Extended Range Prediction Activities at IITM

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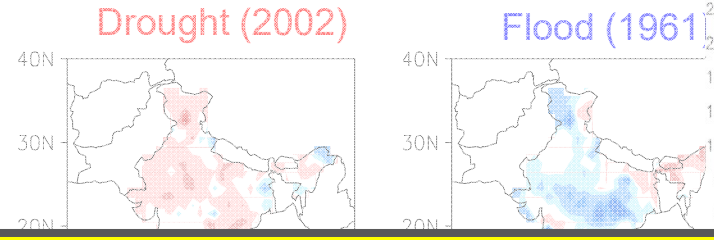
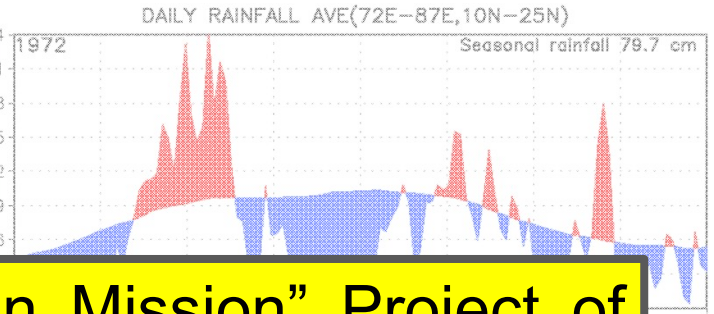
Background and Motivation

Spatial Variability

Temporal Variability



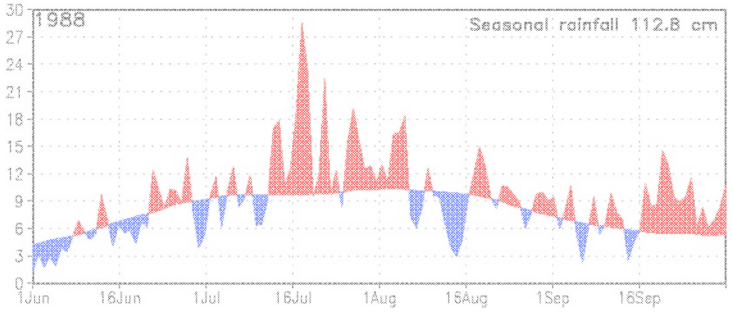


Seasonal JJAS rainfall anomaly dur… floo… year…

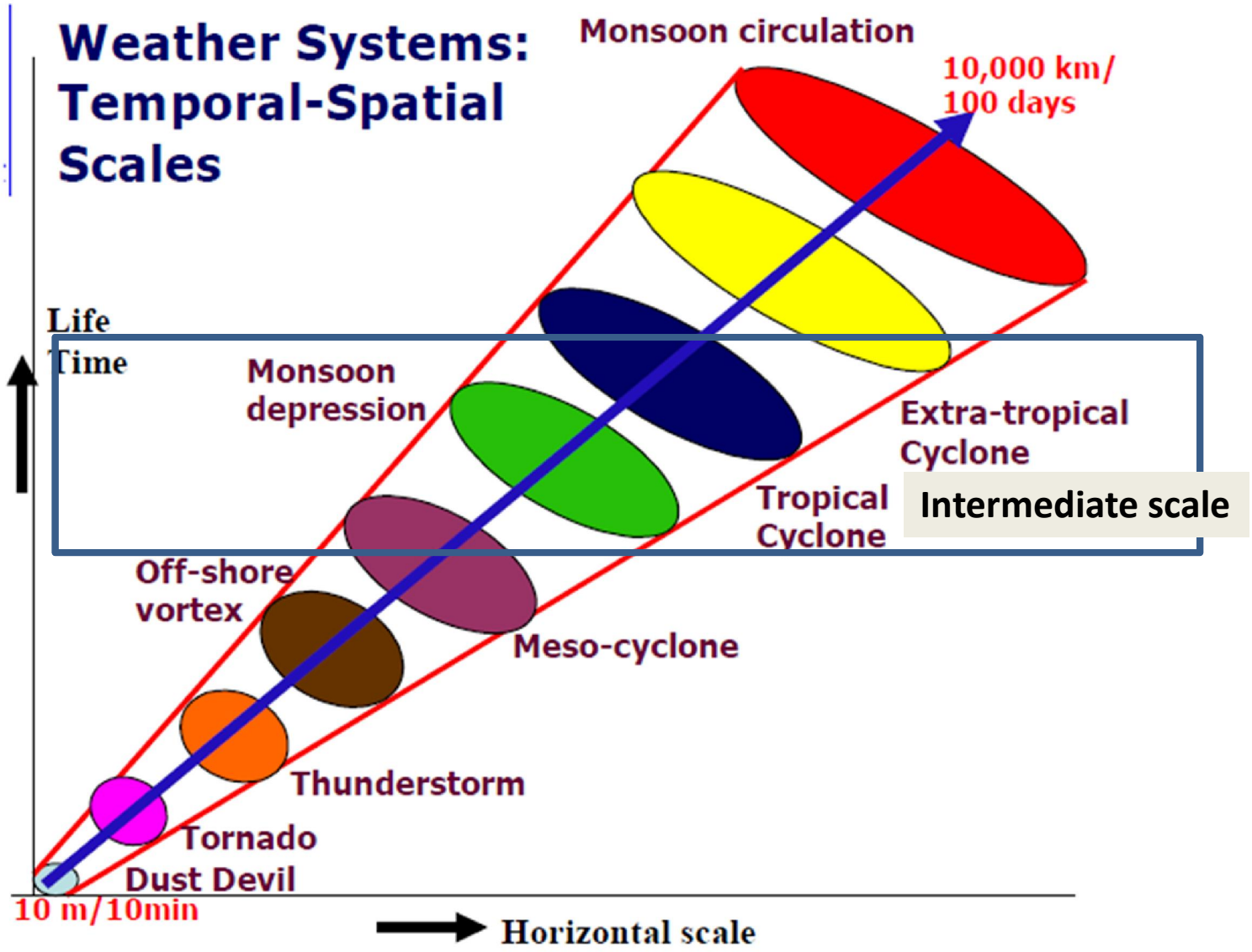
Hence, under the "National Monsoon Mission" Project of Govt. of India, IITM has adopted Climate Forecast System (CFS) coupled model from NCEP for seasonal and extended range prediction of Indian summer monsoon on Indo-US collaborative mode.

Although the prediction of a 'normal' all India rainfall may have a comfort factor, it may not be useful for agricultural, hydrological planning.

Therefore, in addition to the seasonal mean All India rainfall, we need to predict some aspects of monsoon 3-4 weeks in advance on a relatively smaller spatial scale that will be useful for farmers.



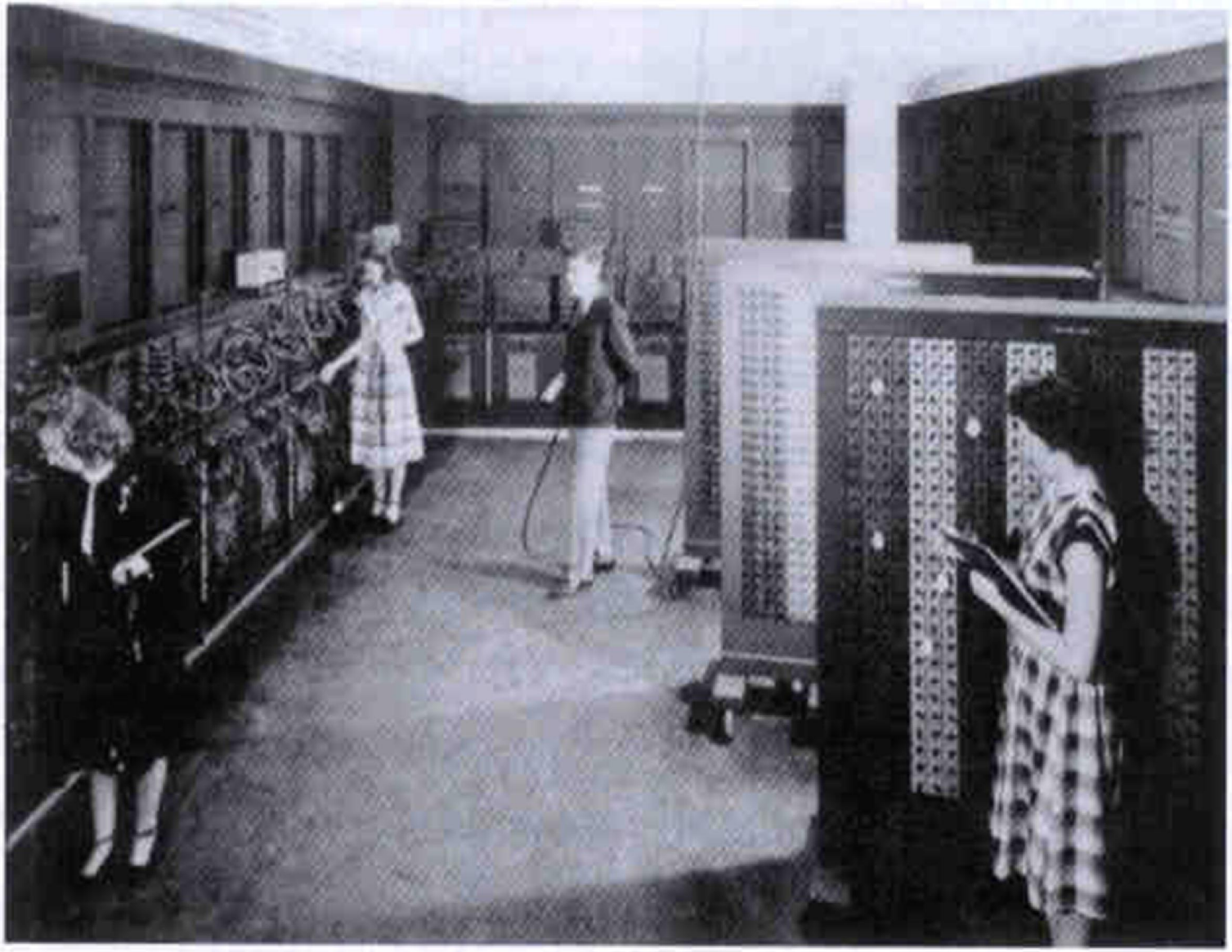
Different systems and their Scales



Predictability

The predictability of a weather system which has source in the knowledge of the initial conditions and which is limited by the flow itself is called Predictability of the First Kind.

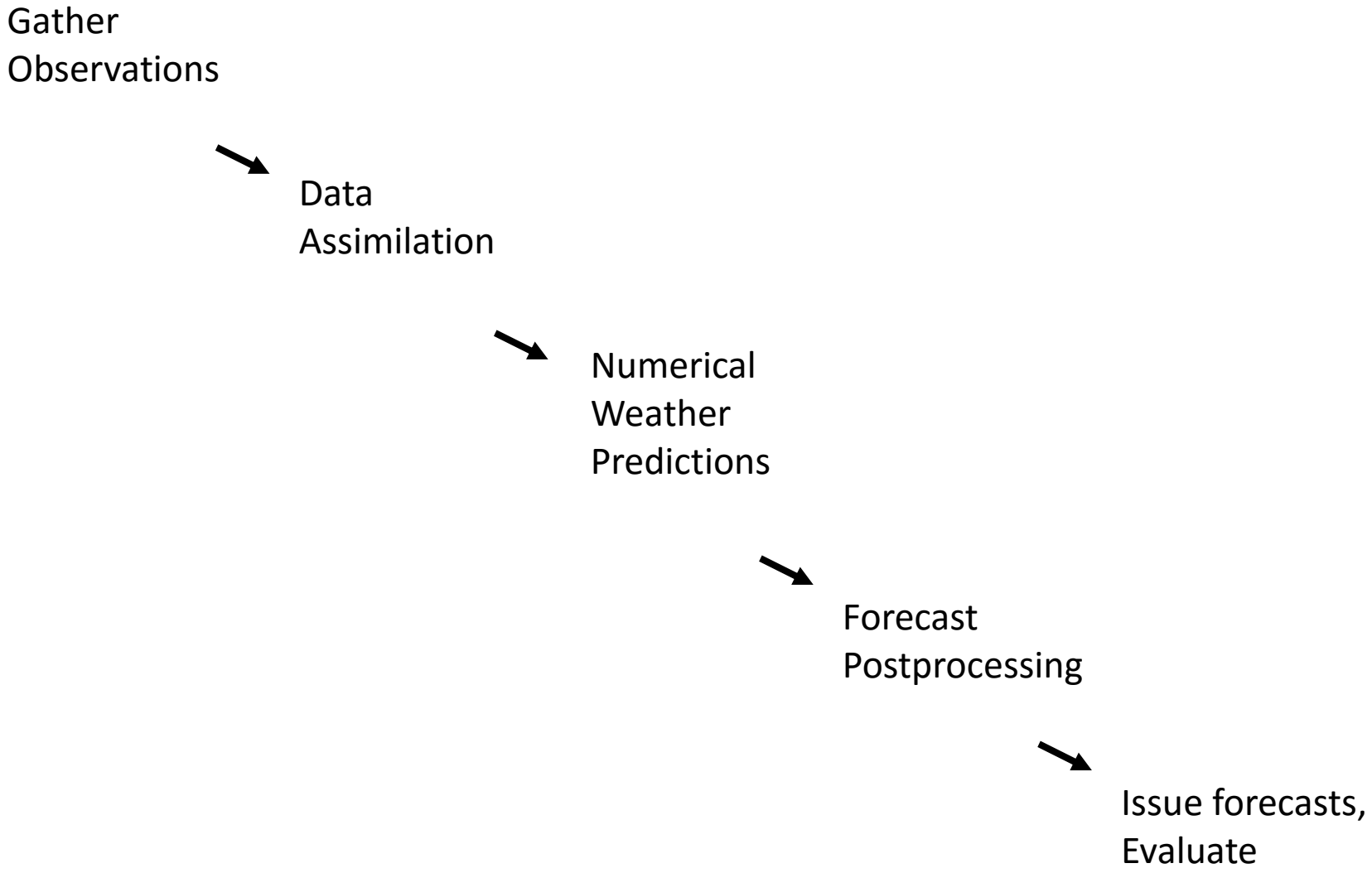
Baroclinic Instability, Barotropic Instability, Interactions of eddies



Electronic Numerical Integrator and Computer

Figure 3: The ENIAC computer in 1948. The operators are changing the plug-in wiring. (PLATZMAN, 1979).

NWP Process to Predict the Systems



WHEN THE PRESENT DETERMINES

THE FUTURE

BUT

THE APPROXIMATE PRESENT DOES NOT

APPROXIMATELY DETERMINE THE FUTURE

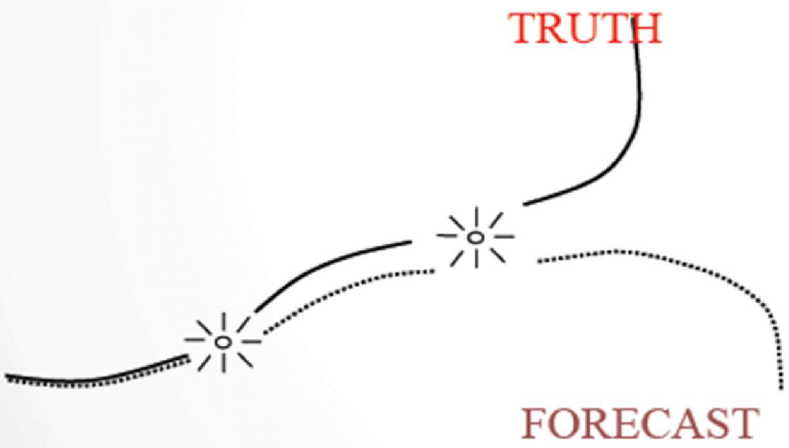
Predictability in the midst of Chaos

Central theorem of chaos (Lorenz, 1960s):

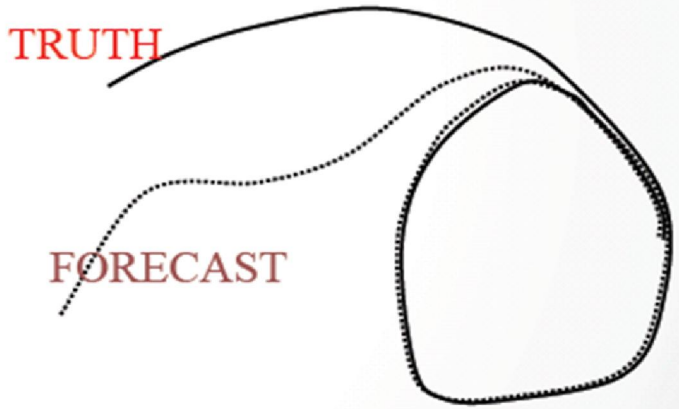
a) Unstable systems have finite predictability (chaos)

b) Stable systems are infinitely predictable

a) Unstable dynamical system

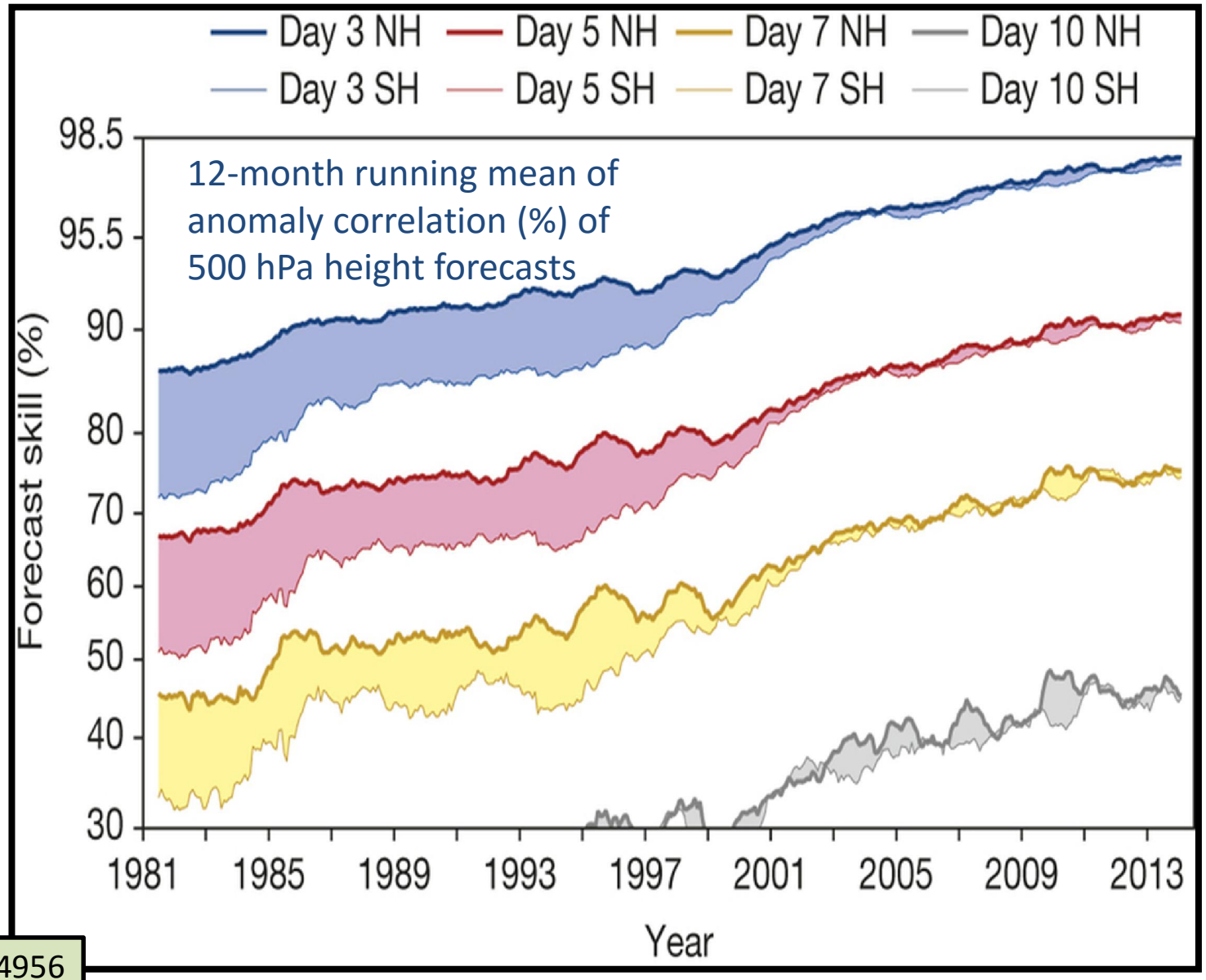


b) Stable dynamical system



AGU Eugenia Kalnay slide

Improvement in forecast skill (better physics, observation, computer)

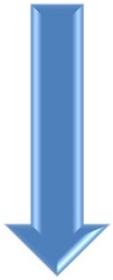


Improvement of 1 day per decade

doi:10.1038/nature14956

Going beyond Weather Prediction

The large scale low frequency variability in global scale is now known to be dominated by Teleconnection which is inherently slowly varying and impacts regional climate



Provides the dynamical basis for prediction beyond weather scale

Charney-Shukla Hypothesis

The predictability of second kind

Charney and Shukla *hypothesized a kind of predictability, one that would operate in low latitudes, and had its source not in the initial conditions but in the Boundary Conditions of sea-surface temperature (SST), albedo, ground moisture and vegetation.*

Hope for Monsoon Prediction in the Long Range which was the demand for Policy makers

THUS....

The basis for long range predictability of IAV of monsoon comes from slowly varying large scale external boundary forcing (arising from ocean-atmosphere interactions).

(Charney and Shukla, 1981, Shukla, 1998; Goswami and Xavier, 2005)

Extended Range Prediction

Overview

- **The extended range prediction refers to a meteorological forecast more than 10 days in advance, which is the normal predictability range of weather systems (storms, cyclones etc.)**
- **It should be remembered that the forecast *does not* involve a prediction of synoptic scale or mesoscale process as such (e.g. formation of cyclones depressions, dust storms,Loo etc etc) .**
- **The extended range forecasting is sandwiched between short range weather prediction (governed by the initial conditions) and the long range prediction (governed by the boundary conditions).**

So, what could possibly be predicted with lead time of more than 10 days?

It is an intuitive notion that the predictability of a phenomenon is proportional to its own period or lifetime (Van den Dool and Saha, 1990, MWR)

The Tropics and the equatorial belt have the low frequency variability in various scales (gravity waves, Rossby Waves, Mixed Rossby-Gravity Waves, Kelvin waves and Convectively coupled Kelvin waves (i.e. Madden-Julian Oscillation).

MJO and MISO are the most important large scale low frequency component in the intraseasonal scale.

This Large-scale low frequency component of intraseasonal variability (10-90 day) of rainfall is generally predicted in the extended range.

Ensemble forecast

Sources of model error

- Numerics
- Physics (radiation, turbulence, moist processes)
- Initial conditions - define the atmosphere's current state…the starting point
- Lateral boundary conditions - define the atmosphere's state at domains' edges
- Lower boundary conditions – conditions at Earth's surface

Small errors in initial conditions will always amplify and, together with model errors and approximations, limit the useful forecast range.

The Butterfly Effect

Ensemble forecasting can be traced back to the discovery of the "Butterfly Effect" (Lorenz 1963, 1965)…

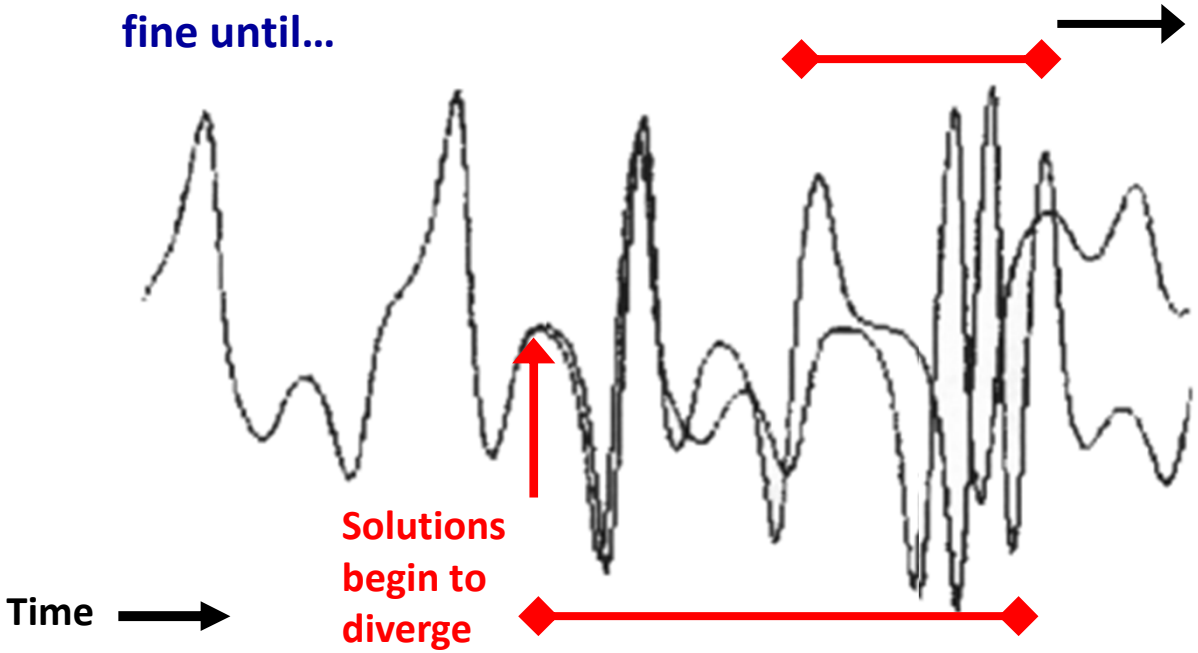
Atmosphere is a non-linear, non-periodic, dynamical system causes even tiny errors to grow upscale ... resulting in forecast uncertainty and eventually chaos.

