Monitoring of extremes over Indian Region on short, extended and seasonal scale: Identification of key physical processes and its representation in Models

Project Team
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Research Objectives

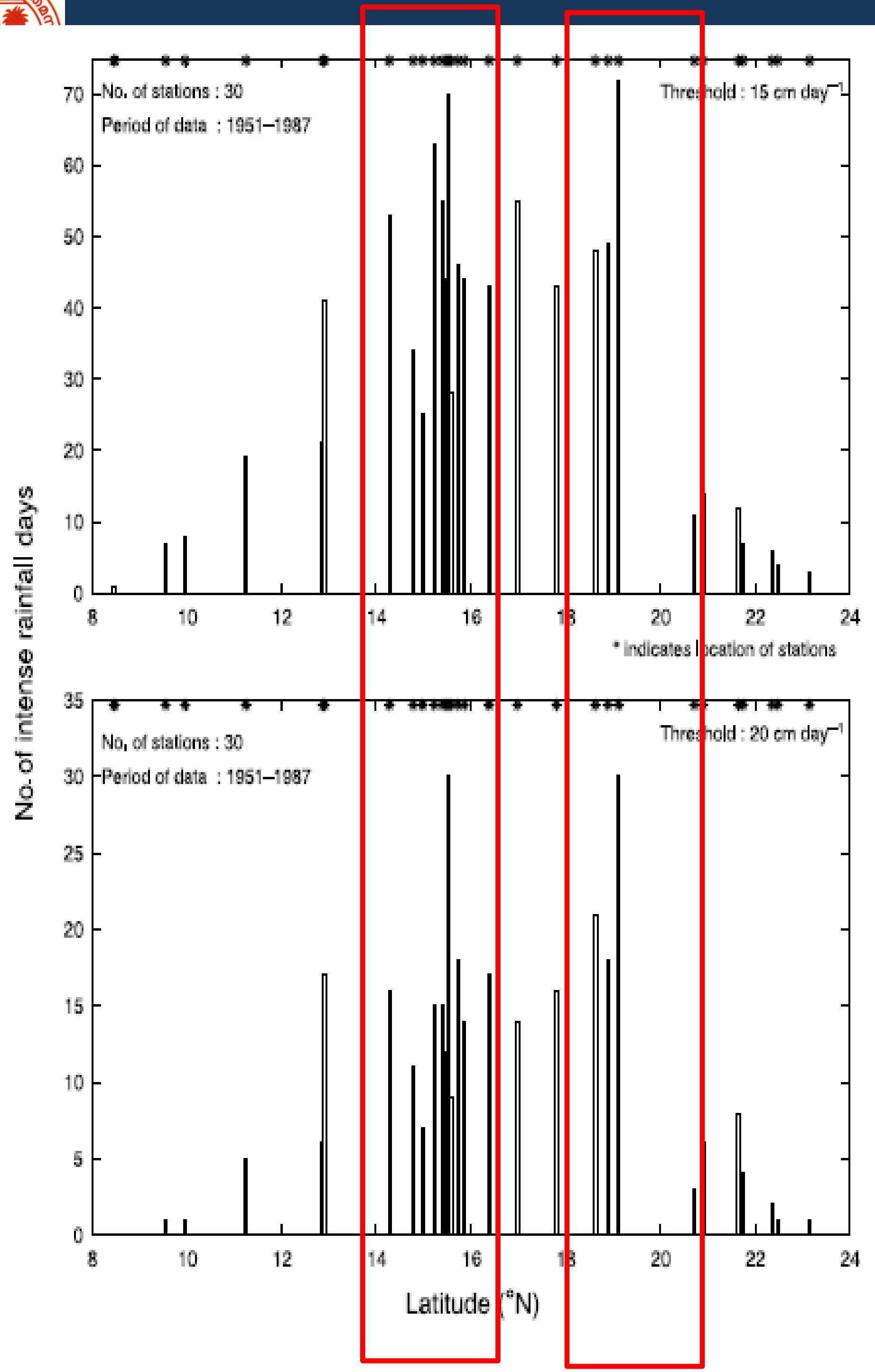
The proposal will mainly focus on understanding extreme weather phenomena and their drivers across different time scales.

- **Identify the role of large, regional and local scale processes and their interactions in the formation of extreme weather events and its representation in models.**
- **Evaluate the models across scales in predicting extremes and quantification of key missing physical processes responsible for such events.**
- **Understand the role of tropical Indo-Pacific SST on seasonal extremes and its inter-annual variability in observations and model simulations.**

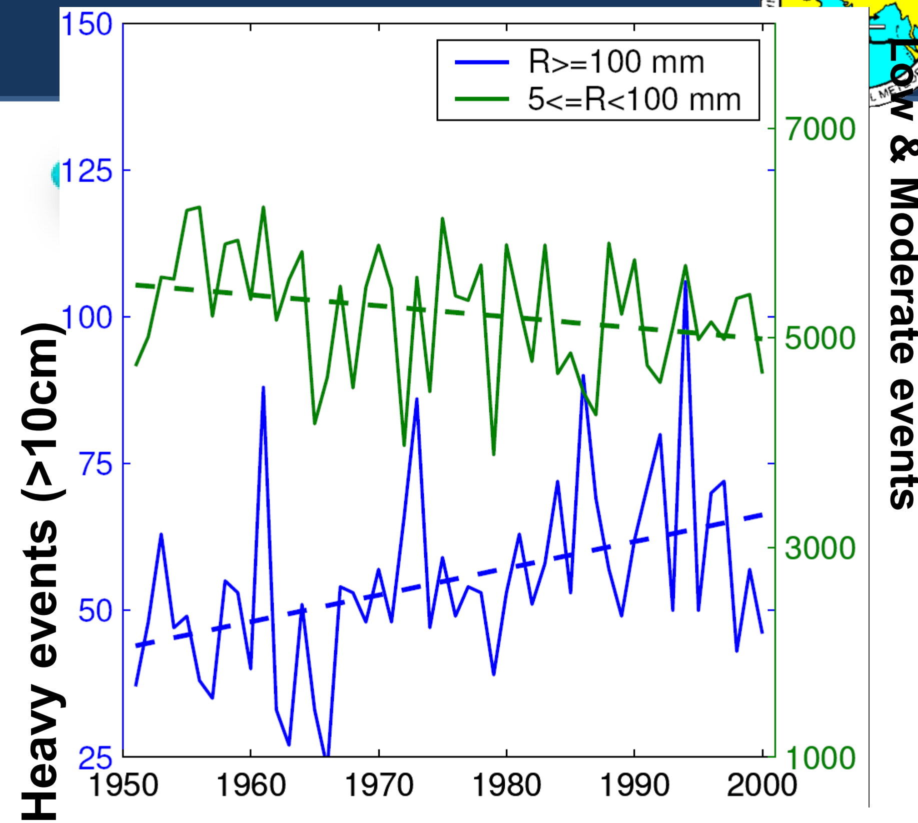
Highlights and Impact

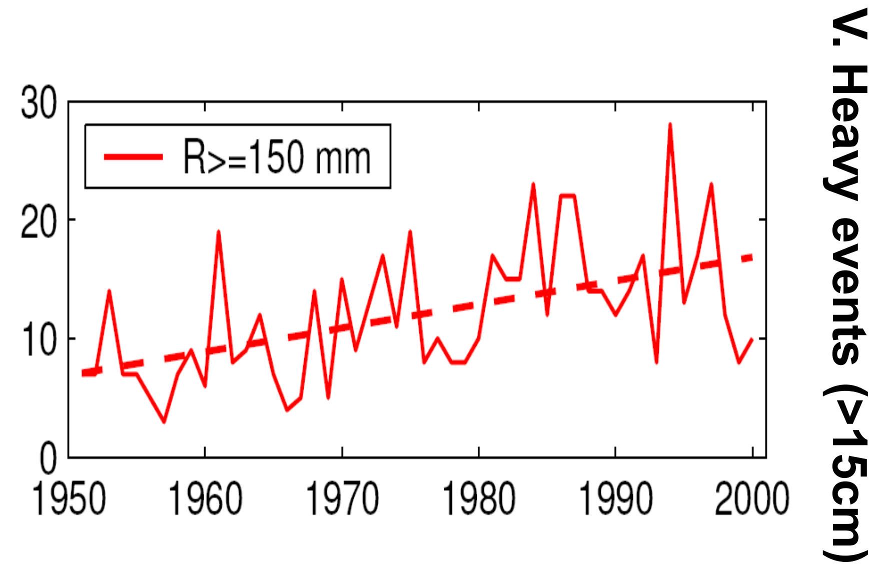
- Understand and predict extreme and high impact weather and climate events including heavy precipitation, drought and severe storms across different scales and integrating them for informed decision making.
- A calibration matrix will be generated for each relevant physical processes for different lead times, especially convection.
- Evaluation of growth of model errors across different lead times.
- The prediction skill for extreme precipitation events will be improved through an increased mechanistic understanding of historical events and a quantitative evaluation of model performance for simulating these events.

Rainfall Trend over C India

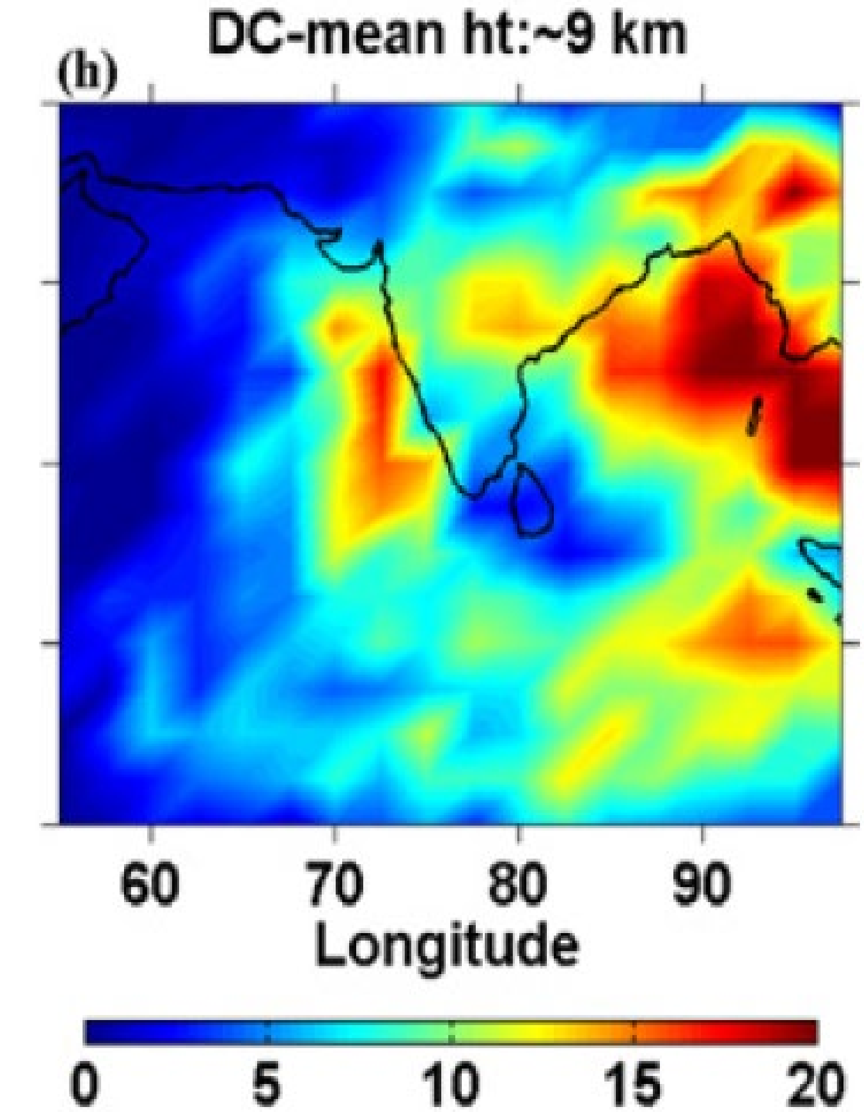


Francis and Gadgil 2006

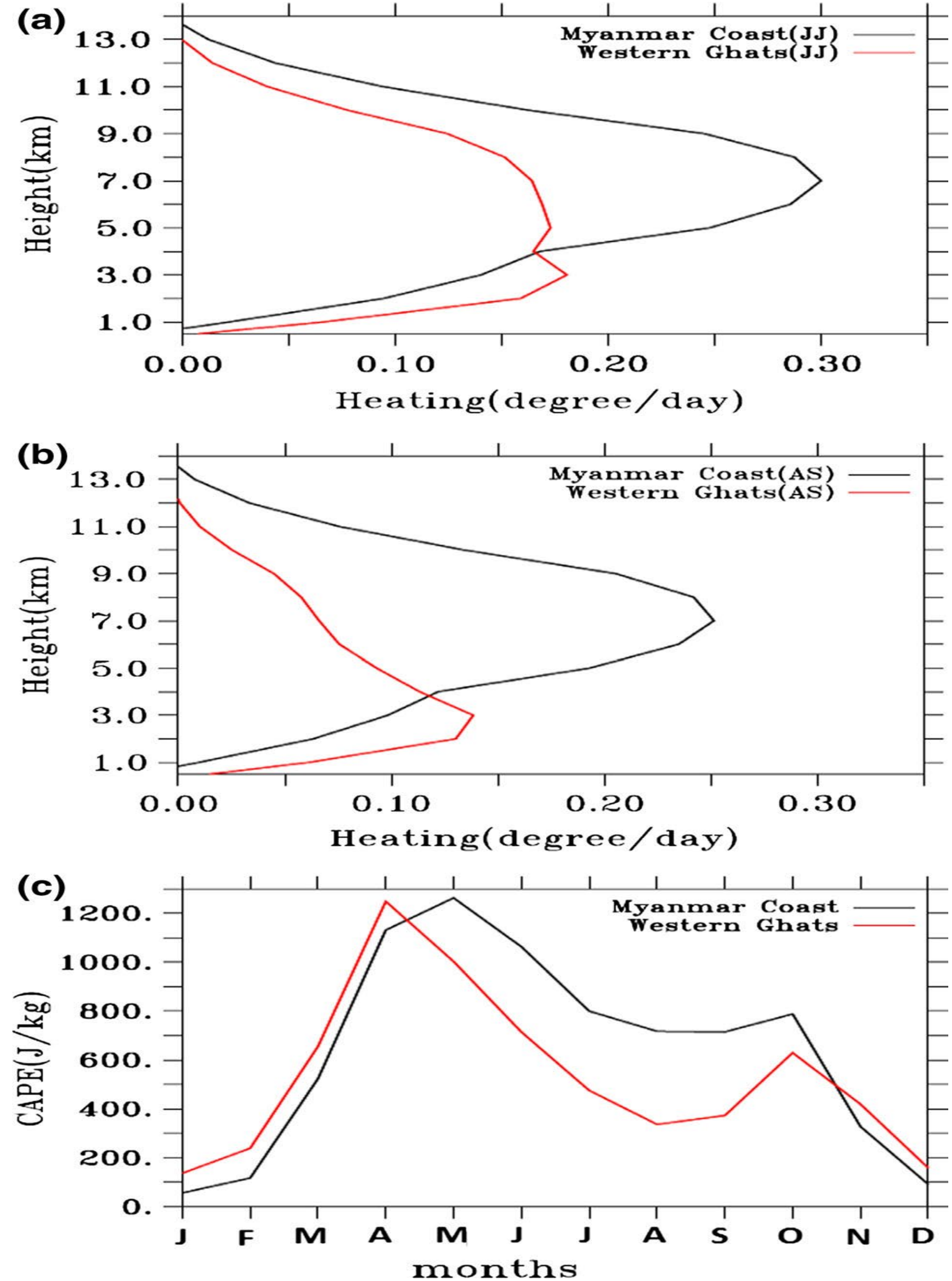




Goswami etal., (2006)

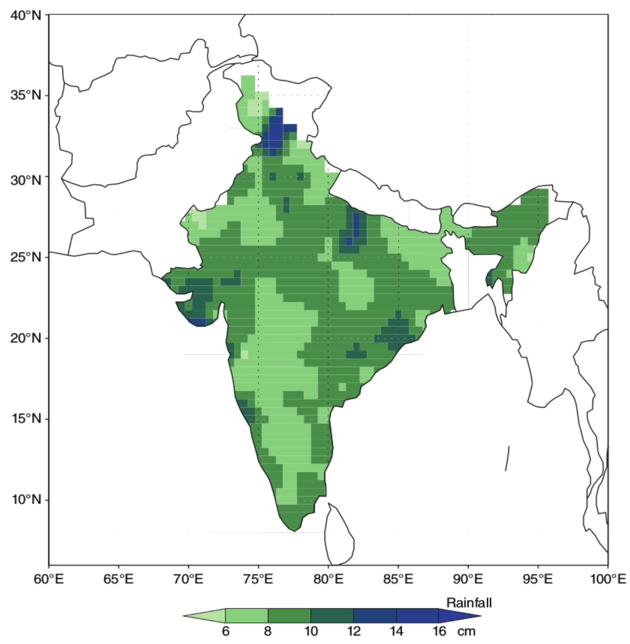


Subrahmanyam and Kumar (2013)

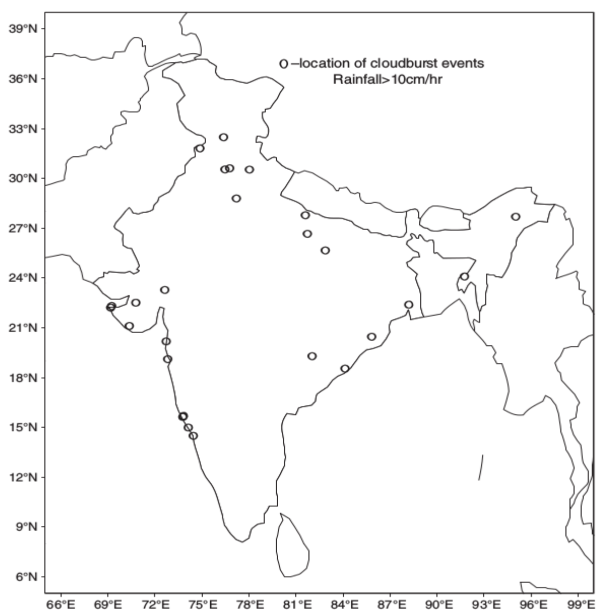


Siddharth et al (2014)

Extreme 1-hr rainfall in cm (1969-2015)



Locations of CBb events (1969-2015)



Cloud Burst category 'a' or CBa : Cloud busrst in Himalayan regions based on flash floods and damages (Irrespective of rainfall, Woolley (1946))

Cloud Burst category 'b' or CBb : rainfall >10 cm/hr (IMD definition)

Mini Cloud Burst (MCB) : rainfall in two consecutive rain-hours is 5 cm or more (Deshpande et al 2017)

2 CB events has occurred in Kerala so far, one at Thiruvananthapuram and the other at Kozhikode

In an MCB event, probability of flash floods is three times higher than in extreme rainfall event (ie, 20 cm in 24 hr)

Figures From **Deshpande et al (2017)**

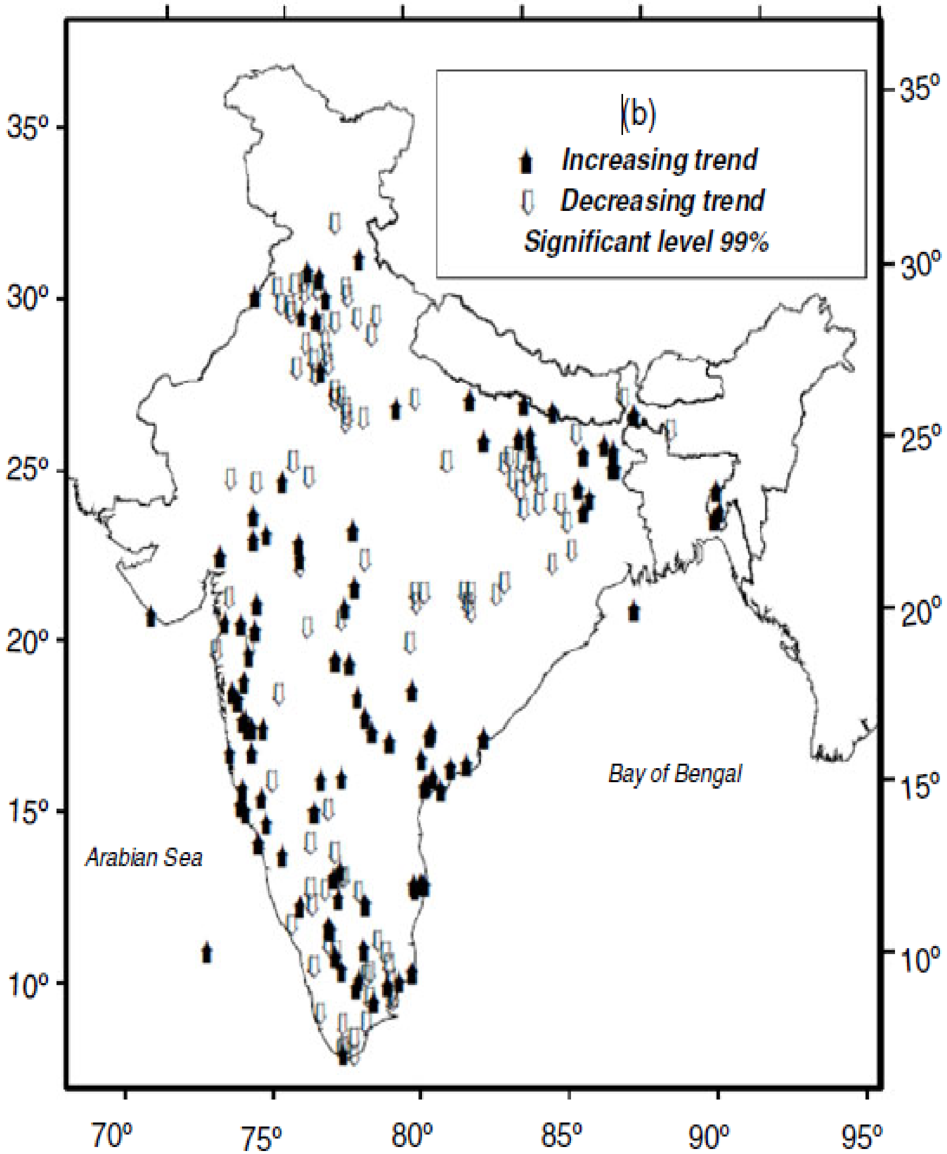
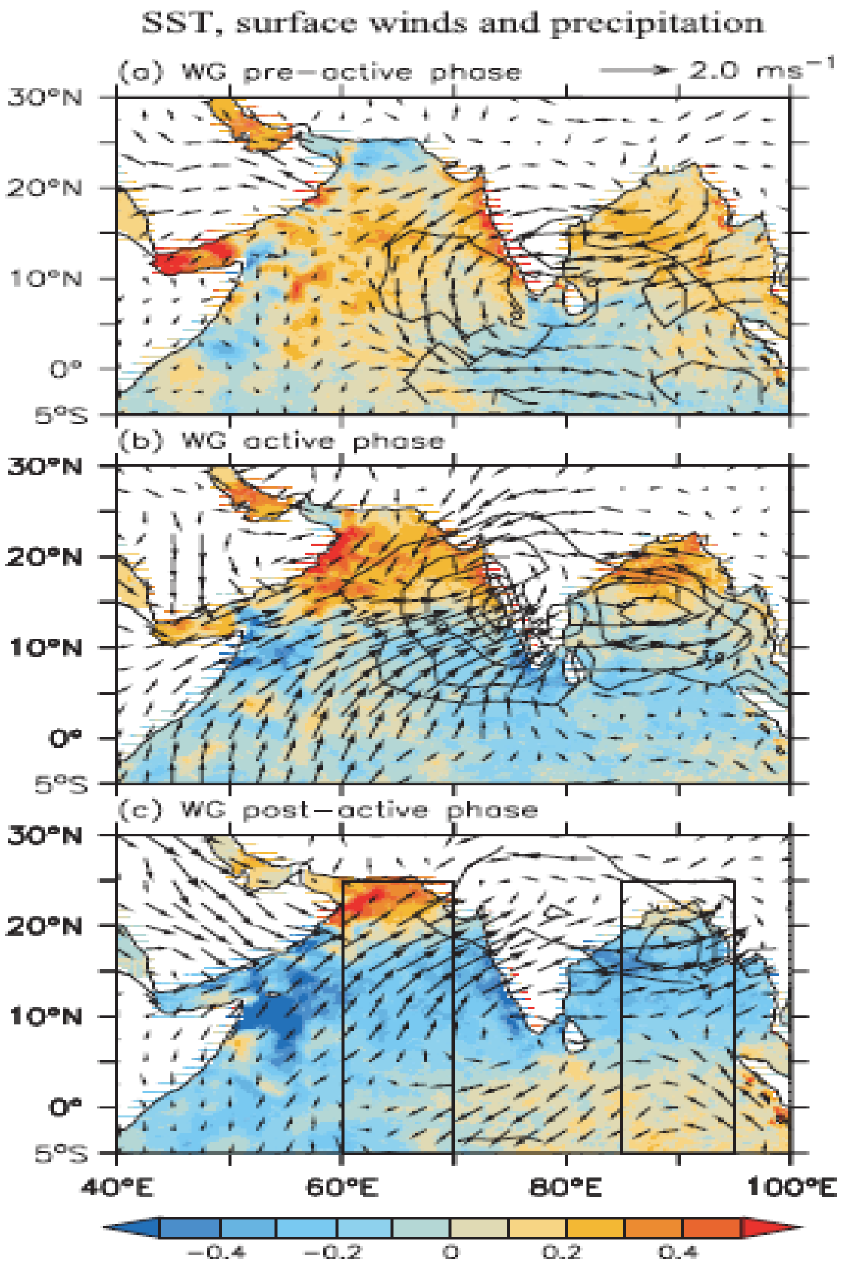


Figure From ***Guhathakurta et al (2011)***

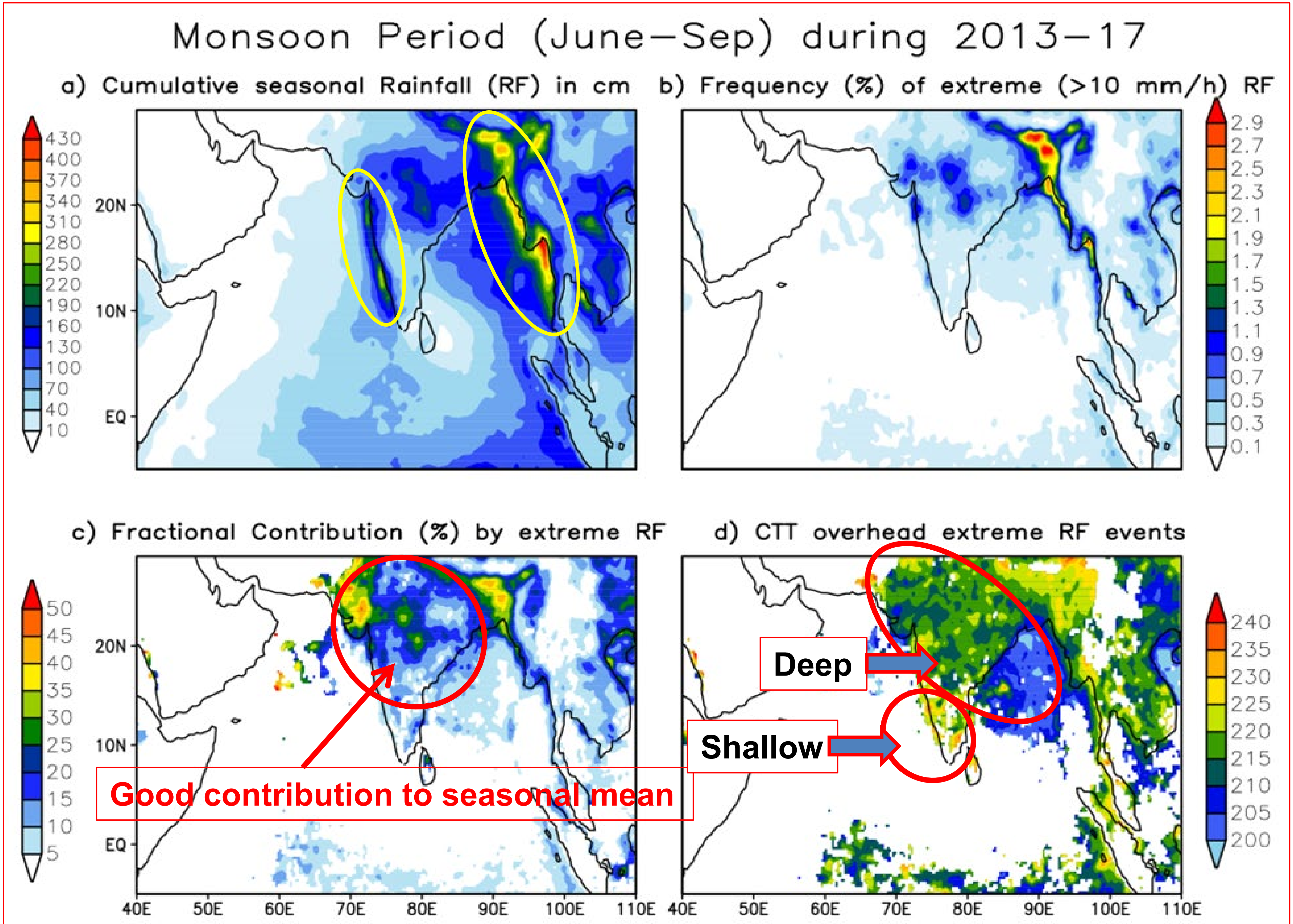
The frequency of heavy rainfall events are decreasing in major parts of central and north India while they are increasing in peninsular, east and north east India *(Guhathakurta, 2011)*



Increase in SST in Arabian Sea (AS) during pre active period followed by strengthening of surface wind over southern parts of AS causing a south-north temperature gradient that create condition favourable for convective activity in WG region *(Roxy and TANIMATO, 2017)*

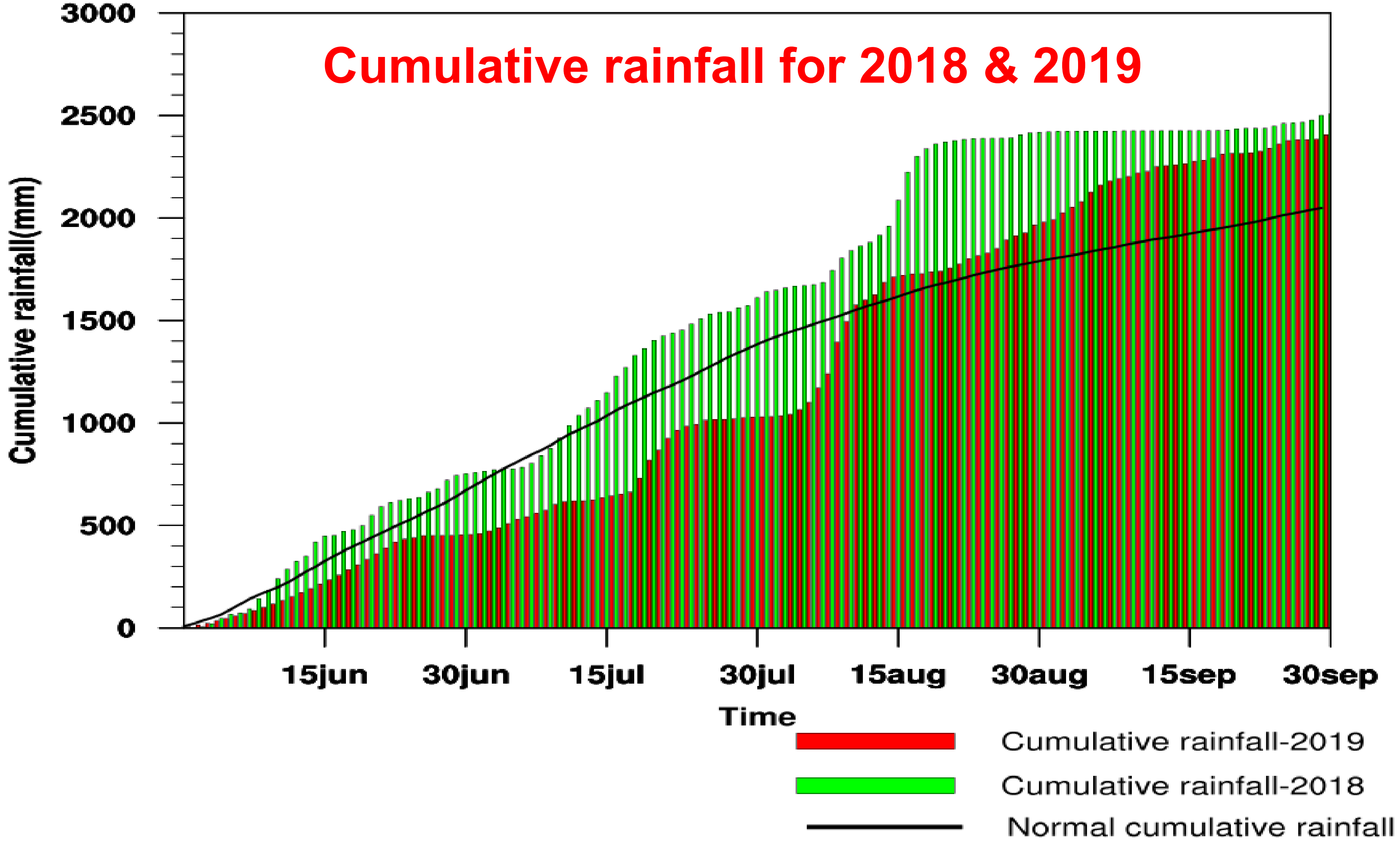
Figure From ***Roxy and TANIMOTO, 2017)***

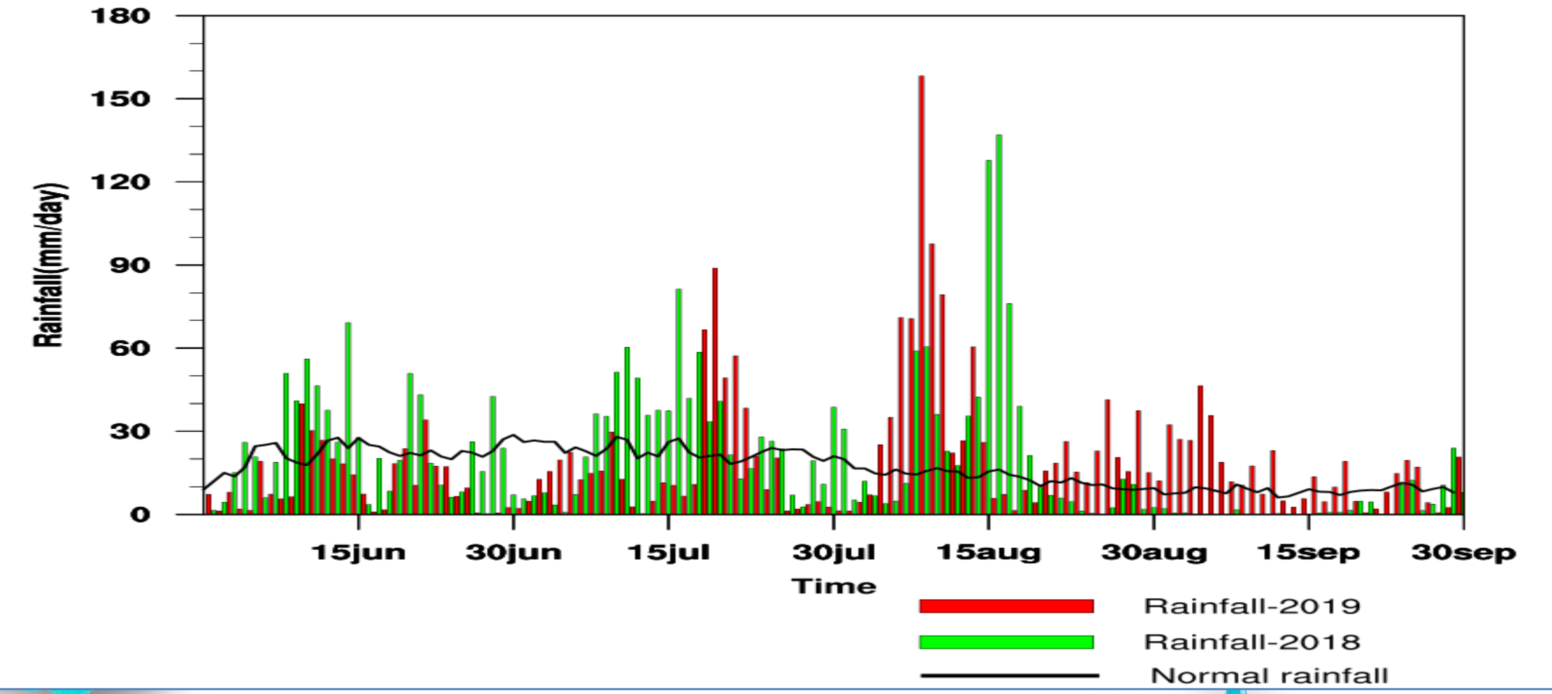
Rainfall and CTT analysis during extreme rainfall events



