Seasonal prediction of the Indian summer monsoon: science and applications to Indian agriculture

- Sulochana Gadgil
- CAOS, IISc , Bangalore

- ECMWF seminar on Seasonal Prediction
- 3-7 September 2012

‘I seek the blessings of Lord Indra to bestow on us timely and bountiful monsoons'

Pranab Mukherjee,

Finance Minister, opening remarks in the budget speech in the Indian parliament,

February 2011

Pranab Mukherjee's concern

- Interannual variation of the monsoon:

- Year to year variation of the Indian summer Monsoon (June-September) Rainfall (ISMR)

  droughts, excess monsoon seasons

- Prediction of extremes is very important for agricultural as well as other applications . I will, therefore, focus on the extremes i.e. droughts and excess rainfall seasons, in this talk on the interannual variation of the ISMR.

Outline

1. ISMR & its interannual variation: nature of the beast

2. Impact of the Indian summer monsoon rainfall on agriculture and GDP; What sort of predictions are required for enhancing rainfed agricultural production ?

3. Interannual Variation of the Indian summer monsoon: present understanding- links to events over the Pacific (ENSO) and the Equatorial Indian Ocean Oscillation (EQUINOO); Relation of the extremes of the ISMR to ENSO and EQUINOO.

4.Current skill of prediction of ISMR. The models at the global centres failed to predict the droughts in the early part of the last decade (2002,4). Despite the recent improvement of the models, as evinced by comparison of the skill of models in ENSEMBLES and those of DEMETER, again the major drought of 2009 was not predicted. Also drought of 2012(?)?

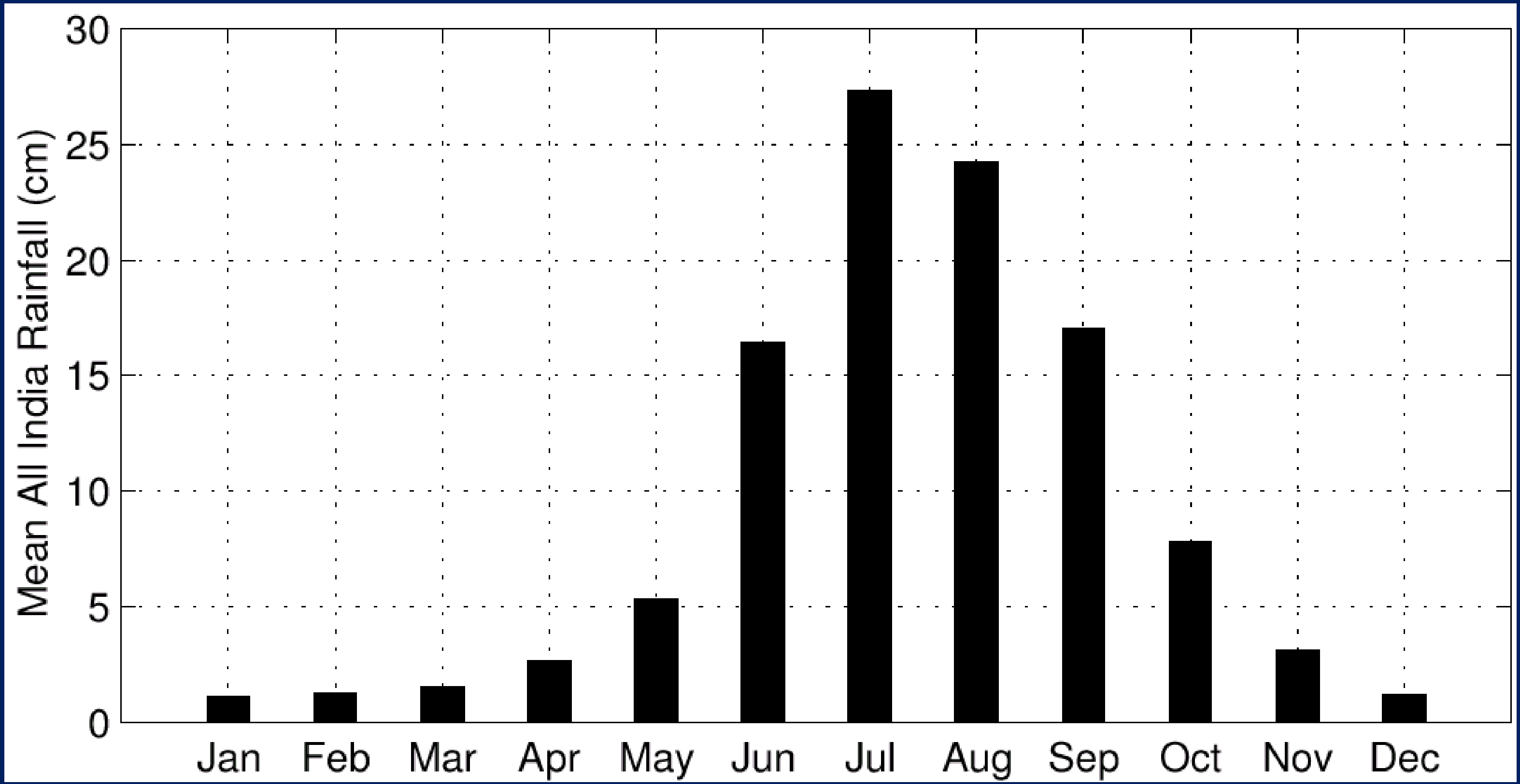
5. Hence further improvement of models is a must. Why is the skill of predicting the interannual variation of the ISMR poor?

Two hypotheses have been suggested (i) The poor skill of AGCMs even when forced by observed SST, has been attributed to poor skill in simulating the SST-rainfall relationship over the warm Indian and Pacific oceans and incorporation of coupling considered critical for skill in simulation of the monsoon (Wang et. al. 2005) (ii) It is attributed to poor skill in the simulation of the link between the monsoon and EQUINOO (Gadgil et. al. 2005). Light shed by analysis of AMIP type runs of AGCMs and SST-rainfall relationship simulated by atmospheric and coupled versions of climate models of IPCC-AR4 is discussed.

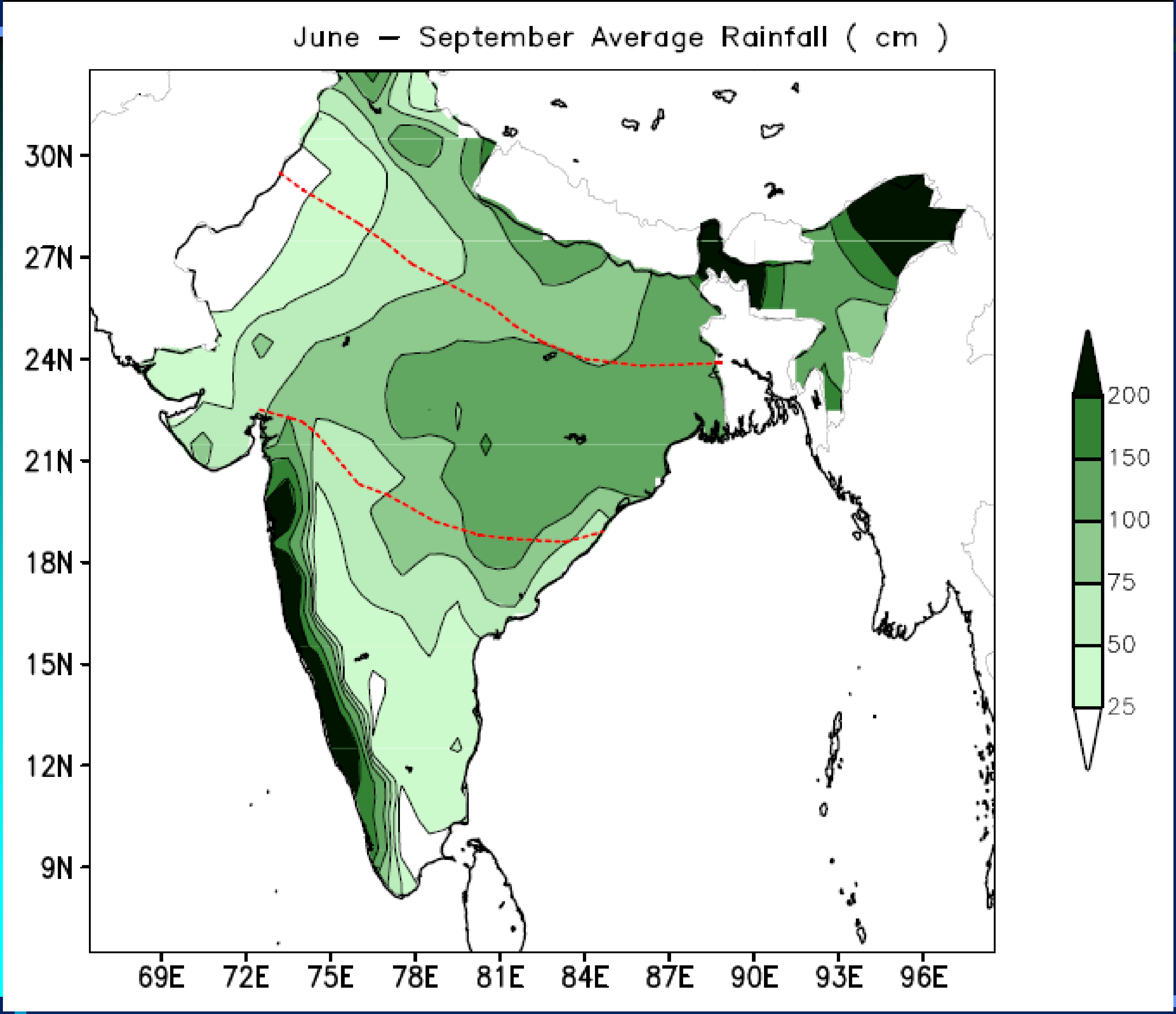
6. Analysis of retrospective predictions by coupled models : Results from ENSEMBLES and for the CFS1 and CFS2. Can we understand why models generate wrong predictions? Lessons learnt about the strategy for improvement of the models.

Basic features of rainfall over India:

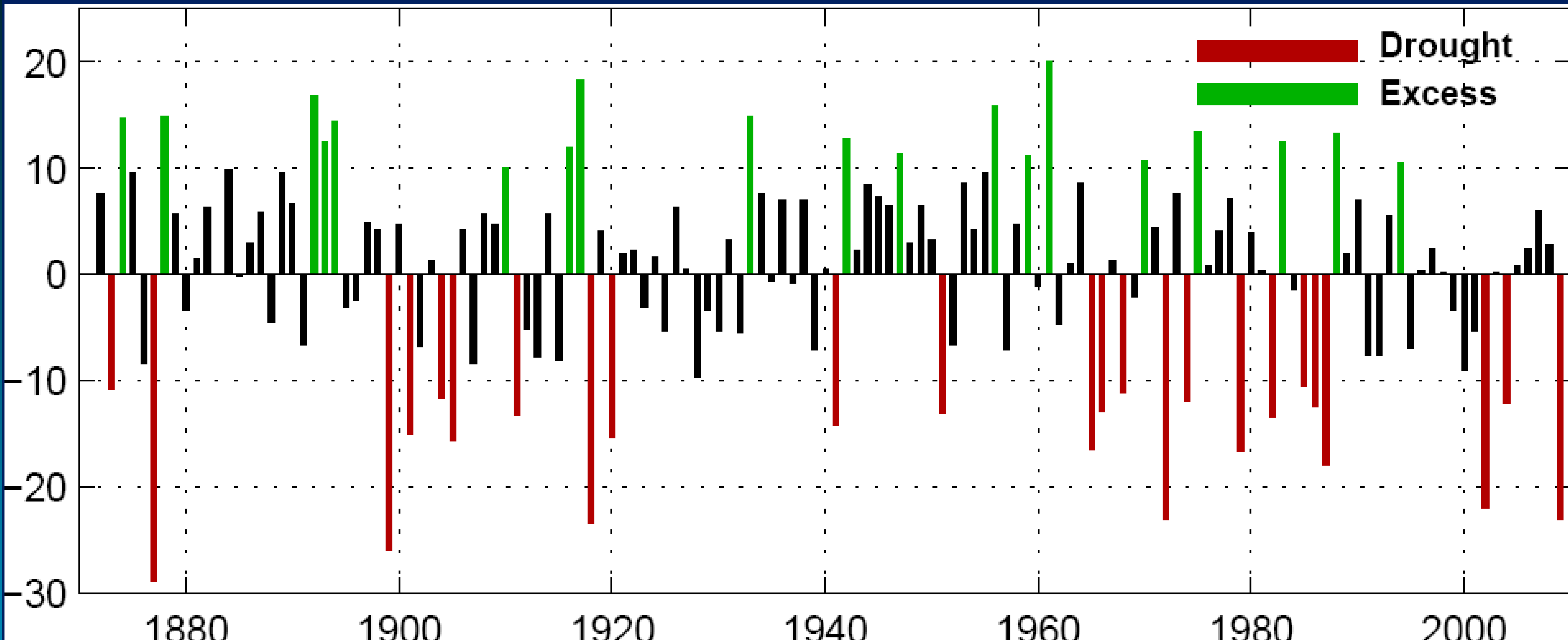
Mean monthly all-India rainfall



Most of the rainfall occurs during June-September-summer monsoon season; the focus of most studies is the summer monsoon. (However, over some parts such as the peninsula, the rainy season is different.)


