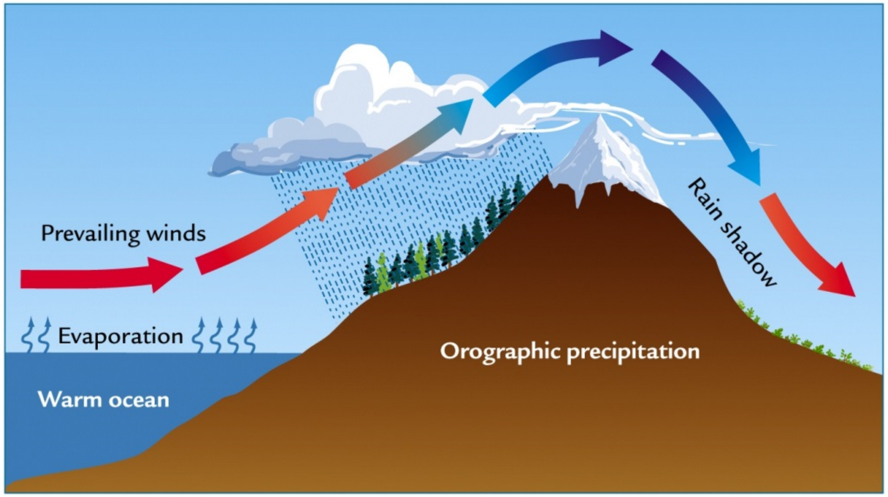


Kumar et al. 2013

✓ Improves features of the precipitation characteristics around mountains and across transition regions.

✓ Therefore, successful simulation of regional scale precipitation depends upon orography representation (grid resolution). *Sato et al. 2013; Prein et al. 2015.*

✓ But unable to simulate the phase of diurnal rainfall and regional surface feedbacks accurately. *Takahashi et al. 2016*



Courtesy : Brian Blaylock

Introduction

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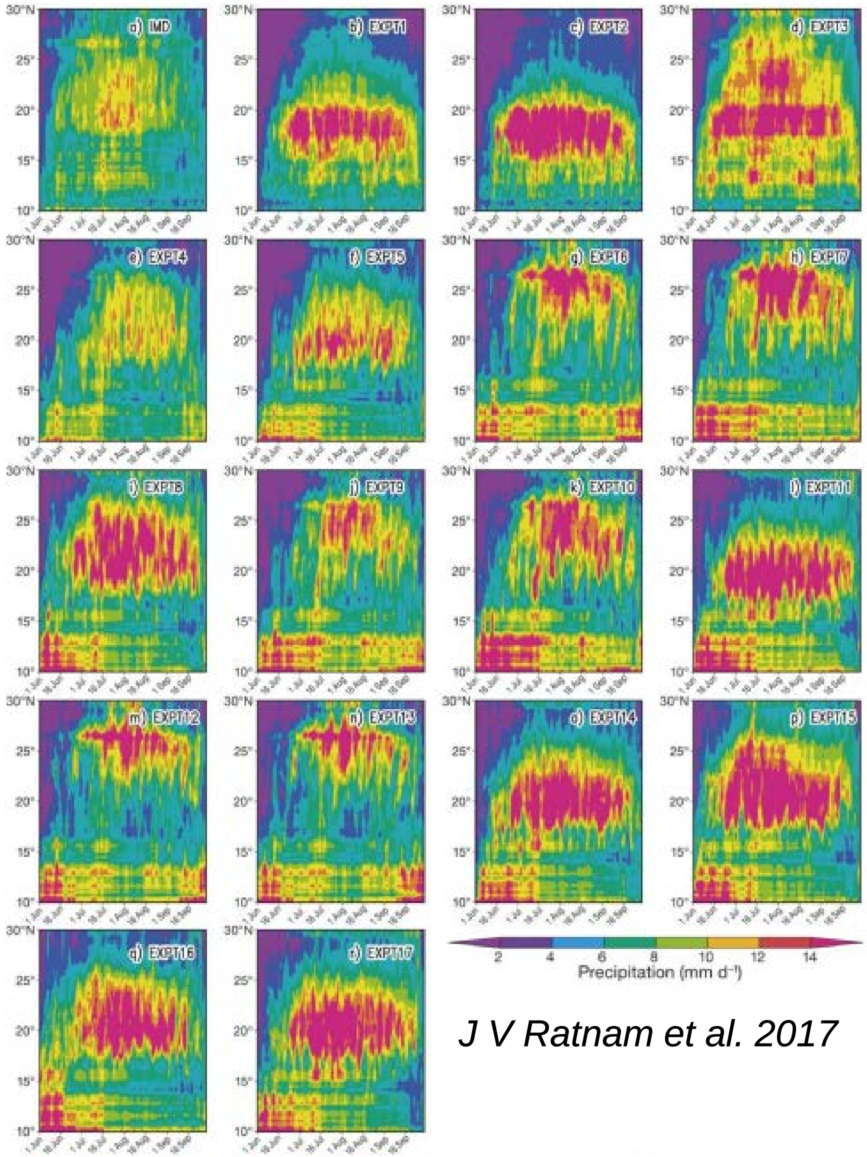
Discrepancies

2) Missing physical processes and feedbacks
(Lucas-Picher et al. 2011; Fersch and Kunstmann, 2014)



J V Ratnam et al. 2017

- ✓ Physical processes parameterization is the key source of error (Betts and Jacob, 2002)

- ✓ The sensitivity of the cumulus parameterization is investigated w.r.t. Indian summer monsoon rainfall. *(Mukhopadhyay et al. 2010; Bhaskarana et al. 2012; Srinivas et al. 2013; Devanand et al., 2017; Kim et al. 2015; Klien et al. 2015)*

- ✓ Ensemble of simulations with different parameterization has shown certain improvement in the simulation of the Indian monsoon rainfall. *(Devanand et al. 2017)*

Objective

Diurnal cycle associated with the solar forcing is the fundamental mode of variability and large contributor to the total precipitation.
(Yang and Slingo, 2001; Dai and Trenberth 2004)

✓As a result model errors affect the diurnal rainfall variations.

✓It intervene with error developments in the land-atmosphere-ocean coupled processes.

Objective

❖ In the current study diurnal cycle of rainfall is used as litmus test to know the simulation of Indian summer monsoon depends on representation of topography or representation of convection and provide a brief note on the rainfall characteristics in the convection off simulations.

Motivation

- Climate simulation of the diurnal cycle of Indian summer monsoon rainfall is a major shortcoming, which is not discussed in the literature.
- Discussion of the model grid resolution and convective parameterization on diurnal cycle of Indian summer monsoon rainfall is untouched.
- Study on continental scale convection permitting simulations of the Indian summer monsoon using climate models is not performed yet.
- *Prein et al. 2015; Takahashi et al. 2016; Roy Rasmussen et al. 2017*

Datasets and Methods Utilized

Datasets Used

1) Indian Meteorological department gridded rainfall dataset	**0.25x0.25**
2) TRMM 3B42v7	**0.25x0.25**
3) CHIRPS (Climate Hazard group Infrared precipitation with Station data)	**0.05x0.05**
4) MERRA-2 reanalysis	**0.60x0.565**
5) Era-Interim reanalysis	**0.75x0.75**

Methods.

1) Mean Absolute Scale Error (R J Hyndman, 2006; A B Koehler)

Scale Independent error calculation

$$MASE = \frac{\sum_{n=1}^{T} e_t}{\frac{T}{T-1}\sum_{n=2}^{T} |Y_n - Y_{n-1}|}$$

Where,

T = time period

$e_t = |Y_n - X_n|$, where Y_n is observational time series and X_n is the prediction time series.

2) Diurnal Cycle computation by using Harmonic Analysis

$$f(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} [a_n \cos(n\omega t) + b_n \sin(n\omega t)]$$

Where,

$a_n = \frac{2}{T}\int_0^T f(t)\cos(n\omega t)\, dt$, for n=0,1,2,3,…

$b_n = \frac{2}{T}\int_0^T f(t)\sin(n\omega t)\, dt$, for n=0,1,2,3,…

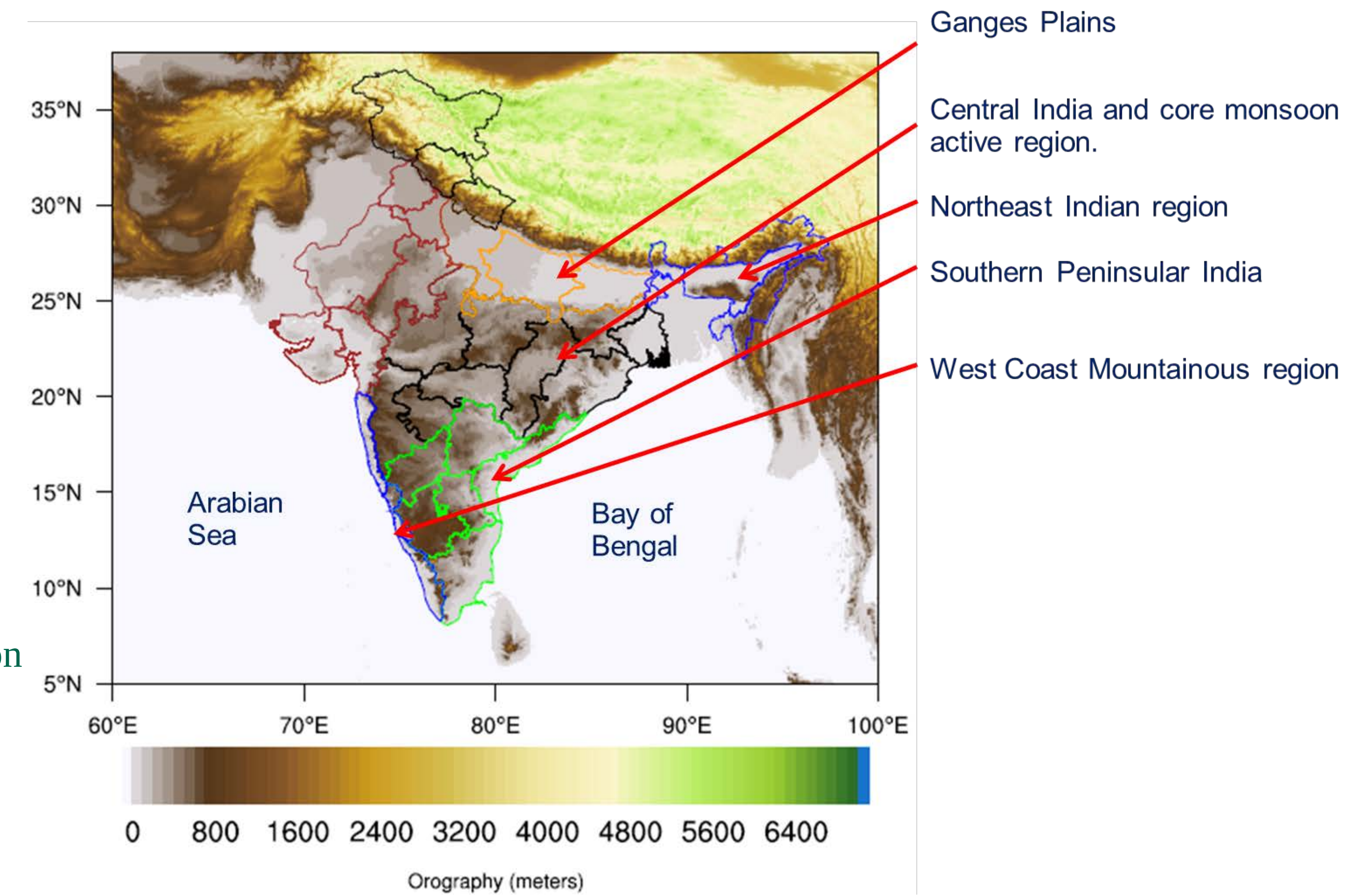
T= 0,1,2,3,4,5,6,7 time steps with 3 hour difference.