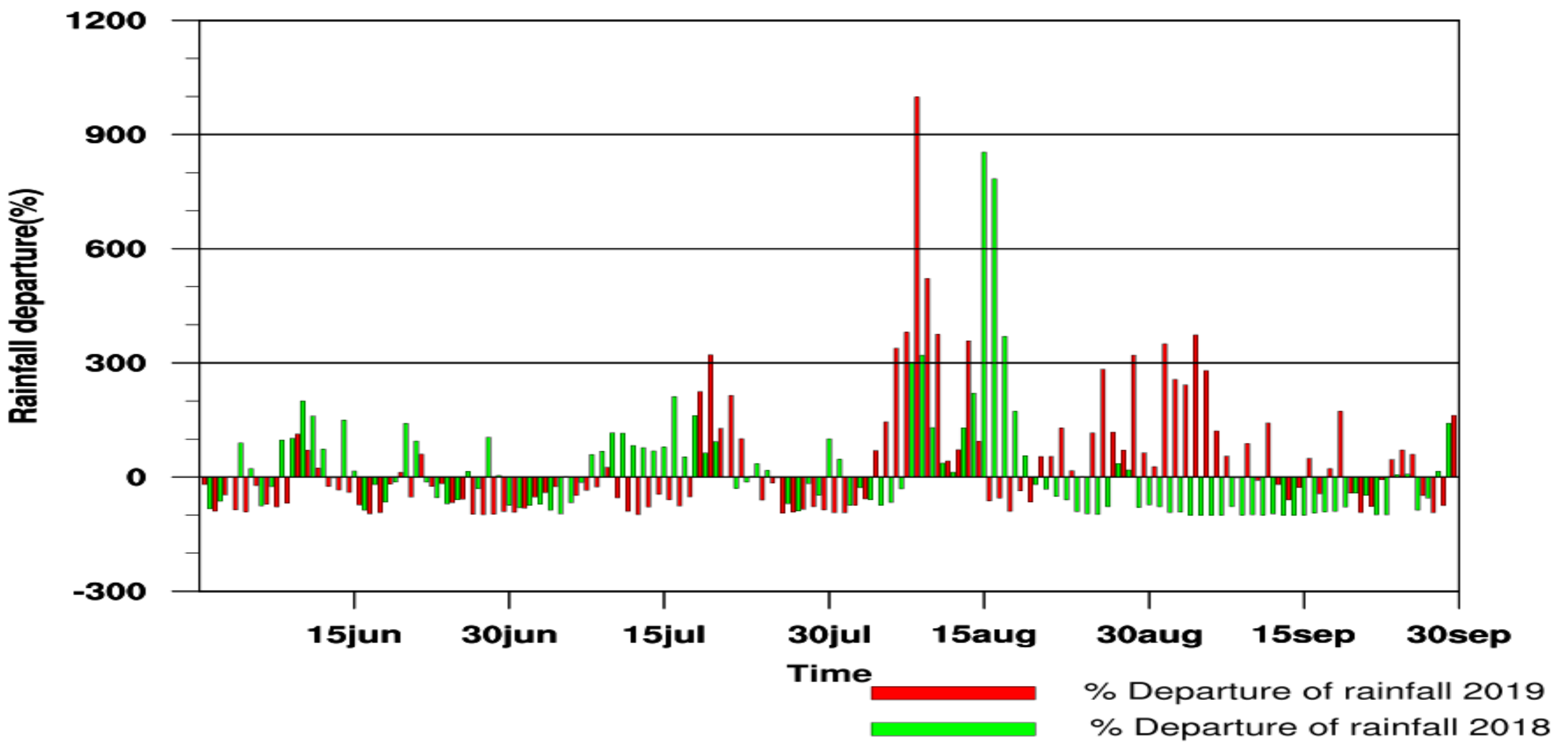
Vijayakumar, Abhilash etal., 2019

Twin floods of Kerala during 2018 & 2019

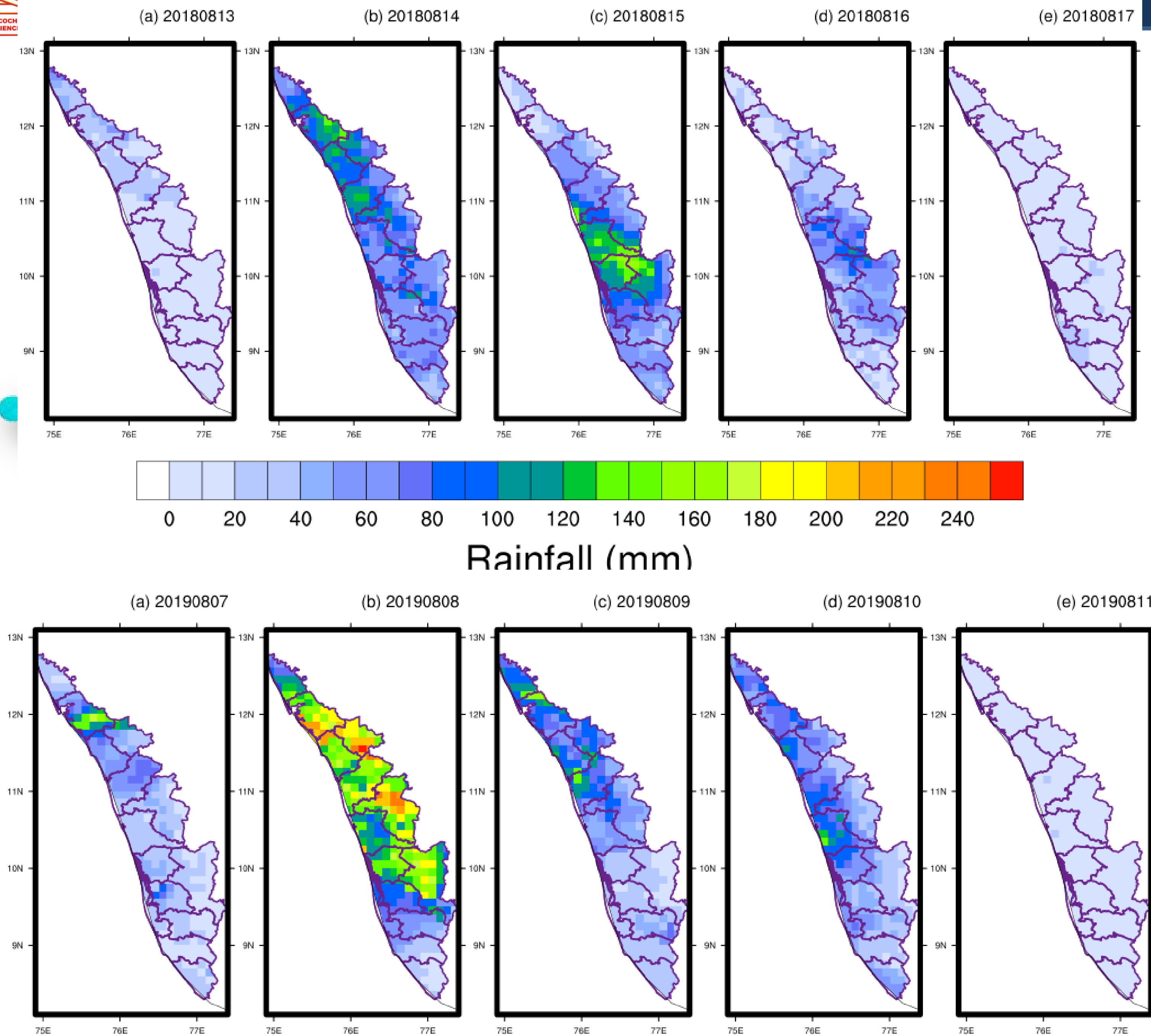




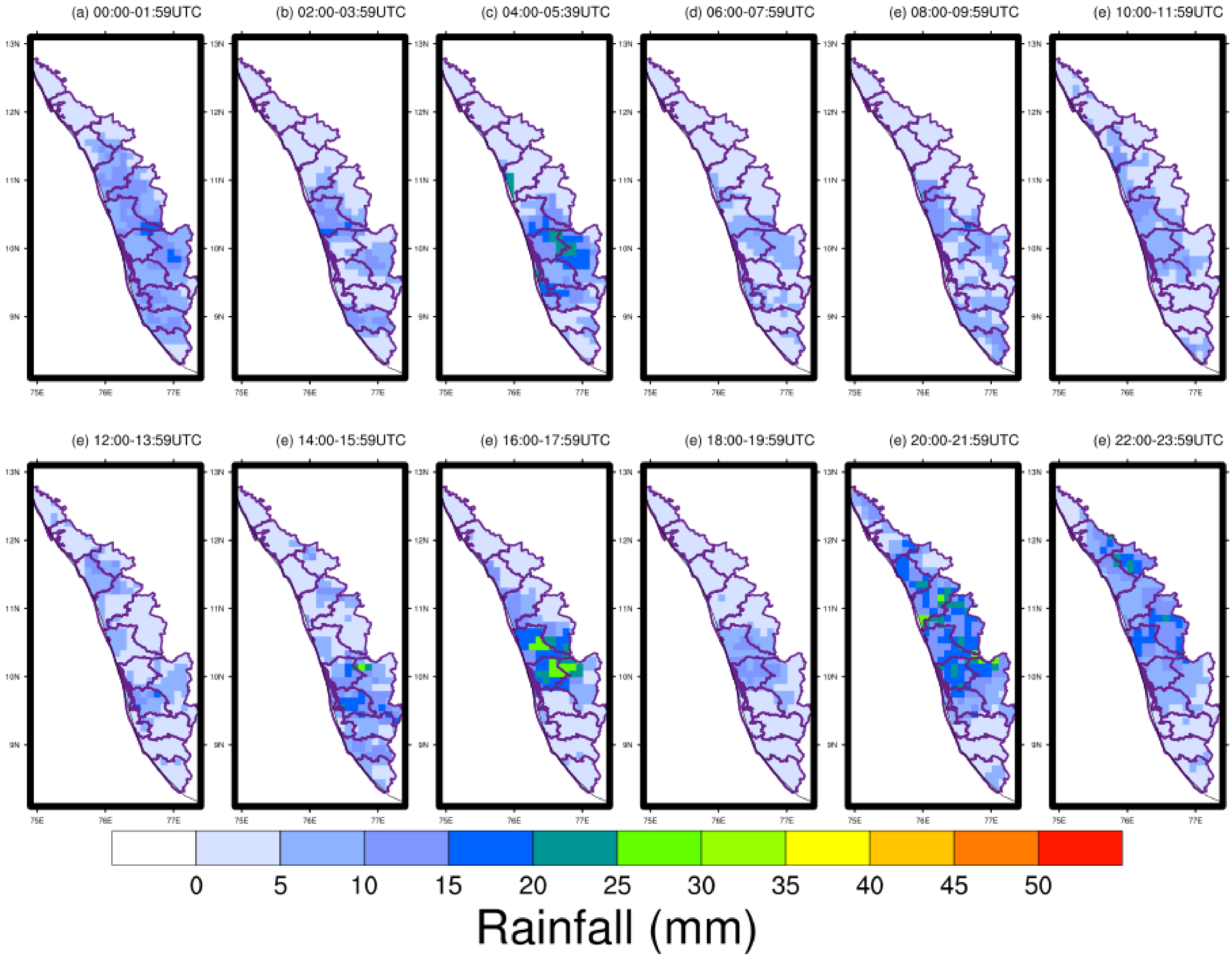
180
150
120
90
60
30
0
Rainfall(mm/day)
15jun
30jun
15jul
30jul
15aug
30aug
15sep
30sep
Time
Rainfall-2019
Rainfall-2018
Normal rainfall



1200
900
600
300
0
-300
Rainfall departure(%)
15jun
30jun
15jul
30jul
15aug
30aug
15sep
30sep
Time
% Departure of rainfall 2019
% Departure of rainfall 2018



(a) 20180813
(b) 20180814
(c) 20180815
(d) 20180816
(e) 20180817
13N
12N
11N
10N
9N
75E
76E
77E
0
20
40
60
80
100
120
140
160
180
200
220
240
Rainfall (mm)
(a) 20190807
(b) 20190808
(c) 20190809
(d) 20190810
(e) 20190811


(a) 00:00-01:59UTC
(b) 02:00-03:59UTC
(c) 04:00-05:39UTC
(d) 06:00-07:59UTC
(e) 08:00-09:59UTC
(e) 10:00-11:59UTC
(e) 12:00-13:59UTC
(e) 14:00-15:59UTC
(e) 16:00-17:59UTC
(e) 18:00-19:59UTC
(e) 20:00-21:59UTC
(e) 22:00-23:59UTC
13N
12N
11N
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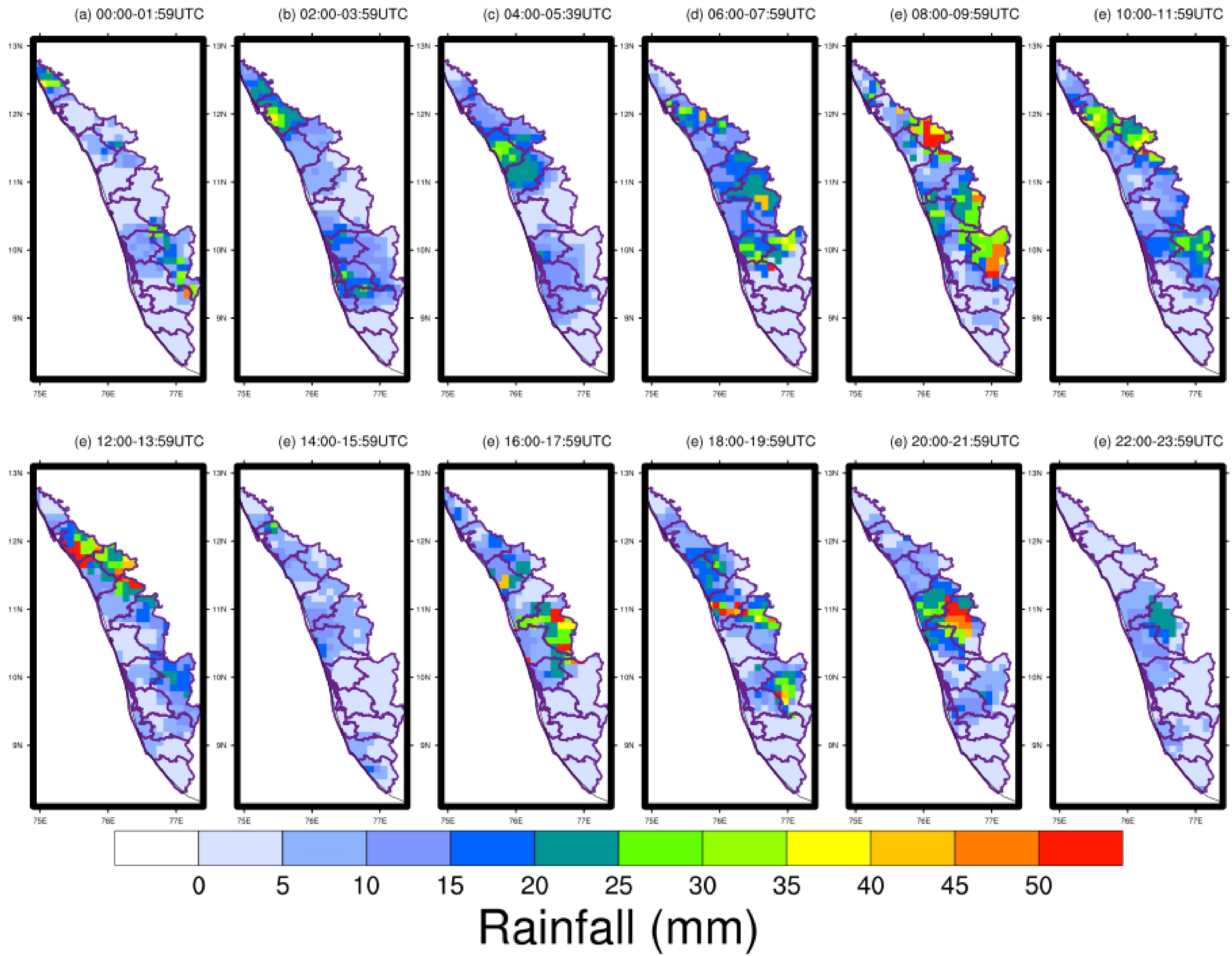
76E
77E
0
5
10
15
20
25
30
35
40
45
50
Rainfall (mm)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13N
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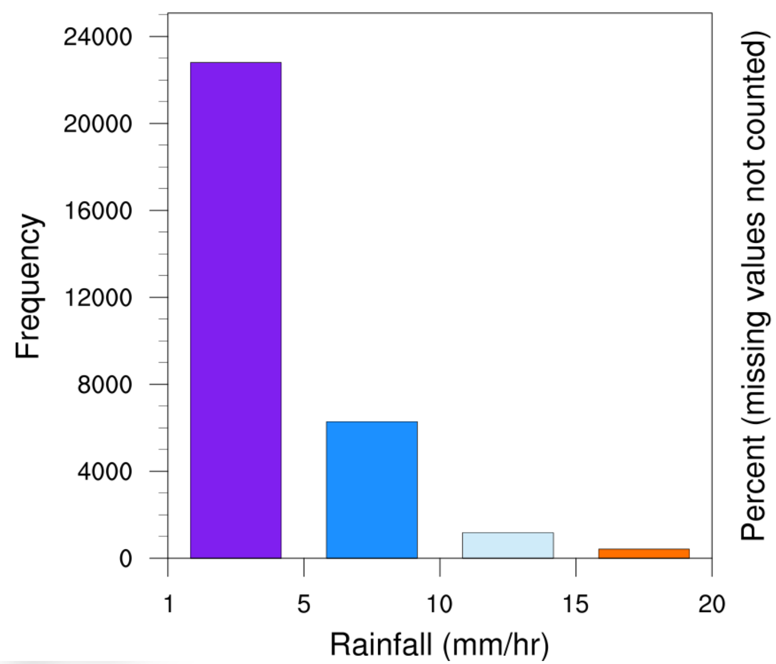
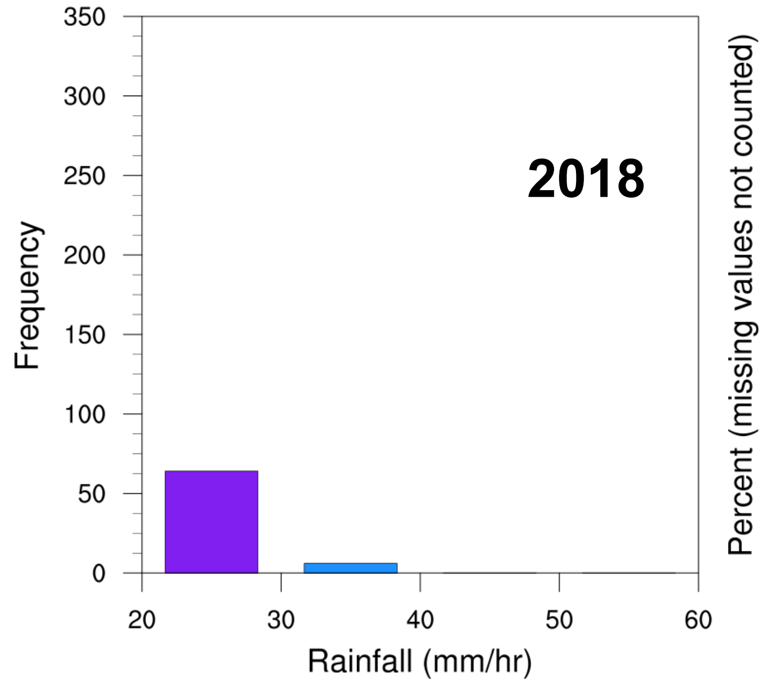
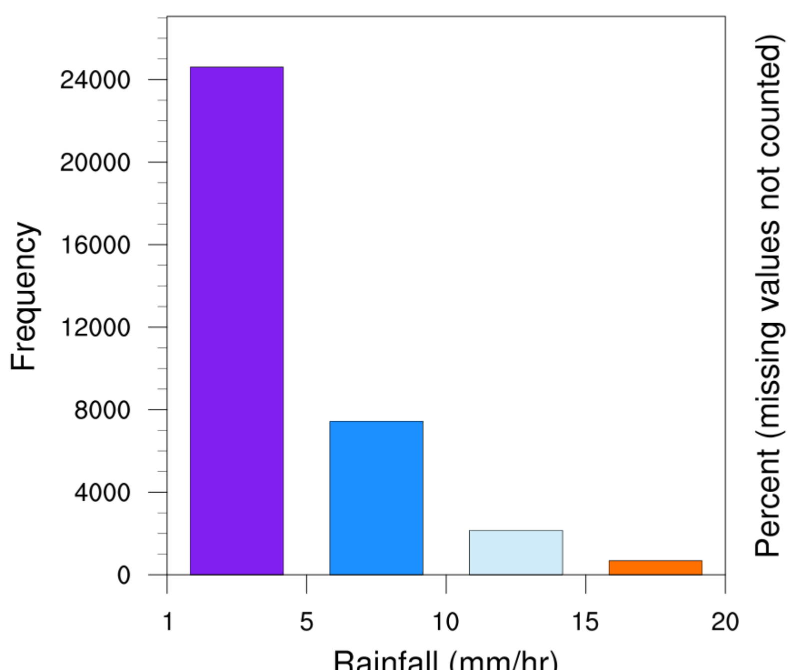
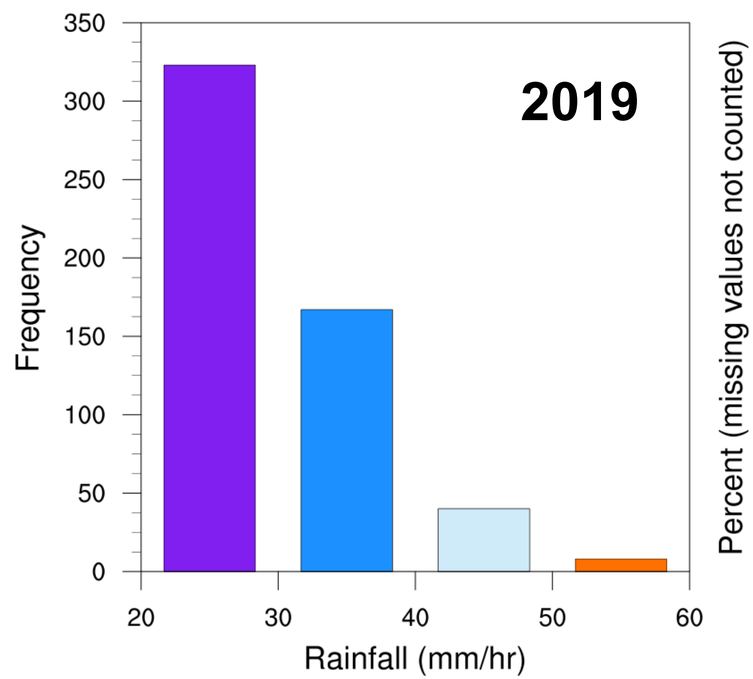
50
Rainfall (mm)



