# Subseasonal Extended Range Prediction and Long-Range Prediction

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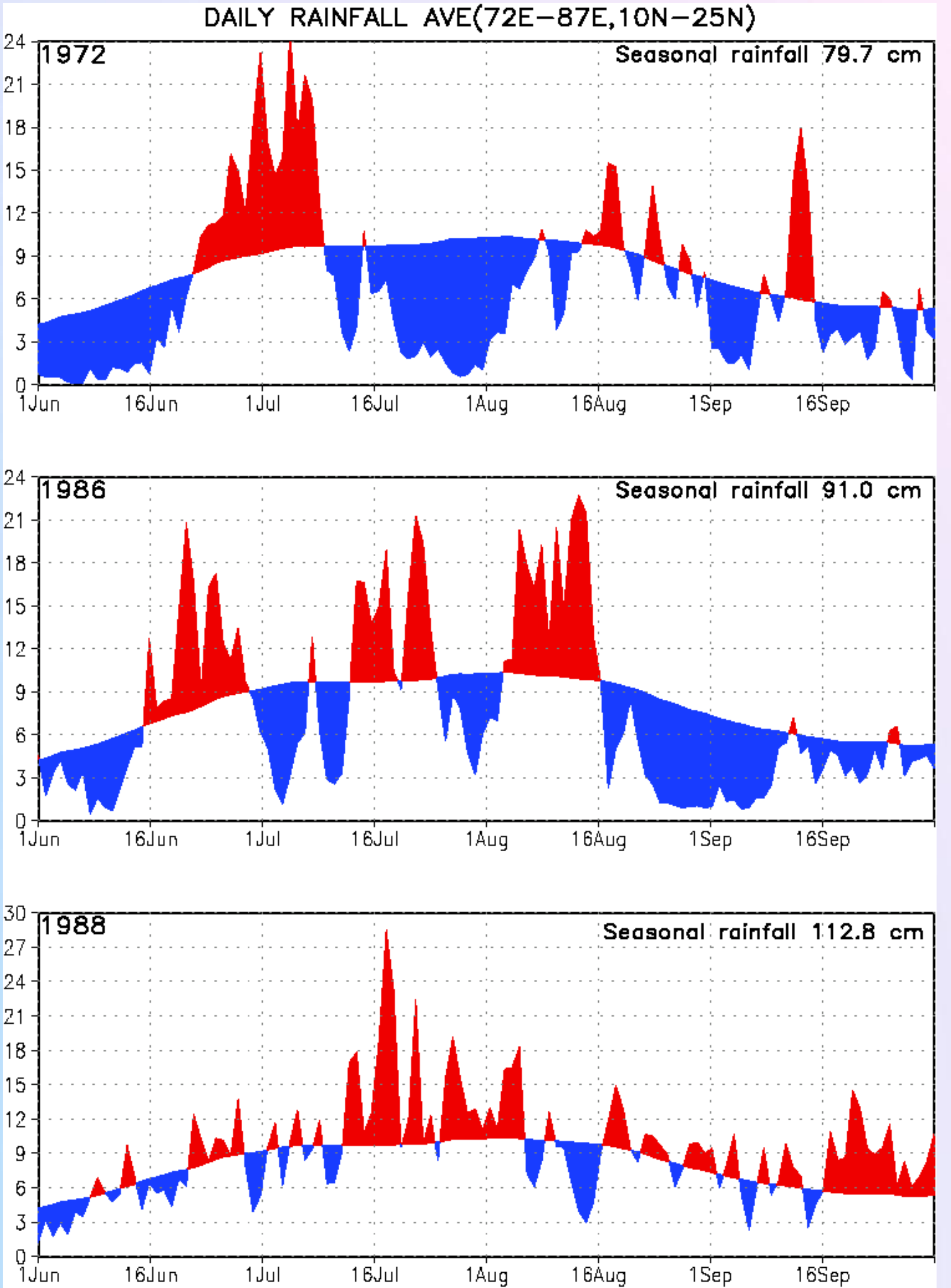
# Active-break spells (cycles)

**Daily rainfall (mm/day) over central India for three years, 1972, 1986 and 1988**

**The smooth curve shows long term mean.**

**Red shows above normal or wet spells while blue shows below normal or dry spells**



Lagged Composites of Daily Rainfall Anomalies for Active Period

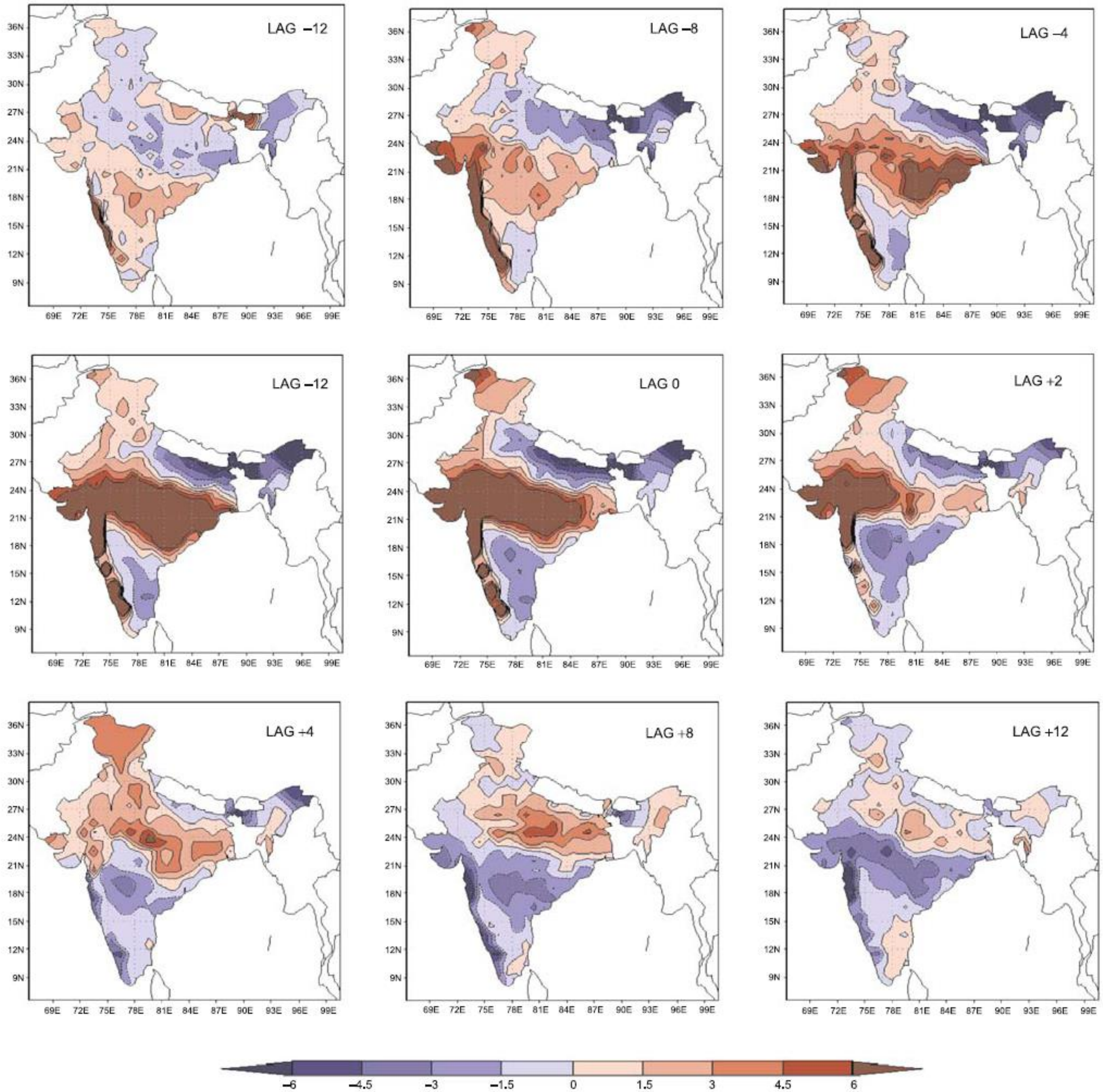



Figure 7(b). Lagged rainfall (mm) composites for the active spells (1951–2004).

Active Composite

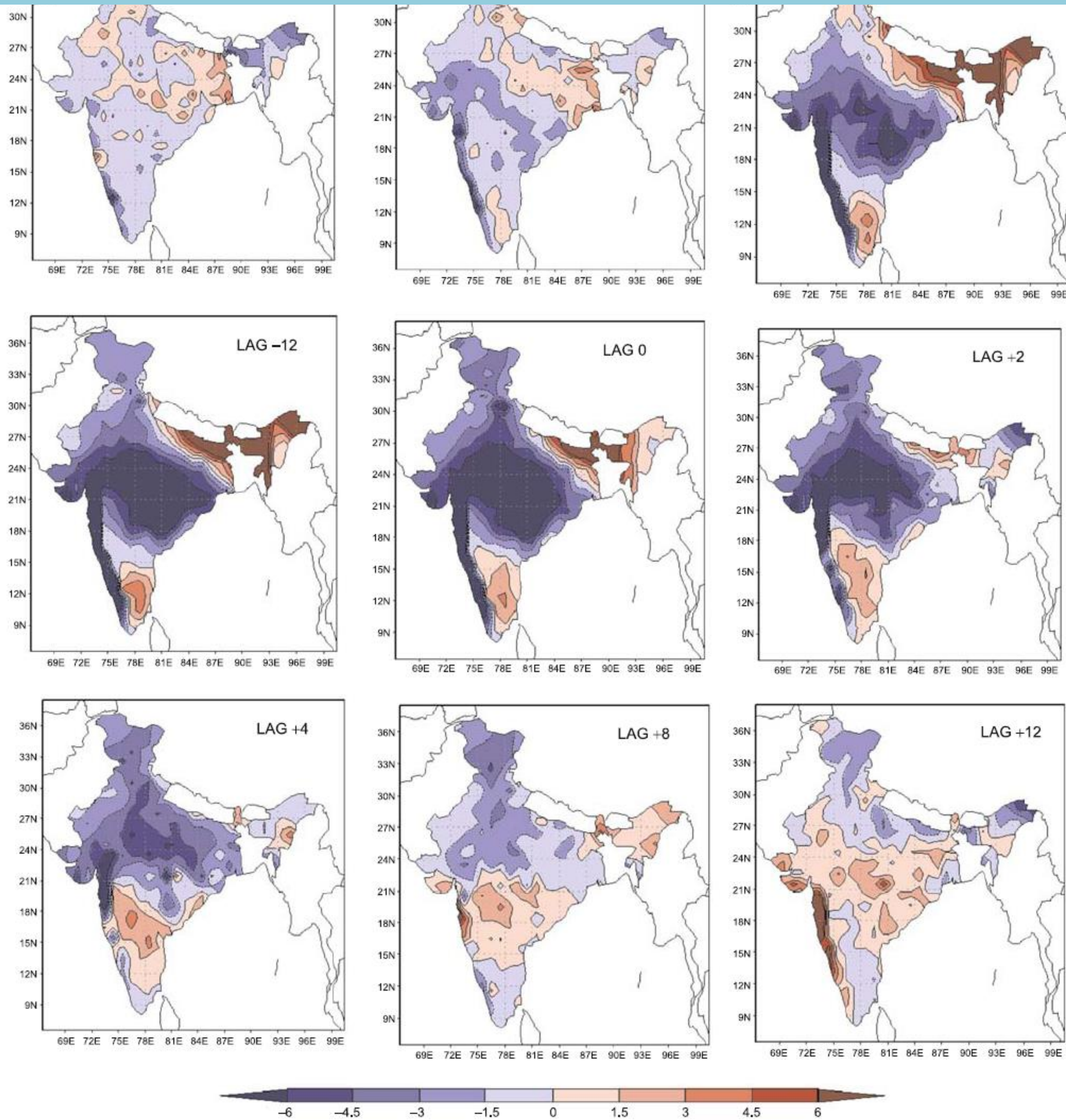



Figure 7(a). Lagged rainfall (mm) composites during the break spells (1951–2004).

Break Composite

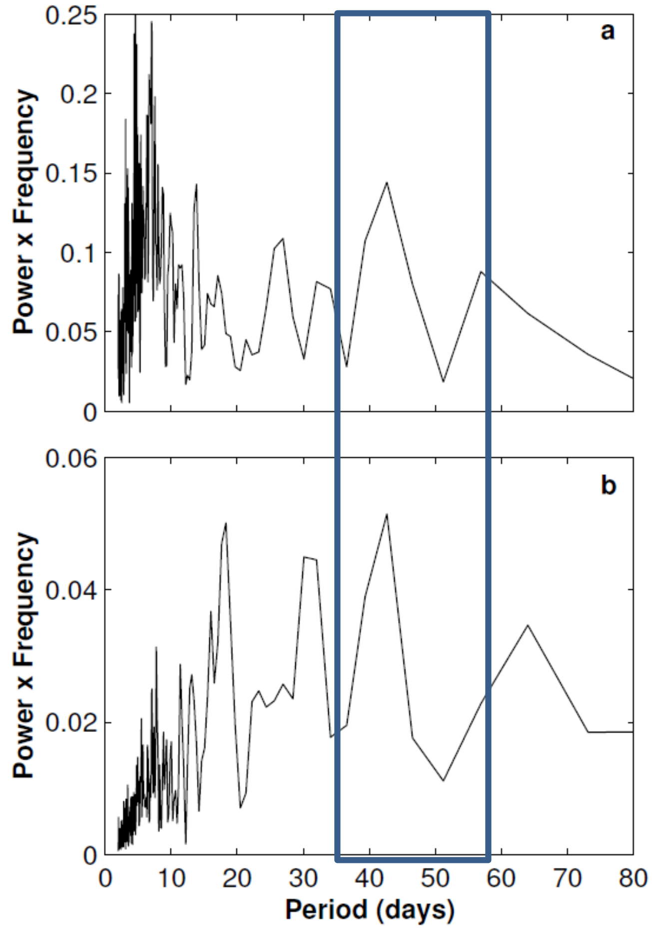
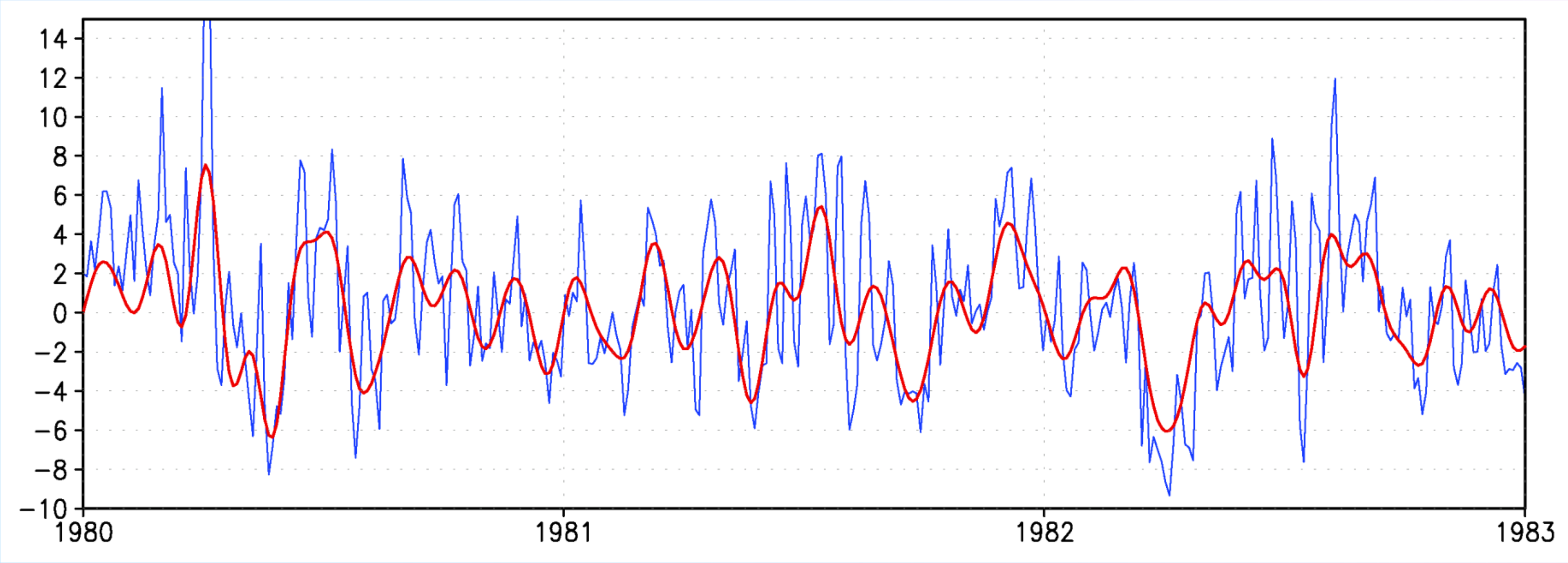


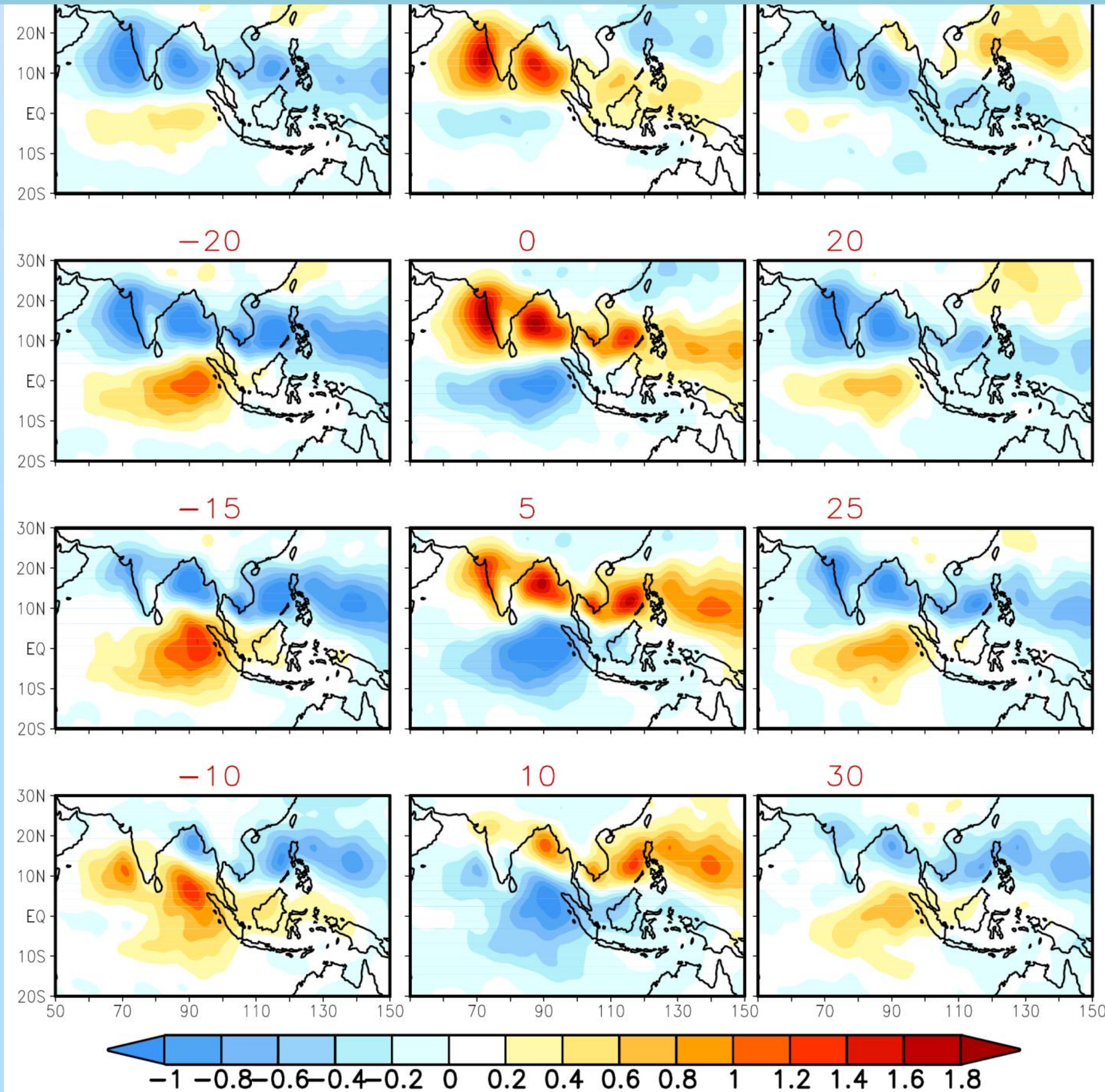

Figure 1: Spectrum of (a) rainfall anomalies for 20 (1971-1989) summer seasons (1 June -30 September) from station data averaged over 75E-85E and 15N-25N and (b) zonal wind anomalies at 850 hPa for 20 (1979-1998) summer seasons from NCEP reanalysis averaged over 55E-65E and 5N-15N.

# Monsoon Intraseasonal Oscillation

## Active Break Spells With Northward Propagation of ITCZ

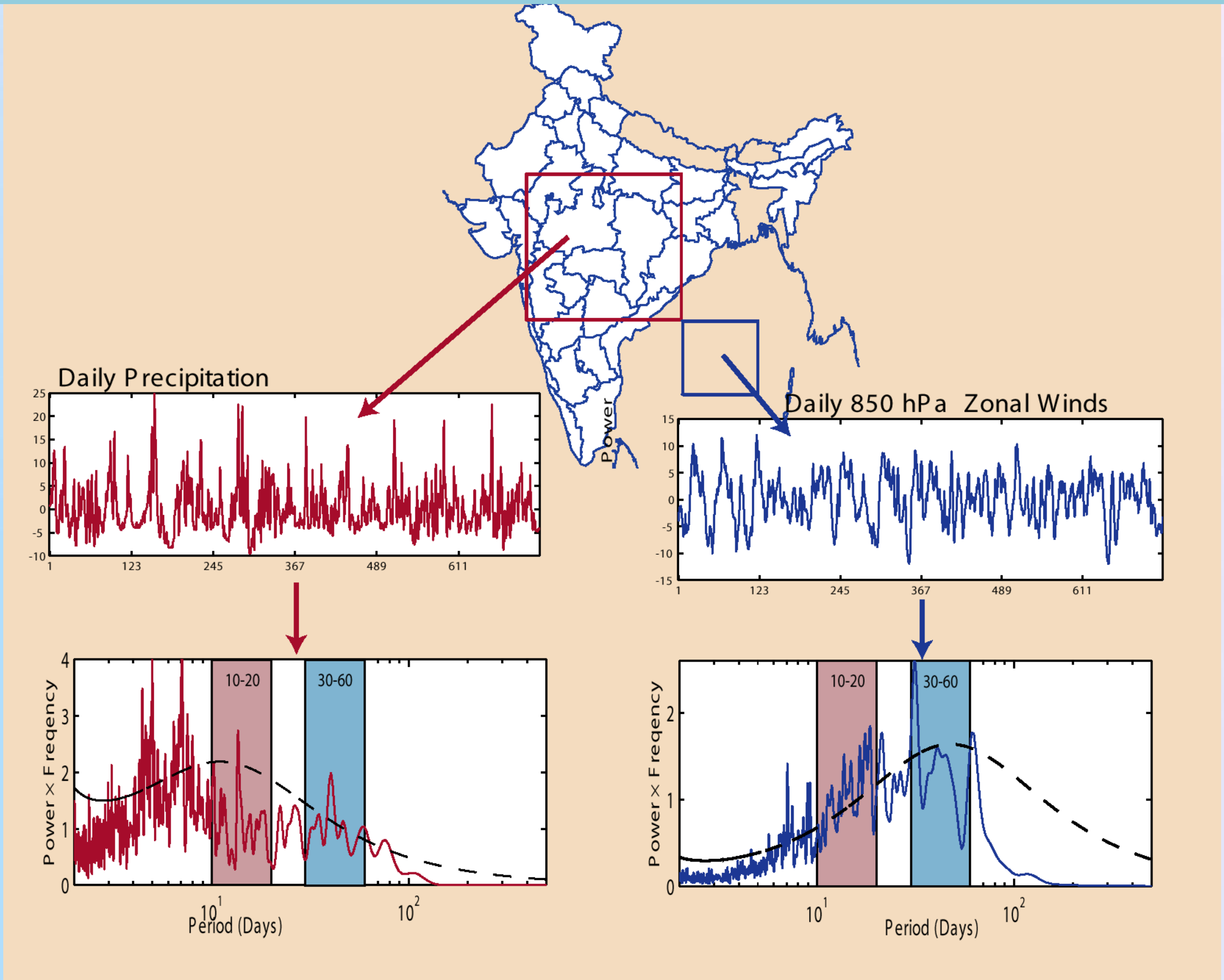



**Time series of daily rainfall anomaly (mm/day) over central India (blue) during 1 June – 30 Sept. for three years and 10-90 day filtered (red) rainfall.**




**Observed evolution of the precipitation anomaly patterns over a full cycle of the 30-70 day mode.**

**Lag regressions of the 30-70 day filtered CMAP anomalies with respect to a reference time series over the monsoon region.**



Daily Precipitation
Daily 850 hPa Zonal Winds
10-20
30-60
10-20
30-60
Power × Freqency
Power × Freqency
Period (Days)
Period (Days)
Power