Model simulation and analysis description

WRF simulations of Indian monsoon

✓**Initial and Lateral boundary conditions**
➢ERAI 1.5°x1.5°
➢OISST

✓ **Model utilized schemes**
➢**MYJ** Boundary Layer Scheme
➢ **KF** cumulus parameterization
(In case of convection on)
➢**WSM6** microphysics scheme
➢**Noah land SM**
➢**38 Vertical eta model levels**
➢ **No Spectral Nudging**



✓**Simulation duration**
o 01st April 2012 to 31st October

o For contrasting years of monsoon
1994 & 2007 – Flood year
2009 - Drought year
2012 – Normal year

✓**WRF grid size (No nesting)**
25 km, 12.5 km, 6.25 km

✓**Experiments**
•**Two experiments each with convection on (CON) and convection off (COFF)**

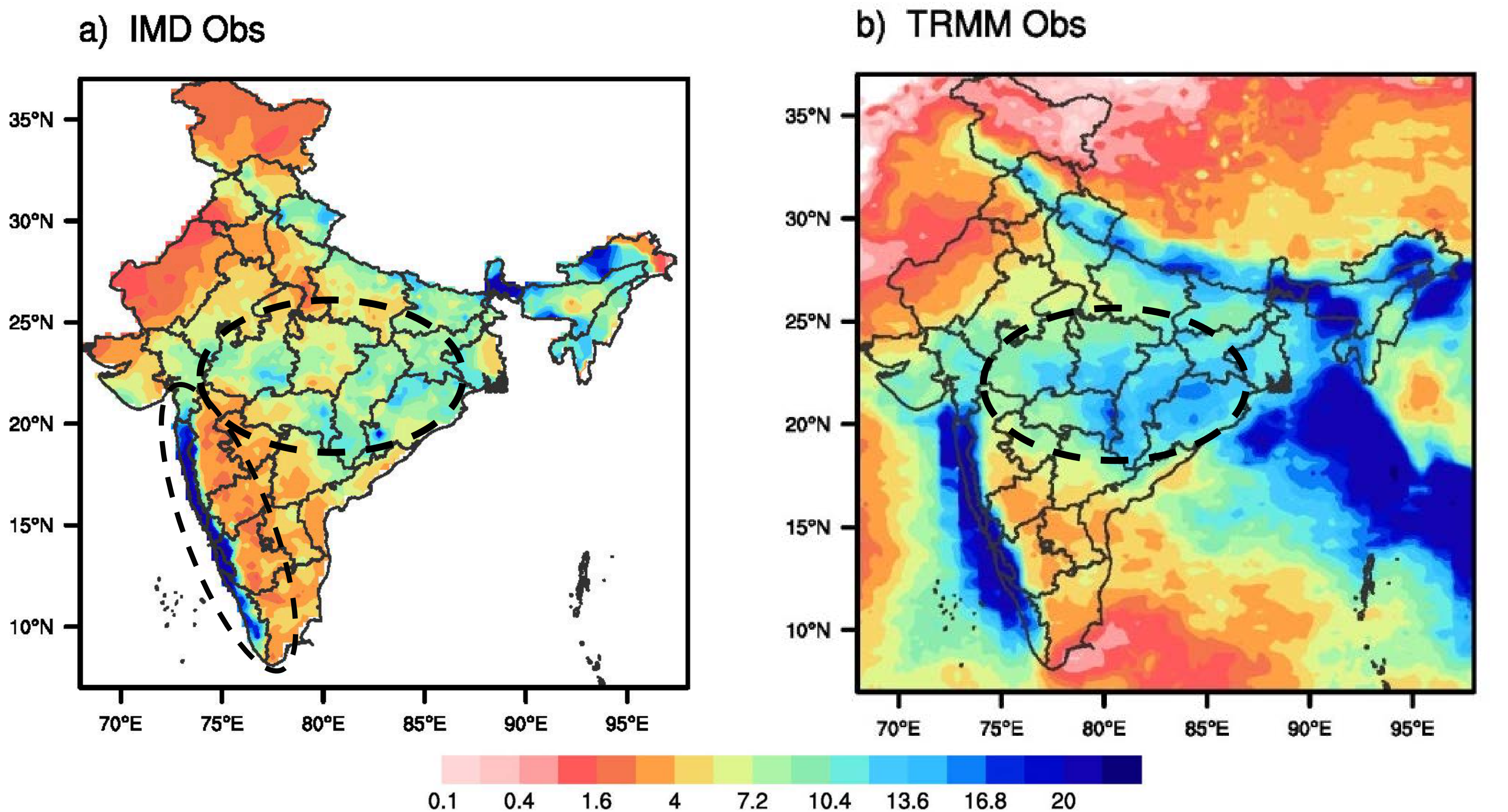
✓**Analysis is done on July-August peak monsoon season mean of the 3 contrasting years**.

- Systematic biases in convection on/off simulations

3 contrasting year Jul-Aug mean is analyzed for

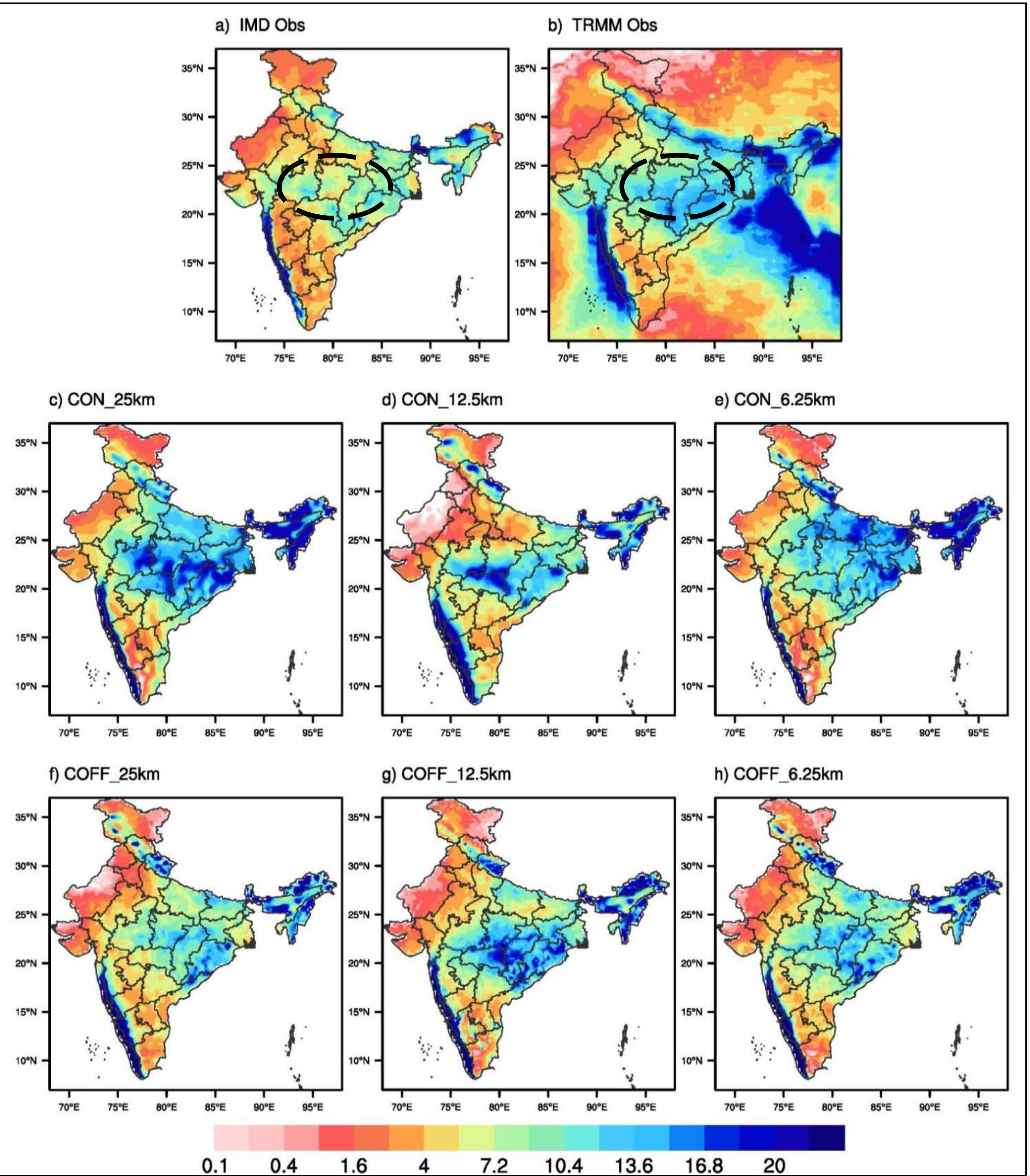
ERA-interim and WRF RCM output at 25, 12.5 and 6.25 km resolution

July-August Peak Monsoon Rainfall



- ✓ Central India is the core monsoon region with rainfall around 7-10 mm/day.
- ✓ Wester coast of India receives heavy rainfall from orographic precipitation.
- ✓ Northeastern India and Himalayan foot hills as well receives higher precipitation with orogenic in origin.
- ✓ Bay of Bengal receives most of the rainfall due to mesoscale convective systems.