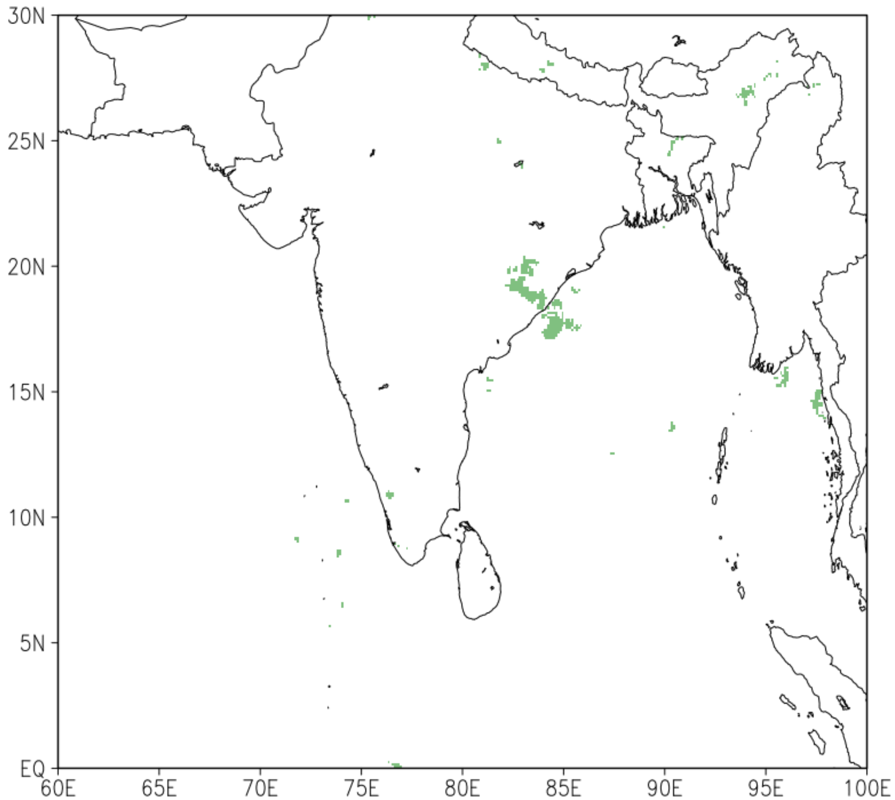




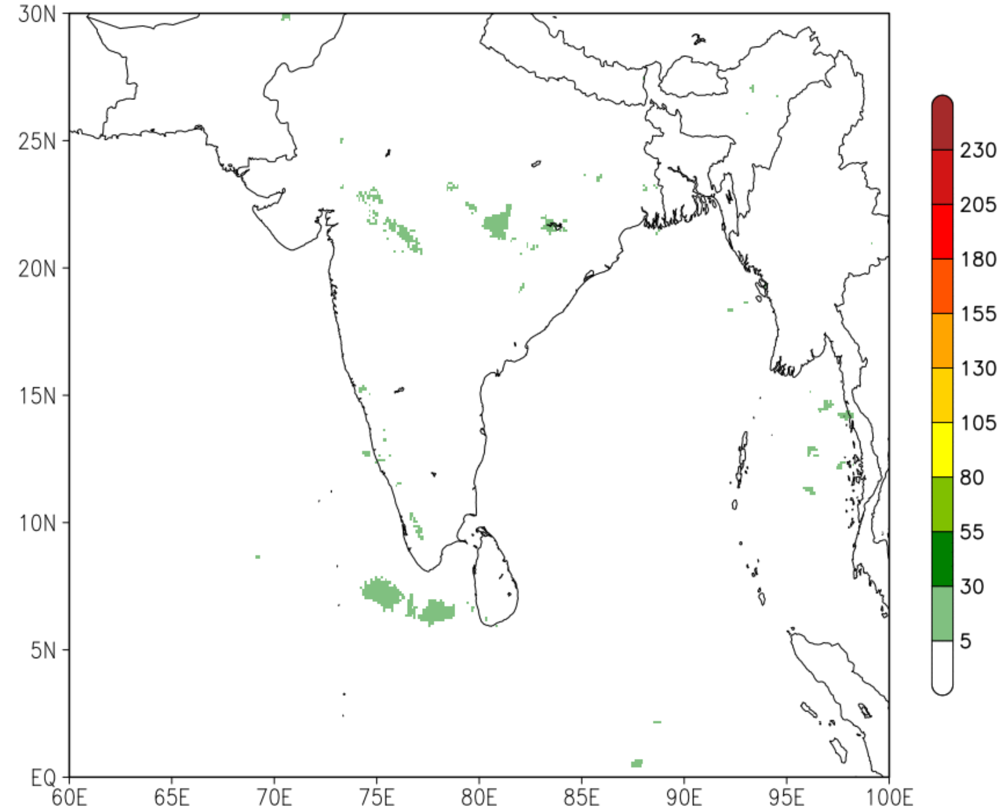


Vijayakumar, Abhilash etal., 2019

15 AUG 2018

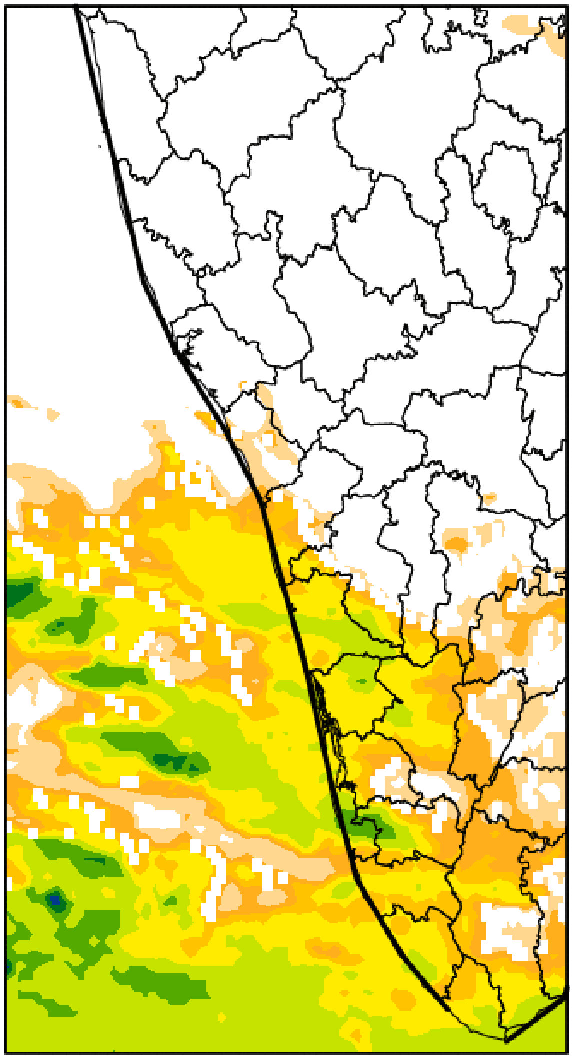


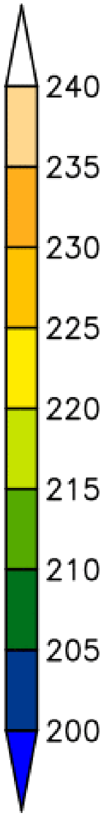
08 AUG 2019



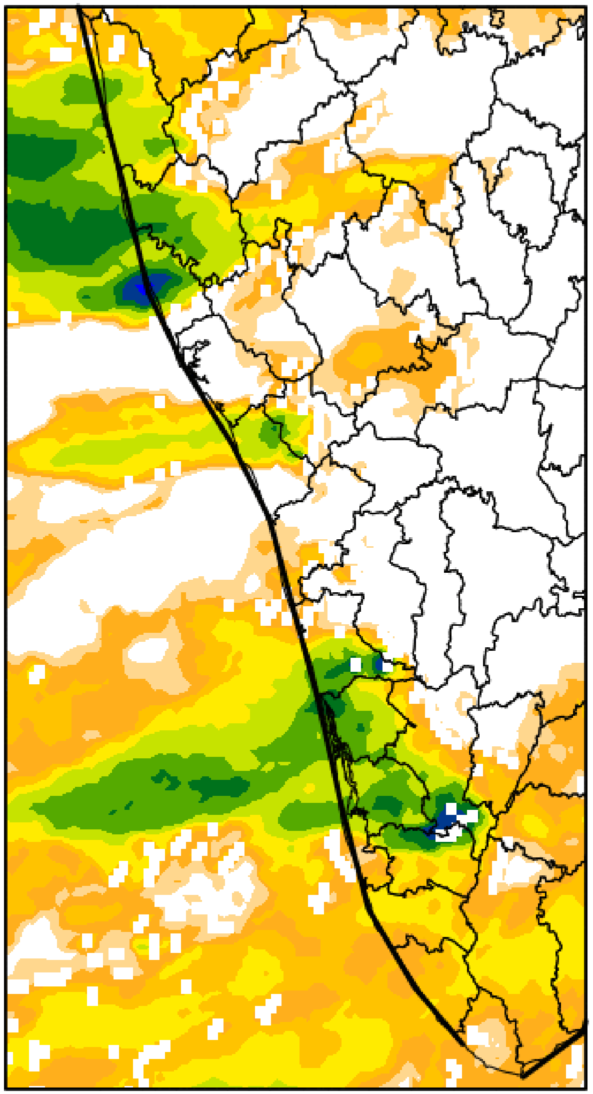
IR BT

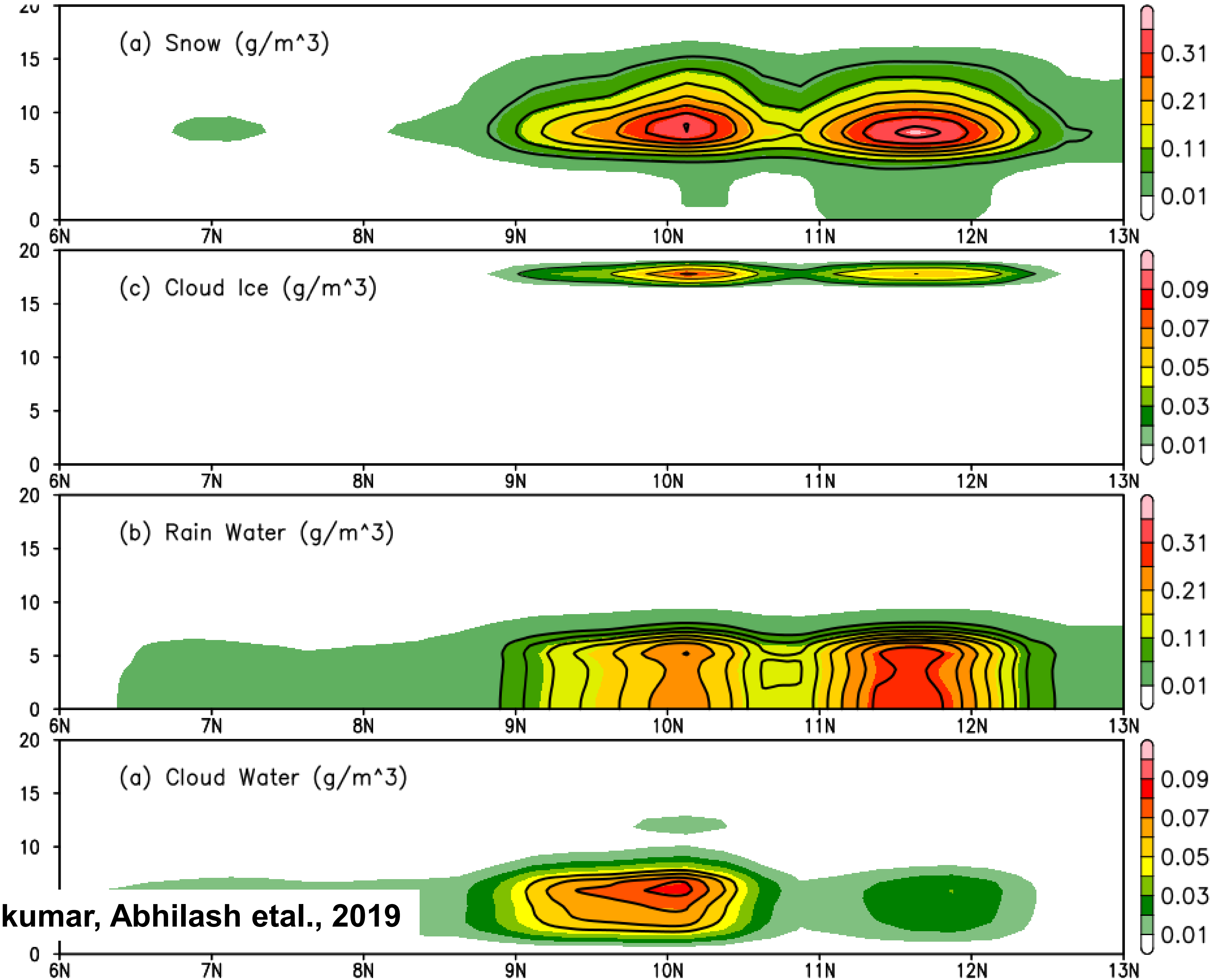
2018



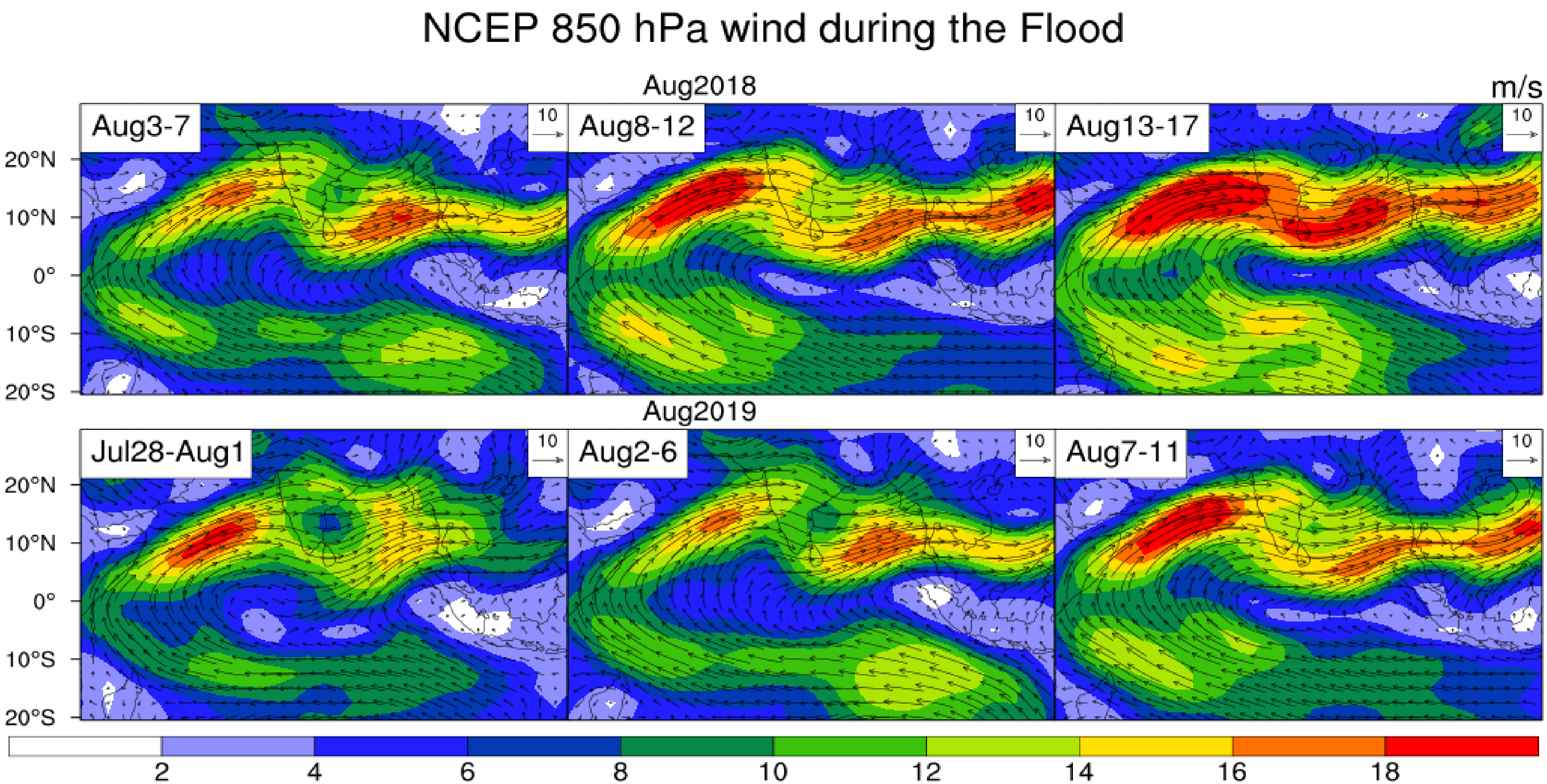


2019

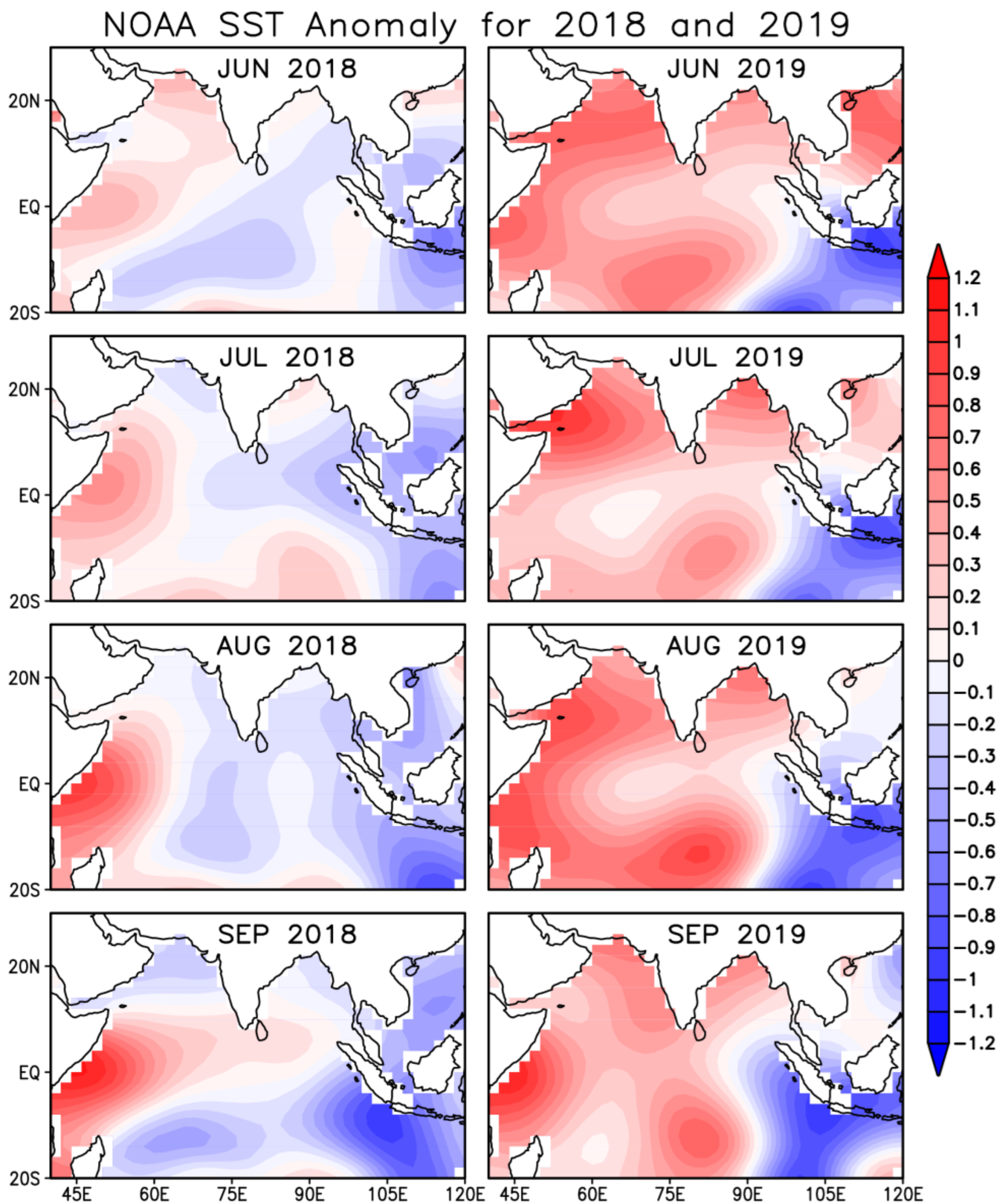




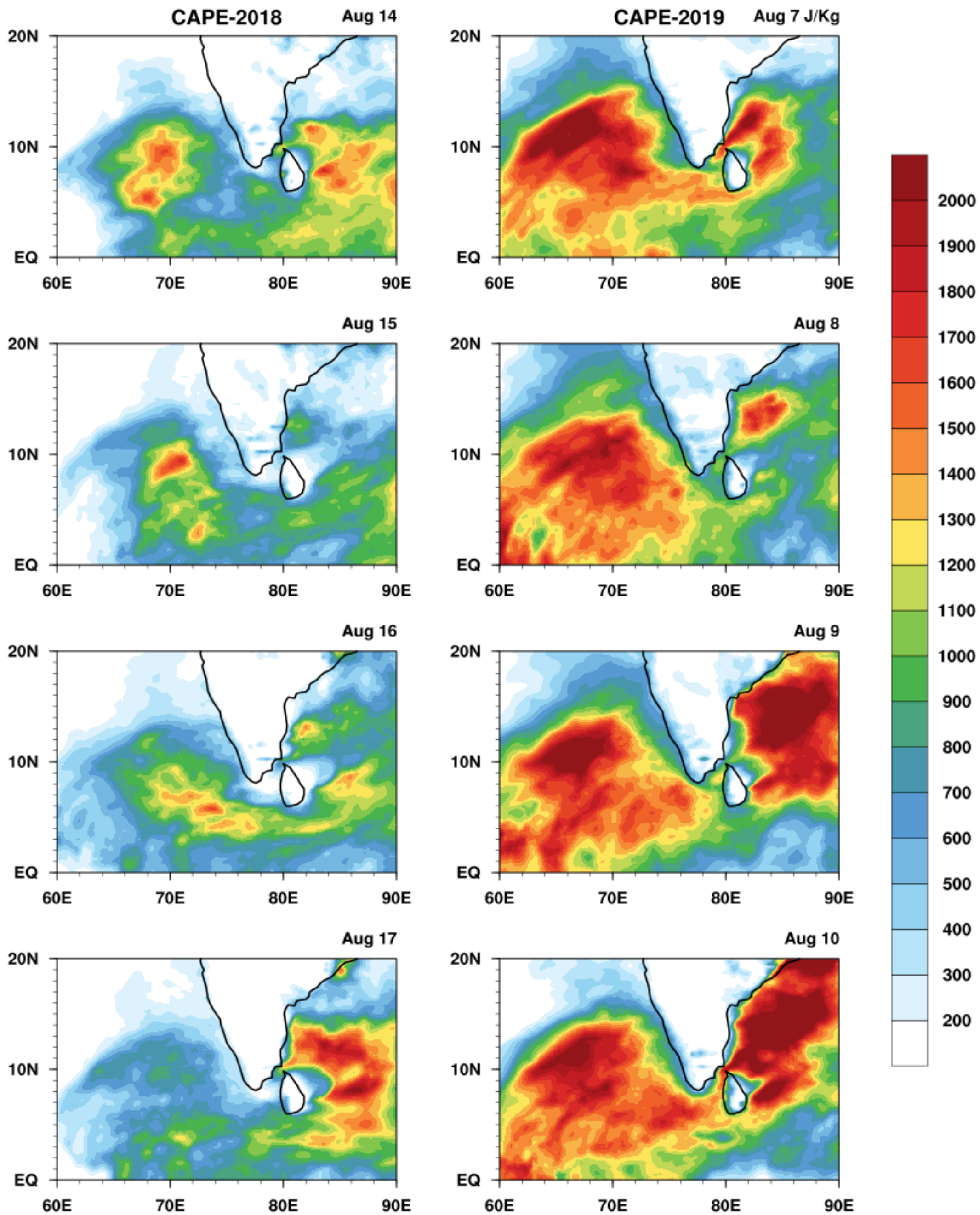
Vijayakumar, Abhilash etal., 2019



LLJ steadily gained strength from early week of August and remained the strongest during the active spell (13-17) that caused Kerala floods in 2018. Compared to 2018, LLJ during the extremely heavy rain spell of August 2019 remained weaker.



Anomalously warmer SST over the entire of NIO during Jun-Sep of 2019 while the anomalies remained insignificant during the same period in 2018



High CAPE values observed in the region during the Active Spell of 2019

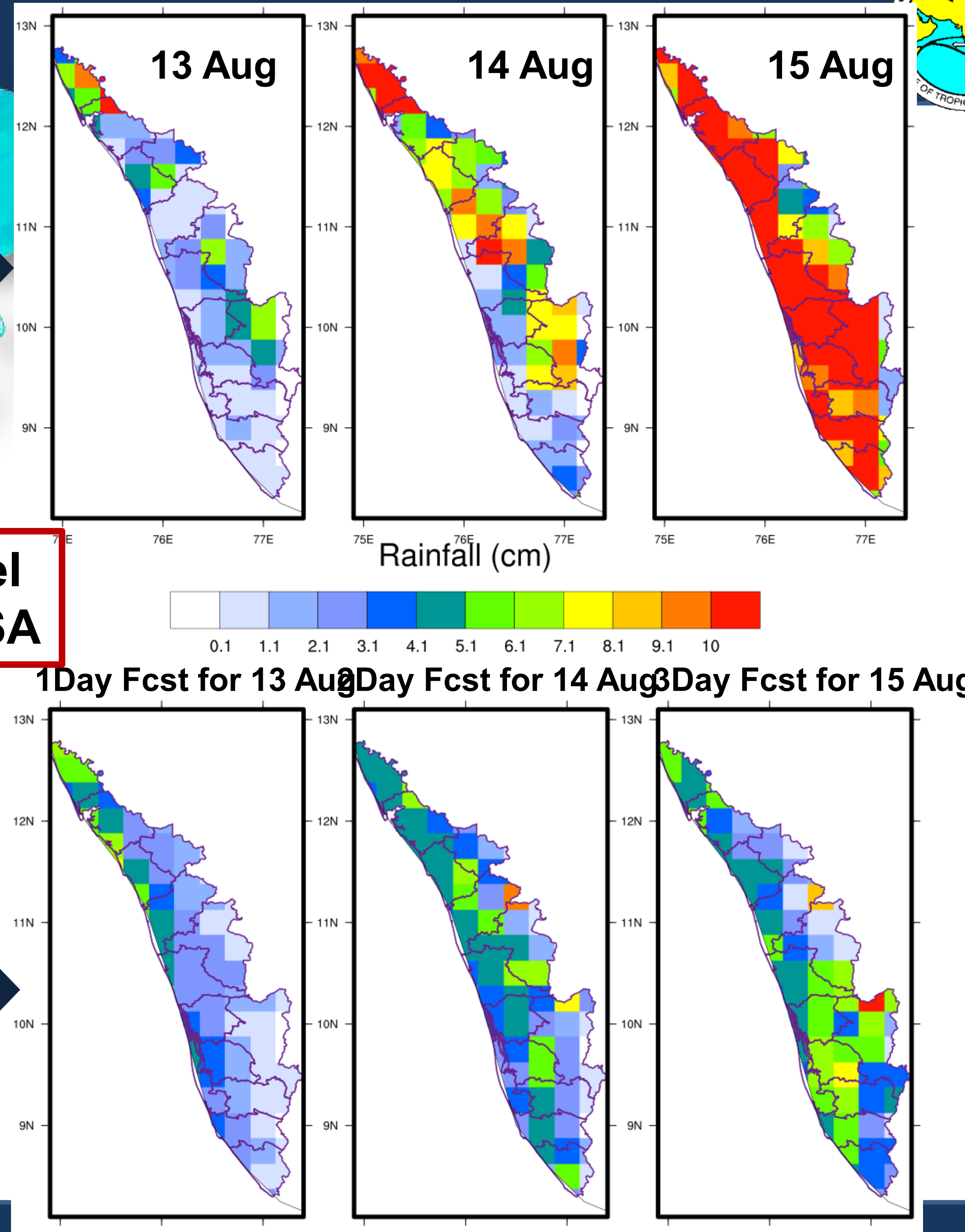
The smaller water droplets over the WG region would evaporate faster and produce more water vapour that will reach to higher levels with strong updraft (when CAPE is high) leading to formation of large amounts of ice and snow *(Siddharth et al 2014)*

Observation V/S Prediction

Actual Received Ra

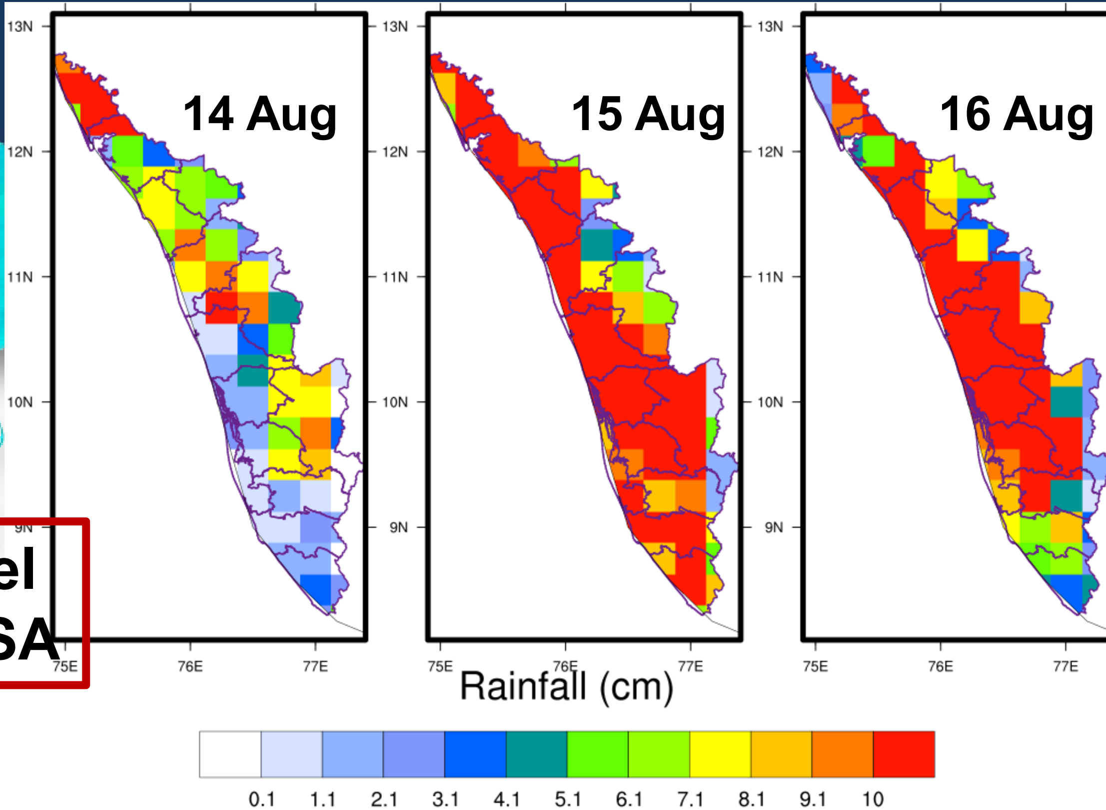
Global Forecast System model GFS Prediction from NCEP USA

Rain Forecast Initialized on 13th



Observation V/S Prediction

Actual Received Ra

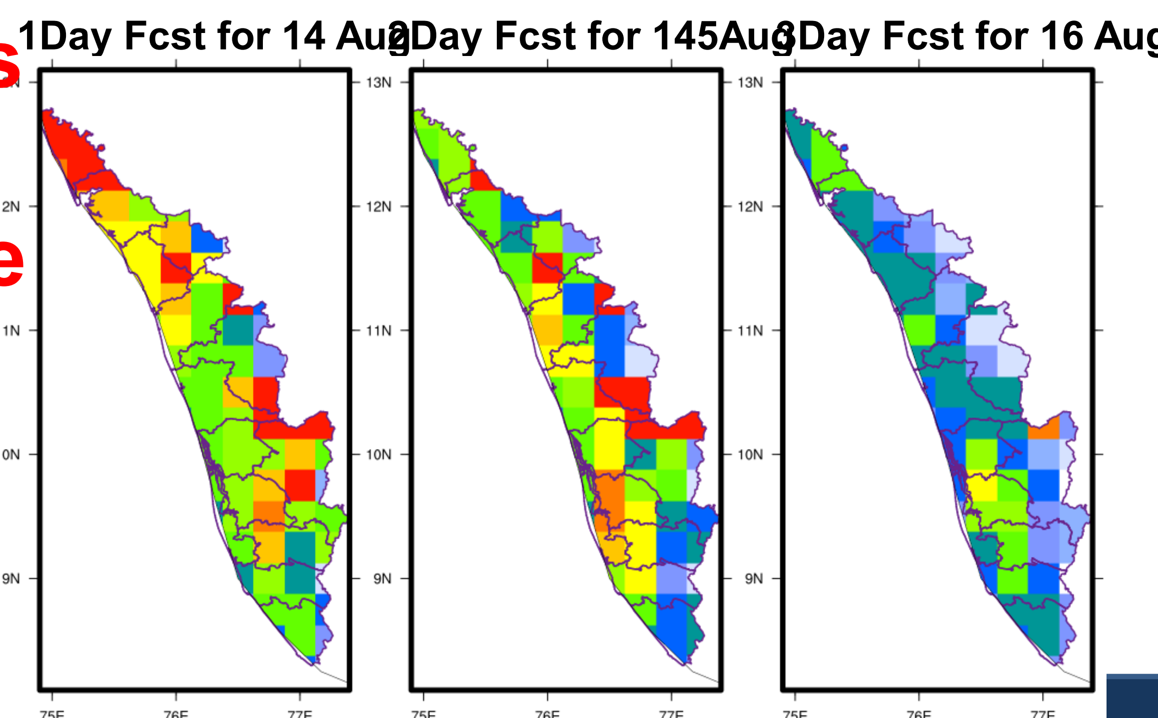


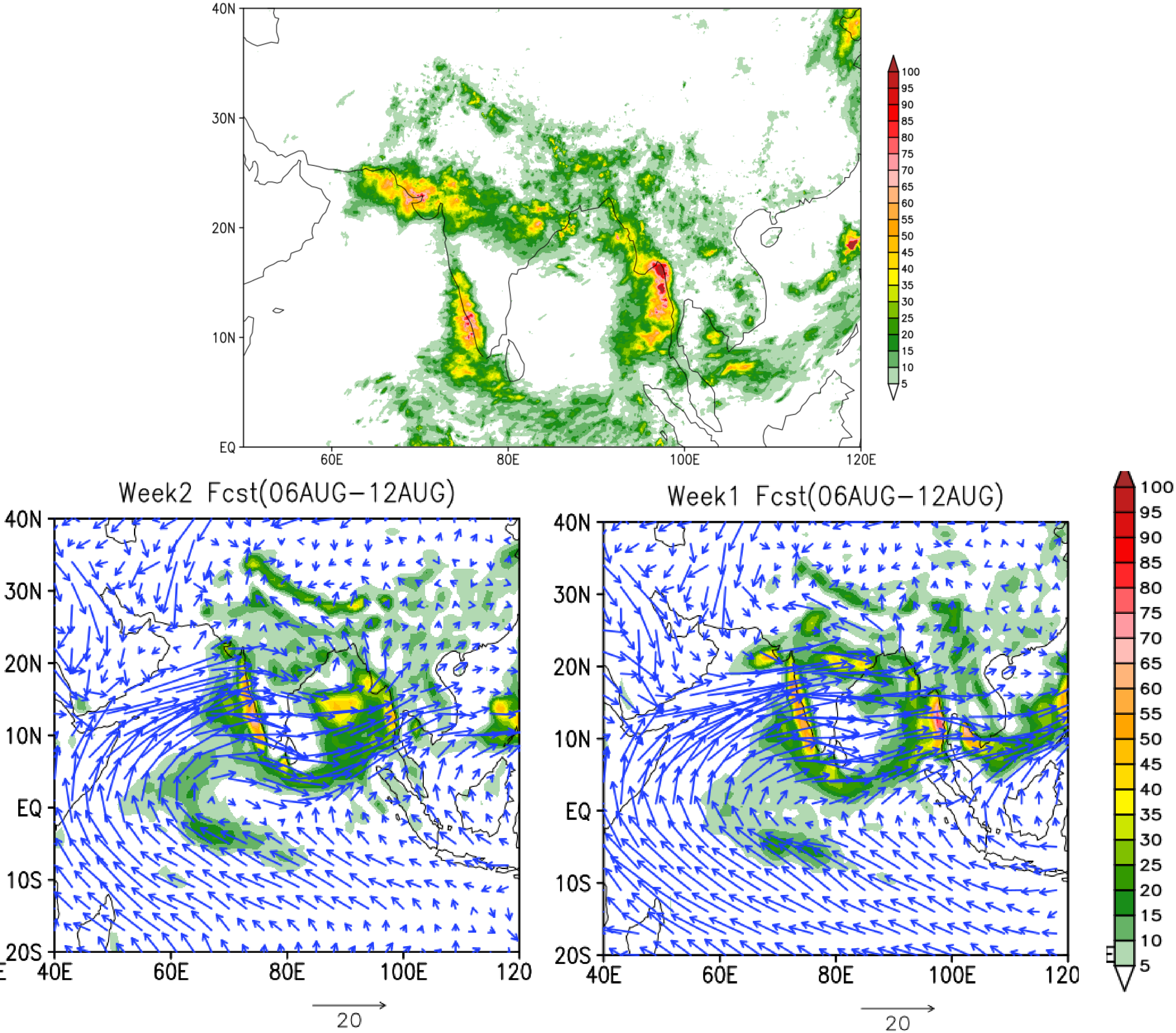
Global Forecast System model GFS Prediction from NCEP USA

Global Truth:!!!

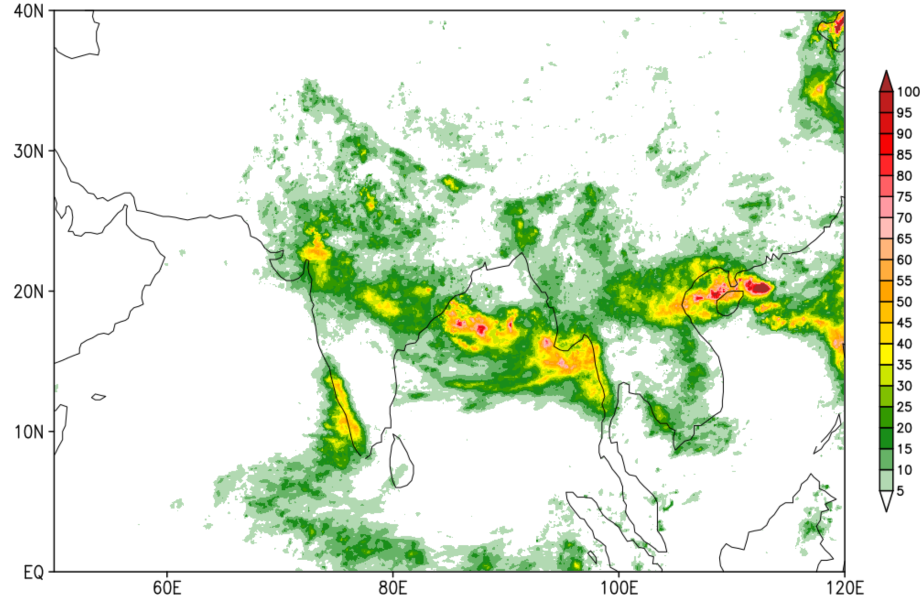
As lead time Increases Models failed to Capture the amplitude

Rain Forecast





40N
30N
20N
10N
EQ
60E
80E
100E
120E
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
Week2 Fcst(06AUG-12AUG)
Week1 Fcst(06AUG-12AUG)
10S
20S
40E
20
20


40N
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EQ
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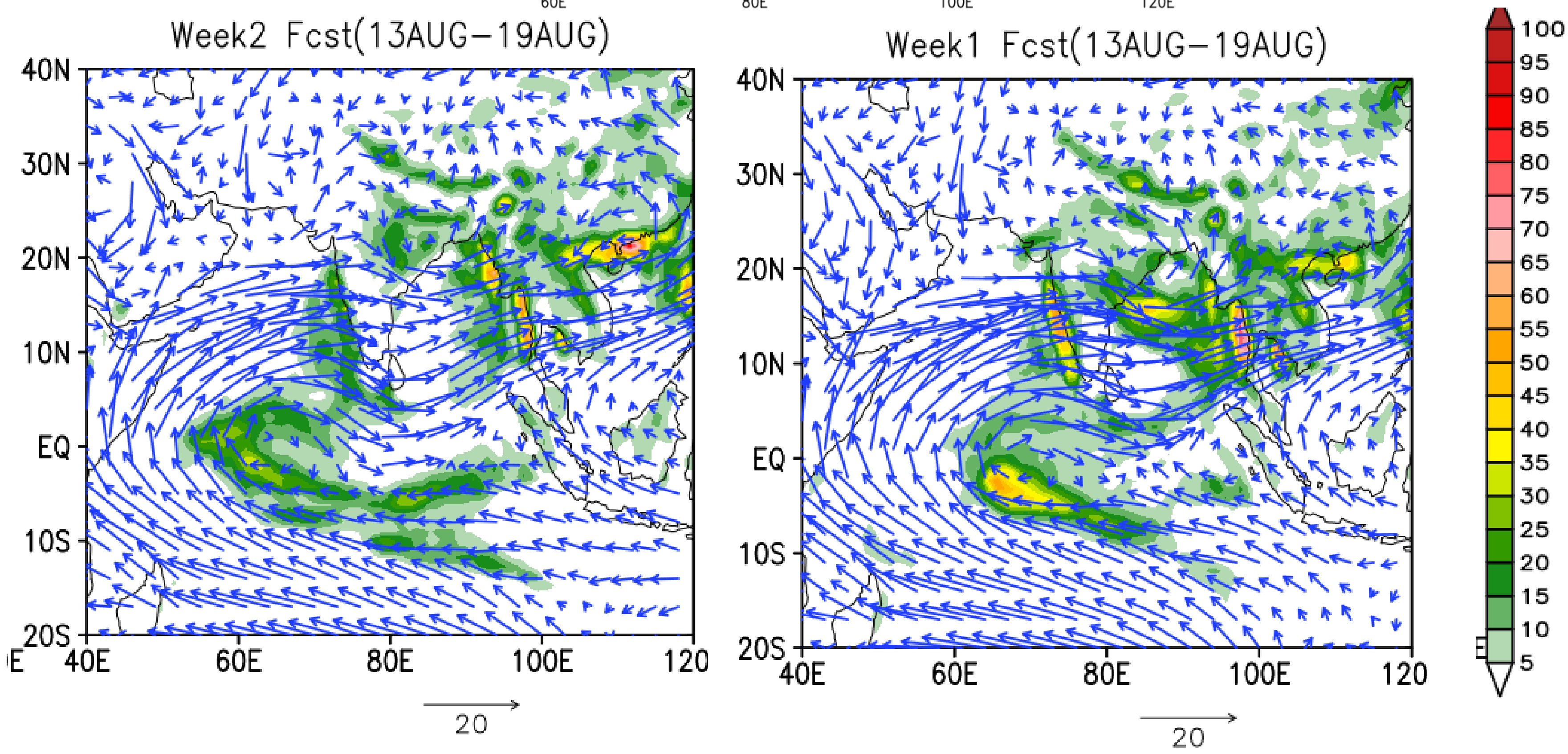
Week2 Fcst(13AUG-19AUG)
Week1 Fcst(13AUG-19AUG)
40N
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EQ
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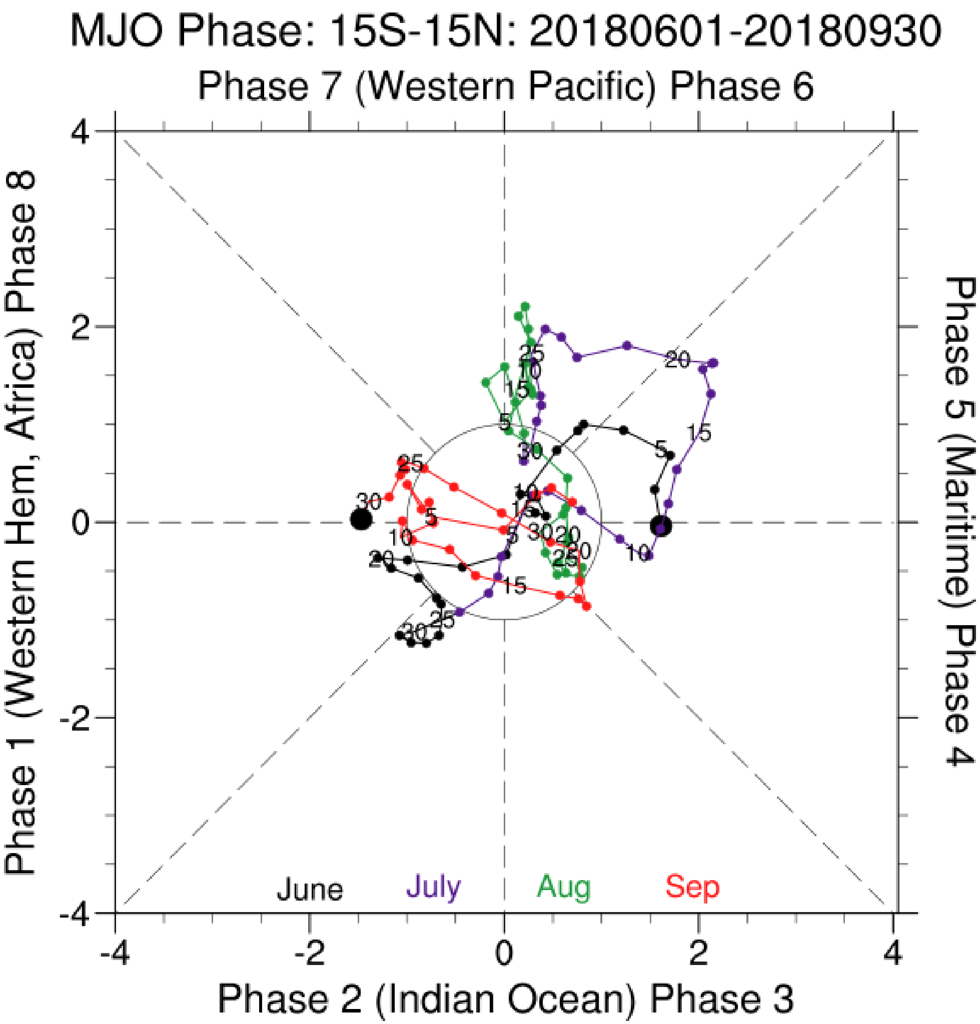
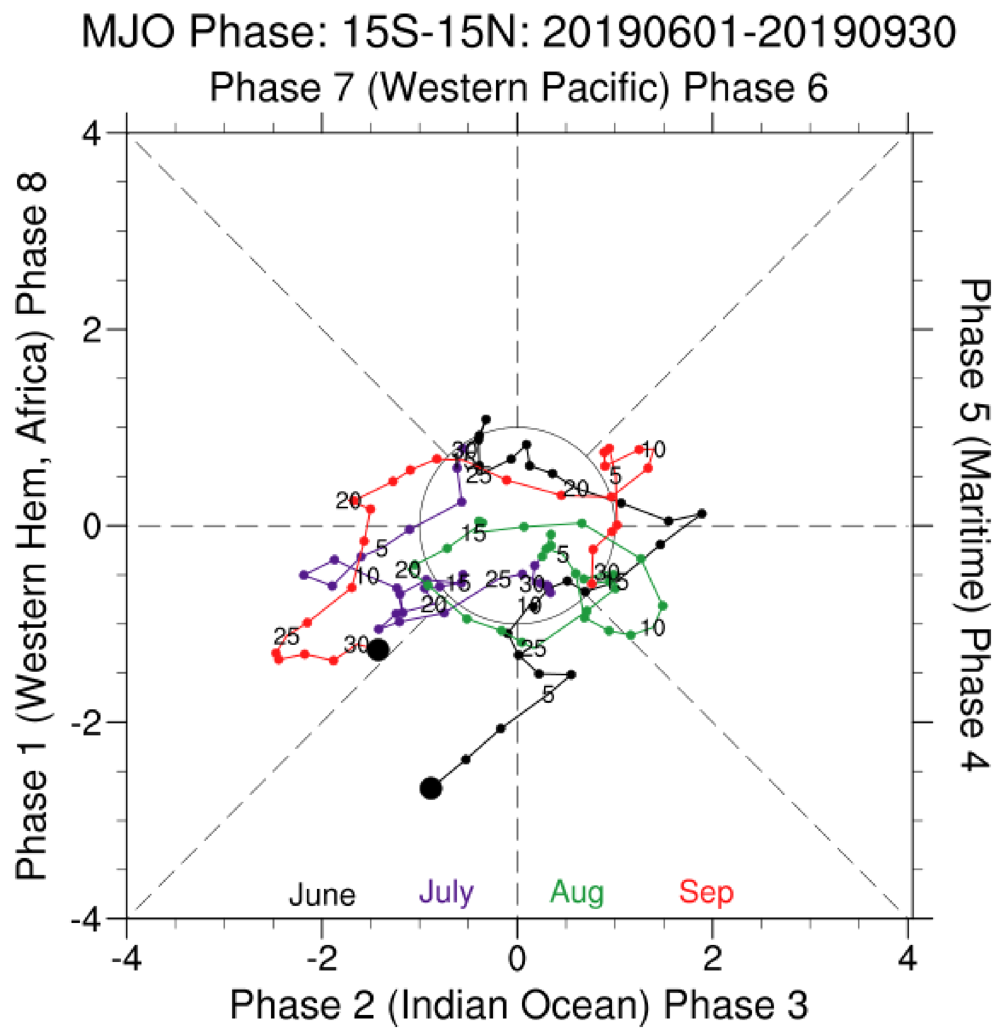