Ensemble forecasts will provide the deterministic forecast as the mean of all forecasts and estimates of uncertainty range as standard deviation of forecasts and also the probability of occurrence of various categories.

The Butterfly Effect

Simplified climate model… When the integration was restarted with 3 (vs 6) digit accuracy, everything was going fine until…

• Eventually, results revealed two uncorrelated and completely different solutions (i.e., chaos)

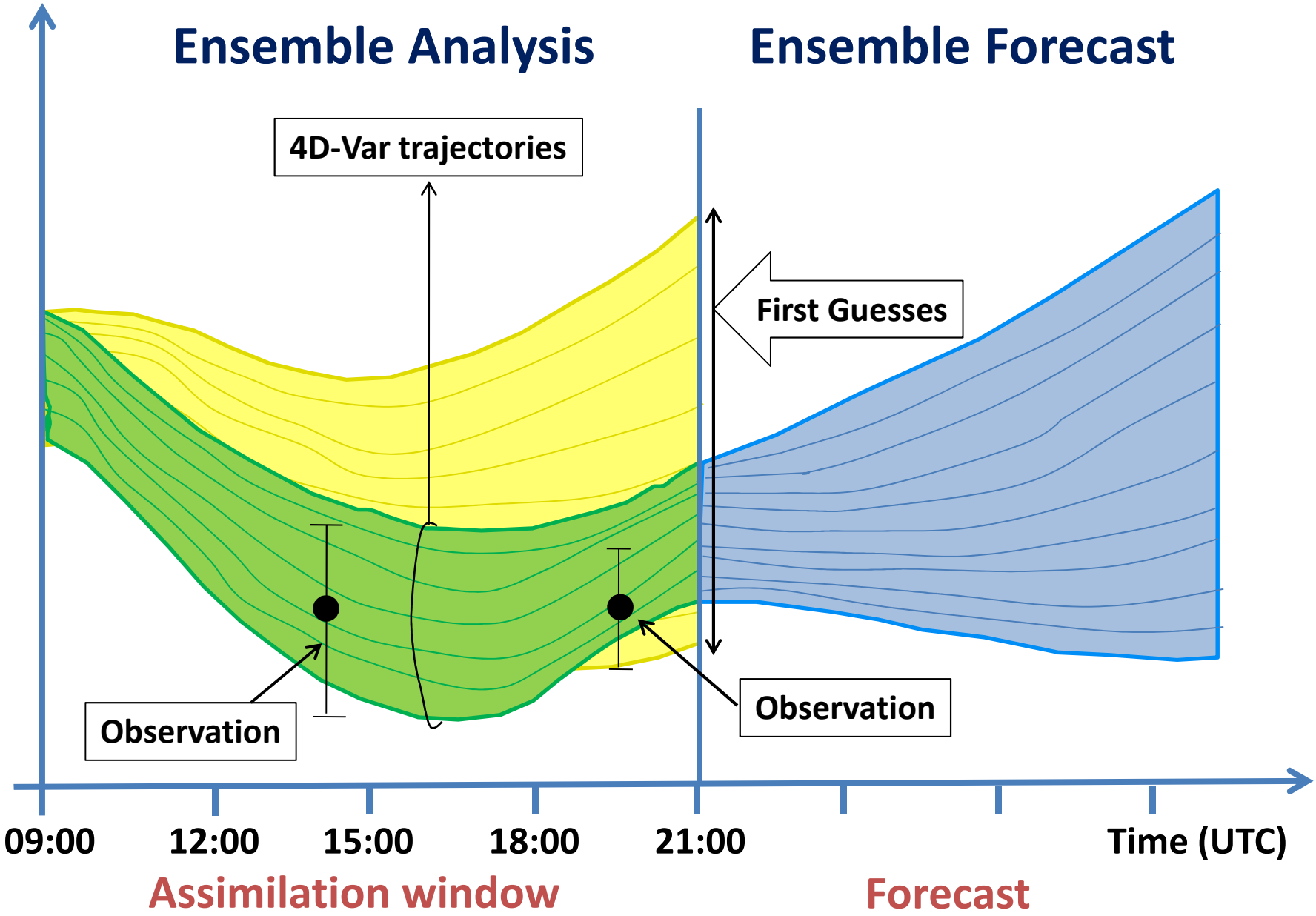


- A deterministic solution is no longer skillful when its error variance exceeds climatic variance
- An ensemble remains skillful until error saturation (i.e., until chaos occurs)

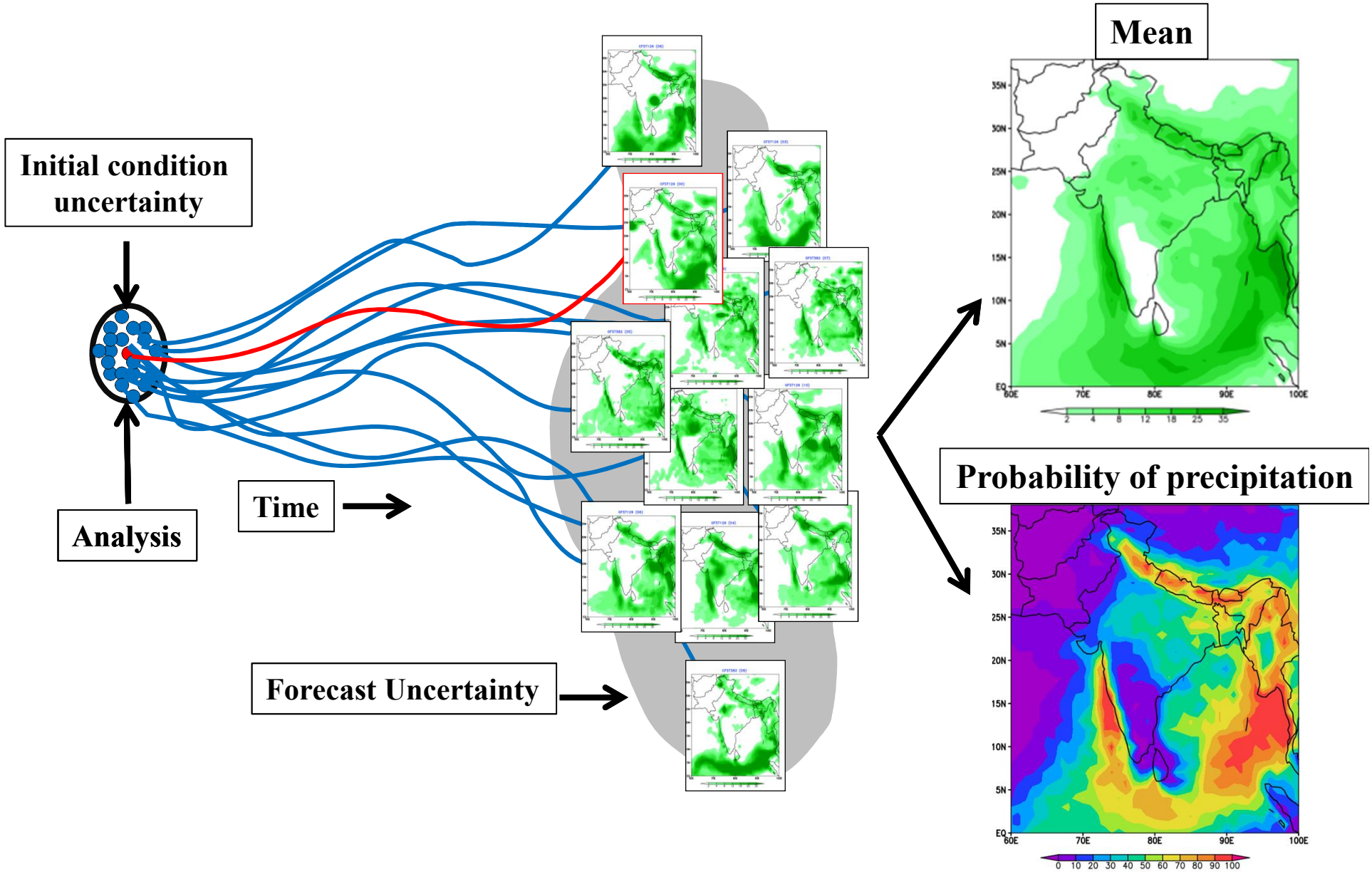
- Ensembles can be used to provide information on forecast uncertainty
- Information from the ensemble typically consists of…

(1) Mean
(2) Spread
(3) Probability

doi:10.1038/nature14956 : ECMWF



Weather prediction is a Initial Value Problem



Time Line of development of IITM ERPS using CFSv2

2011: EPS 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]

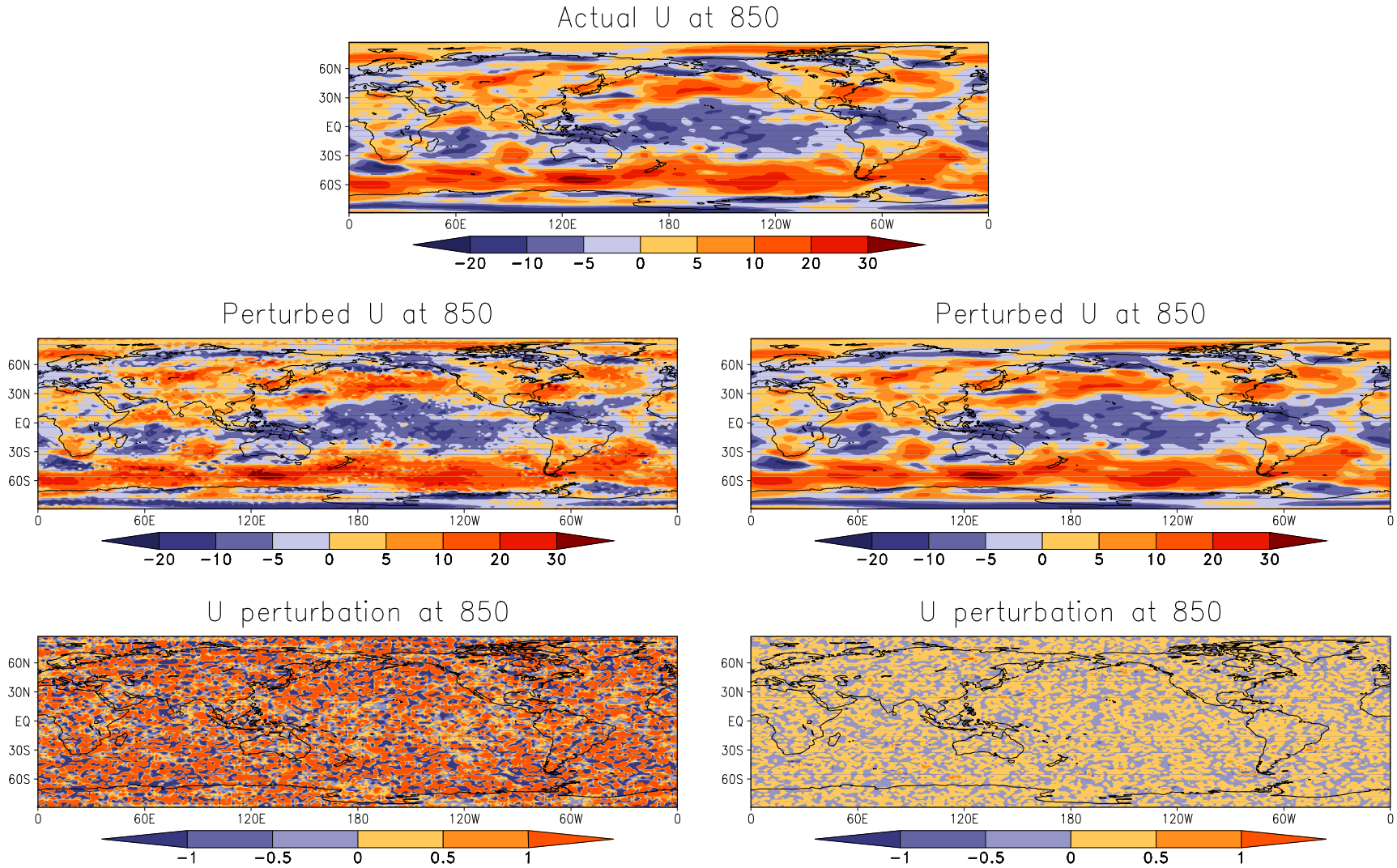
2014: CFS based Grand EPS Implemented [Abhilash etal., 2015, JAMC; Sahai etal., 2015, Cur. Sci]

2015: Forecast for winter and other seasons started

2016: Forecast of heat wave 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]

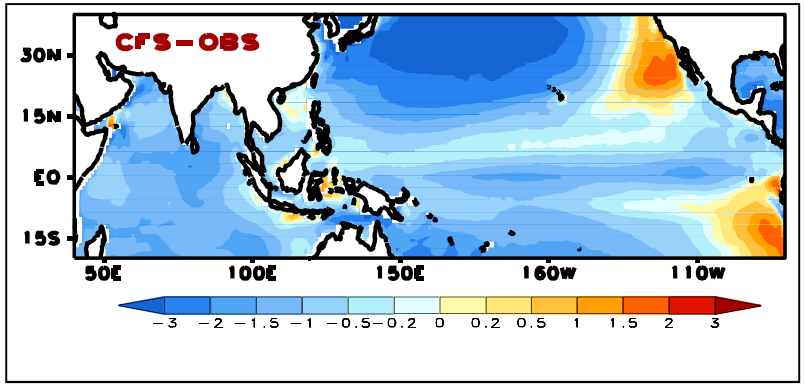
Development, Testing, tuning and reliability of Ensemble Prediction System (EPS)

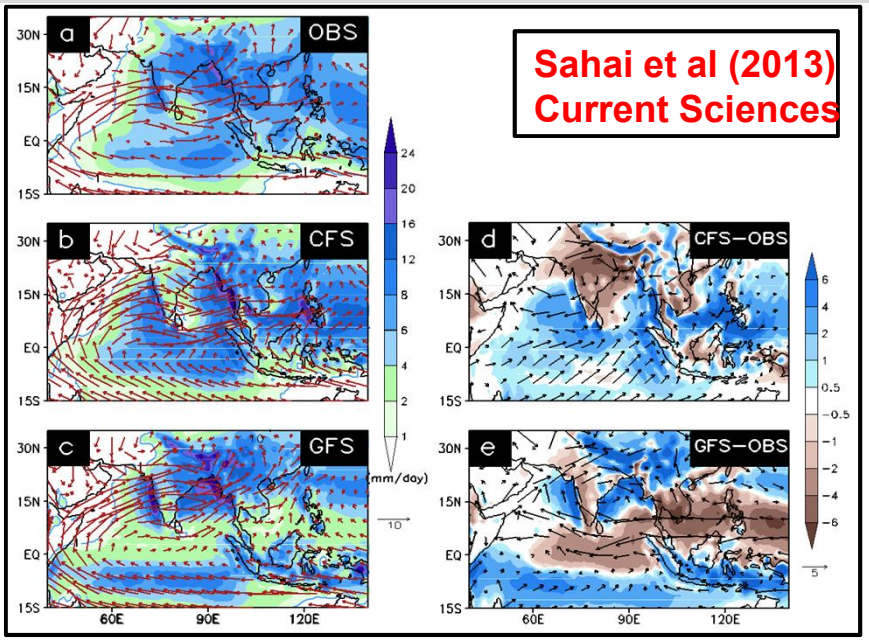


Abhilash et al 2014

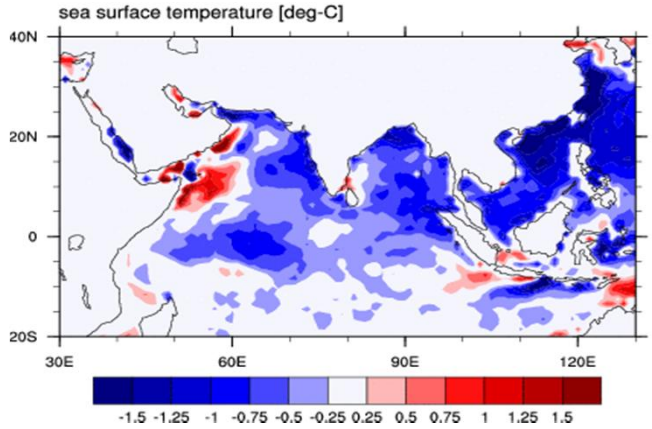
Development of Bias-correction Technique

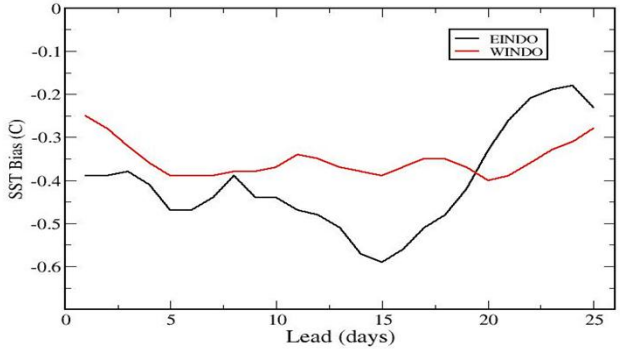
SST Bias from Long Simulation





SST Bias
20 day Lead

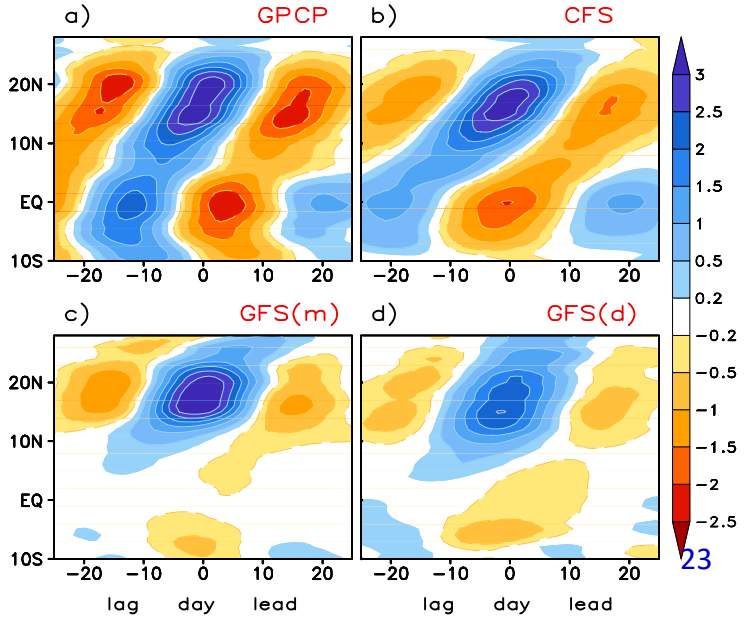




Lead
Dependant
Bias

Abhilash et al., 2013

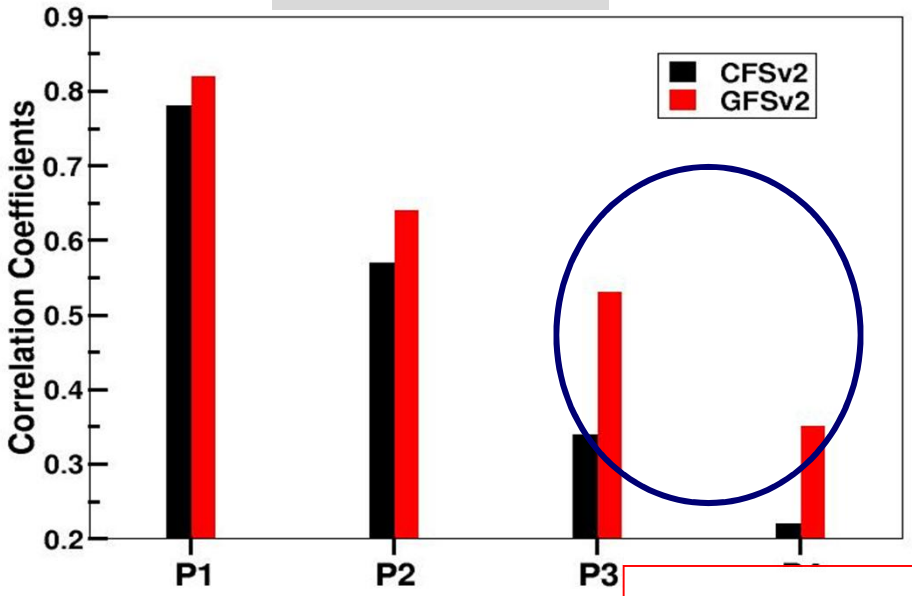
Northward propagation of ISO



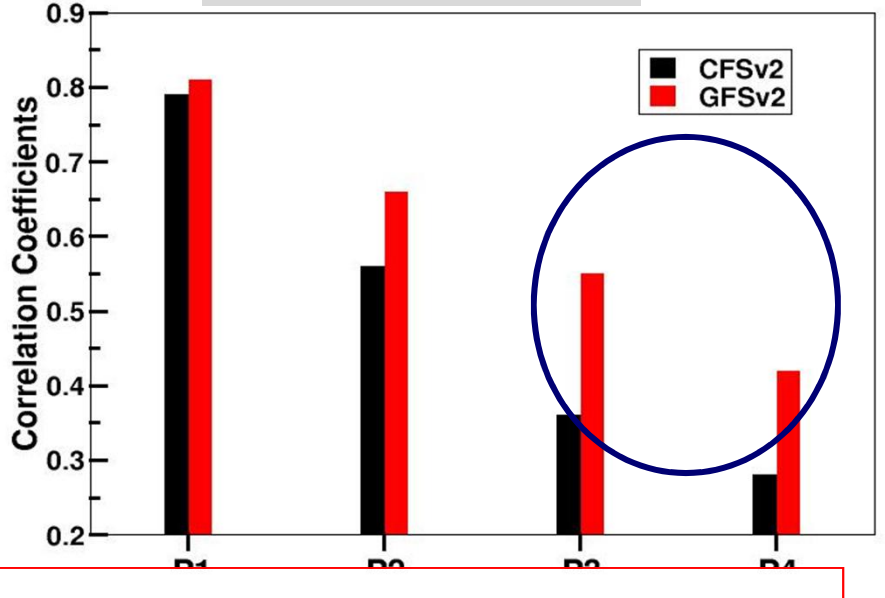
Development of Bias-correction Technique

CC for 24 pentads per year for 12 years (288 points)

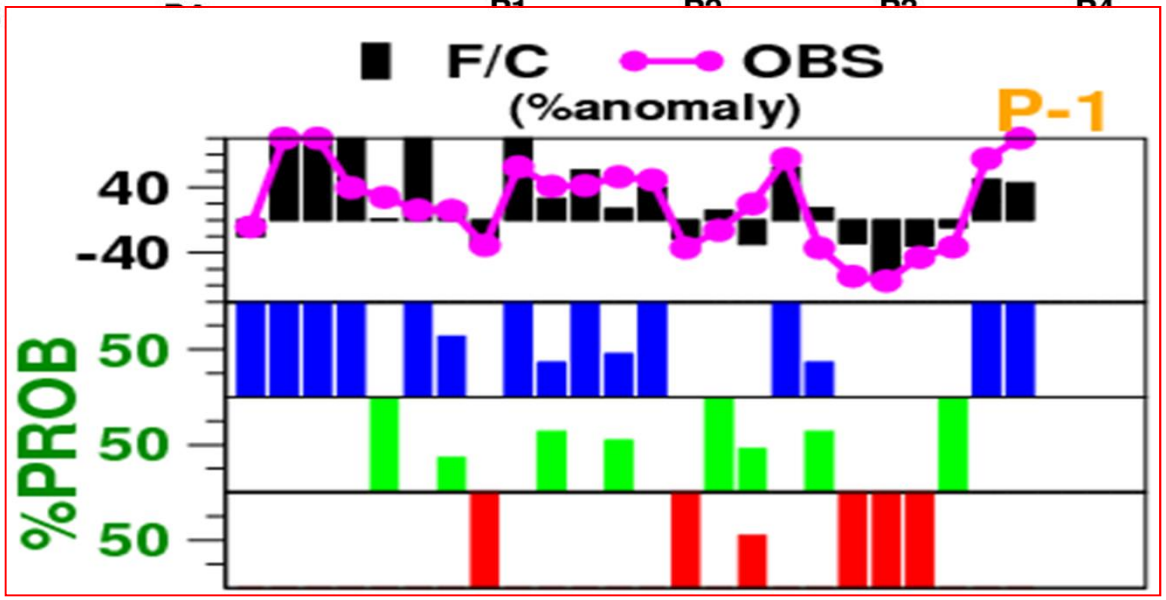
Control run



Ensemble mean

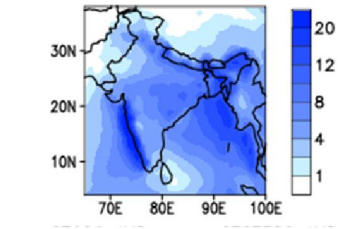


Probability FCST



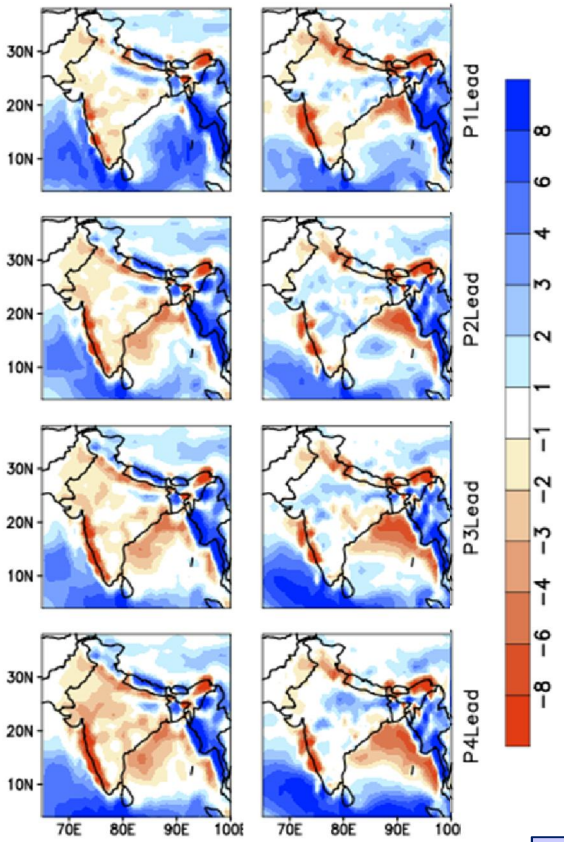
Implementation of High Resolution Version