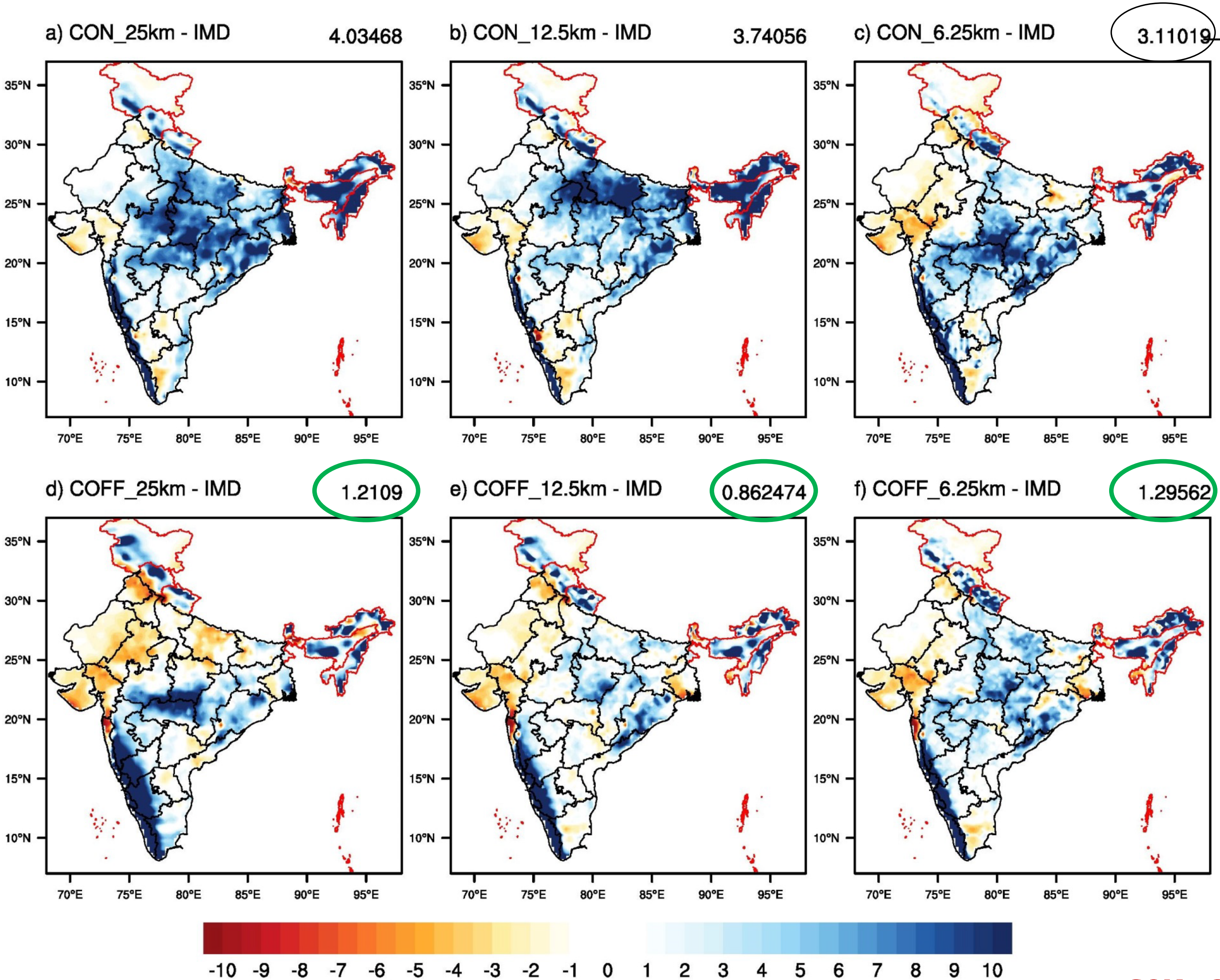
Peak Monsoon Rainfall with model simulations



- ✓ Monsoon rainfall over western Ghats and northeast India shows wet bias.
- ✓ Central India exhibits wet bias in CON and bias totally reduced in COFF.
- ✓ Ganges plains exhibits dry bias , which is more pronounced in CON_12km simulations.
- ✓ COFF simulations over Ganges plains well simulated.
- ✓ Overall, rainfall simulation by WRF model is close to the IMD observations except with some dry/wet biases

CON:- Convection Parameterized
COFF:- Convection Permitting.

Model rainfall biases



Bias

- ✓ Ganges plains exhibits dry bias , which is more pronounced in COFF simulation.
- ✓ Southern peninsula wet bias is mostly observed in the COFF simulations than in CON.
- ✓ Overall, rainfall simulation by WRF model is close to the IMD observations except with some dry/wet biases

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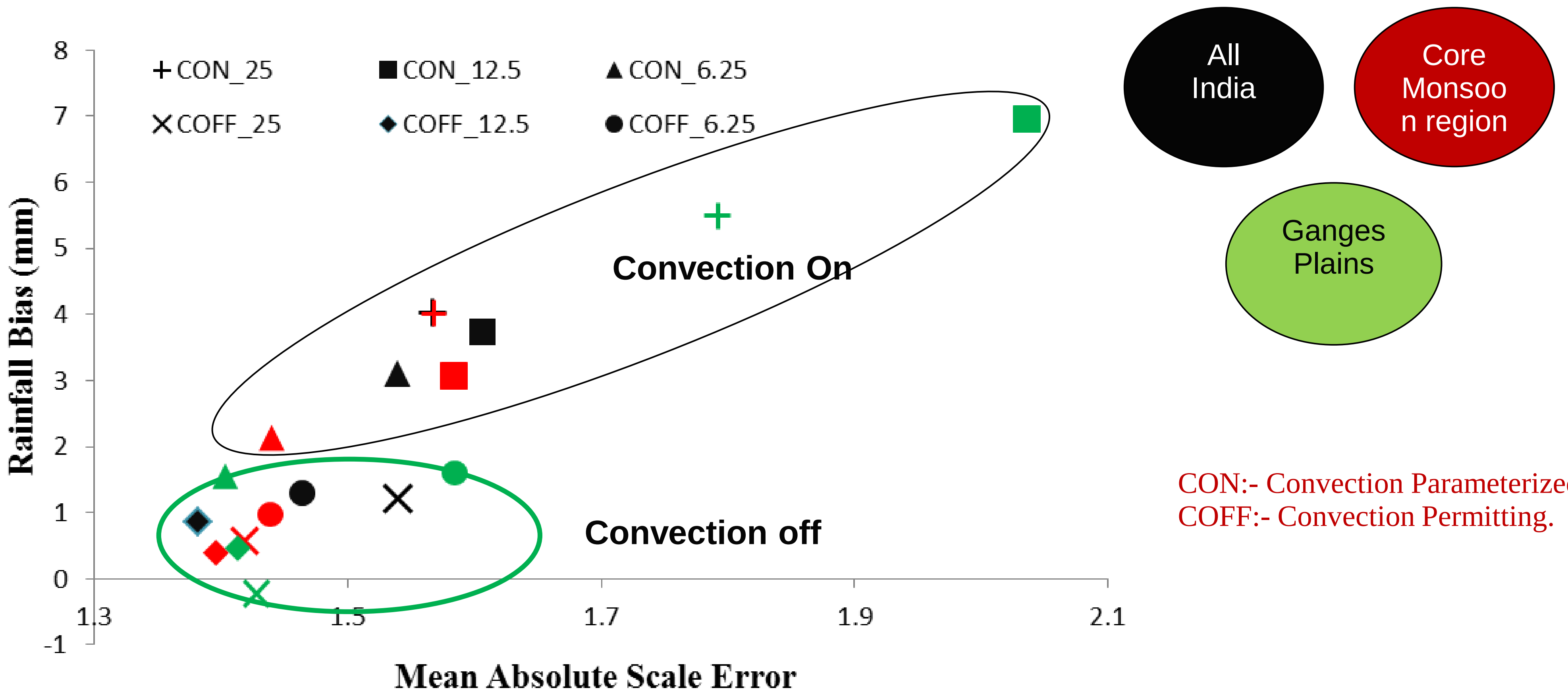
Overview of rainfall biases



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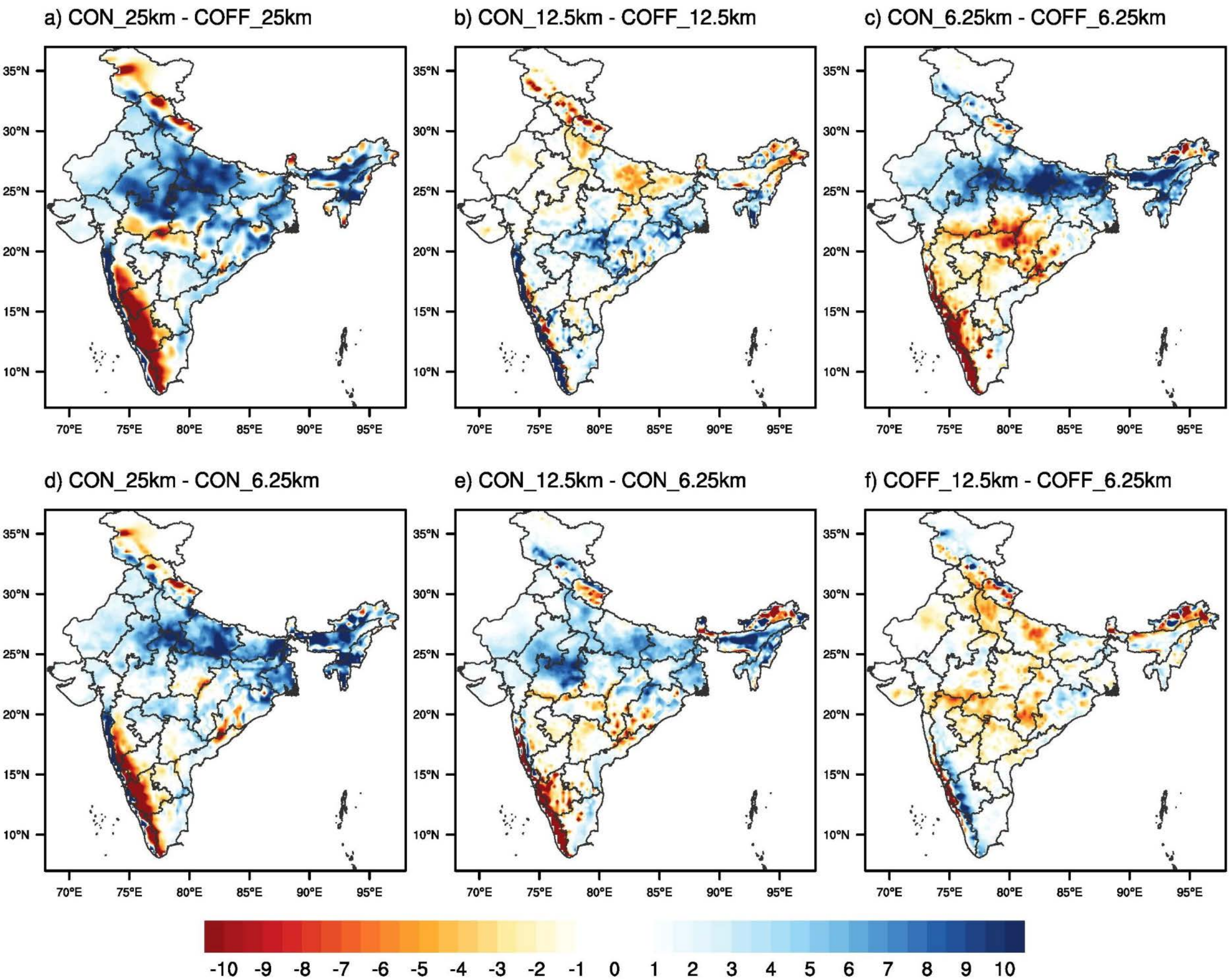
- ✓ **Central India rainfall bias is very less and close to the observations in COFF**
- ✓ **ALL India wet bias is mostly reduced in the COFF simulations than in CON.**
- ✓ **Overall, rainfall simulation is close to the IMD observations except with slight dry/wet biases and low MASE in cases of COFF experiments.**
- ✓ **It very clearly exhibits the added value and capability of the COFF at high resolution as compared to CON.**