MJO Phase: 15S-15N: 20180601-20180930
Phase 7 (Western Pacific) Phase 6
Phase 1 (Western Hem, Africa) Phase 8
Phase 5 (Maritime) Phase 4
Phase 2 (Indian Ocean) Phase 3
June
July
Aug
Sep



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Phase 7 (Western Pacific) Phase 6
Phase 1 (Western Hem, Africa) Phase 8
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Phase 2 (Indian Ocean) Phase 3
June
July
Aug
Sep

VIMFC during enhanced spells over Kerala

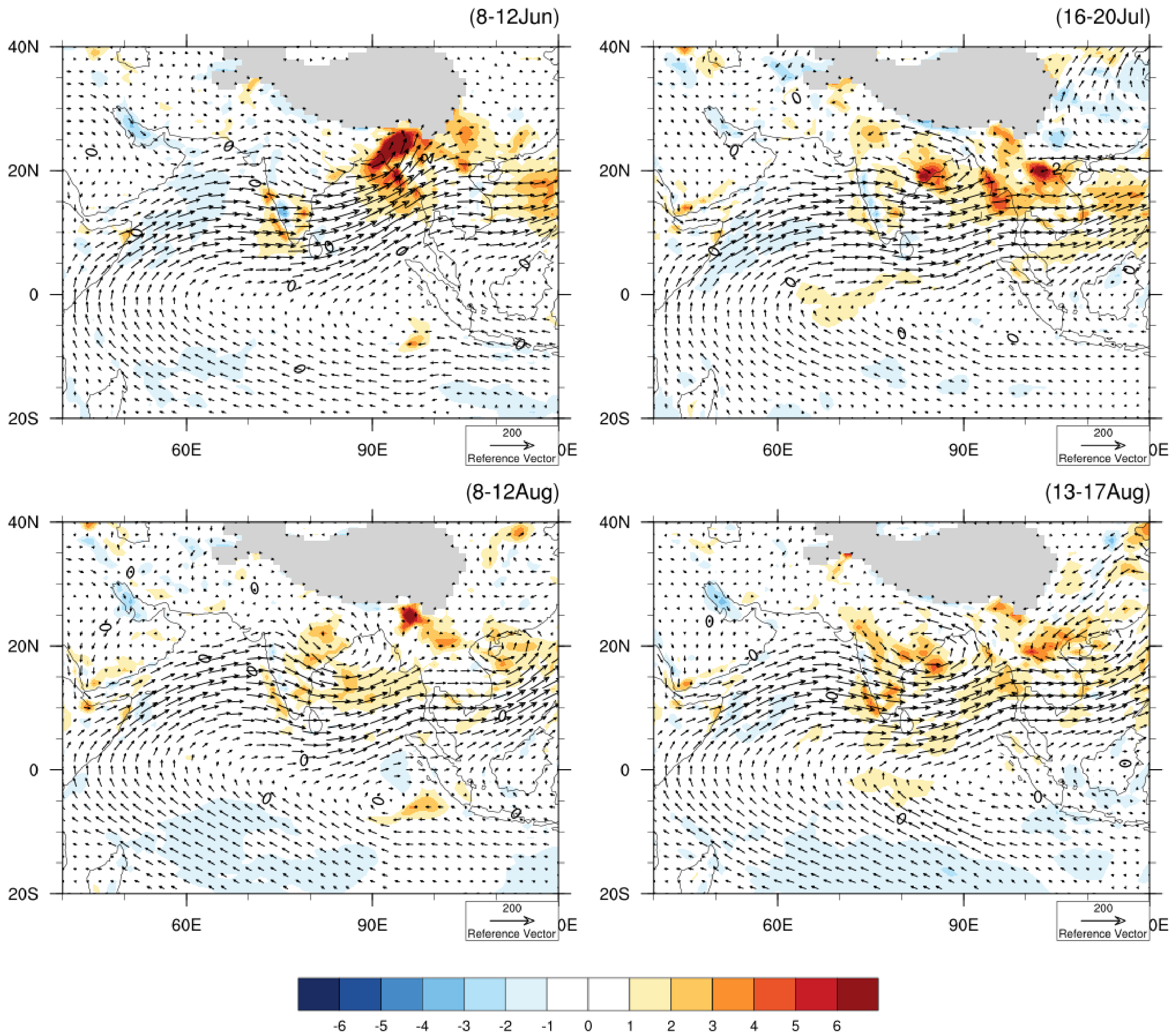


Fig 1 Kerala coast region (55-75°E; 5°N-12°N)

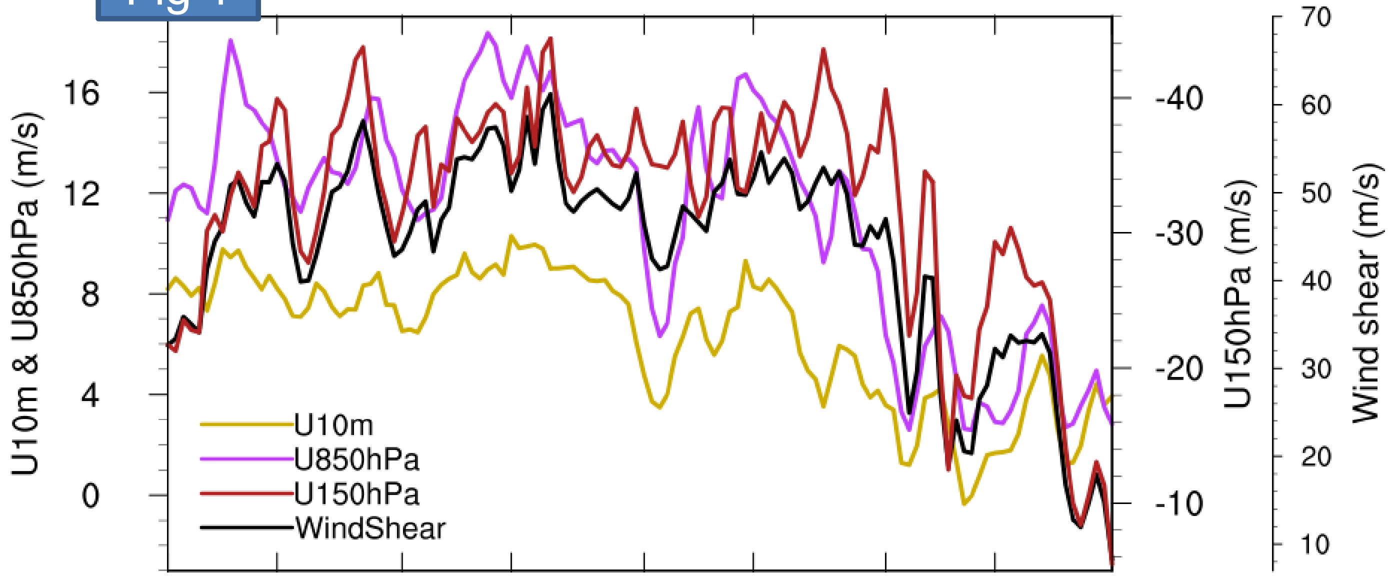
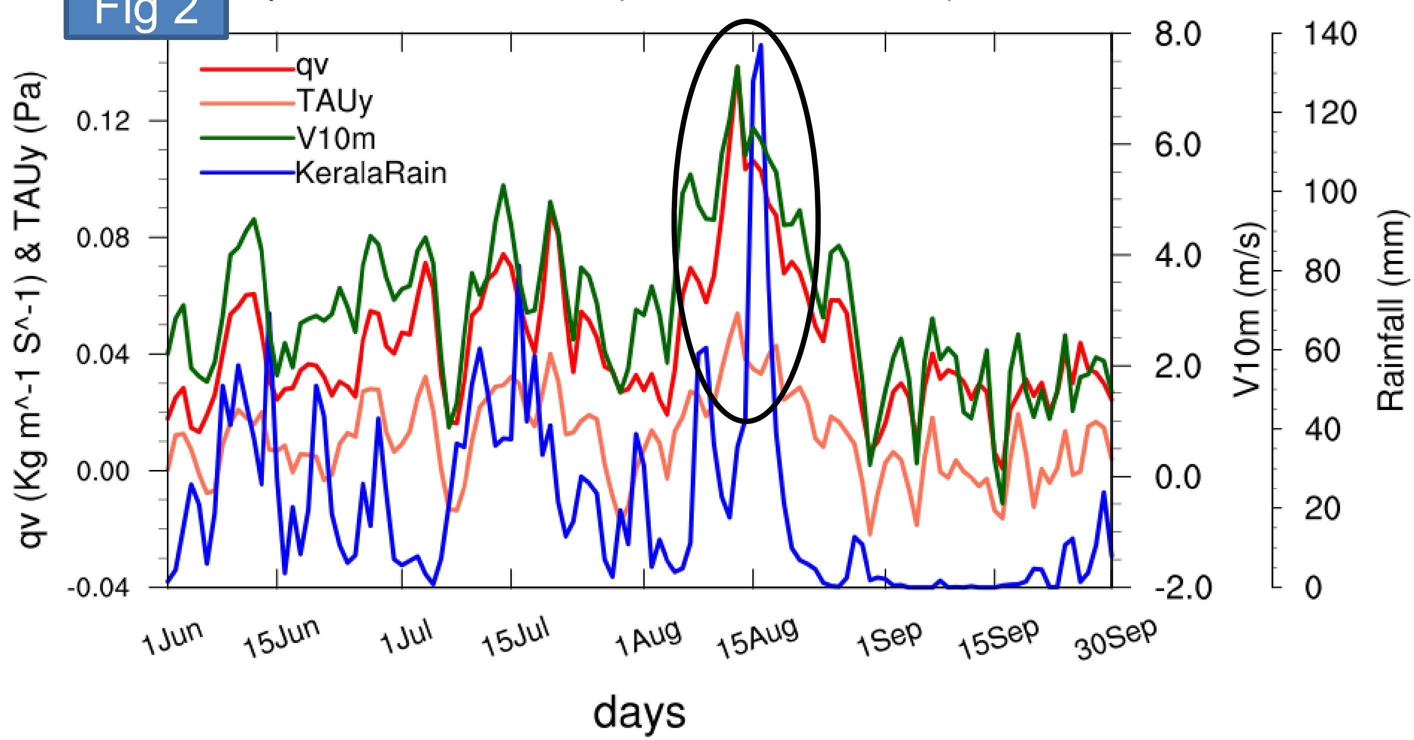


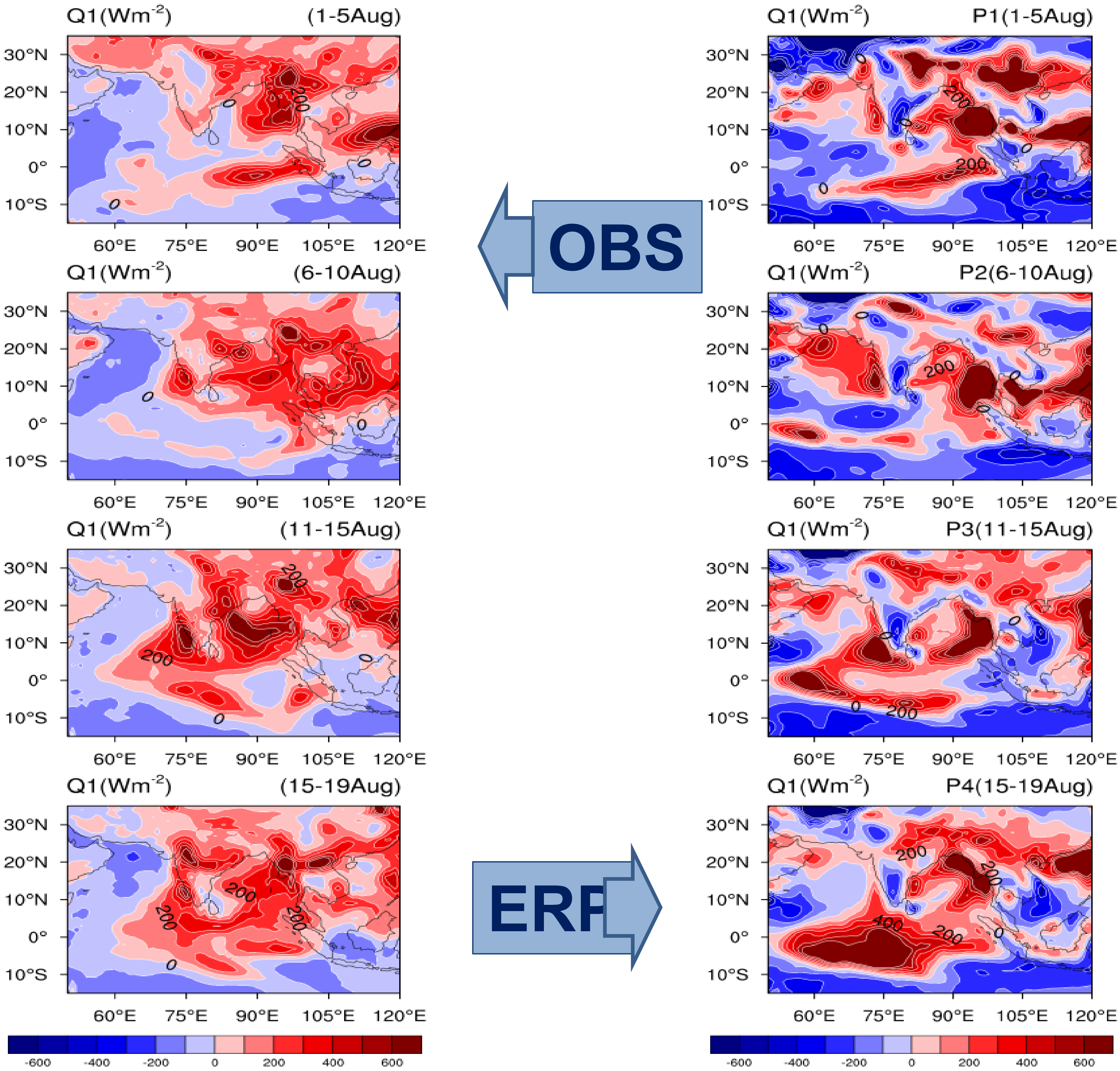
Fig1 is the Area avg time series of U component wind of LLJ region over Kerala and near Kerala coast ocean regions

Fig2 is the area avg time series of V component winds over SEIO to Kerala coast and the Rainfall over Kerala region.

Fig 2 Equatorial Indian Ocean (64-74°E; 15°S-15°N)



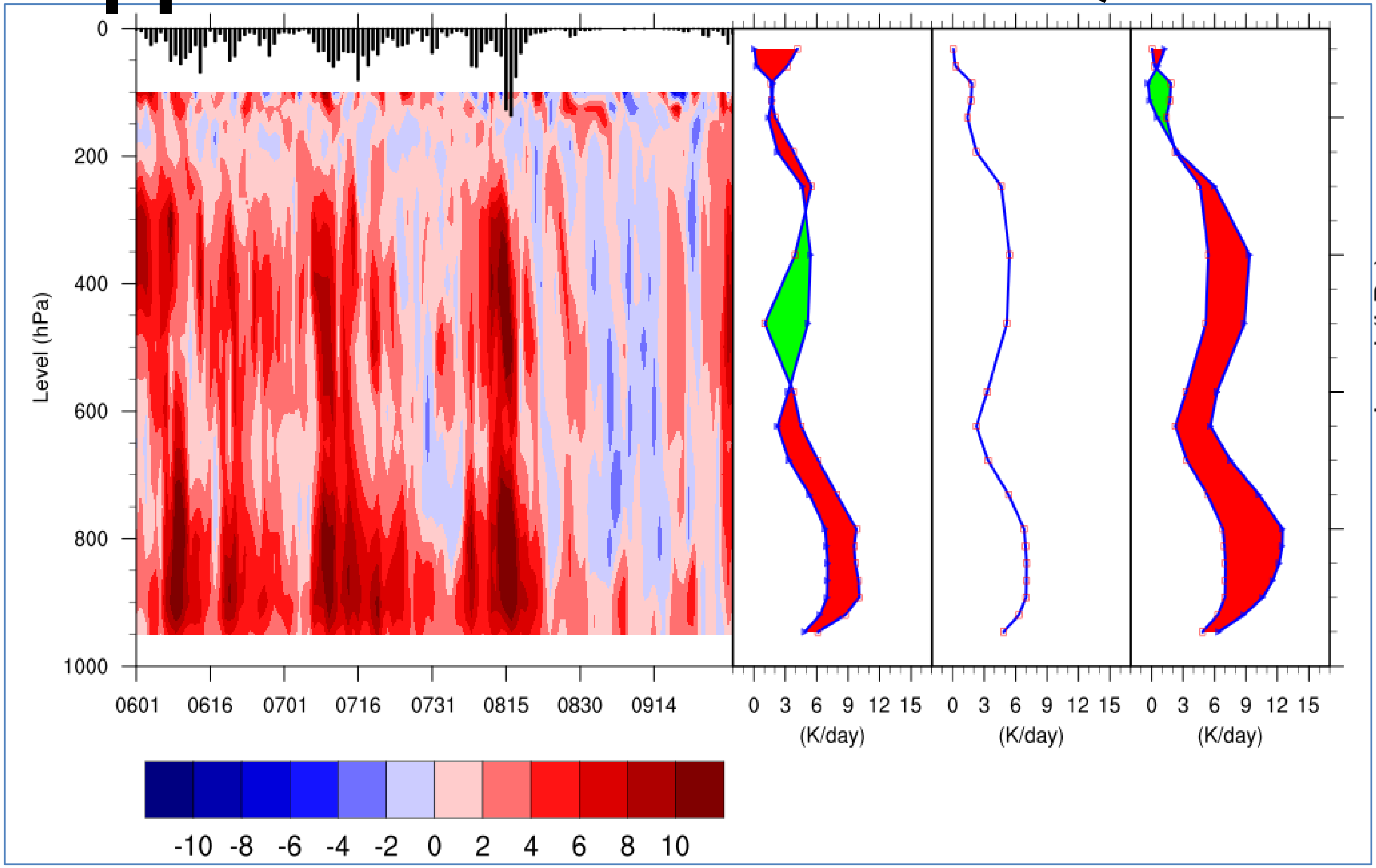
- The peak moisture flux and wind stress are happening on just two days before the extreme rainfall peak on Aug

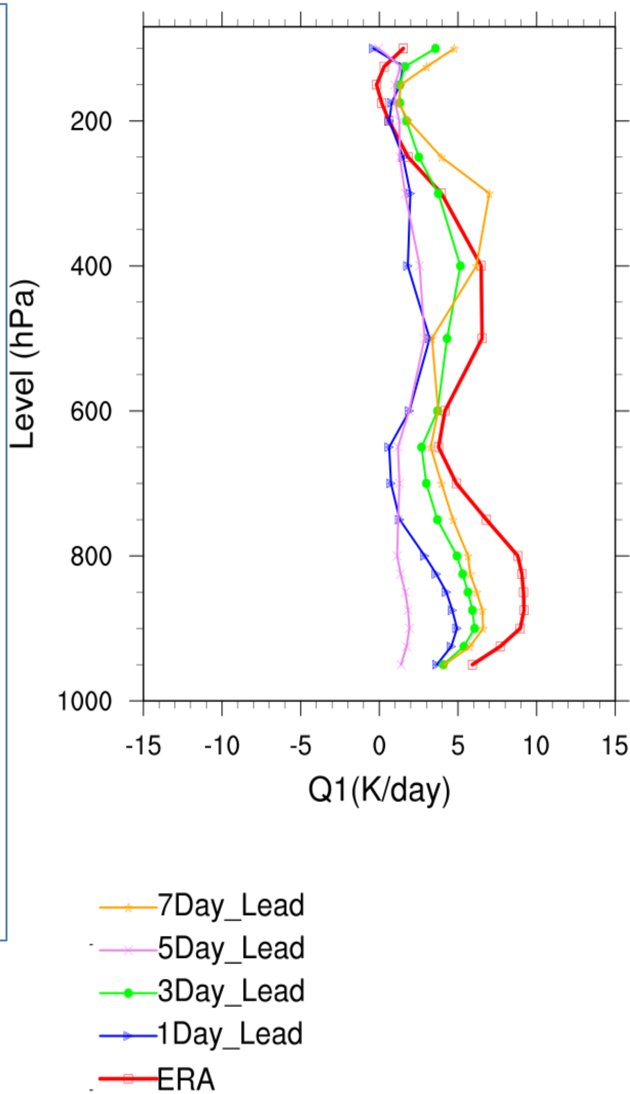


Q1(Wm^{-2}) (1-5Aug)
Q1(Wm^{-2}) P1(1-5Aug)
OBS
Q1(Wm^{-2}) (6-10Aug)
Q1(Wm^{-2}) P2(6-10Aug)
Q1(Wm^{-2}) (11-15Aug)
Q1(Wm^{-2}) P3(11-15Aug)
Q1(Wm^{-2}) (15-19Aug)
Q1(Wm^{-2}) P4(15-19Aug)
ERF
30°N 20°N 10°N 0° 10°S
60°E 75°E 90°E 105°E 120°E
-600 -400 -200 0 200 400 600

Analysis of 2018 Monsoon Season

Apparent Heat Source : Q1





Entrainment formulation in NCEP GFS (Han and Pan 2011)

Han and Pan (2011 WAF) – NCEP GFS:

Following Bechtold et al. (2008), the entrainment is specified as

$$\varepsilon = \varepsilon_0 F_0 + d_1(1 - \mathrm{RH})F_1 \quad \text{and}$$

$$F_0 = \left(\frac{\overline{q}_s}{\overline{q}_{\mathrm{sb}}}\right)^2, \quad F_1 = \left(\frac{\overline{q}_s}{\overline{q}_{\mathrm{sb}}}\right)^3, \tag{8}$$

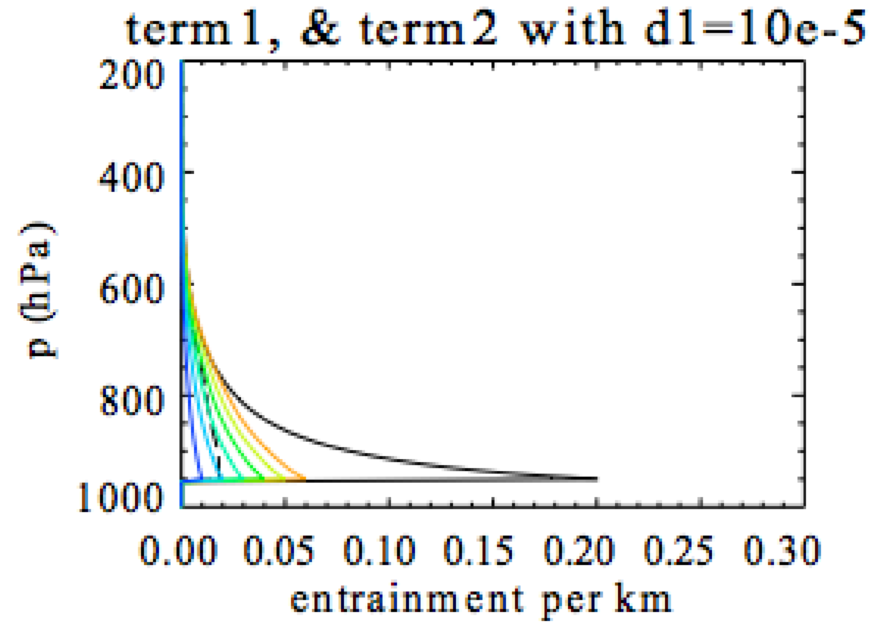
where ε_0 is the entrainment rate at the cloud base; RH the environmental relative humidity; d_1 a tunable parameter of $O(10^{-4})$; q_s and q_{sb} the saturation specific humidities at the parcel level and the cloud base, respectively; and F_0 and F_1 are dimensionless vertical scaling functions that decrease strongly with height. Equation (8) indicates that a drier environment (lower RH) increases the entrainment, suppressing convection.

How to make the conditional dependence (on 1-RH) stronger, while avoiding dilemma?

$$\varepsilon = \varepsilon_0 F_0 + d_1(1 - \mathrm{RH})F_1$$

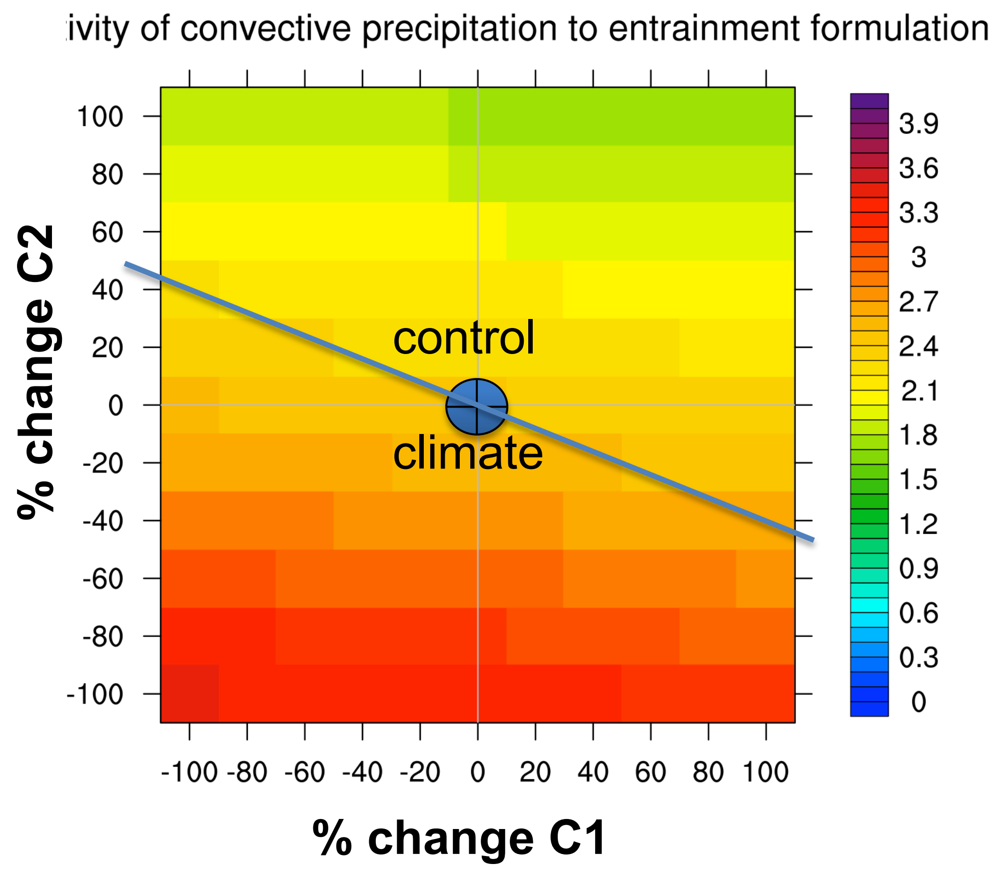
multiply by C_1 <1

multiply by C_2 >1

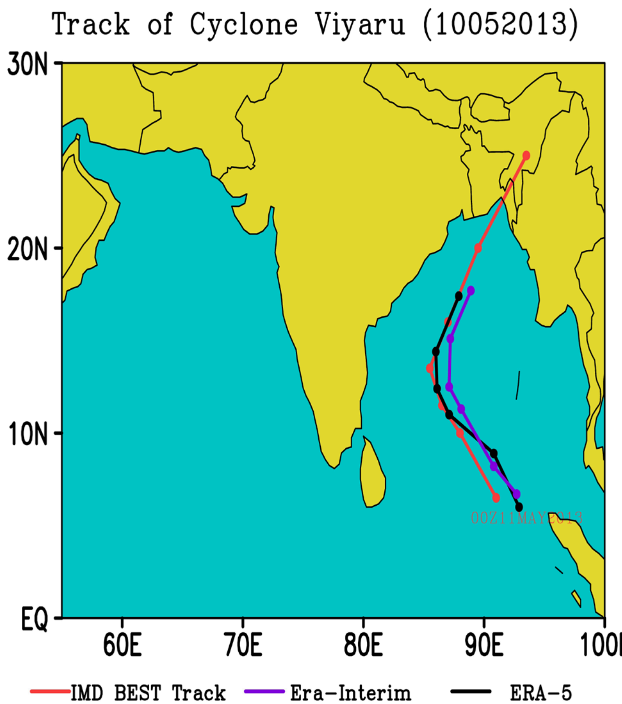


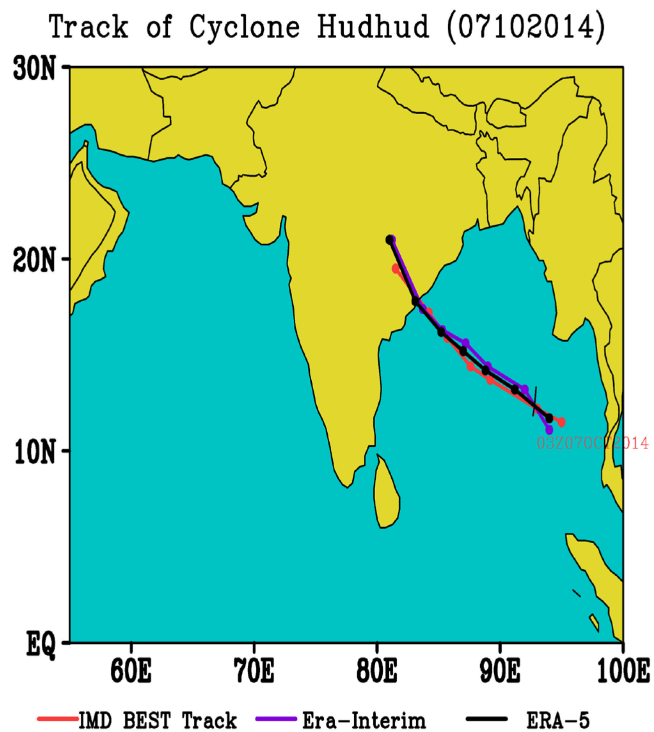
40,50,60,70,80,90

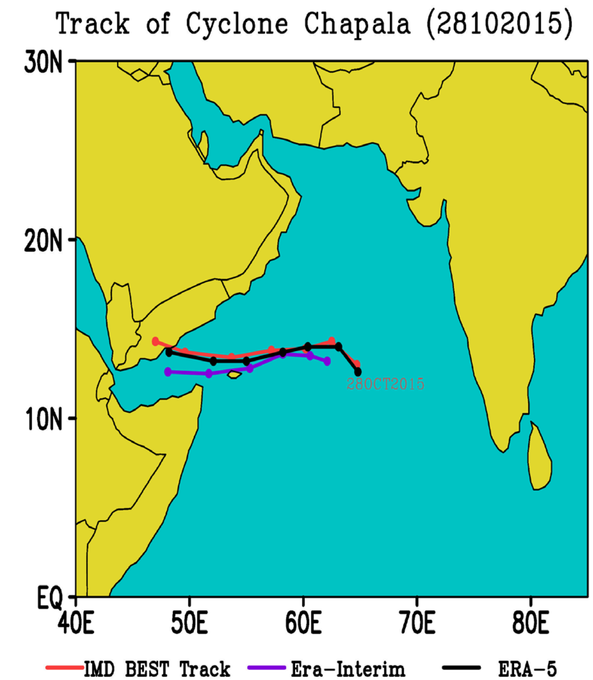
{C1,C2} to compensate what? *PRECC in first time step*:

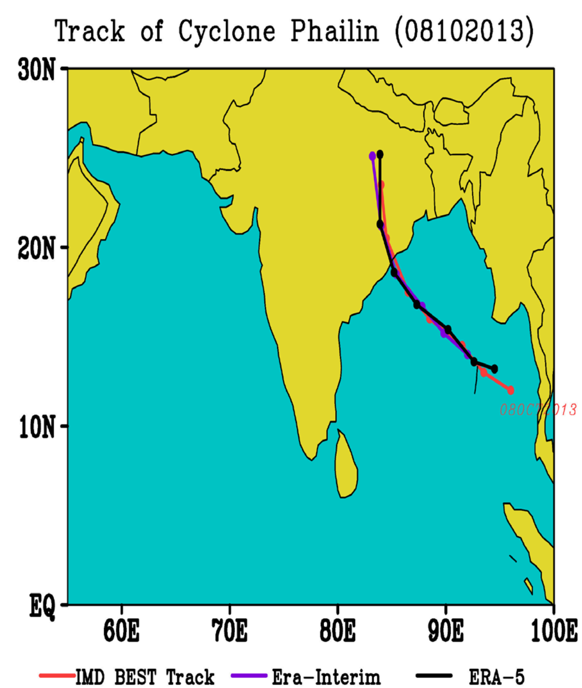


ERA-Interim & ERA-5 Tracks From Vortex Tracker compared with IMD Best Tracks





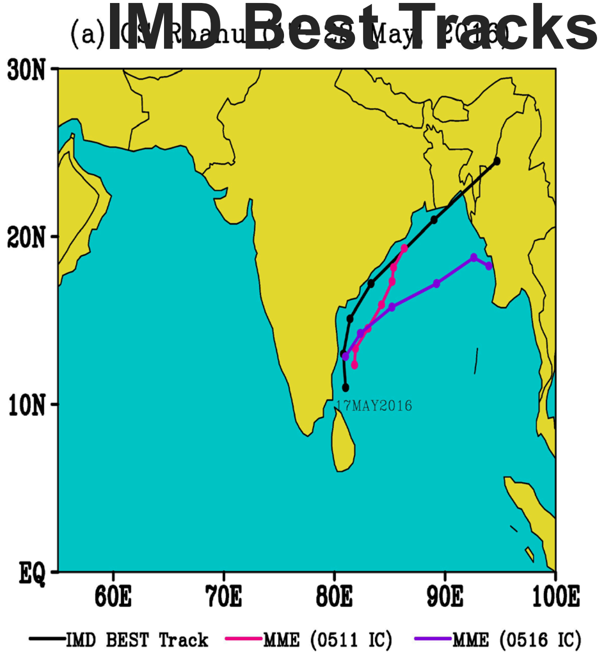


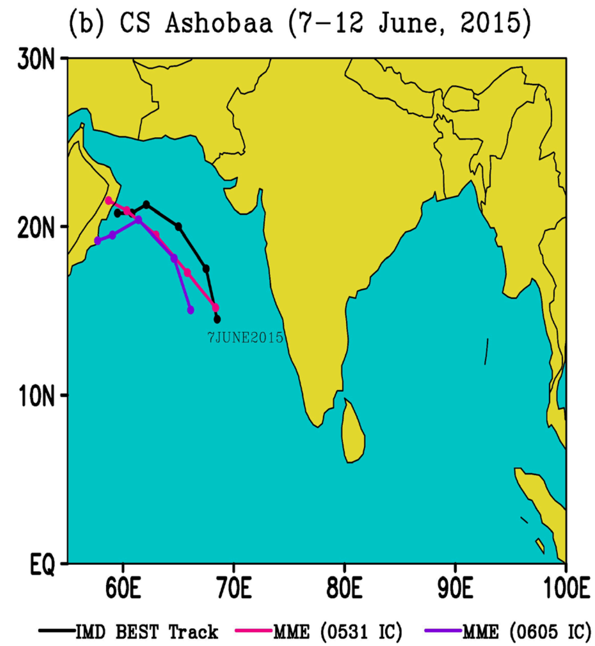


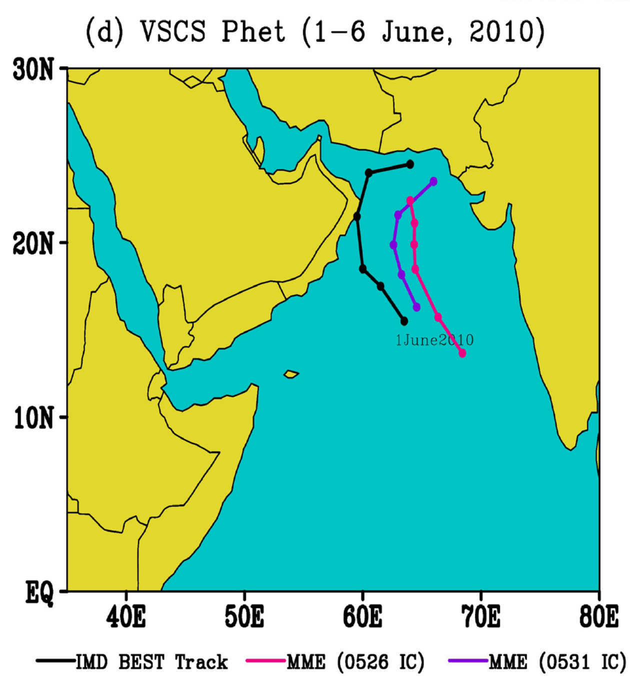
- **The tracks detected by the algorithm are at par with the IMD Best Tracks**

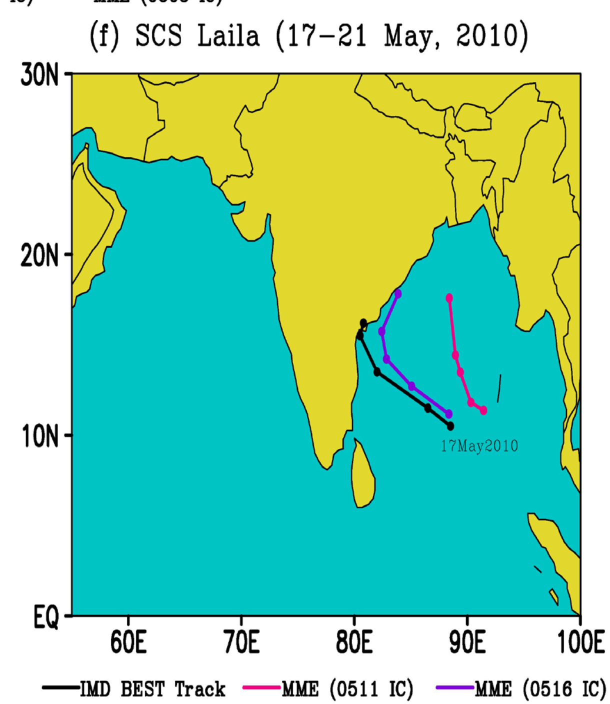
Saranya , Abhilash, sahai, etal., GRL, 2018

MME-mean Tracks for 6 pre-monsoon cyclones predicted from two nearest ICs using Vortex Tracker compared with IMD Best Tracks

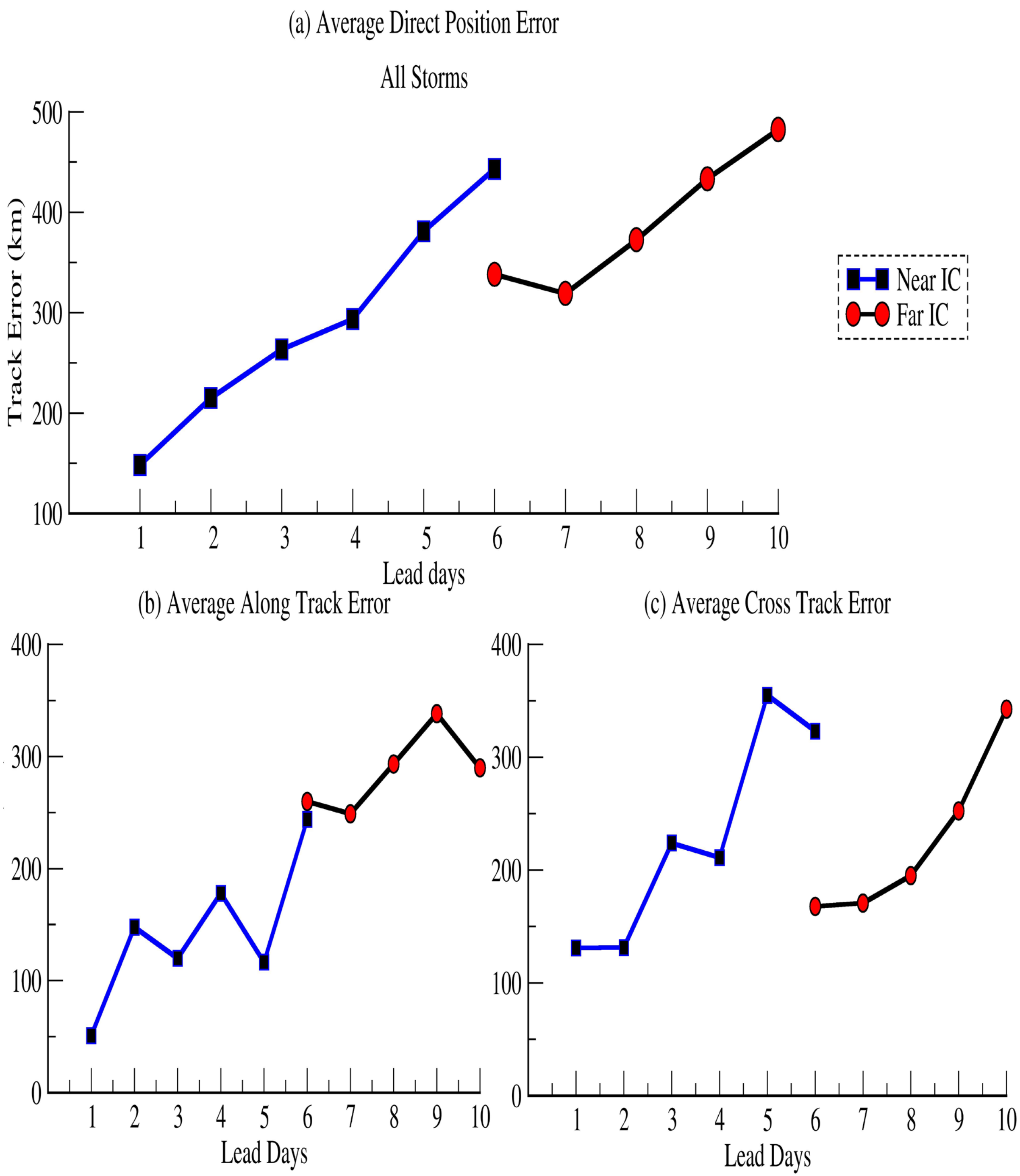








Saranya , Abhilash, sahai, etal., GRL, 2018



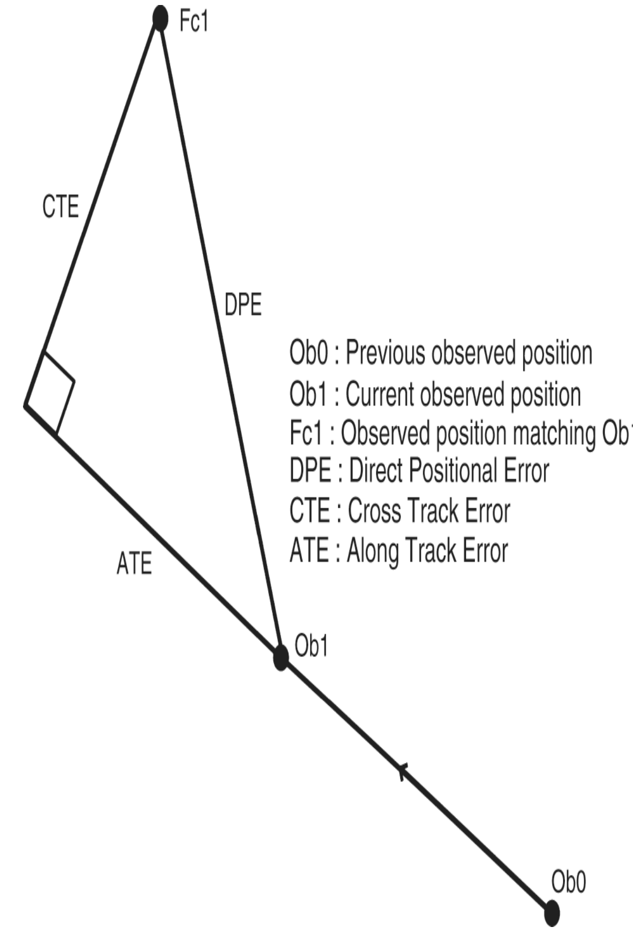


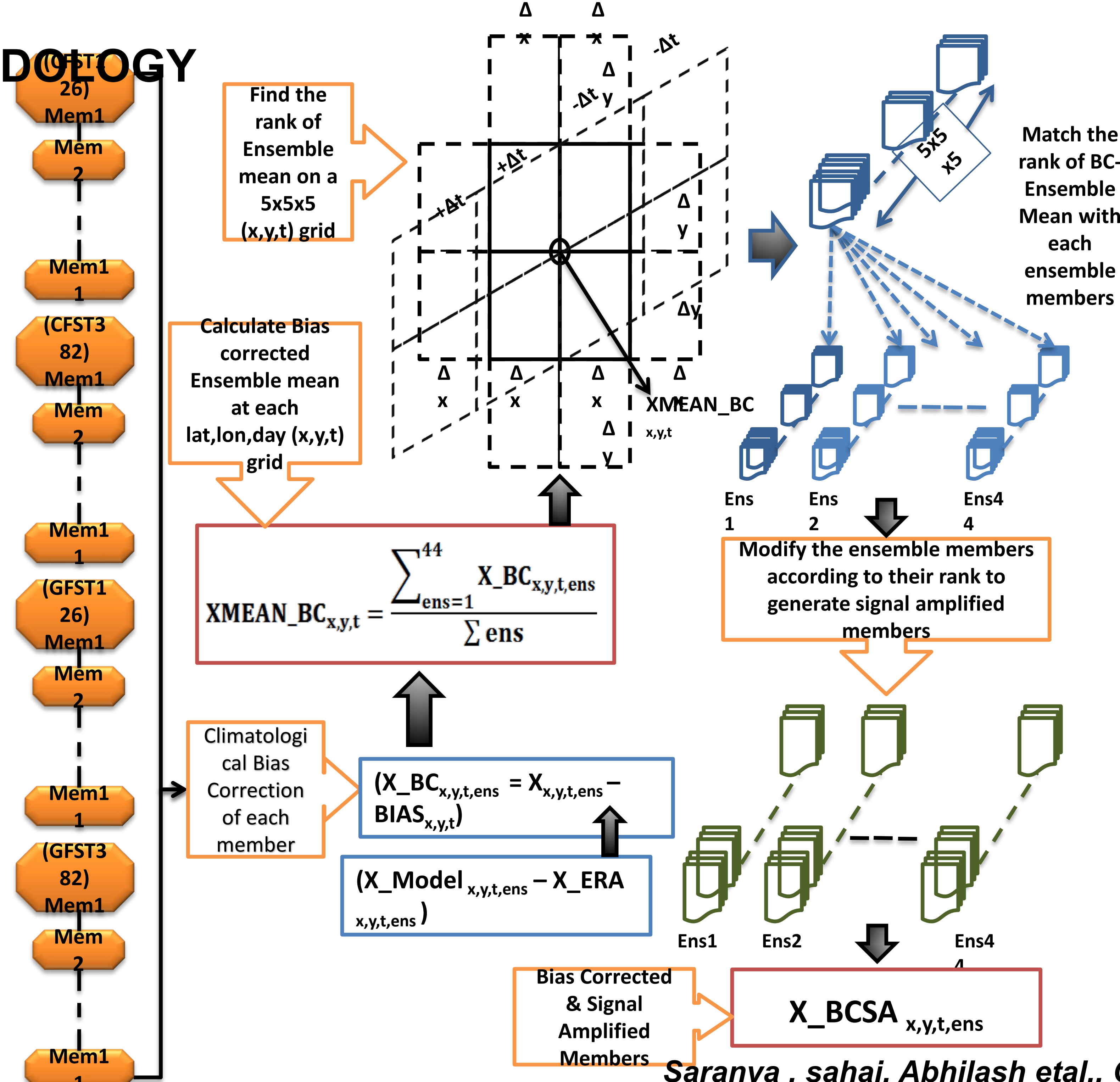
Diagram explaining the Tropical Cyclone Track Forecast Error (Heming, 2017)

Saranya , Abhilash, sahai, etal., GRL, 2018

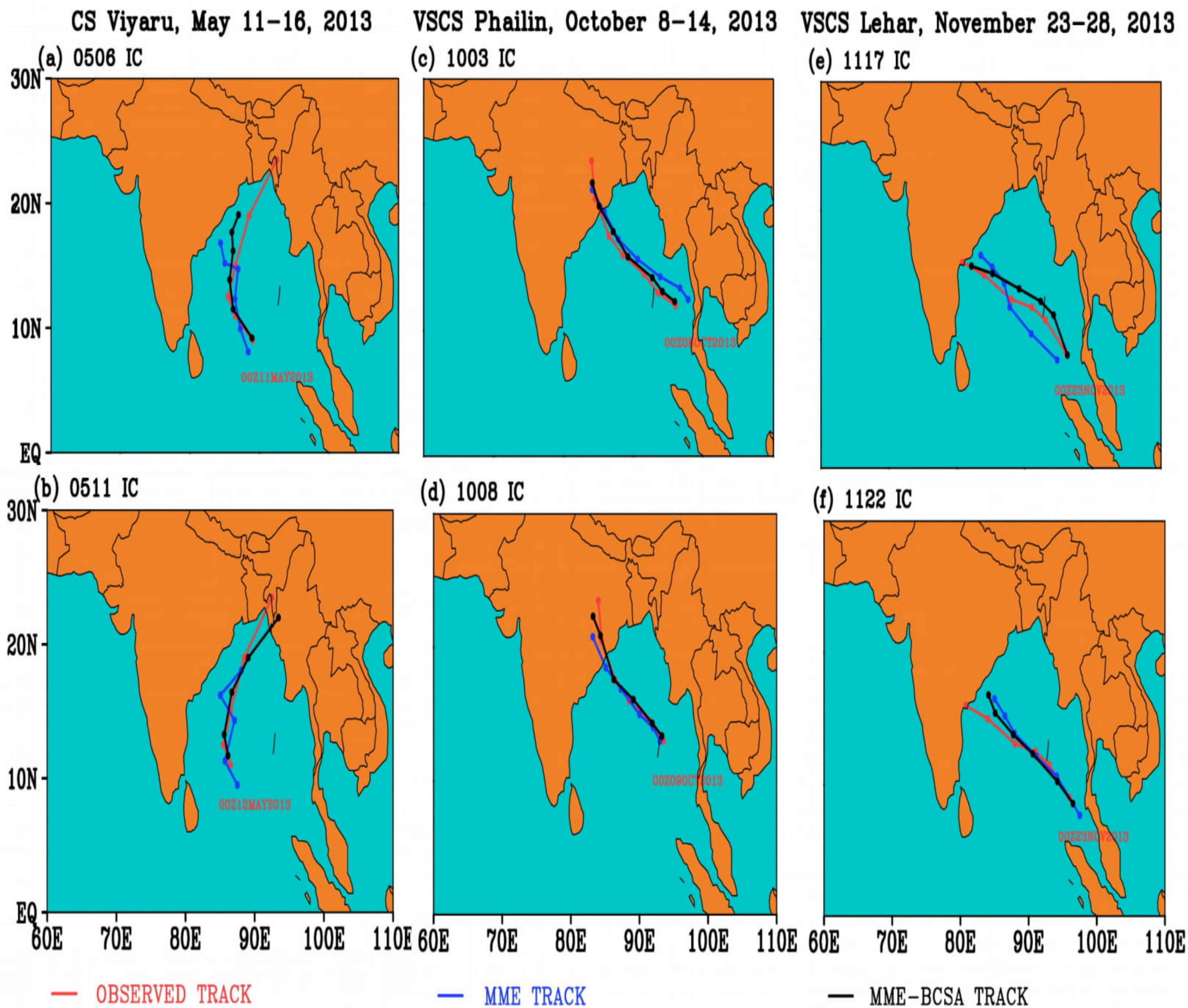
Development of a Bias-Correction and Signal Amplification Technique for further improvements in track and intensity prediction

- A major challenge in MMEPS is that storm intensity gets underestimated and forecast track lags behind observations as lead time increases as numerous ensemble members from different models may give diverse path for the same system thereby increasing timing and directional errors.
- In this frame work, an objective tracking algorithm will always produce large spread in the track, which in turn increase the cone of uncertainty at higher leads, and the ensemble mean tracks obtained from raw MME may not be as smooth as observed.
- Bias Correction and Signal Amplification method is proposed to overcome this drawback by correcting the lead-dependent bias in the raw model predictions and applying a 2-point space and time correction of ensembles based on the leading signal (Ensemble mean). (u850, v850, MSLP, T200, T500, Z200, and Z1000)

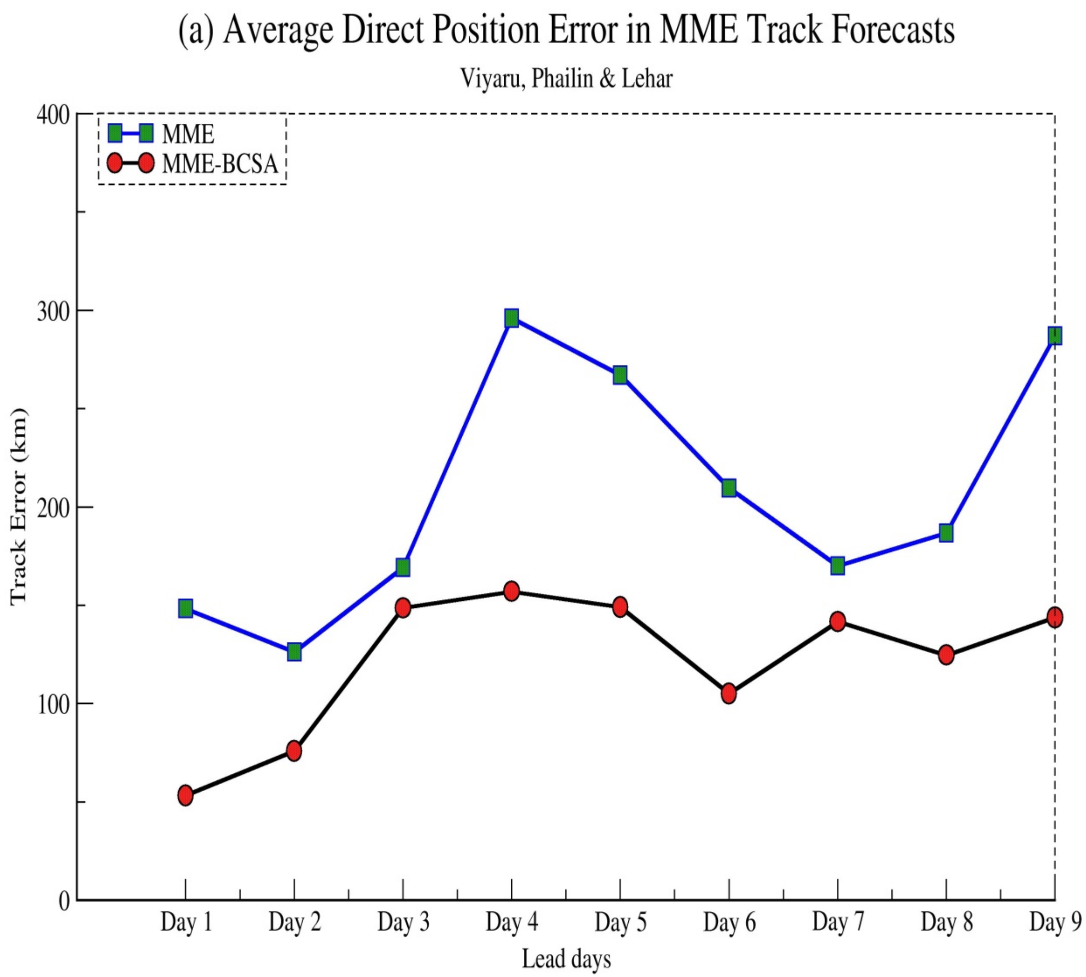
BCSA METHODOLOGY



Saranya , sahai, Abhilash etal., GRL, 2018



Saranya , sahai, Abhilash etal., GRL, 2018



9-days average DPE - MME=206.7530834
9-days average DPE - BCSA= 97.5024516
Percentage of Improvement = 52.84 %

- **Results show that bias-correction and signal amplification technique is, indeed, improving the track forecasts of selected cyclonic storm cases with significant reduction in track errors even at longer lead times.**
- **Track verification also shows that forecasts from MME-BCSA outperform MME for all lead days. A weakness of this method is that ATE has higher frequencies than CTE at longer leads for most cases.**
- **Even then, BCSA is a unique postprocessing tool and computationally less expensive as it can be used on any number of already available MME outputs.**

Saranya , sahai, Abhilash etal., GRL, 2018

New Genesis Potential Index

- ✓ Low-level relative vorticity at 850 hPa (ξ_{850})
- ✓ Scaled magnitude of vertical wind (200-850 hPa) (Vshear) averaged over an annular region between 100 and 200 km from each grid point
- ✓ Averaged Middle tropospheric relative humidity between 700 and 500 hPa

$$MRH = \frac{(RH_{700} + RH_{500})}{2}$$

- ✓ Scaled average Equivalent Potential Temperature of 1000 and 500 hPa

$$I = {(\theta e_{1000} + \theta e_{500})}/_{2}$$

$$\mathrm{IGPP} = A \times B \times C \times M$$

$$A = 10^5 \xi_{850}$$

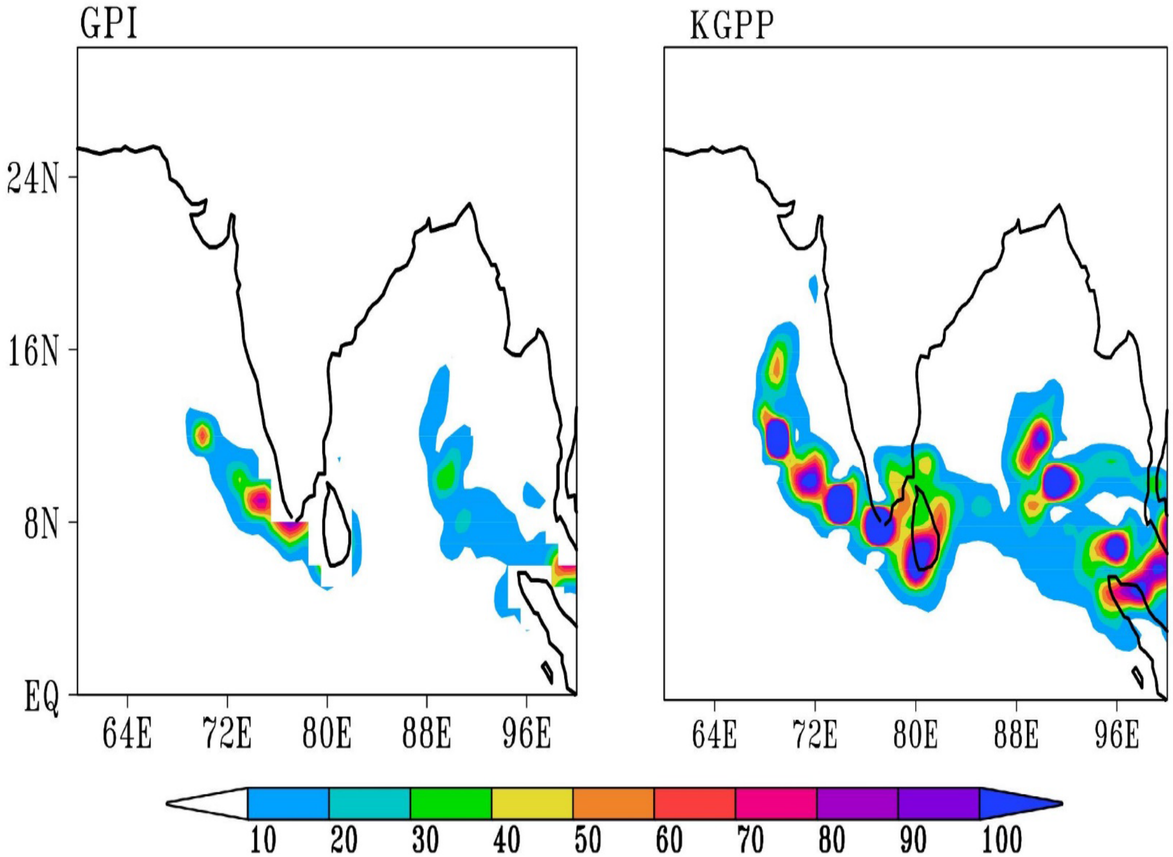
$$B = (I - 273.15)/6$$

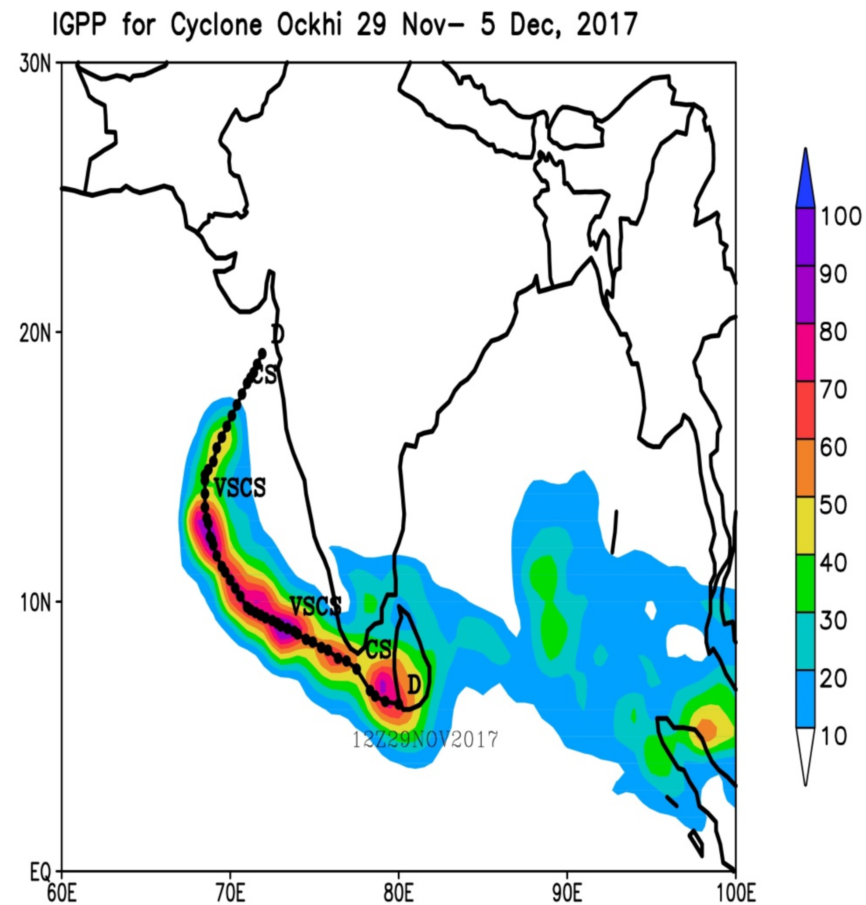
$$C = (1 + .1\,Vshear)^{-2}$$

$$M = \frac{(MRH - 40)}{30}$$

$$\xi_{850} > 0, M > 0, I > 0, V_{shear} > 0$$

Saranya , sahai, Abhilash etal., 2019





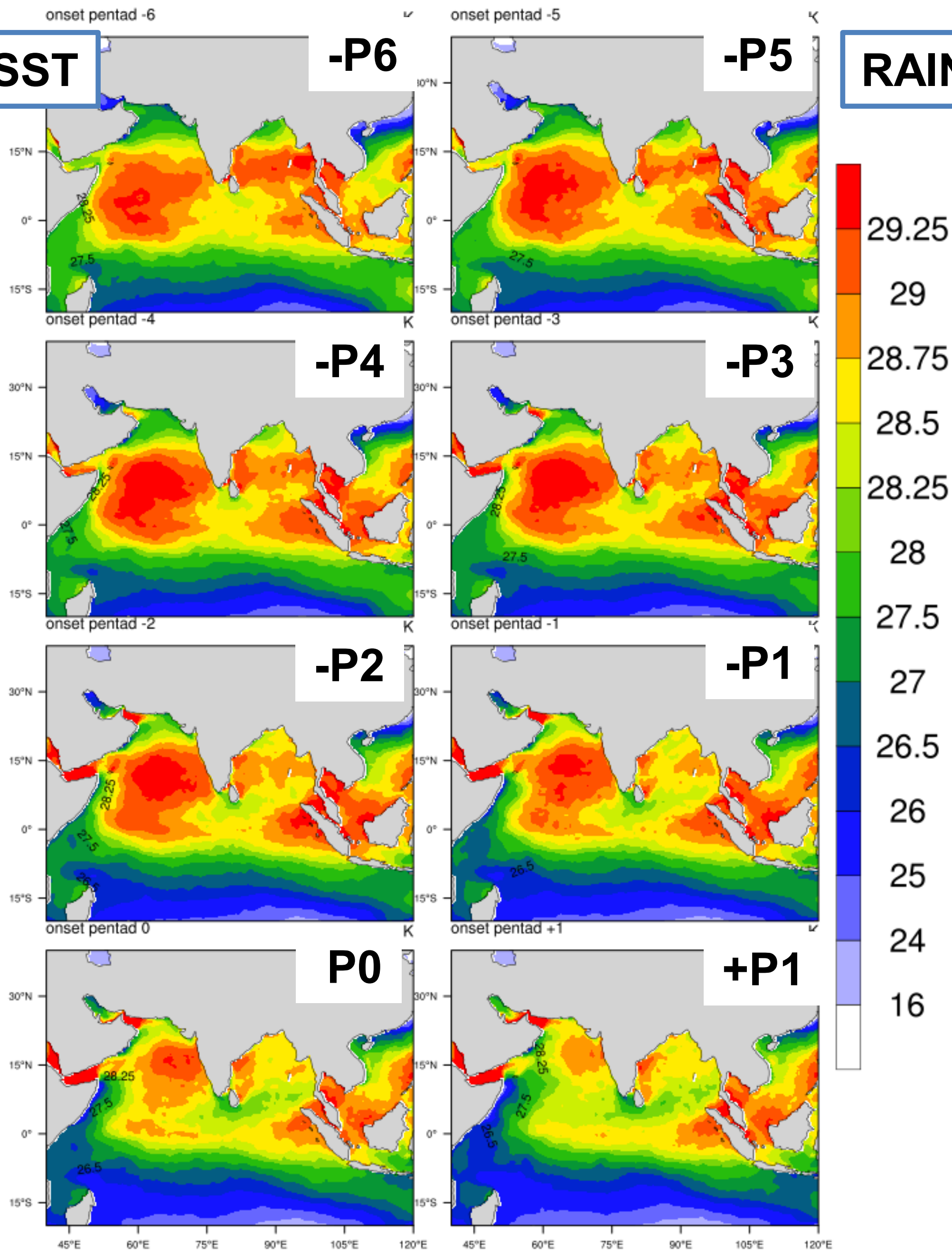
- **Cyclone Ockhi – 19 November to 5 December 2017**
- **ERA-5 daily averaged datasets**
- **Maximum value of indices during storm evolution**

Saranya , sahai, Abhilash etal., GRL, 2018

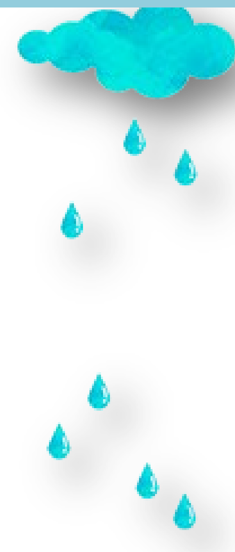
Sequence of Events Before Onset:

The onset of the monsoon is the most anxiously awaited weather singularity in the sub-continent as it heralds the rainy season and marks the end of the hot summer (Ding and Sikka, 2004). (During 1982-2015)