Climatological Rainfall bias

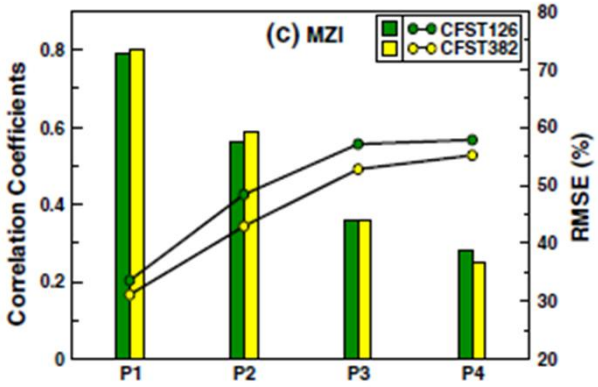


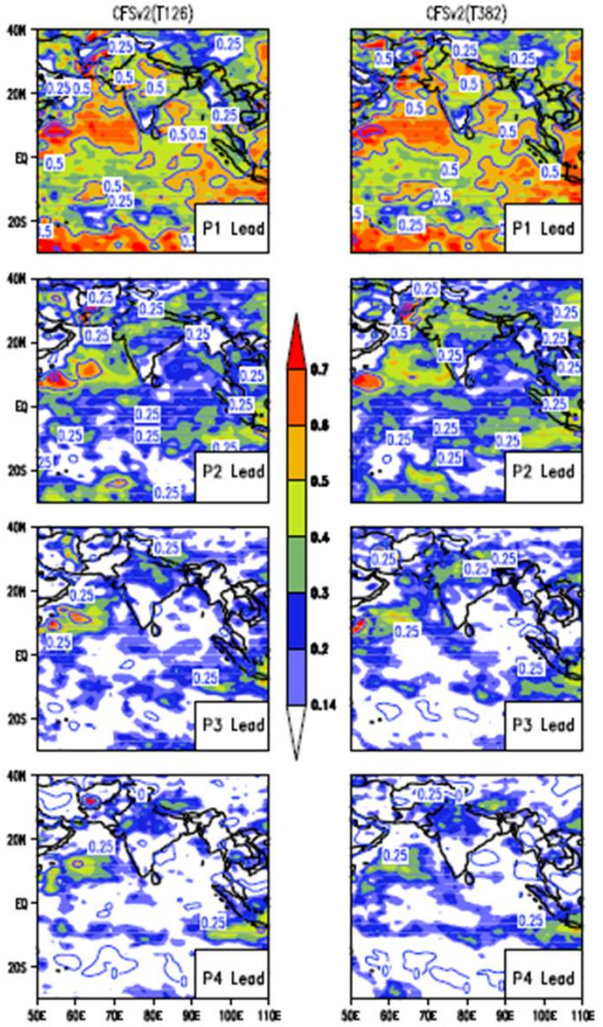
OBS
IMD

CFS126-IMD CFS382-IMD



Pentad correlation skill and RMSE w.r.t. observations for CFST126 and CFST382





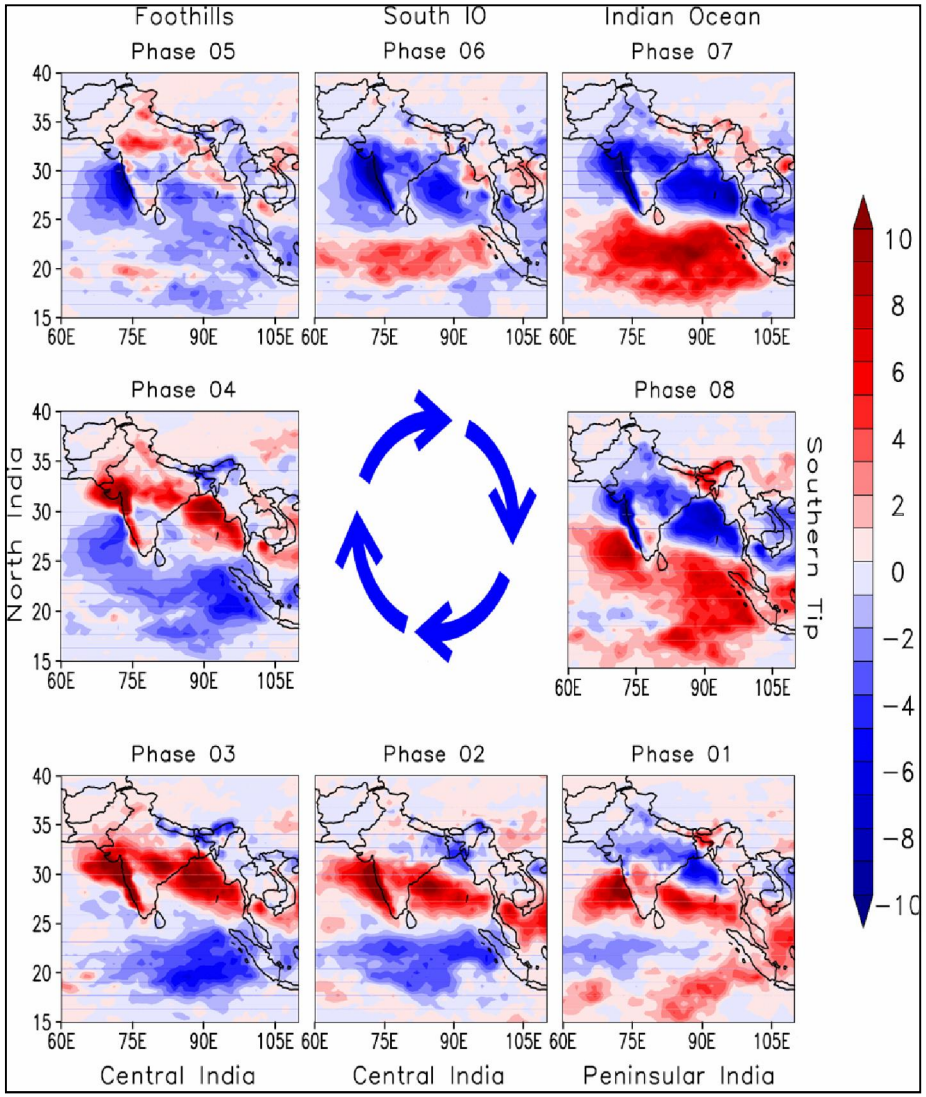
Spatial correlation between forecasted rainfall and observed rainfall

Sahai et al. 2015, Clim Dyn

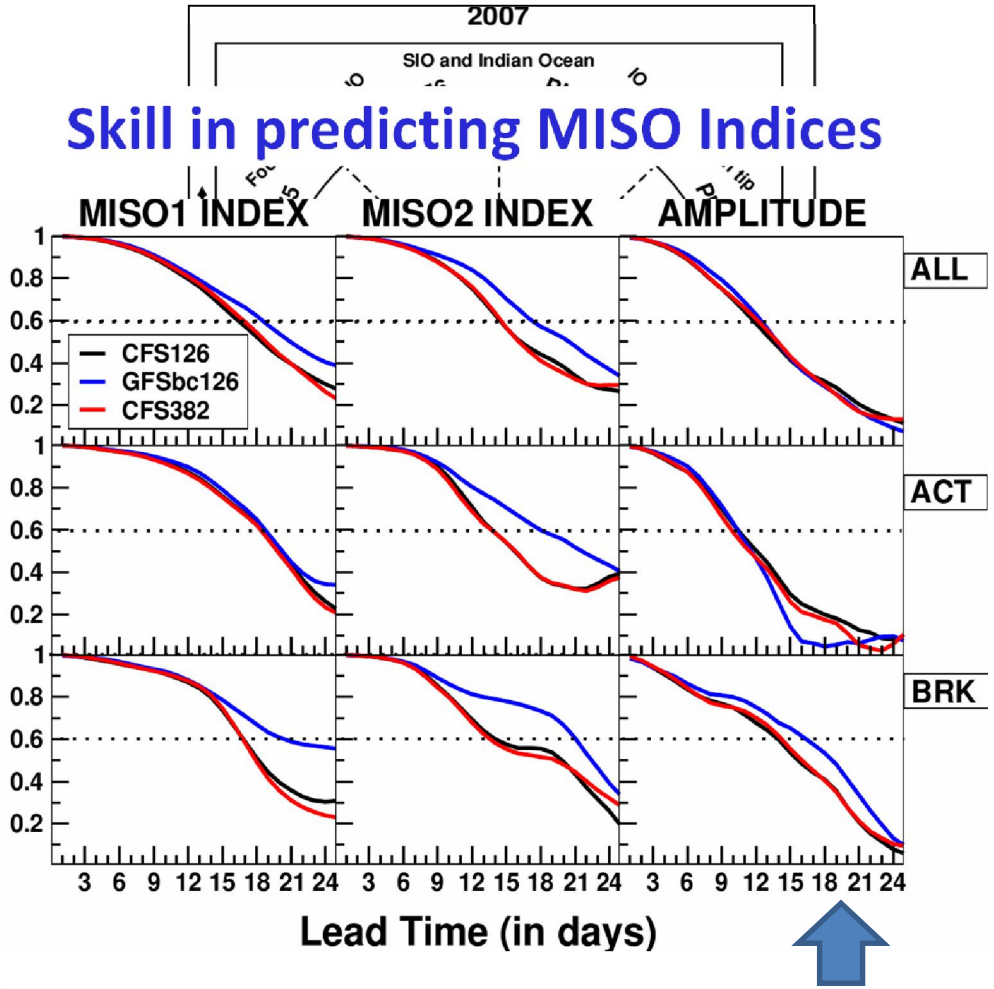
Optimization of Low frequency component over Indian region

RMM----------→ BSISO----------→ MISO--- (*Suhas et al., 2013, Goswami et al., 2013*)

Eight Phase evolution of MISO



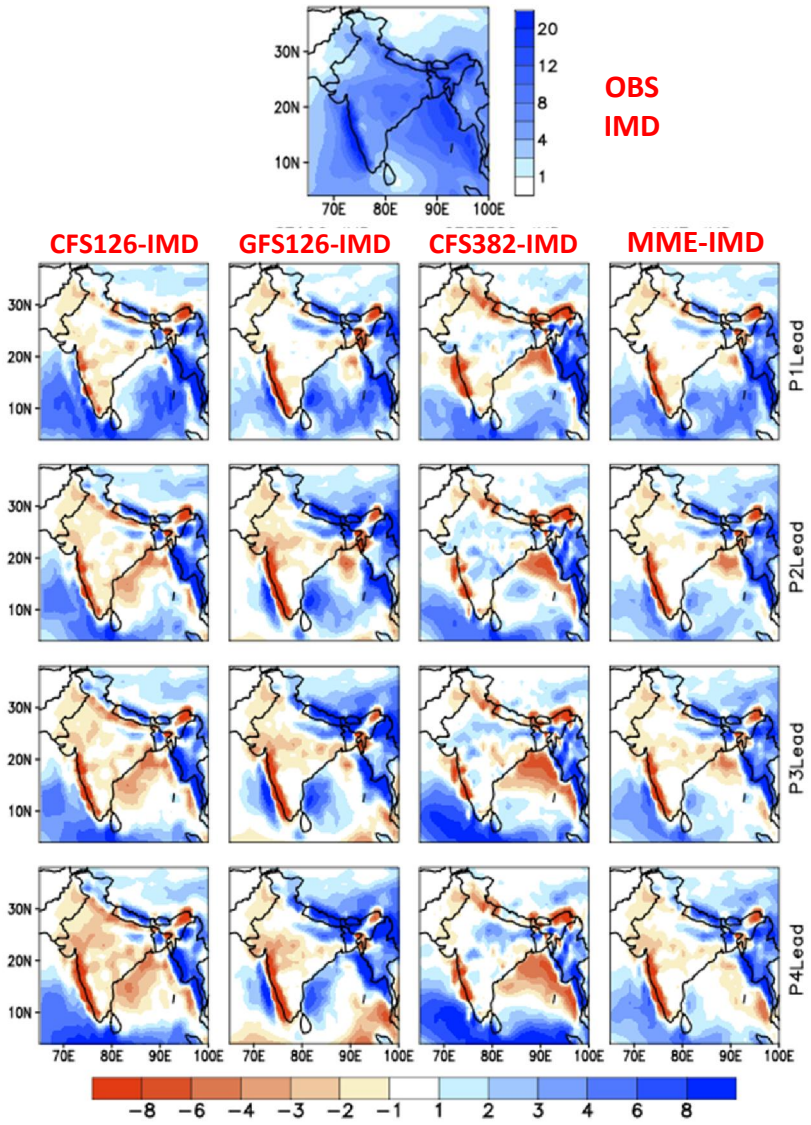
Skill in predicting MISO Indices



Correlations between the MISO1 and MISO2 index and the MISO amplitude as a function of lead-time.

Development of MME

Seasonal mean and difference from OBS

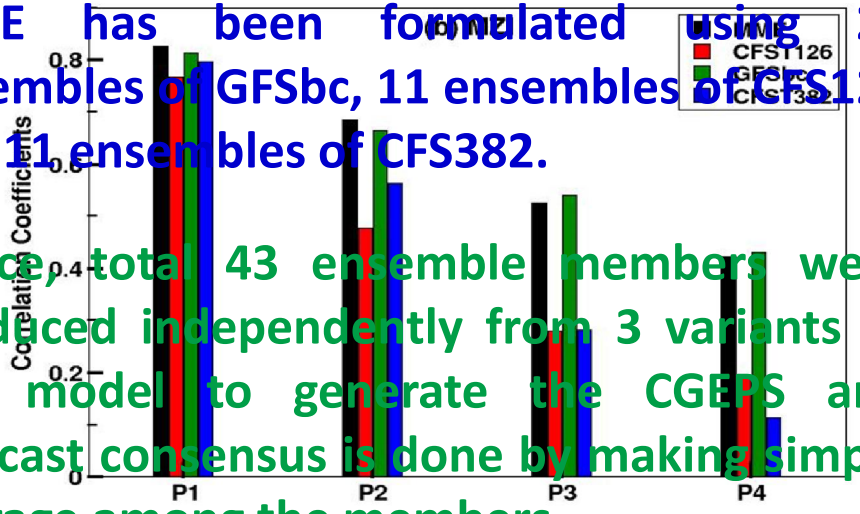


Abhilash et al. 2015, JAMC; BAMS

Deterministic prediction Skill

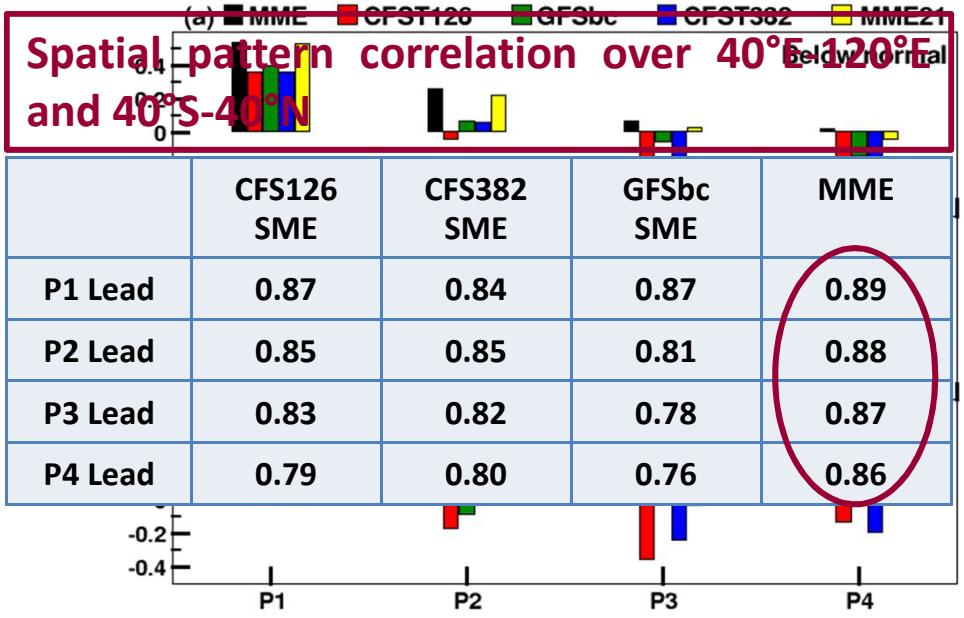
MME has been formulated using 21 ensembles of GFSbc, 11 ensembles of CFS126 and 11 ensembles of CFS382.

Hence, total 43 ensemble members were produced independently from 3 variants of CFS model to generate the CGEPS and forecast consensus is done by making simple average among the members.



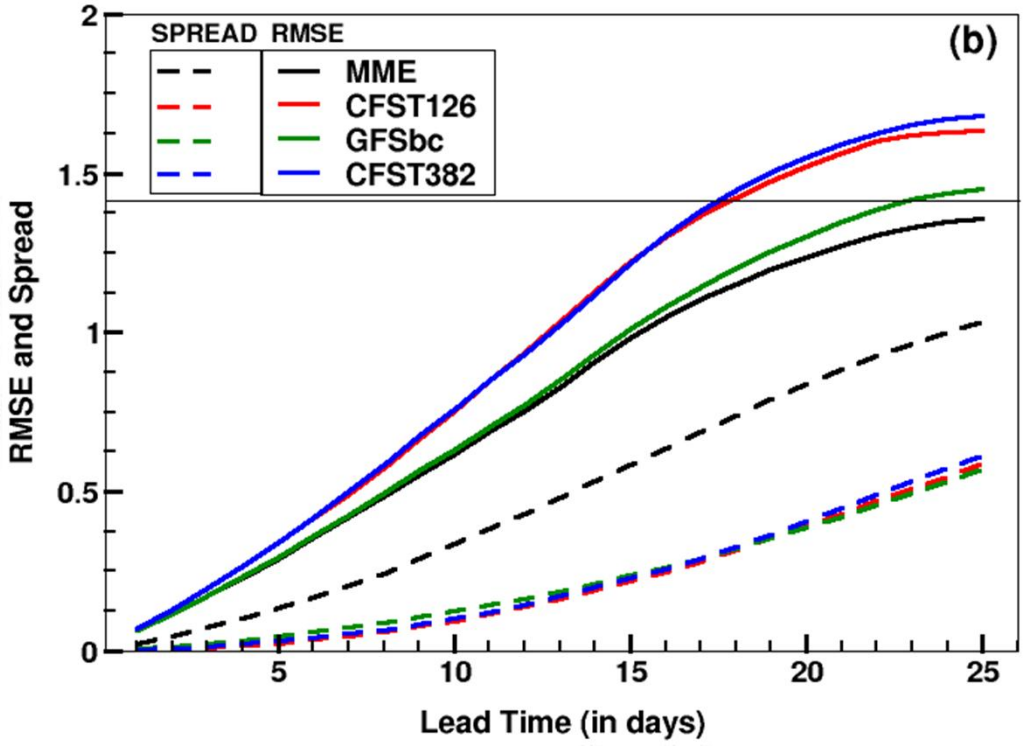
Probabilistic Prediction Skill

Spatial pattern correlation over 40°E-120°E and 40°S-40°N



	CFS126 SME	CFS382 SME	GFSbc SME	MME
P1 Lead	0.87	0.84	0.87	0.89
P2 Lead	0.85	0.85	0.81	0.88
P3 Lead	0.83	0.82	0.78	0.87
P4 Lead	0.79	0.80	0.76	0.86

RMSE and spread of MISO indices

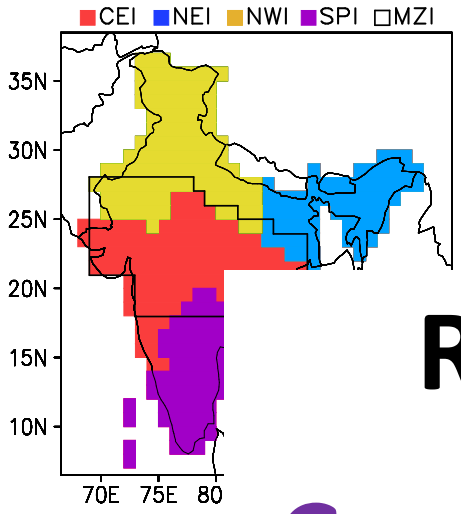


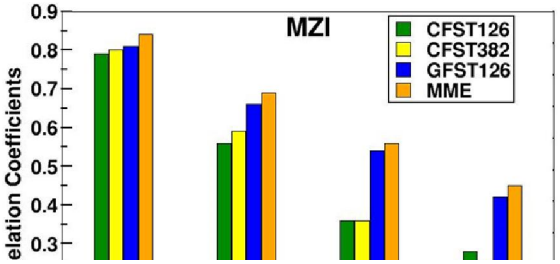
Bivariate RMSE: RMSE w.r.t. observation

Bivariate Spread: Std. Dev of iindividual models w.r.t. Ensemble mean

Considerable improvement in MME is contributed from the increased spread, which overcomes the under-dispersive nature of the individual models in EPS.

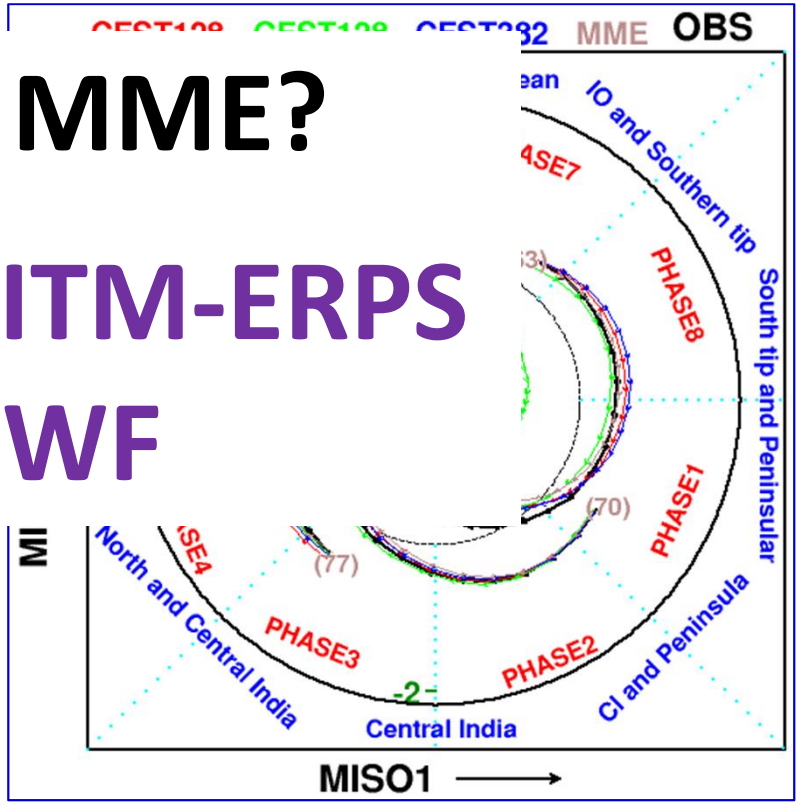
Abhilash et al. 2015, JAMC; BAMS

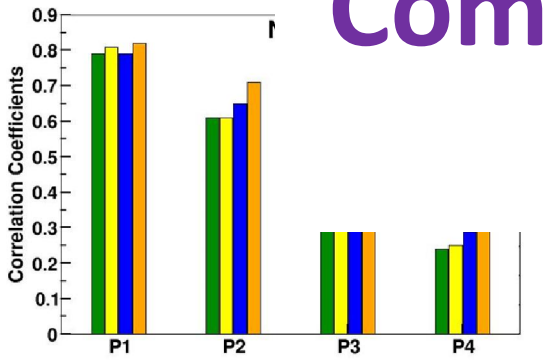


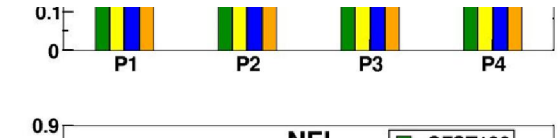


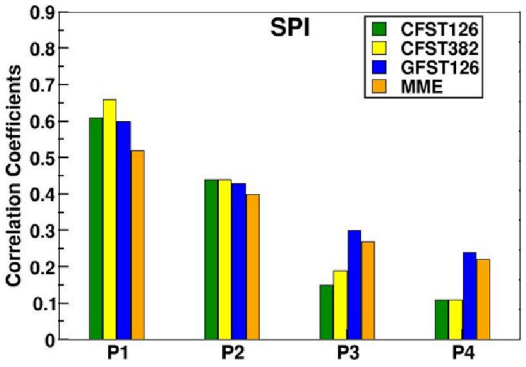
Relook: Why MME?