Improvement in the rainfall in COFF



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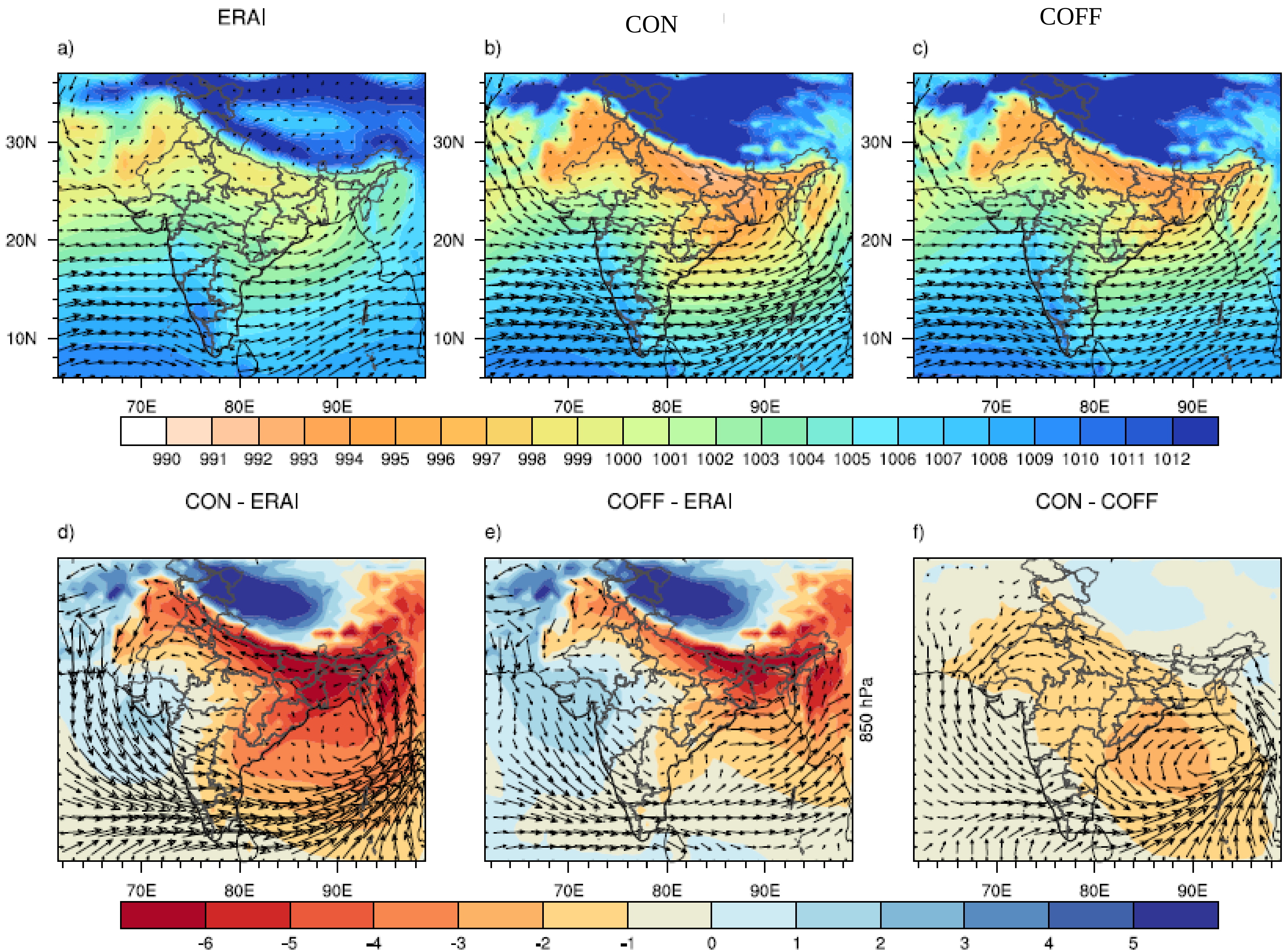
850 hPa Winds and MSLP bias (12km)



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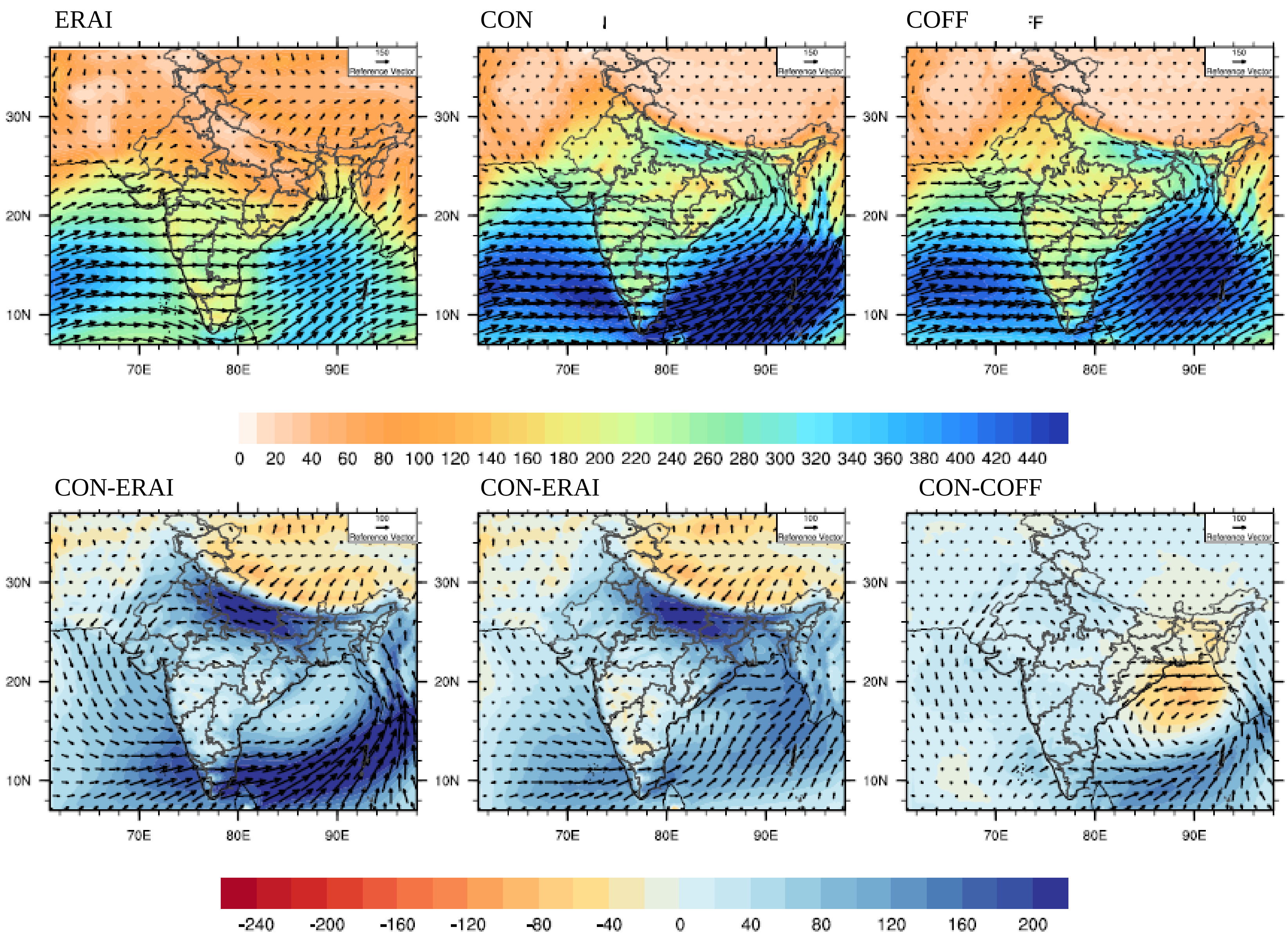
- ✓ Background color represent mean sea level pressure (hPa).
- ✓ Vectors shows wind direction with size of it represents magnitude of wind
- ✓ 850 hPa winds are very strong with cyclonic circulation in CON, but same bias has decreased in COFF.
- ✓ Strong Southeasterly is seen over Ganges plains in CON.
- ✓ MSLP has very strong gradient over land, bay of Bengal and southern Arabian sea in COFF as compared to CON and ERA.
- ✓ It results in strong monsoon trough over central India.

Vertically integrated moisture flux transport bias (12km)

$$\overrightarrow{\mathrm{VIMFT}} = \frac{1}{g}\int_{ptop}^{psurf} q\vec{U}\,dp \;;\; \left|\overrightarrow{\mathrm{VIMFT}}\right| = \sqrt{\left(\overrightarrow{\mathrm{VIMFT}}\right)^2}, \textit{where } q \;= \textit{specific humidity}\,\frac{kg}{kg}$$

$$\vec{U} = \textit{horizontl wind}\,\frac{m}{sec}$$

$$\mathbf{g} \;= \text{acceleration due to gravity } 9.8\ m/sec^2$$



- ✓ Background color represent Vertically integrated moisture flux transport magnitude (Kg m-1 s-1).
- ✓ Vectors represent Vertically integrated moisture flux transport magnitude (Kg m-1 s-1).
- ✓ VIMFT is positively biased in COFF and CON over central India, Ganges plains, northwest India southern Arabian Sea, and Bay of Bengal.
- ✓ Negative bias of VIMFT over southern peninsular India in COFF.
- ✓ VIMFT is very strong over Ganges plains, and over southwesterly branches of winds in Arabian sea and Bay of Bengal in CON. Same bias is reduced in COFF.

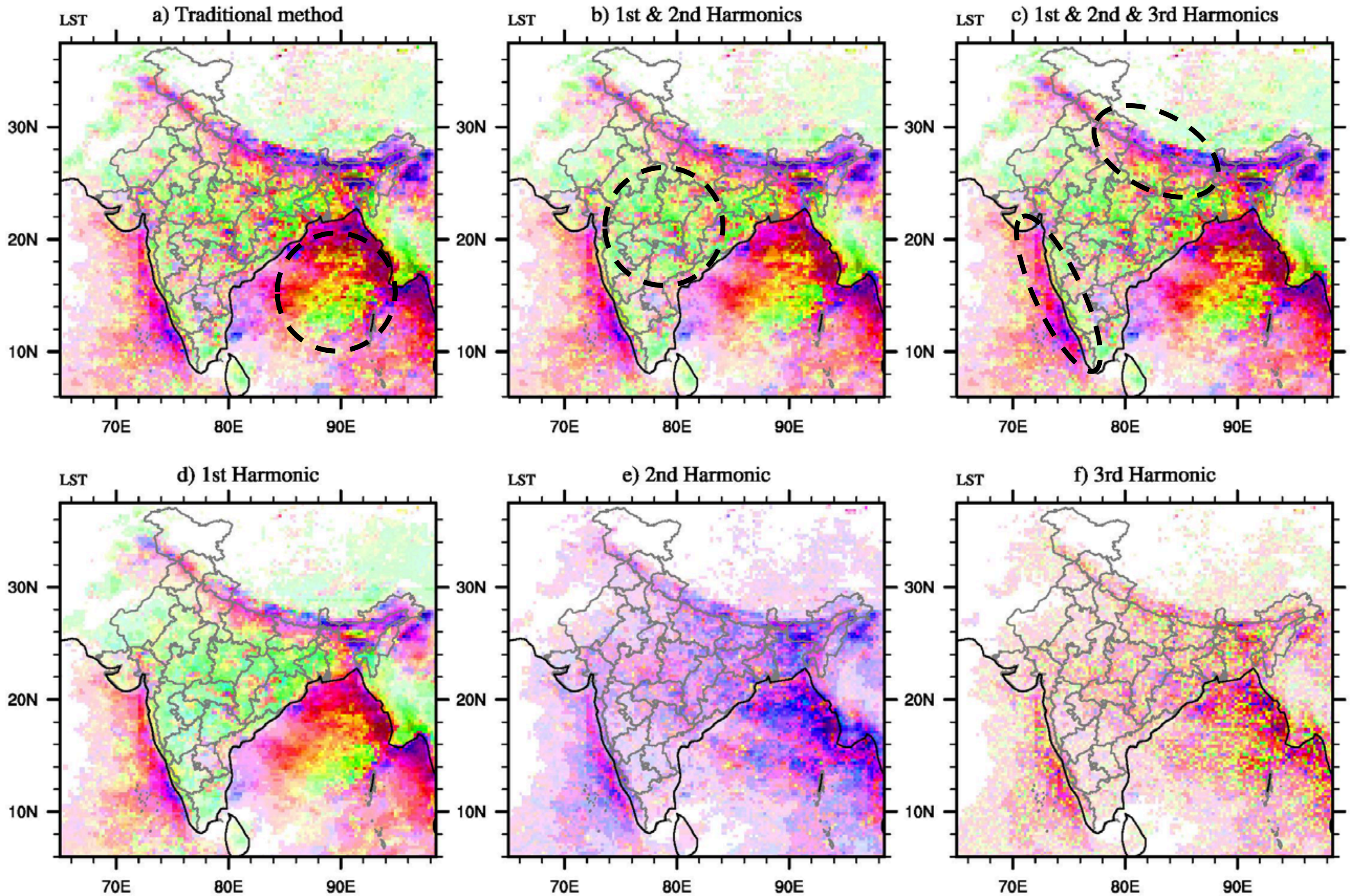
❑ Diurnal cycle perspectives during the peak monsoon season

- ✓ First three harmonics were considered to get the complete diurnal cycle.
- ✓ Diurnal amplitude = Diurnal maxima – Diurnal minima.