June — September Average Rainfall (cm)
30N
27N
24N
21N
18N
15N
12N
9N
69E
72E
75E
78E
81E
84E
87E
90E
93E
96E
200
150
100
75
50
25

Interannual Variation of the anomaly of the Indian summer monsoon rainfall (ISMR) (as % of the mean);



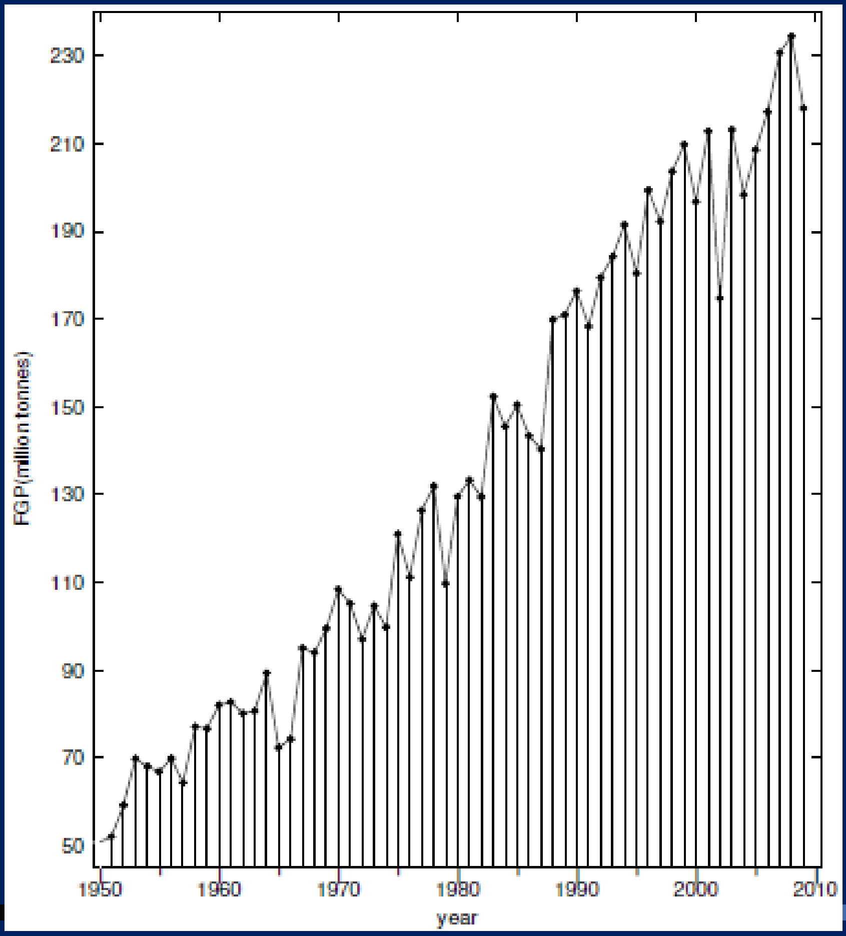
The standard deviation is about 10% of the mean

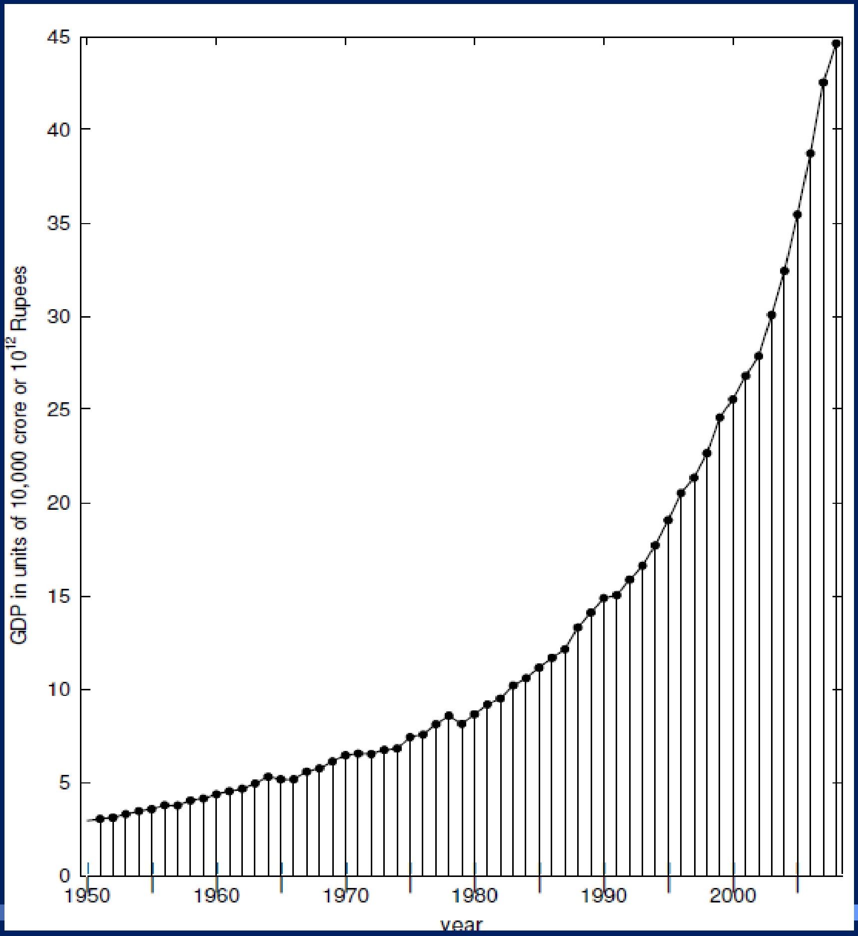
Drought: ISMR anomaly <-10% of the mean or the ISMR anomaly normalized by the std. dev. < -1.0

Excess rainfall seasons: ISMR anomaly >10% of the mean or normalized ISMR anomaly>1.0

2. Impact of the interannual variation of the Indian summer monsoon rainfall on Indian food grain production (FGP) and GDP

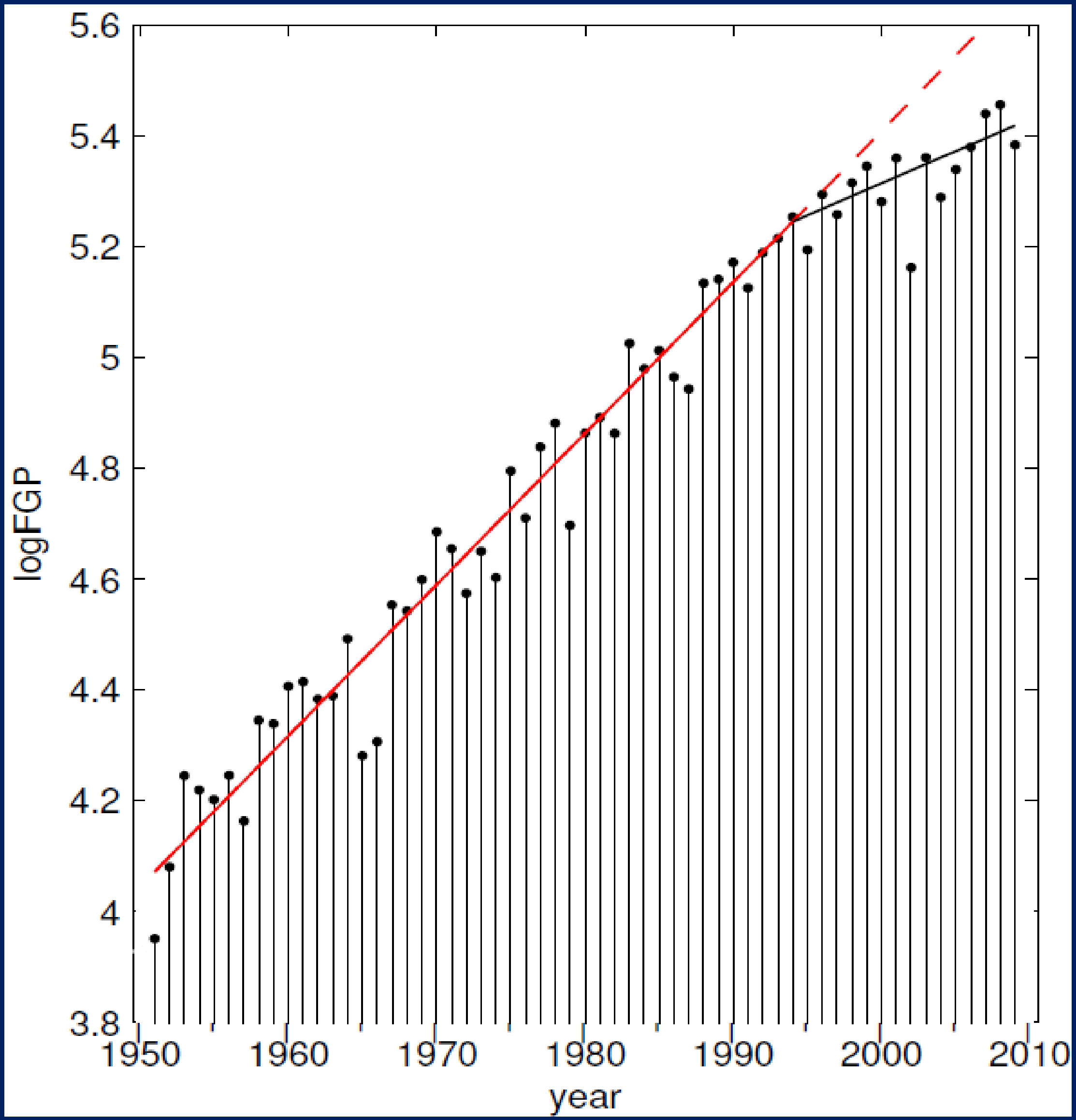
Variation of FGP and GDP since 1950





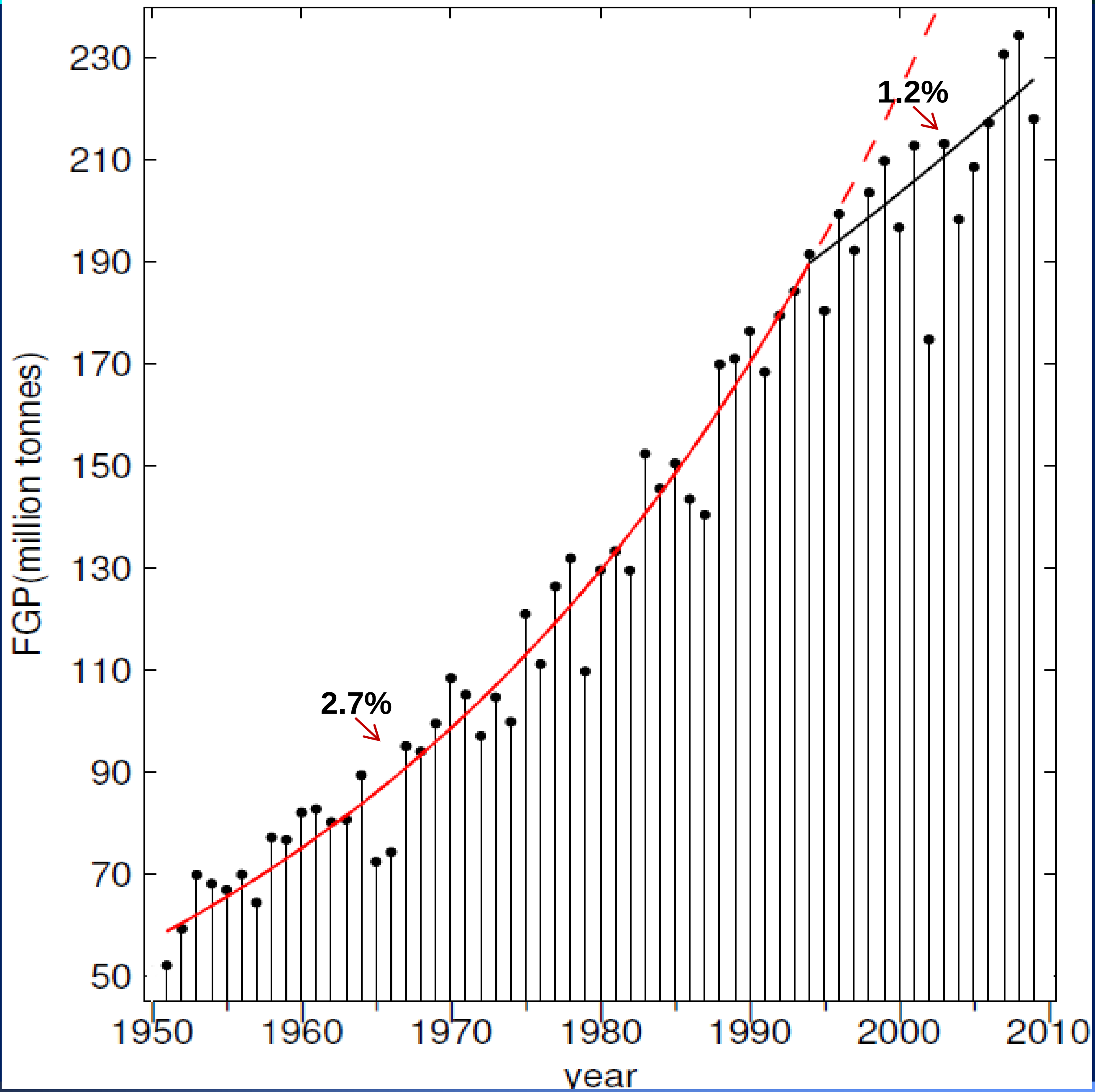
Assessment of impact:

- **Derive trend(s) assuming exponential growth**
- **Impact of the events of any year (i.e. the monsoon or any other major event such as war) is calculated as the deviation from the value it would have if the growth had occurred according to the trend.**
- **Details in:**
- ***The Indian Monsoon, GDP and Agriculture, Gadgil, Sulochana and Siddhartha Gadgil, 2006, Economic and Political Weekly, XLI, 4887-4895***