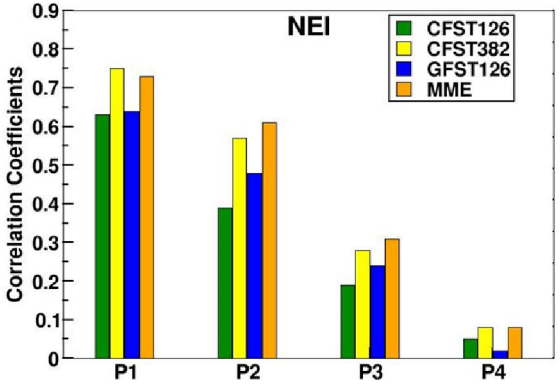
Comparison of IITM-ERPS with ECMWF



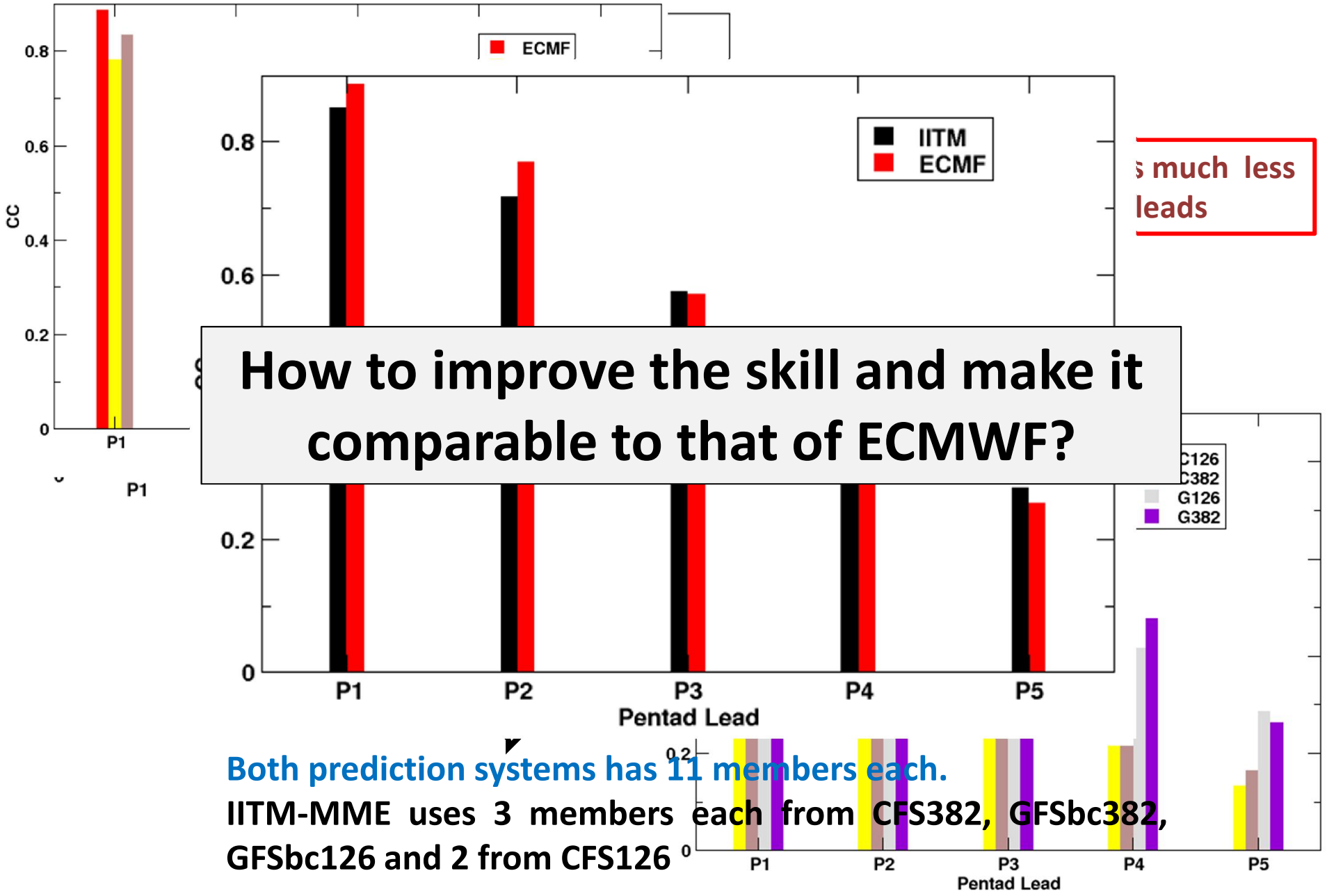








Comparison of IITM-ERPS with ECMWF



s much less leads

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

Both prediction systems has 11 members each.

IITM-MME uses 3 members each from CFS382, GFSbc382, GFSbc126 and 2 from CFS126

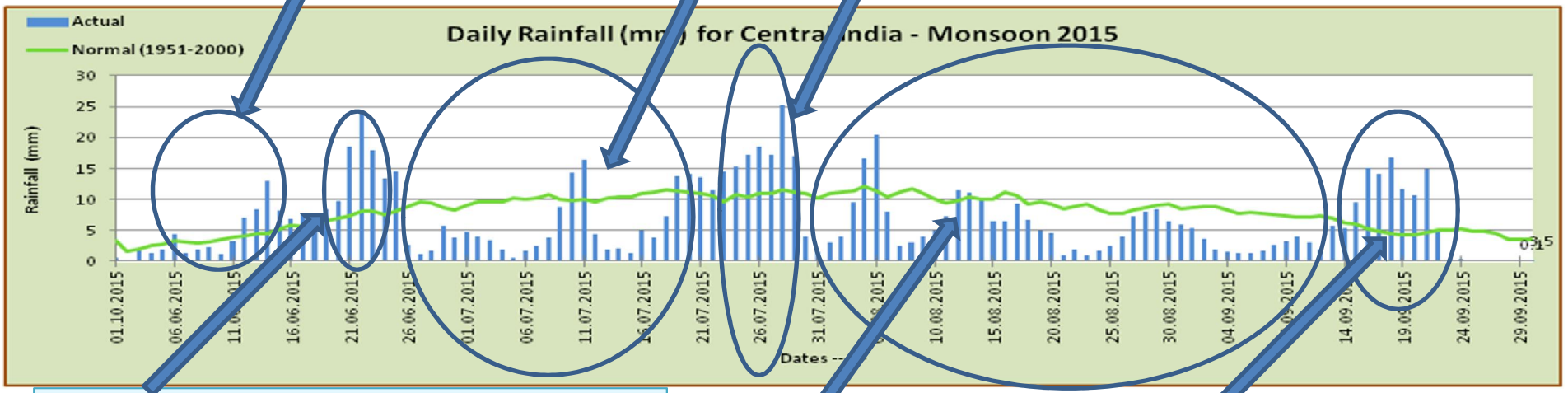
Applications of IITM-ERPS

Prediction of 2015 SW monsoon season

0531: 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.

0620: There will be a large scale reduction of rainfall during 1st half of July.

0710: Large scale monsoon activity is expected to increase by the end of July resulting in revival of monsoon.



0605: It is likely that by 17th June the offshore trough along the west coast will be established and within one week after that, monsoon may reach central India as a feeble current.

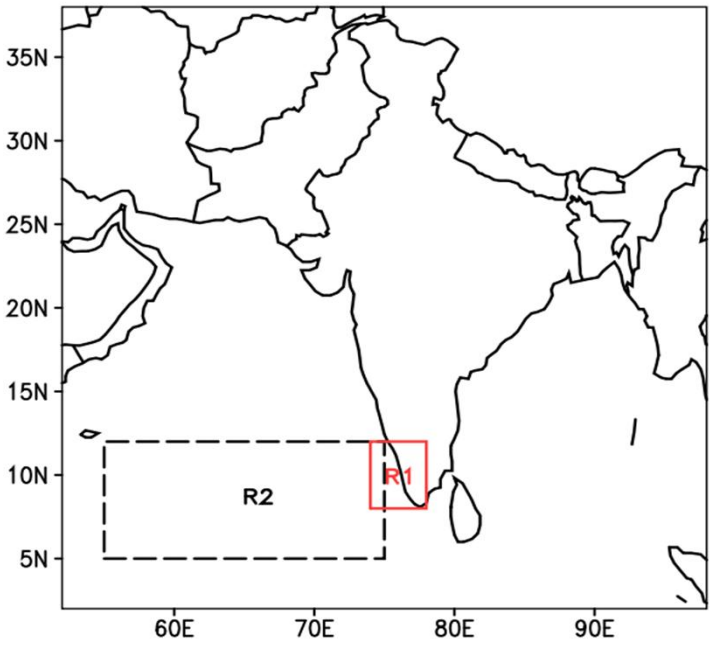
0903: A fresh spell of good rainfall will propagate from Indian ocean to southern peninsula around 20th September and may reach central India around 25th September.

0725: It was forecasted that Monsoon activity will be normal and there is a possibility that it may enter in the break phase around 10th Aug.

ONSET

Criteria for forecasting Monsoon Onset over Kerala (MOK)

Regions for calculating indices



Three indices are defined – one from rainfall over Kerala and others based on the strength and depth of Low level Jet.

ROK index is defined as the rainfall area averaged over 74°-78°E; 8°-12°N (R1); whereas UARAB index is defined as the zonal wind at 850 hPa averaged over 55°-75°E; 5°-12°N (R2). Udepth index is defined as the zonal wind at 600 hPa, averaged over R2 region.

30 day average values of forecasted ROK and UARAB starting from 17 May has been calculated. MOK is defined on the date on which both ROK and UARAB exceed 50% of their mean, and one of them surmounts 70% of its mean, for 5 consecutive days, provided the depth of westerlies is maintained till 600hPa. The ensemble mean MOK date (of all 43 members) is treated as the final predicted MOK date. In this way, the uncertainties arising from the differences in the evolution of monsoon in individual ensemble members are taken care of.

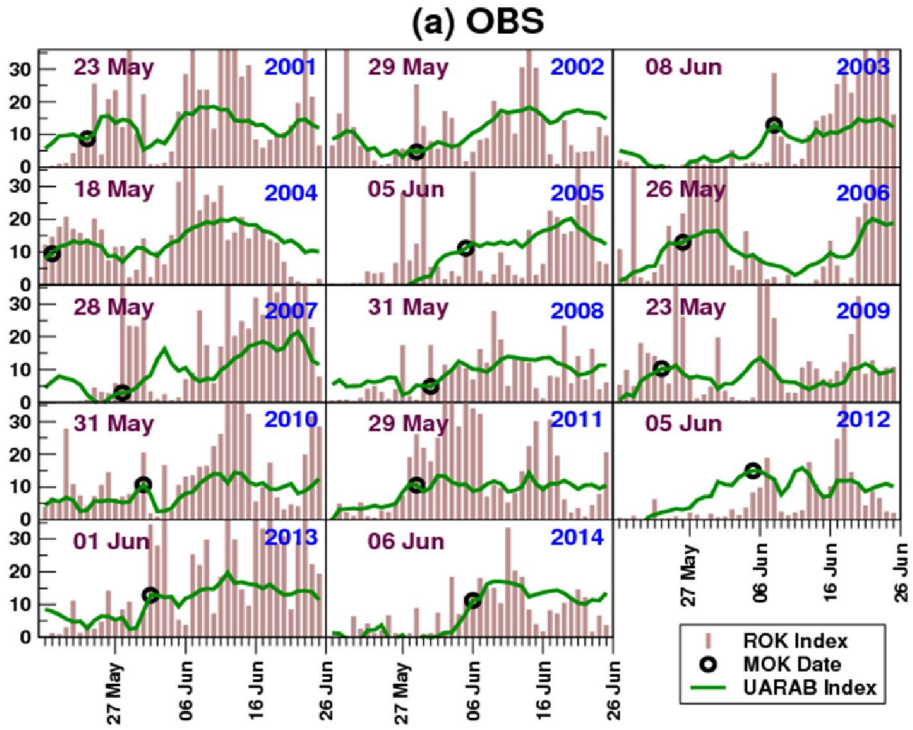
Joseph et al. 2015, J Climate

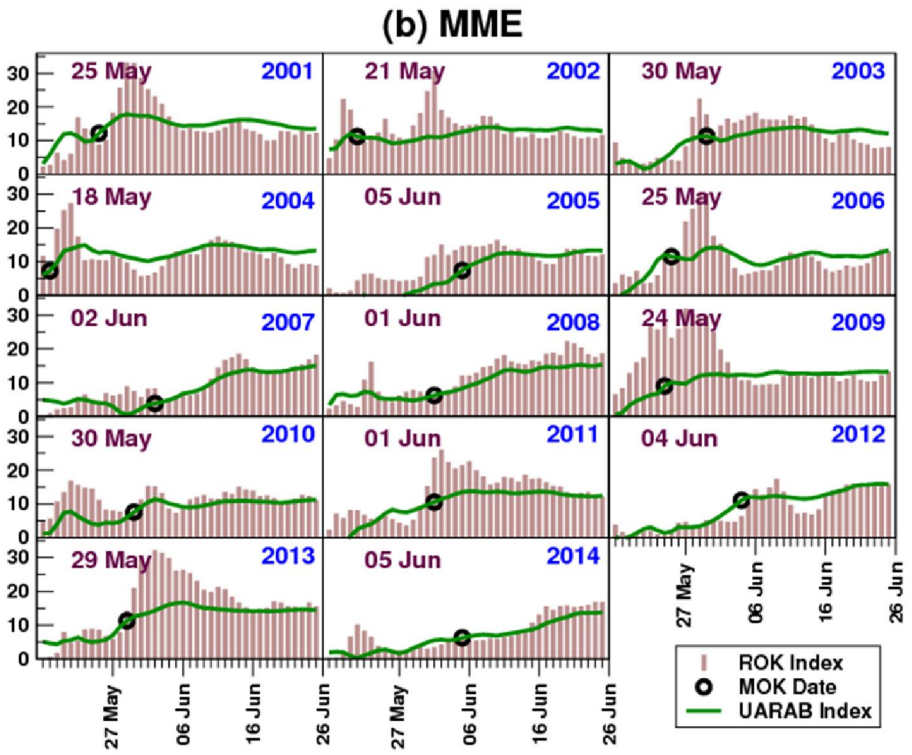
Forecasted and actual MOK for the years 2001-2014

Year	Actual MOK	Forecasted MOK	SD among ensemble members	Difference between actual and forecasted MOK
2001	23 May	25 May	2	2
2002	29 May	21 May	5	8
2003	08 Jun	30 May	5	9
2004	18 May	18 May	1	--
2005	05 Jun	05 Jun	3	--
2006	26 May	25 May	2	1
2007	28 May	02 Jun	8	5
2008	31 May	01 Jun	7	1
2009	23 May	24 May	2	1
2010	31 May	30 May	5	1
2011	29 May	01 Jun	2	3
2012	05 Jun	04 Jun	4	1
2013	01 Jun	29 May	2	3
2014	06 Jun	05 Jun	6	1

Joseph et al. 2015, J Climate

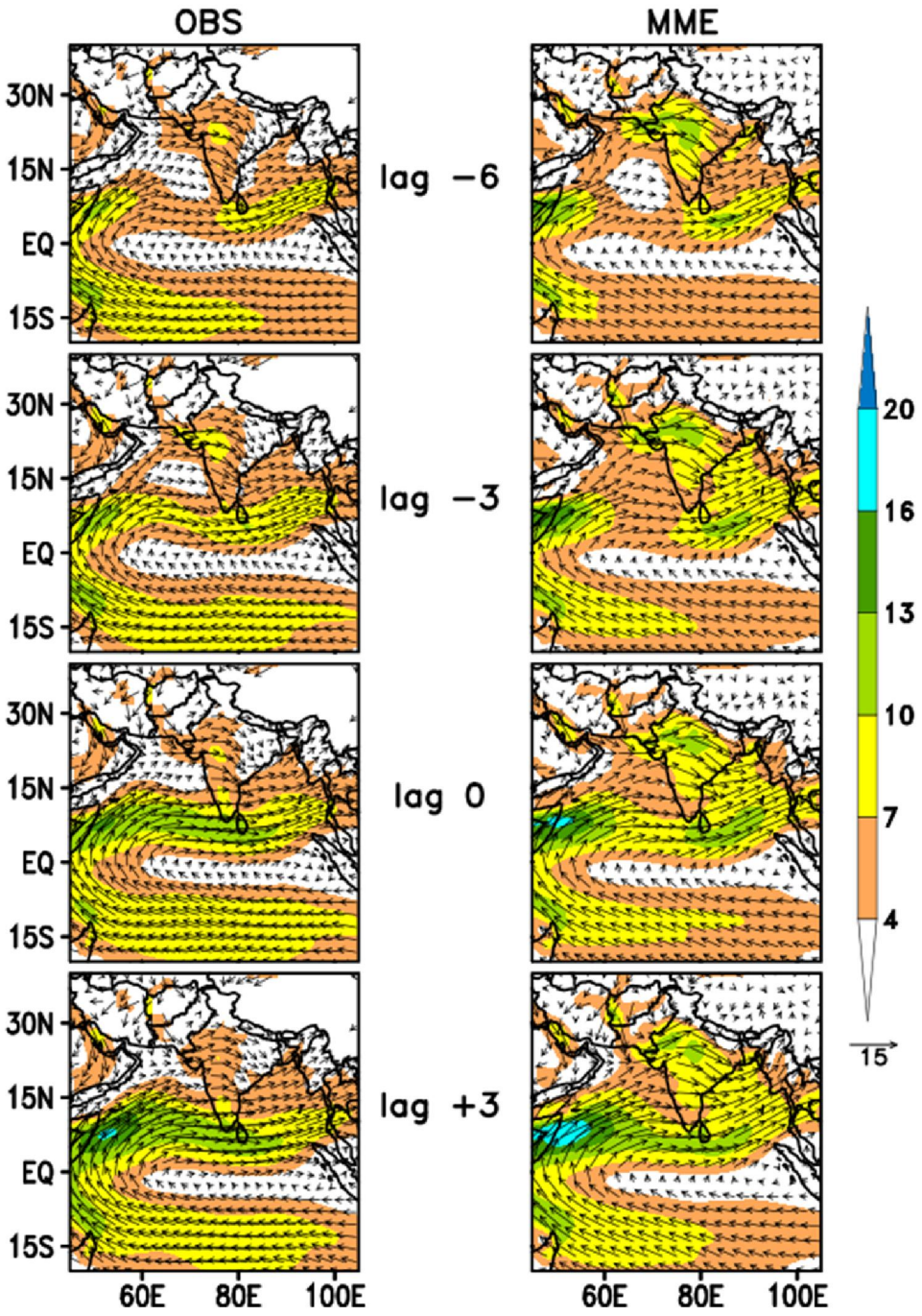
Evolution of ROK index and UARAB index during 2001-14





Joseph et al. 2015, J Climate

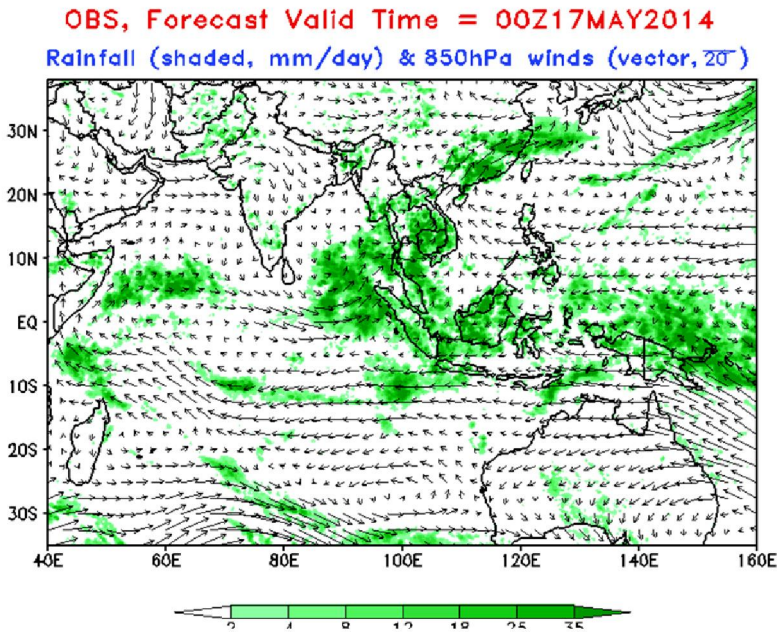
Evolution of wind at 850 hPa

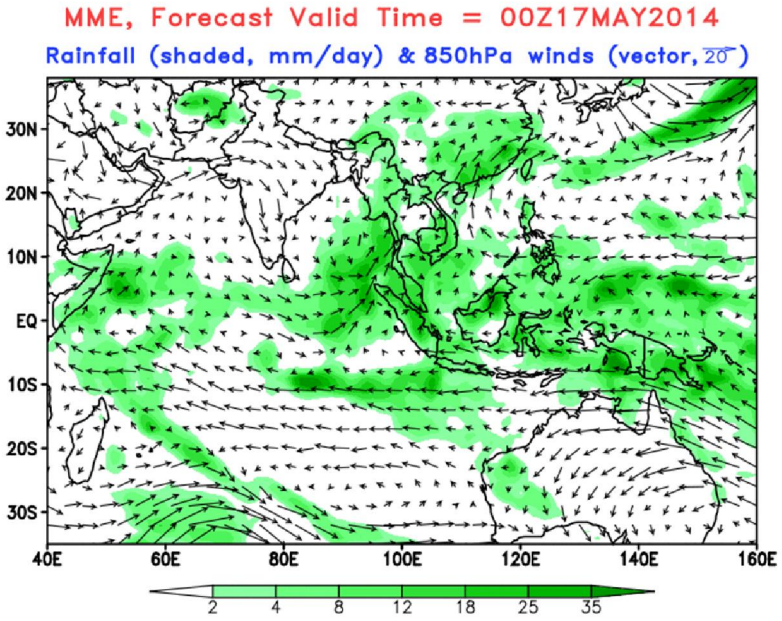


Winds are much stronger in MME compared to OBS.