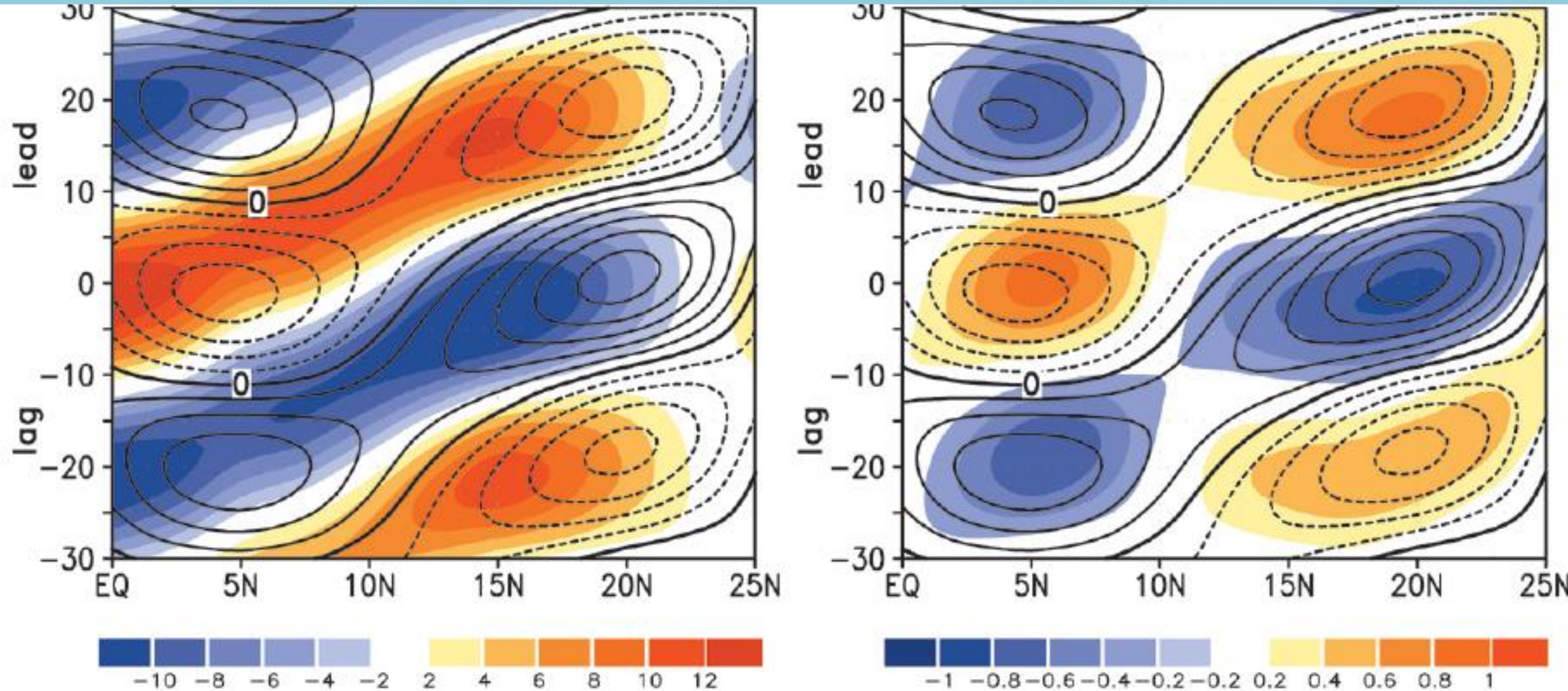
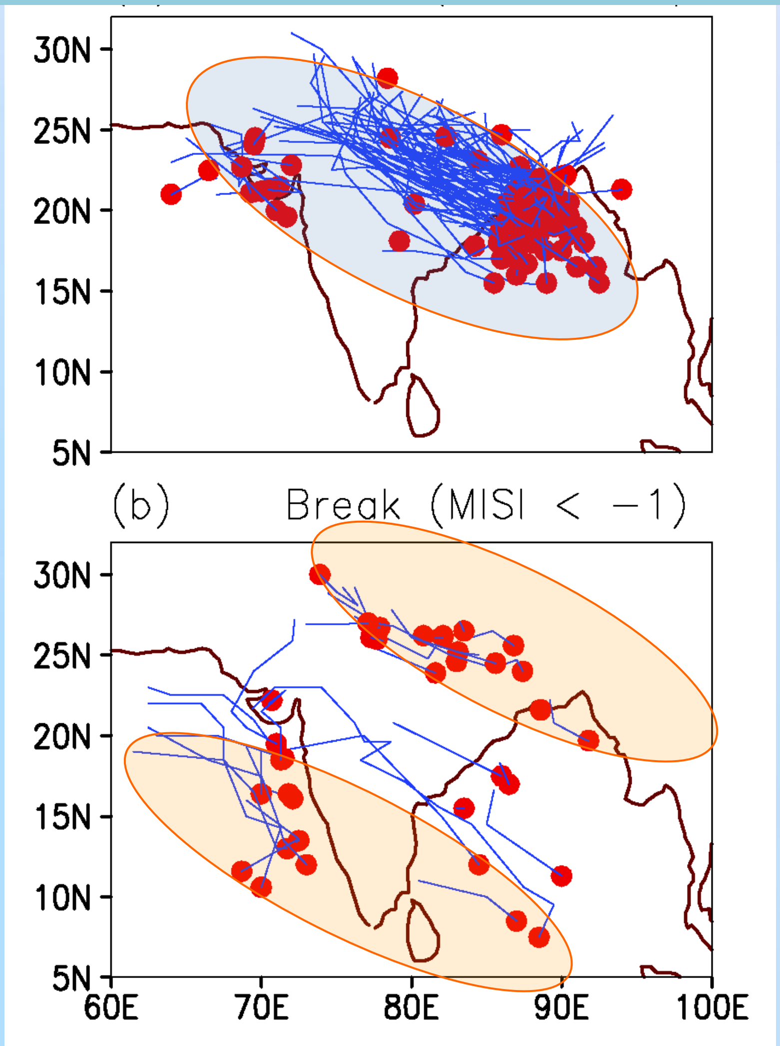



**Figure 2.16.** (a) Regressed 30 to 60-day filtered anomalies of OLR (shaded; $W\,m^{-2}$) and 850 hPa relative vorticity (contour, positive solid and negative dashed, contour interval $1 \times 10^{-6}\,s^{-1}$) with respect to the reference time series described in Figure 2.10 averaged over 80°E–90°E. (b) Regressed 30 to 60-day filtered anomalies of 850 hPa relative vorticity (contour, positive solid and negative dashed, contour interval $1 \times 10^{-6}\,s^{-1}$) and divergence at 925 hPa (shaded; $10^{-6}\,s^{-1}$) with respect to the same reference time series.

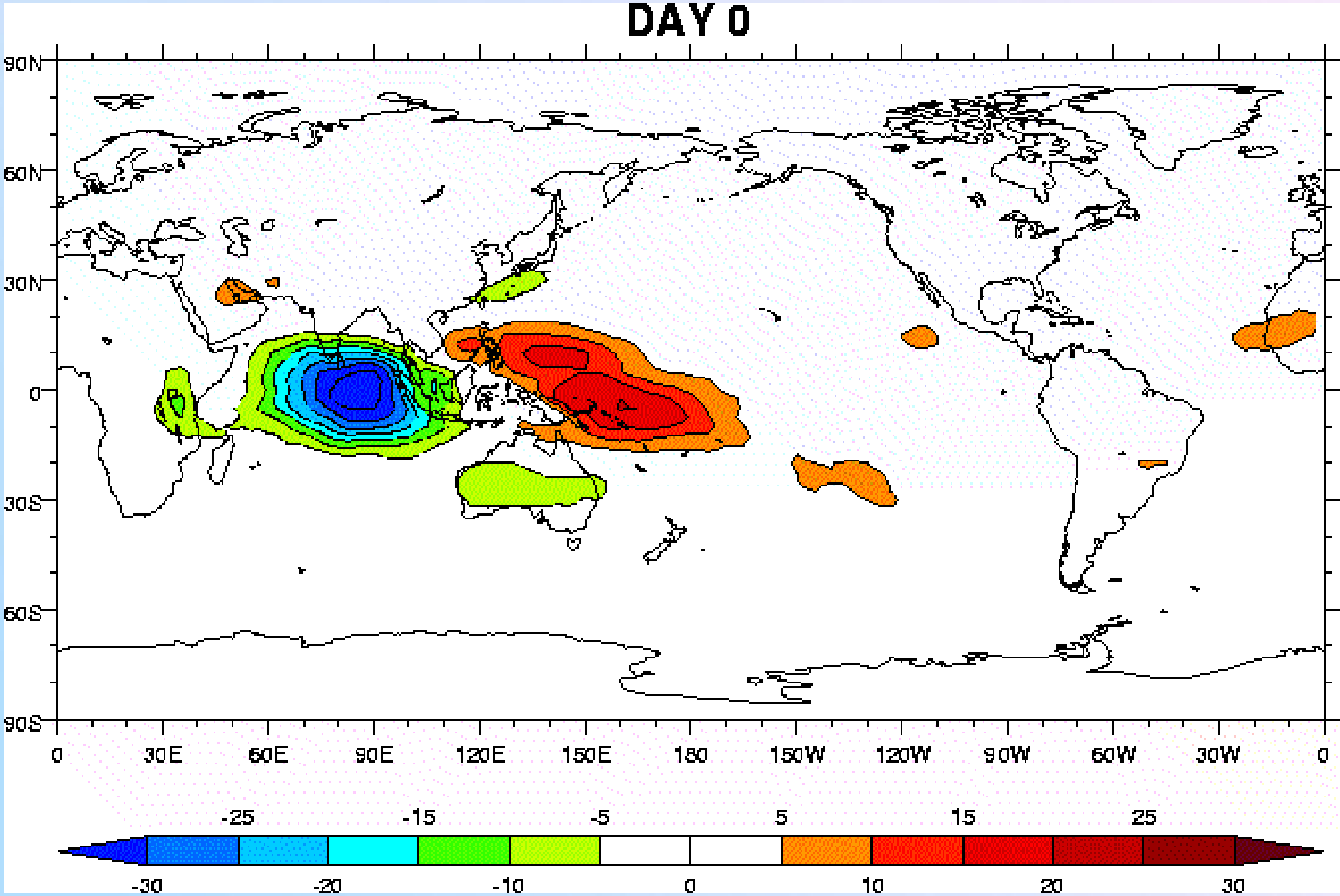
seasonal mean for the period 1997–2007. (c) Amplitude of the annual cycle. Climatological mean absolute value of the difference between JJAS mean and DJF mean for the 1997–2007 period from GPCP.




**Tracks of LPS for the period 1954-1983 during extreme phases of monsoon ISO. (a) 'Active' ISO phase (MISI > +1) and (b) 'Break' ISO phase (MISI < -1). Red dots represent the genesis point and their lines show the tracks.**

Goswami et al. 2003, *GRL*, 30, doi:10.1029/2002GL016734

# MJO life cycle: Convection

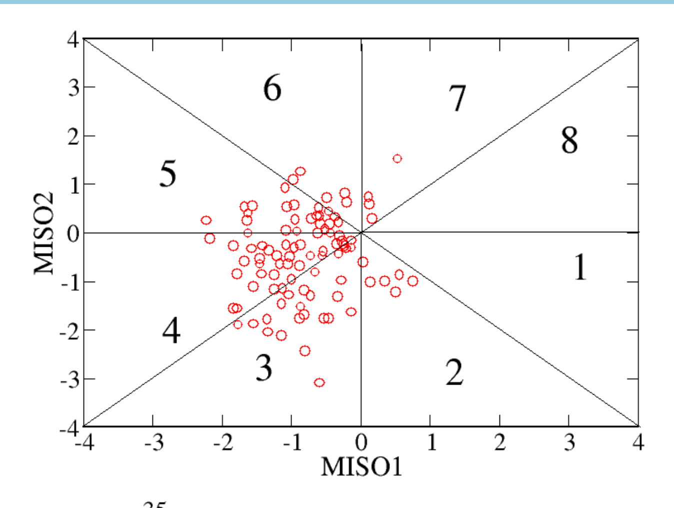


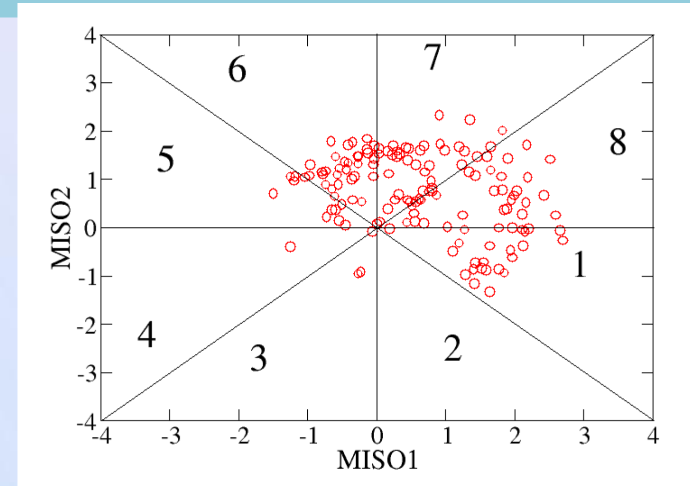

Animation of OLR anomaly maps, formed by regression onto first two EOFs of 20-200-day filtered OLR. Contour interval is 5 W $m^{-2}$.

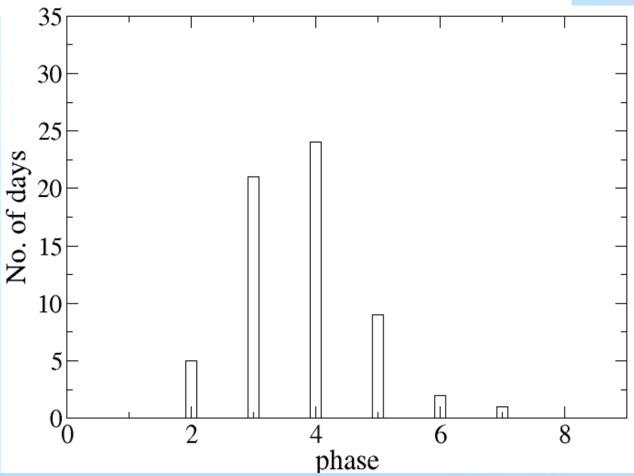
# Relationship between Active/Break spell with phases of MISO.

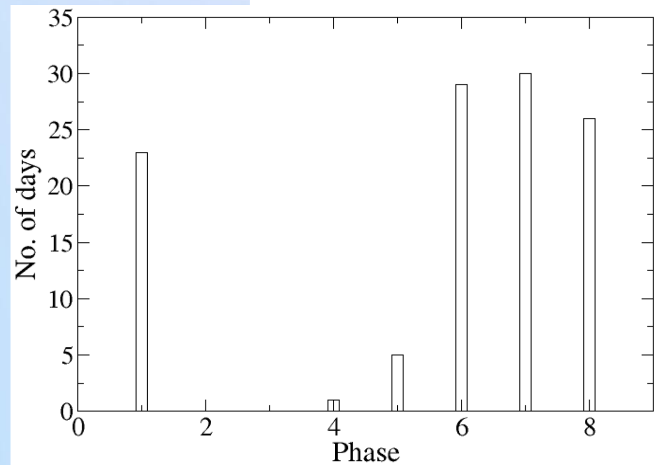
❖**Break**

## Active



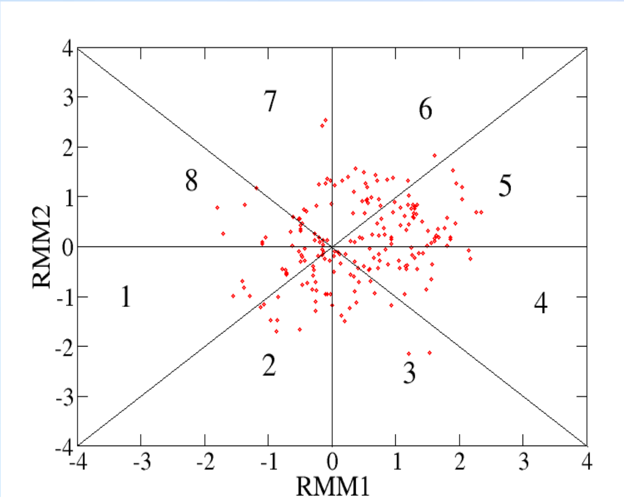



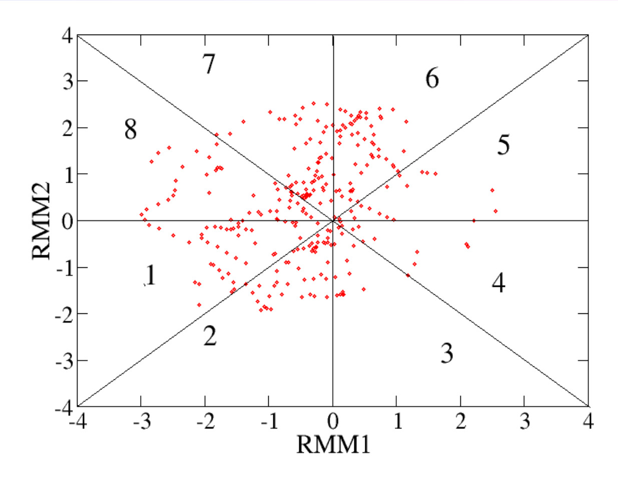

**Phase1: Peninsular India, phase2:CI, phase3: CI, Phase4: NI, phase5:Foothills, phase6: South IO, Phase7: IO, phase8: Southern Tip**

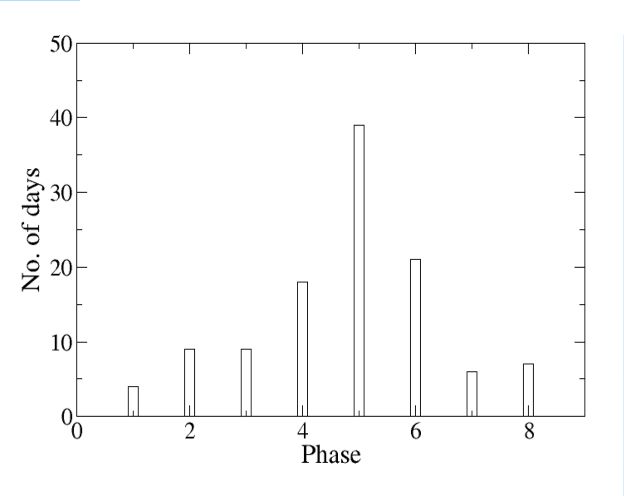
# Relationship between Active/Break spell with phases of MJO.

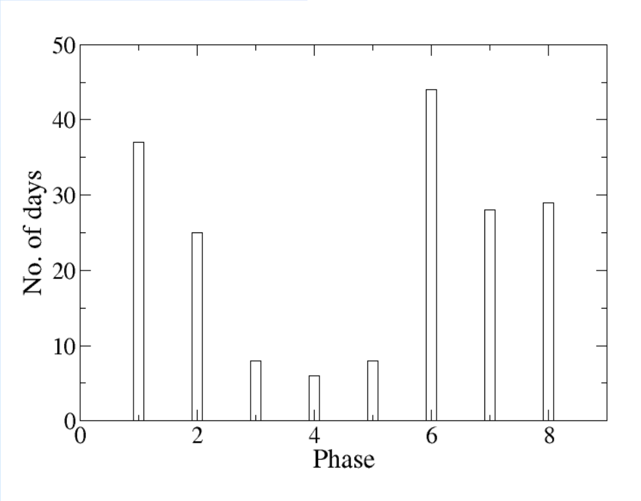
## ❖Break




## Active




**Phase 2 & 3: Indian Ocean, phase 4 & 5: Maritime Continent, phase 6& 7: Western Pacific, Phase 8 &1: West Hem. & Africa,**

# Prediction of MISO/MJO

# Time Line of development of IITM ERPS using CFSv2

**2011: Ensemble Prediction System developed, [Abhilash etal., 2014, IJOC]**

⇩

**2012: Bias Correction of CFS forecasted SST implemented**
**[Abhilash etal., 2014, ASL; Sahai etal., 2013, Cur. Sci.]**

⇩

**2013: High Resolution CFST382 implemented**
**[Sahai etal., 2014, CD;Borah etal, 2014, IJOC]**

⇩

**2014: CFS based Grand EPS Implemented**
**[Abhilash etal., 2015, JAMC; Sahai etal., 2015, Cur. Sci]**

⇩

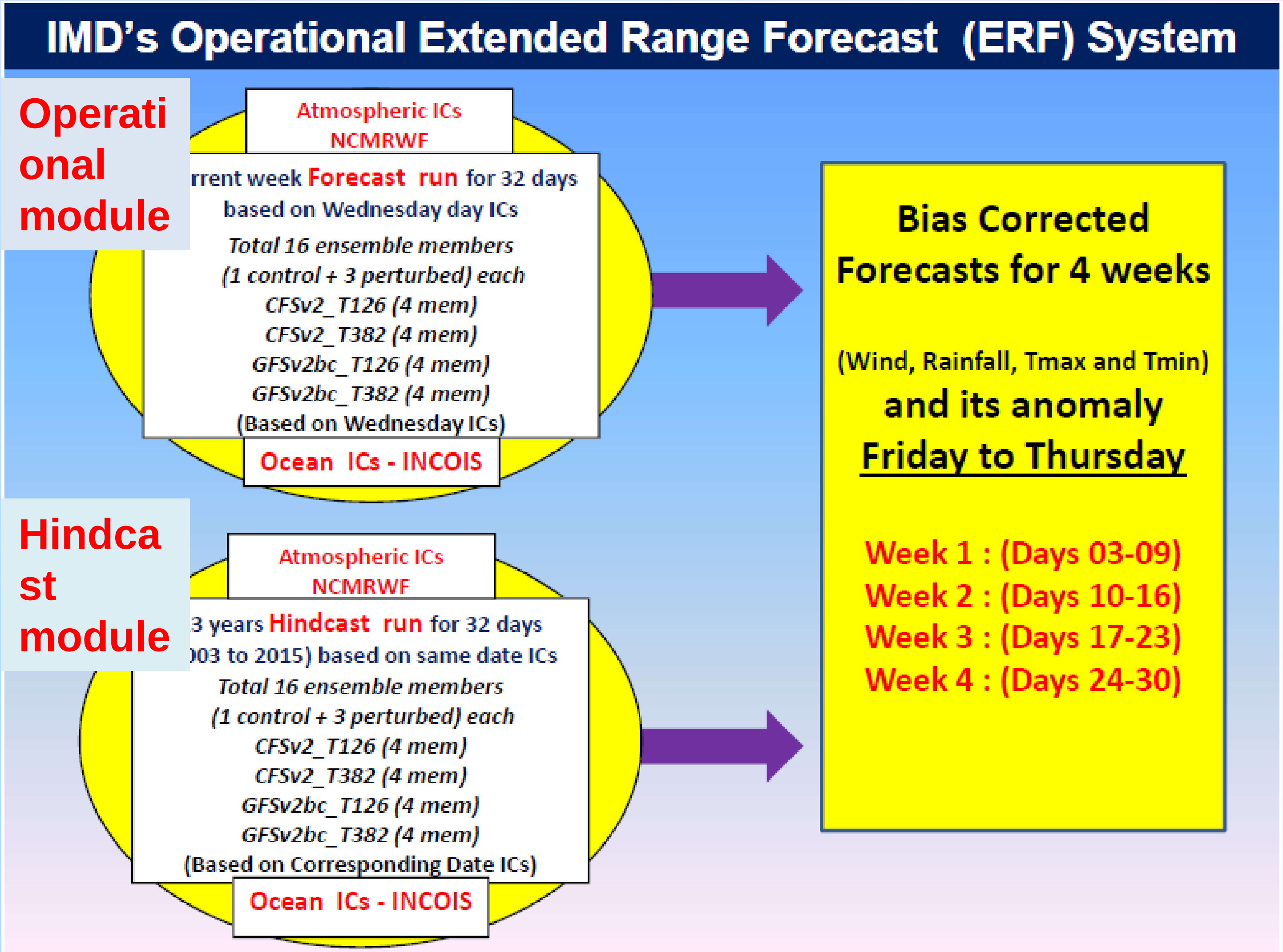
**2015: Forecast for winter and other seasons started**

⇩

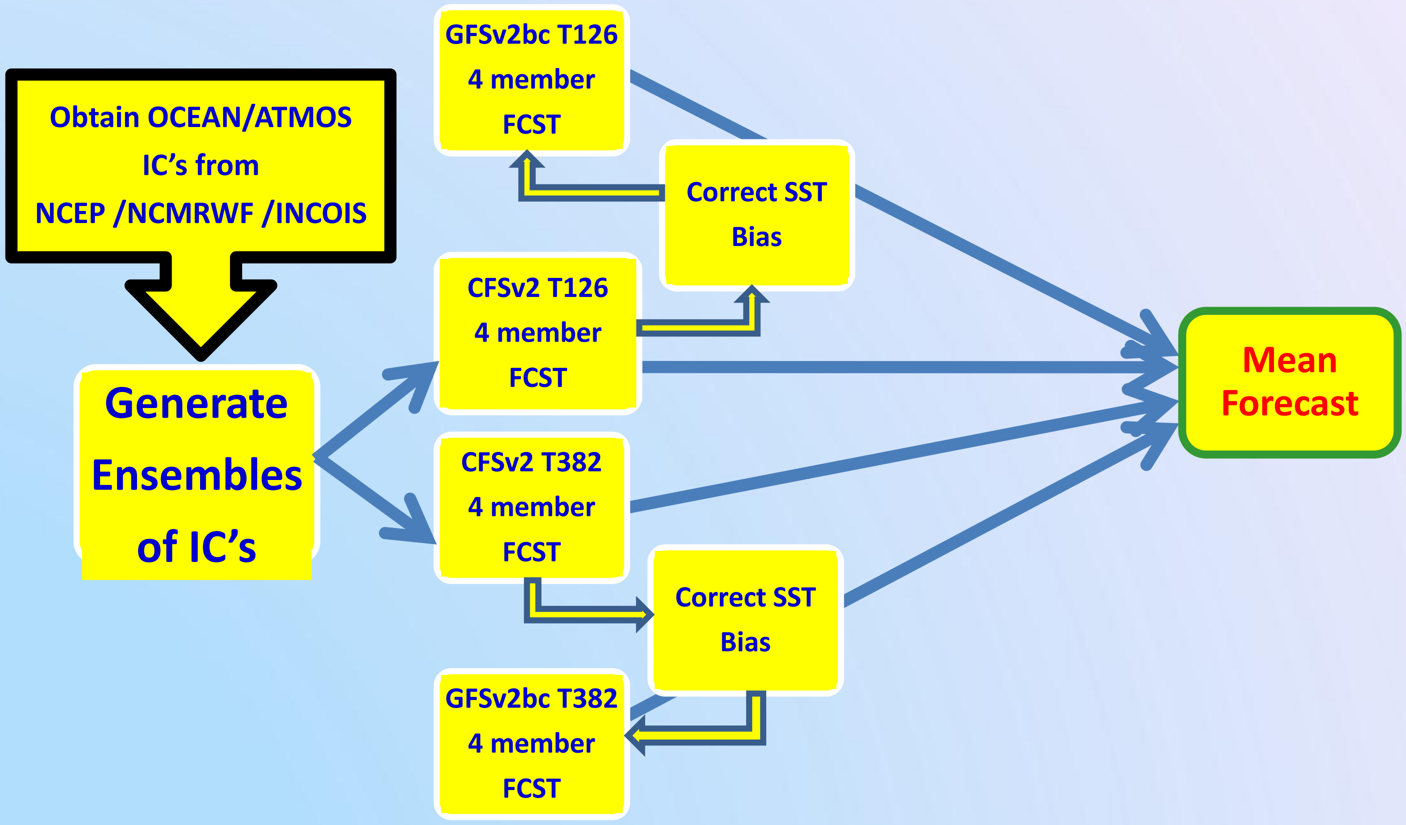
**2016: Forecast for Heat Waves started**