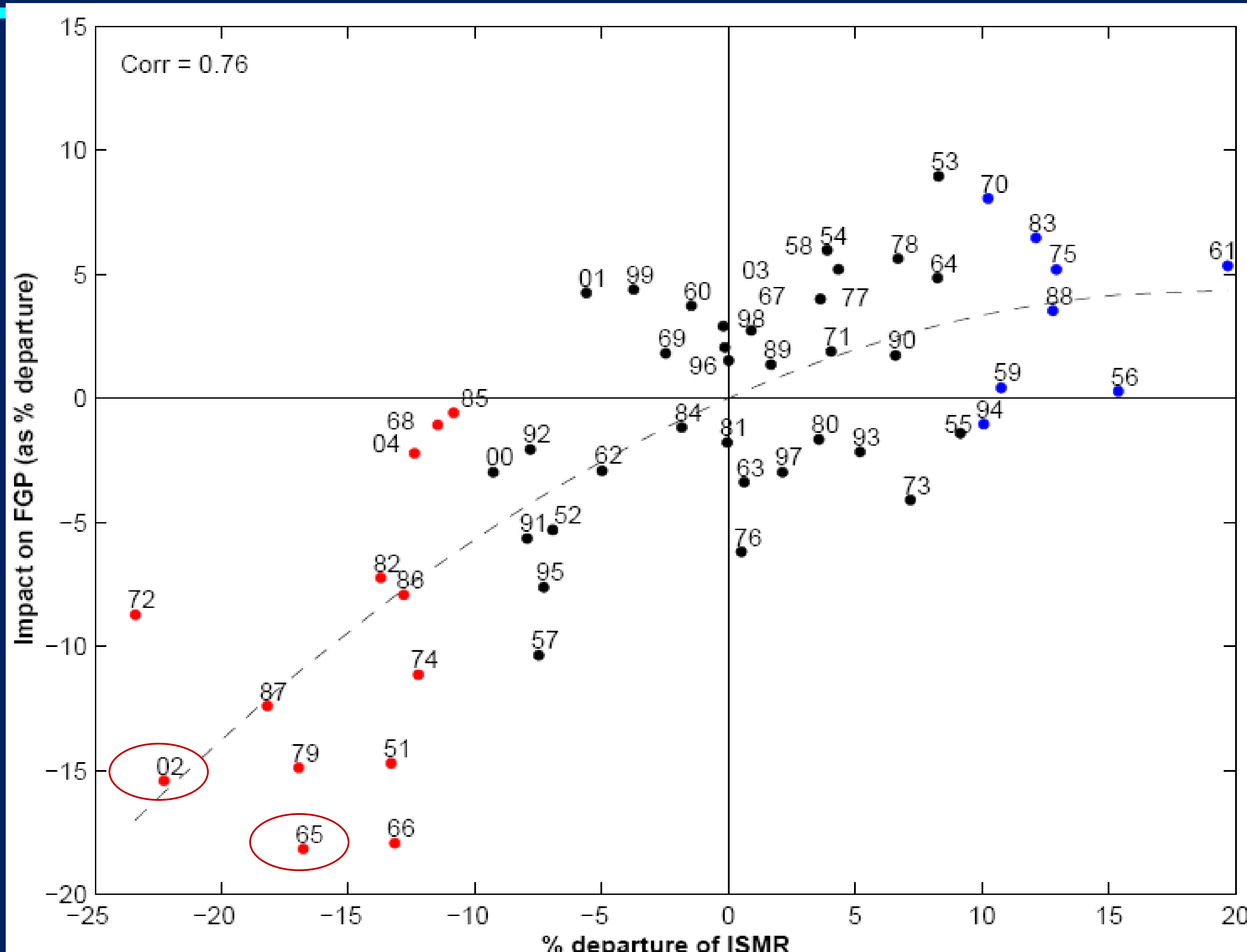


5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
4
3.8
logFGP
1950
1960
1970
1980
1990
2000
2010
year

Note that during 1951-94 the growth rate of FGP was 2.7%. Since then it has slowed to 1.2% (***Fatigue of the green revolution***)



I M P A C T O n F G P

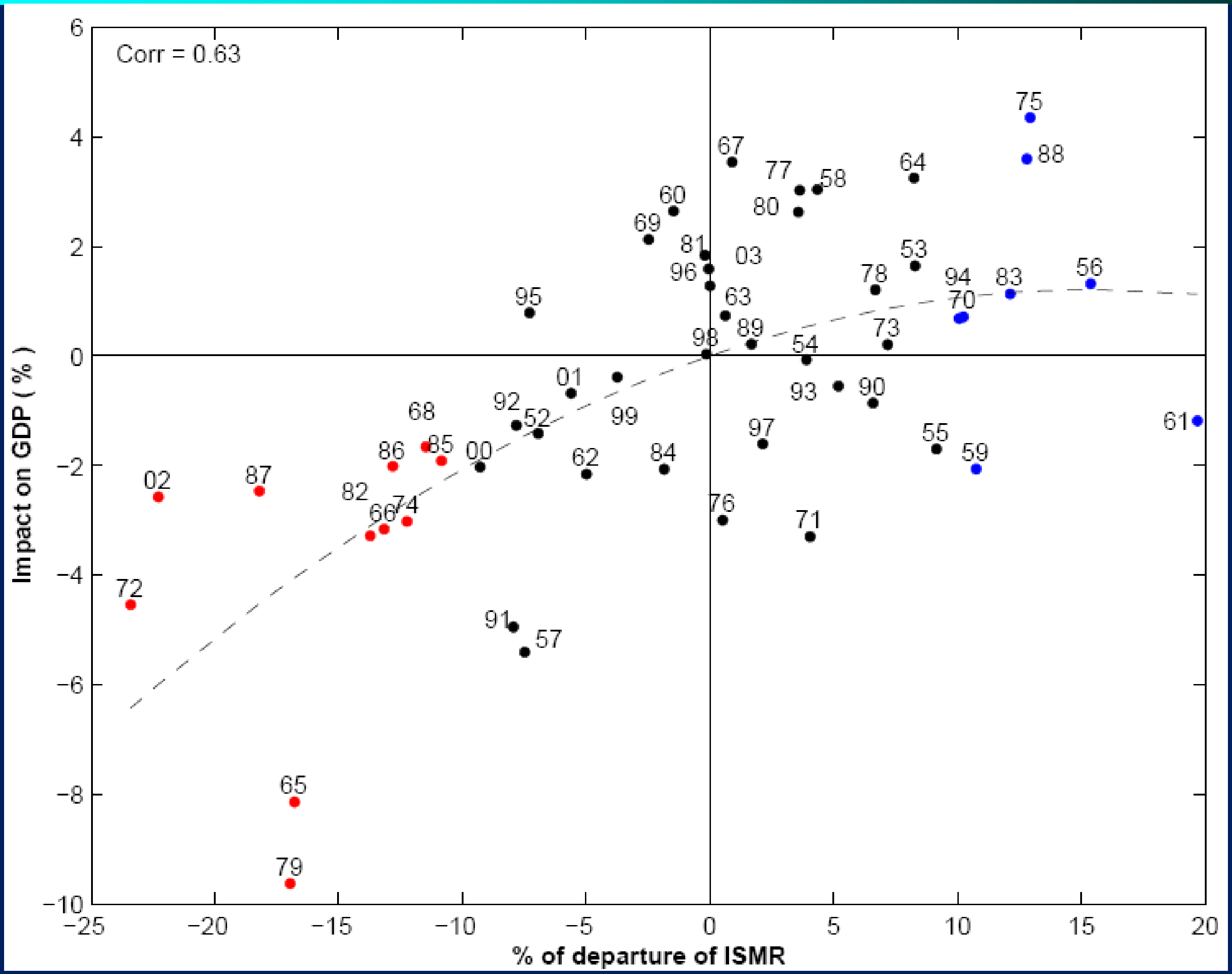


Impact of 2002 comparable to that of 65,66

Monsoon rainfall anomaly

Note that the impact is highly nonlinear. The negative impact of deficit monsoon (-ve ISMR anomaly) is much larger than the positive impact of surplus monsoon (+ve ISMR anomaly of the same mag.).

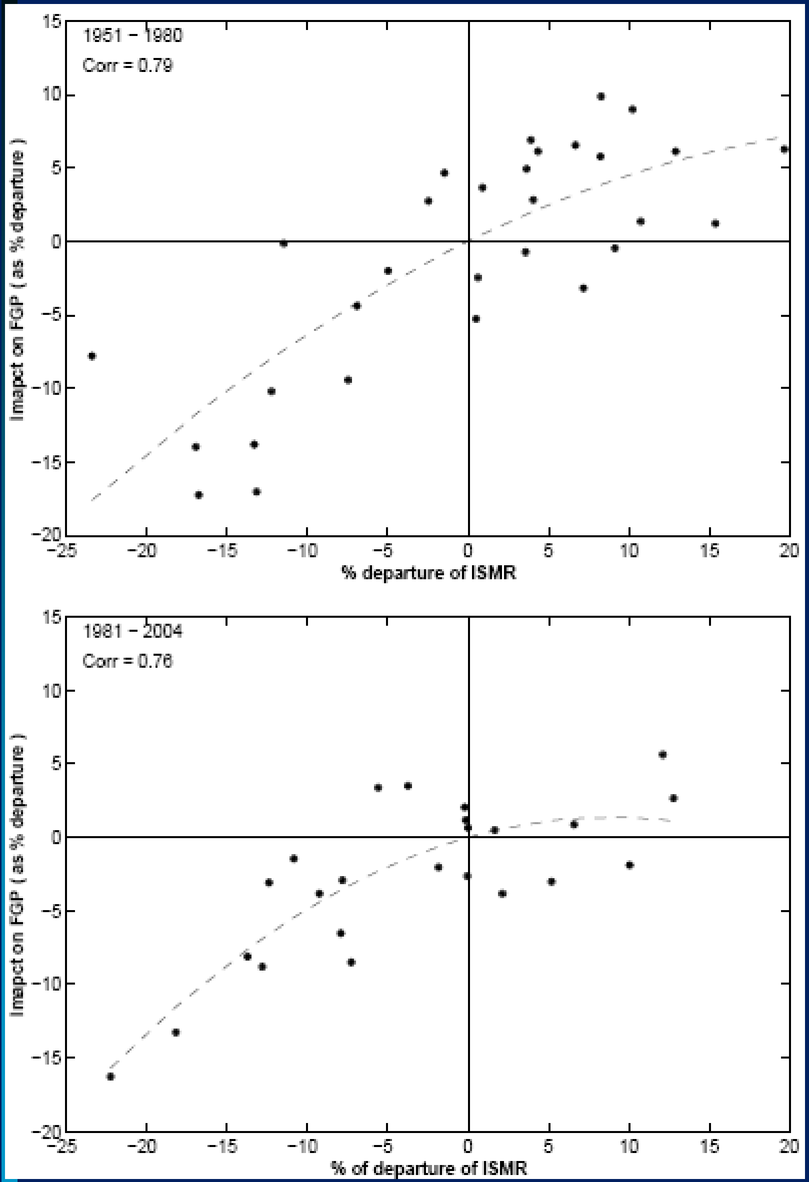
Impact On GDP



Monsoon rainfall anomaly

Note that negative impact of deficit monsoon is much larger than the positive impact of surplus monsoon for GDP also.

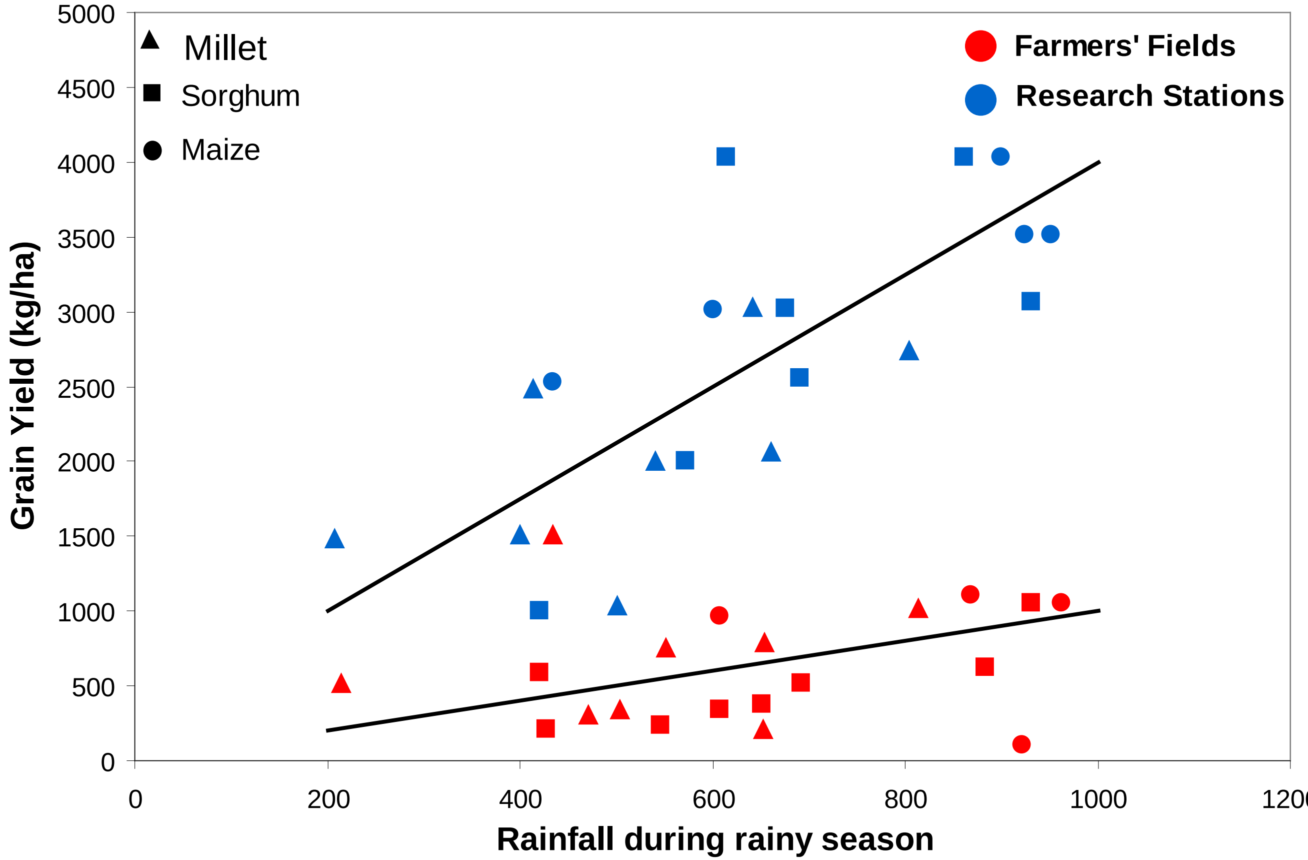
- Thus the impact of the monsoon on FGP and GDP is highly nonlinear, with the magnitude of the impact of a negative ISMR anomaly being larger than that of a positive ISMR anomaly of the same magnitude. Hence even if the ISMR does not vary over long periods, the impact of deficit rainfall years will not be made up by that of normal or good monsoon years.
- Furthermore, this asymmetry in the impact of the monsoon on FGP increased sharply in the last three decades.
- Whereas in the earlier era, the magnitude of the impacts of a drought and a surplus on FGP were comparable in magnitude; while after 1980 the impact of surpluses has become almost negligible.



Period	1951 - 80	1981 - 04
ISMR	FGP	FGP
-25	-19.13	-18.81
-20	-14.41	-13.29
-15	-10.13	-8.65
-10	-6.30	-4.89
-5	-2.93	-2.00
0	0.00	0.00
5	2.48	1.12
10	4.50	1.37
15	6.08	0.73
20	7.21	-0.79

- Can seasonal predictions of monsoon rainfall help in enhancing the production in normal and good monsoon years? If so, what sort of predictions can contribute?
- To address this, we consider the variation with seasonal rainfall, of the yields of some important rain-fed crops on farmers' fields and that of the same varieties of crops under the same soil-climatic conditions at agricultural research stations. The difference between what is achieved with the current level of technology at the agricultural stations and the yields at the farmers' fields is the yield gap.
- Scientists at the ICRISAT have carried out a detailed analysis of yield gaps for several rain-fed crops in semi-arid regions.