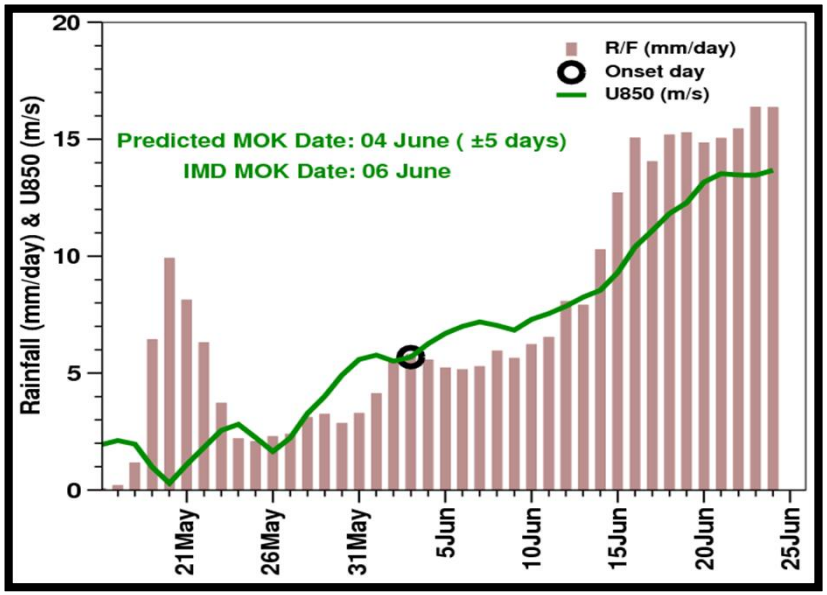
Joseph et al. 2015, J Climate

MOK forecast of 2014 based on IC: 0516





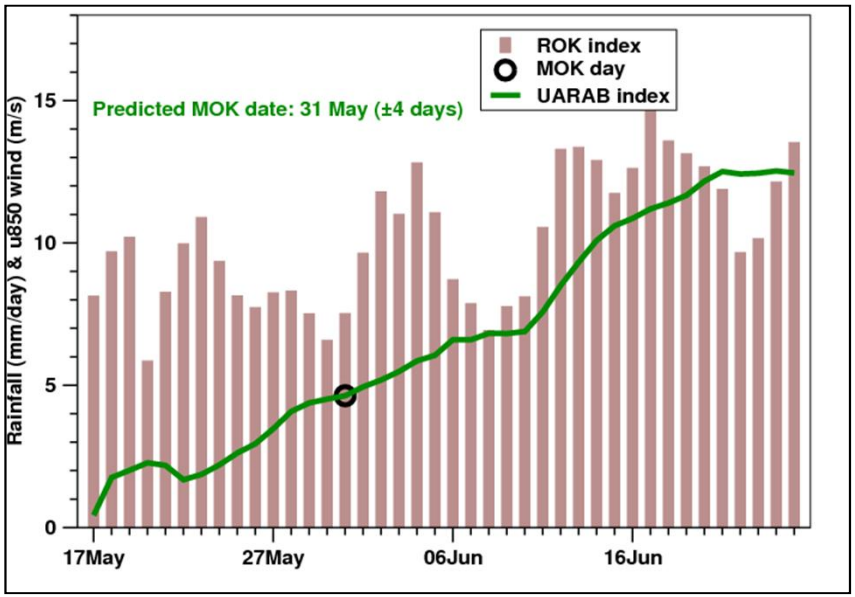
Monsoon Onset over Kerala



Key points from the forecast:

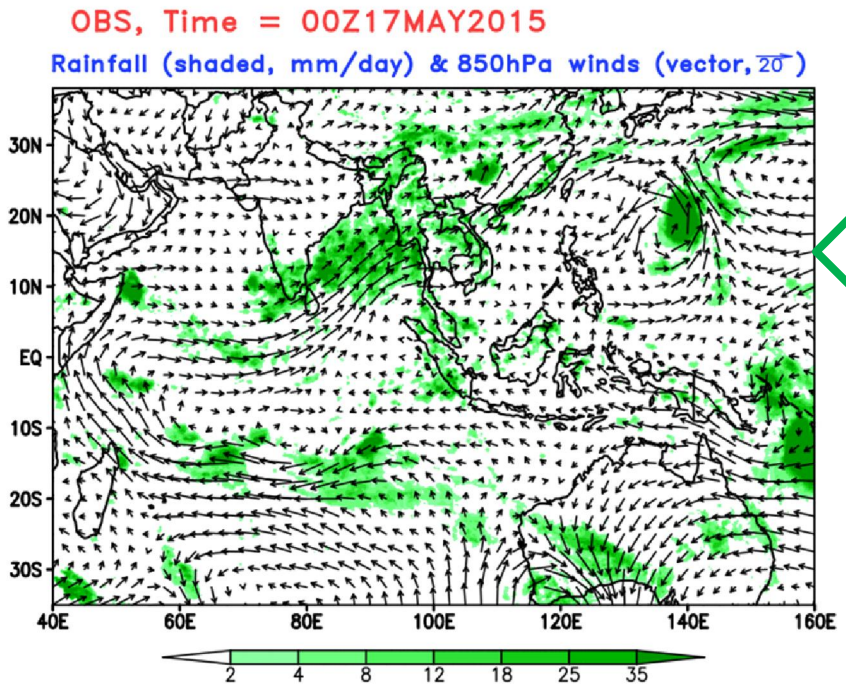
- A low pressure system might form over Bay of Bengal around 25 May 2014 and move northwards.
- South-west monsoon of 2014 would make its onset over Kerala on 04 June.
- However, the strengthening and progression of the monsoon might be slackened till 15 June due to the presence of a low-level anticyclonic circulation over central India. Afterwards, monsoon might strengthen and progress.

Prediction of MOK during 2015 monsoon



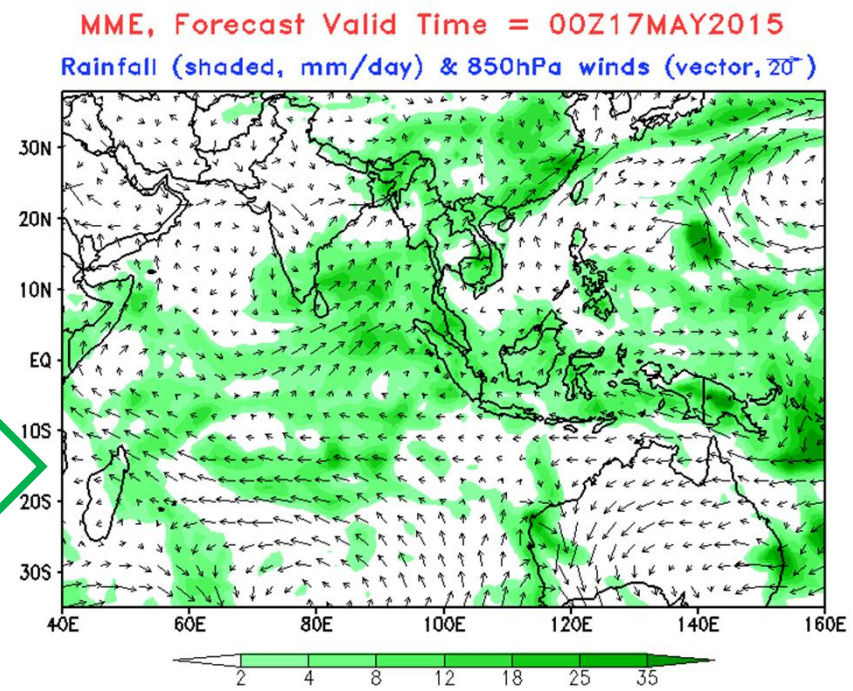
MOK date has been calculated for all 44 members of CGEPS and the mean of all of them is given as the final predicted MOK date.

IC: 16 May



OBS

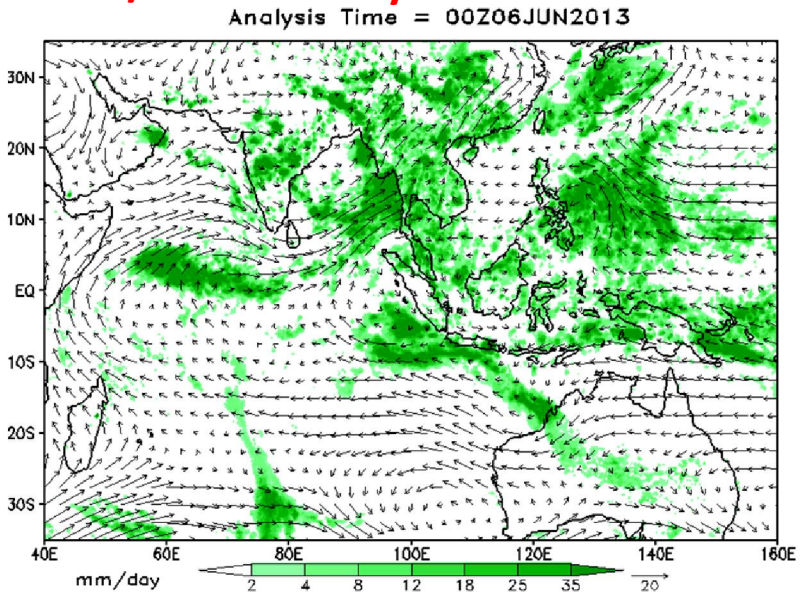
MME



PROGRESSION

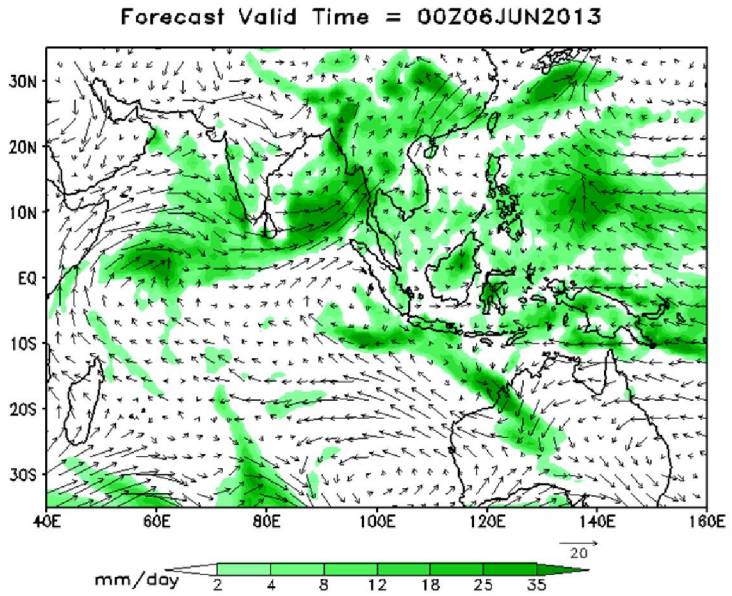
Rapid advancement of 2013 monsoon from IC: 5 Jun

NCEP/TRMM Analysis



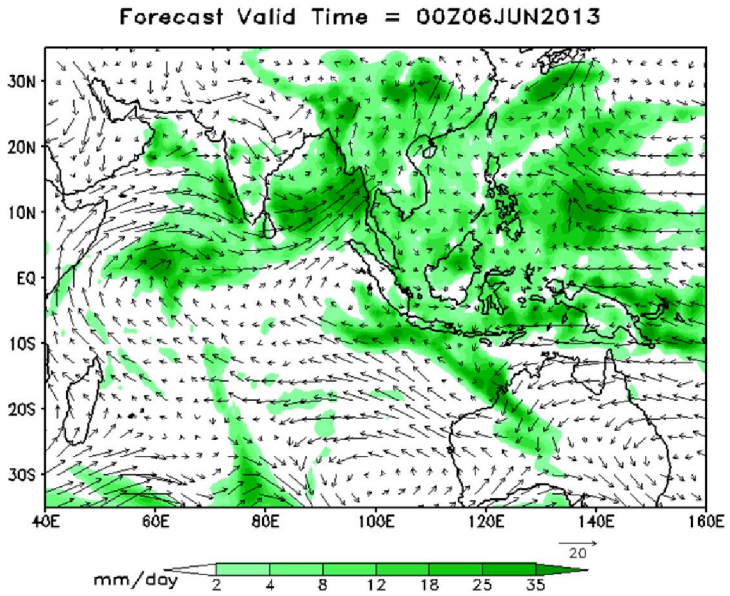
Key points from the forecast:

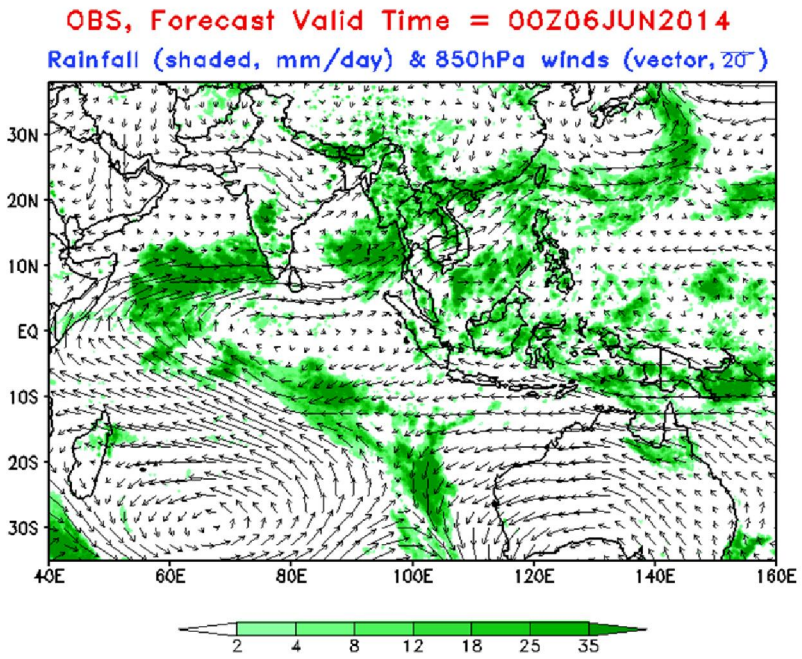
- The low level cross-equatorial flow has strengthened both in CFSv2 and GFSbc. Both CFSv2 and GFSbc show that rainfall over monsoon zone of India (MZI) would start to intensify from 13th Jun onwards. This intensification of rainfall is likely due to the formation of a system over BOB.
- Real time forecast for MISO shows that fresh evolution of MISO is eminent with a prominent northward propagation from both CFSv2 and GFSbc.

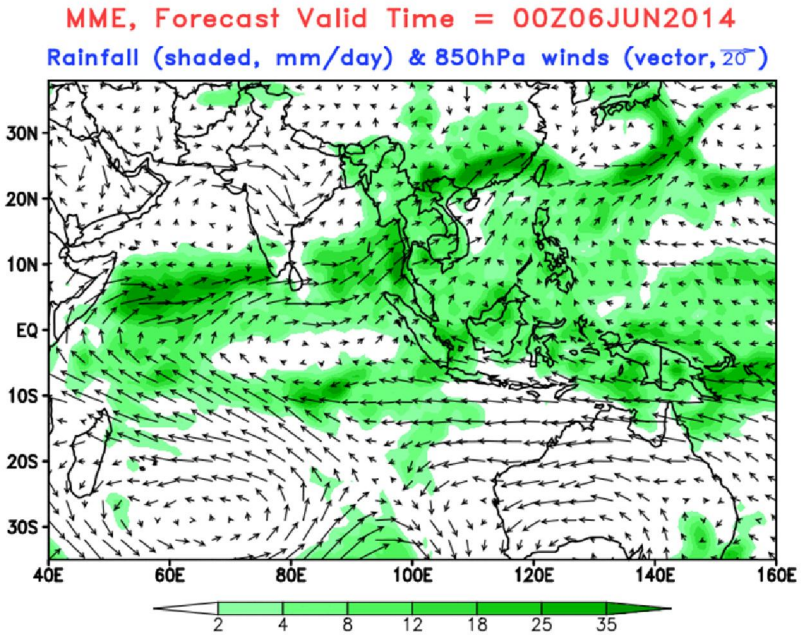


CFSv2

GFSbc







Delayed progression of ISM 2014

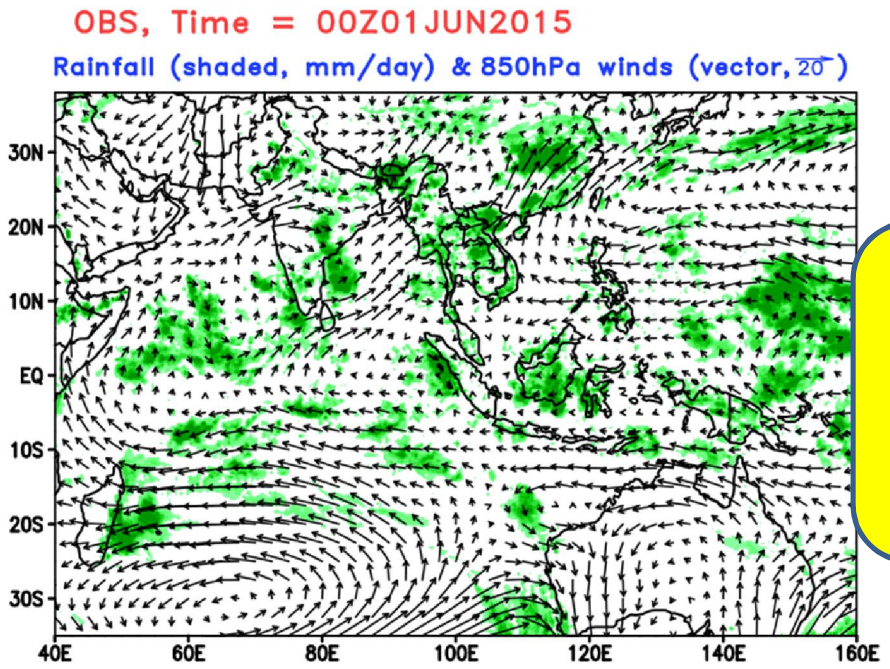
IC: 0605

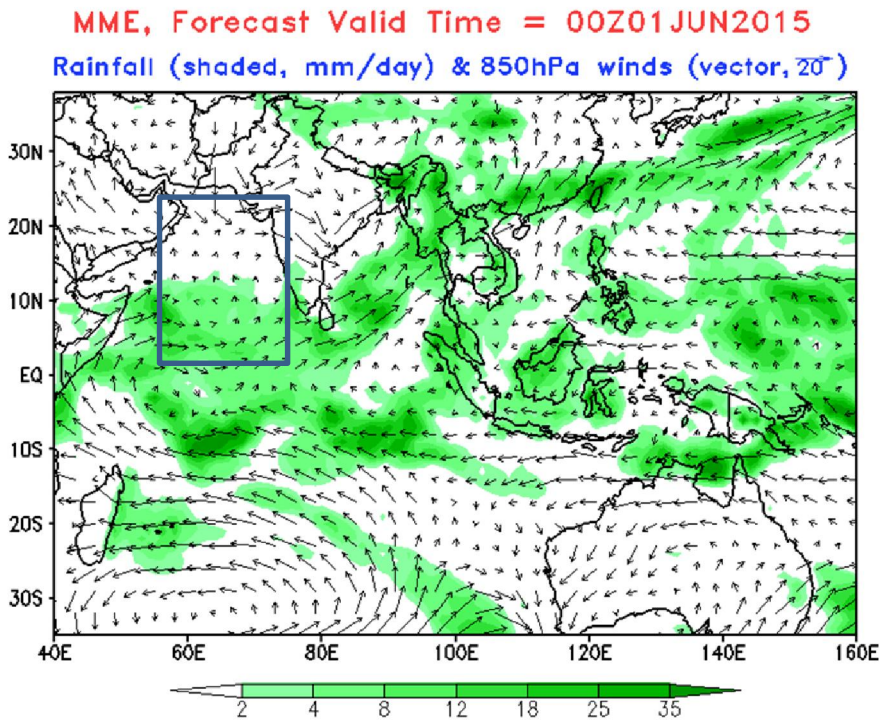
Key points from the forecast:

- **The rainfall would be confined to west coast and NE India up to 20 June.**
- **The surface pressure gradient pattern and low level circulation indicates that the presence of ridge east of western Ghats (anticyclonic circulation over central India) will hamper the establishment of monsoon over Indian land.**
- **Thus, the strengthening and progression of the monsoon seems to be slackened till 20 June and monsoon would reach central India afterwards as a feeble current.**
- **Large scale MISO forecast also suggests that it will be over peninsular India for the next 25 days.**
- **Overall, monsoon activity in June will be mainly confined to west coast, NE India and southern peninsula.**

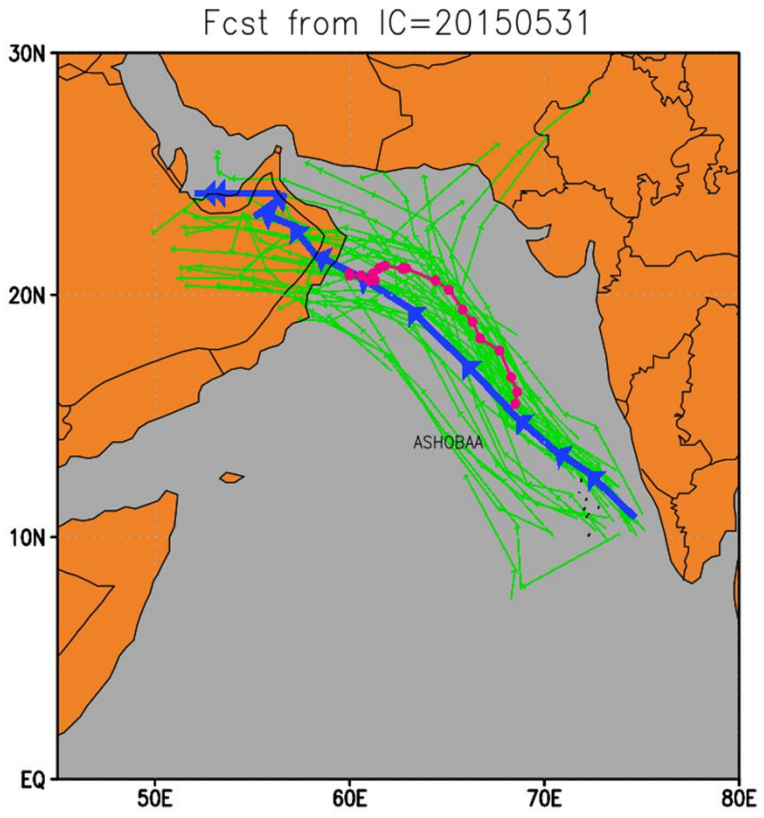
Delayed progression of ISM 2015 due to Cyclone "Ashoba"

IC: 0531



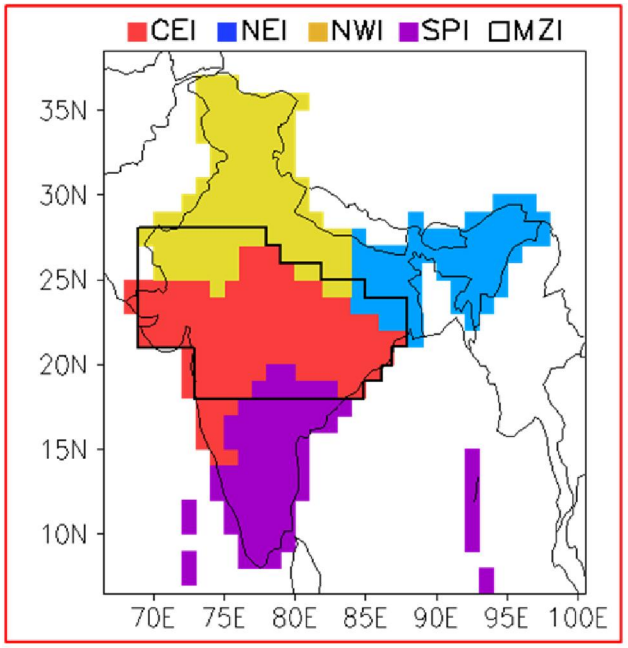


Low Pressure System (LPS) over southern tip of peninsula is likely to intensify and move towards Oman coast. This system may dissipate around 11th June and till then the monsoon activity will be weaker than normal over India.