SST

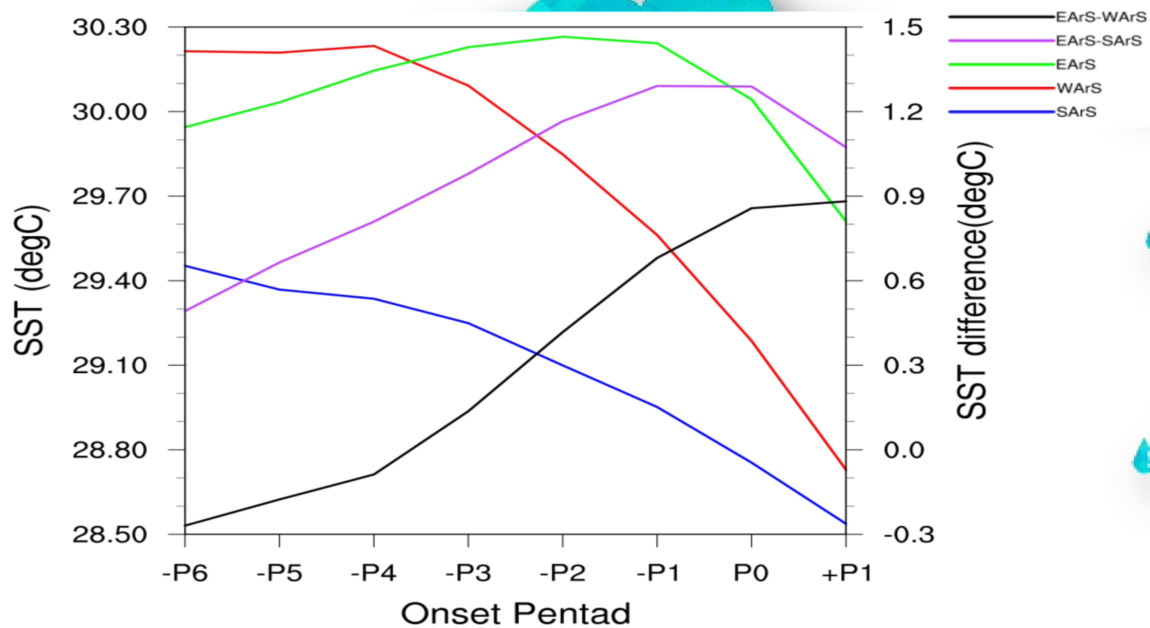


RAIN

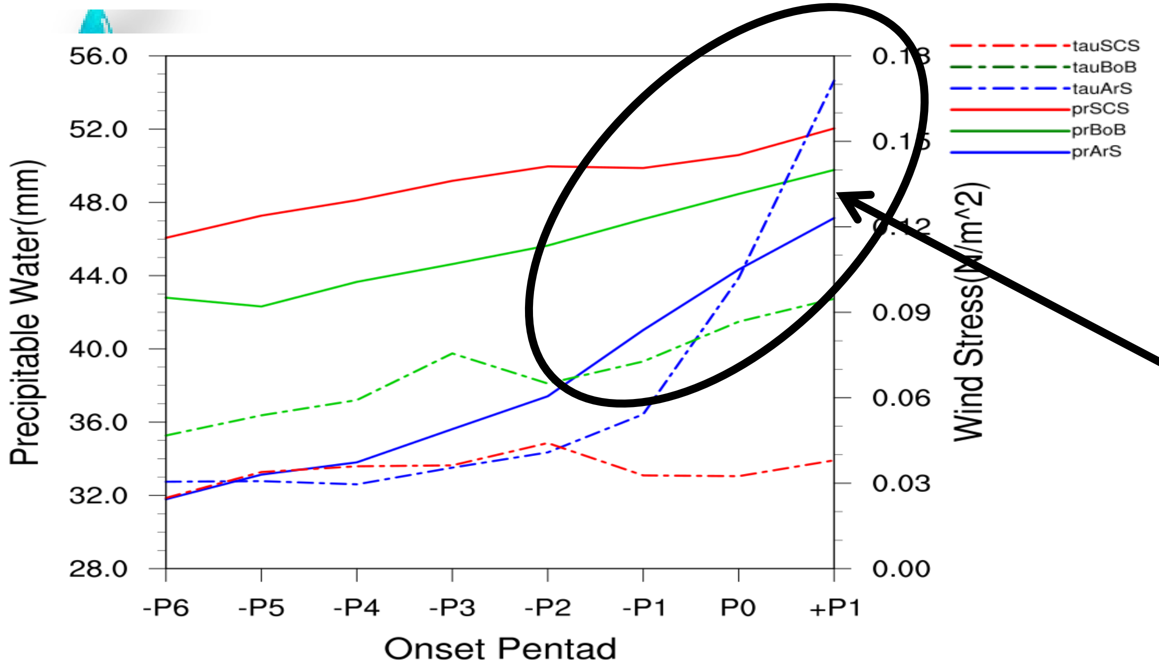


-P6	-P5
-P4	-P3
-P2	-P1
P0	+P1

E-W & N-S SST gradient / Wind Stress & TPW Before Onset:



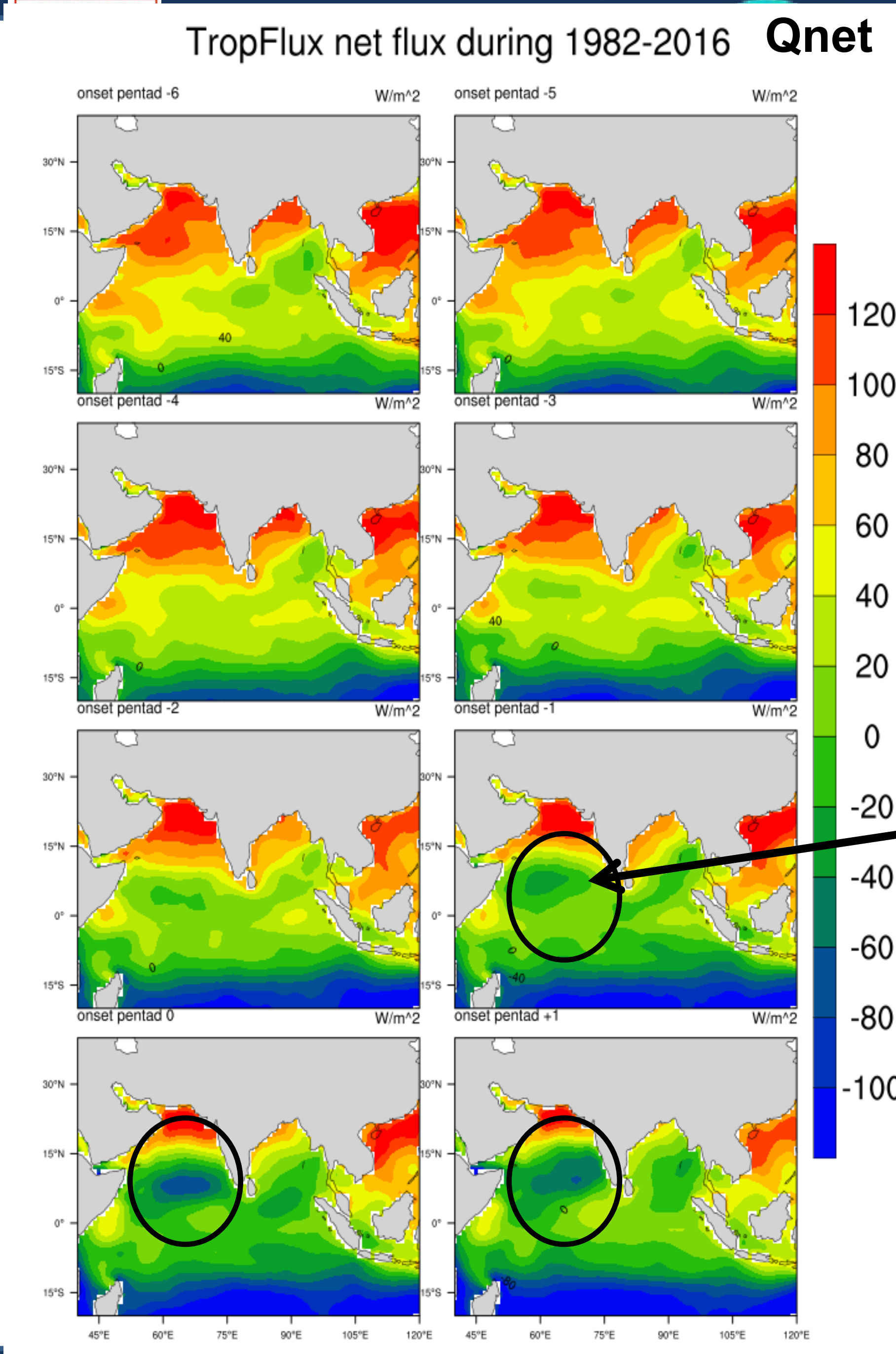
Pentad mean SST and SST gradient for pentads -P6 to +P1 as composites of 35 years (1982-2016) area averaged over EArS (63-75°E; 9-27°N), WArS (51-62°E; 0-11°N) and SArS (63-76°E; 1-10°S) (b)(Lower panel)Pentad mean TPW and wind stress as composites of 35 years (1982-2016) area averaged over ArS (62.5-75°E; 6-15.5°N), BoB (85.5-99°E; 6-16°N) and SCS (107.5-120°E; 11-21°N).



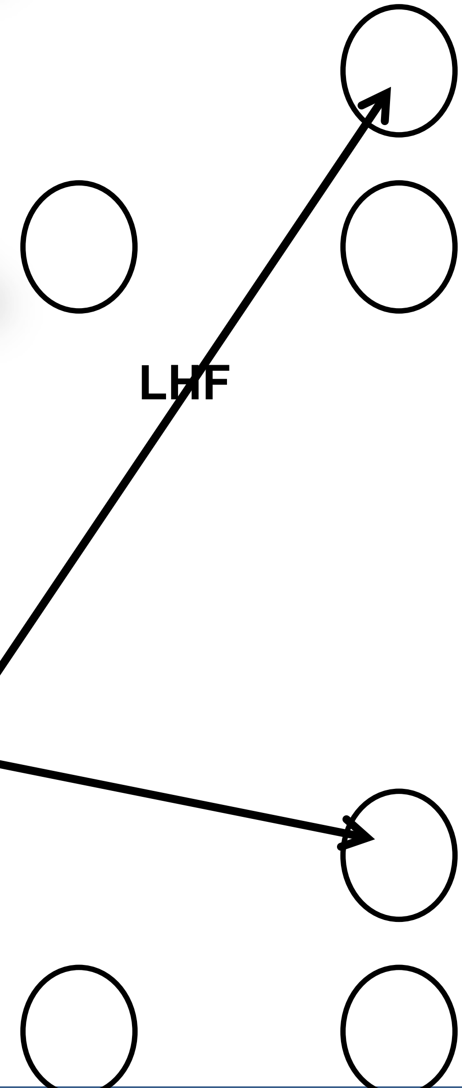
Coherent enhancement of wind stress and TPW over ArS sea

QNet = SWRnet – (LWRnet + LHF + SHF)

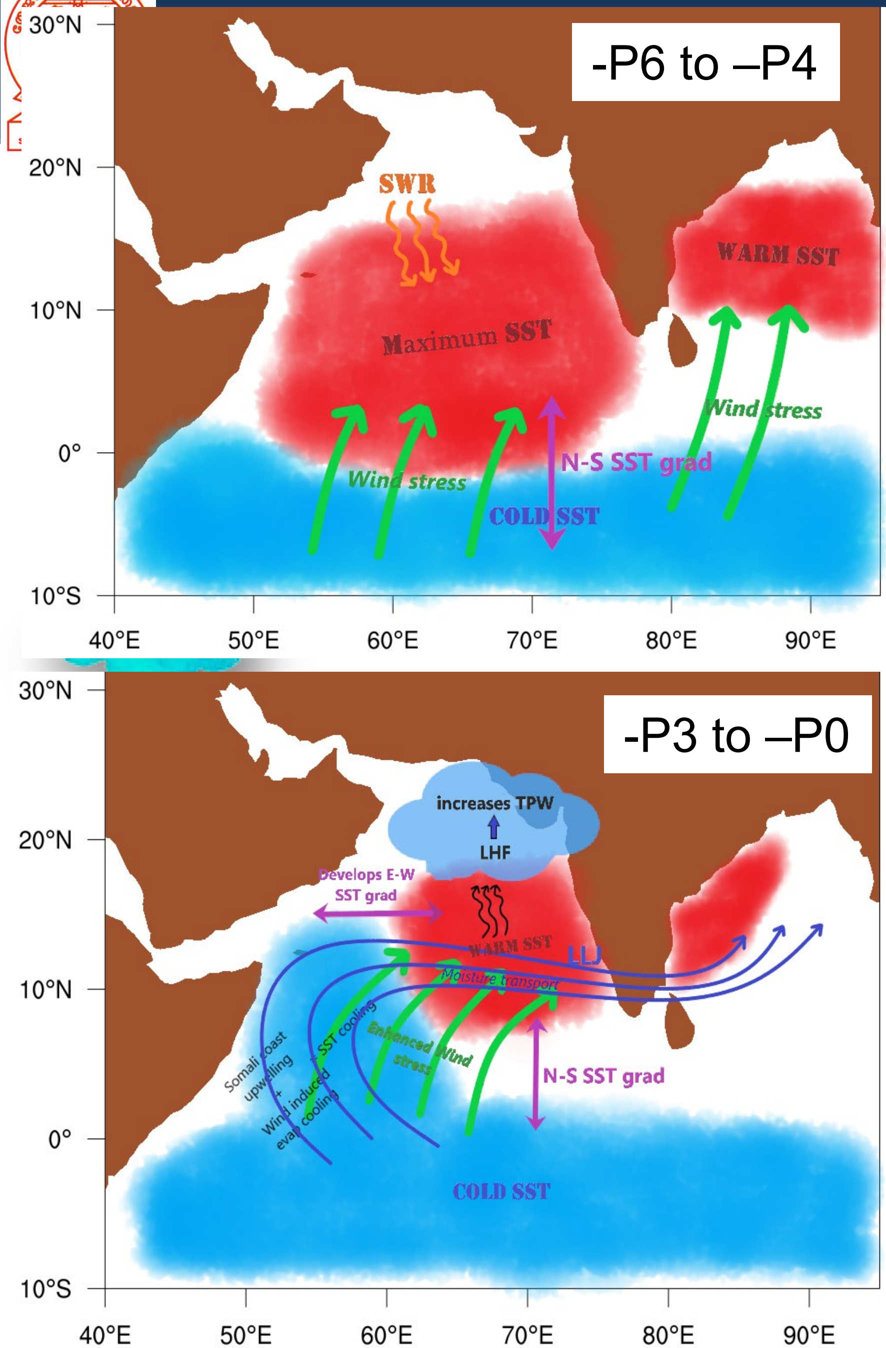
SWR



Ocean to Atmos flux increases around the onset pentad and largely contributed from enhancement of LHF and reduction in SWR



Schematic diagram of evolution of Monsoon onset over Kerala

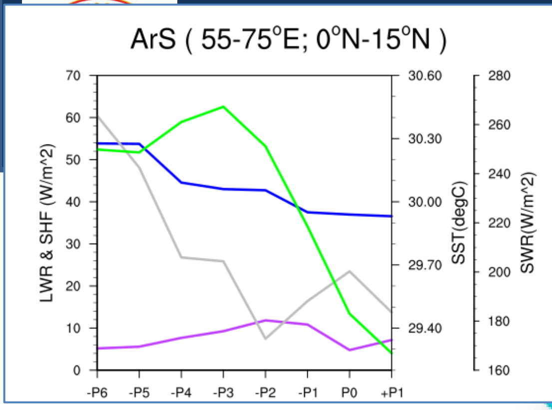


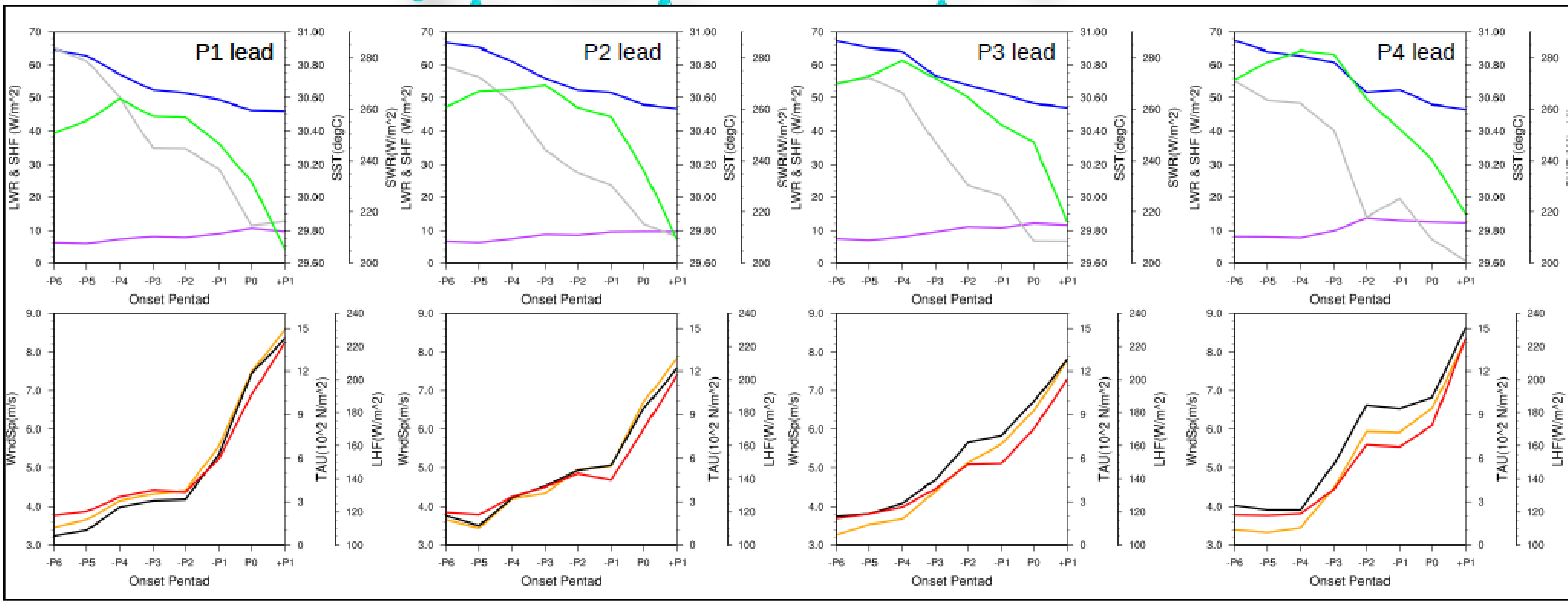
Outcome:

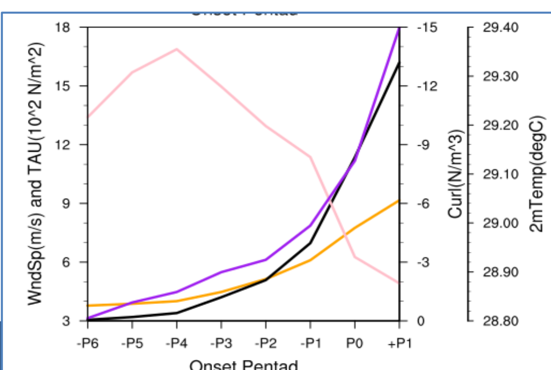
- The EArS remains warmer until the onset occurs, cooling of SArS increases the N-S SST gradient further.
- Initially, the E-W SST gradient is negative and after 4 pentads before MOK, the WArS starts cooling and this increases the E-W SST gradient during the following pentads.
- Associated with E-W SST gradient, wind stress and TPW increases from –P4 onwards.
- Strong relationship between wind stress and TPW observed over ArS and BoB is absent in SCS

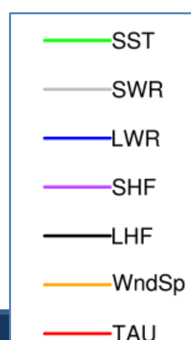
Data Sets Used : Tropflex and OAFlux

Athira and Abhilash (2019), Climate Dynamics, Revision submitted


ArS (55-75°E; 0°N-15°N)
LWR & SHF (W/m^2)
SST(degC)
SWR(W/m^2)
-P6 -P5 -P4 -P3 -P2 -P1 P0 +P1

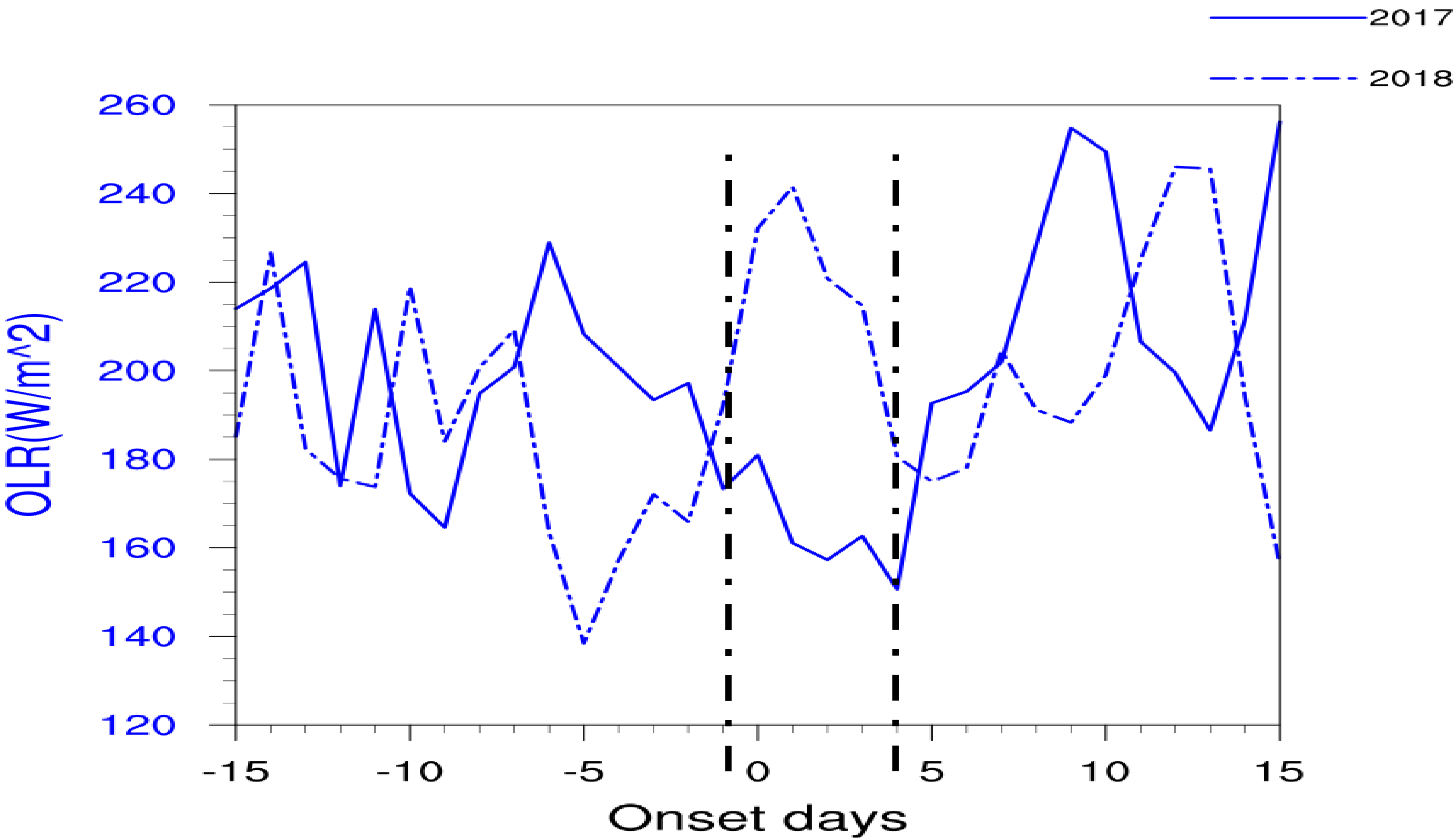

P1 lead
P2 lead
P3 lead
P4 lead
LWR & SHF (W/m^2)
SST(degC)
SWR(W/m^2)
Onset Pentad
WndSp(m/s)
TAU(10^2 N/m^2)
LHF(W/m^2)
Onset Pentad


WndSp(m/s) and TAU(10^2 N/m^2)
Curl(N/m^3)
2mTemp(degC)
-P6 -P5 -P4 -P3 -P2 -P1 P0 +P1
Onset Pentad


SST
SWR
LWR
SHF
LHF
WndSp
TAU

Distinct Atmosphere-Ocean coupling processes on the Onset phase of Indian Summer Monsoon during 2017 and 2018 as revealed through SCATSAT and its comparison with CFSv2.

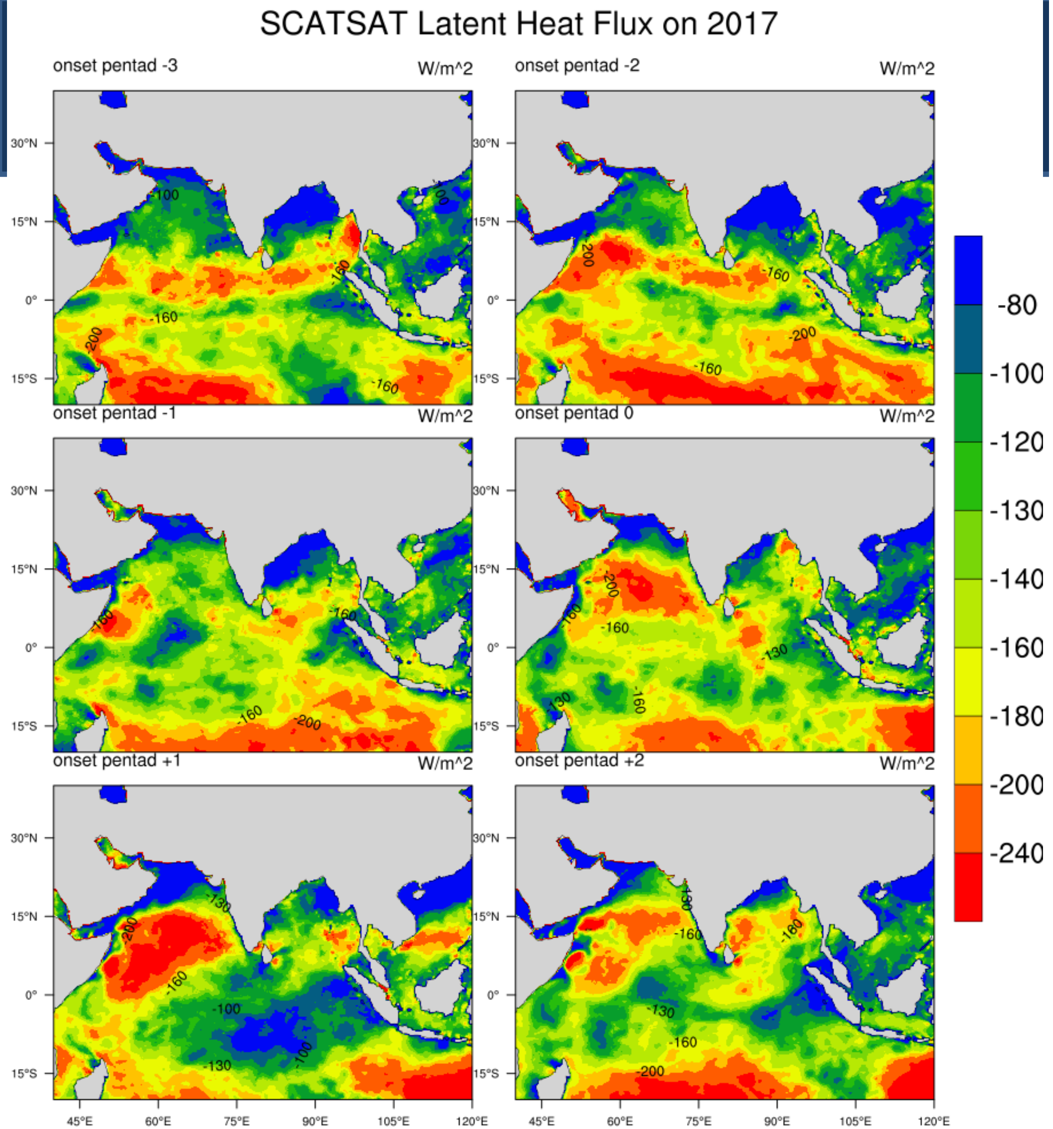
Evolution of OLR around South East Arabian Sea Off Kerala Coast during 2017 & 2018

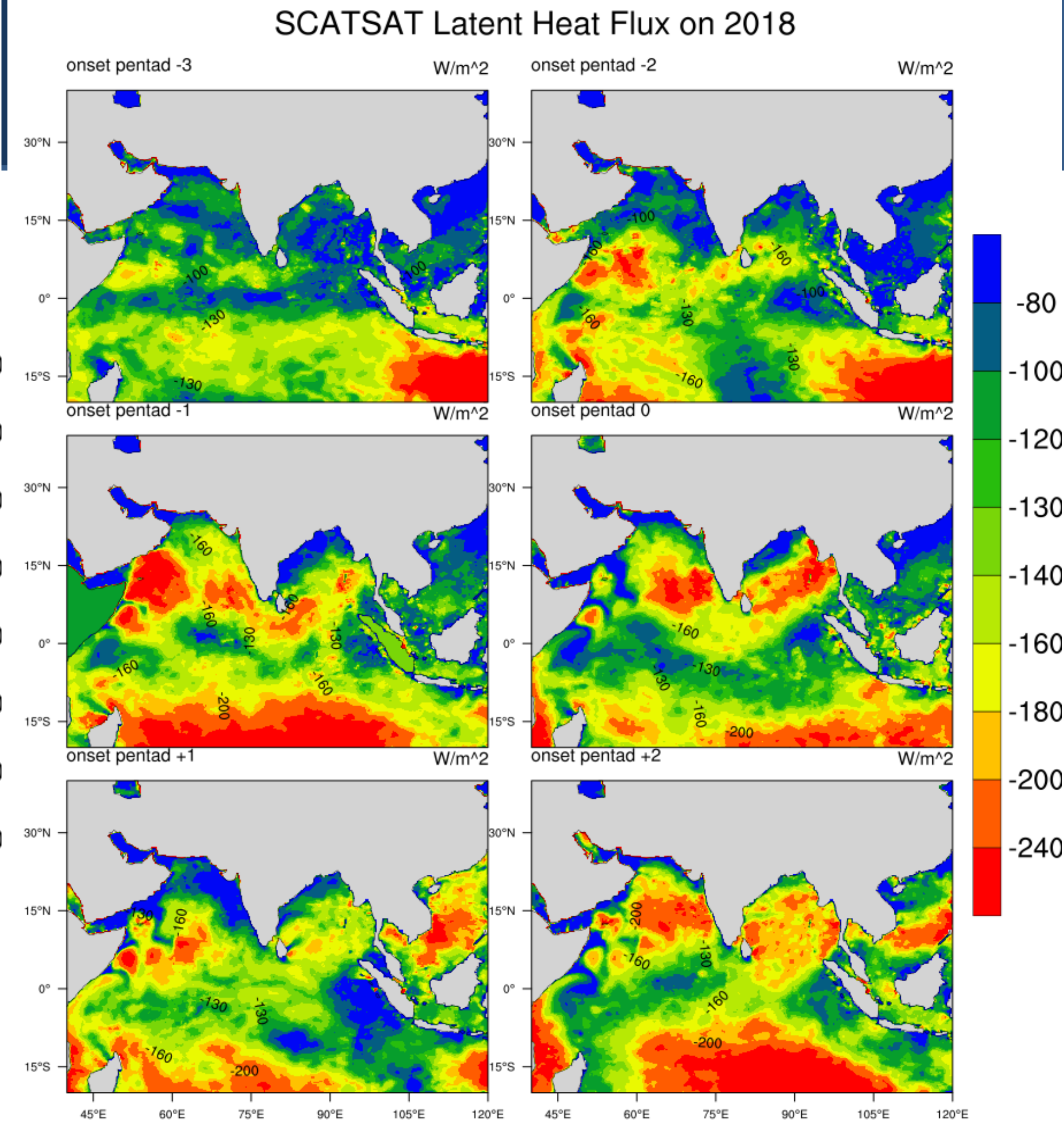


The declared DMOK by IMD

- During 2017 – May 30
- During 2018 – May 29

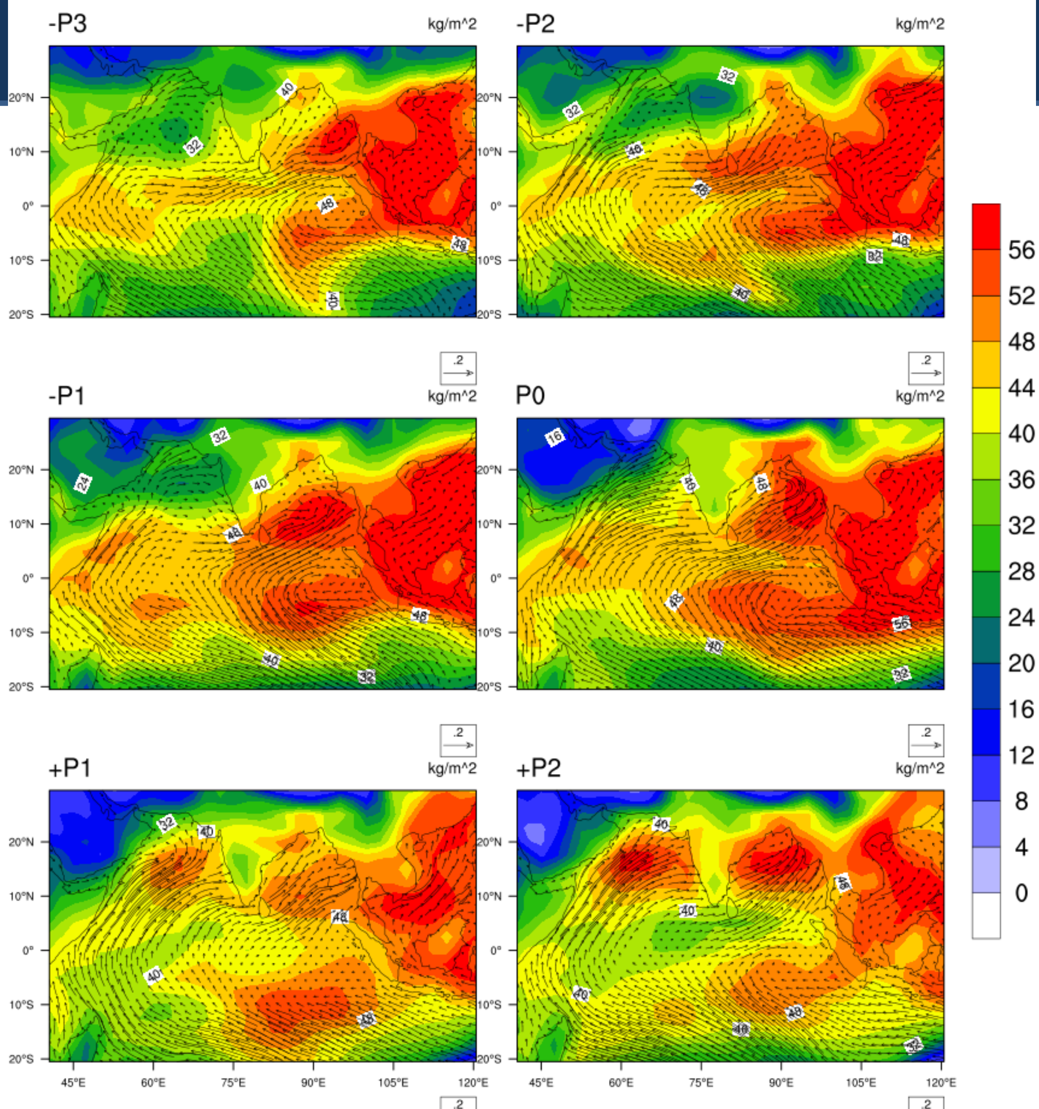
During 2018, the OLR becomes low i.e., below 200 W/m^2 only about a pentad after the declared date of MOK by IMD.