⇩

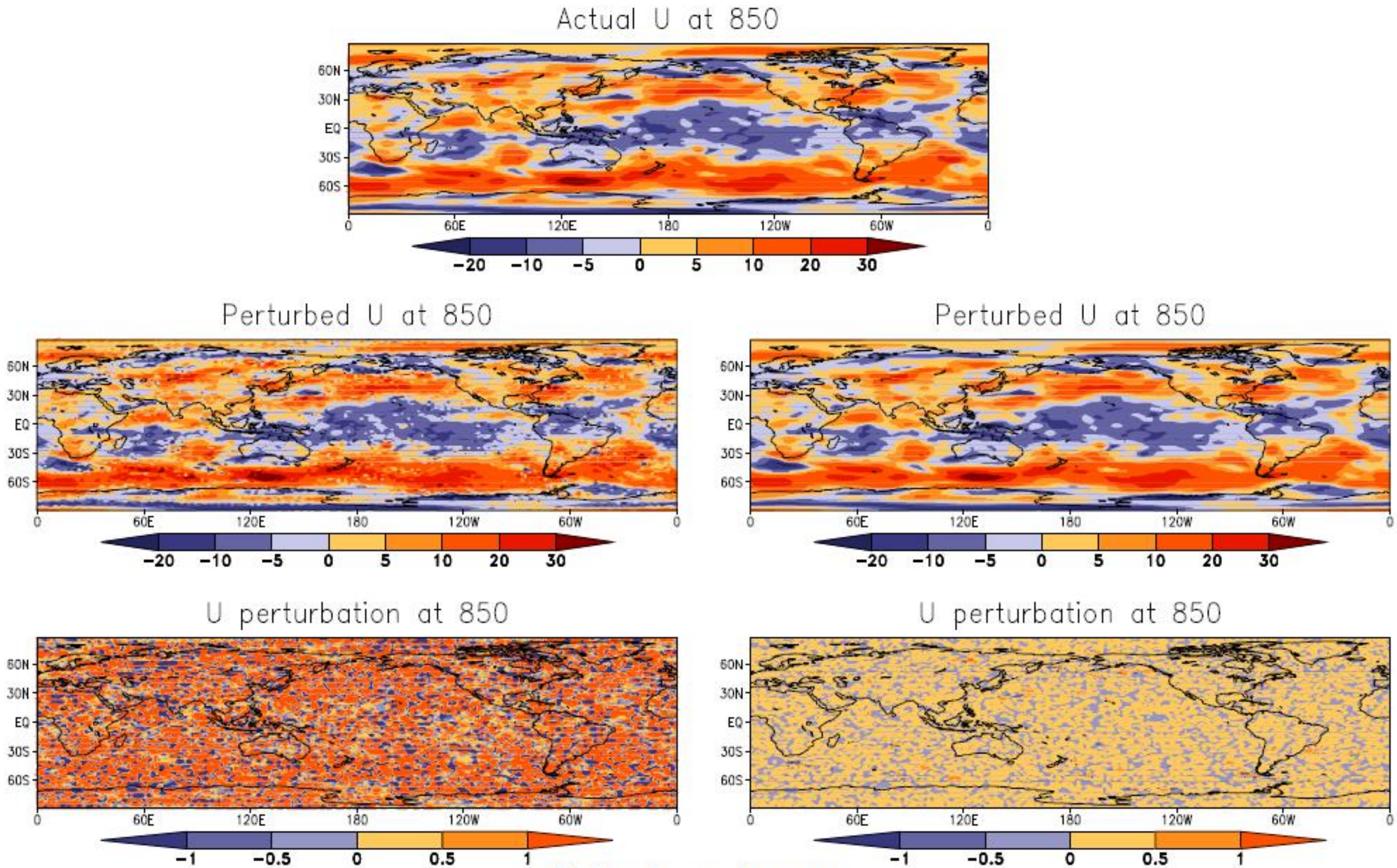
**[Applications: Onset Prediction: Joseph etal, 2014, JC; Uttrakhand Heavy Rainfall: Joseph etal, 2014, CD; Skill of CFST126: Abhilash etal., 2014, CD; Comparison 2013 and 2014 June extremes: Joseph etal., QJRMS, 2015; Prediction skill of MJO: Sahai et al., 2016, IITM-RR]**


IMD's Operational Extended Range Forecast (ERF) System
Operational module
Atmospheric ICs NCMRWF
rrent week Forecast run for 32 days based on Wednesday day ICs
Total 16 ensemble members
(1 control + 3 perturbed) each
CFSv2_T126 (4 mem)
CFSv2_T382 (4 mem)
GFSv2bc_T126 (4 mem)
GFSv2bc_T382 (4 mem)
(Based on Wednesday ICs)
Ocean ICs - INCOIS
Hindcast module
Atmospheric ICs NCMRWF
3 years Hindcast run for 32 days
)03 to 2015) based on same date ICs
Total 16 ensemble members
(1 control + 3 perturbed) each
CFSv2_T126 (4 mem)
CFSv2_T382 (4 mem)
GFSv2bc_T126 (4 mem)
GFSv2bc_T382 (4 mem)
(Based on Corresponding Date ICs)
Ocean ICs - INCOIS
Bias Corrected Forecasts for 4 weeks
(Wind, Rainfall, Tmax and Tmin)
and its anomaly
Friday to Thursday
Week 1 : (Days 03-09)
Week 2 : (Days 10-16)
Week 3 : (Days 17-23)
Week 4 : (Days 24-30)

# IMD/IITM Ensemble Prediction System



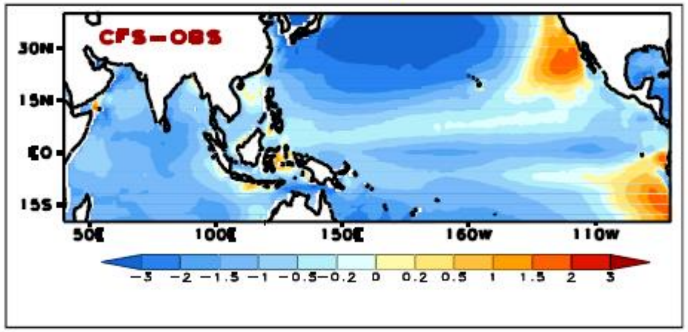
# Development, Testing, tuning and reliability of Ensemble Prediction System (EPS)



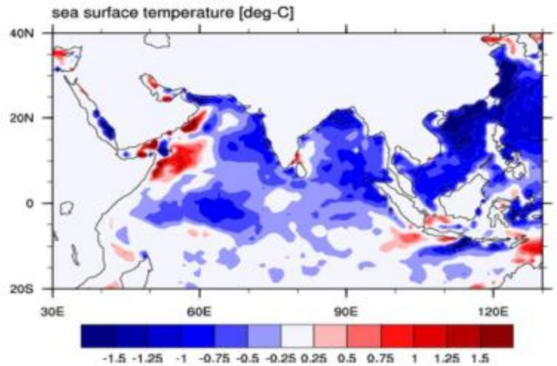

**Abhilash et al 2014**

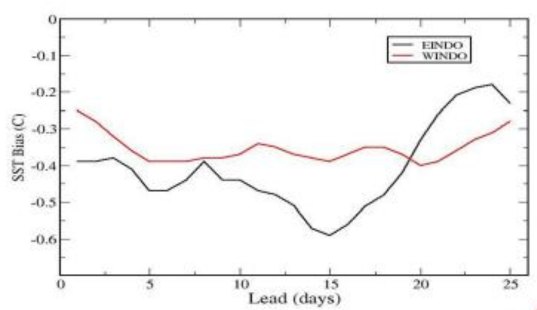
# Development of Bias-correction Technique

## SST Bias from Long Simulation



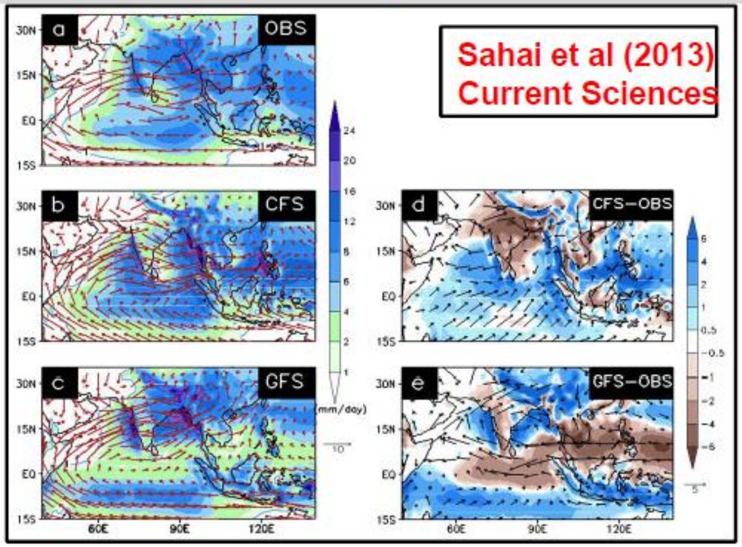

SST Bias
20 day Lead



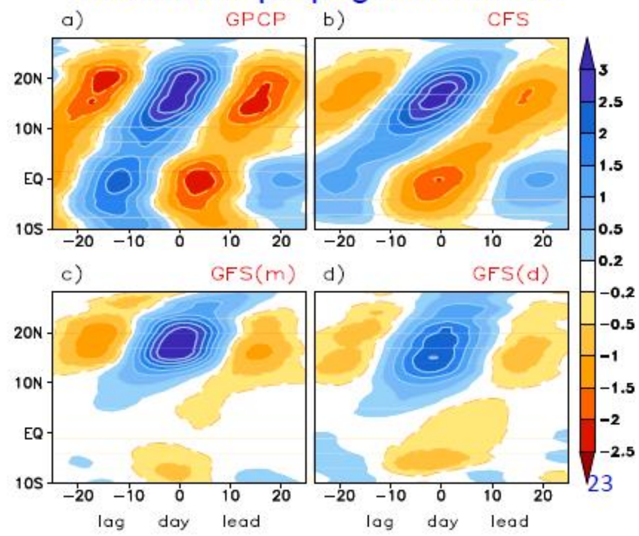

Lead
Dependant
Bias

*Abhilash et al., 2013*




Sahai et al (2013)
Current Sciences

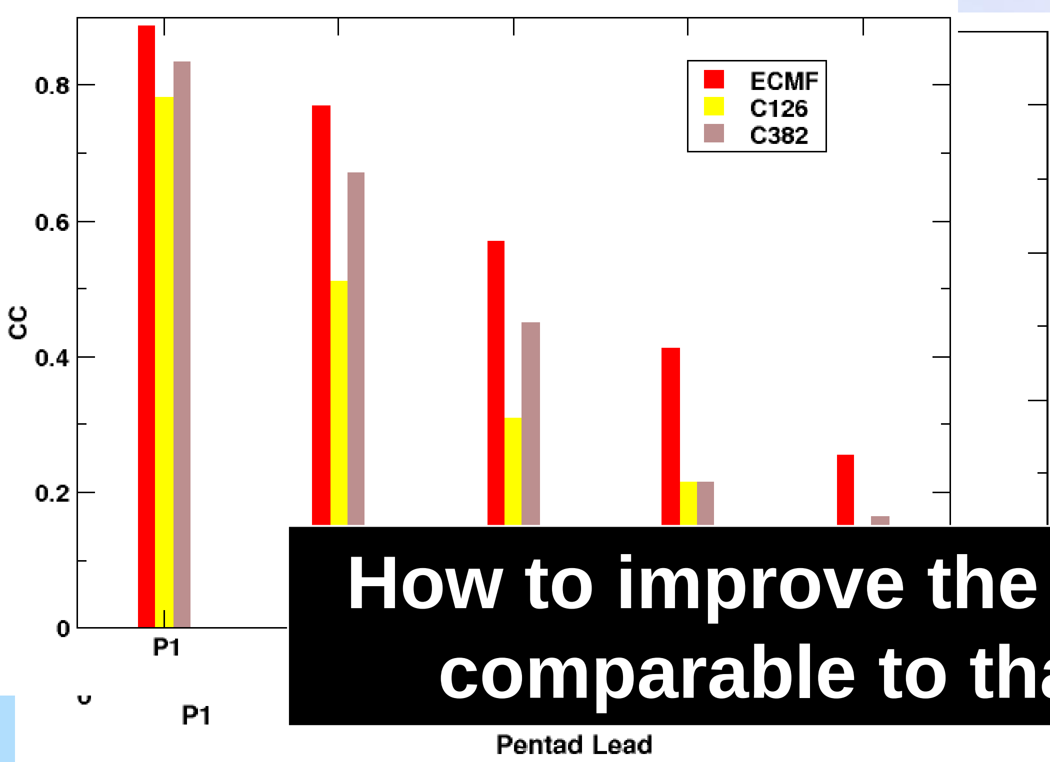
## Northward propagation of ISO



# Relook: Why MME?

# Comparison of IITM-ERPS with ECMWF

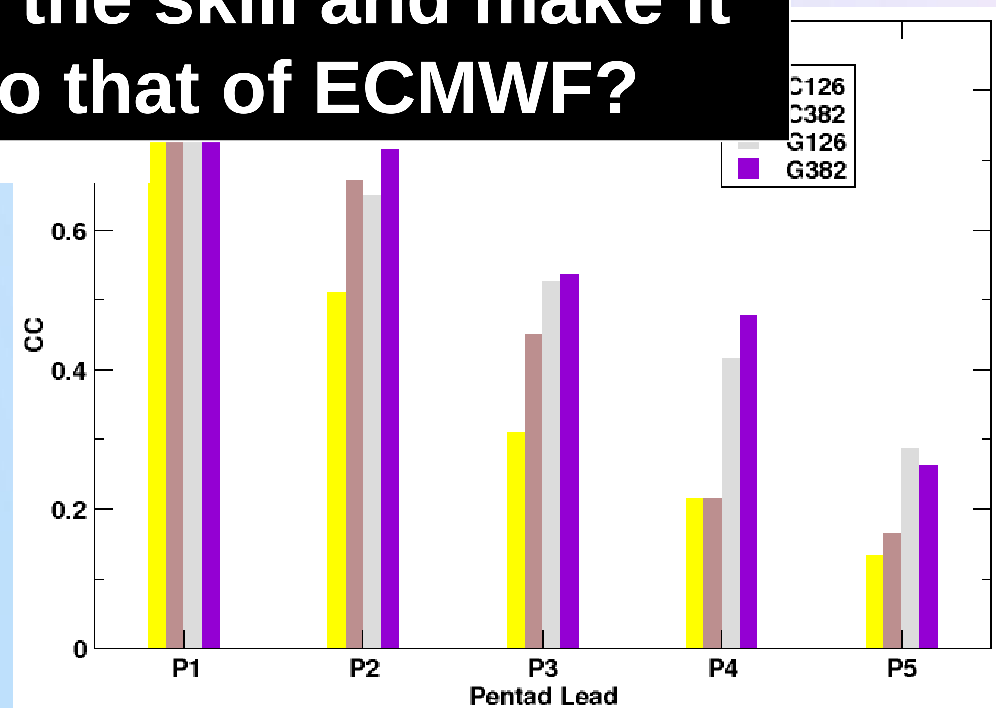
# Comparison of IITM-ERPS with ECMWF



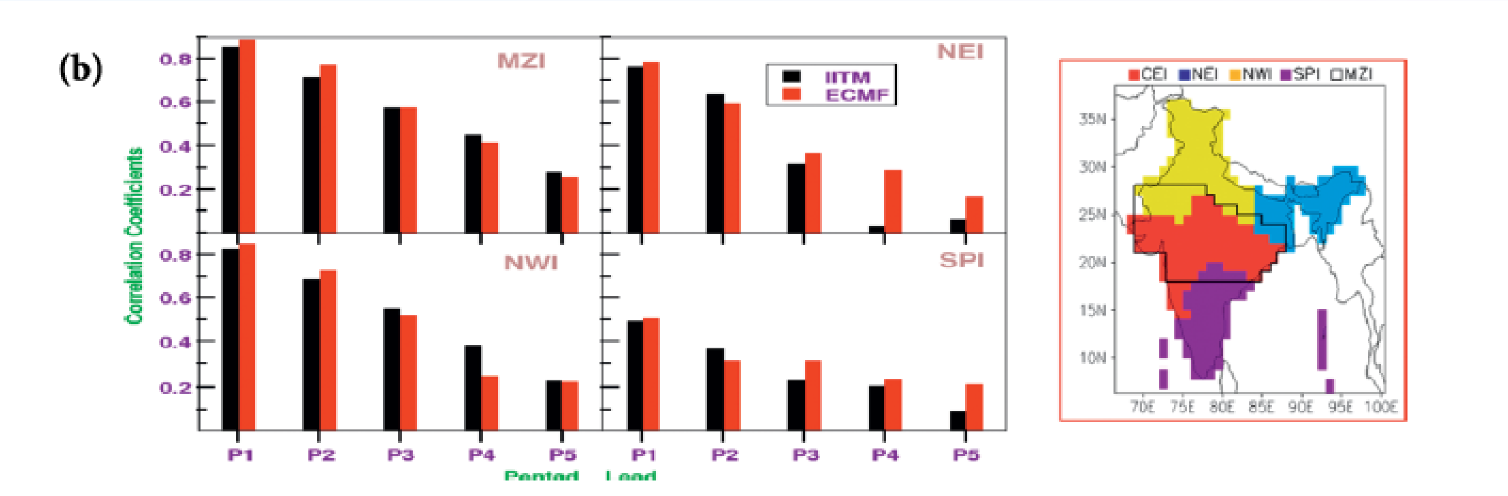

Skill of CFST126/T382 is much less than ECMWF in longer leads

**How to improve the skill and make it comparable to that of ECMWF?**

Skill improved due to bias correction



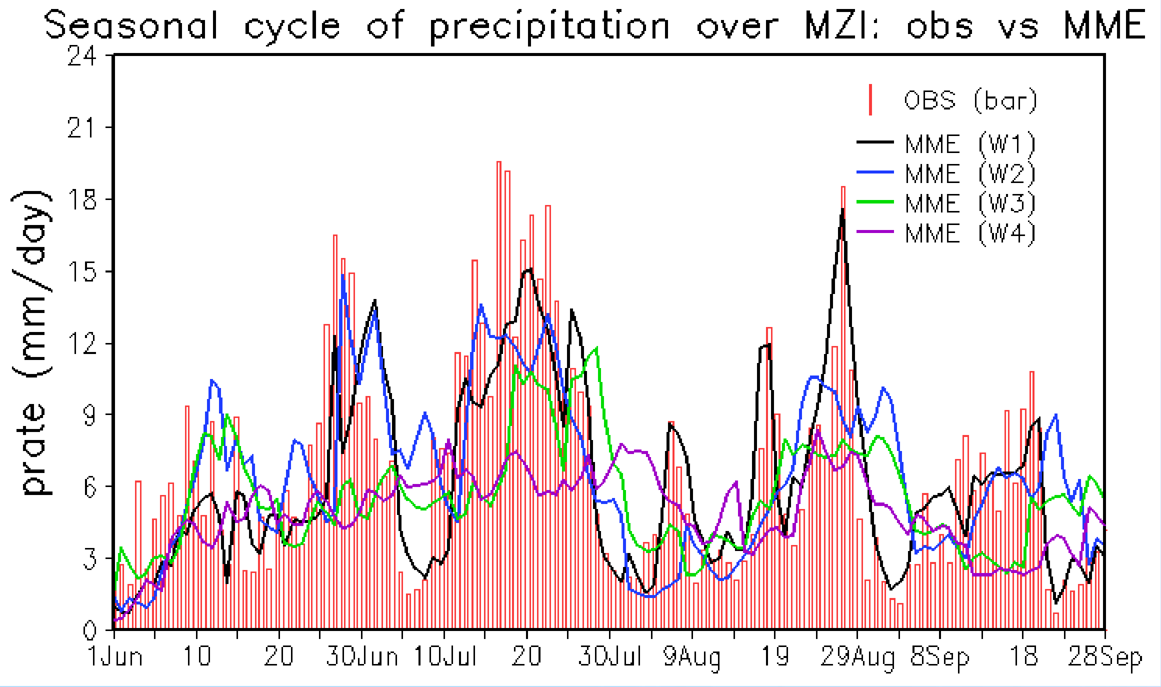
# Extended Range Forecast Skill

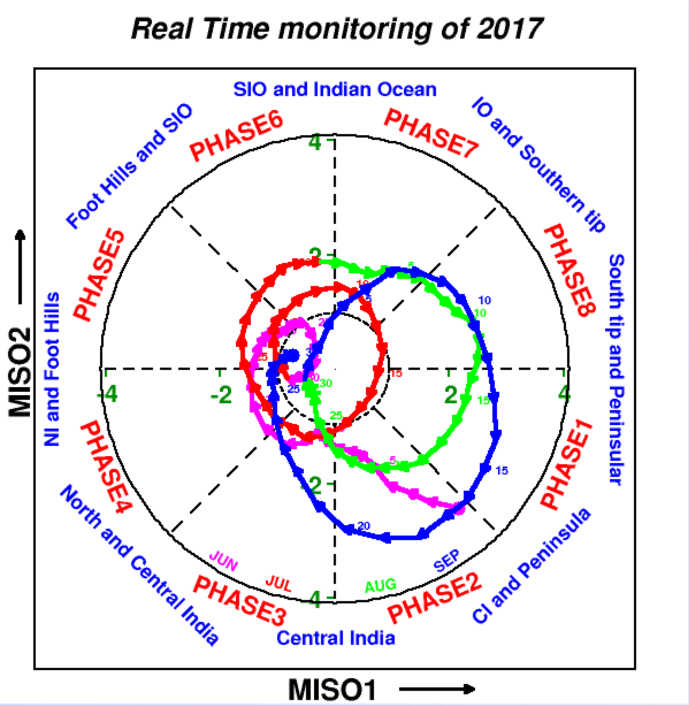


# Applications of IITM ERPS: Some Examples

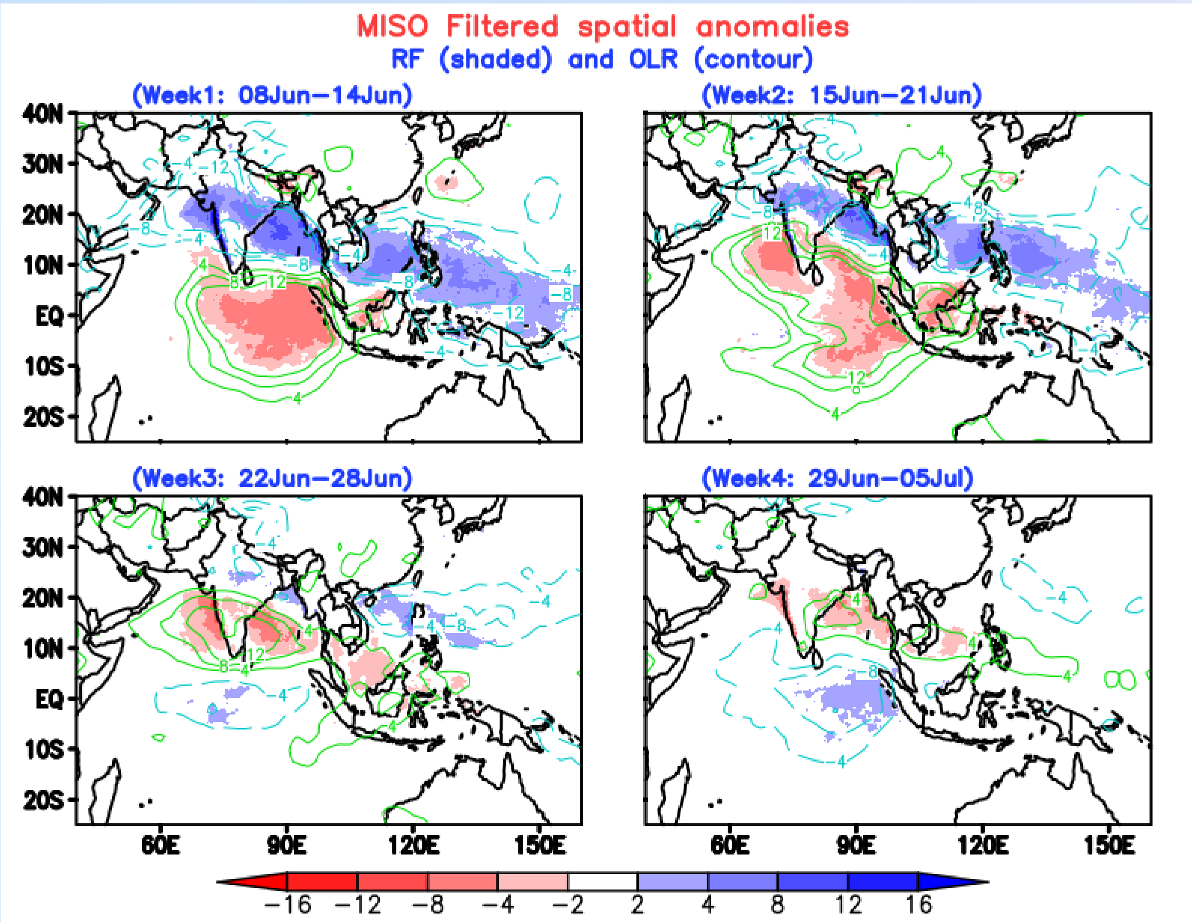
Observed and Predicted seasonal cycle of rainfall over MZI Region