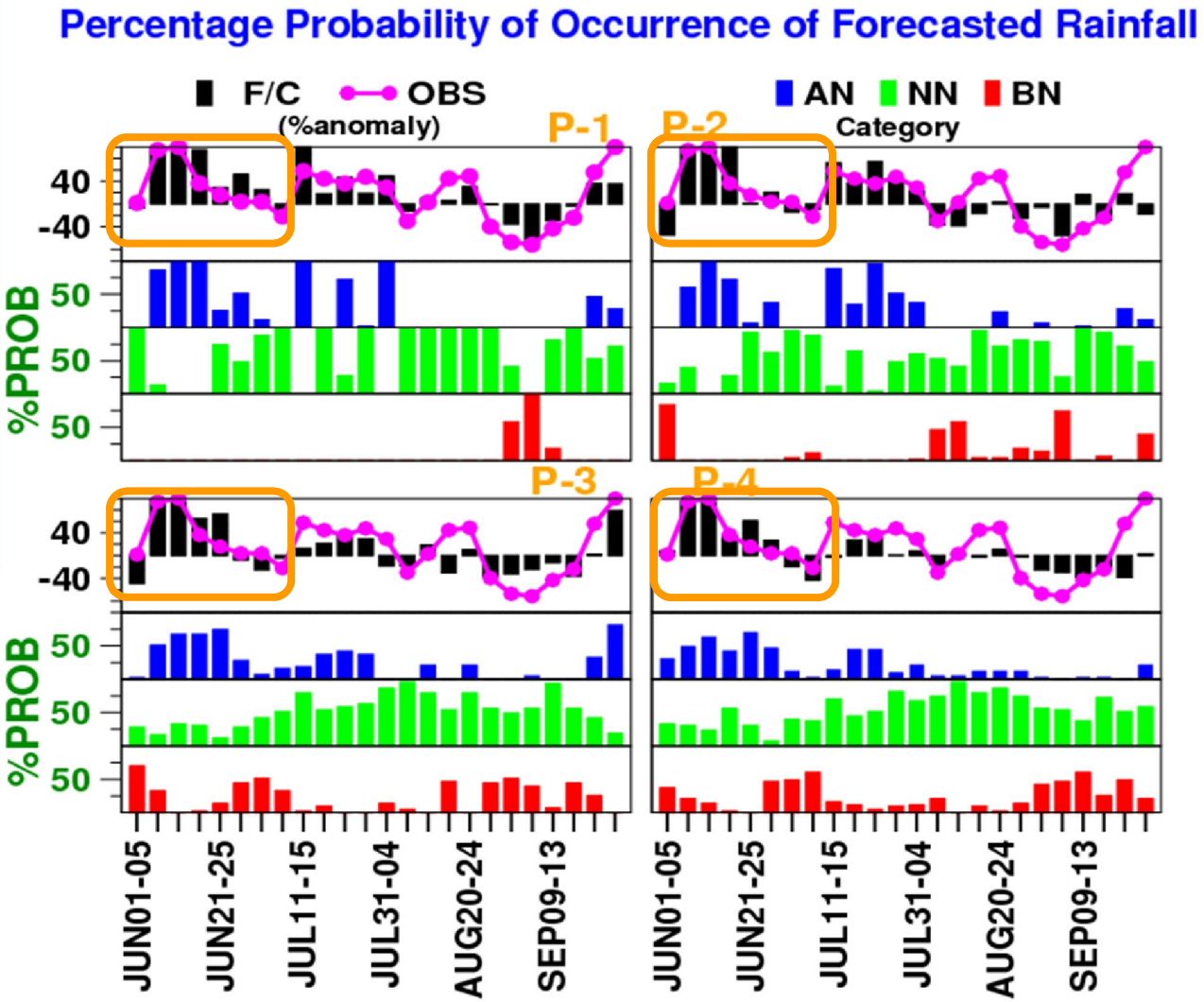


Monthly Extremes

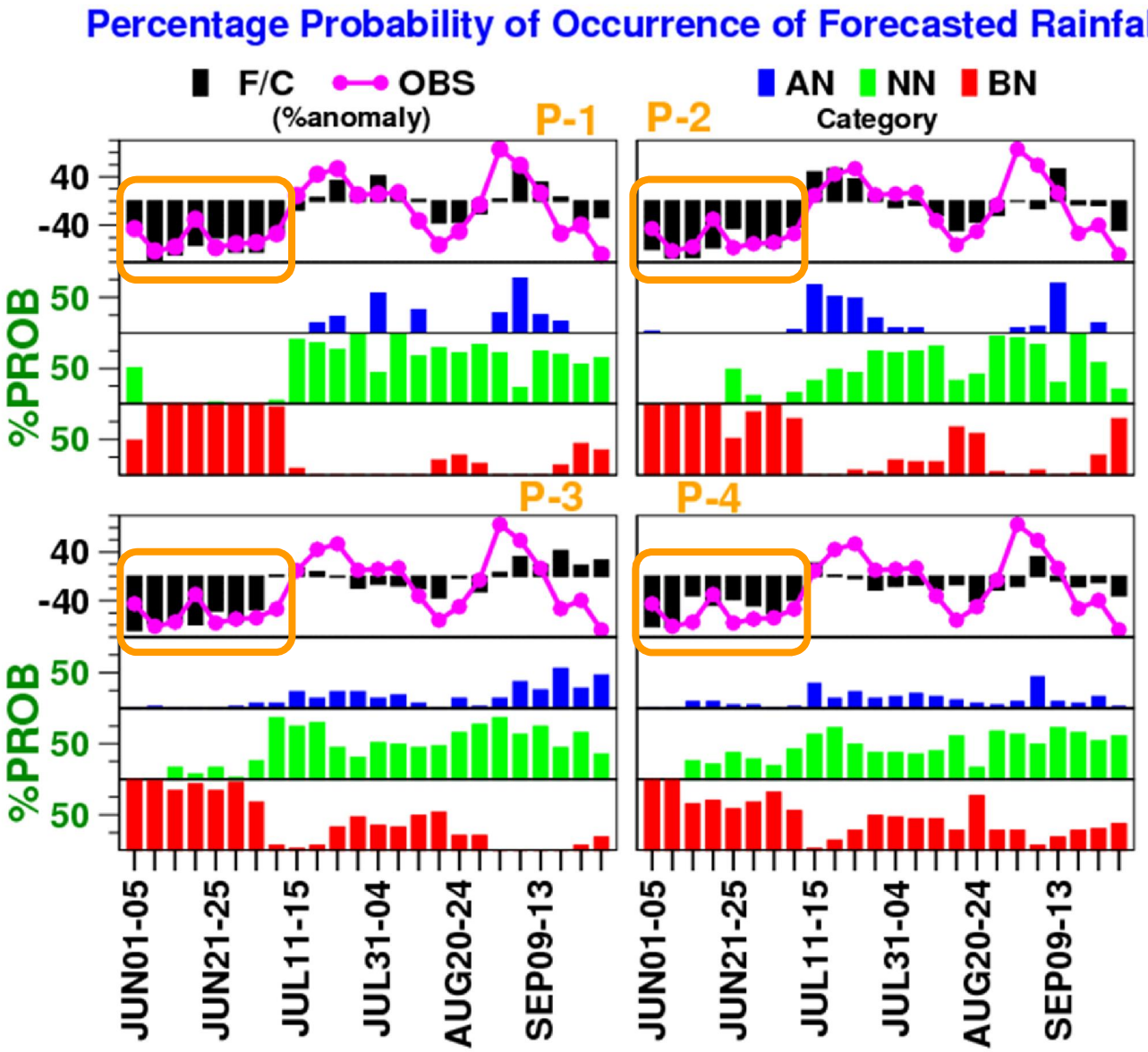
Forecast of 2013 ISM over monsoon zone (MZI)



	CC	RMSE (%)
P1	0.83	29
P2	0.66	41
P3	0.75	34
P4	0.64	39



Forecast of 2014 monsoon over MZI

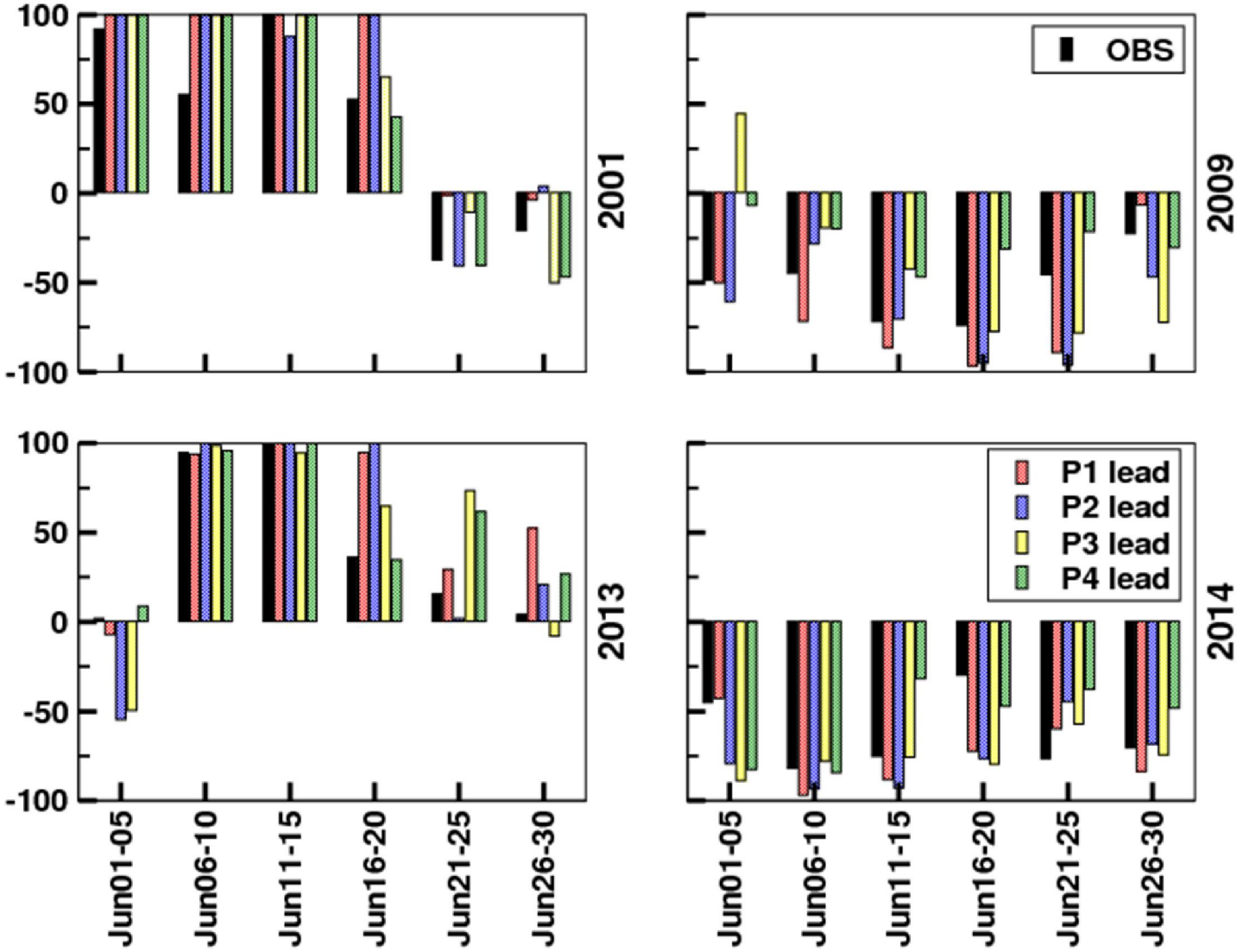


	CC	RMSE (%)
P1	0.82	31
P2	0.79	34
P3	0.57	46
P4	0.72	38

Observed June Rainfall during 2001-14

Year	June Rainfall	Departure from Mean
2001	219.0	35.6
2002	180.1	9.4
2003	179.9	9.8
2004	158.7	-0.8
2005	143.2	-9.5
2006	141.8	-12.7
2007	192.5	18.5
2008	202.0	24.3
2009	85.7	-47.2
2010	138.1	-15.6
2011	183.5	12.2
2012	117.8	-28.0
2013	219.8	34.4
2014	92.4	-43.5

ERP of June extremes by CGEPS MME



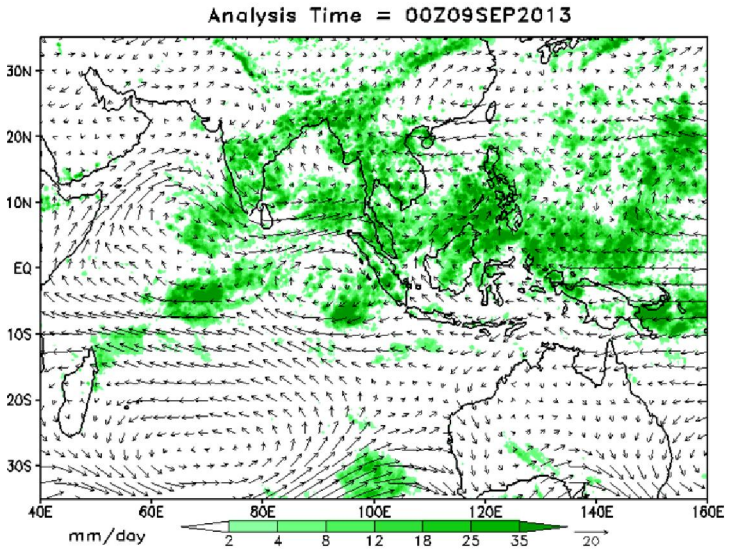
The model has remarkable skill in predicting the June extremes !!!

Joseph et al. 2016, QJRMS

WITHDRAWAL

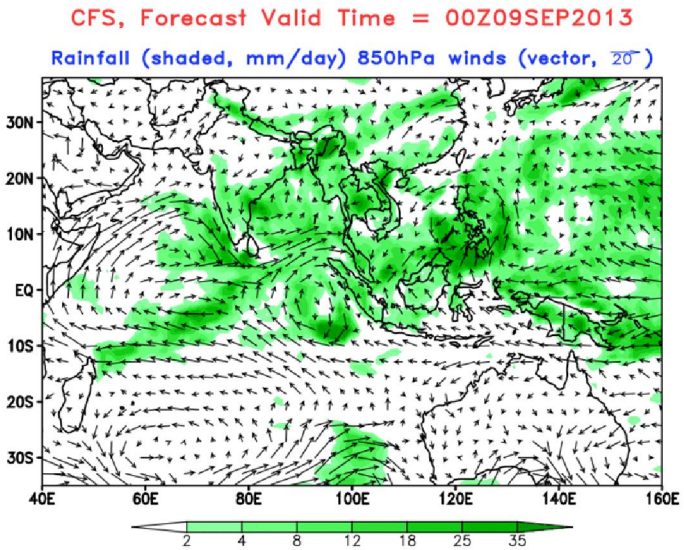
Revival of monsoon was well predicted from 08 September IC, which helped IMD in declaring the withdrawal of monsoon

2013

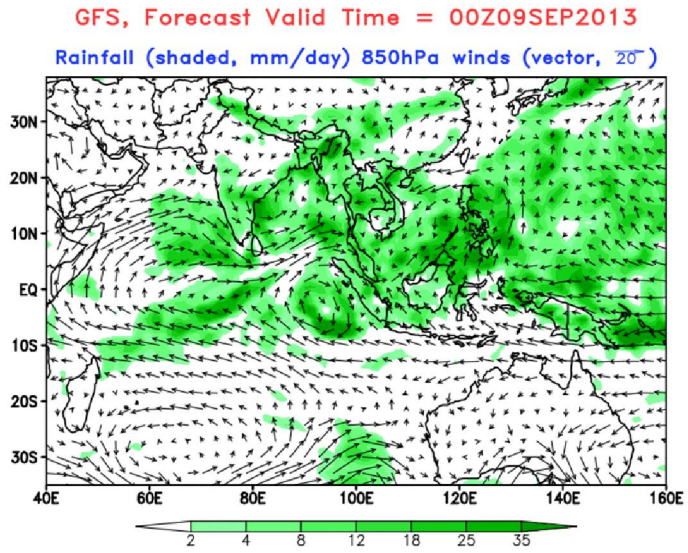


CFST126

OBS

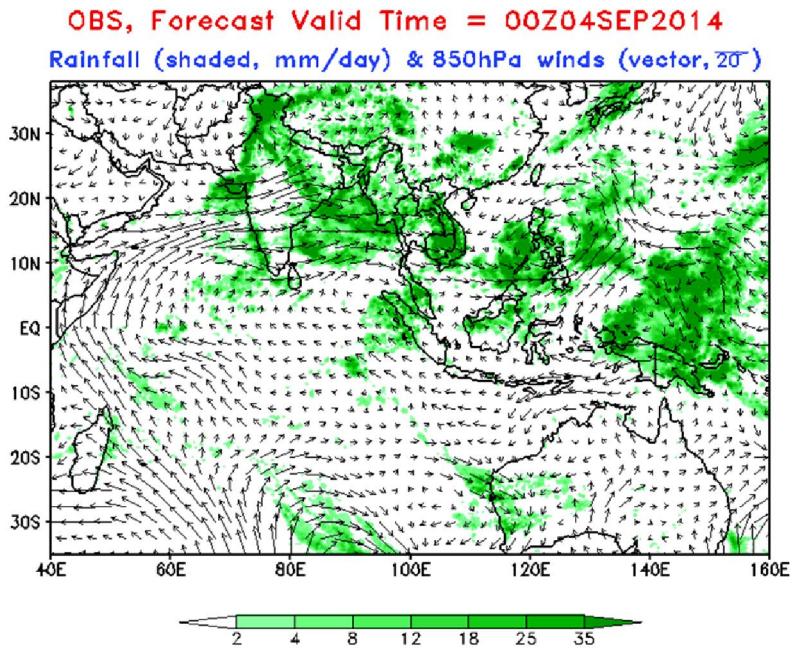


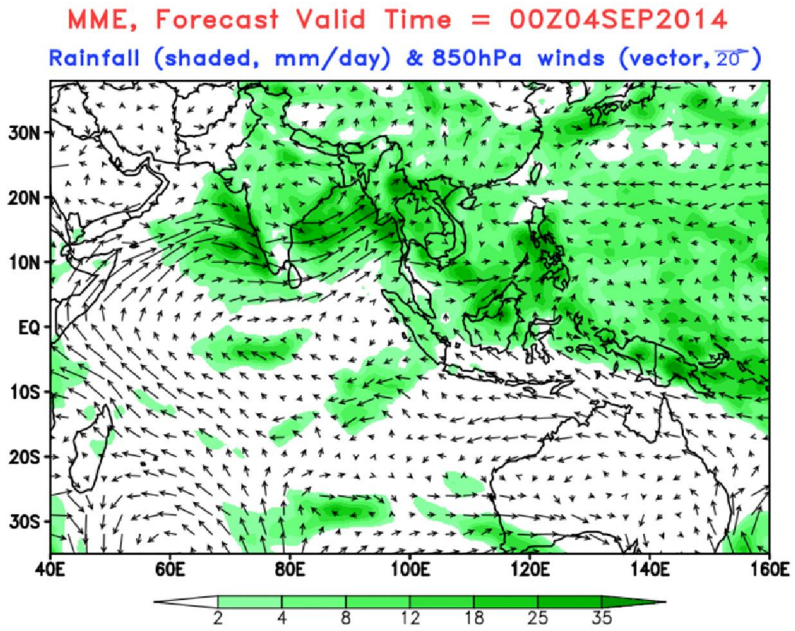
GFSbc



Key points from the forecast:

- **It is expected that monsoon will revive in next few days. Forecast shows that rainfall activity is likely to be near normal to above normal over Peninsula in P1 and over Central and North India in P2-P3.**
- **Real time forecast for MISO shows that associated convective activity is likely to propagate from Peninsula to North India through Central India.**





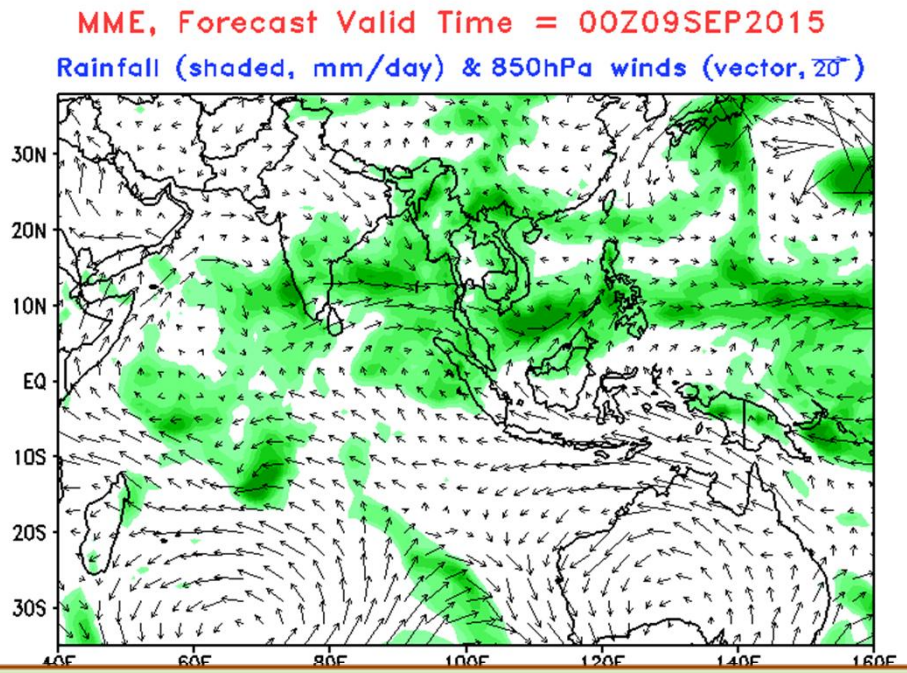
Withdrawal of ISM 2014

IC: 0903

Keypoints from the forecast:

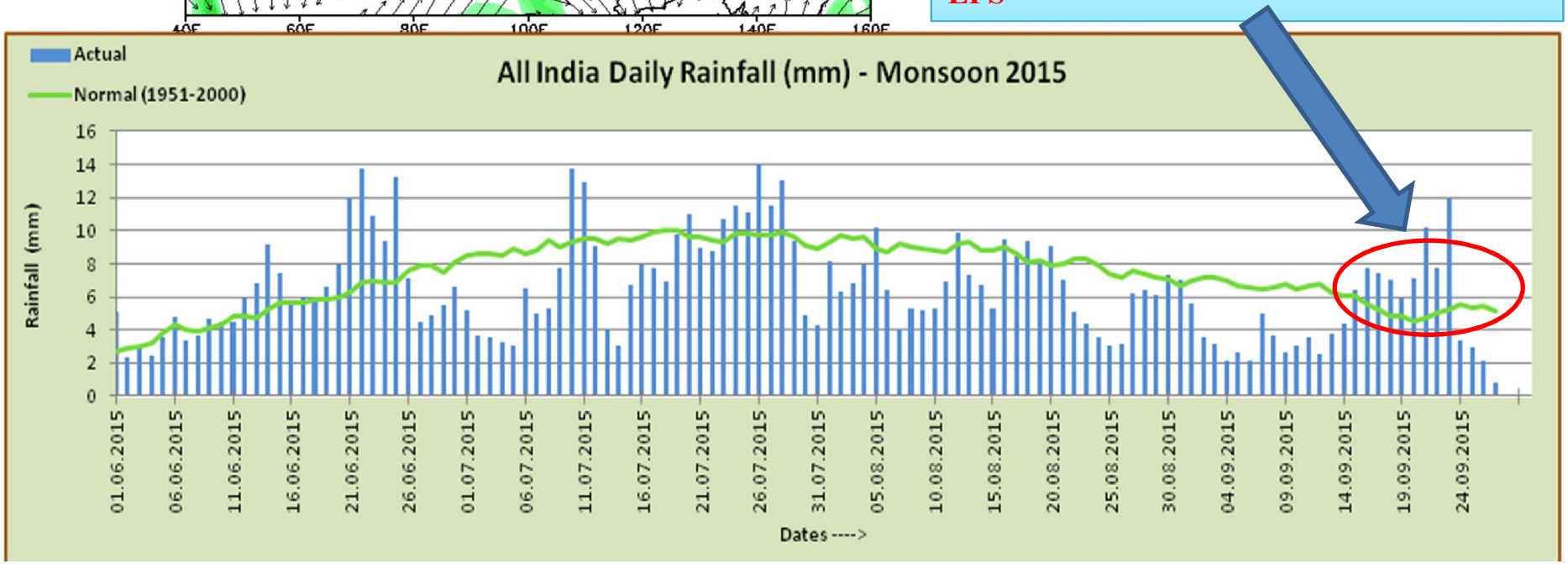
- **Although monsoon activity will be normal over northern India (with increased amplitude over northwest India) for the next 5-10 days, conditions of withdrawal is expected to occur 20 September onwards.**
- **Large scale MISO activity is shifting towards the foothills and will be active over northern India for the next 10-15 days.**

Outlook for September 2015 (8 Sep IC)



Daily evolution of rainfall and wind at 850hPa (by MME)

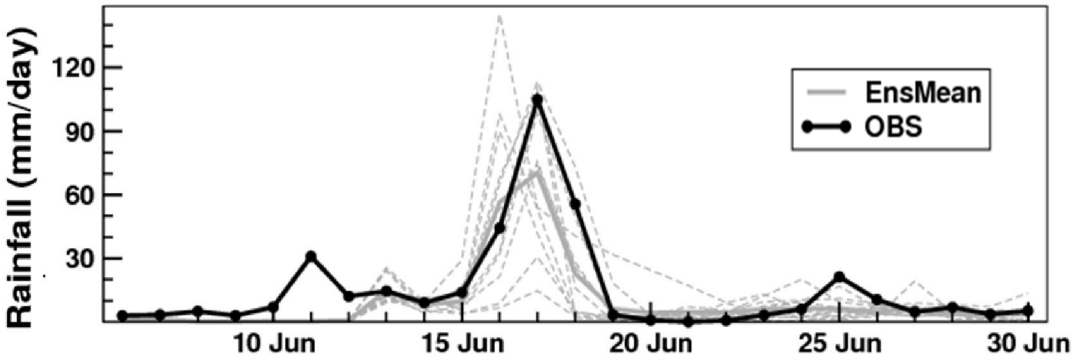
It was forecasted that monsoon will be active after 17 September due to formation of twin LPS