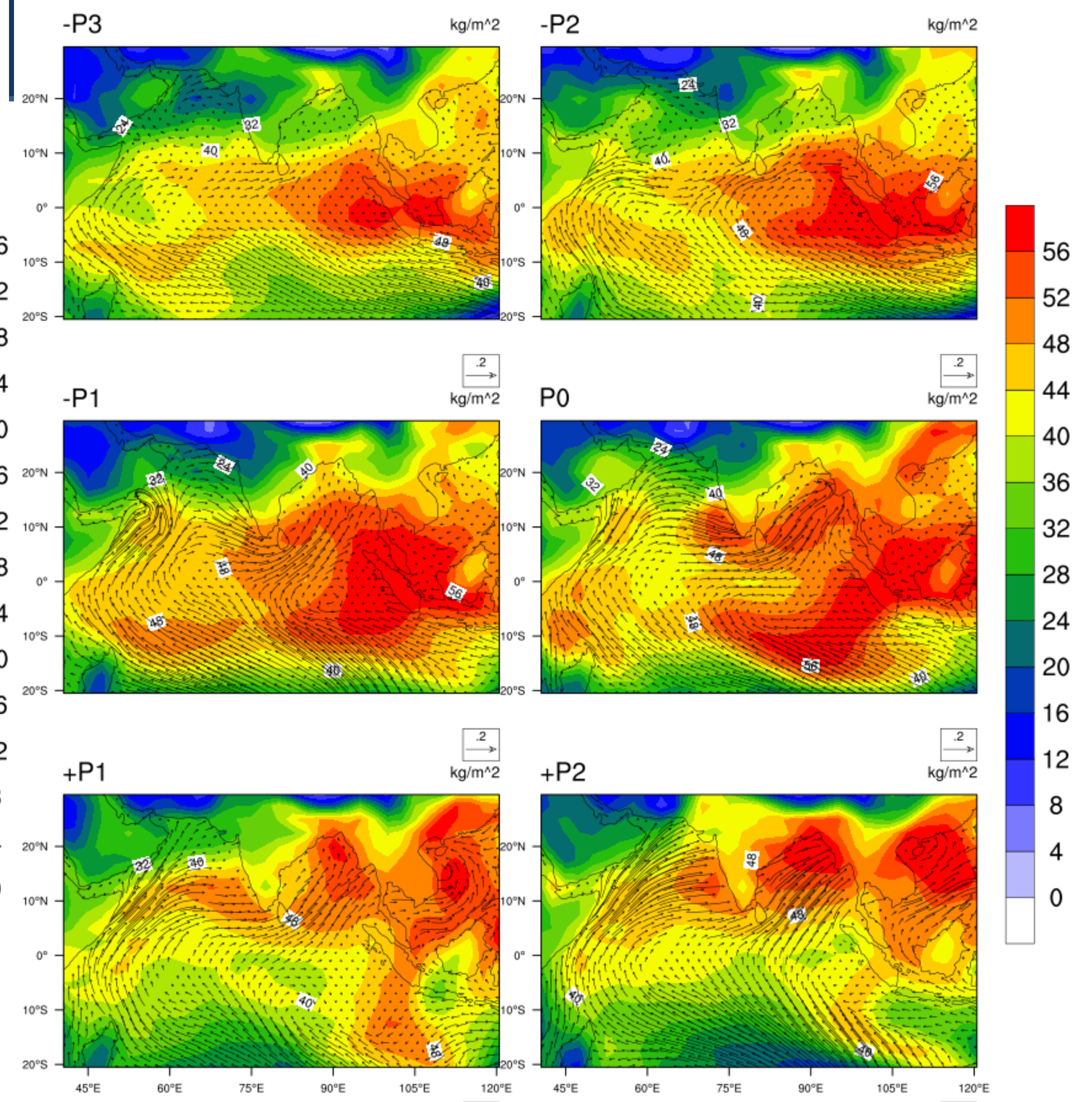


LHF increased from -P3 onwards on 2017 over North Indian Ocean is not visible in 2018 where as after one pentad only it starts.
A peak vortex of LHF is seen on +P1 on 2017 is absent in 2018, but on +P2, it starts to build.
Cyclone Mekunu is seen -P2 and -P1 on western Arabian Sea.

SCATSAT TAU and NCEP TPW during 2017



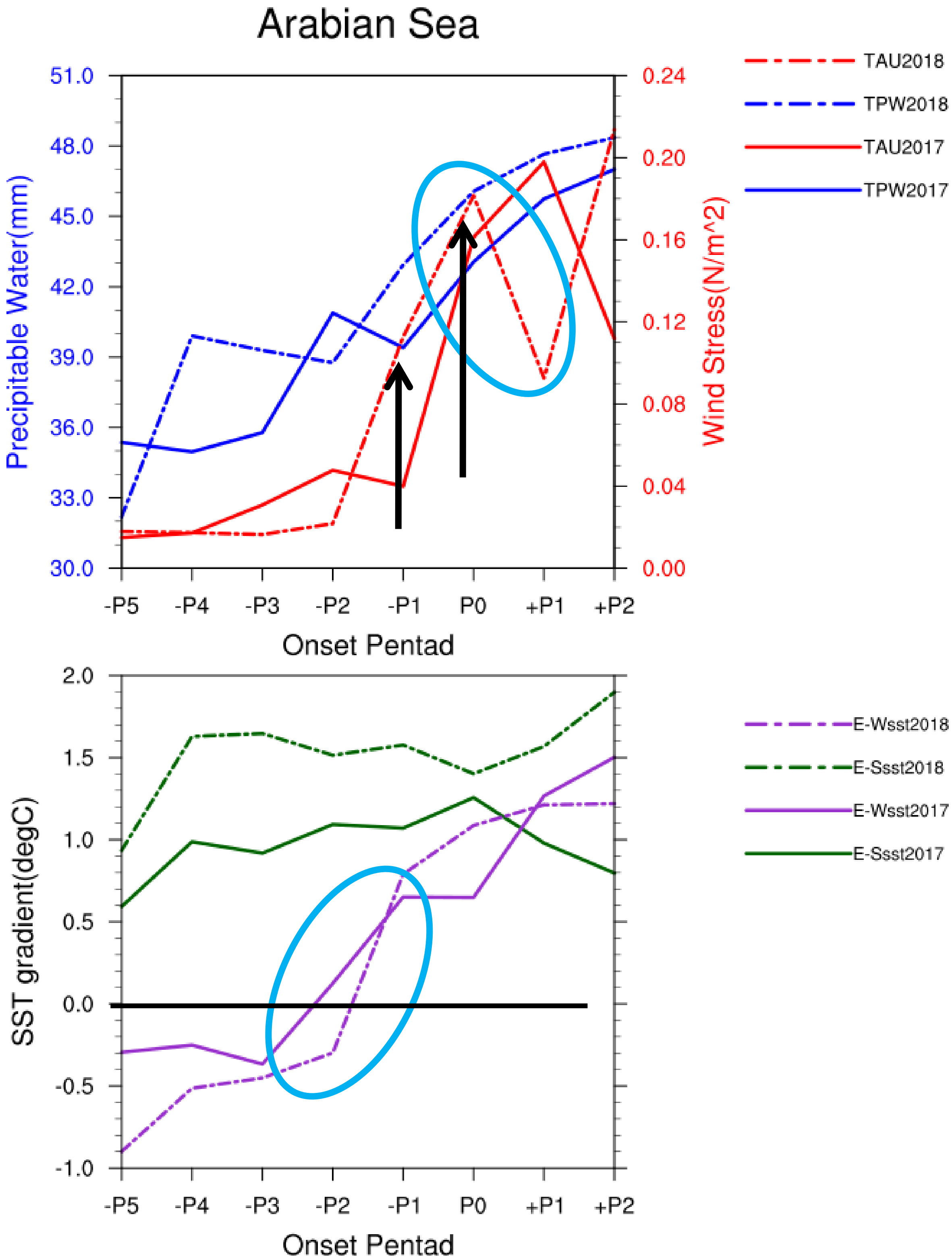
SCATSAT TAU and NCEP TPW during 2018



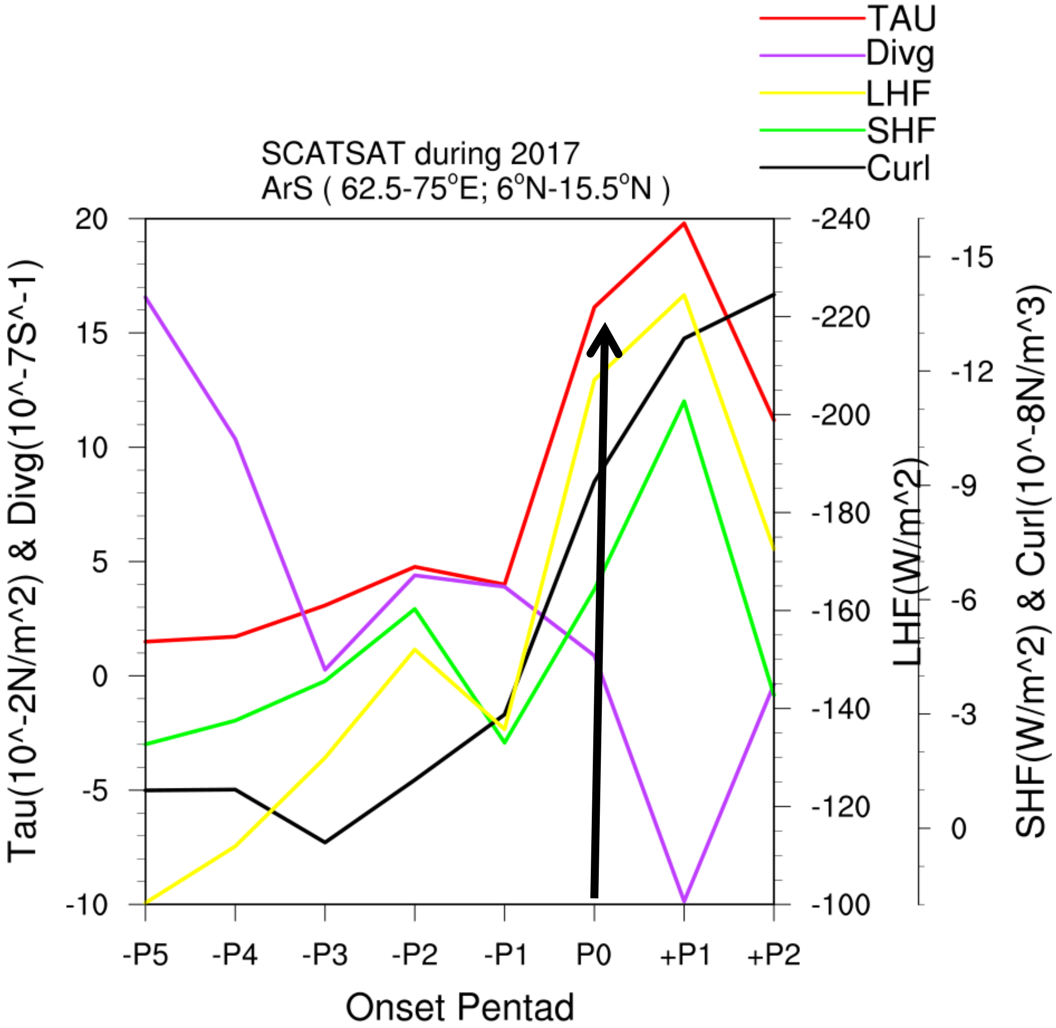
Here also North Indian Ocean response is happens only after one pentad on 2018 but the TPW doesn’t shows the delay.

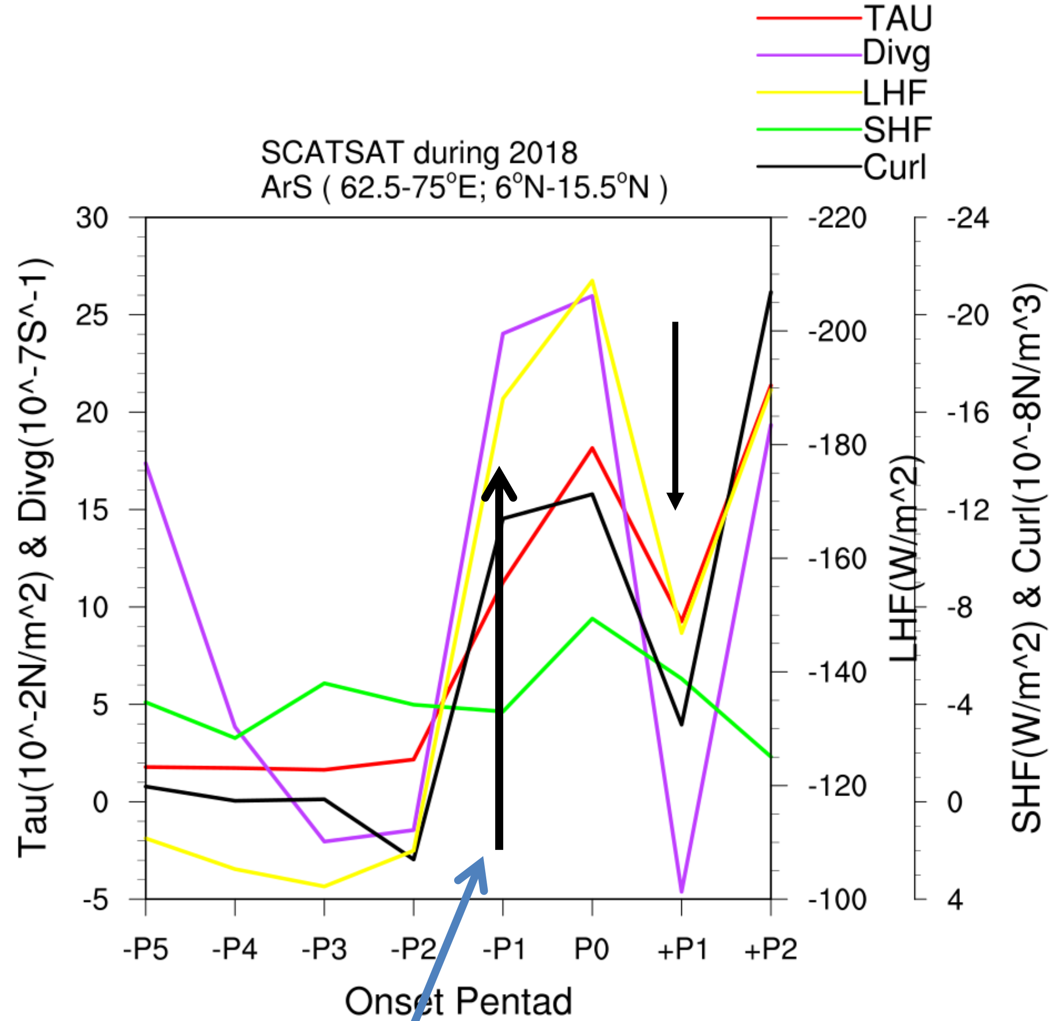
During 2018, it is clearly visible that the intensified wind stress over Western ArS towards east is drags back due to Cyclone Mekunu over there which weakens the wind stress over the eastern ArS especially on +P1.

During +P1 the wind stress is very weak towards the Kerala coast.



- Over ArS, rapid increase of TAU and TPW occurs only on P0 and it further increases on next pentad and then decreases in 2017.
- But in 2018, TAU and TPW increases on –P1 itself due to the Mekunu cyclone and it continues to P0 and then an abrupt decrease is visible.
- Occurrence of positive E-W SST gradient is also shows one pentad delay on 2018 compared with 2017.

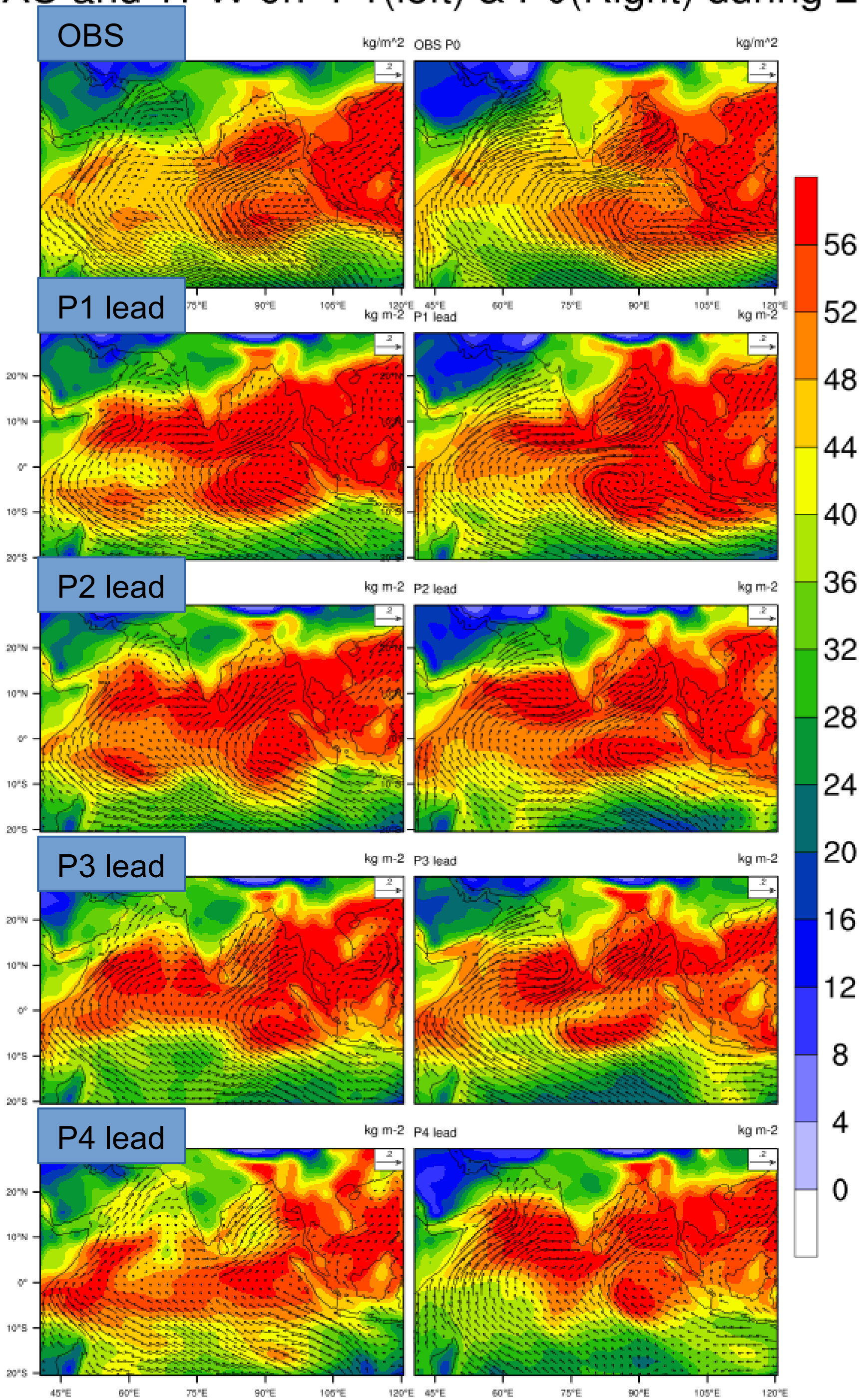




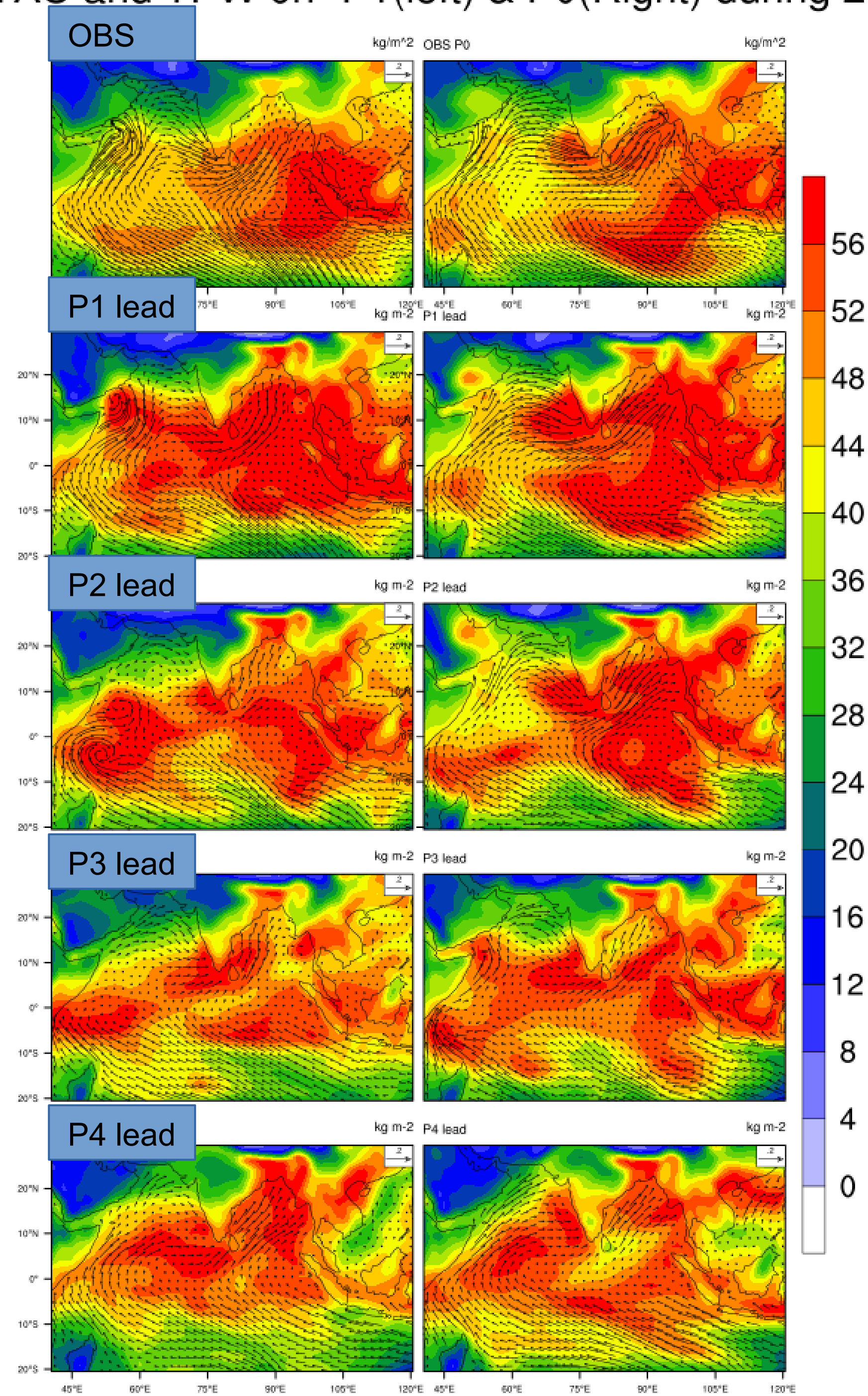
Due to existence of Mekunu cyclone

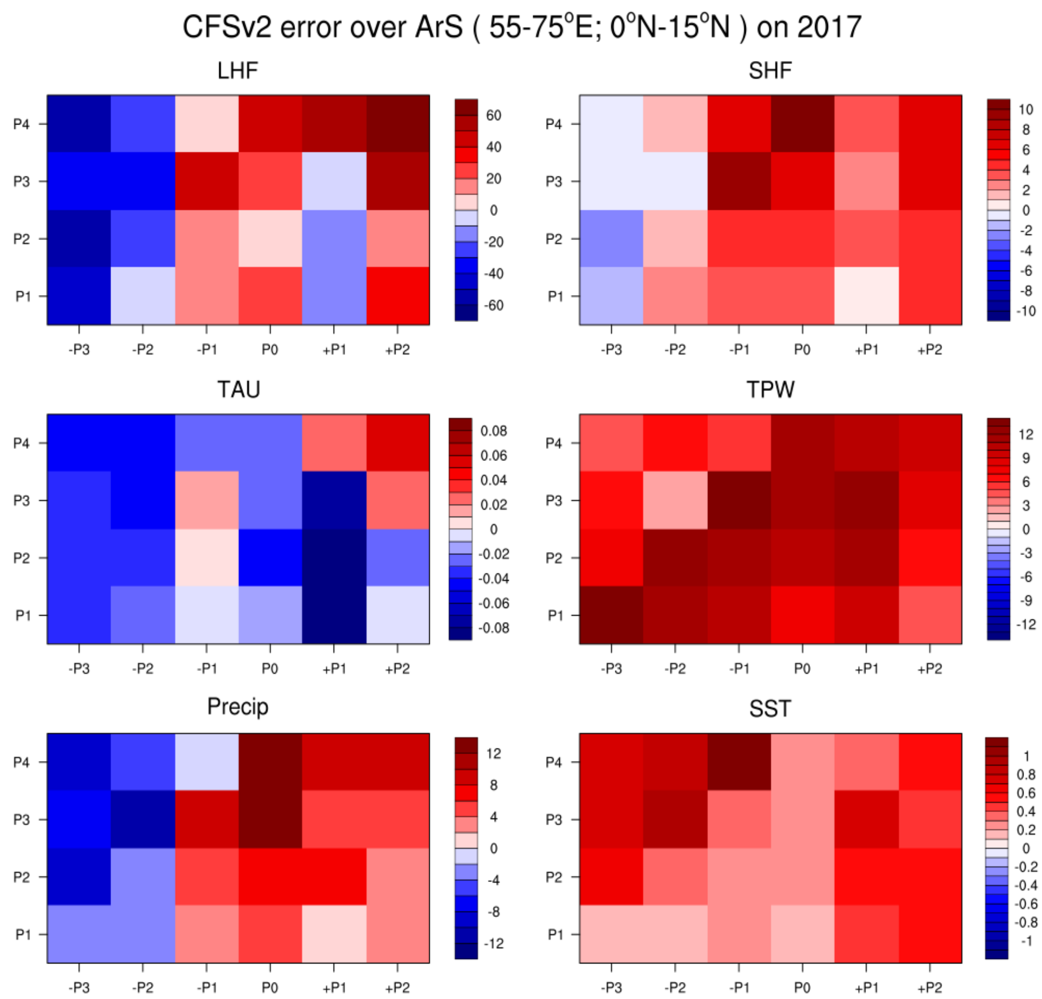
CFS v2 Model comparison with different leads

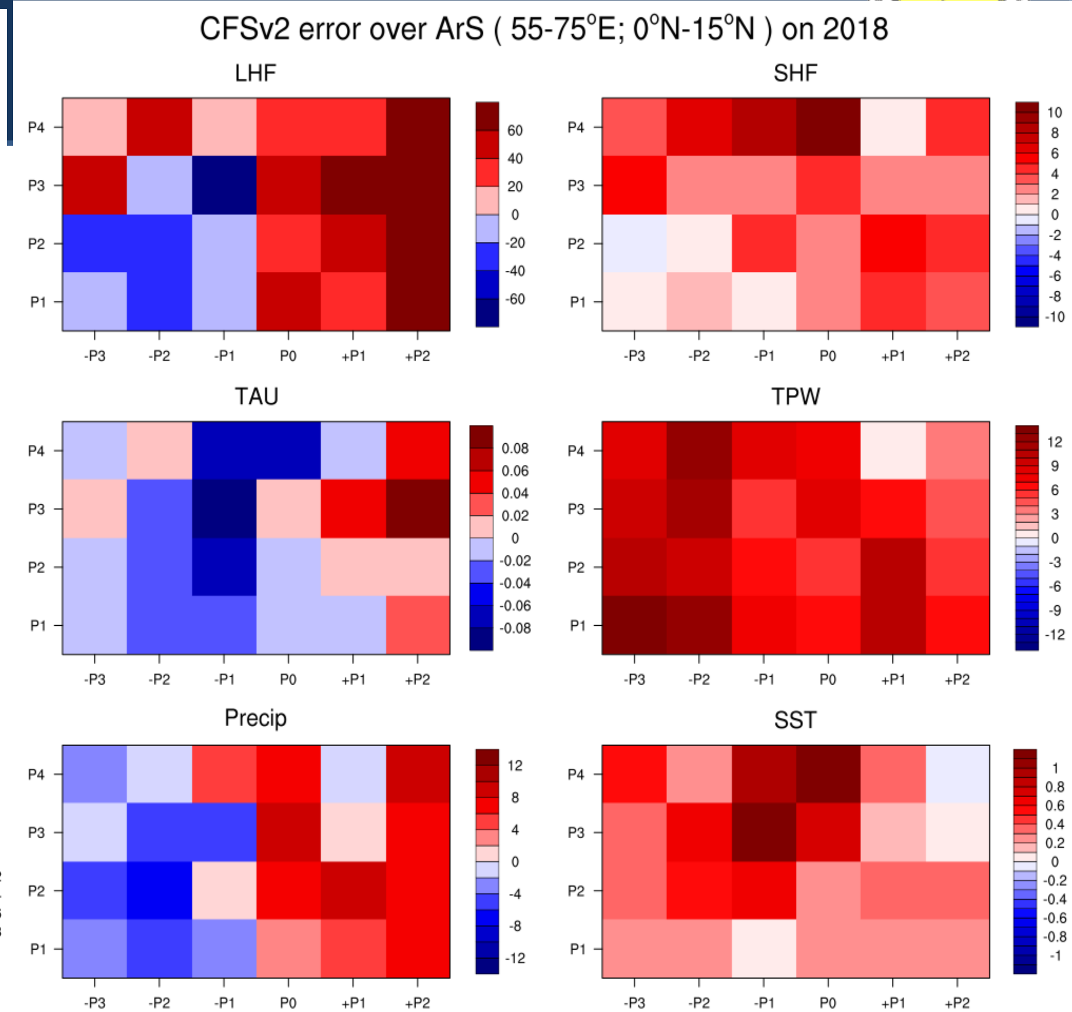
TAU and TPW on -P1(left) & P0(Right) during 2017



TAU and TPW on -P1(left) & P0(Right) during 2018

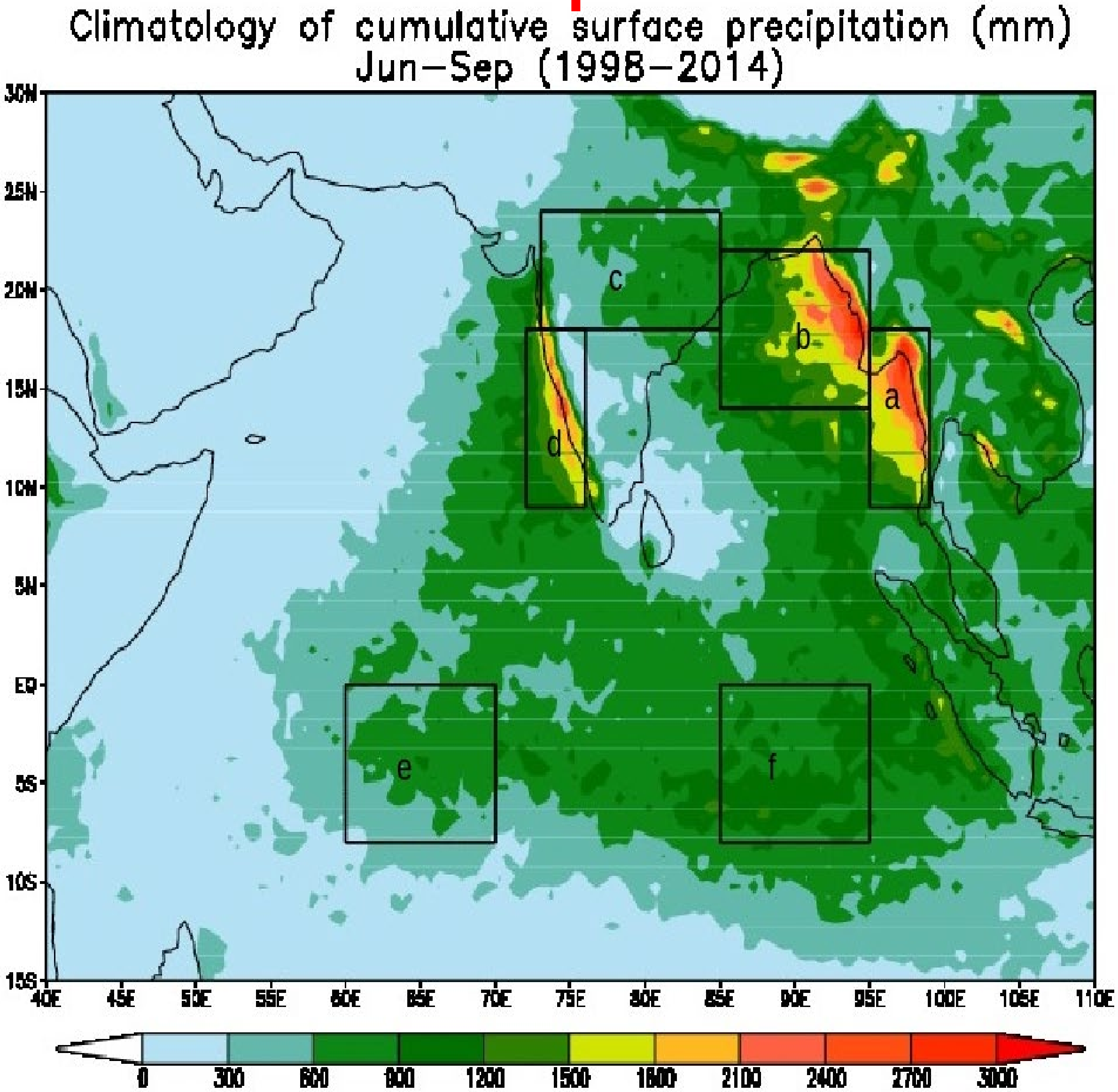






- The TPW is highly overestimated during all the pentads
- SHF and SST are also overestimated almost all the cases.
- The erratum of Rainfall depends on especially the inaccuracy of LHF and also some dependence of TAU.