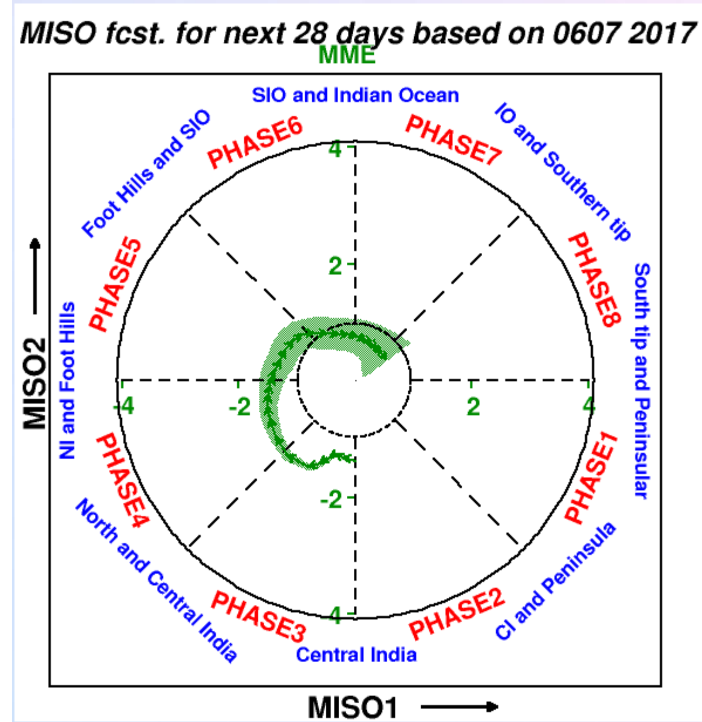
# MISO



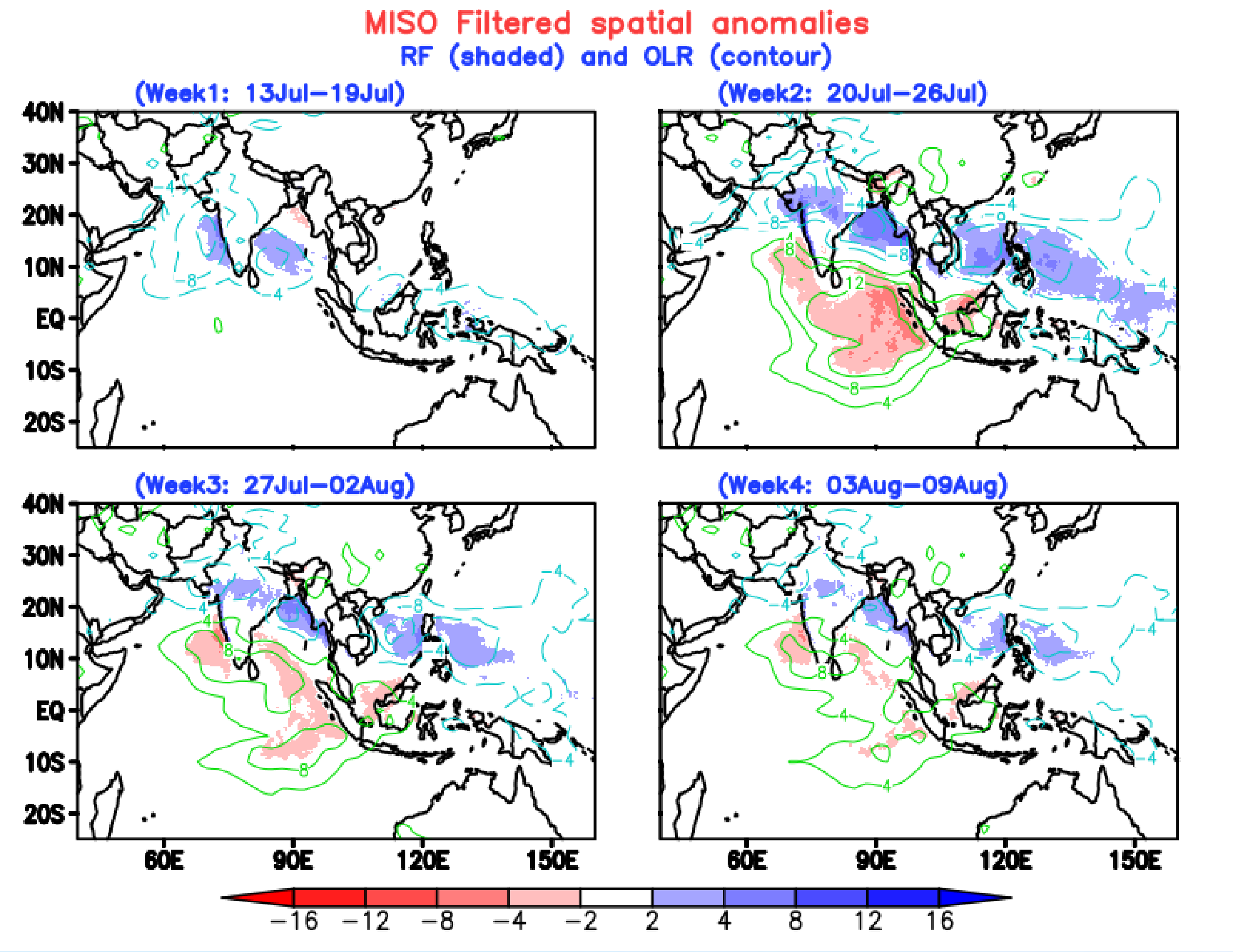



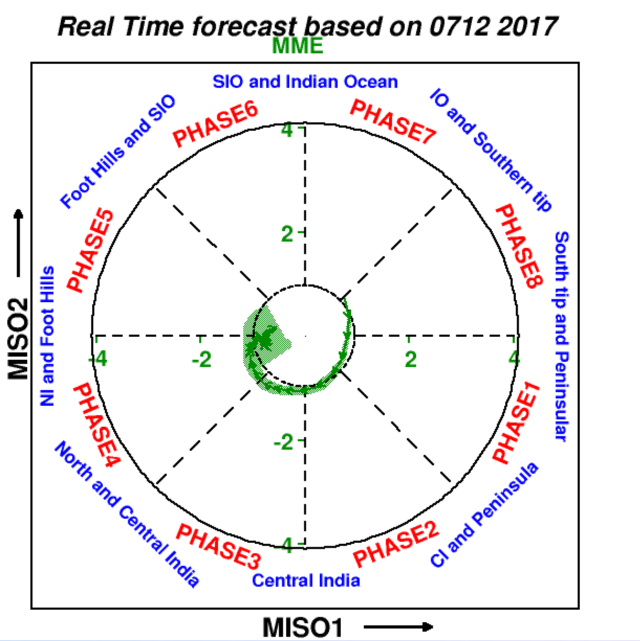
# MISO forecast for 28 days during June 2017



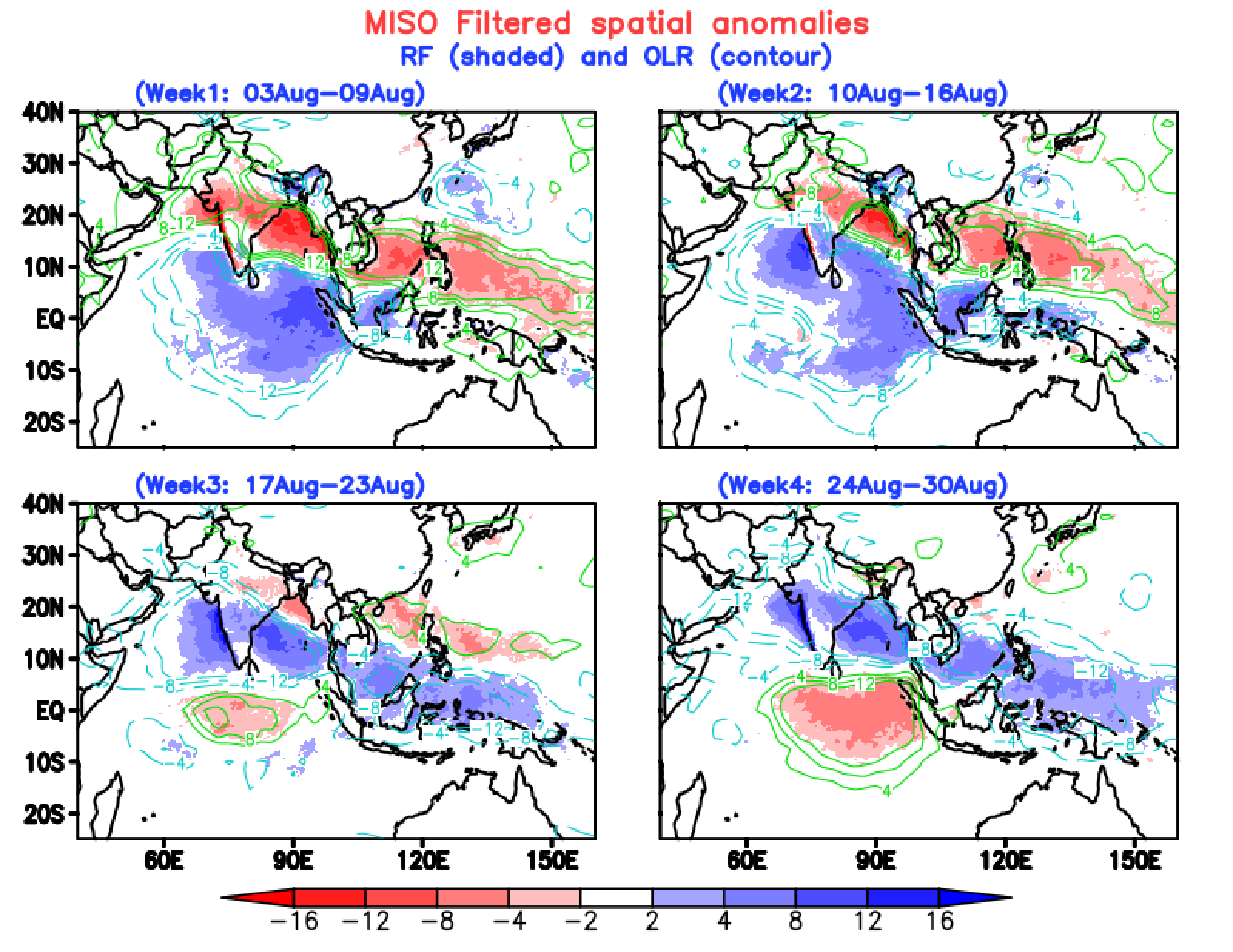



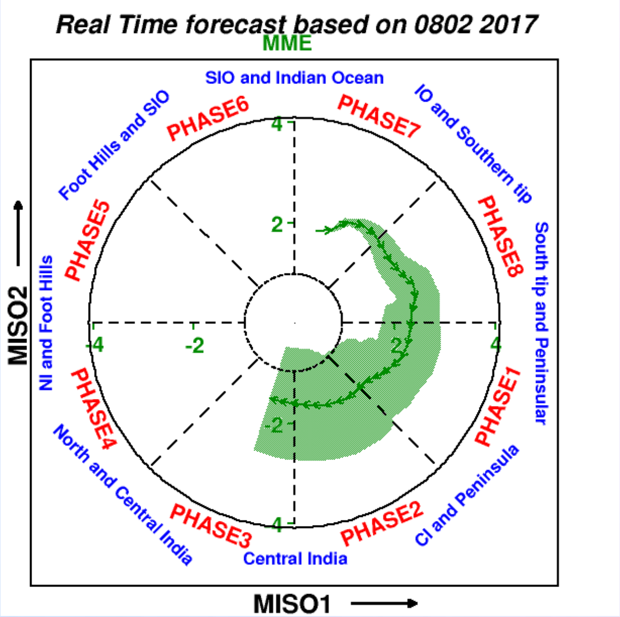
# MISO forecast for next 28 days



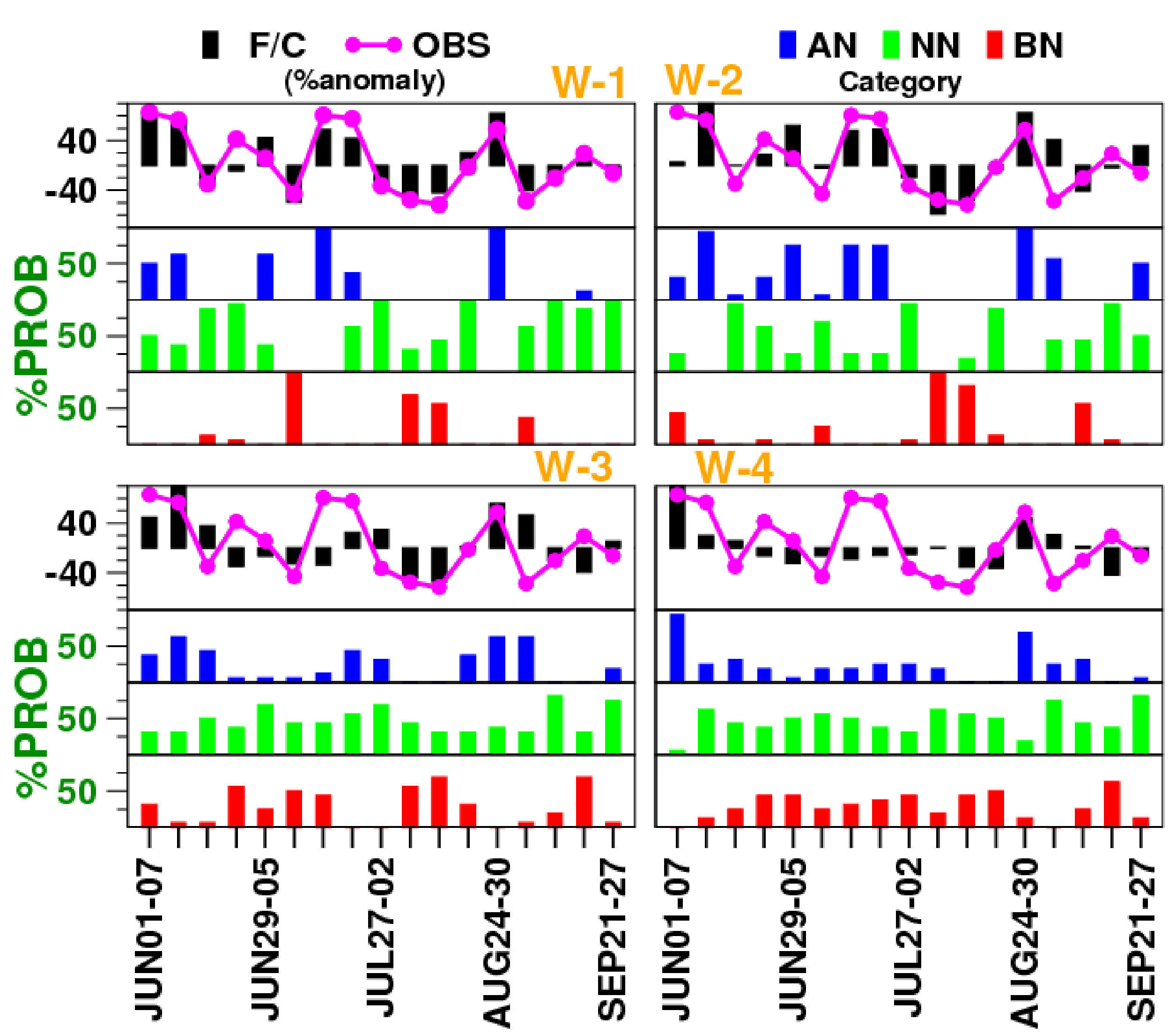



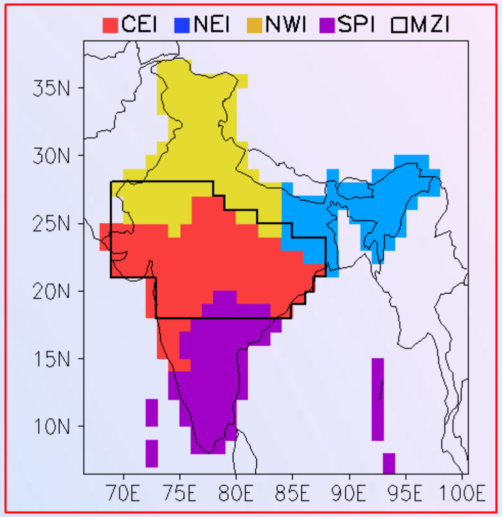
# MISO forecast for next 28 days

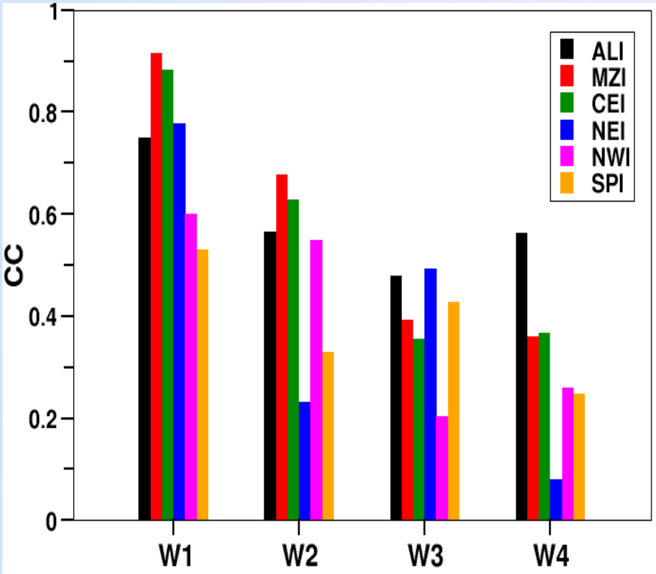


# Week-wise verification of rainfall over MZI Region



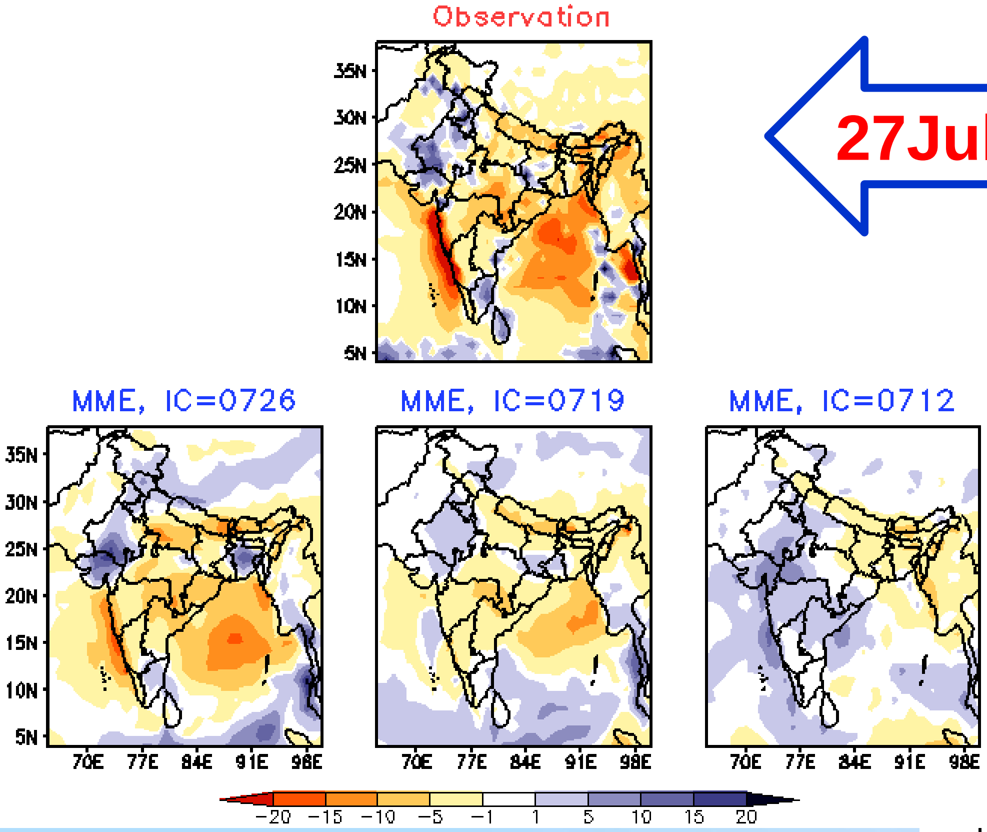



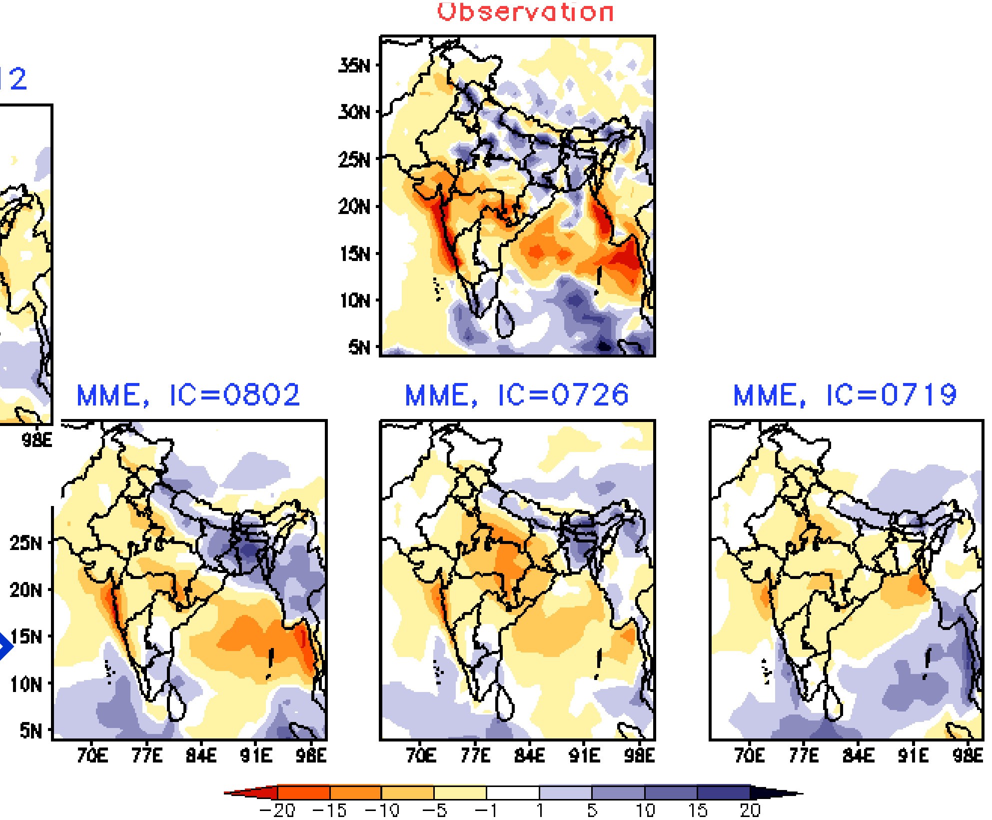
# Observed as well as predicted weekly averaged rainfall