Variation of the yields at the farmers' fields and at agricultural stations with seasonal rainfall



Relationship between rainfall during the rainy season and yield of maize , sorghum and millet at 15 dryland locations in India (after Shivakumar et al. 1983)

ICRISAT

Yield gap is large only for above average rainfall years. Similar result for groundnut, soyabean, pigeonpea and chikpea

- Note that when the seasonal rainfall is low the yields at agricultural stations are comparable to those on the farmers' fields.
- As the seasonal rainfall increases, the yields at agricultural stations increase much more rapidly than those at the farmers' fields. Hence the yield gap increases with the seasonal rainfall.
- The major difference in the management at agricultural stations and farms is in the application of fertilizers and pesticides. In the recent decades, with large tracts of land under monoculture, leading to high intensity of attack by pests and diseases, and loss of fertility of the land due to intensive cultivation, it is not possible to get high yields without application of fertilizers and pesticides.

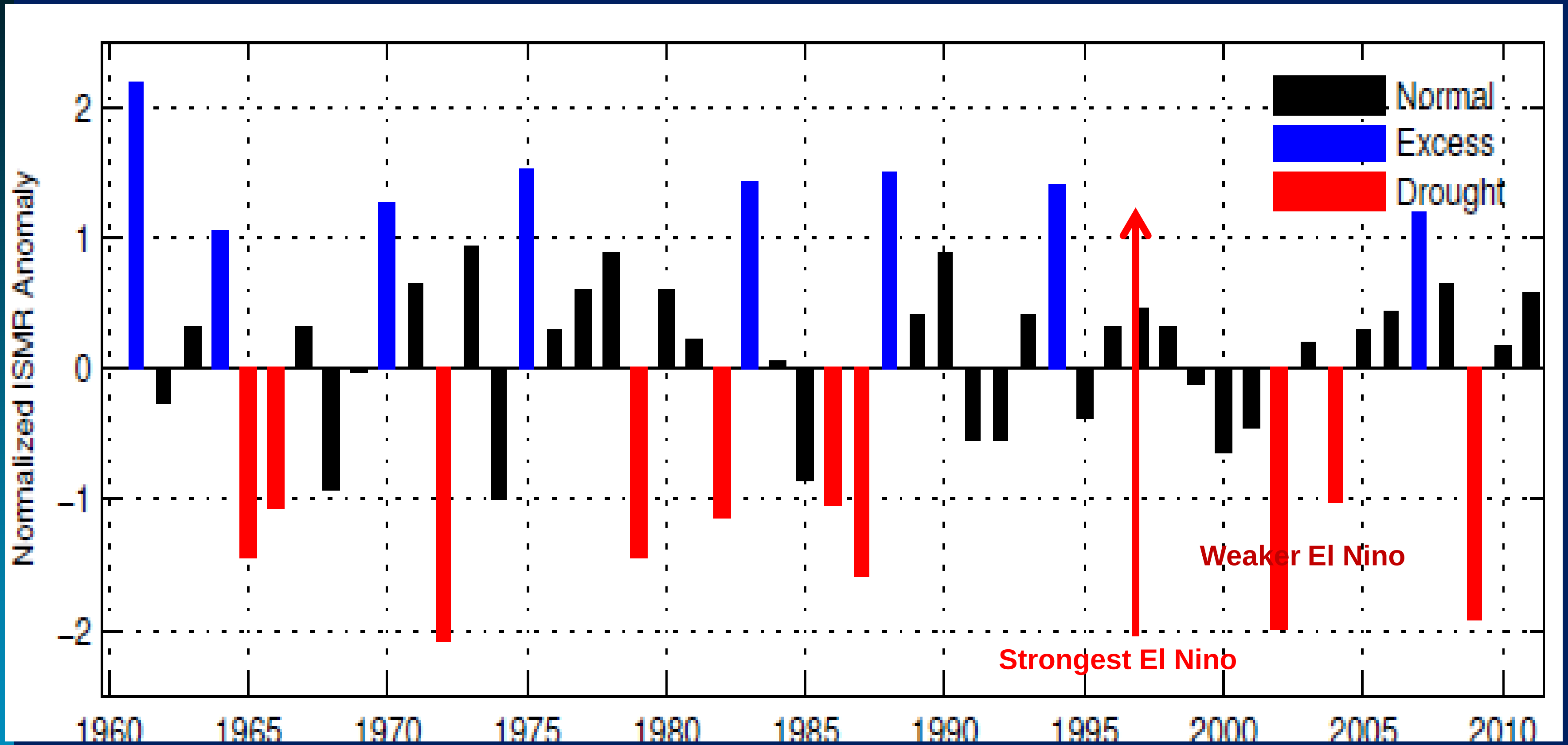
- However, in the absence of a reliable prediction of seasonal rainfall, the farmers do not know whether the investment in fertilizers and pesticides will lead to enhanced yields i.e. will be cost effective. Hence, the farmers do not invest in them (although they have the know-how and do apply them over irrigated patches).
- On the other hand, at agricultural stations, farm economics is irrelevant and liberal doses of fertilizers and pesticides can be applied. Even then, the yields are not very much better than the farmers' yields in poor rainfall years. In normal or good monsoon years the yield enhancement due to this application is very large. Hence the yield gap increases with seasonal rainfall.

- The farmers are adopting a strategy which is insensitive to climate variation and is not appropriate for a majority of the years (for example ISMR deficit is large only for 25% of years during 1958-2010).
- Clearly knowledge and prediction of the variability should have an impact on this strategy. In particular, a reliable prediction of non-occurrence of droughts could have a large impact on the farming strategies and hence on agricultural production.
- The focus in prediction for this as well as other reasons should be on prediction of extremes. I also focus in this lecture on prediction of extremes.

3. Interannual Variation of the Indian summer monsoon: present understanding

- **I:Monsoon-ENSO relationship**
- **High propensity of droughts during EL Nino and of excess rainfall during La Nina**
- **(Sikka 1980, Pant and Parthasarathy (1981), Rasmusson and Carpenter (1983) etc.)**
- ***Led to hope that seasonal prediction of the monsoon would be possible in view of the success in prediction of ENSO.***
- **We define ENSO index= -SST anomaly of Nino3.4**
- **normalized by the standard deviation**
- **Positive values of the ENSO index (cold phase) are favourable for the monsoon**

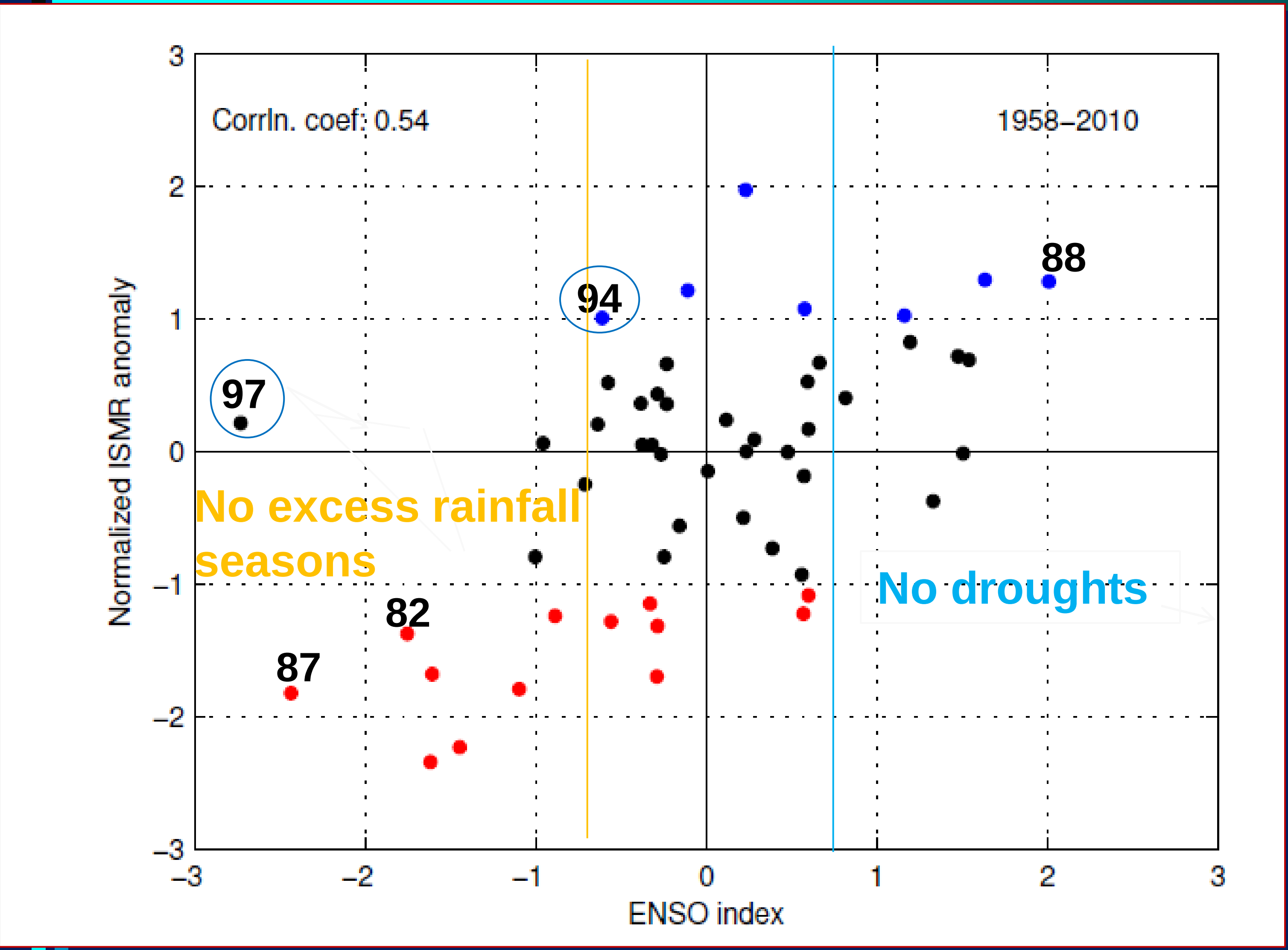
Observed variation of ISMR during 1961-2011



Mean and standard deviation used is for 1961-2005

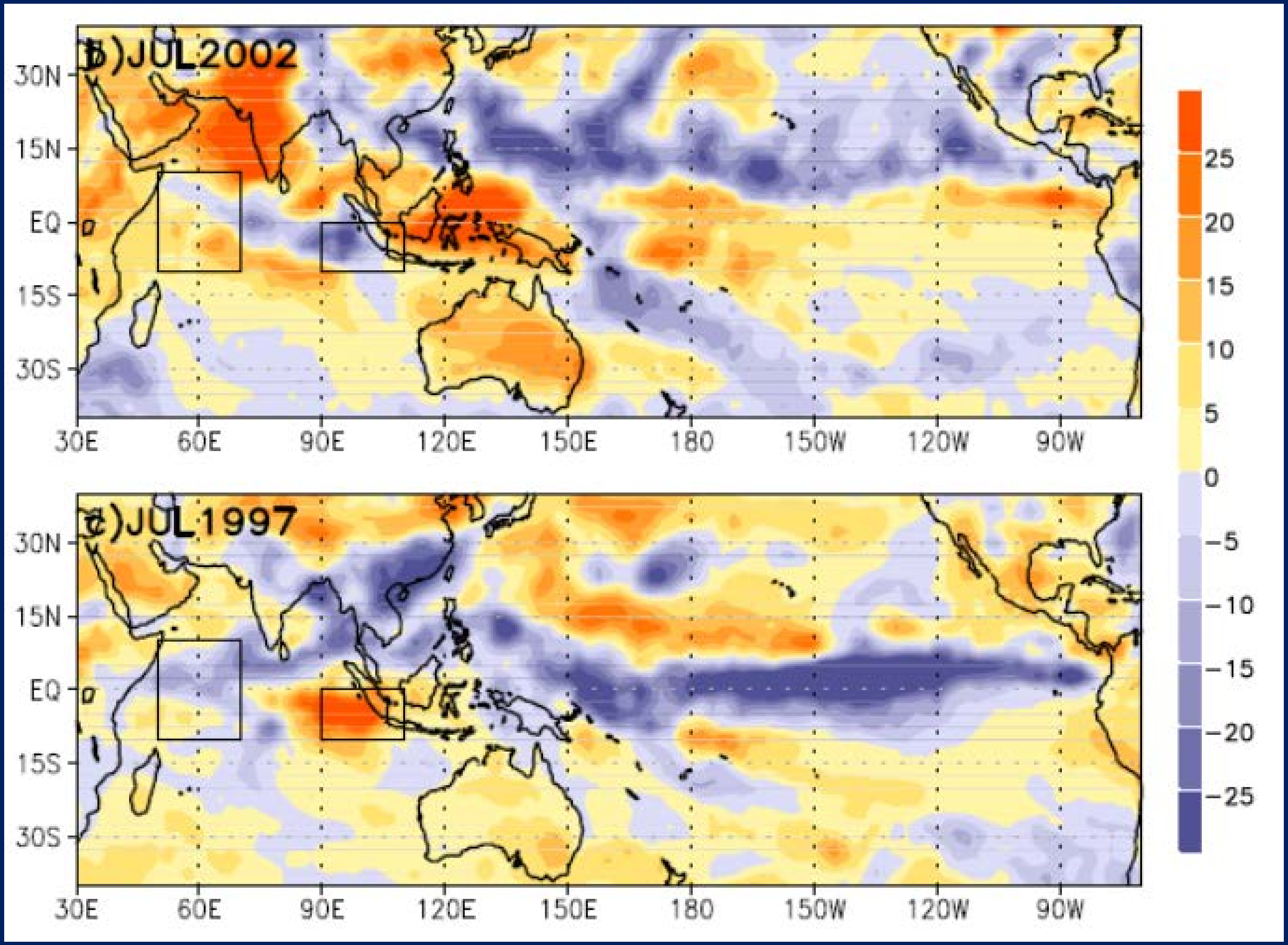
Droughts:1965,66,72,79,82,86,87, 2002,4,9