Climatology of cumulative surface precipitation for the period from 1998 to 2014



Sub-Regions are:

a) Eastern Bay of Bengal (EBB)
b) Head Bay of Bengal (HBB)
c) Central Indian Land Region (CILR)
d) Eastern Arabian Sea and West Coast of India (EASWCI)
e) South West Indian Ocean (SWIO)
f) South East Indian Ocean (SEIO)

Vijayakumar, Abhilash etal., 2019

Spatial and Temporal Resolutions of Data sets Used:

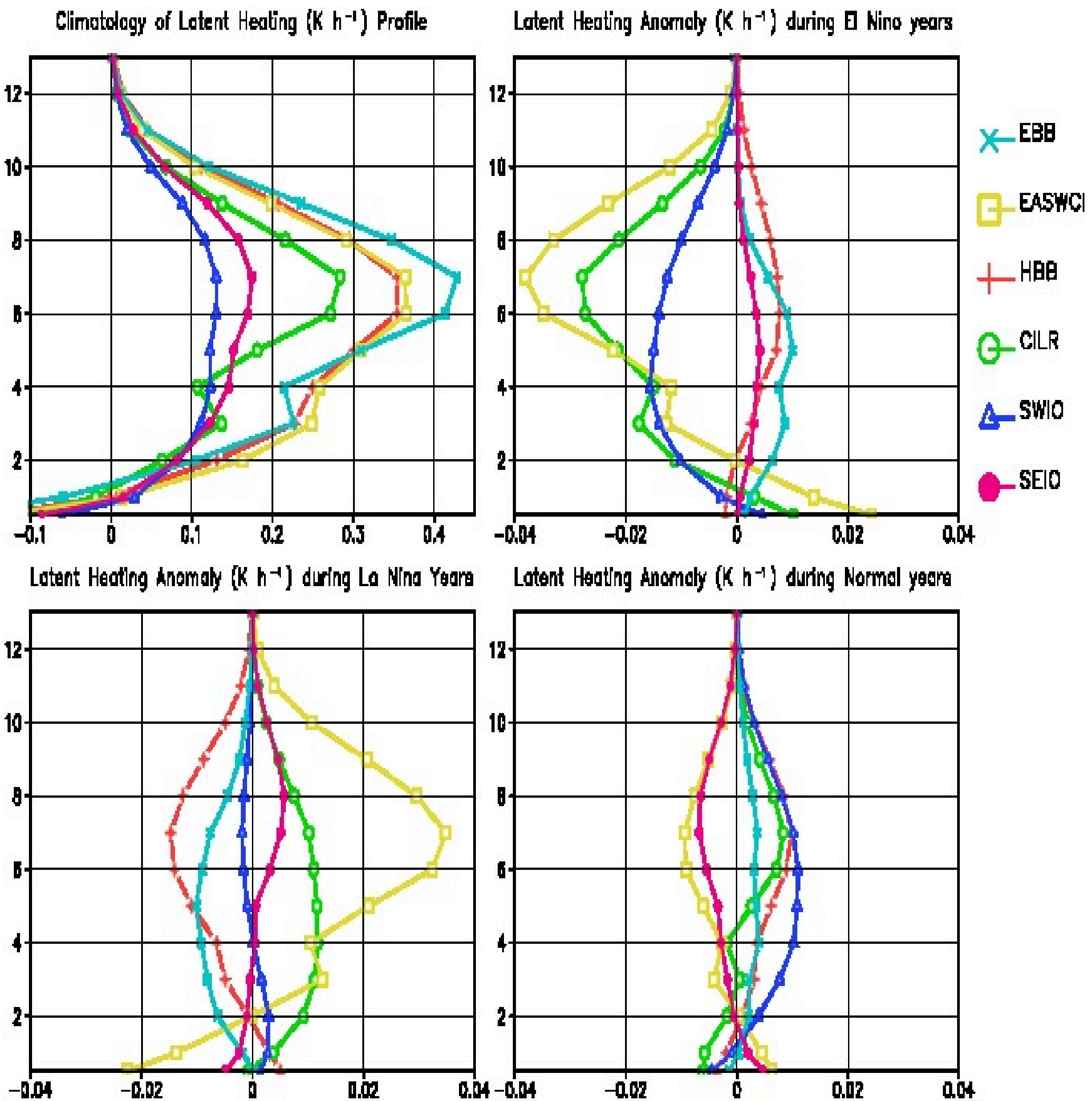
1. TRMM-TMI-PR (combined)
   (a) CSH-LH (3H31) : 0.5^o X 0.5^o, monthly
   (b) 3B32 : Rainwater, graupel & snow
2. NCEP-NCAR Omega : 2.5^o X 2.5^o, monthly

Study Period:

Jun-Sep of 1998-2014

	El Niño	**La Niña**	**Normal**
Years	2002 (M)	1998 (M)	2001
	2004 (W),	1999 (M)	2003
	2006 (W)	2000 (W)	2005
	2009 (M)	2007 (M)	2008
		2010 (M)	2012
		2011 (W)	2013
			2014

Profiles of (a) climatological latent heating in sub-regions



Vijayakumar, Abhilash etal., 2019

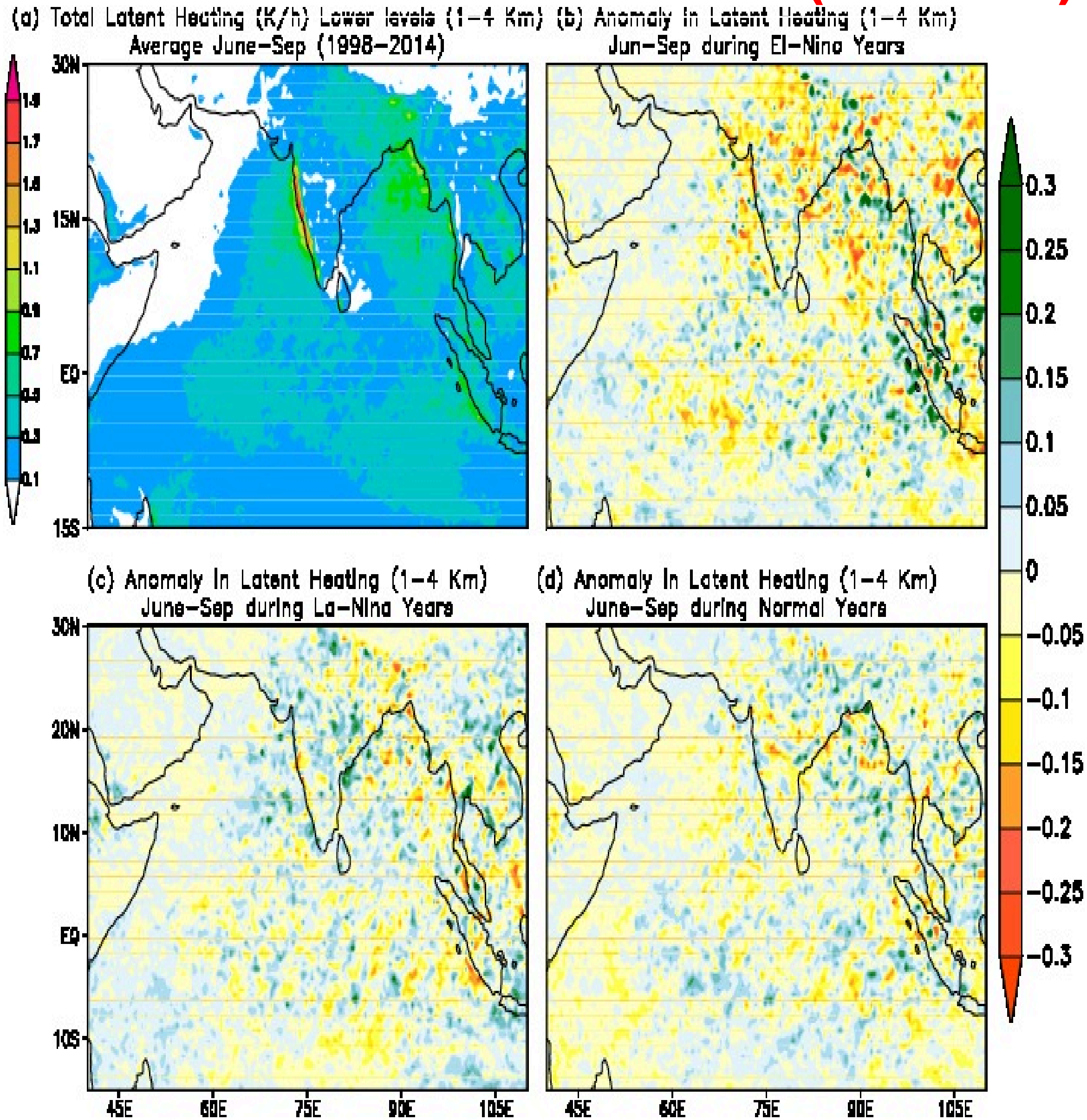
Climatological maximum is observed over EBB followed by EASWCI, HBB, CILR, SEIO and SWIO

Sub regions east and west of 85°E longitude have opposing anomalies during El Nino and La Nina

Magnitude of –ve anomaly is maximum over EASWCI followed by CILR and SWIO

La Nina favours EASWC and CILR significantly

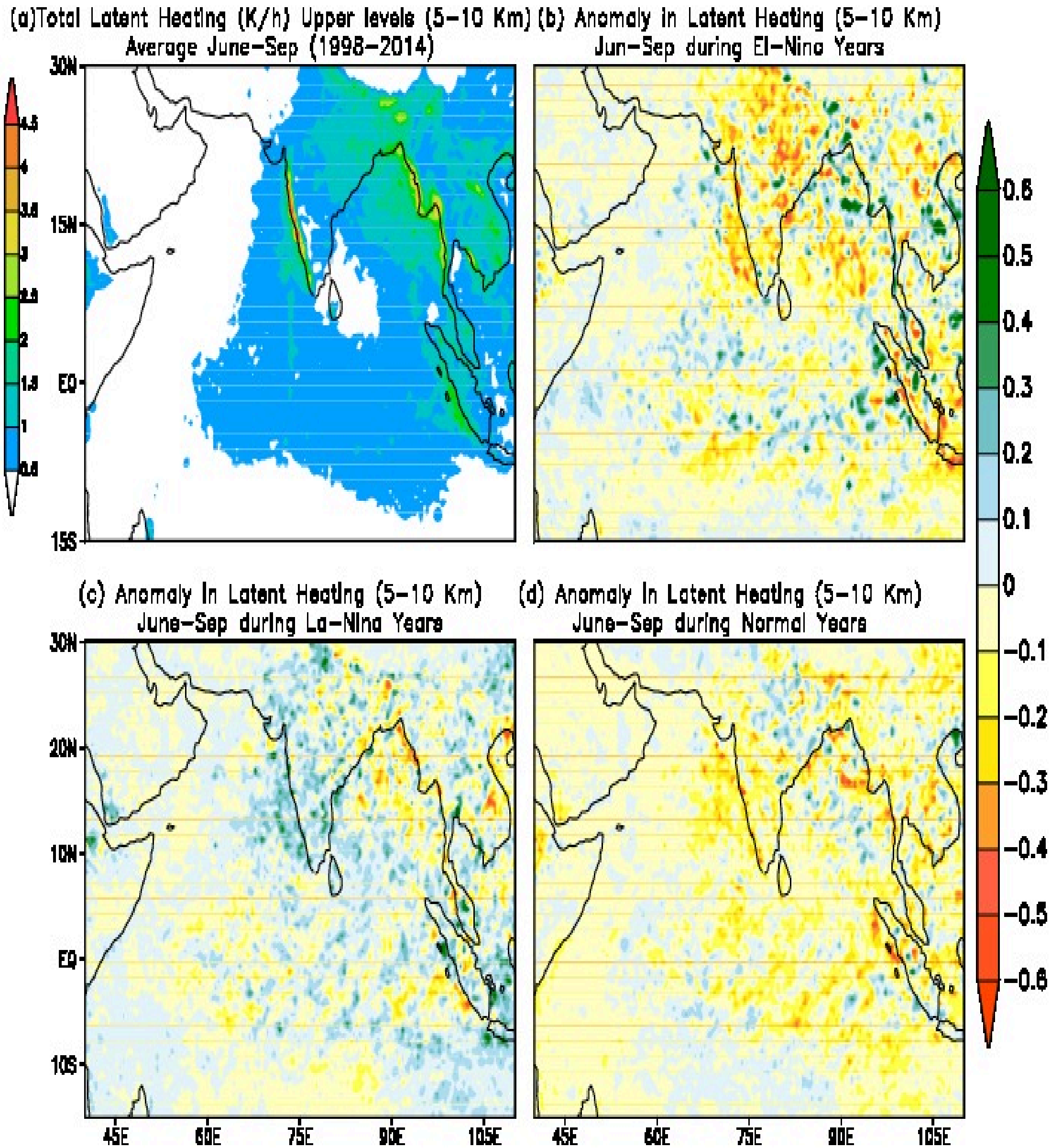
Integrated latent heating in lower levels (1-4 Km)



Lower level LH over Indian mainland is –ve during El Nino and generally +ve during La Nina

Neutral years have mixed pattern

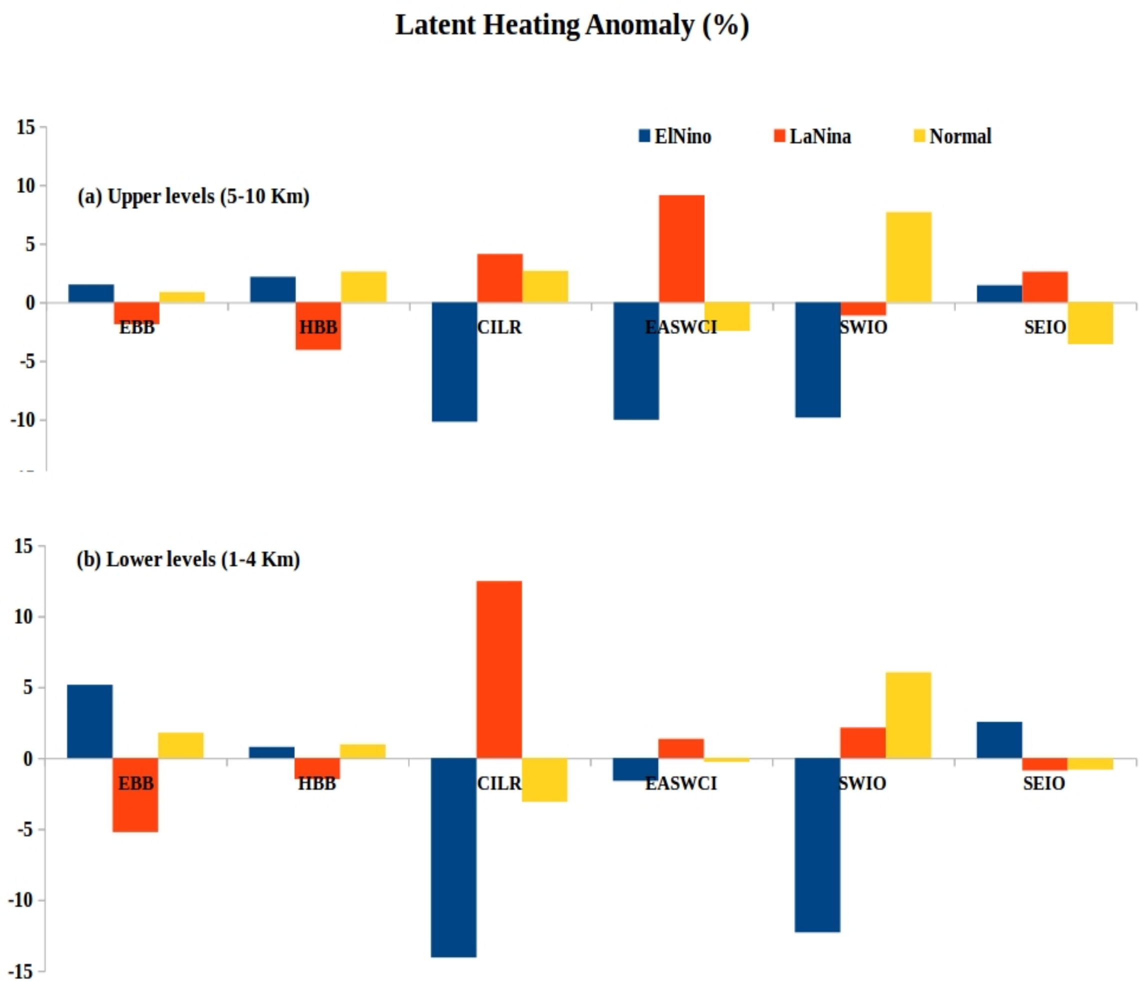
Integrated latent heating in upper levels 5-10 Km)



Upper level LH over Indian mainland follows same pattern as lower levels, –ve during El Nino and generally +ve during La Nina

Neutral years have mixed pattern

Percentage deviation from climatology of latent heating in the lower (1-4 Km) and upper (5-10 Km) levels



Most El Nino depleted (-14 %) as well as La Nina fed (+12%) region is lower CILR

Influence of El Nino and La Nina at lower level EASWCI is insignificant (orography)

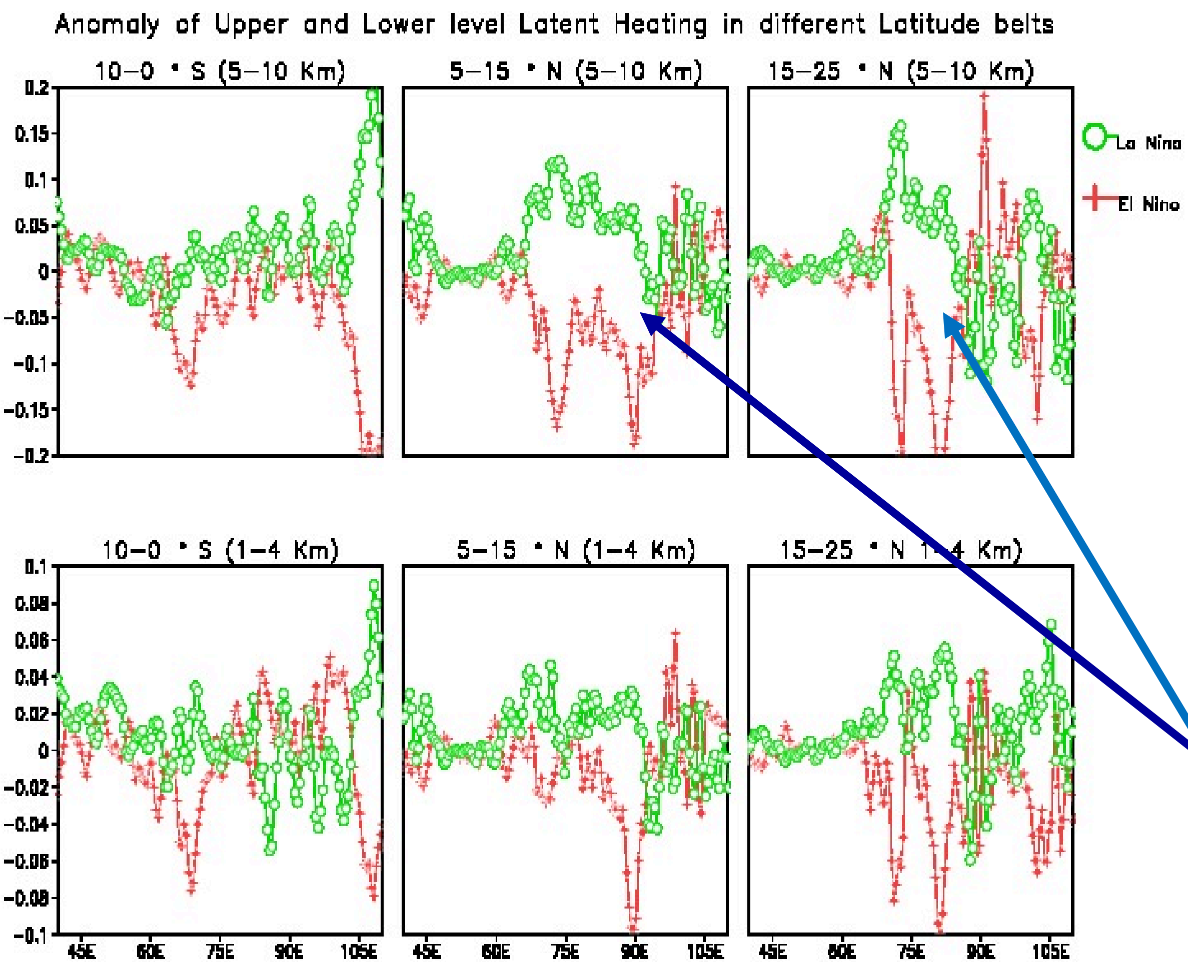
Upper levels of EASWCI region has significant anomalies during El Nino (-10%) and La Nina (+9%)

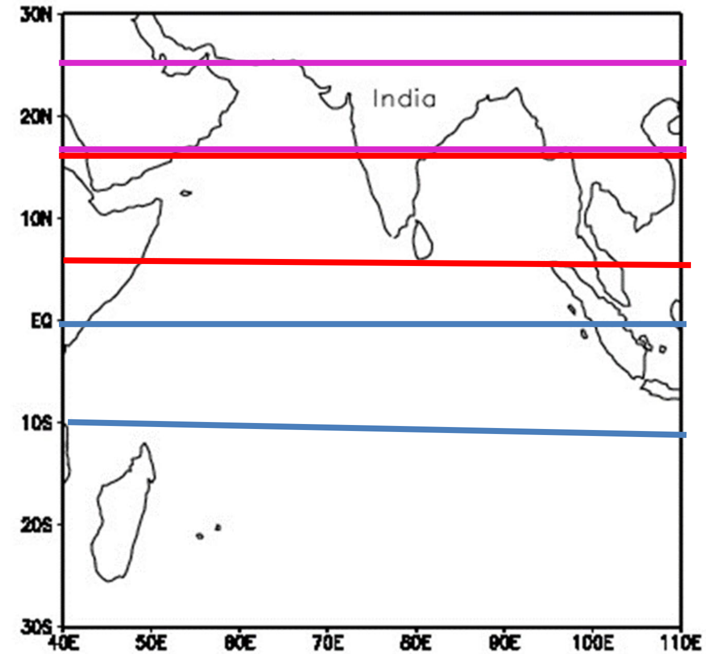
El Nino influence on lower (-12%) and upper levels of SWIO is significant, but anomalies during La Nina are negligible.

Sub regions east of 85°E line has reverse pattern during El Nino and La Nina

Vijayakumar, Abhilash etal., 2019

Latent heating anomaly during El Niño and La Niña years in different latitude belts for the period Jun-Sep





Most affected regions are the upper levels over Indian land region

- Distinctly different responses to the El Niño and La Niña in the sub regions considered is observed
- Roughly across the 85^{o}E longitude, El Niño and La Niña have opposing influences
- The negative impact of El Niño in terms of reduced rain availability is suffered mostly by the central regions of Indian mainland
- La Niña period is witnessed with enhanced convective activity over the Indian mainland at all altitudes leading to more stratiform and convective type rainfall

Approach

- **Understand and predict extreme and high impact weather and climate events including heavy precipitation, drought and severe storms across different scales and integrating them for informed decision making.**
- **A calibration matrix will be generated for each relevant physical processes for different lead times, especially convection.**
- **Evaluation of growth of model errors across different lead times.**
- **The prediction skill for extreme precipitation events will be improved through an increased mechanistic understanding of historical events and a quantitative evaluation of model performance for simulating these events.**

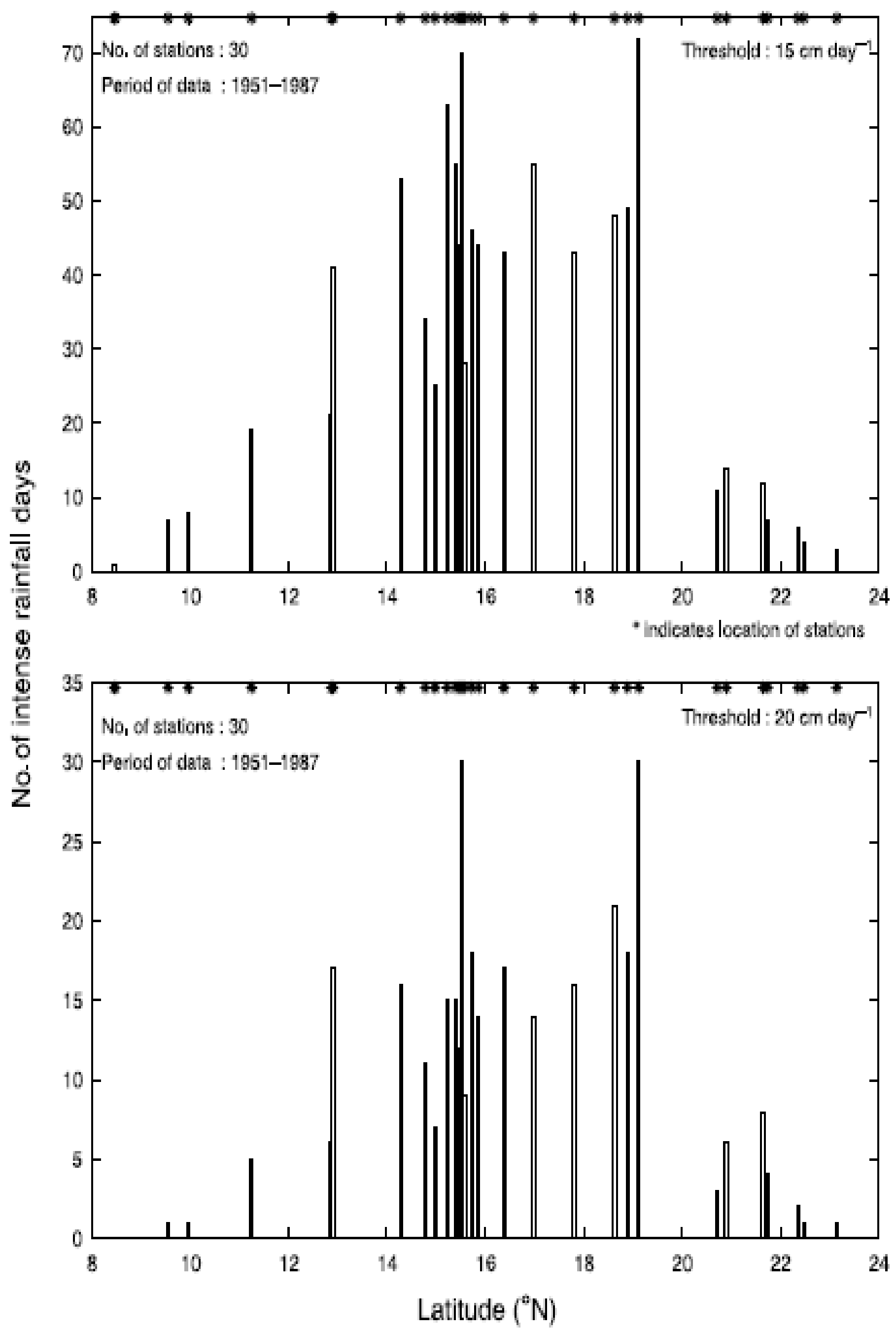


Figure from ***Francis and Gadgil 2006***

Francis and Gadgil (2006) identify two hotspots in Western Ghats (WG) region where heavy rainfall (above 15 cm and 20 cm per day) are found to occur more frequently

(i) Between 14 and 16 °N Latitude and

(ii) Near 19 °N Latitide

Monitoring of extremes over Indian Region on short, extended and seasonal scale: Identification of key physical processes and its representation in Models

Project Team
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Parters from IITM:
Dr. A. K. Sahai, Dr. A. S. Rao, Dr. Partha
Cochin University of Science and Technology, Cochin.

Research Objectives

The proposal will mainly focus on understanding extreme weather phenomena and their drivers across different time scales.

- **Identify the role of large, regional and local scale processes and their interactions in the formation of extreme weather events and its representation in models.**
- **Evaluate the models across scales in predicting extremes and quantification of key missing physical processes responsible for such events.**
- **Understand the role of tropical Indo-Pacific SST on seasonal extremes and its inter-annual variability in observations and model simulations.**

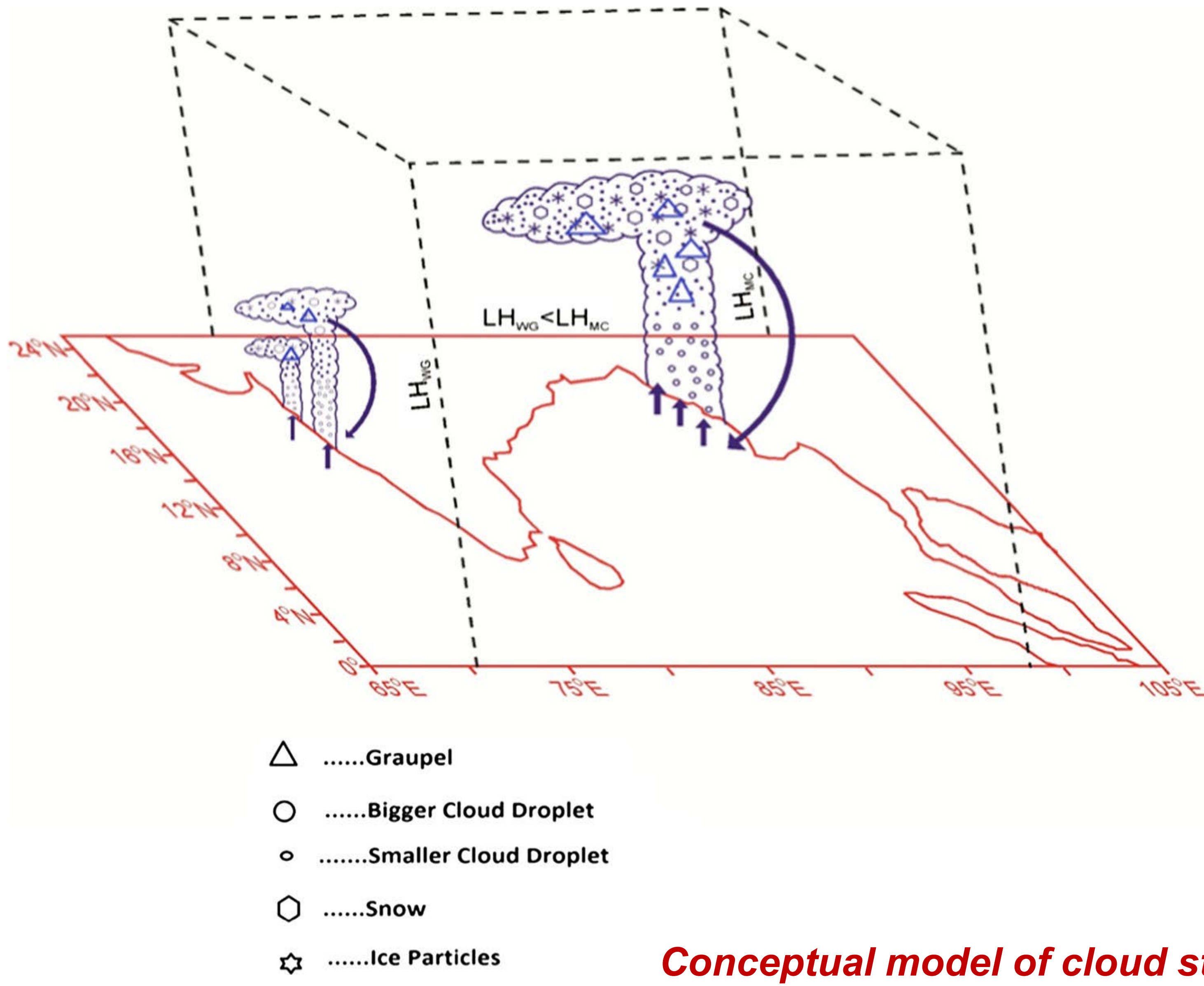
Highlights and Impact

- Understand and predict extreme and high impact weather and climate events including heavy precipitation, drought and severe storms across different scales and integrating them for informed decision making.
- A calibration matrix will be generated for each relevant physical processes for different lead times, especially convection.
- Evaluation of growth of model errors across different lead times.
- The prediction skill for extreme precipitation events will be improved through an increased mechanistic understanding of historical events and a quantitative evaluation of model performance for simulating these events.

Type of convective system	No. of intense rainfall days associated
TCZ	63
Offshore convection	15
MTC	6
Offshore vortex	1
Offshore convection + TCZ	8
TCZ + MTC	5
Offshore convection + MTC	2

*Table from **Francis and Gadgil (2006)***

Francis and Gadgil (2006) find one or a combination of four kinds of systems responsible for intense heavy rainfall events over WG region



Conceptual model of cloud structure Figure from ***Siddharth et al (2014)***

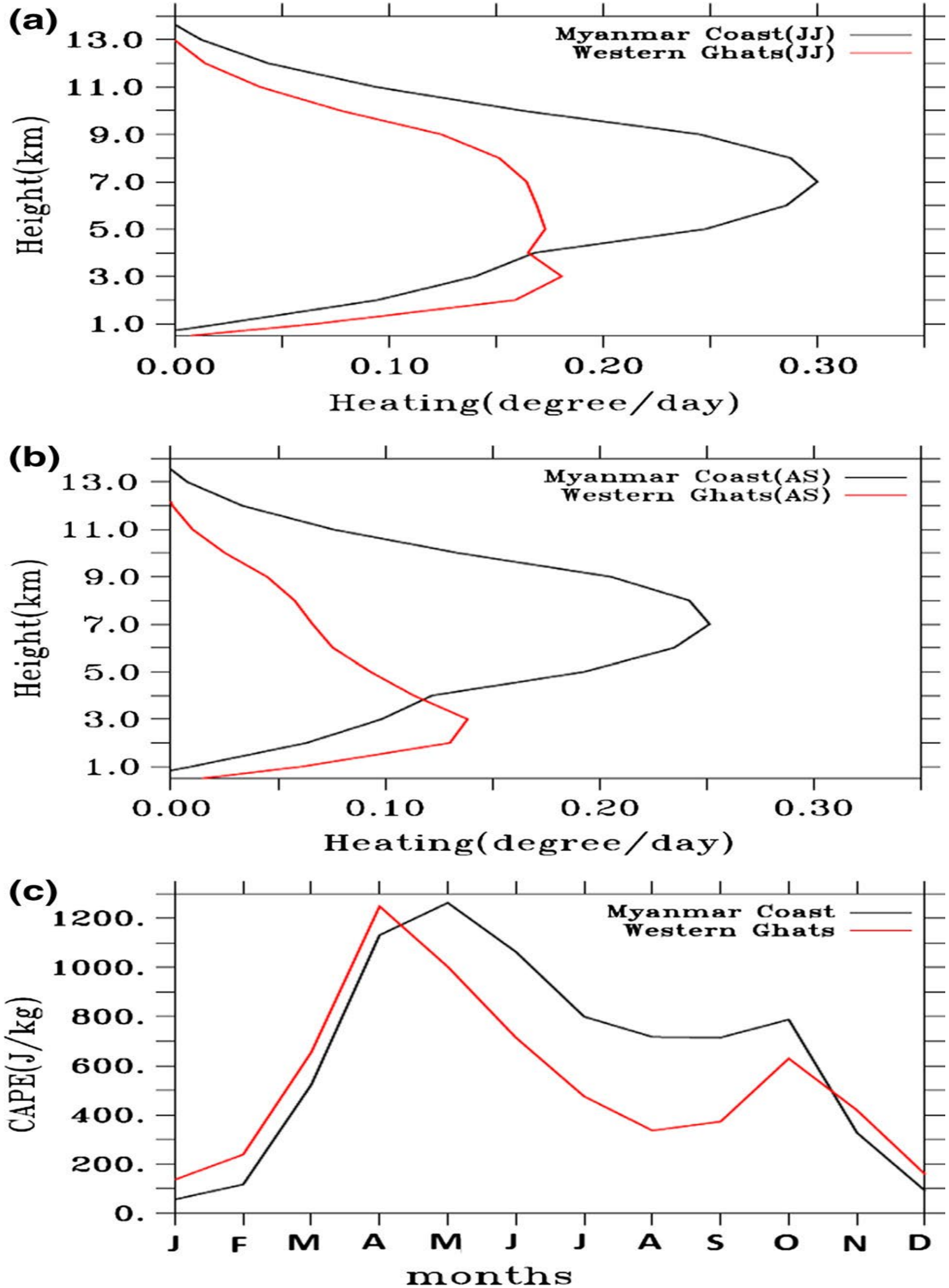


Figure From Siddharth et al (2014)

Siddharth et al (2014) suggest that the low values of CAPE is responsible for suppression of ice and graupel formation in the WG region

Latent heating values over WG region drops in Aug-Sep than from Jun-Jul, indicating lesser condensation at higher altitude during second half of monsoon