**Long Break Spell – 31 Jul-17 Aug**

27Jul-02Aug




03-09Aug

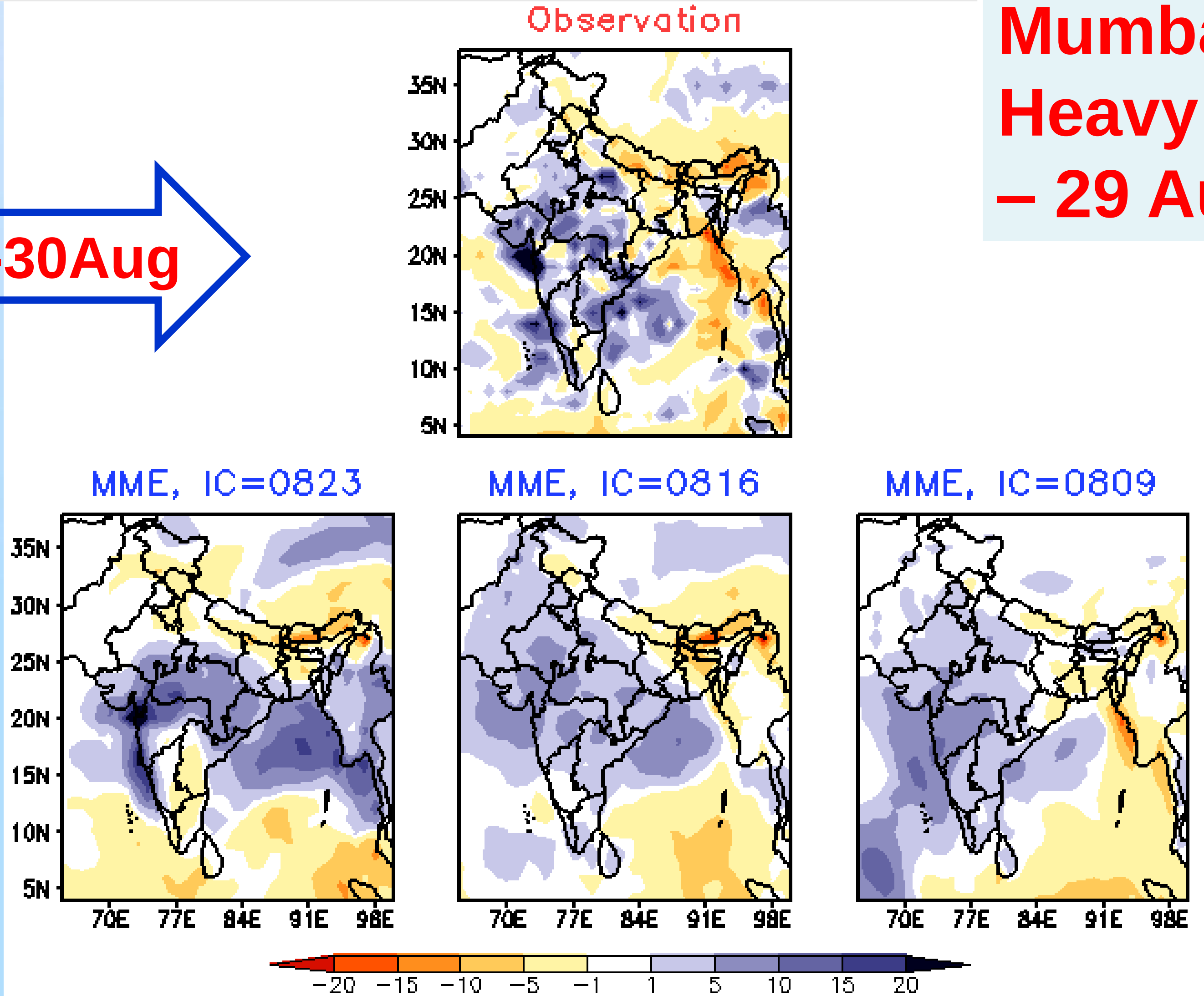



## Verification of Selected Active/Break Spells

# Observed as well as predicted weekly averaged rainfall

**Mumbai Heavy rainfall – 29 Aug**

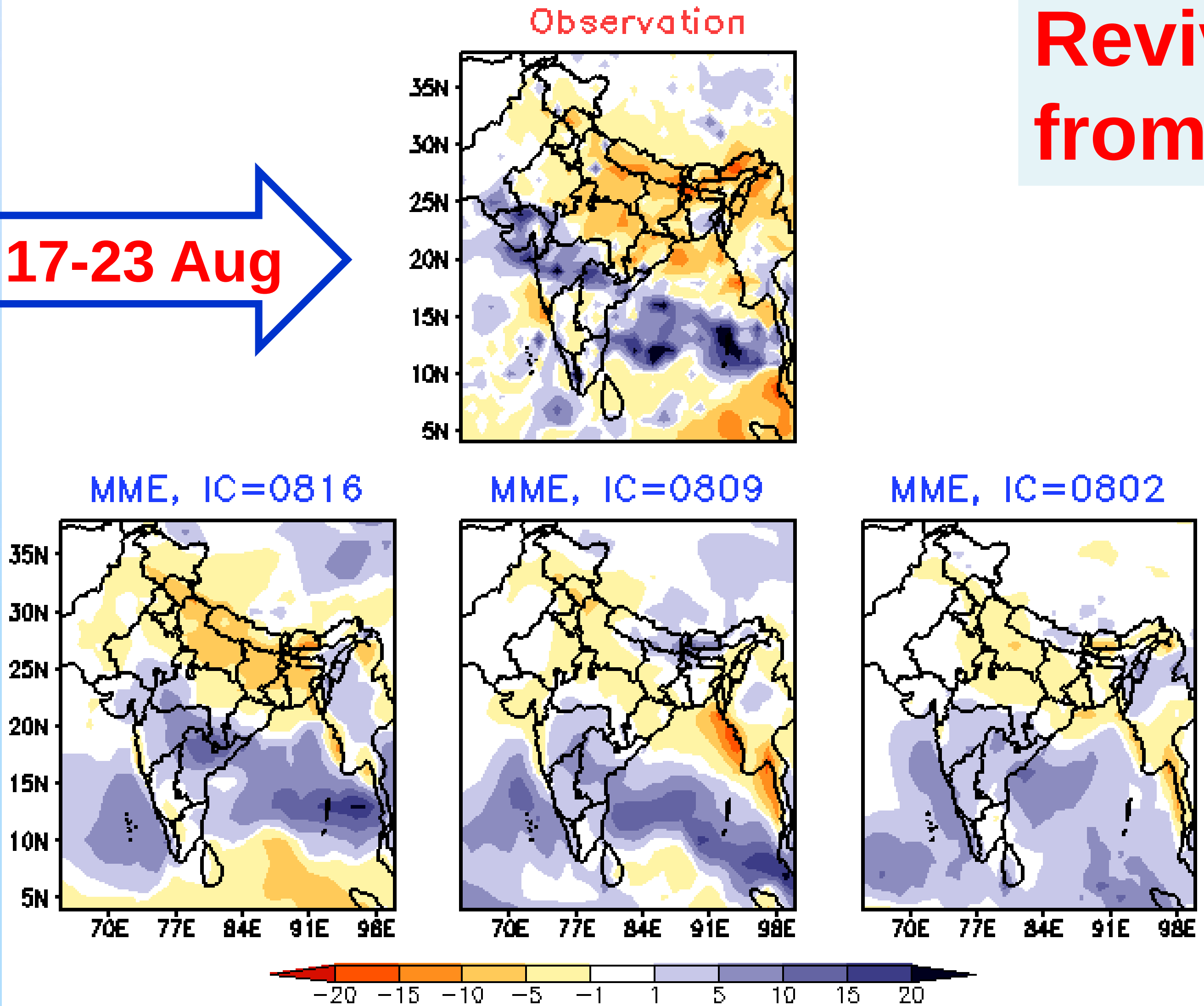
**24-30Aug**




## Verification of Selected Active/Break Spells

**Revival from Break**

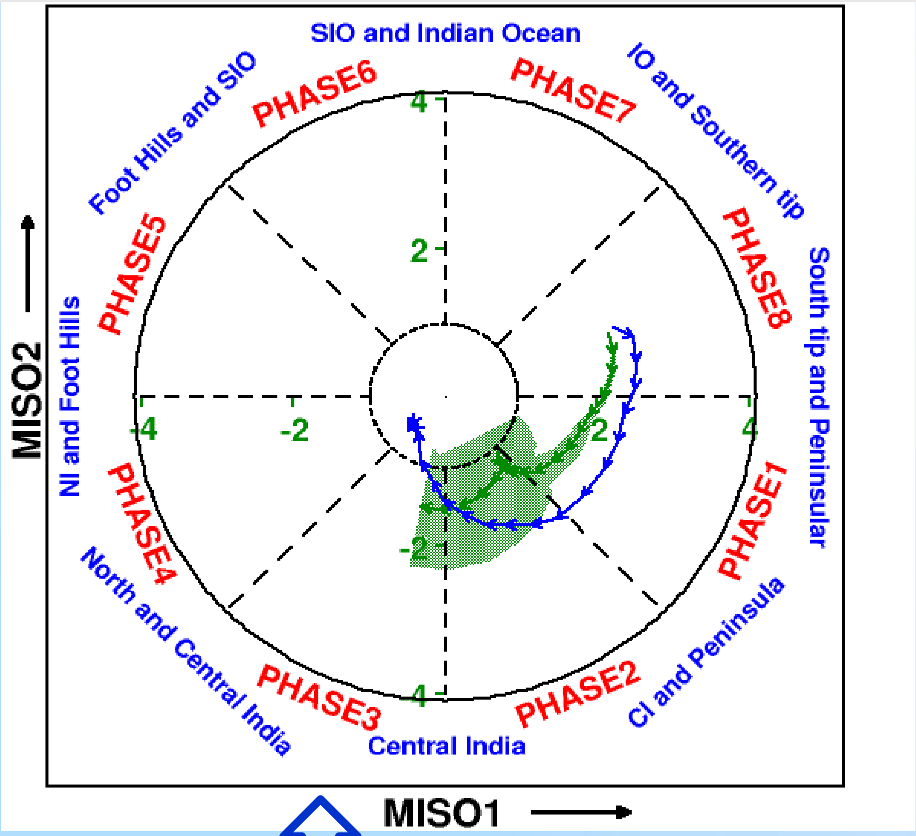
**17-23 Aug**




# Verification of Selected Active/Break Spells

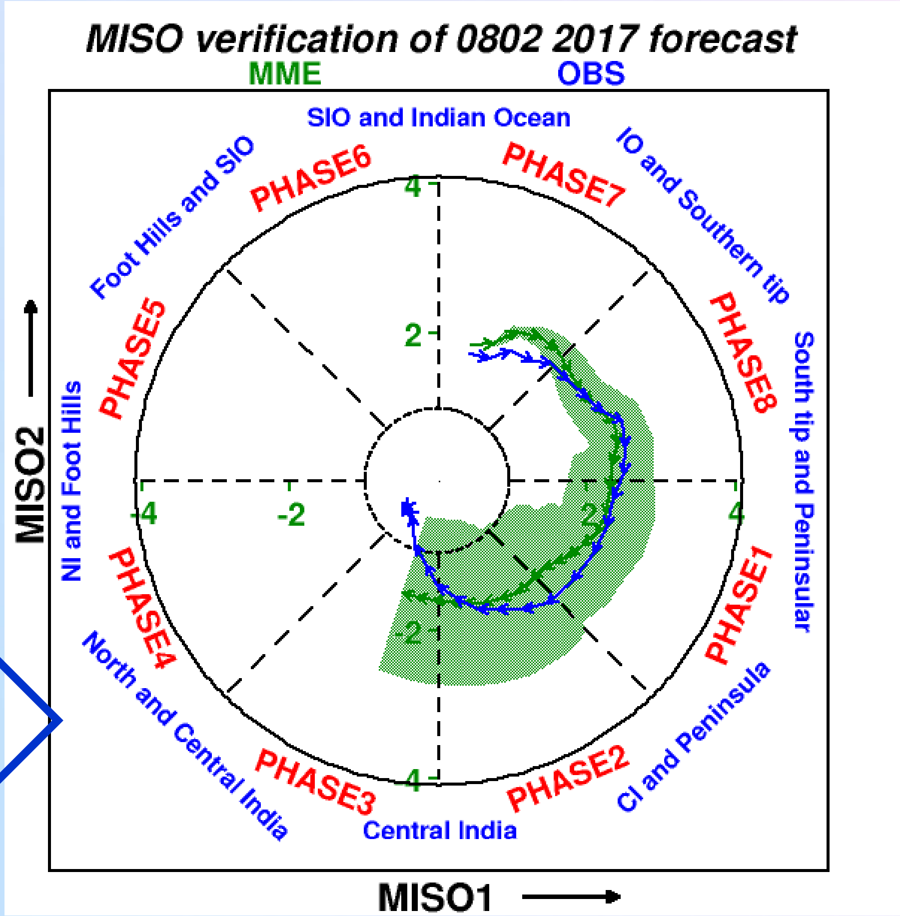
# Observed as well as predicted MISO during 2017

Revival from Break

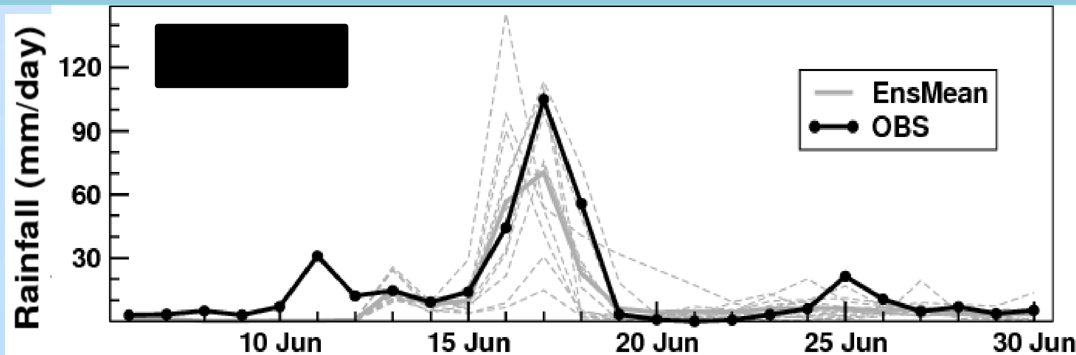



IC: 09 Aug

IC: 02 Aug

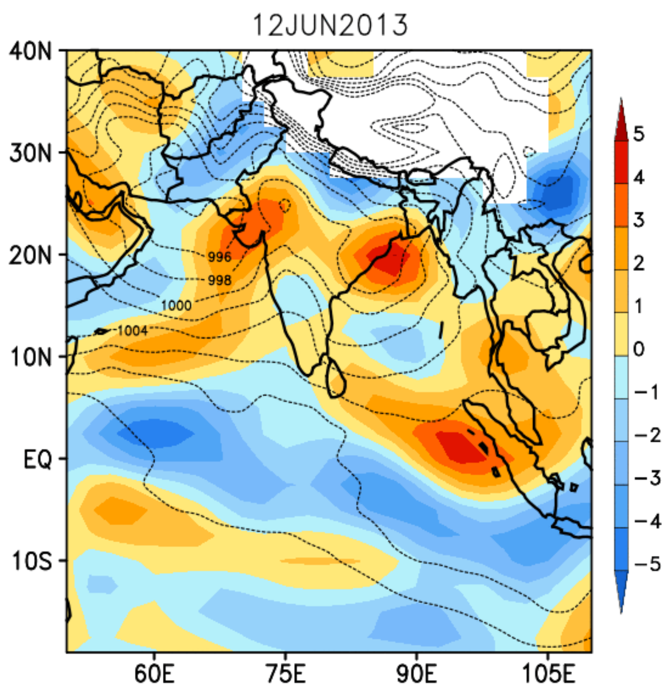


# EXTREME EVENTS



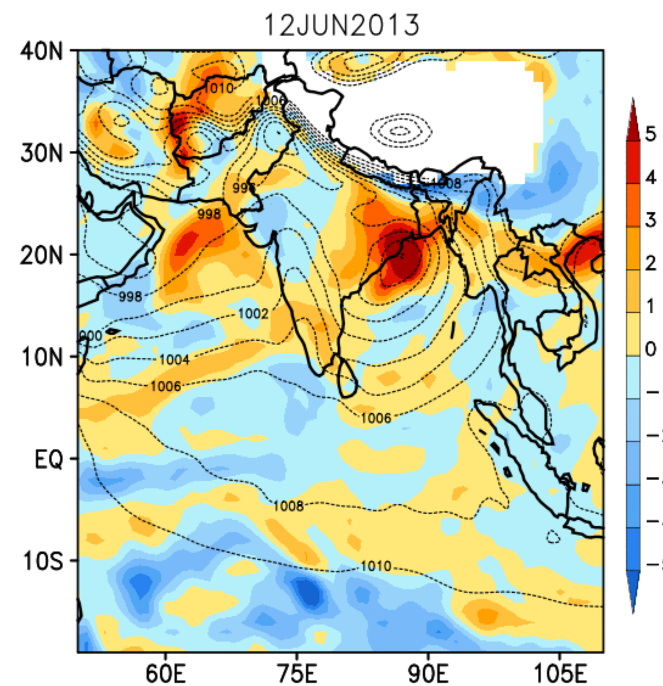

# Uttarakhand event in June 2013

## Evolution of Potential Vorticity (PV; $x10^{-7}\ s^{-1}$) anomalies at 700 hPa and mean sea level pressure

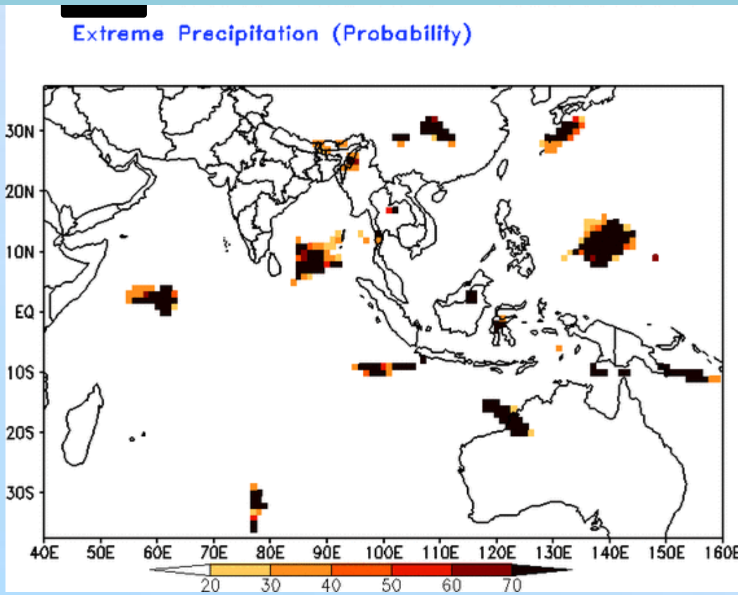


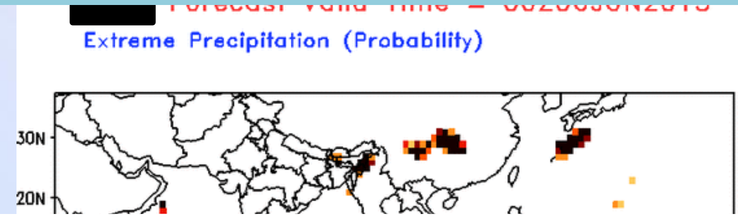

OBS

Forecast

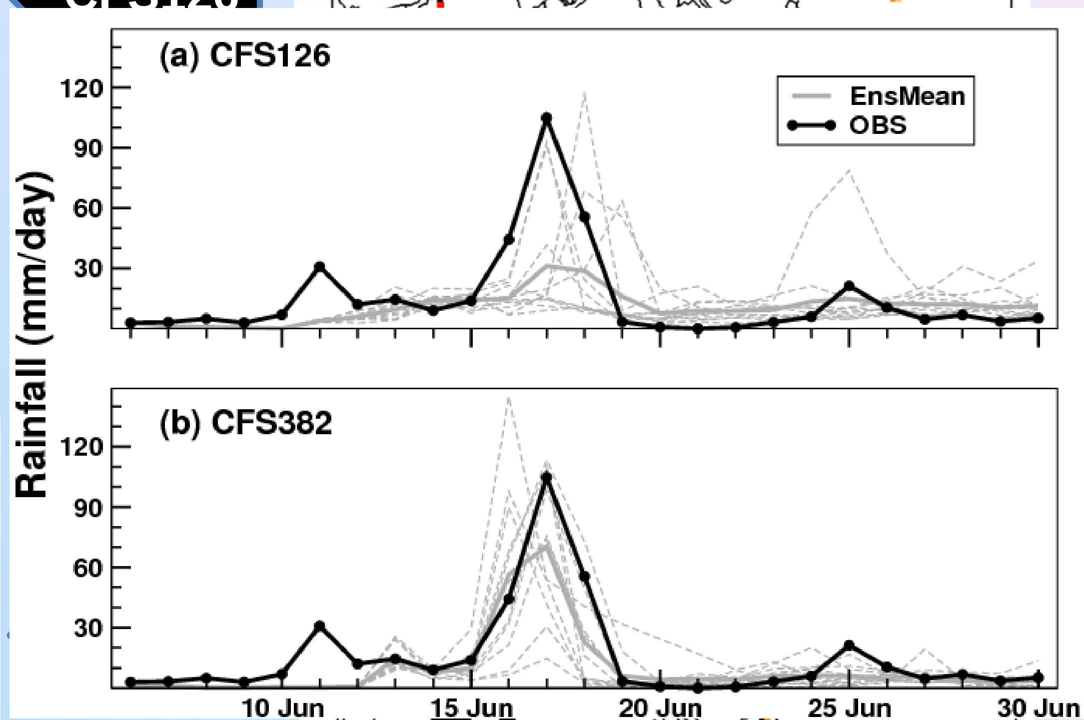


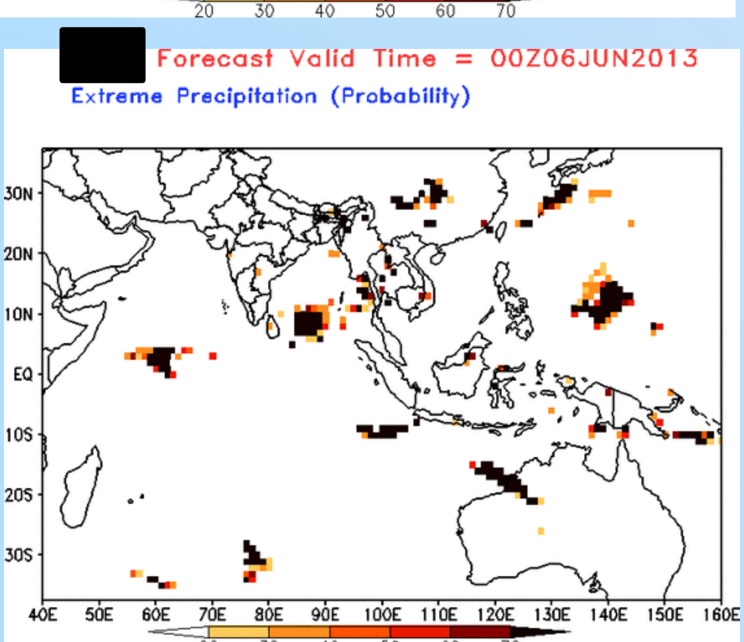

h et al 2016,



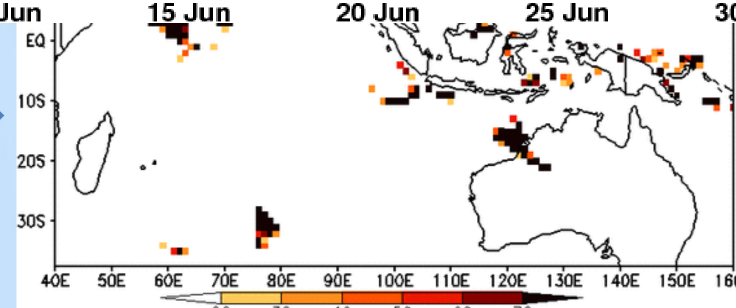




CFS126



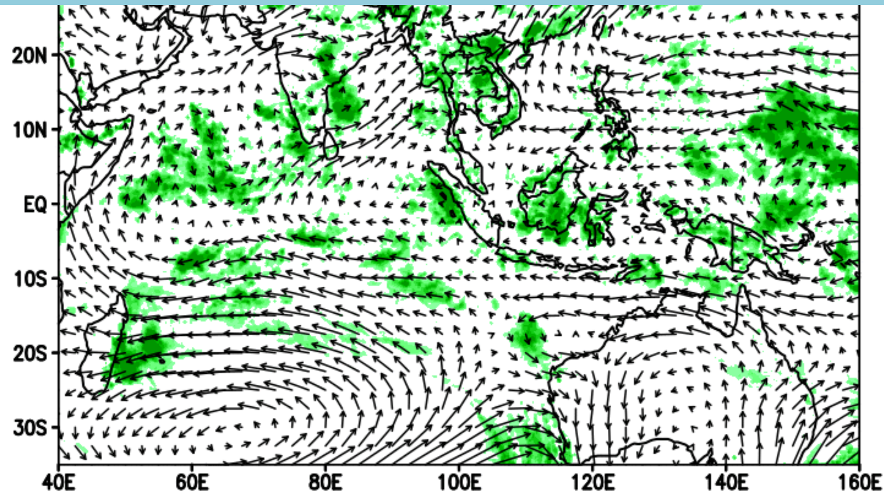




GFS382



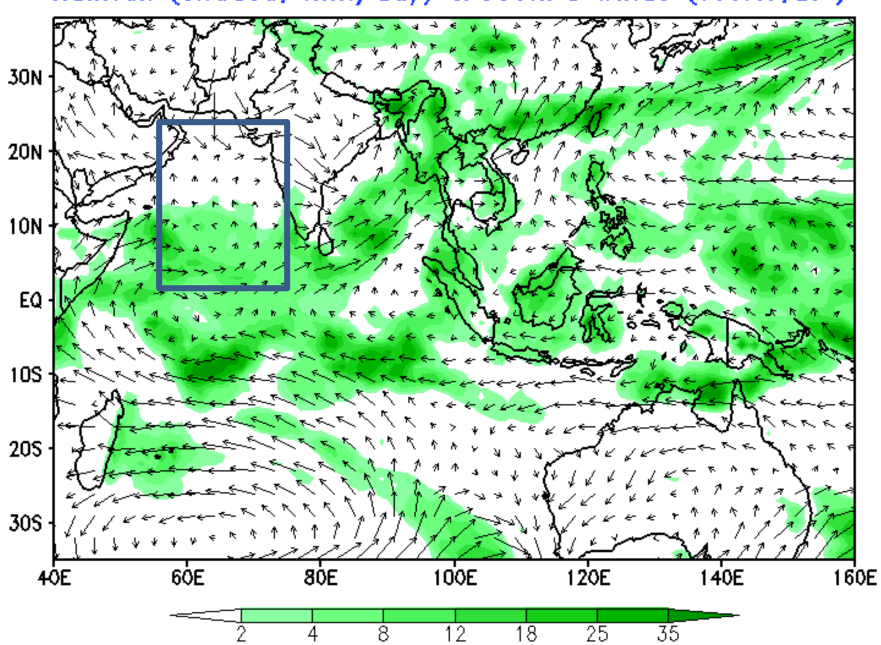
## Cyclone “Ashobaa” during Onset phase of 2015 monsoon

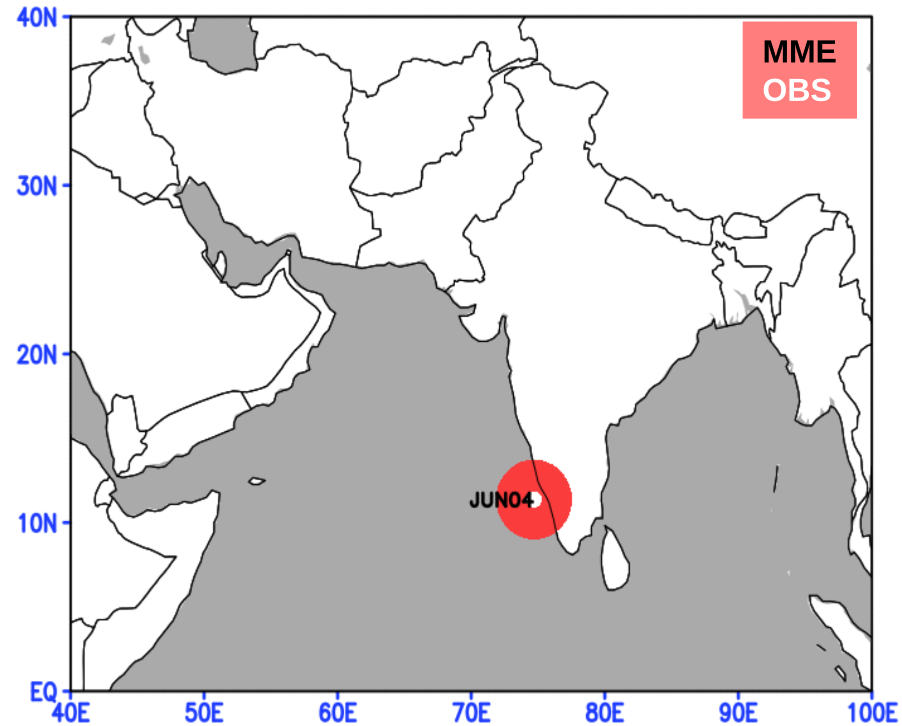
**IC: 0531**




MME, Forecast Valid Time = 00Z01JUN2015

Rainfall (shaded, mm/day) & 850hPa winds (vector, 20)

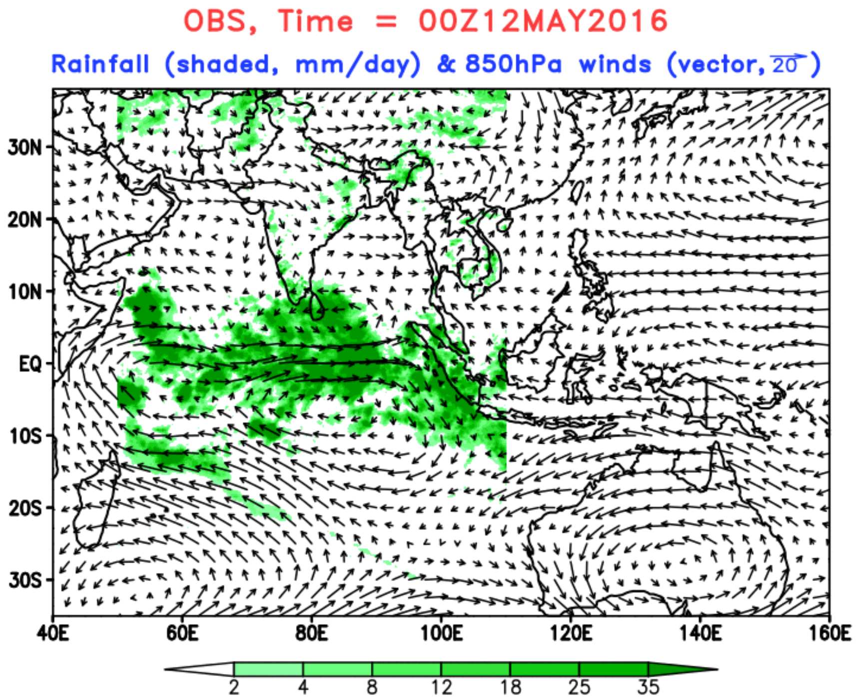


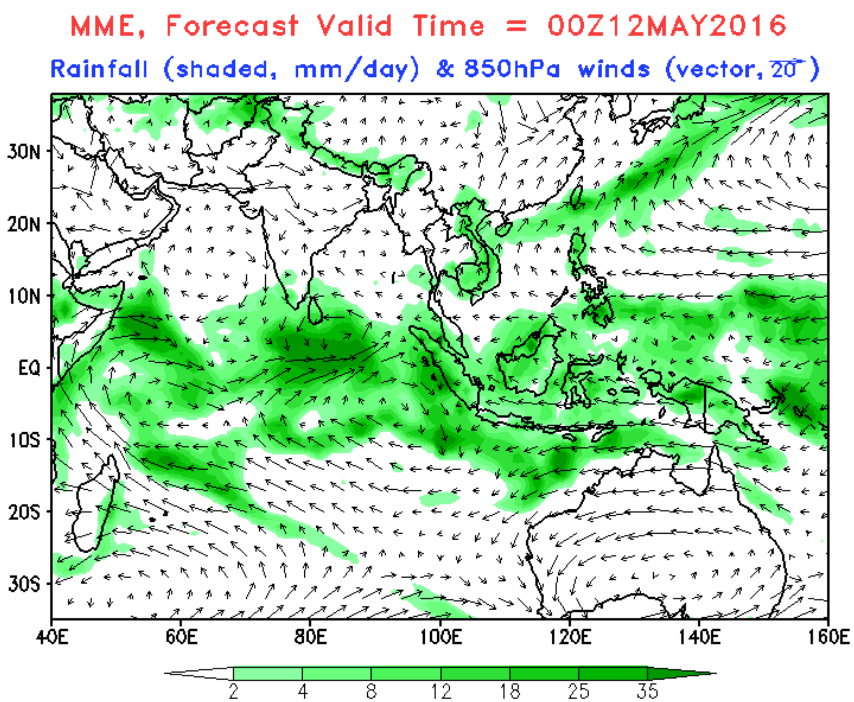



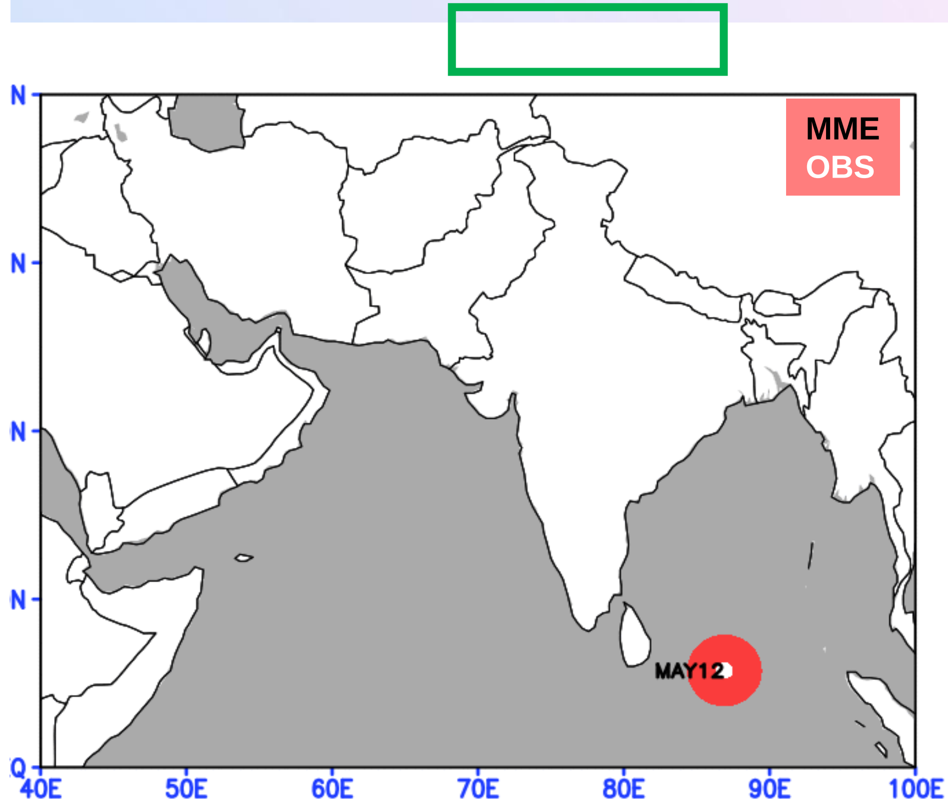

Low Pressure System (LPS) over southern tip of peninsula is likely to intensify and move towards Oman coast. This system may dissipate around 11th June and till then the monsoon activity will be weaker than normal over India.