Diurnal cycle computation by using harmonics.

- ✓ Color wheel in clockwise direction shows Local Solar Time (LST) .
- ✓ The magnitude ranges from 0.1-1.6 mm/hr from center of wheel till edge

Jul-Aug Ensemble TRMM



- ✓ Late afternoon/evening rainfall over central India.
- ✓ Himalayan foothills shows early morning/morning rainfall.
- ✓ Off the western coast of India has peak in the early morning/morning.
- ✓ Importantly center Bay of Bengal has rainfall peak in the afternoon.

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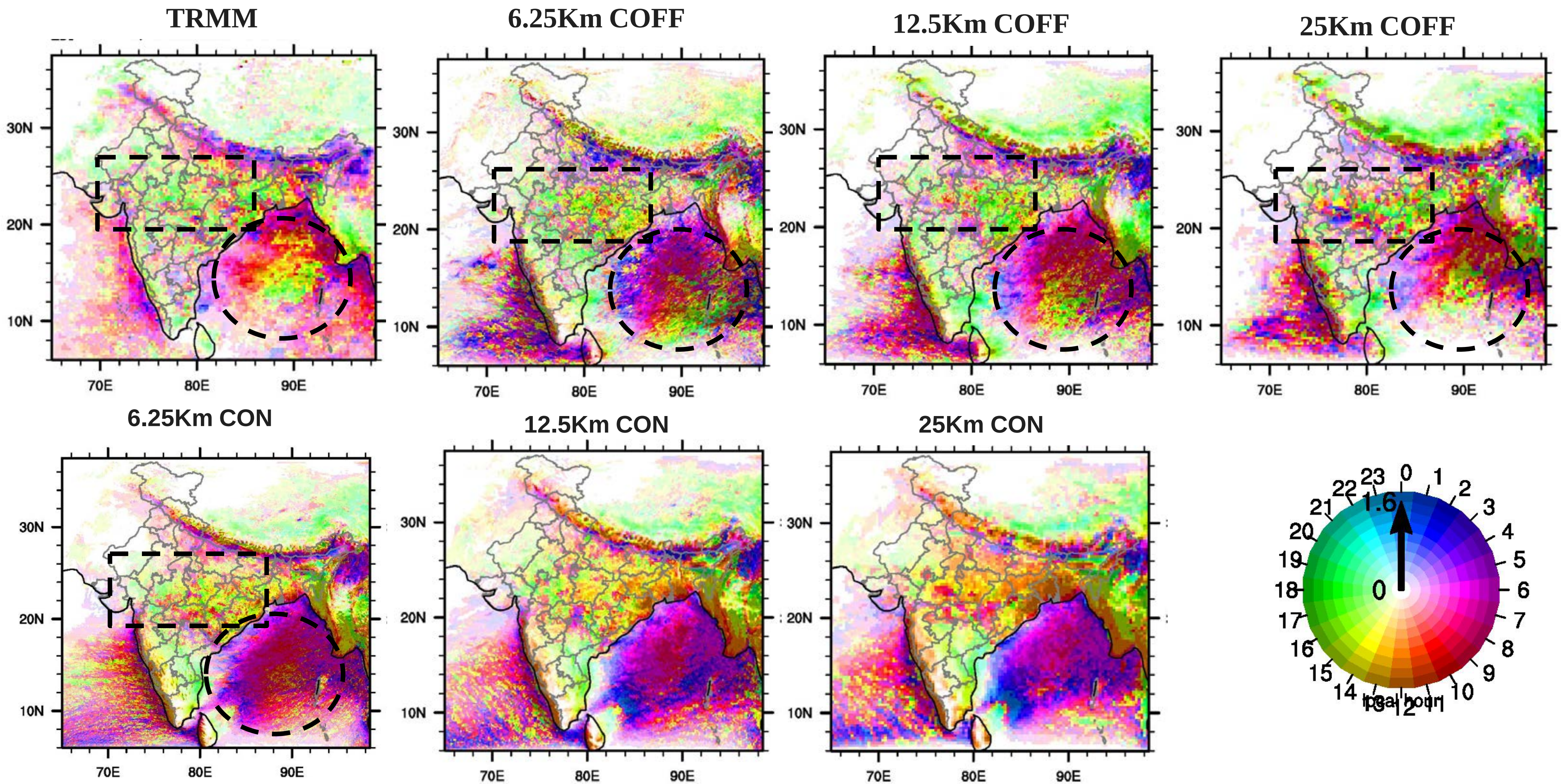
Diurnal cycle of observation and model simulated rainfall



- ✓ **Afternoon/evening rainfall over central India is clearly seen in COFF_6.25km simulation.**
- ✓ **CON simulations shows peak in the noon/late morning over central India.**
- ✓ **Diurnal peak over Himalayan foothills is around morning, unlike COFF and TRMM.**
- ✓ **Diurnal peak over center Bay of Bengal around afternoon is rightly simulated in COFF but displaced to further south.**
- ✓ **Afternoon peak over Bay of Bengal is absent in all CON simulations**

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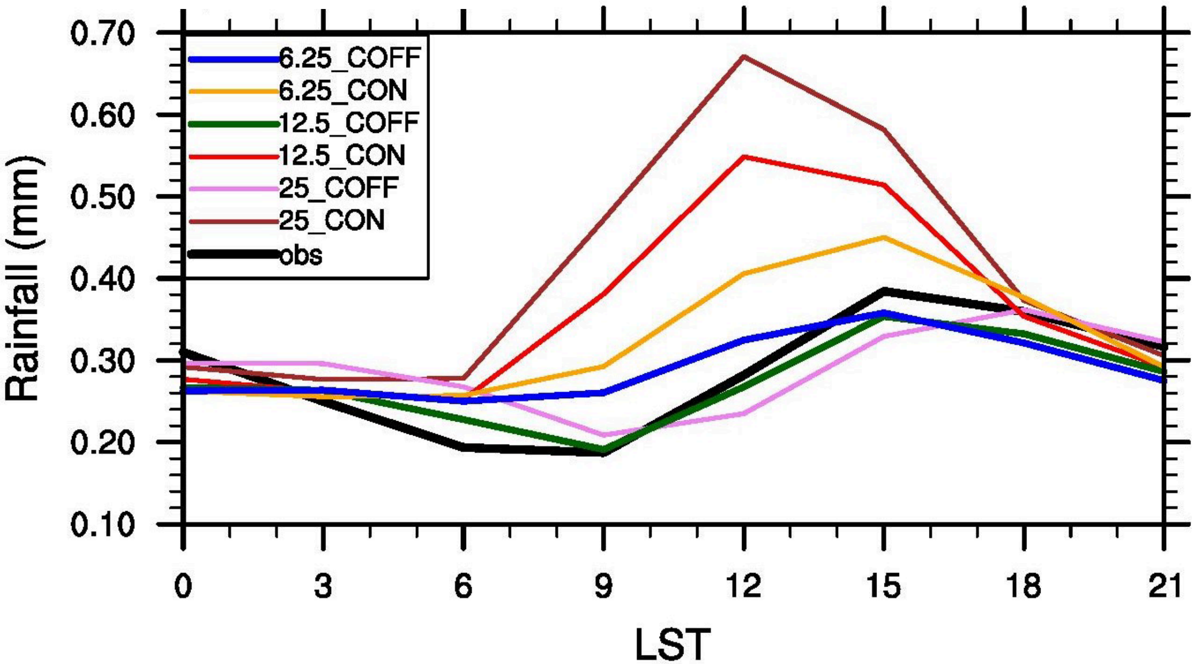
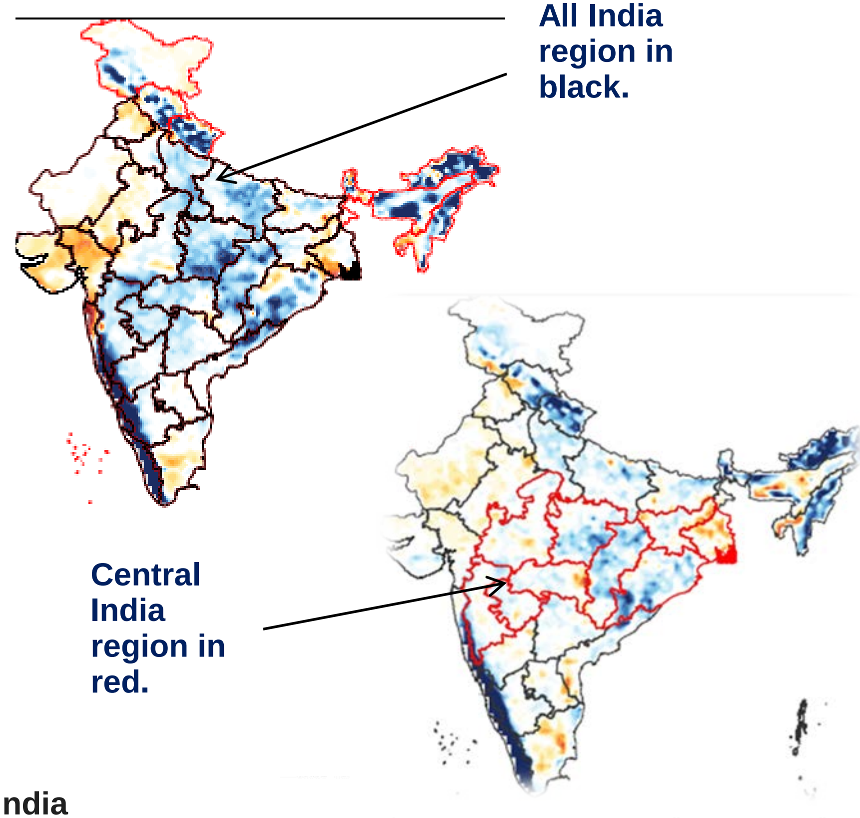
Diurnal cycle of rainfall