Excess rainfall seasons:1961,64,70,75,83,88,94



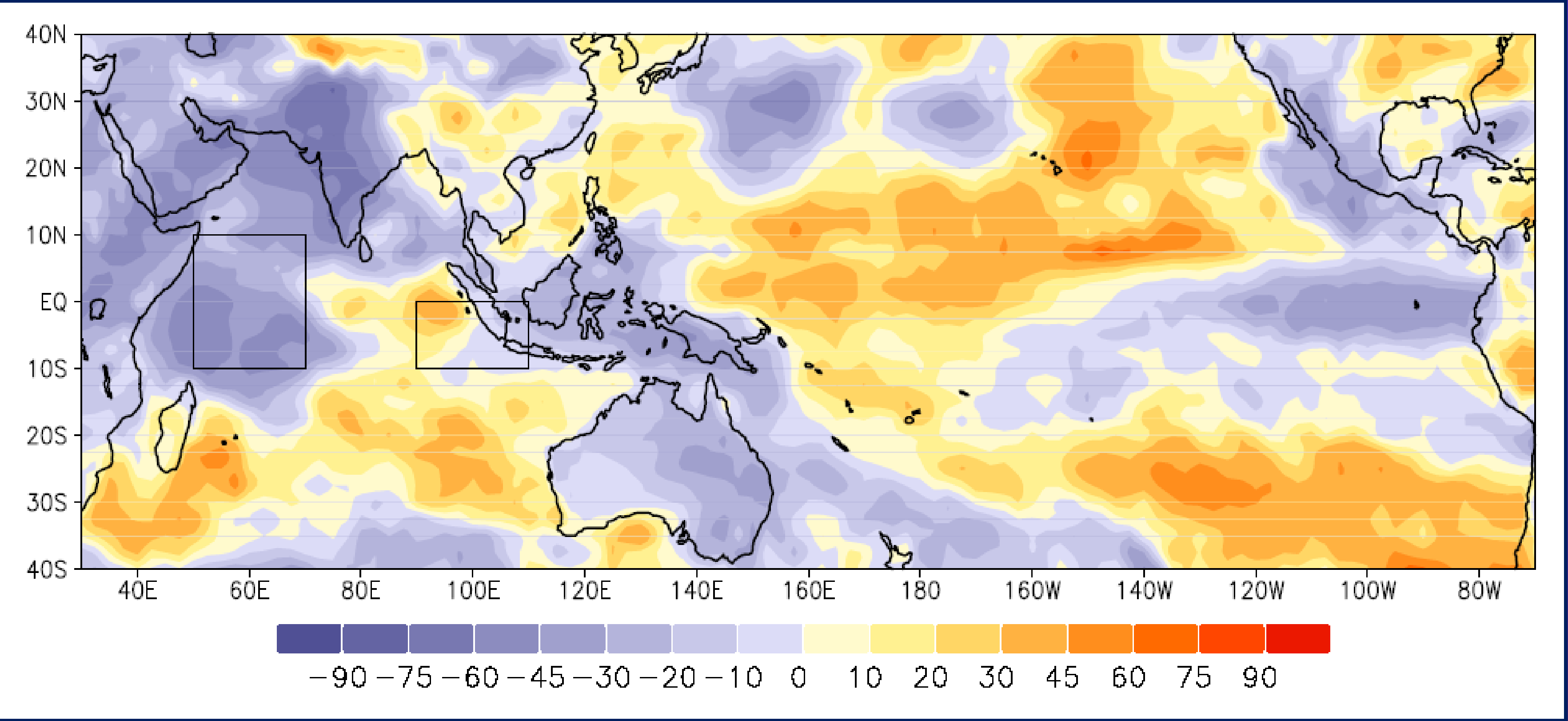
One sided prediction; (non-occurrance of of one of the extremes); however several extremes for -.8<index<0.6

As expected, El Ninos of 1982,87 droughts and La Nina of 1988 excess rainfall season, **however, 1994 excess, despite a weak El Nino and 1997 normal despite the strongest El Nino.**



Note that the major difference is in the pattern over the equatorial Indian Ocean.

Correlation between ISMR and OLR



Note that the positive correlation of ISMR with the convection over the western equatorial Indian Ocean is of comparable magnitude to the negative correlation of ISMR with convection over the central Pacific (ISMR-ENSO link)

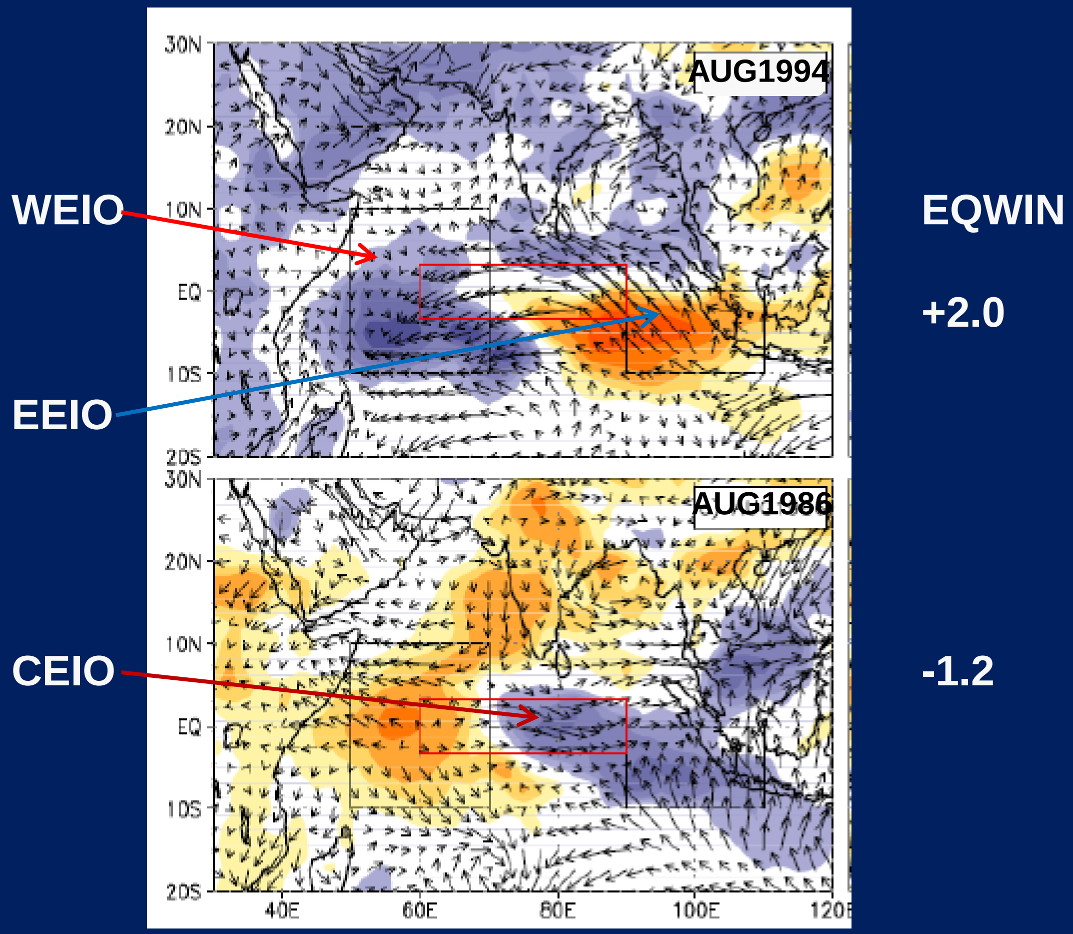
Studies* in this decade have revealed that one more mode plays an important role in interannual variation of the monsoon viz. the Equatorial Indian Ocean Oscillation (EQUINOO).

***Gadgil, Sulochana, Vinaychandran, P. N., Francis, P. A. and Gadgil, Siddhartha, Extremes of Indian summer monsoon rainfall, ENSO, equatorial Indian Ocean Oscillation. *Geophys. Res. Lett.*, 2004, 31, doi: 10.1029/2004GL019733.**

***Ihara, C., Kushnir, Y., Cane, M. A. and De la Peña, V., Indian summer monsoon rainfall and its link with ENSO and the Indian Ocean climate indices. *Int. J. Climatol.*, 2007, 27, 179–187.**

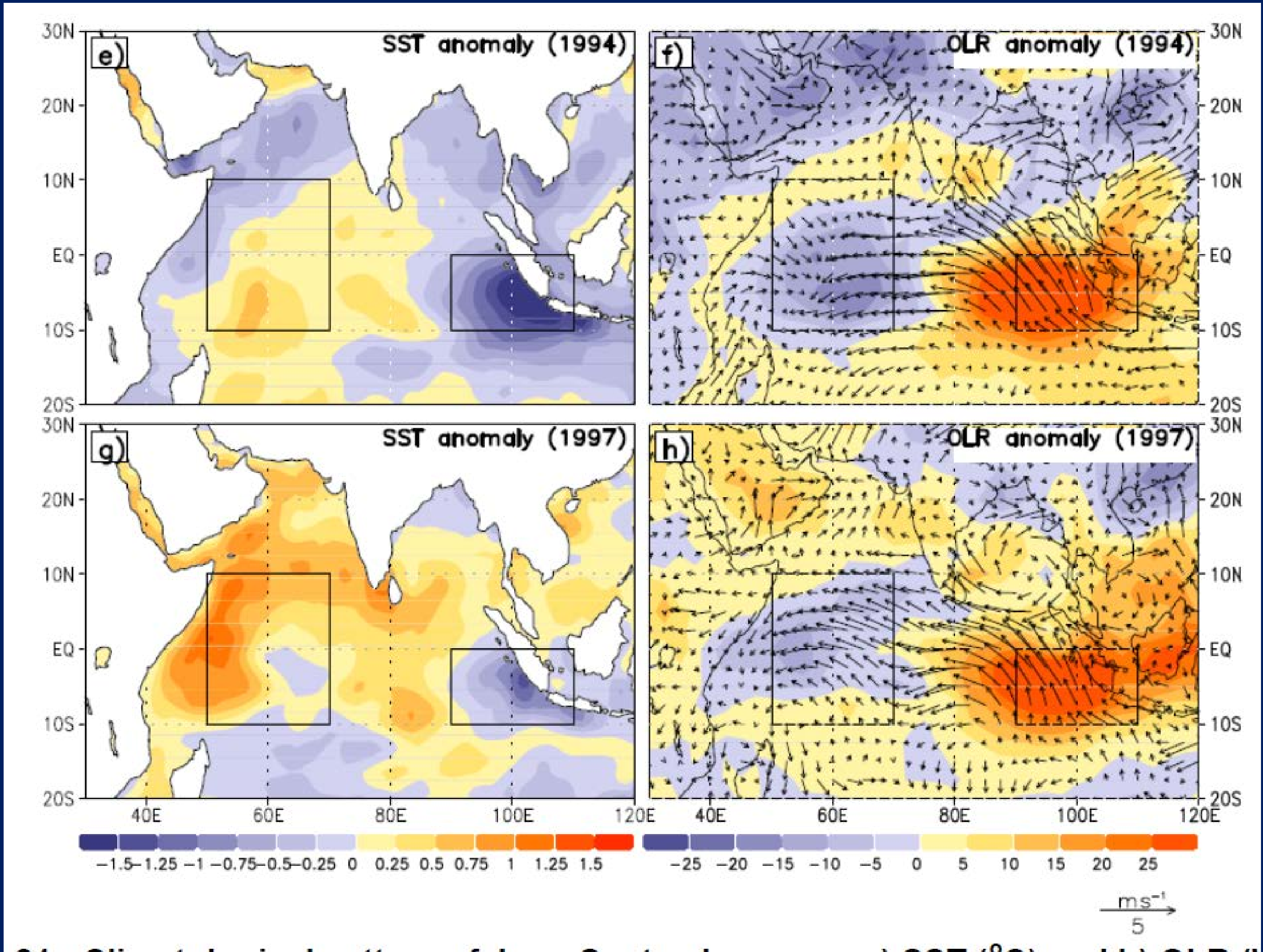
- **EQUINOO**
- **Negative OLR anomalies over the western equatorial Indian Ocean (WEIO) tend to be associated with positive OLR anomalies over the eastern equatorial Indian Ocean (EEIO).**
- **Equatorial Indian Ocean Oscillation (EQUINOO) is the oscillation between a state with positive OLR anomalies over EEIO and negative OLR anomalies over WEIO (positive phase) and that characterized by OLR anomalies of the opposite sign (negative phase).**
- **The positive phase of EQUINOO is associated with easterly anomalies in the equatorial zonal wind; whereas the negative phase (i.e. with enhanced (suppressed) convection over the EEIO (WEIO)), is associated with westerly anomalies of the zonal wind at the equator.**

We use EQWIN an index of EQUINOO, defined as the **negative** of the anomaly of the surface zonal wind averaged over 60^0E-90^0E:2.5^0S-2.5^0N (so that positive values of EQWIN imply favourable for the monsoon), normalized by its standard deviation.



- **EQUINOO has been considered to be the atmospheric component of the Indian Ocean Dipole/zonal mode. However, EQUINOO and the oceanic component of the IOD mode are not as tightly coupled as ENSO.**
- **Westerly wind anomaly along the equator (i.e. positive phase of EQUINOO) is involved in the development of positive IOD events such as 1994 and 1997. Once such positive IOD events develop, positive EQUINOO is sustained (next slide). However, such a positive EQUINOO phase can lead to a positive IOD event only when the EEIO mixed layer is sufficiently shallow so that upwelling can lead to a substantial cooling of the EEIO.**