# Prediction of Cyclogenesis

## Cyclone Roanu in May 2016



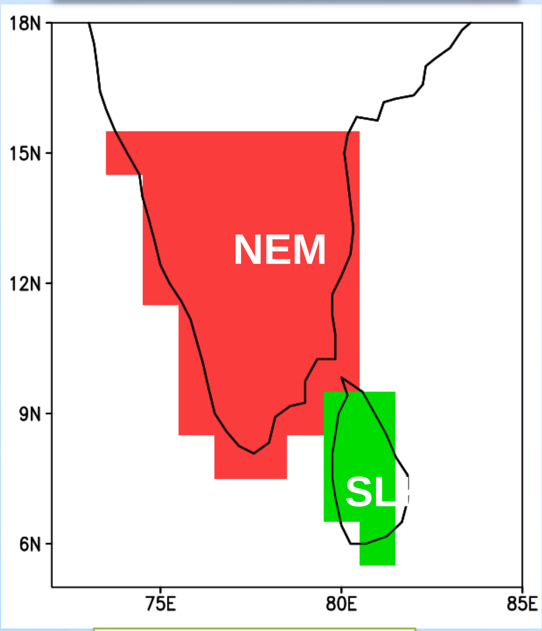



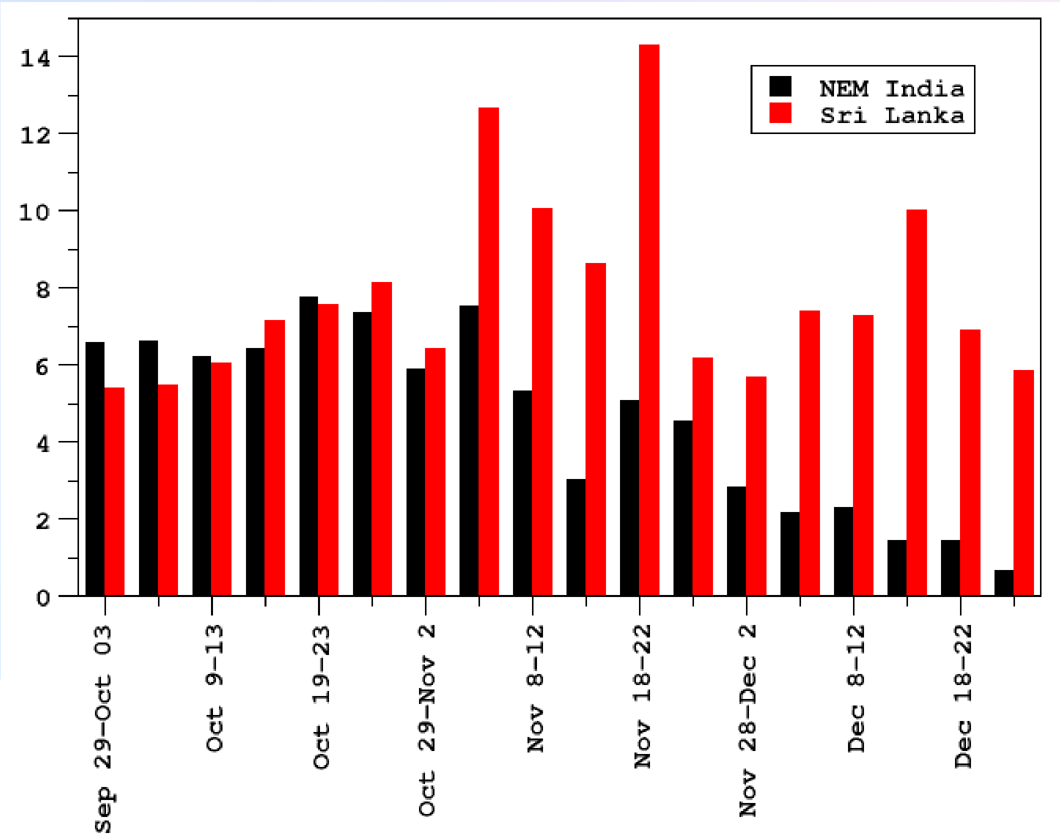
# Prediction of North-East Monsoon (NEM)

# Hindcast Skill for Post Monsoon/NEM

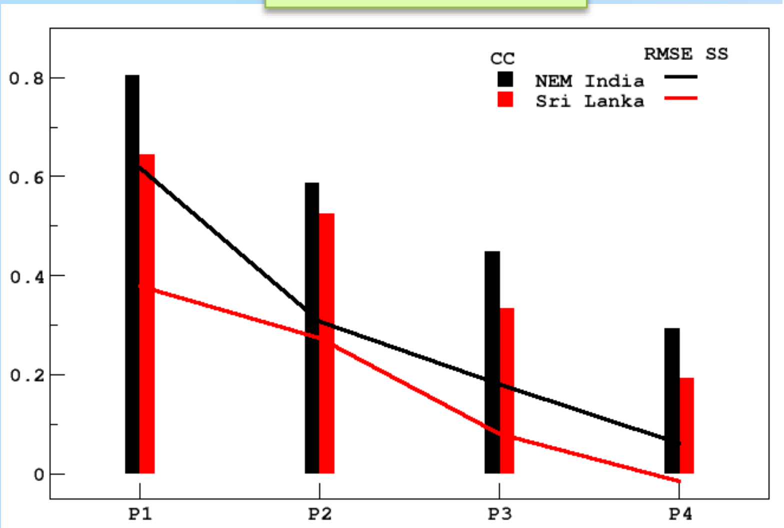
NEM and SLK region




Climatological rainfall

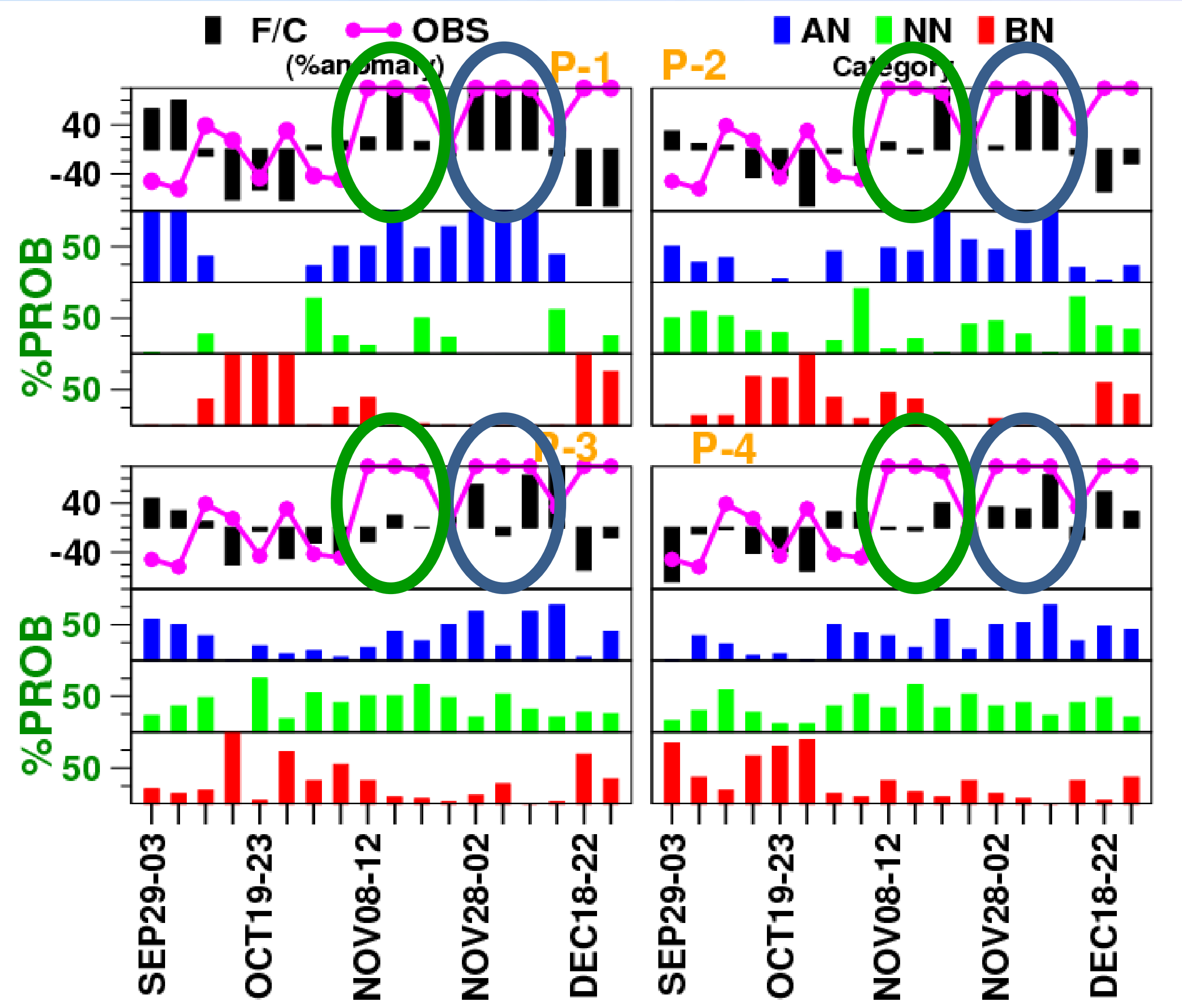



Hindcast Skill




NEM (SLK) region exhibits useful skill up to 3(2) Pentad

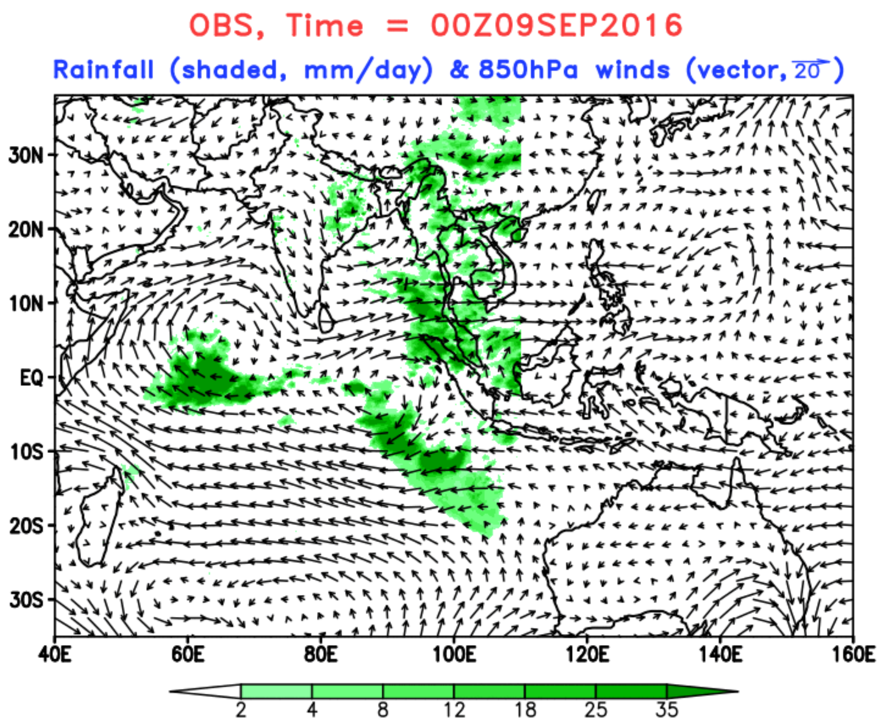
# Area averaged rainfall over NEM region during 2015 predicted by MME

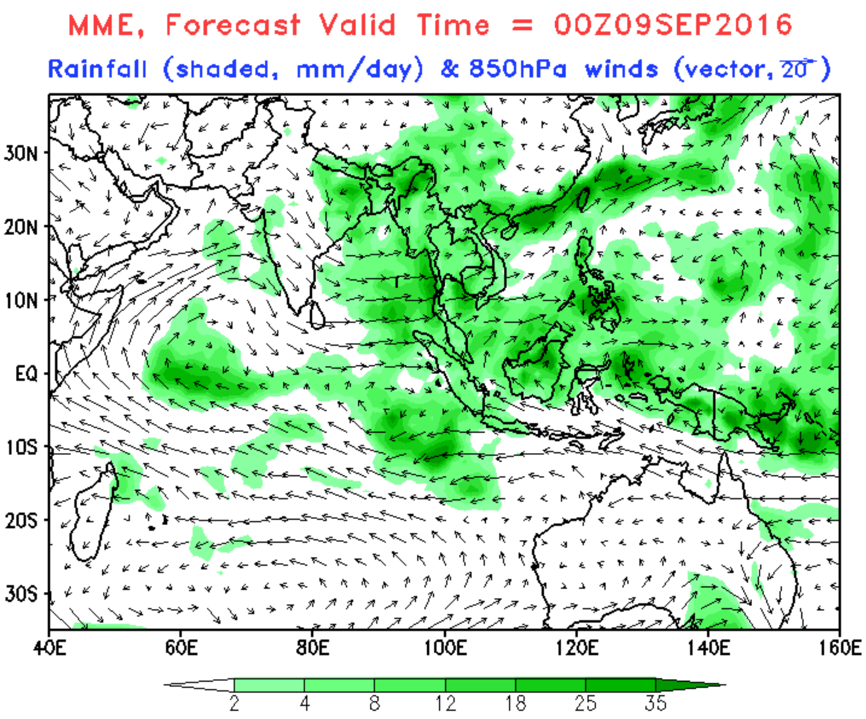



The CGMME system predicted the above normal rainfall activity over Chennai and NEM region well in advance. The CGMME system able to capture this high impact continuous rainfall activity during the last week of November and first week of December around Chennai region from 4th pentad lead

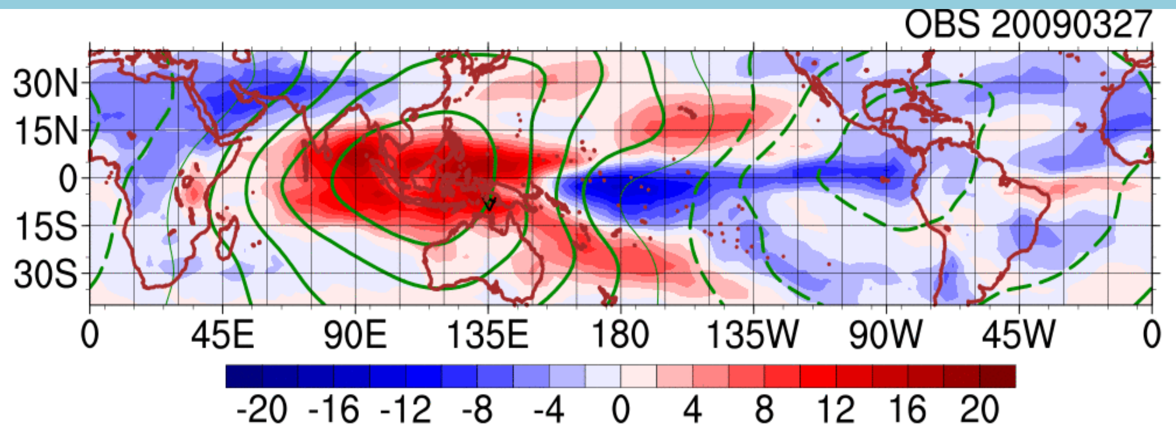
# Case Example :Withdrawal of ISM 2016 (IC: 0908)

**The revival of monsoon due to the formation of a LPS around 13-14 September and subsequent westward movement was forecasted well from 08 September IC.**



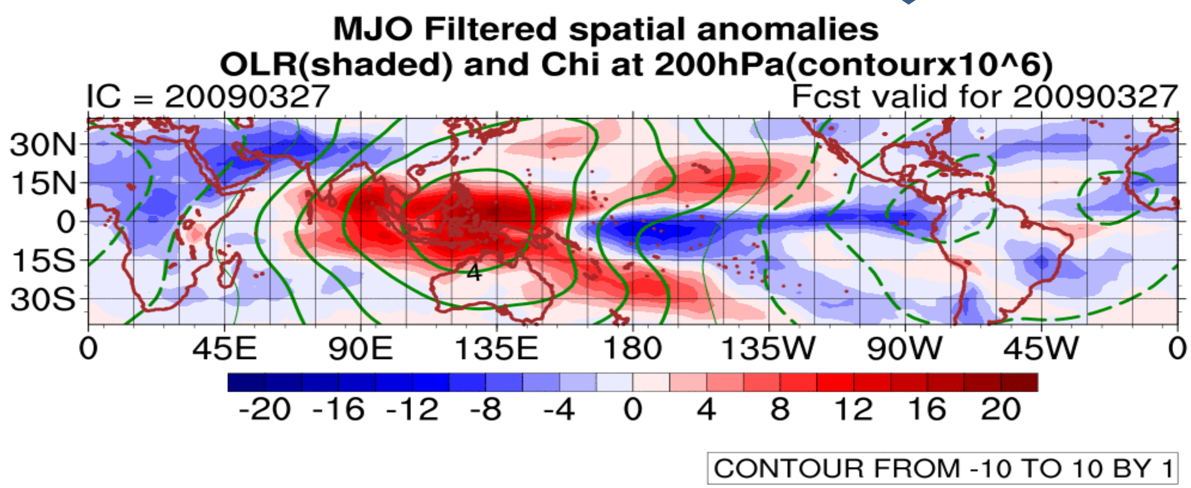



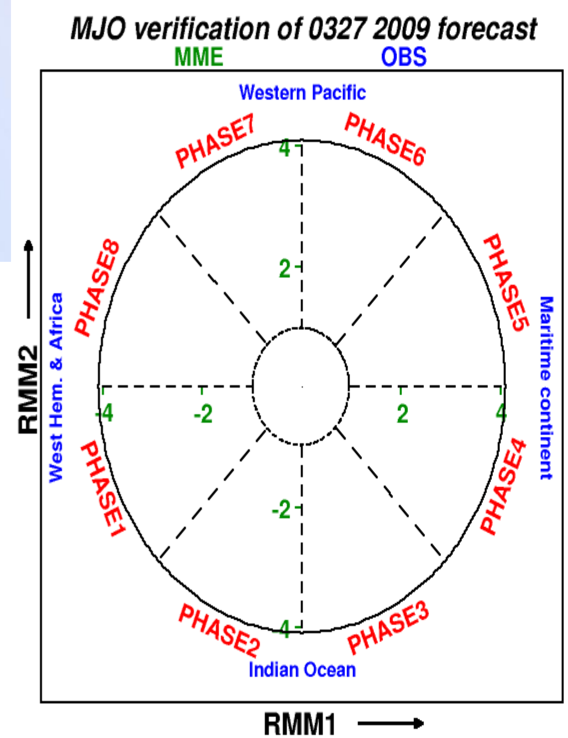
# MADDEN-JULIAN OSCILLATION


OBS 20090327
30N
15N
0
15S
30S
0
45E
90E
135E
180
135W
90W
45W
0
-20 -16 -12 -8 -4 0 4 8 12 16 20

OBS

model


MJO Filtered spatial anomalies
OLR(shaded) and Chi at 200hPa(contourx10^6)
IC = 20090327
Fcst valid for 20090327
30N
15N
0
15S
30S
0
45E
90E
135E
180
135W
90W
45W
0
-20 -16 -12 -8 -4 0 4 8 12 16 20
CONTOUR FROM -10 TO 10 BY 1


MJO verification of 0327 2009 forecast
MME
OBS
Western Pacific
PHASE7
PHASE6
PHASE8
PHASE5
West Hem. & Africa
Maritime continent
PHASE1
PHASE4
PHASE2
PHASE3
Indian Ocean
RMM2
RMM1
4
2
-2
-4

# Conclusions

- ✓ The CGEPS MME from operational runs could realistically provide an outlook on the intraseasonal fluctuations within the 2017 monsoon season.
- ✓ The EPS proved to be useful but imperfect prediction technology, in the face of the mostly-unpredictable.
- ✓ It can supplement the weather information.

# Forecast Verification

## Why is a forecast Errorneous?

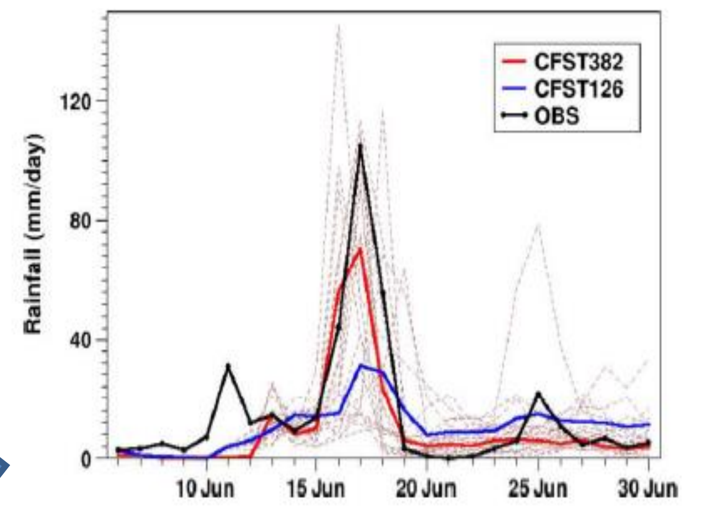
**A. Model Deficiency**

**(Resolution, parameterization, numerical approximations etc.)**

**B. Error in Initial conditions**

**(Error in instrument, data assimilation, spatially or temporal sparse)**

FIG. 10 Example of extreme weather forecasts for the Uttarakhand heavy rainfall event of June 2013. The *dotted line* shows the evolution of rainfall from individual ensemble members of both CFST382 and CFST126, and the *solid red (blue) line* shows the same for the ensemble mean of CFST382 (CFST126).




deterministic

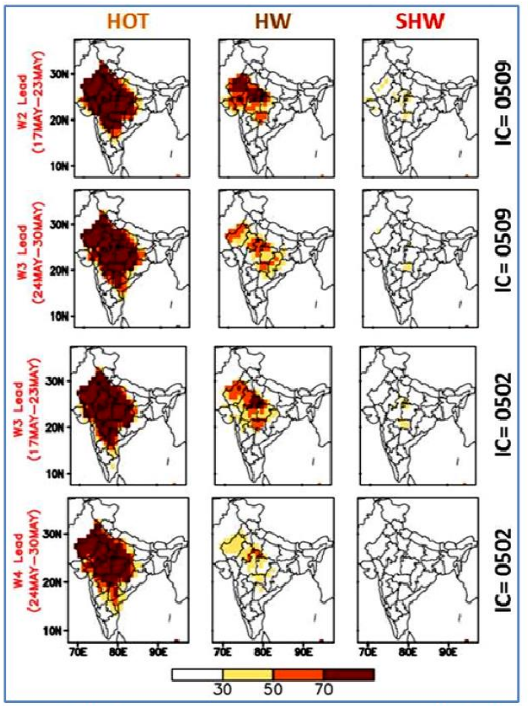



**Fig. 11.** Weekly averaged probabilistic forecasts of HOT, HW and SHW conditions for different lead time for HW spell

# Forecast Verification

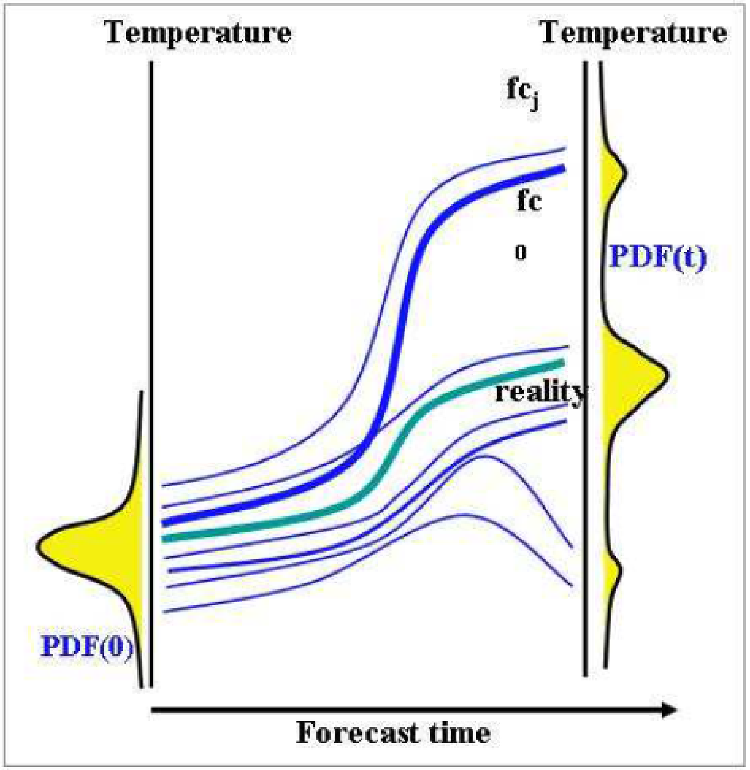
**https://www.hereon.de/imperia/md/assets/clm/neu3_tl4.pdf**

**https://www.cawcr.gov.au/projects/verification/**

# Why verification?

- The forecast is x % better/worse than a reference forecast (e.g. climatology, persistence,other model)
- The forecast is valuable up to a lead-time of x days?
- Forecast quality depends on time of the day, region, season, meteorological conditions…
- Will I have economical benefit from using the forecasts for decision making?
- The forecast is/is not calibrated
- The forecast is capable of representing the location, timing, shape, magnitude of objects (e.g. rain cells)

# Types of forecasts




Deterministic model

- Decide for in initial state and start a single integration

Ensemble prediction

- Make many integrations (e.g. from different initial states, or multi model or analogue ensemble…)

# However,

**The Observation may or may not represent g ground truth**

**Verification against observations is (almost) always flawed**

• Model value is a grid box average and observations within a grid box might vary strongly. Many ways exist to match observation to grid point

• Is the observed value really what you want you model to predict?