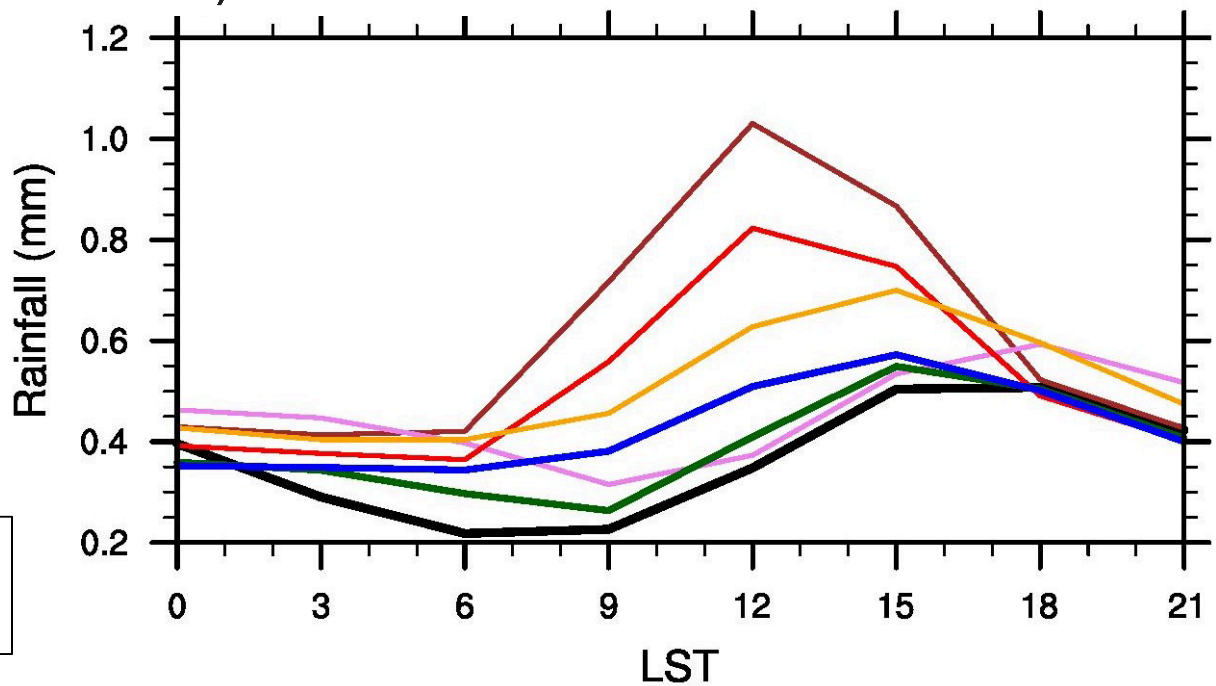
a) All India



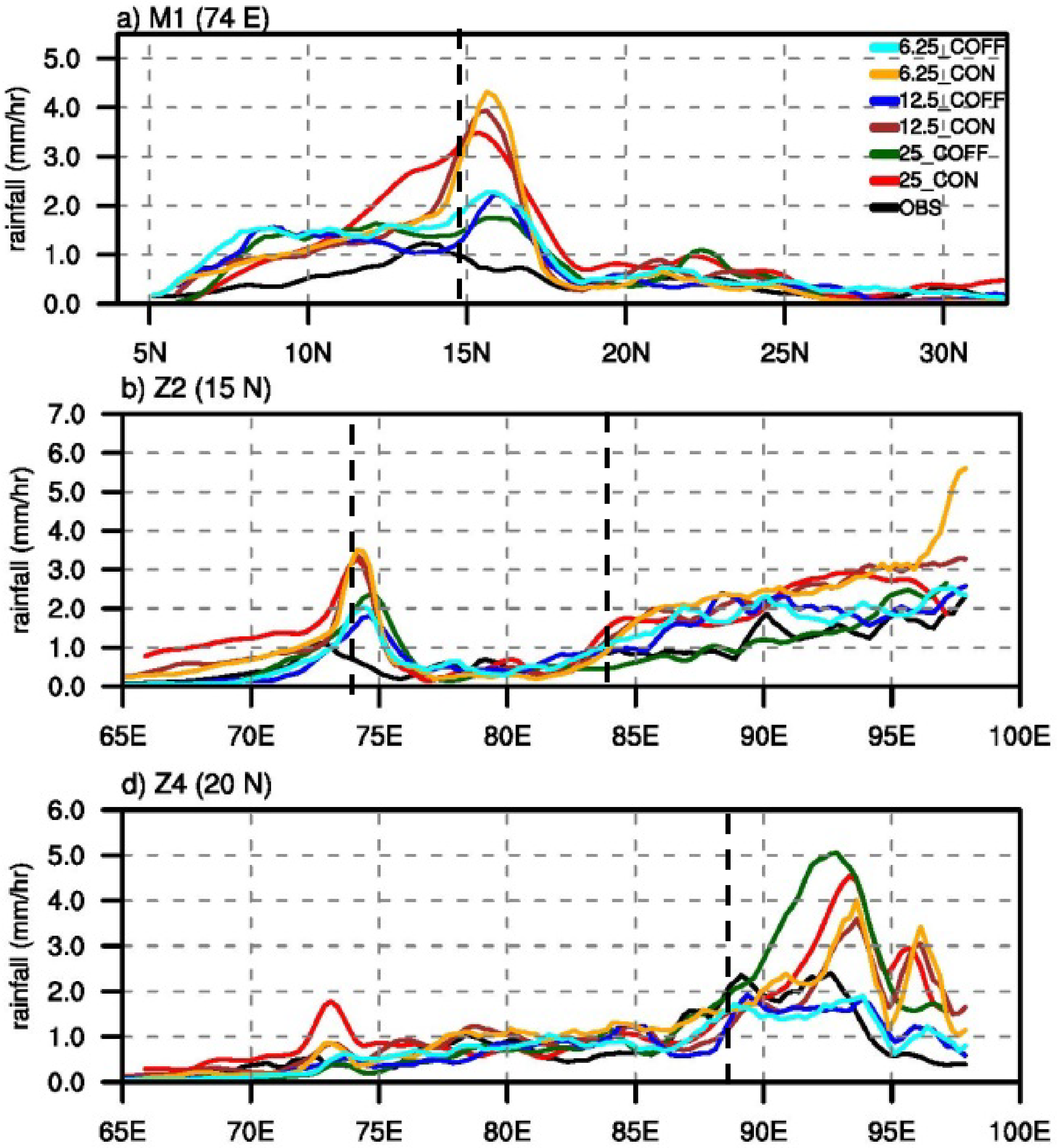


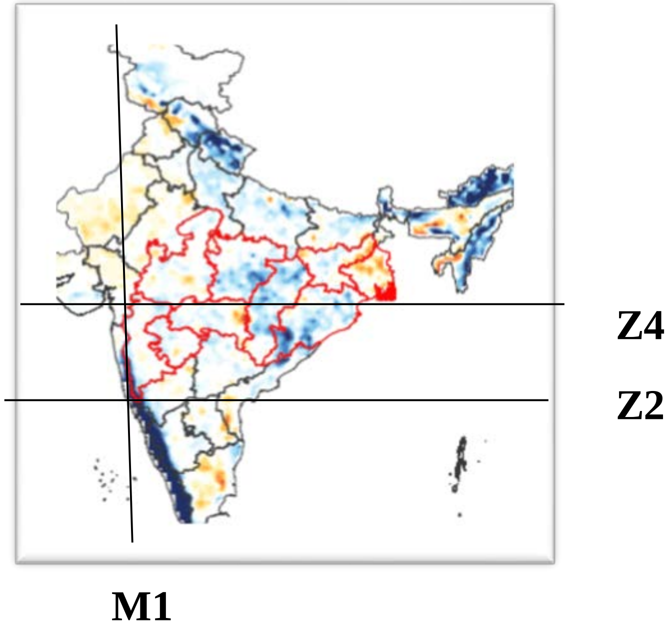
- ✓ Over Central India and all India rainfall diurnal phase and magnitude of COFF simulations are in good agreement with TRMM.
- ✓ COFF_6.25 and COFF_12.5 exhibits similar diurnal magnitude as that of TRMM also they shows peak rainfall around afternoon/evening.
- ✓ CON Simulations of 25km and 12.5km shows noon peak and the diurnal magnitude is very high.
- ✓ CON 6.25km simulation simulate afternoon rainfall peak but high in magnitude as compared to TRMM.
- ✓ **Current analysis confirms the realistic simulation of diurnal peak and magnitude in COFF as compared to CON.**

b) Central India



Transect analysis





- ✓ Diurnal magnitudes of COFF are very close with respect to the observations
- ✓ All CON simulations have higher diurnal magnitude, especially over transitions.
- ✓ Over orography, orogenic precipitation is highly biased in CON.
- ✓ **Current analysis confirms the realistic simulation of diurnal magnitude in COFF as compared to CON.**