Two major IOD events

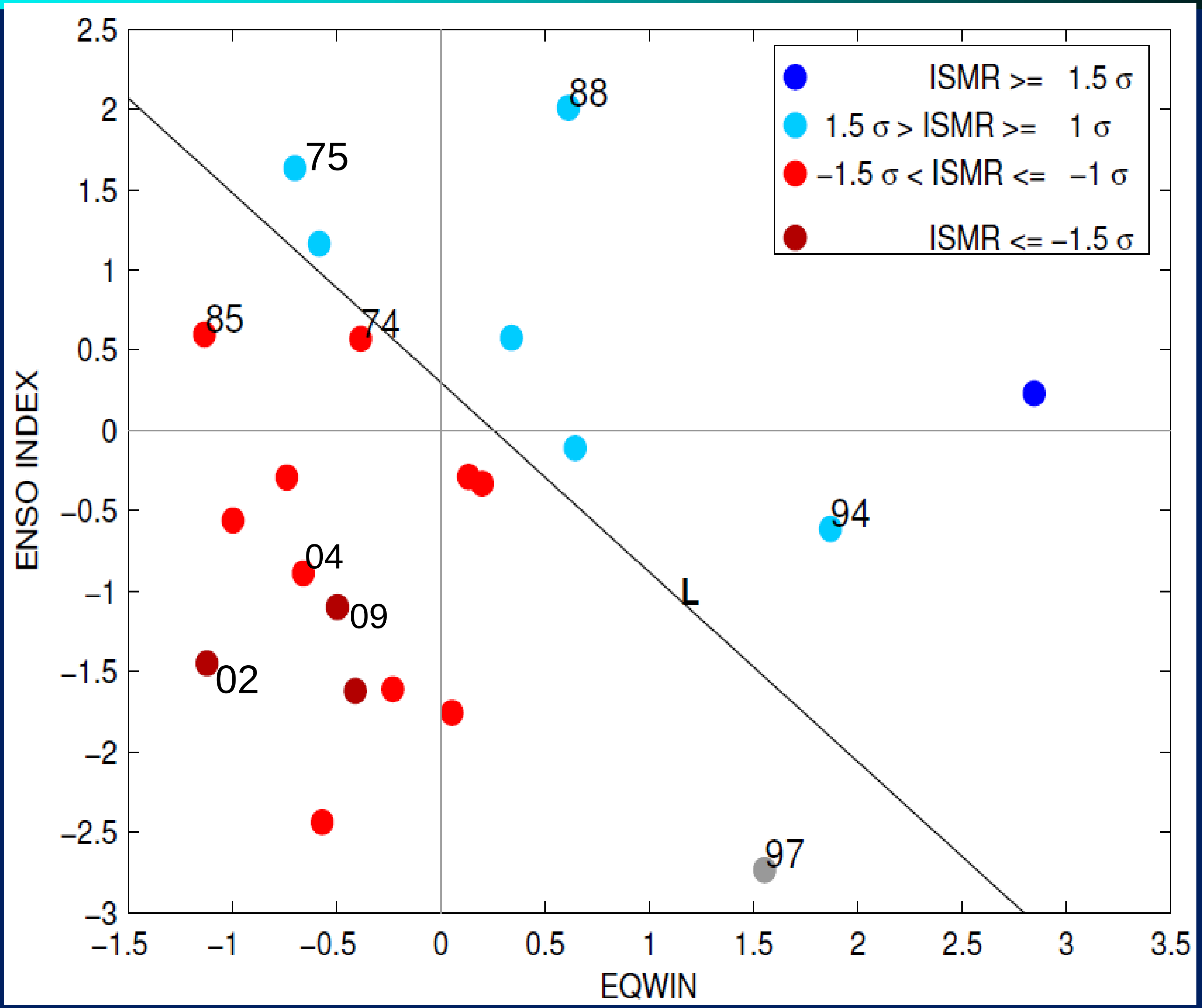


ENSO and EQUINOO

- **We find that with the two modes: ENSO and EQUINOO, we can ‘explain’ all the extremes of ISMR.**
- **Droughts occur when one or both of the modes are unfavourable (with the most severe droughts associated with both unfavourable) and excess rainfall when one or both are favourable.**
- ***(Sulochana Gadgil, P. N. Vinayachandran, P. A. Francis and Siddhartha Gadgil , 2004)***

Extremes of ISMR in the phase plane of ENSO index & EQWIN 1958-2010

Note: in 1994 and 1997 strong EQUINOO opposes El Nino

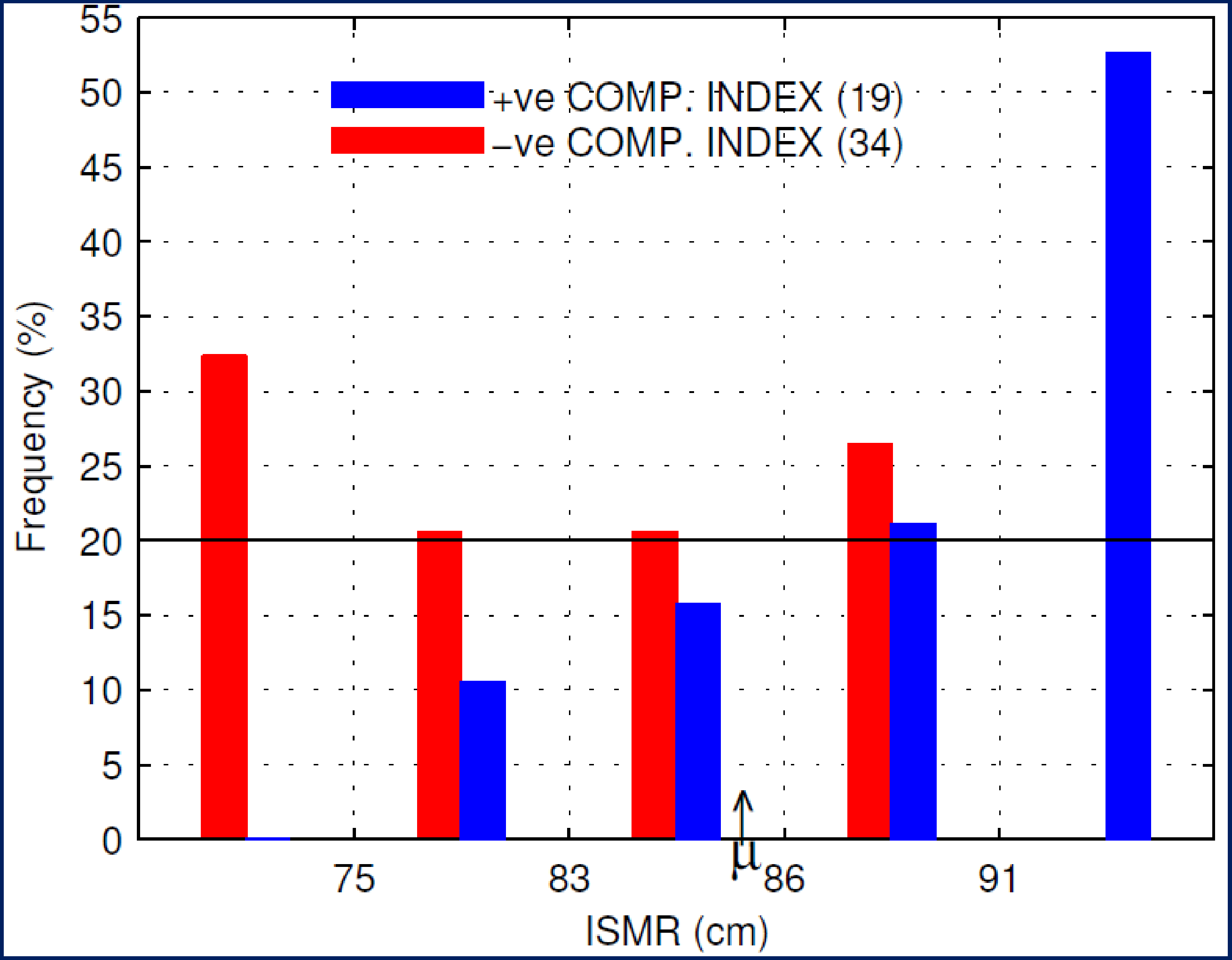


No droughts if the ENSO index &EQWIN values imply that the point is above the line and no excess rainfall seasons if it is below.

Again one-sided prediction, but it is available for all years

- No droughts if the ENSO index &EQWIN values imply that the point is above the line and no excess rainfall seasons if it is below.
- We define a composite index as a linear combination of ENSO index and EQWIN which measures the distance from the line of separation (L) which is negative below the line and positive above the line.
- Thus positive values of the composite index imply no droughts and negative index implies no excess rainfall seasons.

Rainfall classes chosen so that the climato-logical proba-bility of occur-rence of each is 20%



Large Impact on extremes

Composite index is a linear combination of ENSO index and EQWIN which measures the distance from the line of separation (L) which is negative below the line and positive above the line.

- Ihara et. al 2007's analysis of the data from 1881 to 1998 (i.e. over a much longer period than 1958-2003 analyzed by Gadgil et. al.2004) showed that the linear reconstruction of ISMR on the basis of a multiple regression from the Nino3 and EQWIN better specifies the ISMR than from Nino3 alone. However, it is not better specified with Nino3 and DMI (Dipole mode index which is the index of the ocean component defined as the difference between SST anomalies).
- It is thus not surprising that the correlation of ISMR with DMI is poor (as shown by Saji et. al. 1999).

Simulation and prediction of ISMR

- **Facts of life**

  None of the models at the global centres were able to predict the droughts of 2002,2004 and 2009!

  (Gadgil et. al. 2005, Nanjundiah 2009)
- The jury is still out on the current drought(?).
- Clearly the models have to be improved.
- Recent papers suggest that the models have, in fact, improved in the last few years.

Climate Models Produce Skillful Predictions of Indian Summer Monsoon Rainfall

by

Timothy DelSole and J Shukla

Geophys. Res. Lett. 2012

http://dx.doi.org/10.1029/2012GL051279

Reported about in

Predicting the Indian monsoon

Nature news and views 19 April 2012

Monsoon Prediction: Are dynamical models getting better than statistical models?

Gadgil and Srinivasan, Curr Sc. 10Aug 2012

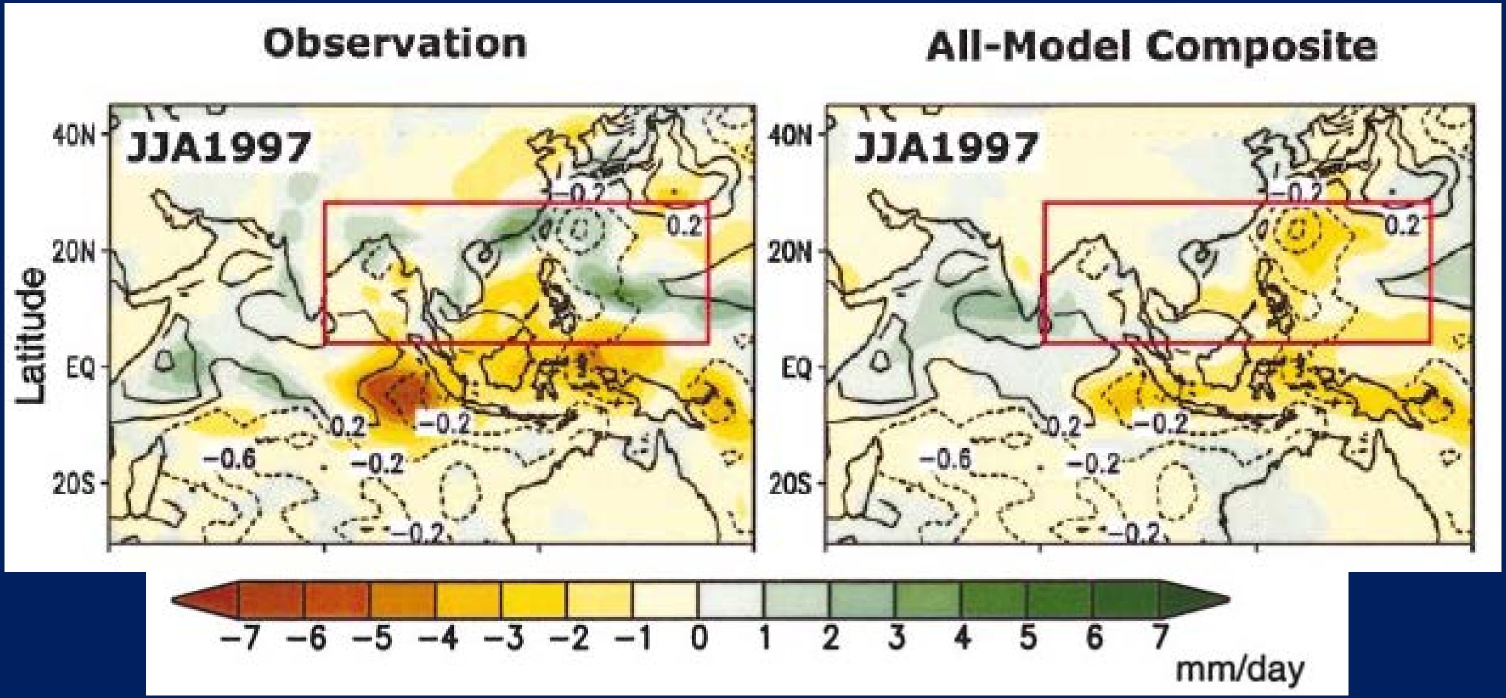
- Improved skill referred to by Delsole and Shukla :
- Corr. Coeff. between the prediction by MME of models in ENSEMBLES with observed ISMR is 0.45 as compared to that of MME of models in DEMETER of 0.22 (Rajeevan et. al. Climate Dynamics 2012, henceforth Raj12)
- Changes in the models from DEMETER:
- Higher resolution, better representation of sub-grid physical processes and the more wide-spread use of assimilation for ocean initialization (Raj12)
- However, even now only about 20% of the variance is explained and even with these versions of the models, the drought of 2009 was not predicted.
- Clearly, further improvement, particularly in the skill of prediction of extremes, is a must.

- How are the models to be improved?
- Why is the skill not at a satisfactory level?
- Two kinds of explanations suggested for the poor skill in prediction of interannual variation of ISMR :
- (i) lack of incorporation of an important process such as coupling when AGCMs are used (as suggested by Wang et. al 2005)
- (ii) a poor skill in simulation of the monsoon-EQUINOO link (Gadgil et. al. 2005).
- The appropriate strategy for improvement depends on the diagnosis of poor skill, large errors.
- Consider first the simulation by a two tier system with AGCMs when forced with observed SST (AMIP type).

- Analysis of AMIP results (1979-93) showed that the skill of the AGCMs, in simulating the interannual variability of the Asian/Indian summer monsoon rainfall is poor (Sperber and Palmer 1996; Gadgil and Sajani 1998 etc.).
- Wang et. al (2004) analyzed ensemble simulations of Asian–Australian monsoon (A–AM) anomalies in 11 AGCMs for the unprecedented El Nin˜o period of September 1996–August 1998.
- Results: (i) The simulations of anomalous Indian/Asian summer rainfall patterns were considerably poorer than in the El Nin˜o region. (ii) Skill in the ensemble simulations with the SNU model for 1950-98 of the Indian monsoon is significantly higher than the skill for the period 1996–98.

They concluded that ‘During 1997/98 El Nin˜o, the models experienced unusual difficulty in reproducing correct Indian summer monsoon anomalies’

Precipitation anomalies



Note that the positive phase of EQUINOO is simulated, but rainfall over the Indian region is deficit

They suggested that the cause of the models' deficiencies is failure to simulate correctly the relationship between the summer rainfall and the local SST over the Philippine Sea, the South China Sea, and the Bay of Bengal. This led to a paper by a slew of experts that has received a lot of attention.