• Gridded observations or analysis might be a work around but then, those rely on models (statistical or physical) again and might not be independent from the forecast.

**Deterministic prediction system**

**Bias** - mean error, absolute error

**Association** - e.g. correlation, root-mean square, index of agreement

**Ensemble prediction system**

**Reliability** - conditional bias over several categories (usually forecast probabilities)

**Resolution** - ability to resolve events in different subsets

**Sharpness** - spread of the forecast distribution

**Uncertainty** - observation variability

**Both deterministic and ensemble forecast :**

**Skill - Value w.r.t. a reference forecast (e.g. persistence or climatology)**

**Value - Is the forecast helpful for decision making**

# Types of verification

**Continuous**
For deterministic predictions as time-series, spatial data or both combined
Example: temperature, pressure, upper-air variables

**Dichotomous (binary, 2 categories, yes/no, special case multiple categories)**
For deterministic predictions as time-series, spatial data or both combined
Example: rain yes or no? cloud amount category, wind speed, warnings

**Ensemble**
For ensemble models considering the forecast distribution
Example: Does the ensemble spread capture the forecast uncertainty

**Probabilistic**
For probabilities derived from ensemble models
Example: probability to exceed wind speed of 10 m/s?

**Spatial**
Mostly deterministic model
Example: Are objects predicted at the correct location?

# Deterministic Forecast

## BIAS (mean error)

$$Mean\ Error = \frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)$$

**Shows the average direction of the error (positive or negative)**

**In NWP defined positive (negative) if model forecast quantities are larger (smaller) than observed**

**Does not indicate the magnitude of the error as positive an negative values might cancel each other out**

**Same unit as variable**

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**Does not indicate the magnitude of the error as positive an negative values might cancel each other out**

**Same unit as variable**

## MAE (mean absolute error)

$$MAE = \frac{1}{N}\sum_{i=1}^{N} | F_i - O_i |$$

## RMSE (root mean squared error)

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N} (F_i - O_i)^2}$$

# Correlation coefficient & anomaly correlation

$$r = \frac{\sum (F-\bar{F})(O-\bar{O})}{\sqrt{\sum (F-\bar{F})^2}\sqrt{\sum (O-\bar{O})^2}}$$

$$AC = \frac{\sum (F-C)(O-C)}{\sqrt{\sum (F-C)^2}\sqrt{\sum (O-C)^2}}$$

**Correspondence between forecast and observations**

**Measures linear association and phase errors.**

**Independent from biases.**

**Can give misleading results if verification sample is inhomogeneous (e.g. temperature correlation with day and night values in one sample)**

**(Anomaly correlation should be used to reduce effects of inhomogeneity)**

# Combined CC and RMSE Indices

## Wilmott's index of agreement

Willmott (1981) proposed an index of agreement (d) as a standardized measure of the degree of model prediction error which varies between 0 and 1. The index of agreement represents the ratio of the mean square error and the potential error. The agreement value of 1 indicates a perfect match, and 0 indicates no agreement at all. The index of agreement can detect additive and proportional differences in the observed and simulated means and variances; however, d is overly sensitive to extreme values due to the squared differences.

$$d = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(|P_i - \bar{O}| + |O_i - \bar{O}|)^2} \quad , \qquad 0 \leq d \leq 1$$

where Oi is the observation value and Pi is the forecast value and Obar is the average observation values and Pbar is the average forecast values.

# Categorical Forecasts

- **Used for binary data**
- **If data is not binary, decide for a threshold (e.g. precipitation > 10mm/h) and make your data binary**
- **Sum up all entries in the contingency table**

| | | Observed yes | Observed no | Total |
|---|---|---|---|---|
| Forecast | yes | *hits* | *false alarms* | *forecast yes* |
| | no | *misses* | *correct negatives* | *forecast no* |
| Total | | *observed yes* | *observed no* | *total* |

# Categorical Forecasts


Lieutenant John Park Finley
Signal Service, United States Army

!!CAUTION!!

**Famous example: Tornado forecast verification**

**Collection of tornado forecasts (yes/no) and outcomes**

| | | Observed | | |
|---|---|---|---|---|
| | | yes | no | Total |
| Forecast | yes | *28* | *72* | *100* |
| | no | *23* | *2680* | *2703* |
| Total | | *51* | *2752* | *2803* |

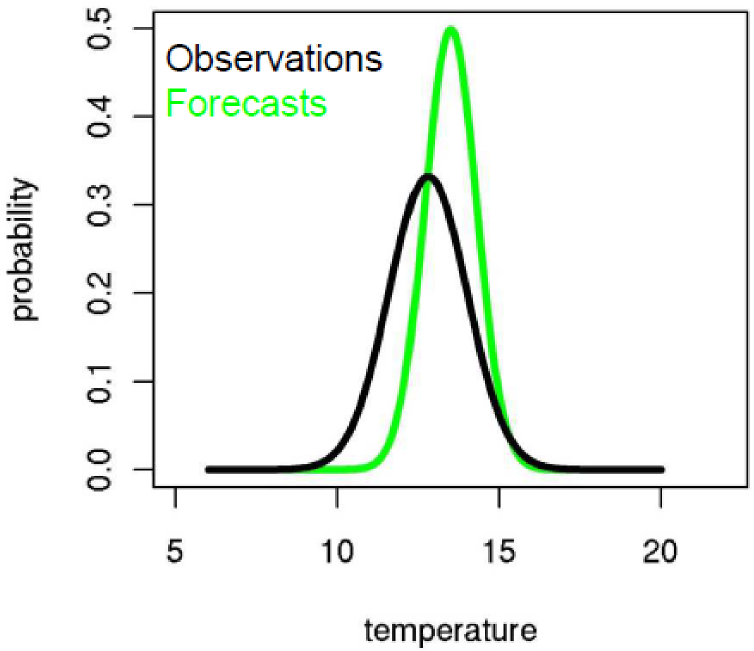
**Accuracy = (28+2680)/2803 = 96.6% (published in Americ. Meteorol. Journal 1884)**

**If no tornados were forecast at all: Accuracy = (0+2752)/2803 = 98.2%**

**It is advisable to use more measures than just accuracy…**

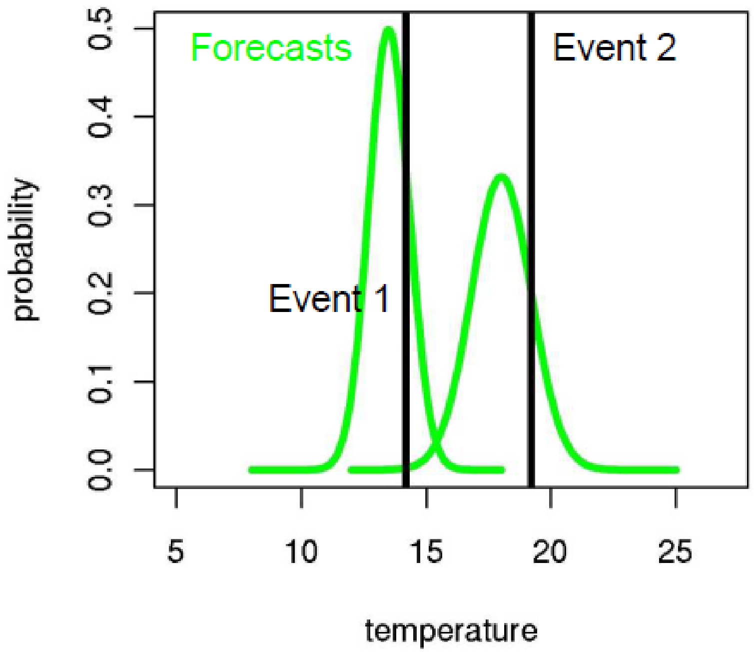
# Ensemble Forecasts

## Reliability




**Measures average agreement**

## Resolution




**Measures ability to discriminate different events**

# Categorical Forecasts

$$Accuracy = \frac{hits + correct\ negatives}{total}$$

fraction of correct forecasts (best=1)

$$BIAS = \frac{hits + false\ alarms}{hits + misses}$$

under or over forecasting (best=1)

$$POD = \frac{hits}{hits + misses}$$

correctly forecast events (best=1)

$$FAR = \frac{false\ alarms}{hits + false\ alarms}$$

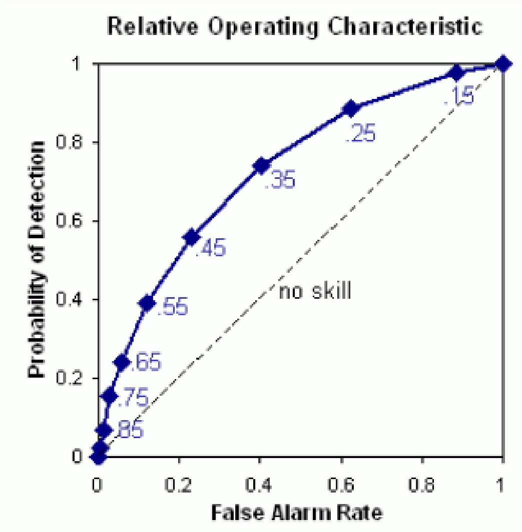
wrongly forecast events (best=0)

$$HK = \frac{hits}{hits + misses} - \frac{false\ alarms}{false\ alarms + correct\ negatives}$$

Can forecast separate yes from no events (best=1)

# Probabilistic Forecasts

ROC (relative operating characteristic)




- Decide for an event threshold
- Calculate contingency table entries for a set of probability thresholds
- Plot POD against FAR
- Perfect when area under ROC curve = 1
- Measures forecast resolution (forecasts can discriminate events)
- If line falls under diagonal, forecast is worse than a random guess
- Can be used to compare with deterministic forecast

# Skill Scores

question: What is the relative improvement of the forecast over some reference forecast?

$$\text{Skill score} = \frac{score_{forecast} - score_{reference}}{score_{perfect\ forecast} - score_{reference}}$$

**Brier Score**: The Brier score was originally proposed to quantify the accuracy of weather forecasts, but can be used to describe the accuracy of any probabilistic forecast. Roughly, the Brier score indicates how far away from the truth your forecast was.

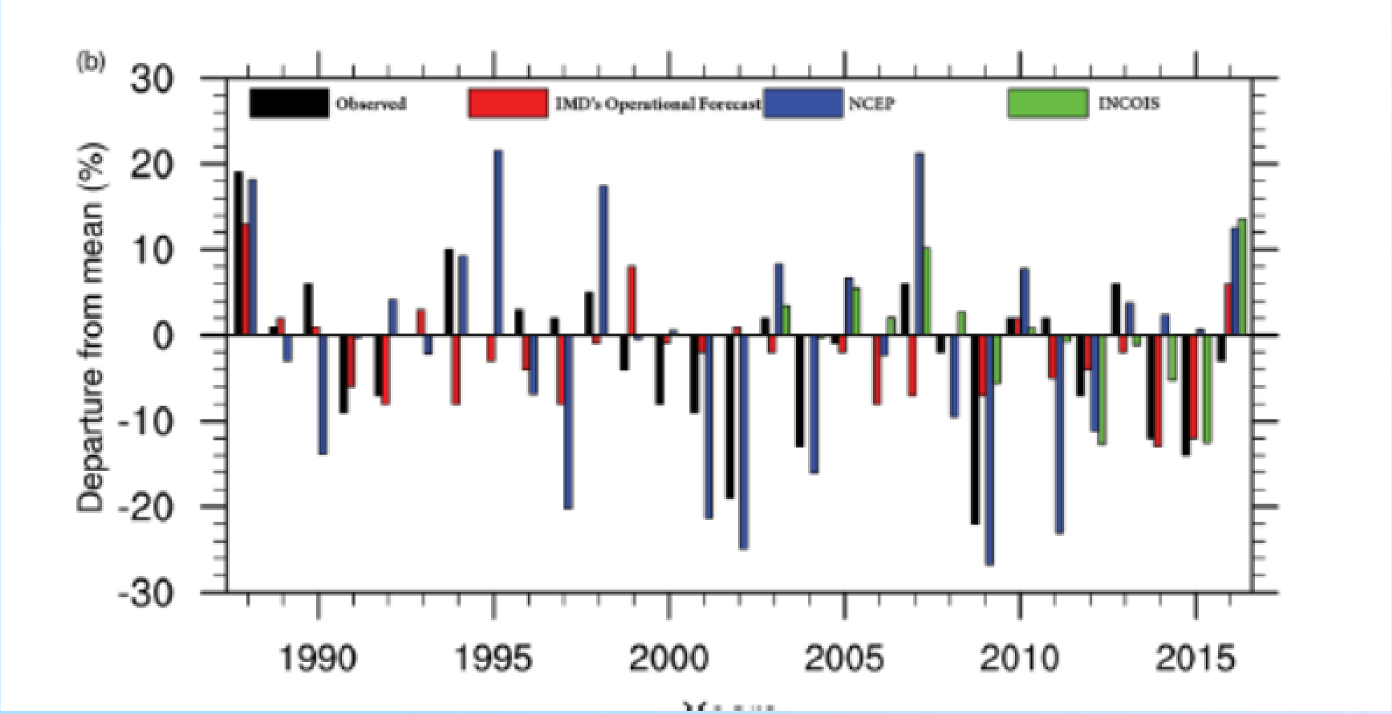
The Brier score is the squared error of a probabilistic forecast. To calculate it, we divide your forecast by 100 so that your probabilities range between 0 (0%) and 1 (100%). Then, we code reality as either 0 (if the event did not happen) or 1 (if the event did happen). For each answer option, we take the difference between your forecast and the correct answer, square the differences, and add them all together. For a yes/no question where you forecasted 70% and the event happened, your score would be (1 – 0.7)2 + (0 – 0.3)2 = 0.18. For a question with three possible outcomes (A, B, C) where you forecasted A = 60%, B = 10%, C = 30% and A occurred, your score would be (1 – 0.6)2 + (0 – 0.1)2 + (0 – 0.3)2 = 0.26. The best (lowest) possible Brier score is 0, and the worst (highest) possible Brier score is 2.

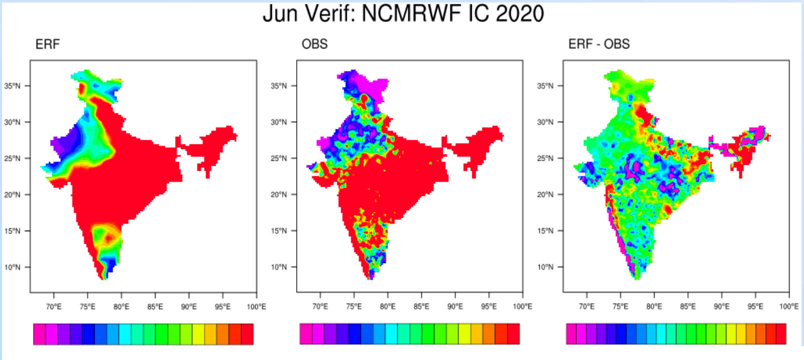
$$BS = \frac{1}{N}\sum_{i=1}^{N}(p_i - o_i)^2 =$$

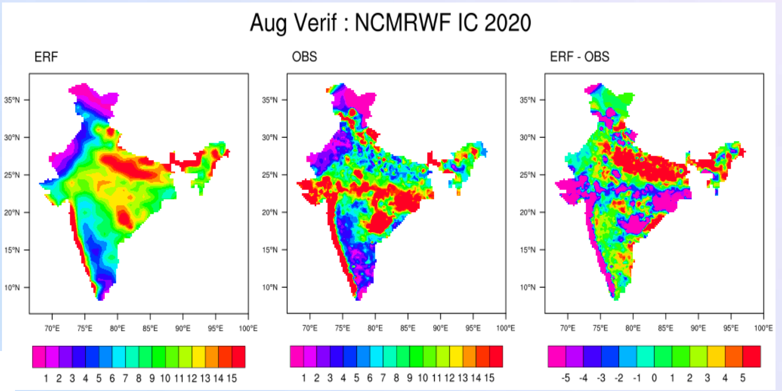
***Brier skill score -***

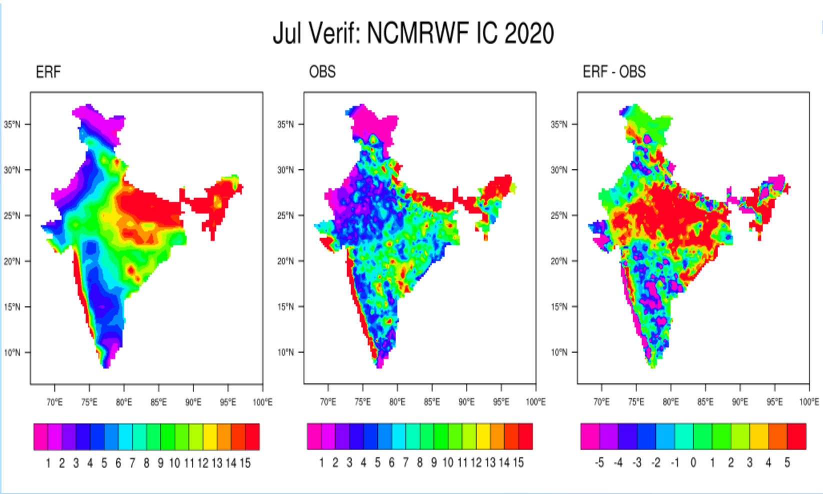
$$BSS = \frac{BS - BS_{reference}}{0 - BS_{reference}} = 1 - \frac{BS}{BS_{reference}}$$

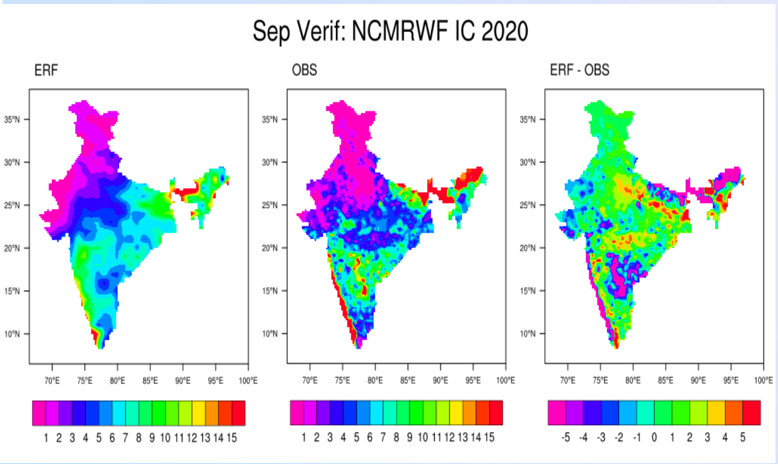
# Examples of IMD Forecast Verification





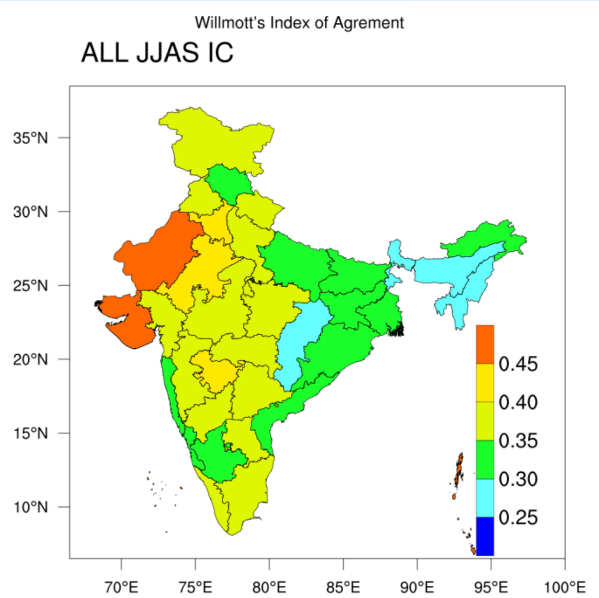



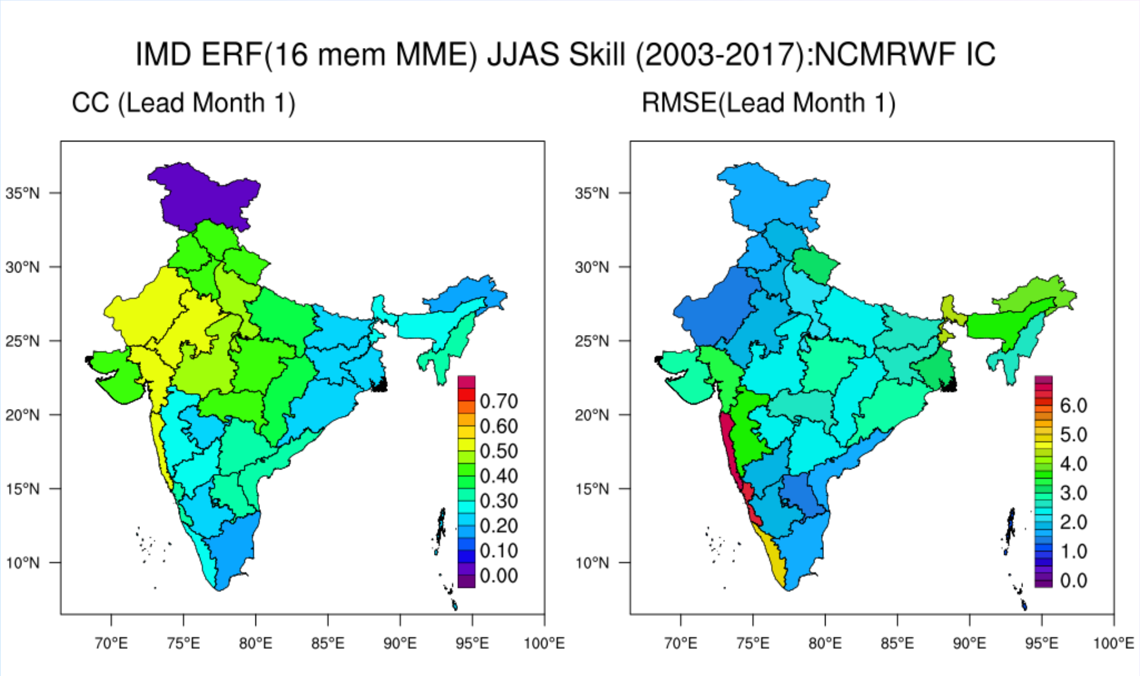

| | Pat CC |
|---|---|
| jun | 0.74 |
| jul | 0.62 |
| aug | 0.53 |
| sep | 0.66 |

# 2020 Verification

**ICs : 03/06 01/07 29/07 09/02**

# All IC JJAS: IMD ERF




**Wilmott's index of agreement** **cc** **rmse**

Low RMSE, higher CC better Index of agreement

$$ACC(\tau) = \frac{\sum_{t=1}^{N}[p1(t)q1(t,\tau) + p2(t)q2(t,\tau)]}{\sqrt{\sum_{t=1}^{N}[p1^2(t) + p2^2(t)]}\sqrt{\sum_{t=1}^{N}[q1^2(t,\tau) + q2^2(t,\tau)]}}$$

$$RMSE(\tau) = \sqrt{\frac{1}{N}\sum_{t=1}^{N}\left[(p1(t) - q1(t,\tau))^2 + (p2(t) - q2(t,\tau))^2\right]}$$

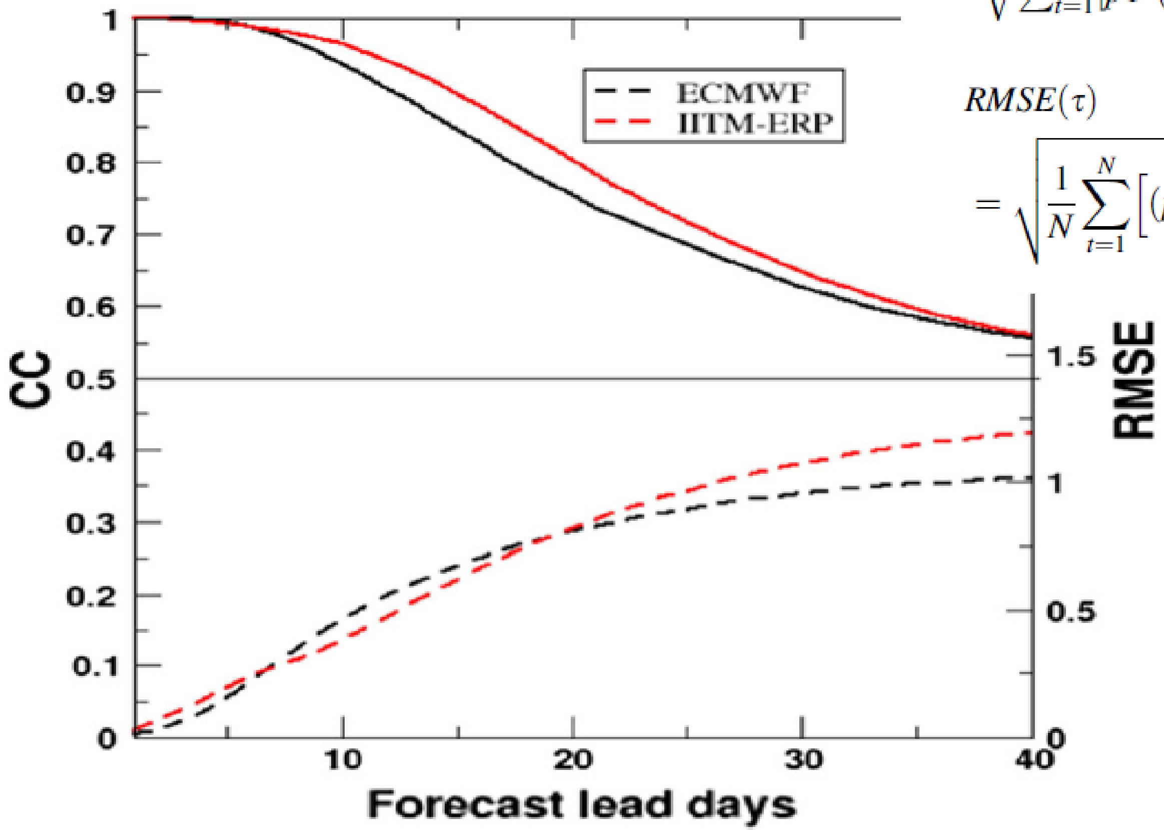



Figure 1
Predictability (ACC; solid and RMSE; dashed) for IITM-ERP (red) and ECMWF (black) as a function of lead day. The horizontal line intersects at 0.5 on correlation axis (left) and at 1.41 along RMSE axis (right)