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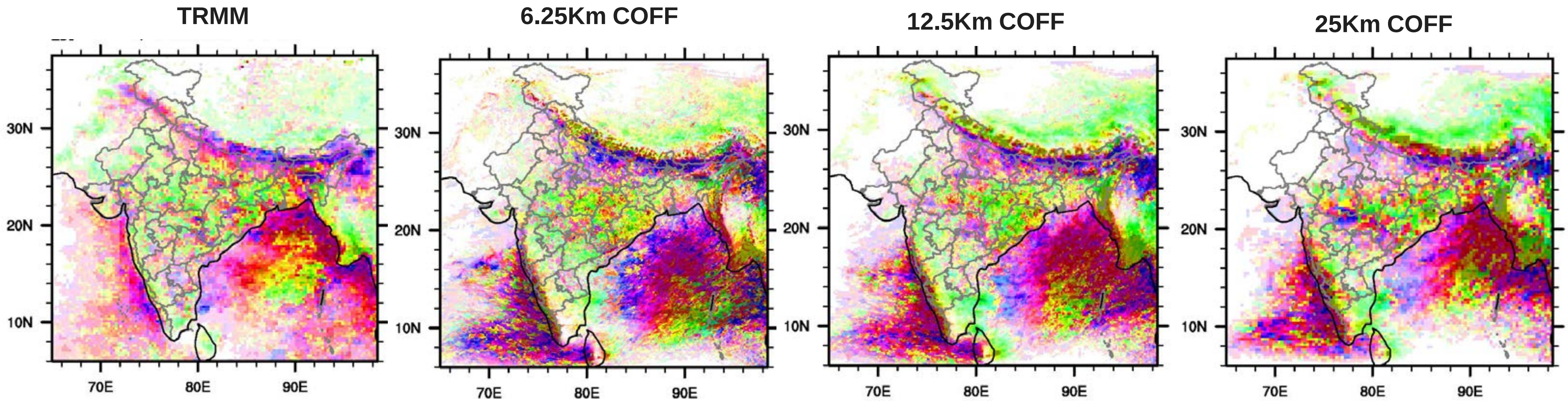
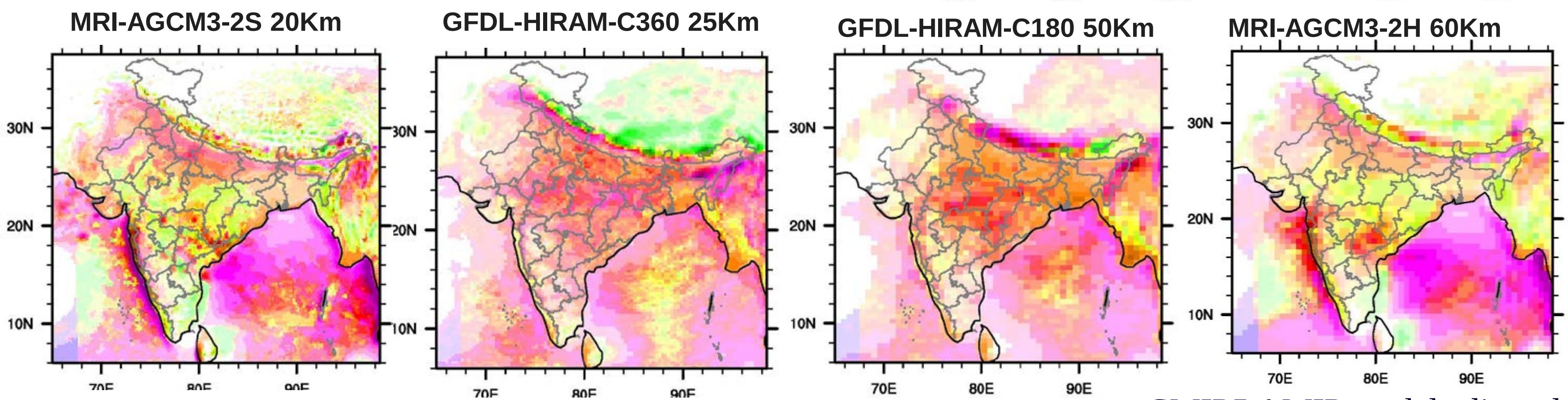
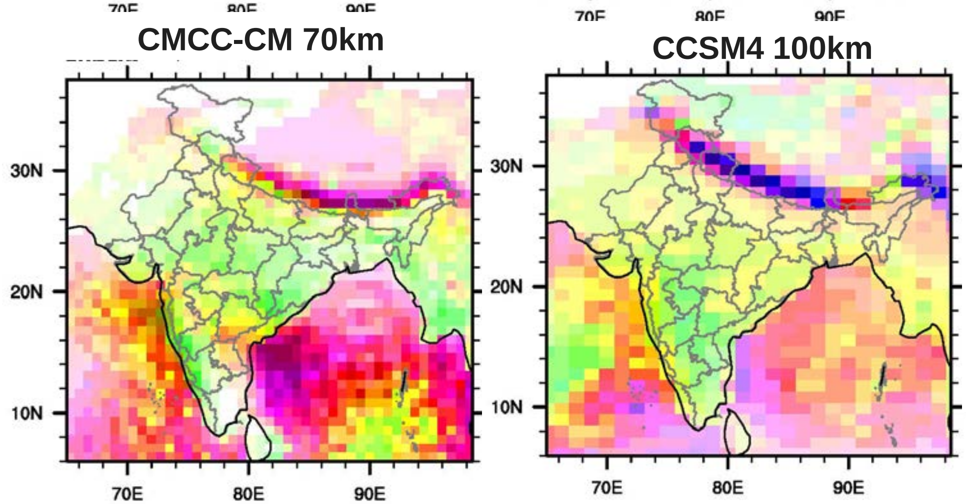
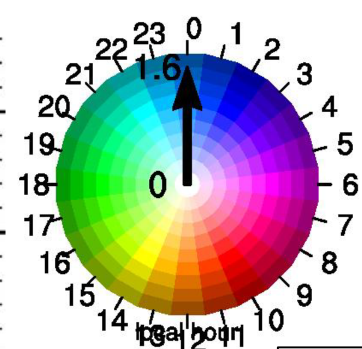
Diurnal cycle w.r.t COFF and CMIP5 AMIP





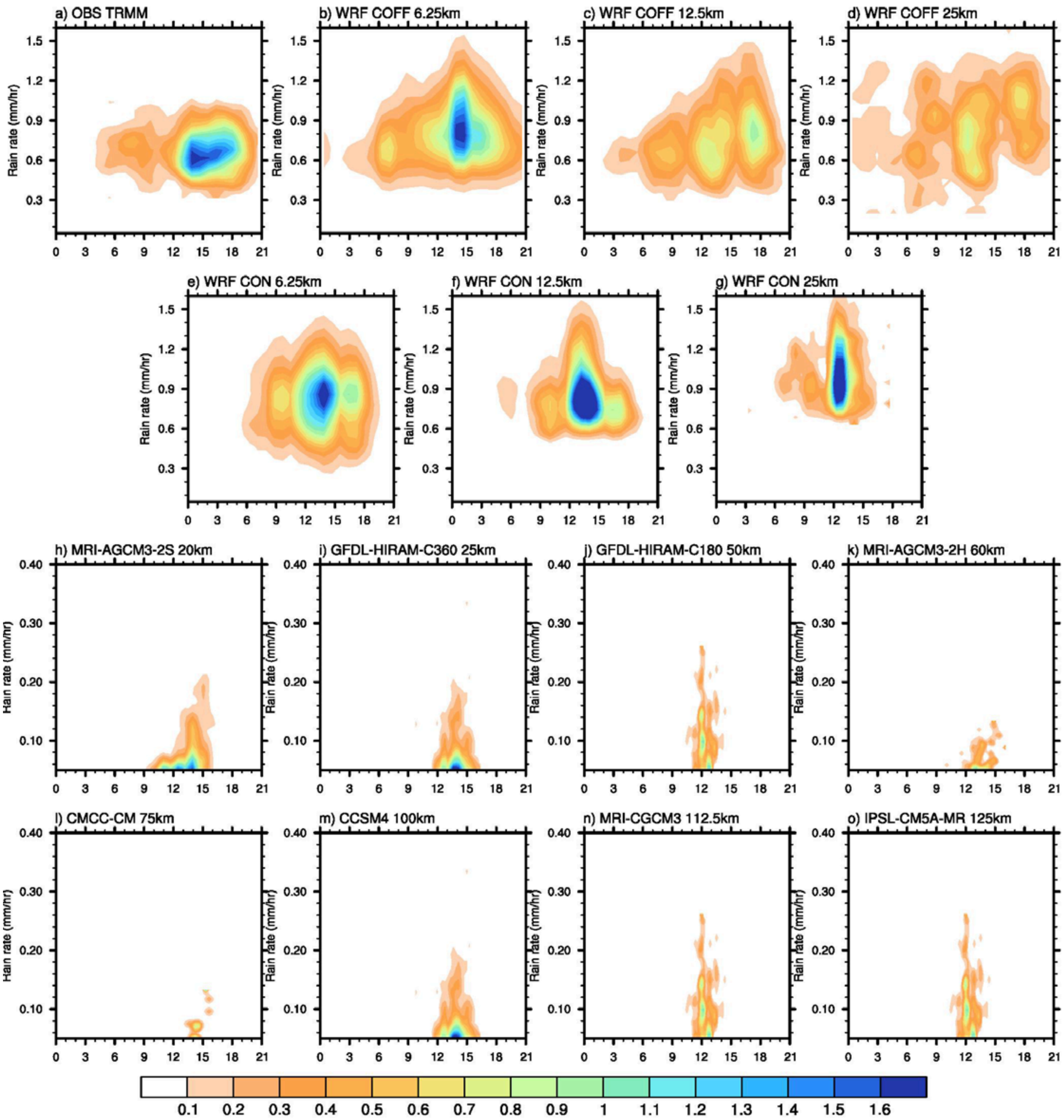
Last 10 years mean is conside red.

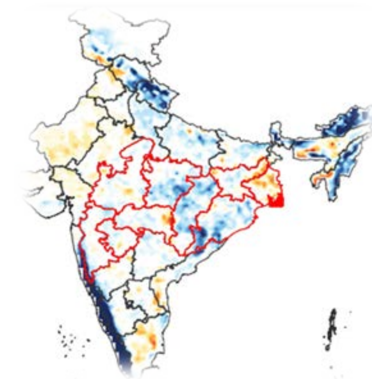




- ✓ CMIP5 AMIP models diurnal cycle is poorly simulated both in terms of diurnal phase.
- ✓ High resolution GCM could capture the diurnal phase over central India around noon.
- ✓ **It implies that the high resolution AMIP model simulation could not improve diurnal cycle phase.**

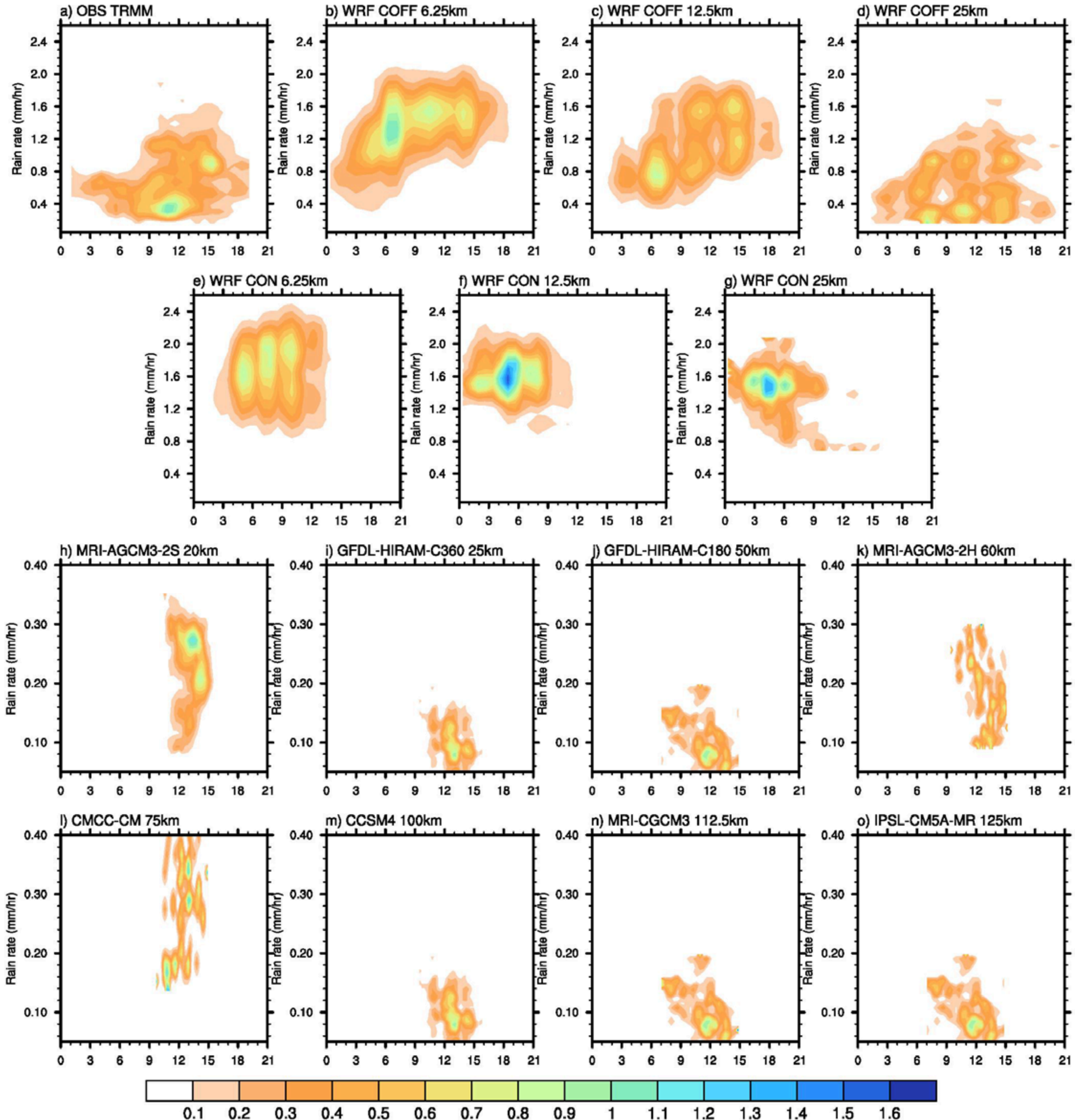
Joint Probability distribution of Diurnal rainfall (Central India)