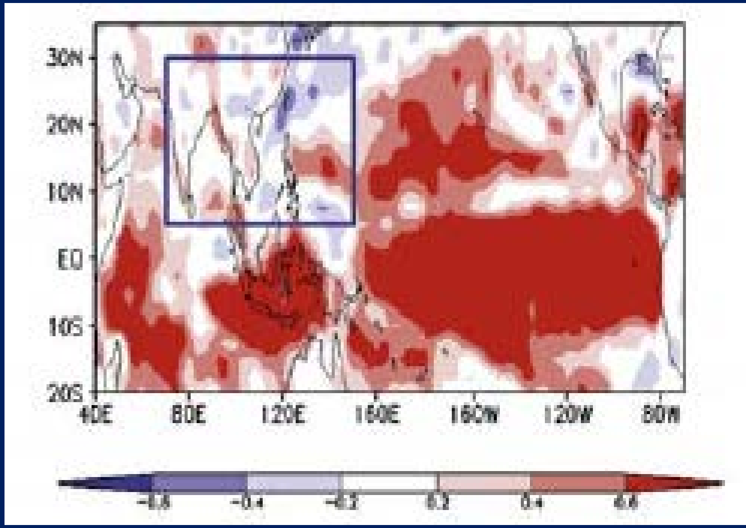
Fundamental challenge in simulation and prediction of summer monsoon rainfall

Bin Wang, Qinghua Ding, Xiouhua Fu, In-Sik Kang, Kyung Jin, J. Shukla, and Francisco Doblas-Reyes

GRL, VOL. 32, L15711, doi:10.1029/2005GL022734, 2005

They examined the simulation skill of five state-of-the-art AGCMs, forced by identical observed SST and sea-ice, in seasonal precipitation for a 20-year period of 1979–1998.

Correlation coefficients between the observed CMAP (1979–1999) and the simulated June–August precipitation anomalies made by five-model multi-ensemble mean.



Skill very poor over Indian/Asian monsoon region

They pointed out that the correlations of the observed local SST and precipitation anomalies are negative in the West north Pacific and insignificant in the Bay of Bengal and that the SST-rainfall correlations in the MME simulation disagree with observations primarily in the Asian-Pacific monsoon regions.

They attribute the unsuccessful simulations of the rainfall variability in the Asian-Pacific summer monsoon under AMIP-type experimental design to the neglect of air-sea interaction in the warm Indo-Pacific oceans, and suggest that the coupled atmosphere-ocean processes are extremely important in the heavily precipitating monsoon regions.

If this hypothesis is valid, the coupled models as a class would have higher skill than the AGCMs, in simulation SST-rainfall relationships over the warm Indo-Pacific oceans and hence also of the variability of the Indian/Asian monsoon.

Thus it is important to assess the skill in simulation of the SST-rainfall relationship by AGCMs and CGCMs. This has been done by Rajendran et. al. 2012.

Relationship between rainfall and local SST

Consider first the nature of the observed relationship. The observed SST-rainfall relationship is highly nonlinear (Gadgil et. al 1984, Graham and Barnett 1987, Waliser et al. 1993; Zhang 1993; Bony et al. 97; Lau and Sui 97etc.) It has been shown that,

(i) there is a threshold around 27.5^{0}C;

(ii) there is a high propensity for organized convection /high rainfall over oceans with SST above the threshold.

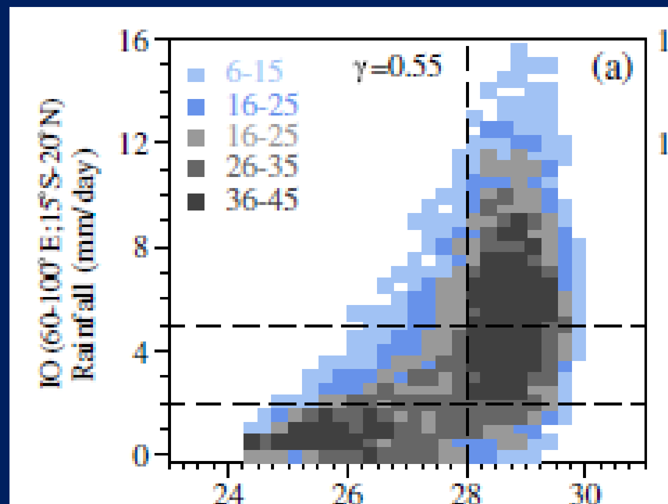
(iii) When the SST is above the threshold, the OLR/rainfall varies over a large range from almost no convection/rainfall to high rainfall/intense deep convection for each SST.

June, July, August 1979-2009

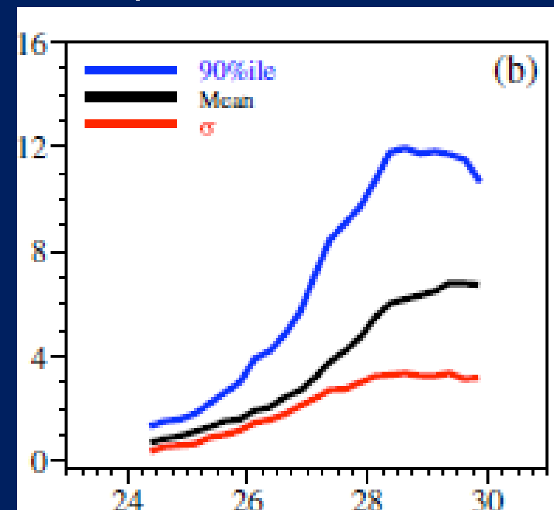
IO: 60-100E, 15S-20N
C.C 0.56

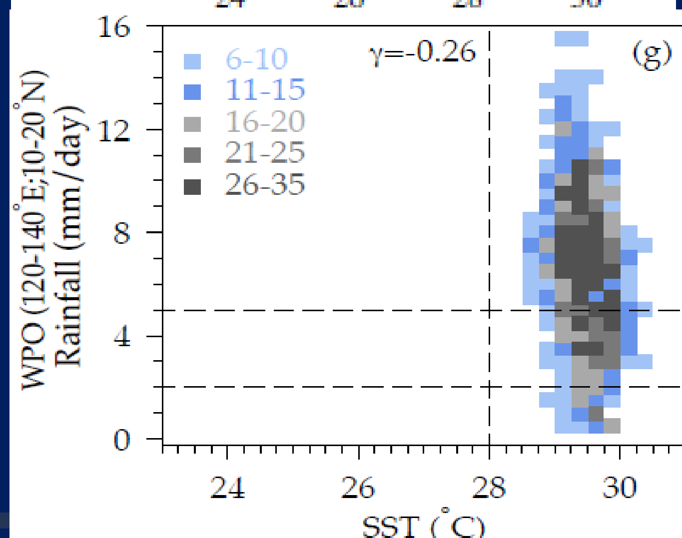
WPO: 120-140E, 10-20N
C.C -0.26 is not significant even at 90%

Number of points for each 0.25C SST & 0.5mm/day rainfall bin

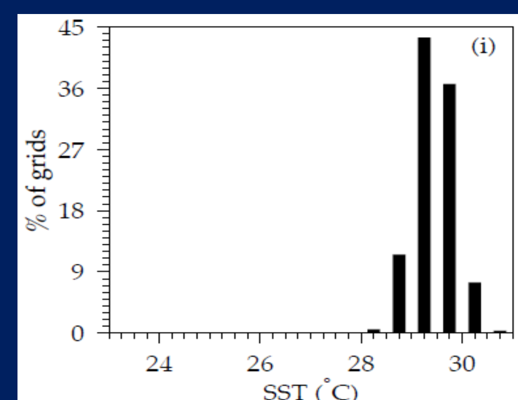


Variation with SST of the mean,90%ile and std. dev





No. of grids versus SST

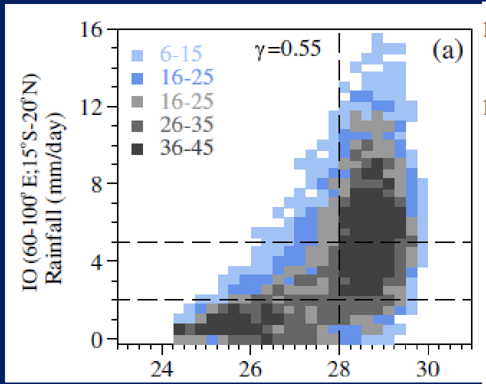


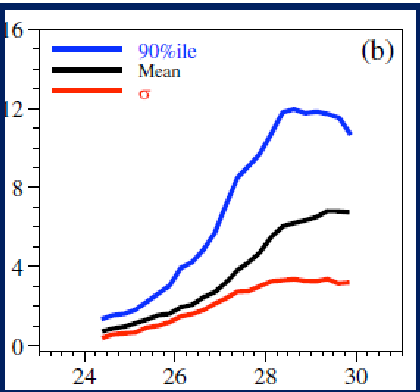
Data Had-SST, GPCP

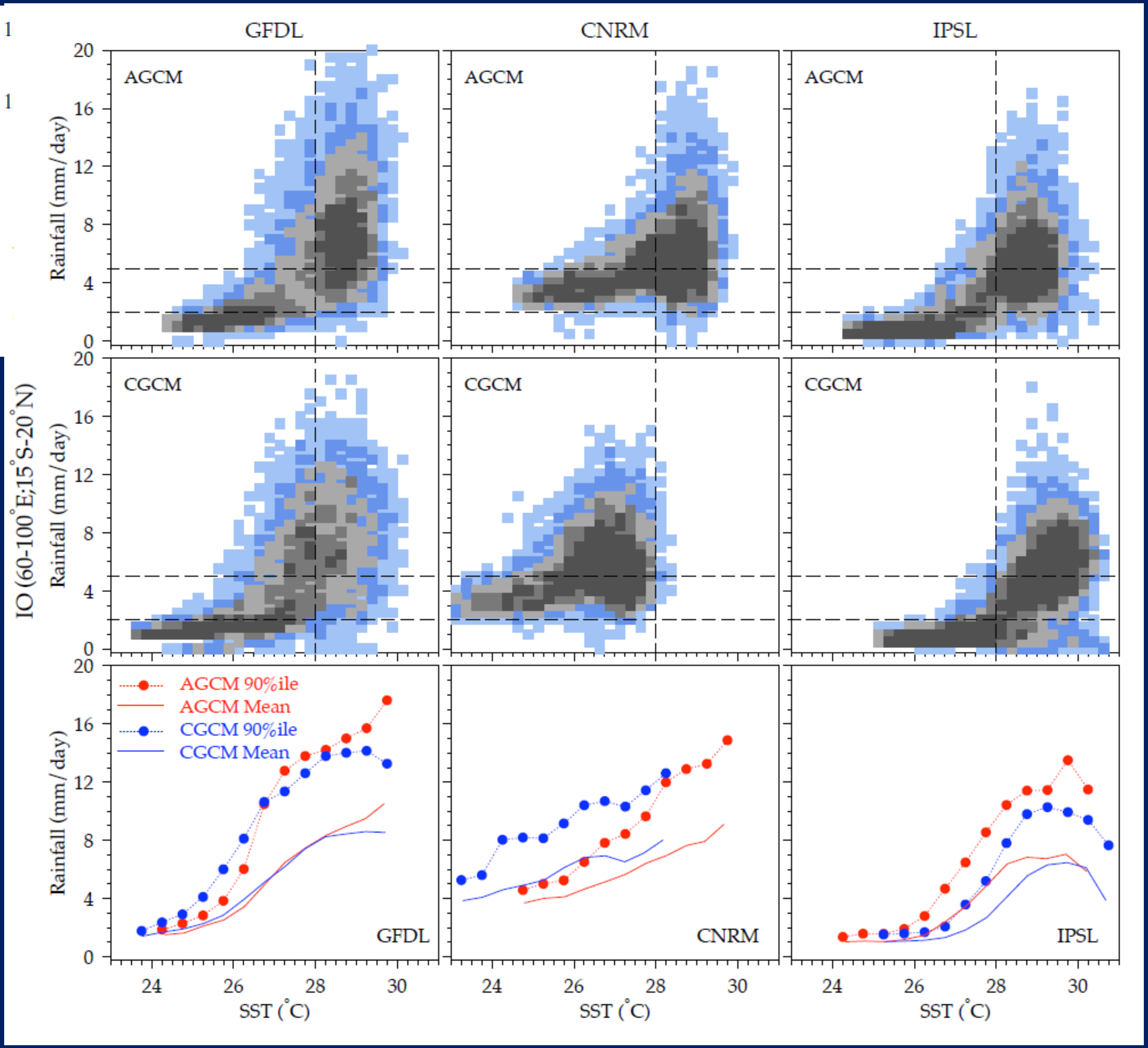
- The correlation coefficient between the local SST and the convection/rainfall depends on the range of SST (Gadgil et. al . 1984). When SST varies over a large range across the threshold, the correlation is significantly positive (as for IO) . However, for oceanic regions with SST maintained above the threshold (such as the Bay of Bengal, tropical West Pacific etc.) the correlation is insignificant (Gadgil et. al 1984).
- Clearly, for such a nonlinear relationship, correlation is not an appropriate measure. However, in the Wang et al studies, simulation of the SST-rainfall relationship was assessed by a comparison of the observed and simulated correlation between the rainfall and local SST.
- An important question that arises is: ‘How good are the simulations of tropical SST–rainfall relationship by atmospheric and coupled models?’