EXTREME EVENTS

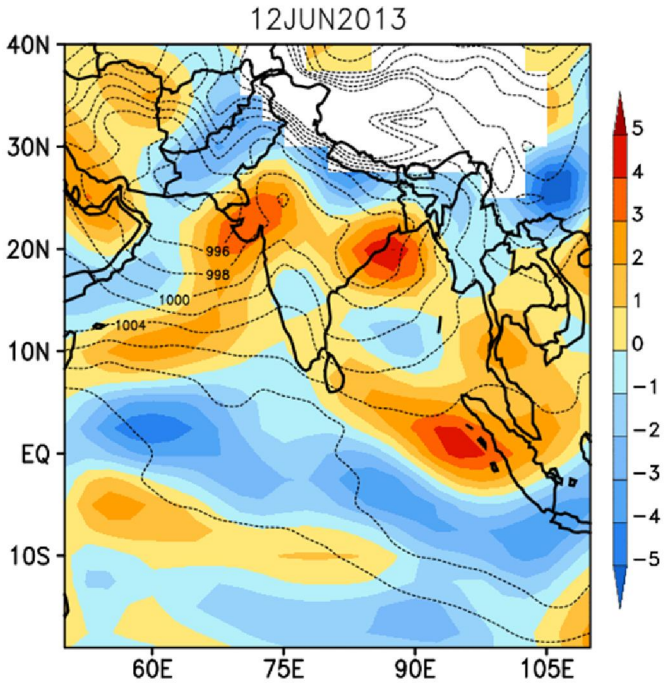
Prediction of Heavy Rainfall Events

IC: 05 June



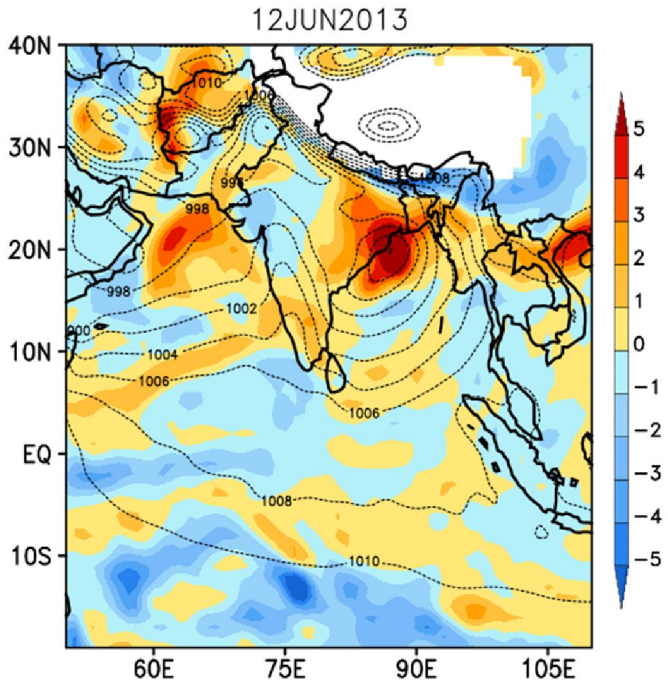
Uttarakhand event in June 2013

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

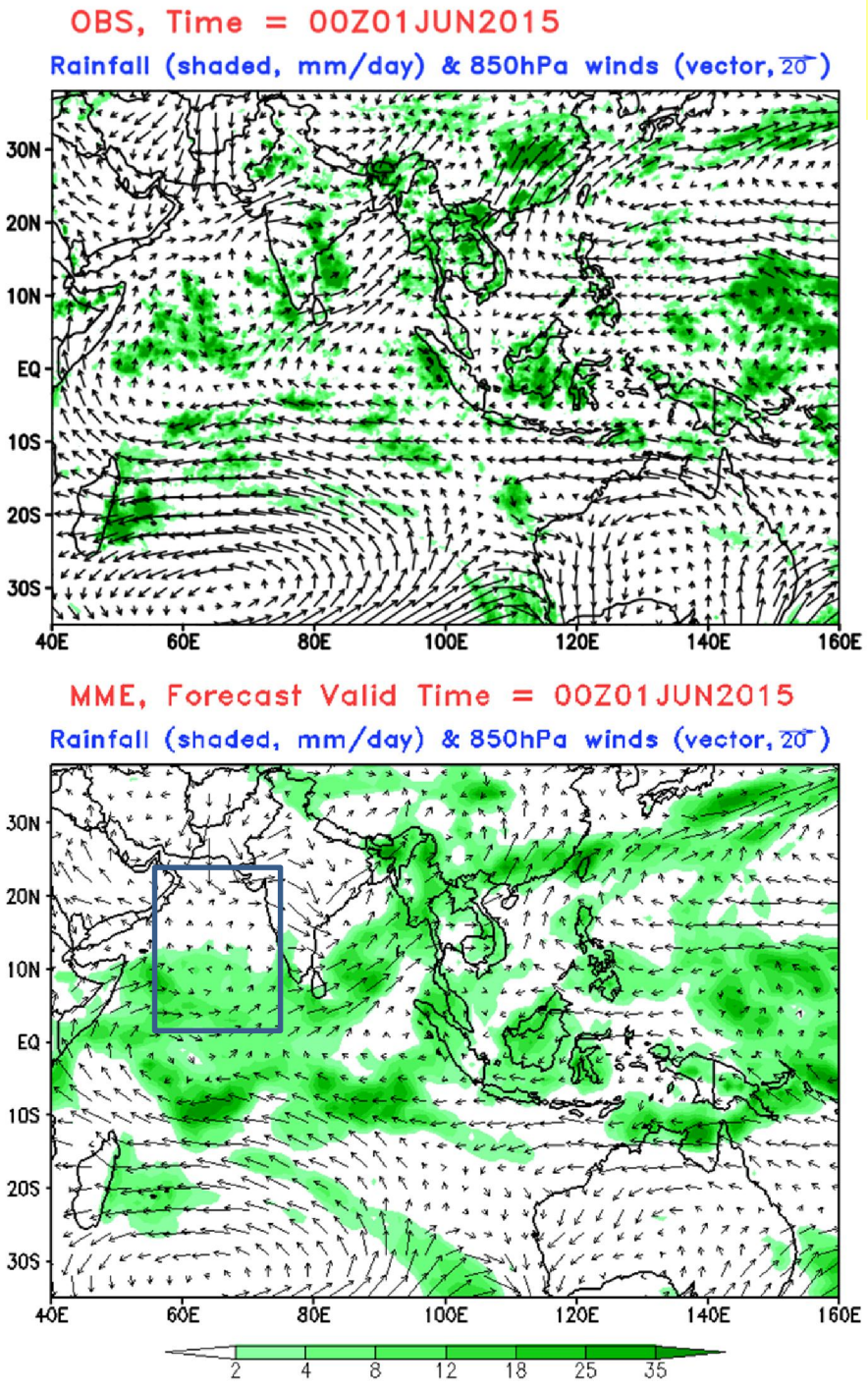


OBS

Forecast

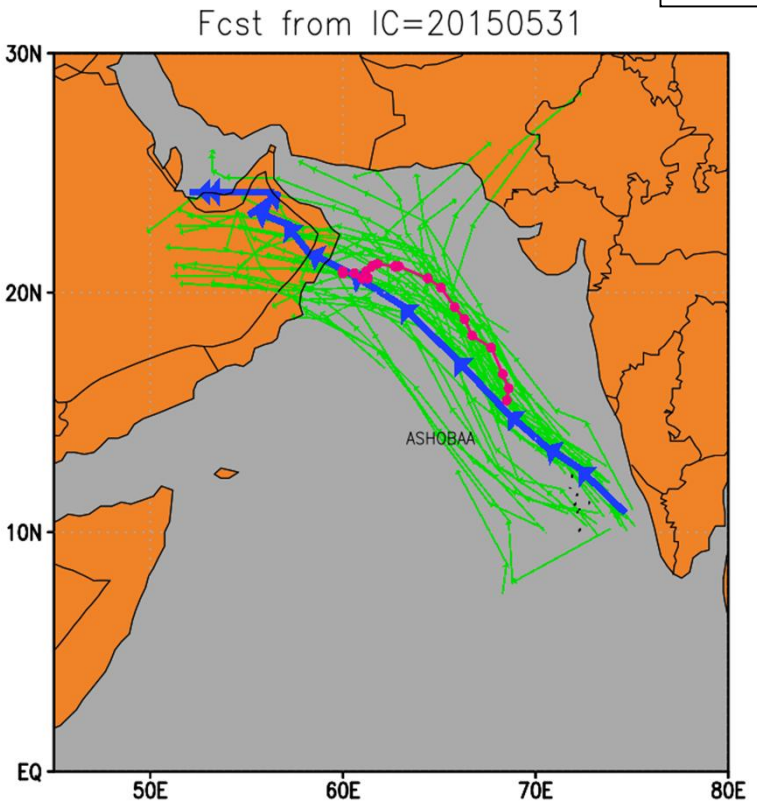


Prediction of Cyclogenesis



Cyclone "Ashobaa" during Onset phase of 2015 monsoon

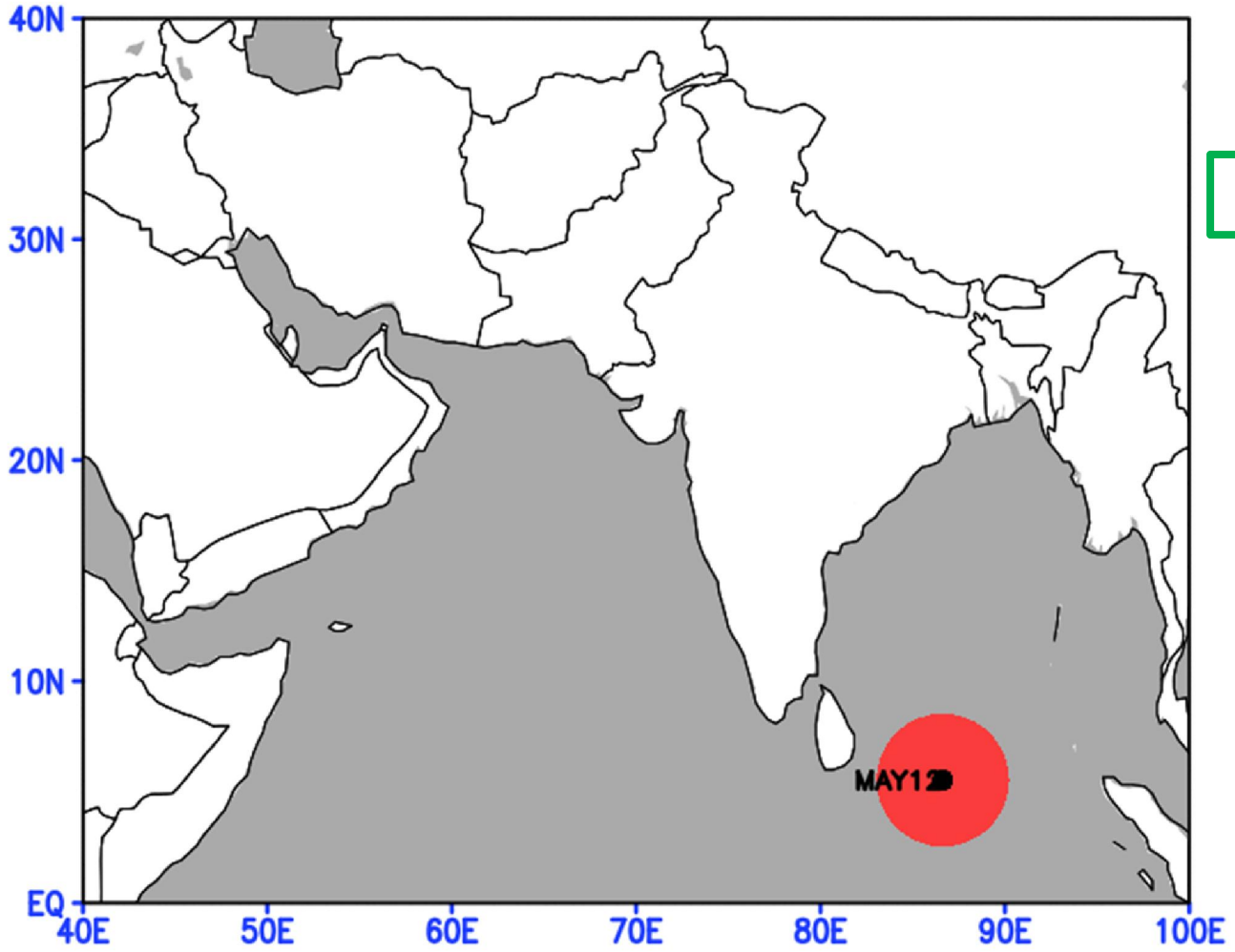
IC: 0531



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

Extended Range Prediction of Cyclone – Roanu in May 2016



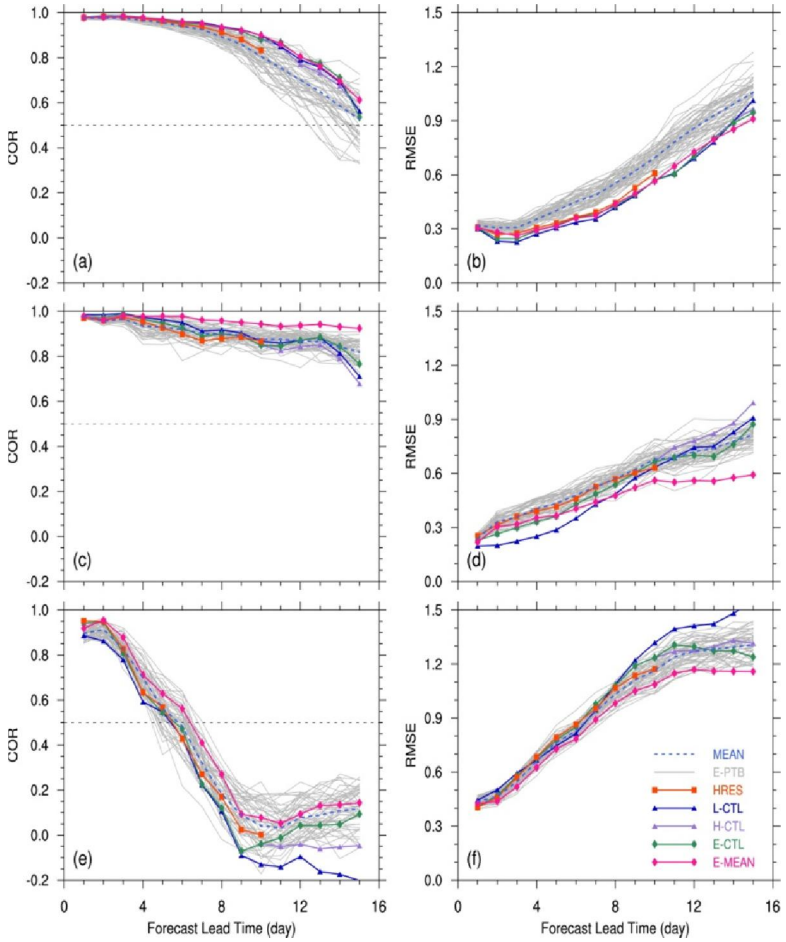
IC: 11 May

OBS

MME

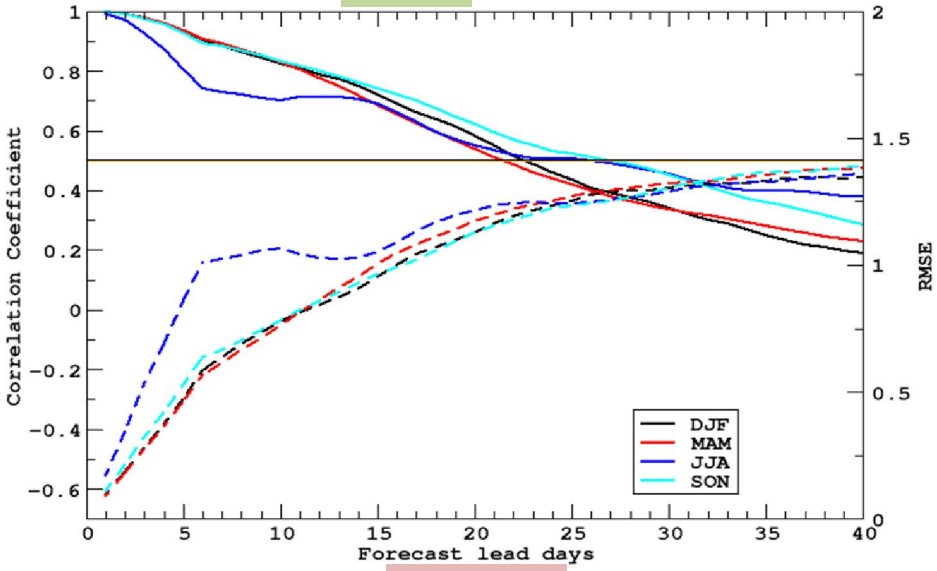
Prediction of MJO

ECMWF

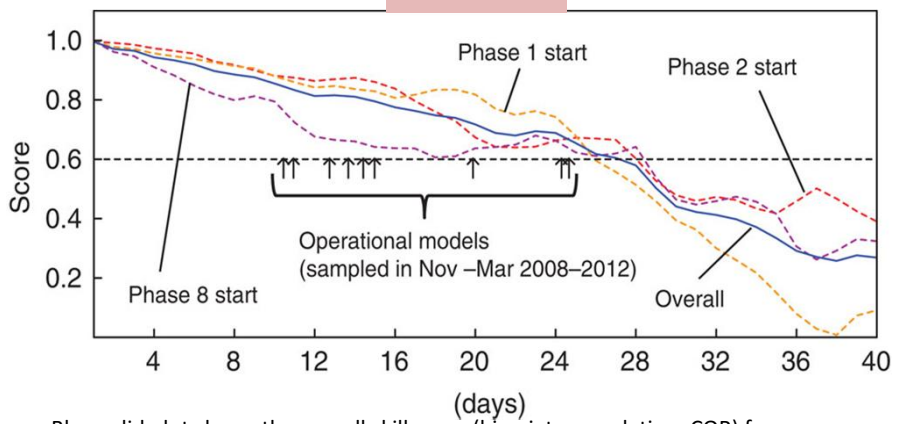


Jian Ling, Peter Bauer, Peter Bechtold, Anton Beljaars, Richard Forbes, Frederic Vitart, Marcela Ulate, and Chidong Zhang, 2014: Global versus Local MJO Forecast Skill of the ECMWF Model during DYNAMO. Mon. Wea. Rev., 142, 2228–2247.doi: http://dx.doi.org/10.1175/MWR-D-13-00292.1

IITM



NICAM

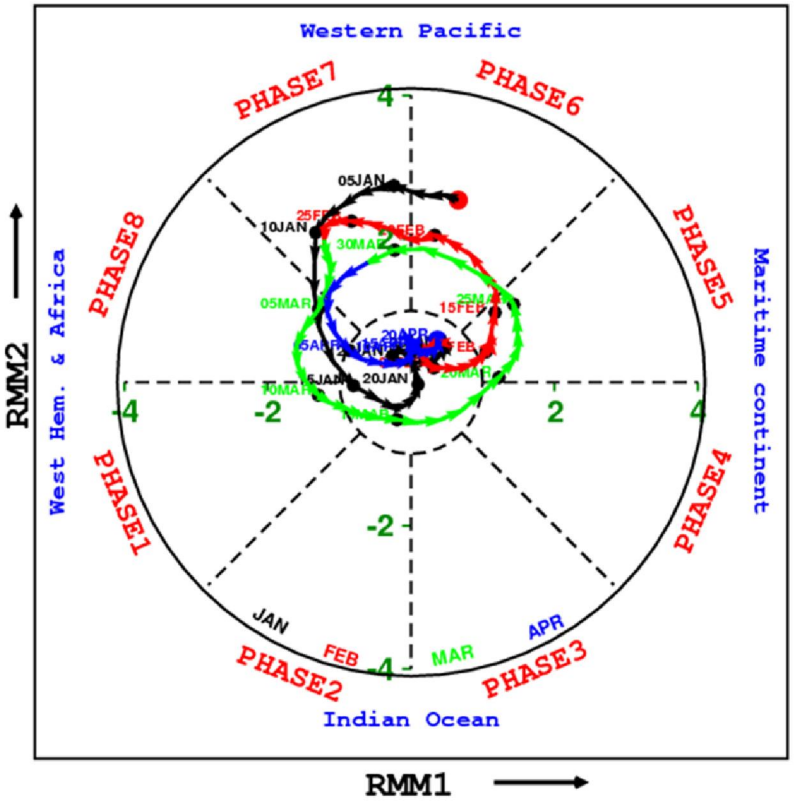


Blue solid plot shows the overall skill score (bivariate correlation; COR) for all 54 simulations. Broken plots show COR for groups of simulations initialized at phase 8 (purple, 17 members), phase 1 (orange, 18 members) and phase 2 (red, 19 members). Arrows indicate the durations COR>0.6 is maintained by recent operational models

Miakawa et al., Nature Comm (2014).,5, doi:10.1038/ncomms4769

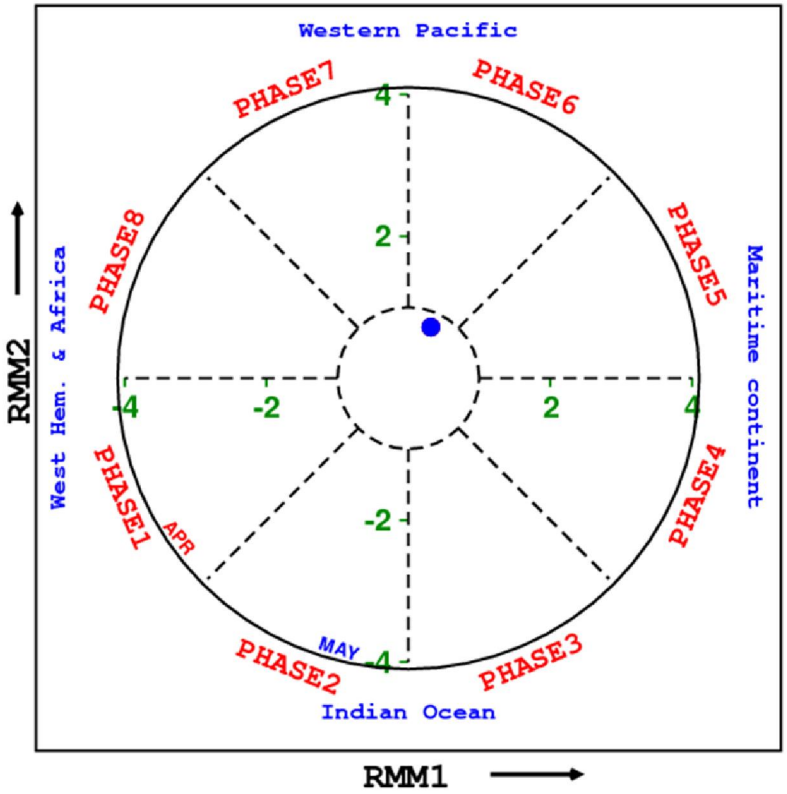
Extended Range Prediction of MJO

Real Time MJO monitoring of 2016 JAN APR



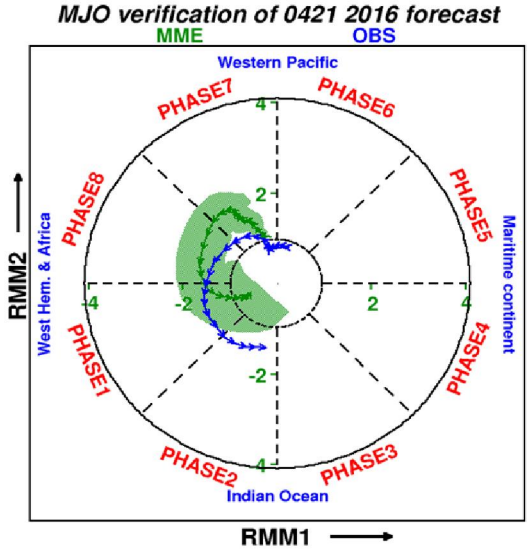
Observed MJO during 01Jan-20Apr 2016

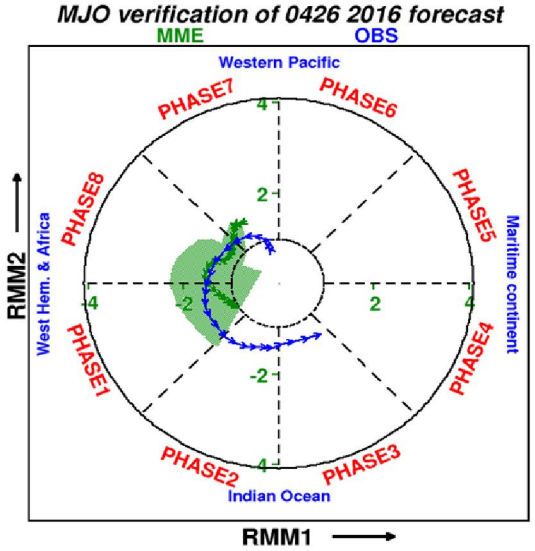
Real Time MJO monitoring of 2016 APR MAY