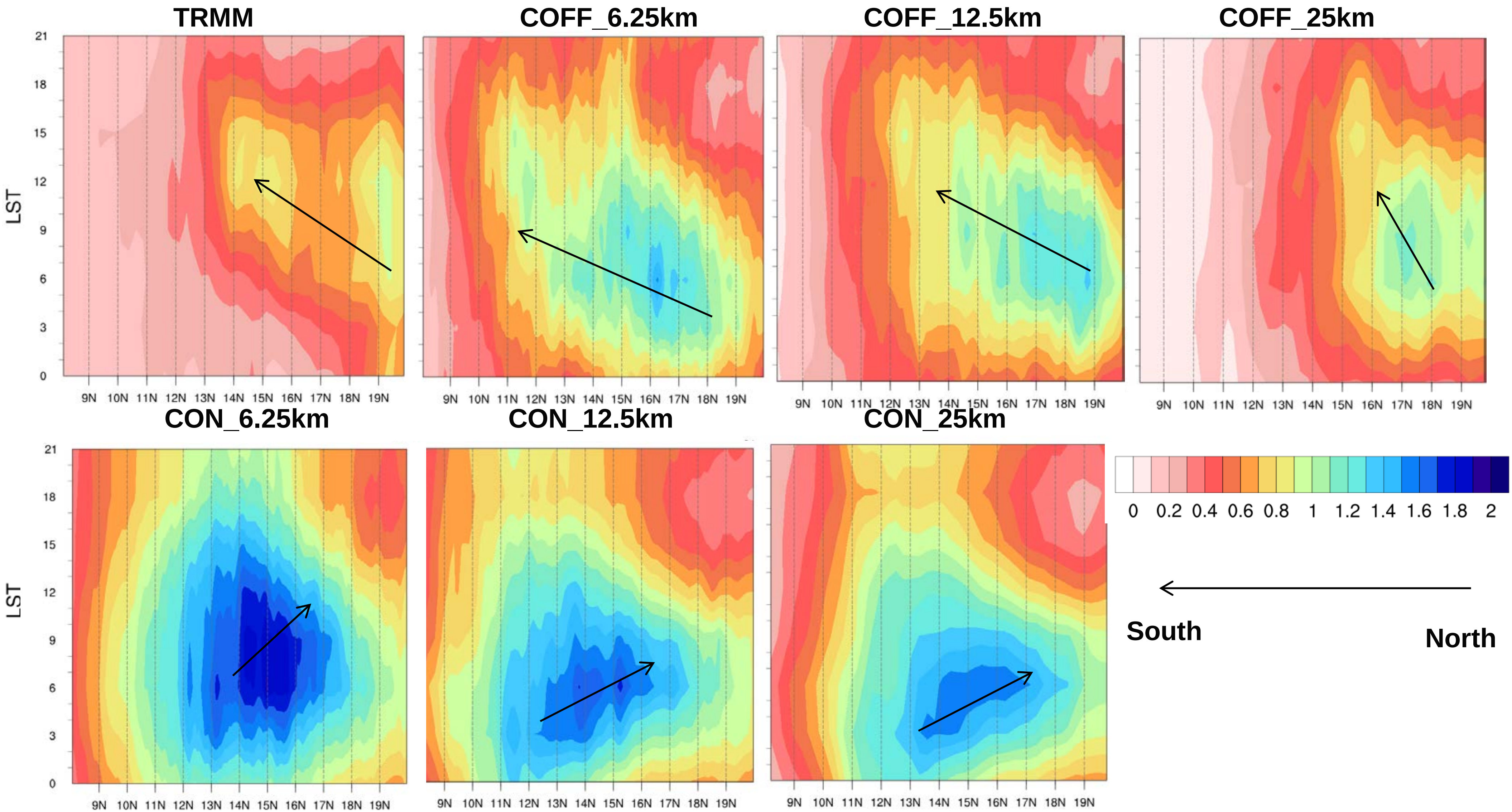
- ✓ JPD of COFF simulated rainfall is in good agreement with TRMM in terms of diurnal phase and magnitude..
- ✓ ALL GCMs could capture the diurnal phase over central India around noon/afternoon like in the 25km and 12.5km CON simulations but it is not in agreement with TRMM and COFF.
- ✓ Also CON simulations do not capture actual diurnal cycle as captured in COFF_6.25km simulation.
- ✓ **It implies that the statistically high resolution model simulations could not improve diurnal cycle both phase and magnitude.**

Joint Probability distribution of Diurnal rainfall (Bay of Bengal)



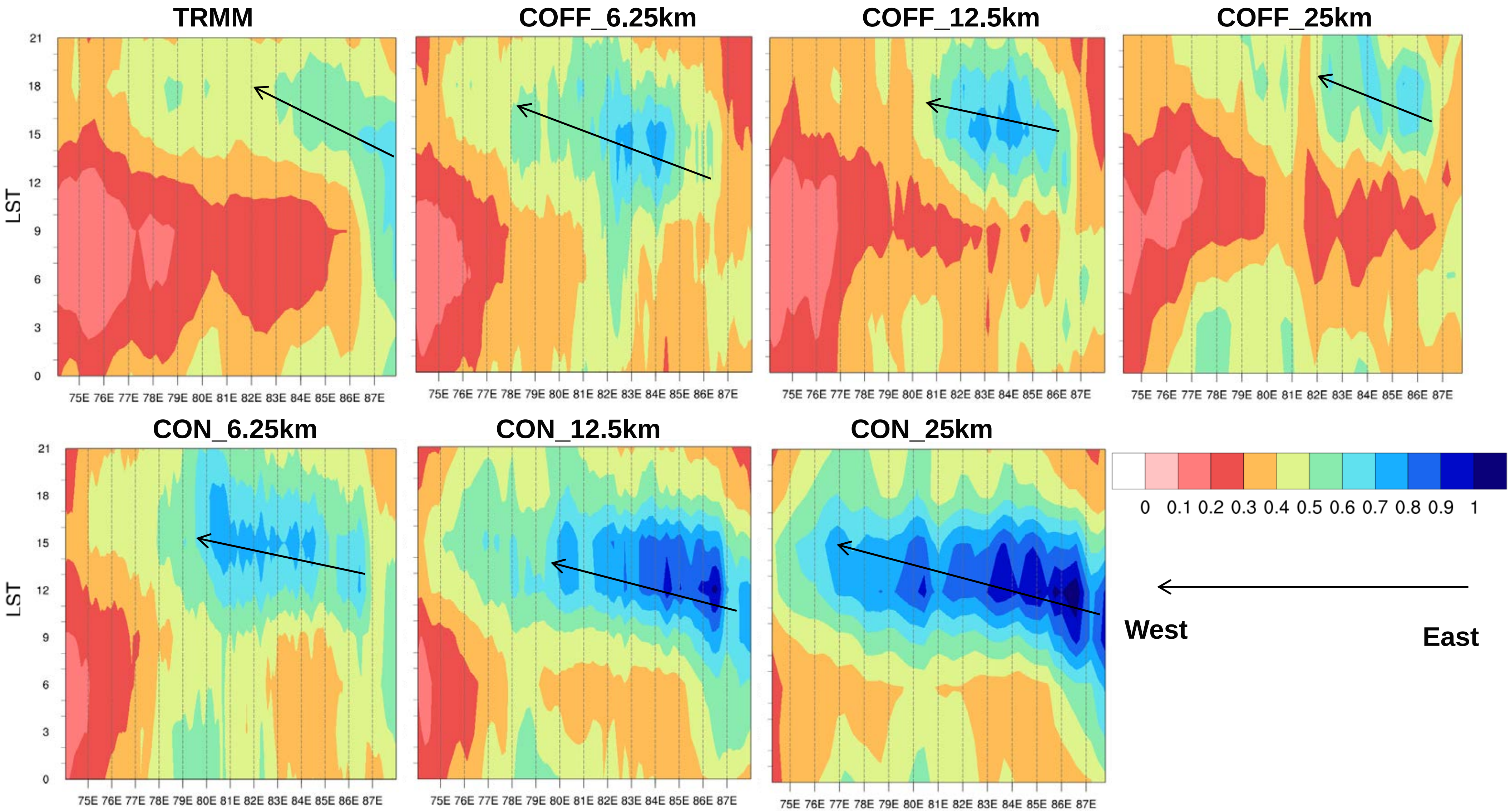
- ✓ JPD of COFF simulated rainfall is in good agreement with TRMM in terms of diurnal phase and magnitude.
- ✓ COFF and TRMM shows diurnal cycle inclination from early morning to afternoon.
- ✓ CON simulations do not capture actual diurnal cycle but they show diurnal peak only in the late nights. Not afternoon peak
- ✓ ALL GCMs could not capture the diurnal phase over Bay of Bengal.
- ✓ **It implies that the diurnal cycle of rainfall over Bay of Bengal is properly simulated in Convection off cases.**

Propagation of the diurnal cycle of rainfall :
1) Bay of Bengal & Southern Peninsula



- ✓ Over Bay of Bengal diurnal cycle of rainfall at early morning shows southward propagation from north Bay of Bengal towards south Bay of Bengal and reaches southern end in the afternoon.
- ✓ **COFF simulations only could simulate the southward propagation.**

Propagation of the diurnal cycle of rainfall :
2) Core monsoon region (Central India)



- ✓ Over Central India, diurnal cycle of rainfall at noon shows westward propagation from the north Bay of Bengal and reaches western edge of central India by late evenings..
- ✓ COFF and CON both could simulate westward propagation, but in CON diurnal rainfall magnitude is very high.

Summary

CON:- Convection Parameterized
COFF:- Convection Permitting.

Rakesh et al. in prep. 2018

- **It is very clearly that the capability of the COFF (convection permitting) at high resolution has more added value in the seasonal mean simulation as compared to CON (convection parameterized) at high resolution.**
- **Large scale features are better captured in COFF and monsoon trough strong bias in CON is reduced in COFF.**

- **Better simulation of seasonal mean in COFF is due to realistic representation of diurnal cycle phase and magnitude in the COFF, especially at high resolution.**
- **Large scale features are better captured in COFF and monsoon trough strong bias in CON is reduced in COFF.**
- **The high resolution WRF simulations and AMIP model simulation could not improve diurnal cycle phase and amplitude.**
- **The southwards propagation of the diurnal cycle of rainfall over Bay of Bengal and westward propagation over central Indian is well simulated in the COFF simulations as compared to CON.**

- ✓ Due to different topographical features, surface fluxes and CAPE act differently. As a result they support in the development of convection.
- ✓ Precipitable water as well shows diurnal variability with respect to the regions.

- **Appreciably, current analysis finds out that Indian summer monsoon rainfall depends upon the convection resolving at high resolutions, apart from its only dependence on model spatial resolution.**