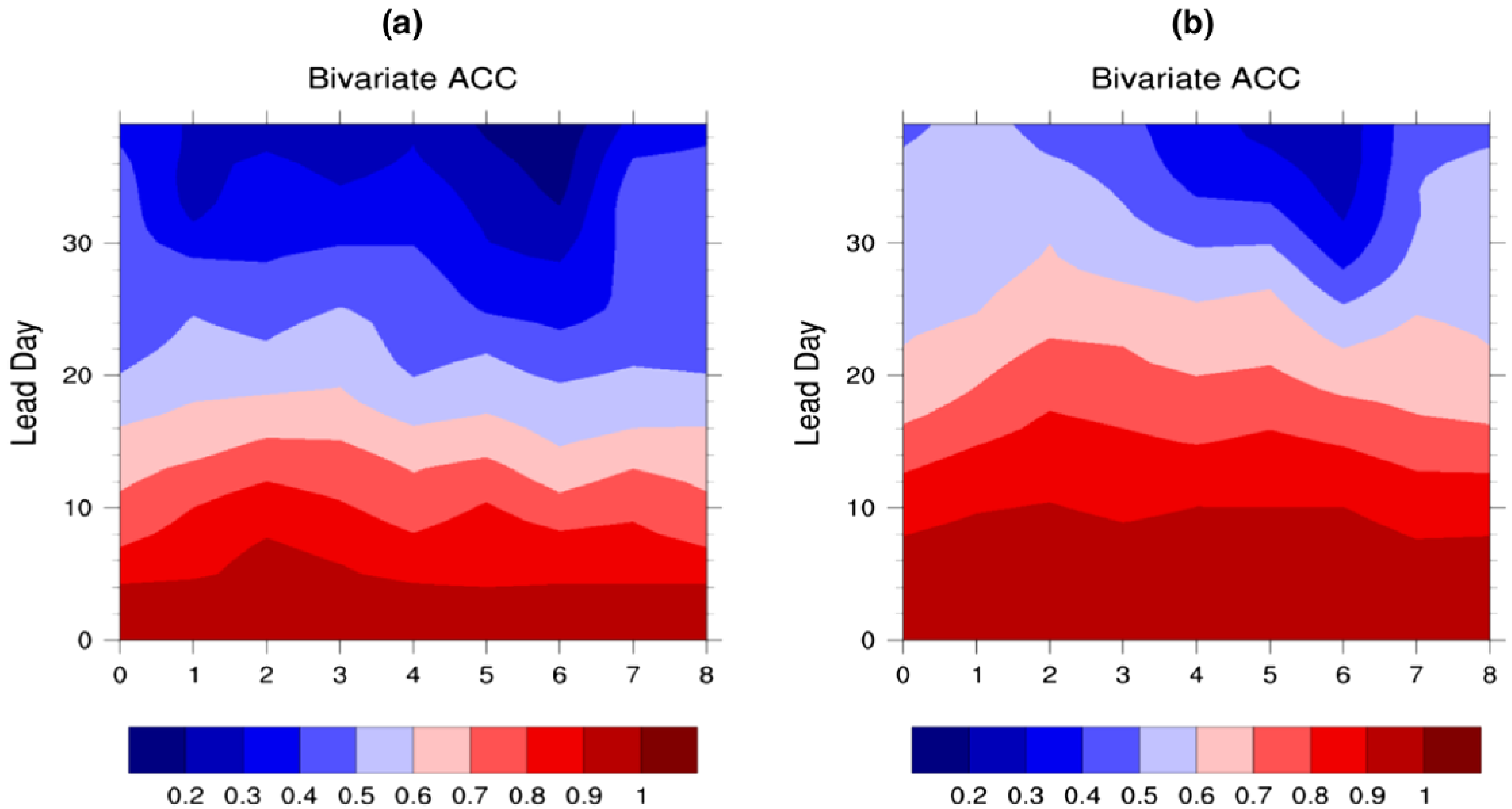



Figure 3
Bivariate ACC **a** IITM-ERP and **b** ECMWF as a function of lead time and initial phase

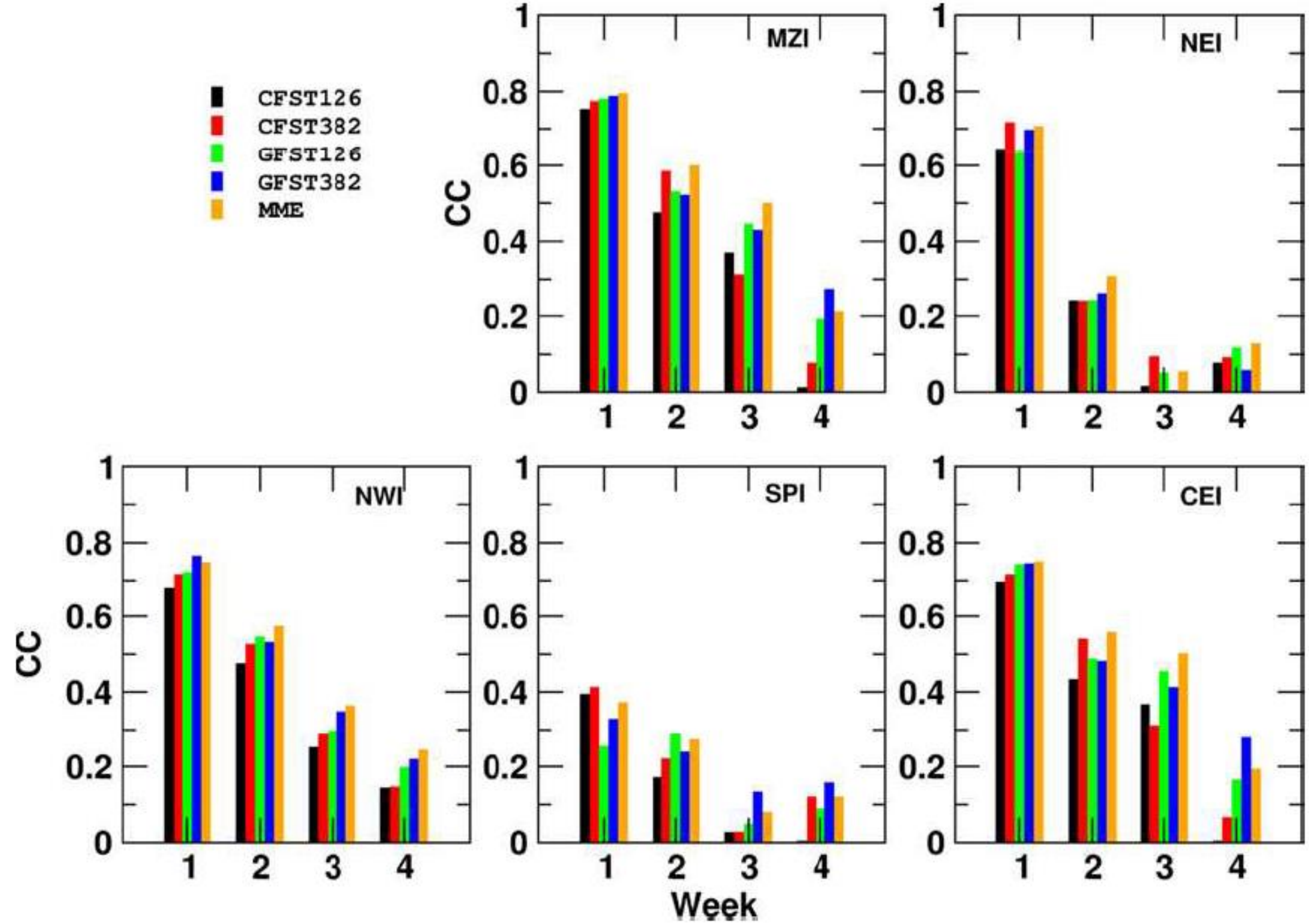



FIG. 7 The deterministic correlation skill (CC) of weekly lead prediction of area-averaged rainfall with observations for the hindcast period (2003–14) over the homogeneous zones of India.

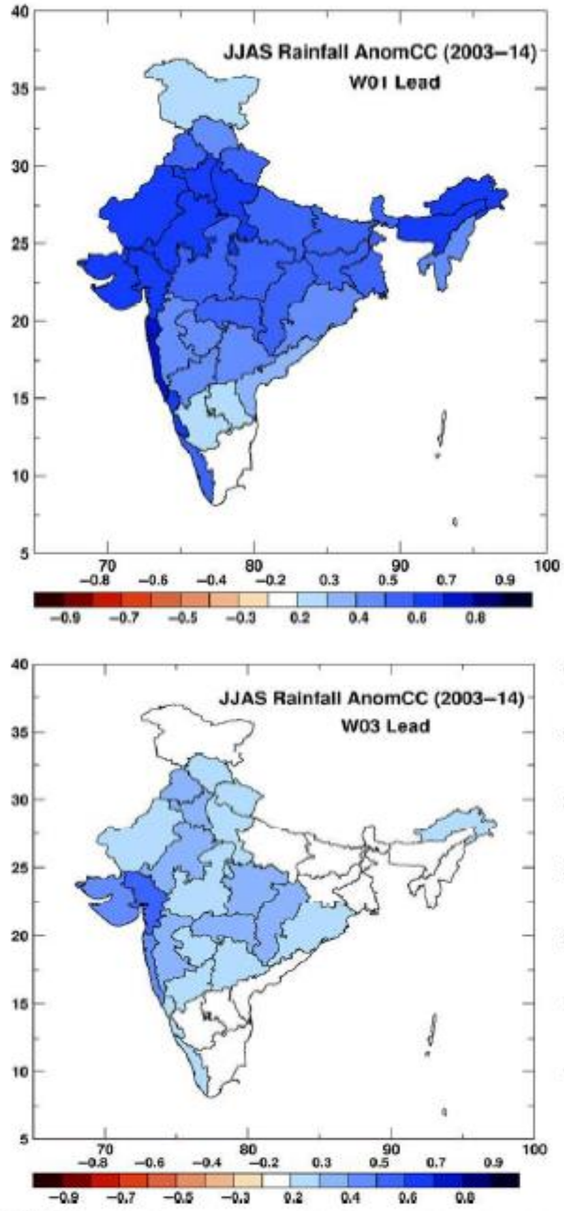



FIG. 8 The deterministic skill of weekly lead prediction of area-averaged JJAS rainfall with observations for the hindcast period over the meteorological subdivisions of India.

# Brier Skill Score From IITM extended Range models

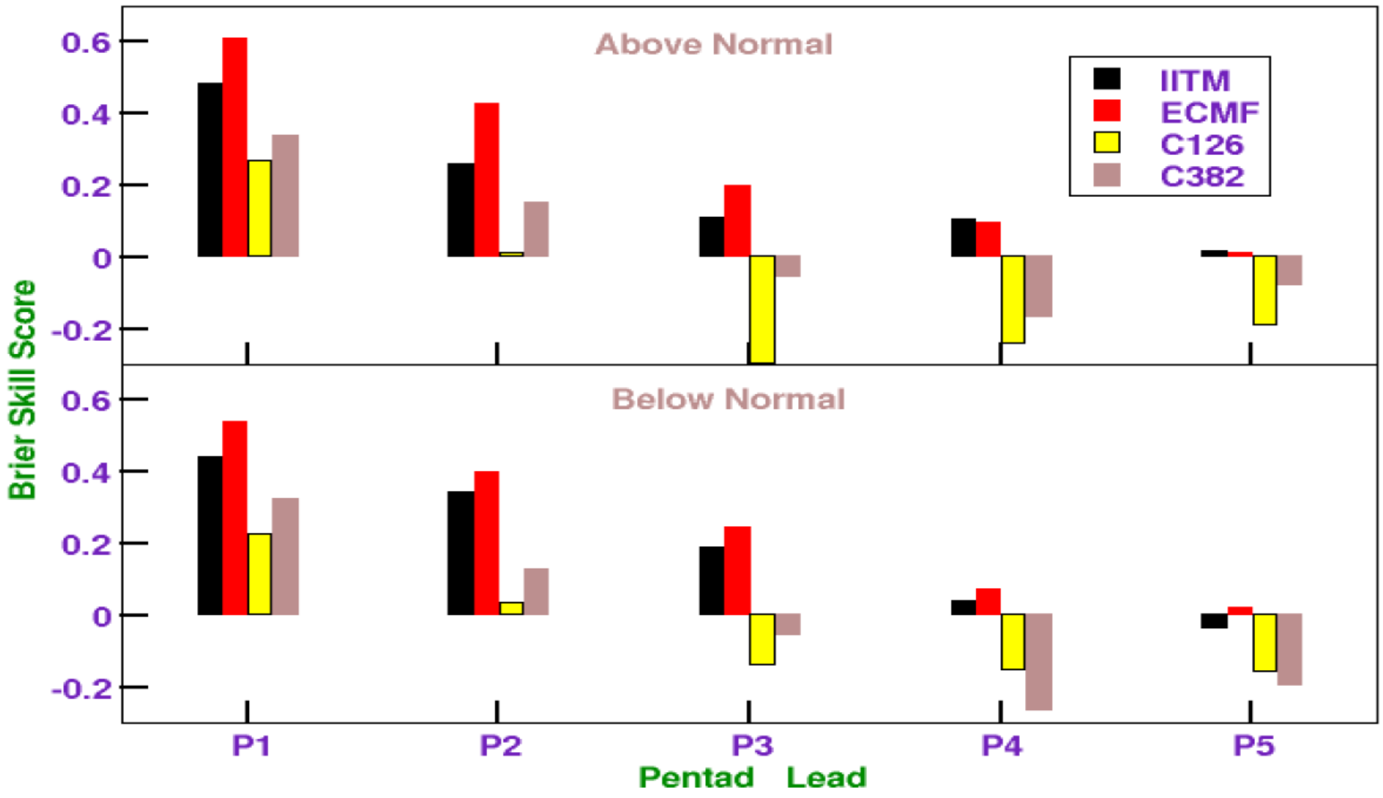



**Figure 3: Brier Skill score for the monsoon zone for the above normal and below normal categories for the IITM MME and the ECMF ENS. Also shown the same for individual component models. Skill score is based on 11 members taken from each of the models.**

# R OC Curve Example

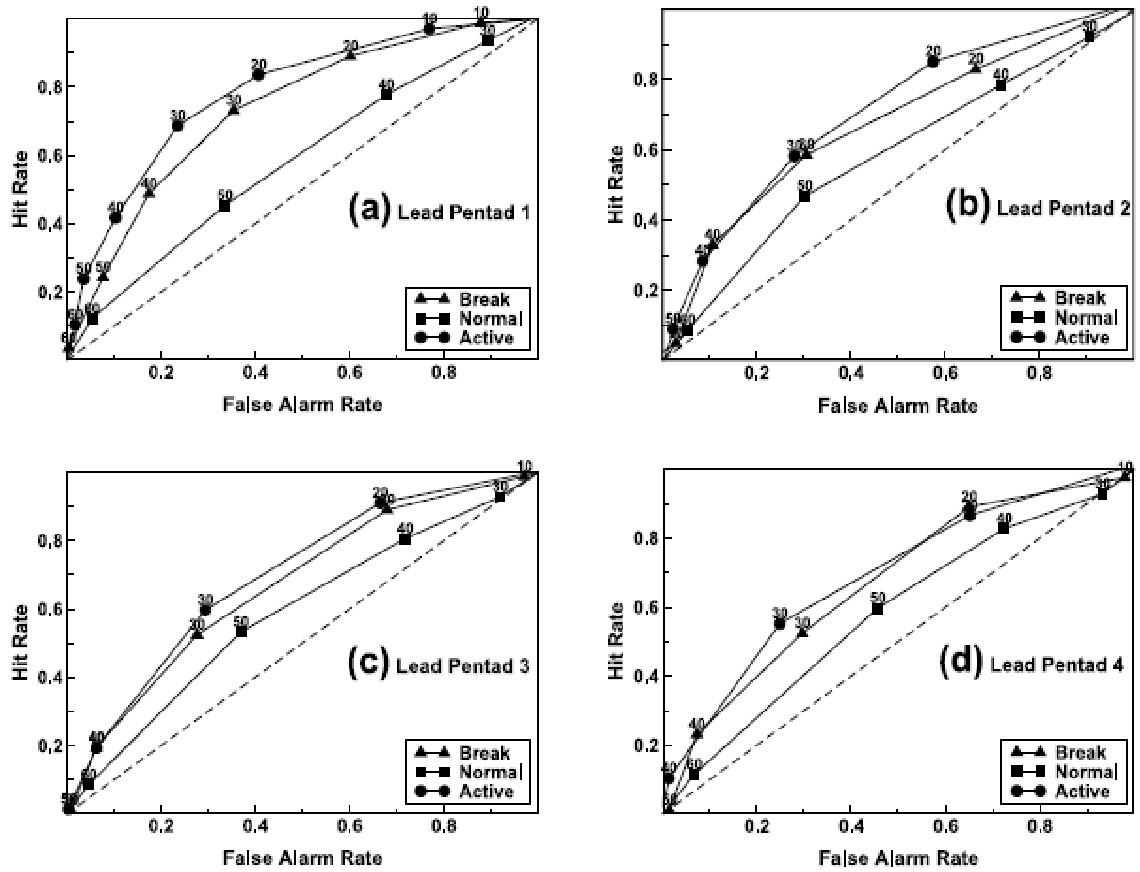
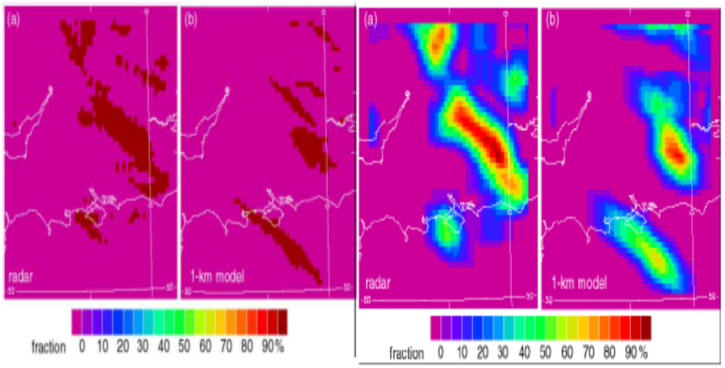



**Figure 7.** The ROC curve constructed on the basis of the three forecast categories in (a) first pentad, (b) second pentad, (c) third pentad, and (d) fourth pentad lead for the hindcast period. The area under the curve (AUC) for each category is listed in Table 3.

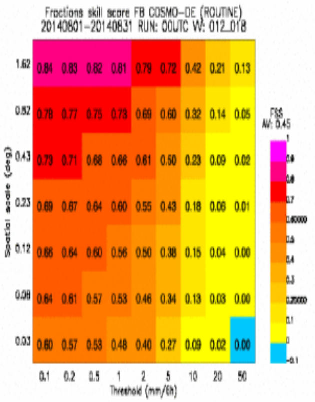
# Spatial Verification

FUZZY (neighborhood)




- Decide for a set of thresholds
- Gradually smooth forecast and/or observed fields
  (set of smoothing functions are possible)
- Decide for a verification measure, e.g. Fraction Skill Score

$$FSS = 1 - \frac{\frac{1}{N}\sum_{i=1}^{N}(P_{fcst} - P_{obs})^2}{\frac{1}{N}\sum_{i=1}^{N}P_{fcst}^{\,2} + \frac{1}{N}\sum_{i=1}^{N}P_{obs}^{\,2}}$$




| Spatial scale (deg) | 0.1 | 0.2 | 0.5 | 1 | 2 | 5 | 10 | 20 | 50 |
|---|---|---|---|---|---|---|---|---|---|
| 1.62 | 0.84 | 0.83 | 0.82 | 0.81 | 0.79 | 0.72 | 0.42 | 0.21 | 0.13 |
| 0.82 | 0.78 | 0.77 | 0.75 | 0.73 | 0.69 | 0.60 | 0.32 | 0.14 | 0.05 |
| 0.43 | 0.73 | 0.71 | 0.68 | 0.66 | 0.61 | 0.50 | 0.23 | 0.09 | 0.02 |
| 0.23 | 0.69 | 0.67 | 0.64 | 0.60 | 0.55 | 0.43 | 0.18 | 0.06 | 0.01 |
| 0.12 | 0.66 | 0.64 | 0.60 | 0.56 | 0.50 | 0.38 | 0.15 | 0.04 | 0.00 |
| 0.06 | 0.64 | 0.61 | 0.57 | 0.53 | 0.46 | 0.34 | 0.13 | 0.03 | 0.00 |
| 0.03 | 0.60 | 0.57 | 0.53 | 0.48 | 0.40 | 0.27 | 0.09 | 0.02 | 0.00 |

- Useful if forecast and observation are available as grid (e.g. observation from rain radar)
- Shows useful scales of predictability
- Popular for comparing models with different horizontal resolution
- Reduced double penalty effect with larger scales
- Many dichotomous or probabilistic scores can be used for analysis

## IMD ERPS FSS

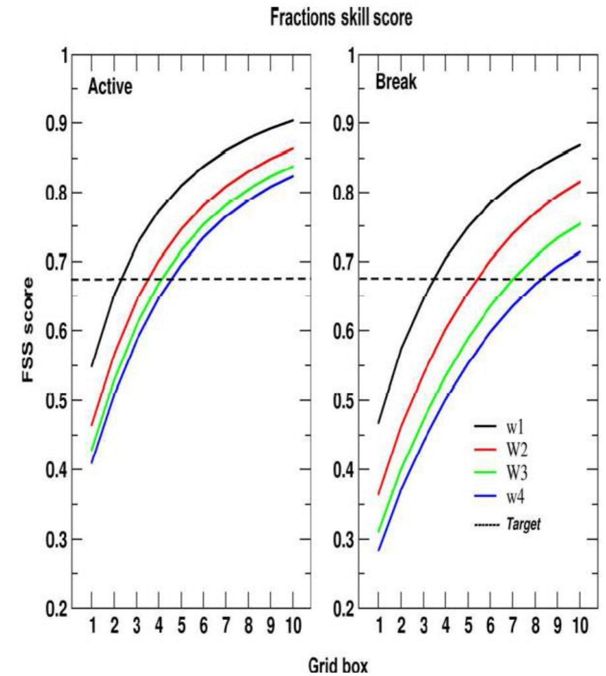



FIG. 9 FSS for the JJAS Active and Break Spells during the 2003–14 hindcast period.

# Monthly Forecast Verification

## Homogeneous region mask skill Single IC: IMD ERF and Glosea5 (inside braces)

**and UKMO(7mem, inside braces) and IMD ERF(8mem) grandMME (underline)**

| June(29/05) | CC | RMSE |
|---|---|---|
| WNW | 0.71(0.75)<br>0.88 | 0.69(0.89)<br>0.82 |
| CE | 0.66 (0.48)<br>0.70 | 1.32(1.88)<br>1.53 |
| ENE | 0.52 (0.42)<br>0.67 | 1.51 (2.21)<br>1.40 |
| SP | 0.54 (0.64)<br>0.53 | 1.01(1.04)<br>1.03 |
| MZI | 0.64(0.48) | 1.12(1.53) |
| AI | 0.47(0.71) | 0.99 (0.83) |

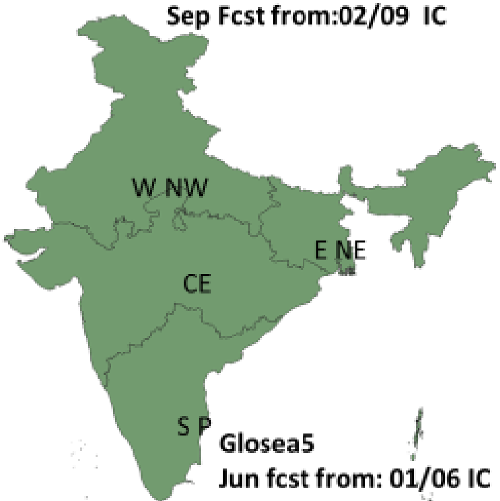
| July(01/07) | CC | RMSE |
|---|---|---|
| WNW | 0.47(0.63)<br>0.42 | 1.15(1.38)<br>1.04 |
| CE | 0.35(0.64)<br>0.14 | 1.71(2.23)<br>2.03 |
| ENE | 0.42(0.01)<br>0.18 | 1.98(2.38)<br>1.69 |
| SP | 0.42(0.82)<br>0.52 | 1.19(0.92)<br>1.20 |
| MZI | 0.34(0.62) | 1.34(1.88) |
| AI | 0.62(0.64) | 0.77 (1.03) |

| Aug(31/07) | CC | RMSE |
|---|---|---|
| WNW | 0.43(0.72)<br>0.43 | 1.31(0.97)<br>1.24 |
| CE | 0.46(0.66)<br>0.70 | 2.15(1.68)<br>1.83 |
| ENE | 0.18(0.56)<br>0.04 | 2.26(1.61)<br>2.06 |
| SP | 0.32(0.76)<br>0.25 | 1.40(0.96)<br>1.21 |
| MZI | 0.56(0.77) | 1.62(1.13) |
| AI | 0.53(0.67) | 0.80(0.64) |

| Sep(02/09) | CC | RMSE |
|---|---|---|
| WNW | 0.79 (0.69)<br>0.68 | 0.87 (1.07)<br>1.03 |
| CE | 0.58(0.81)<br>0.55 | 1.63(1.19)<br>1.22 |
| ENE | 0.33(0.26)<br>0.47 | 1.72(1.71)<br>1.26 |
| SP | 0.37(0.68)<br>0.10 | 1.33(0.98)<br>1.30 |
| MZI | 0.64(0.85) | 1.28(0.90) |
| AI | 0.67(0.77) | 0.82(0.67) |

**Skill wrt to IMD 0.25 deg data**

**IMD ERF**
**Jun fcst from: 29/05 IC**
**Jul Fcst from : 07/01 IC**
**August Fcst from: 07/31 IC**
**Sep Fcst from:02/09 IC**




**Glosea5**
**Jun fcst from: 01/06 IC**
**Jul Fcst from : 01/07 IC**
**August Fcst from: 01/08 IC**
**Sep Fcst from: 01/09 IC**