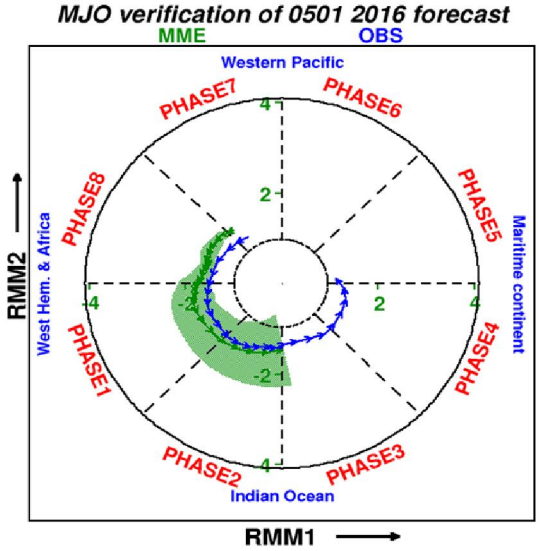


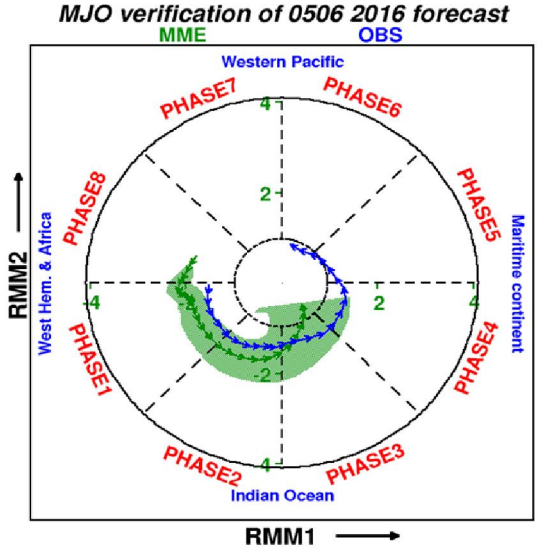
Observed MJO in May 2016

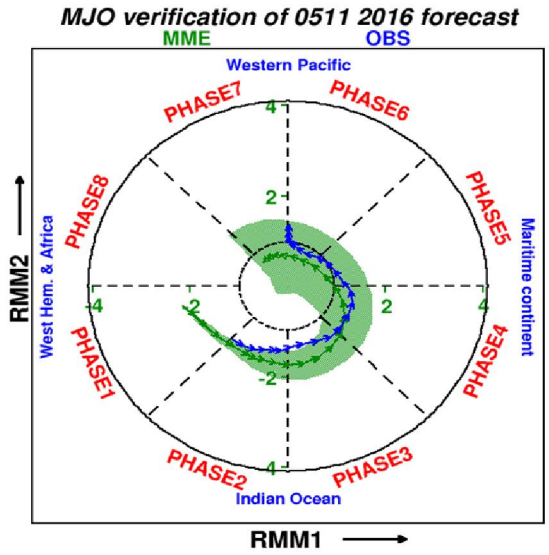
Extended Range Prediction of MJO







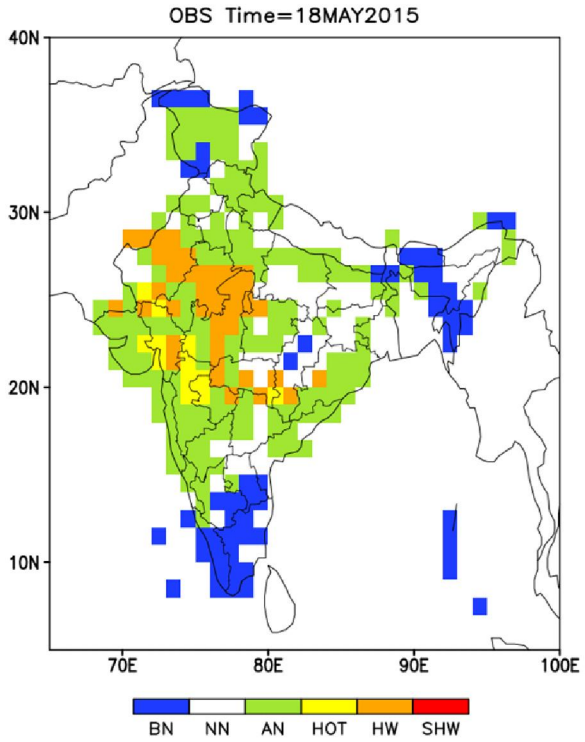




(PC1, PC2) phase space plot for next 25 days for MAY 2016 MJO event. Blue is for Observation and green is for the IITM extended range forecast for different ICs

Prediction of Heat Waves

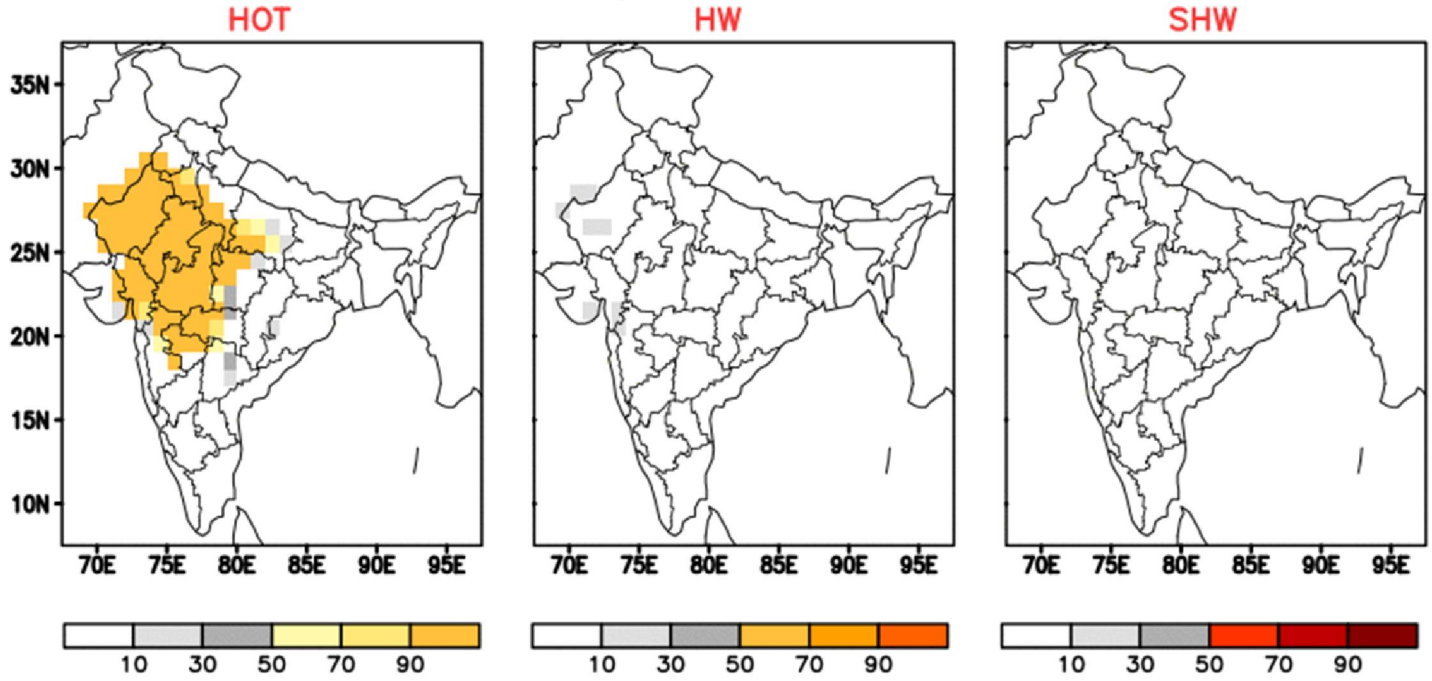
2015 Heat Wave over East Coast of India



Observed Heat Index

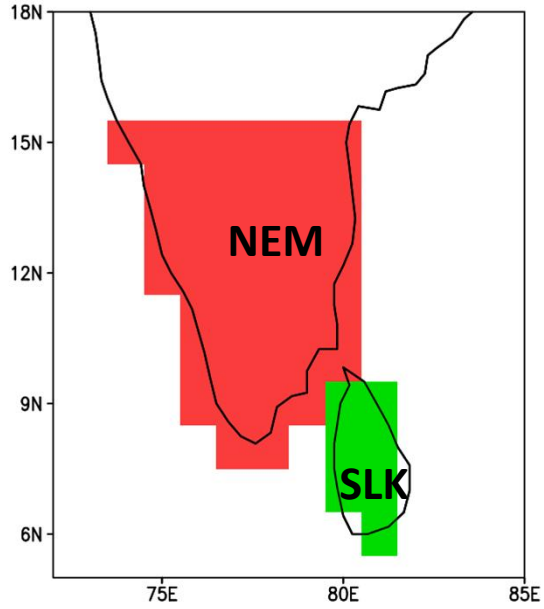
Predicted Heat Index

IC: 0516



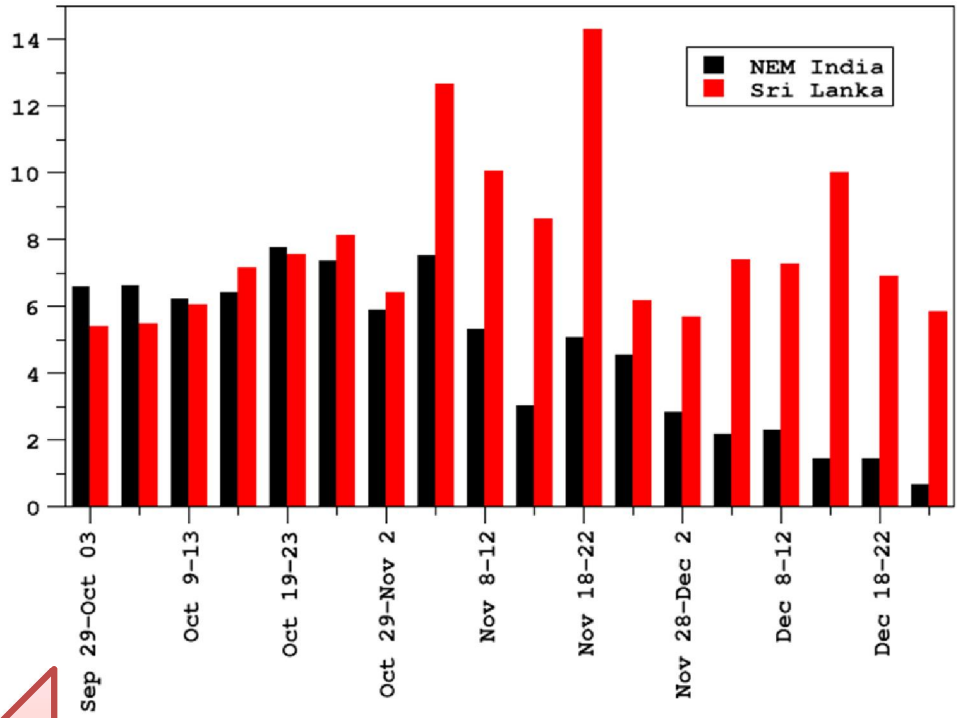
Prediction of North-East Monsoon (NEM)

NEM and SLK region

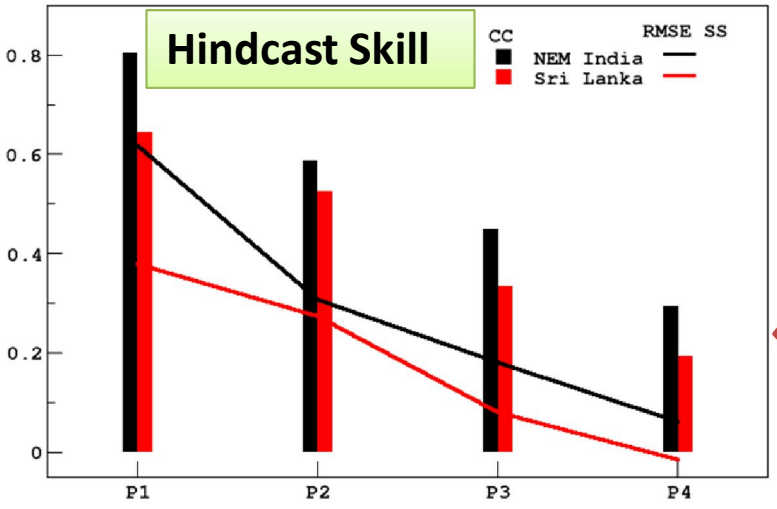


Hindcast Skill for Post Monsoon/NEM

Climatological rainfall



Hindcast Skill

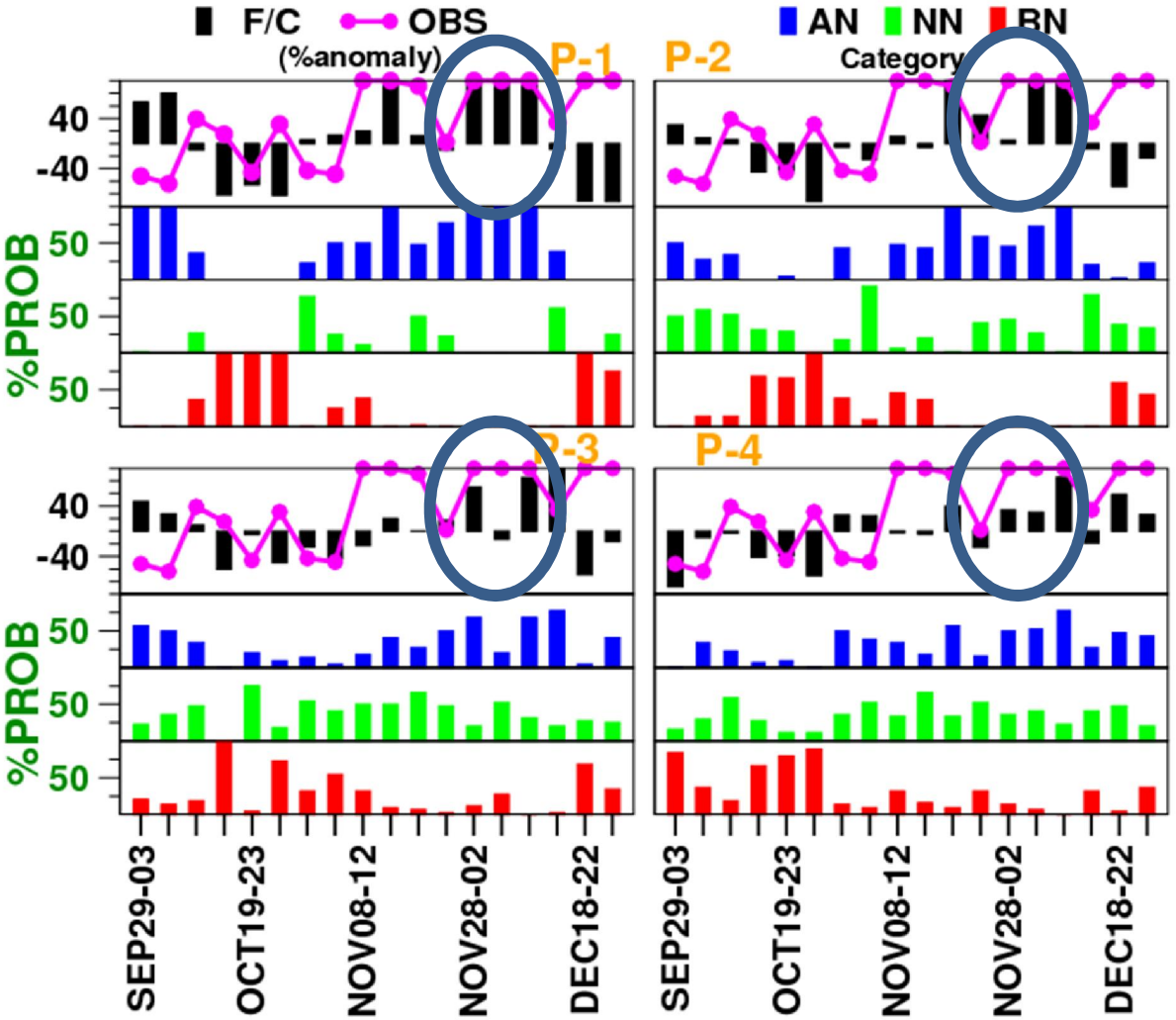


NEM (SLK) region exhibits useful skill up to 3(2) Pentad

Rains create havoc in Chennai: Rail, road, air traffic disrupted (29 Nov to 02 Dec 2015)

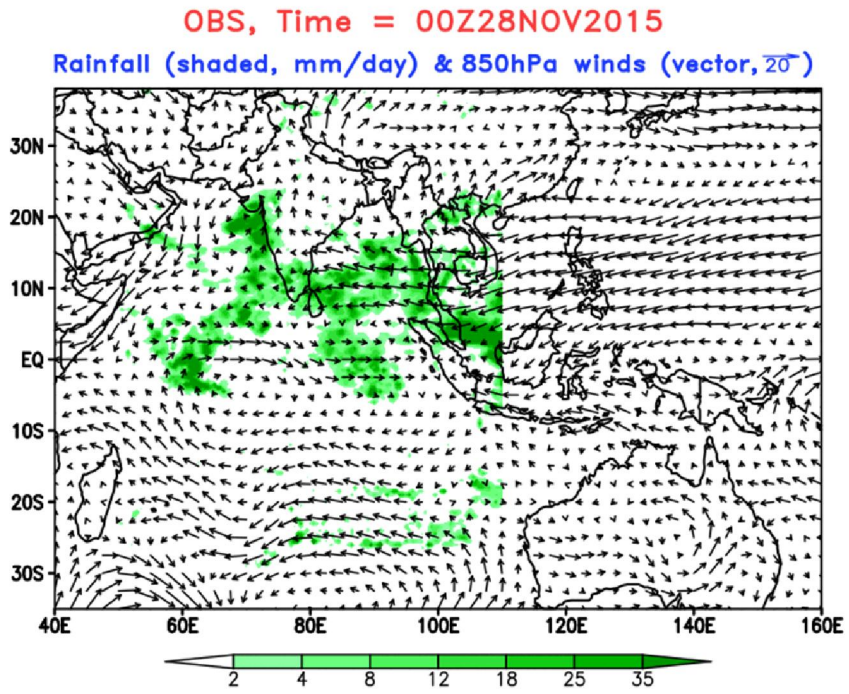
Prediction of North-East Monsoon (NEM)

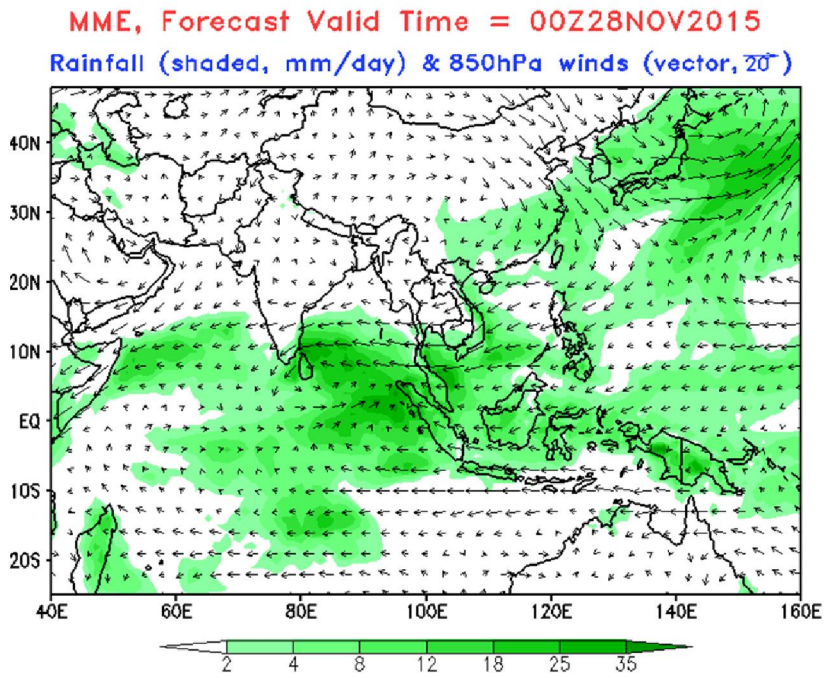
Area averaged rainfall over NEM region during 2015 predicted by MME



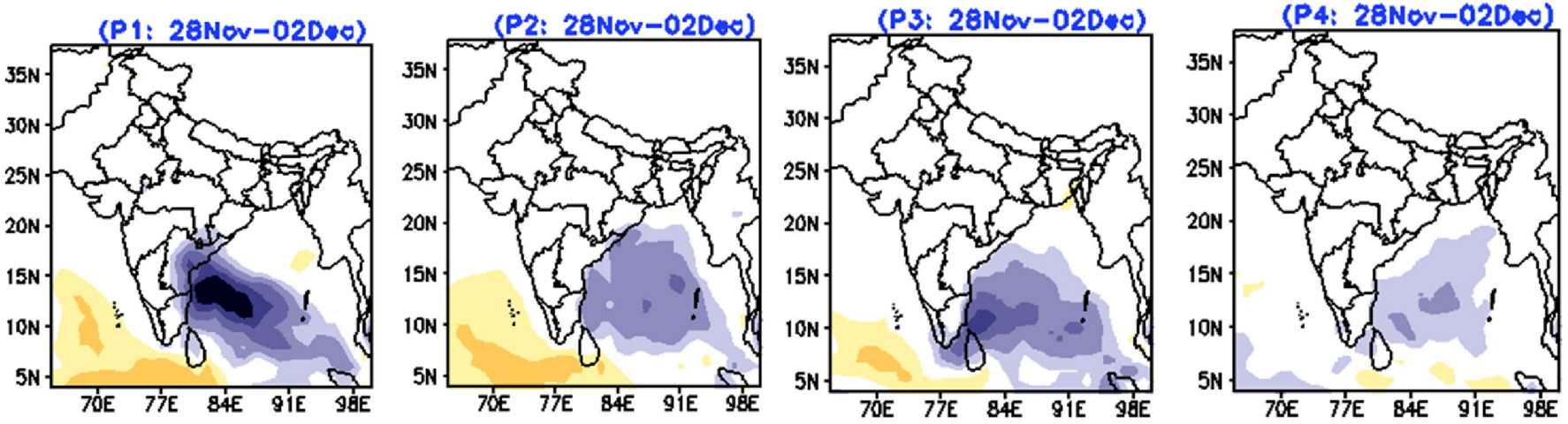
The CGMME system well predicted the above normal rainfall activity over Chennai and NEM region well in advance. The CGMME system able to capture this high impact continuous rainfall activity during the last week of November and first week of December around Chennai region from 4th pentad lead

Fcst Valid for 28Nov-02Dec from IC=17Nov2015(P3Lead)

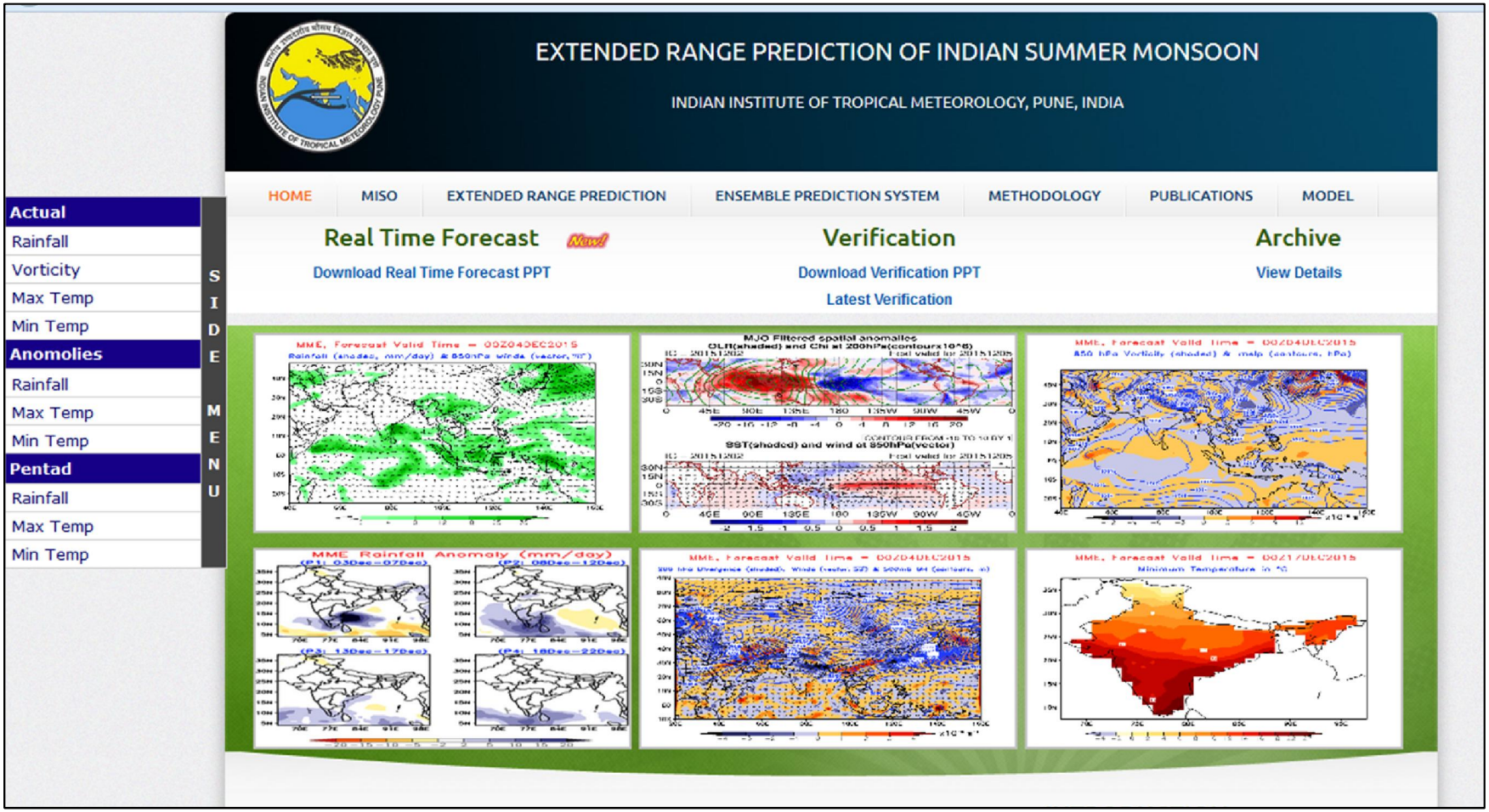




Predicted pentad wise rainfall (by IITM-CGEPS)



http://www.tropmet.res.in/erpas/index.php



Thank You!!!