Observations (IO)

Simulations by IPCC-AR4 models

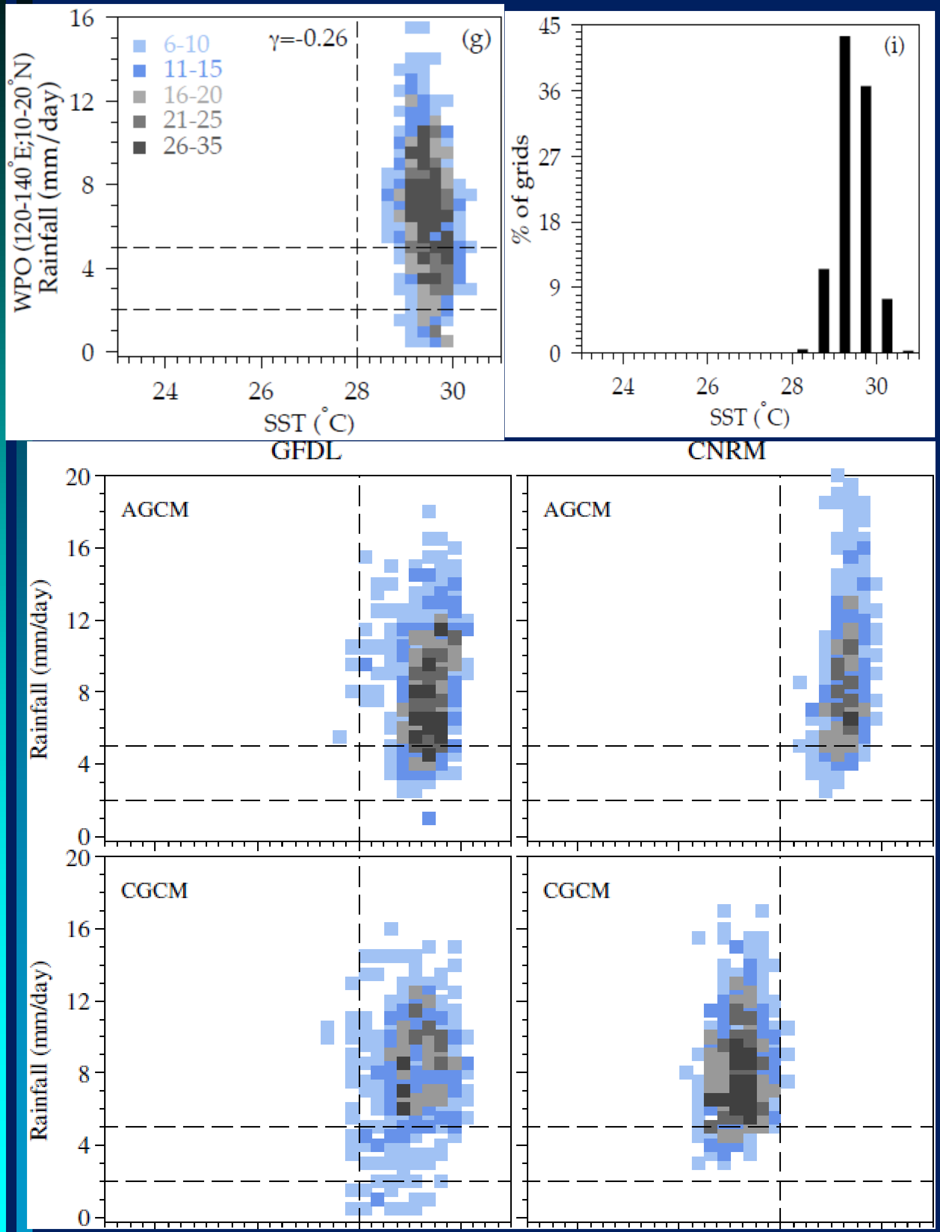






Results of Rajendran et. al. (2012)

Warm oceans : WPO



Observations

AGCMs

CGCMs

When maintained above the threshold, SST is no longer a limiting factor; whether there is convection/rainfall or not depends on the dynamics i.e. low level convergence (Graham & Barnett 1987).

- In fact, the SST-rainfall relationship, even over warm oceans such as WPO, is well simulated by AGCMs and CGCMs.
- The SST-rainfall pattern simulated by the coupled versions of these models is rather similar to that from the corresponding atmospheric one, except for a shift of the entire pattern to colder/warmer SSTs when there is a cold/warm bias in the coupled version. (Rajendran et. al 2012, JESS).
- Hence the poor skill in simulation and prediction of ISMR with AGCMs cannot be attributed to the skill in simulation of the SST-rainfall relationship.

Alternative hypothesis

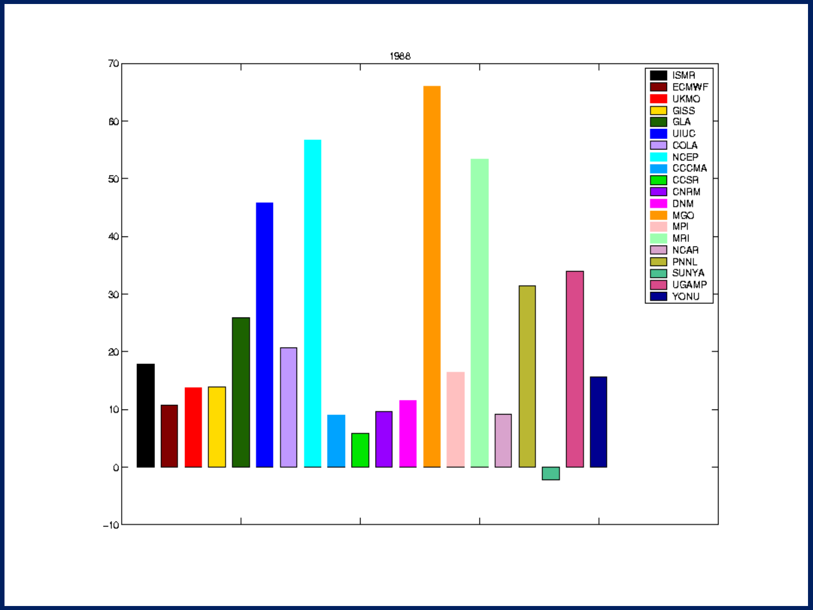
- An alternative explanation is, in fact, suggested from an analysis of AMIP results. We find that there are large errors in simulation of only some seasons which lead to the overall poor skill.
- Of the extremes of ISMR, for those associated with ENSO, most of the models simulate at least the sign of ISMR accurately*. For example, the La Nina of 1988.
- On the other hand, in cases such as 1994 in which excess rainfall occurred despite a weak El Nino, the skill is very poor. The case of normal rainfall in 1997 despite a strong El Nino has also been difficult to simulate (Wang et. al. 2004).
- ***This is no fluke. There were concerted efforts by many modelling groups under MONEG to get the ISMR anomalies of 1987 and 88 right.**

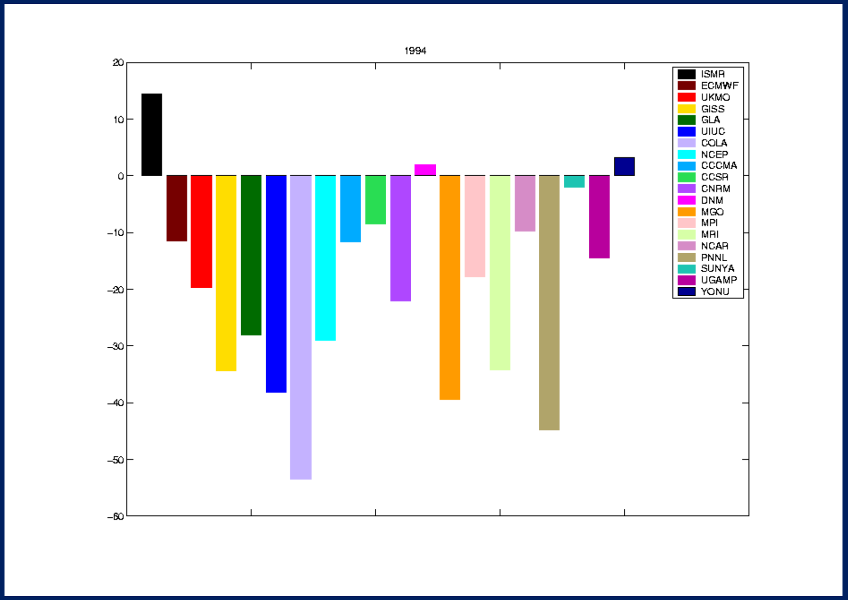
AMIP results

From "Monsoon Prediction, why yet another failure? Gadgil et.al 2005

1988:Excess rainfall - La Nina

1994: Excess rainfall: positive IOD, hence fav. EQUINOO, unfav. ENSO





Note: Also, very few models simulated positive anomaly for 1983
Skill of AGCMs (forced with obs. SST as in AMIP) in simulating normal monsoon for the strong El Nino and strong +ve IOD season of 1997 was found to be poor (Wang et. al 2004)

- Occurrence of large errors only for a few years suggests that the low skill in simulation of the interannual variation of the monsoon arises from a poor simulation of an important facet/phenomenon and/or of the teleconnections rather than the omission of an important process such as coupling.

- Note that 1994 and 1997 seasons are characterized by a positive phase of EQUINOO, associated with strong positive IOD events. The anomalies over the equatorial Indian Ocean associated with the positive phase of EQUINOO is simulated by the AGCMs forced with observed SST. Hence, Gadgil et. al (2005) suggested that poor skill in simulation of the monsoon-EQUINOO link leads to the poor skill of AGCMs in simulation of interannual variation of ISMR.

Why are AGCMs not able to simulate the link between the Indian summer monsoon and EQUINOO?

Two possibilities

(i) models are incapable of simulating the link with EQUINOO (suggested by Gadgil et. al 2005)

(ii) Models are not inherently incapable of simulating the link with EQUINOO, but are unrealistically sensitive to the anomalies over the Pacific i.e. ENSO and not sufficiently sensitive to those over the Indian Ocean.

The latter hypothesis supported by results of SPIM (Seasonal prediction of the Indian Monsoon) – a national inter-comparison experiment with 5 AGCMs used in the country for seasonal prediction, for 1985-2004 (Gadgil and Srinivasan 2010).

- For each model, 5 member ensemble runs were made with initial conditions specified from observations at the end of April Two expts were run.
- Expt 1: forced with observed SST
- As expected from AMIP results, while all models could simulate the excess rainfall for the La Nina of 1988, almost all the models simulated deficit for the positive EQUINOO season of 1994.
- Expt 2: Forced by SST derived with the assumption that April anomalies persist . This implied weaker SST anomalies than observed, over the equatorial Pacific & Indian Oceans. With the weaker El Nino, the monsoon-EQUINOO link and positive anomalies of ISMR were simulated for 1994, by the two best models (PUM,SFM).

Lessons from experiments with AGCMs

- AGCMs are able to simulate the monsoon-ENSO link but not the monsoon-EQUINOO link when forced by the observed SST for some IOD events such as 1994.
- Some of the AGCMs do simulate the positive impact of positive phase of EQUINOO on ISMR in 1994 when forced by weaker SST anomalies (i.e. weaker EL Nino than observed). Hence we expect that they would simulate the positive ISMR anomaly in 1961 which was associated with a weak La Nina.
- Just as the improvement in the simulation of the monsoon-ENSO link by AGCMs was achieved under MONEG and efforts thereafter, it should be possible to improve the simulation of the monsoon –EQUINOO link even for realistic SST forcing.
- .

Retrospective predictions with coupled models

- ENSEMBLES project:

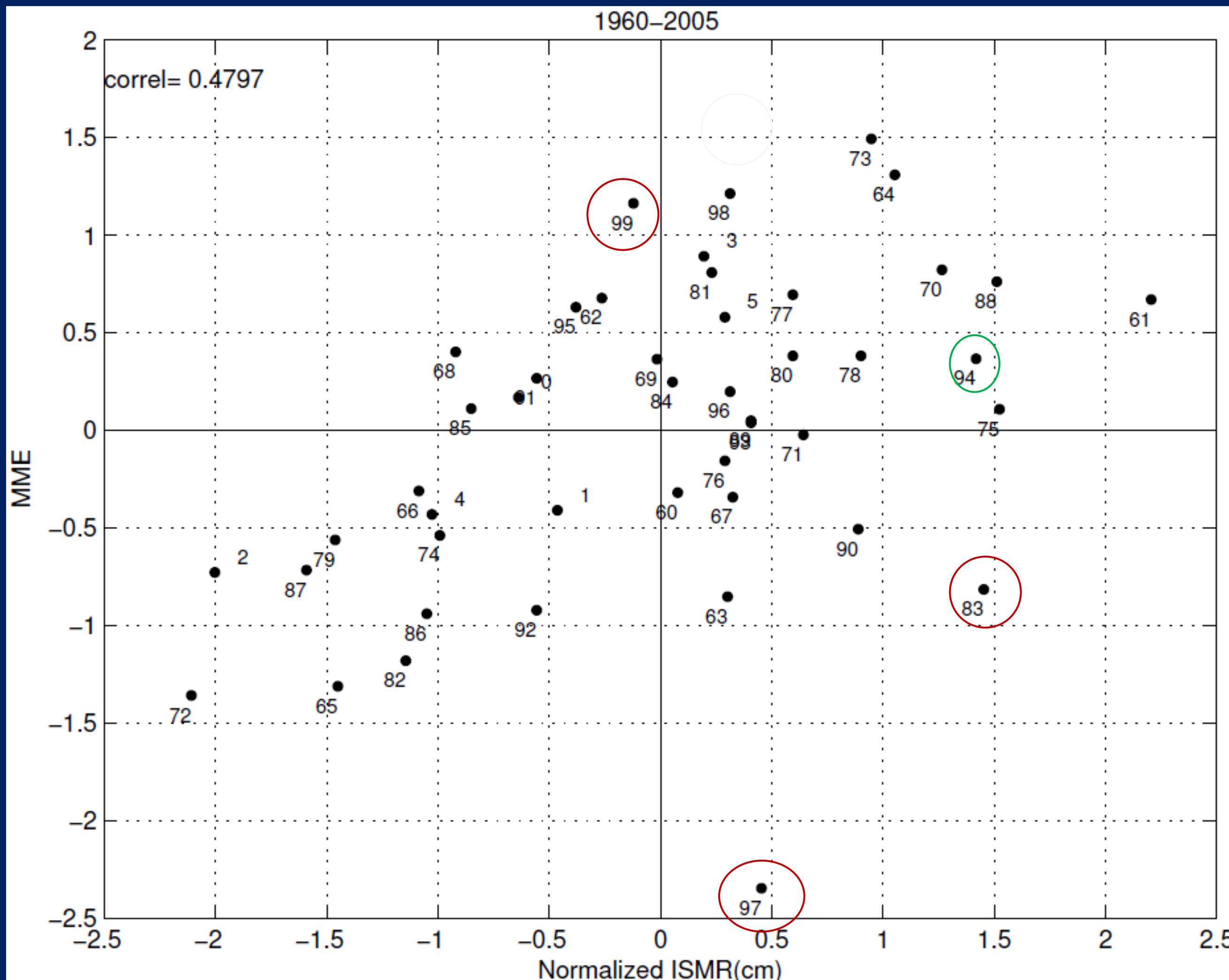
- CMCC-INGV, ECMWF, IFM-Geomar, Meteo-france, UKMO and MME ,
- 1960-2005 (after Raj12)

- From the NCEP models-CFS1, CFS2
- 1982-2009
-

- ENSEMBLES

- Correlation between the predicted and observed ISMR) by MME (0.45) is positive and significant. On the whole, the MME skill is also reasonable for the ISMR extremes.
- Thus MME predicted negative ISMR anomaly for all the 9 droughts during 1961-2005.
- The MME prediction for 6 of the 7 excess monsoon seasons was positive ISMR anomaly; however for 1983 the prediction was for large deficit.
- The scatter plot of MME predicted versus observed ISMR anomalies (next slide) shows that the major outliers in the wrong quadrants (i.e. with predicted and observed ISMR anomalies of opposite signs and either the observed or predicted being extreme), are 1983, 1997 and 1999.

ISMR anomaly predicted by MME of ENSEMBLES versus observed 1960-2005



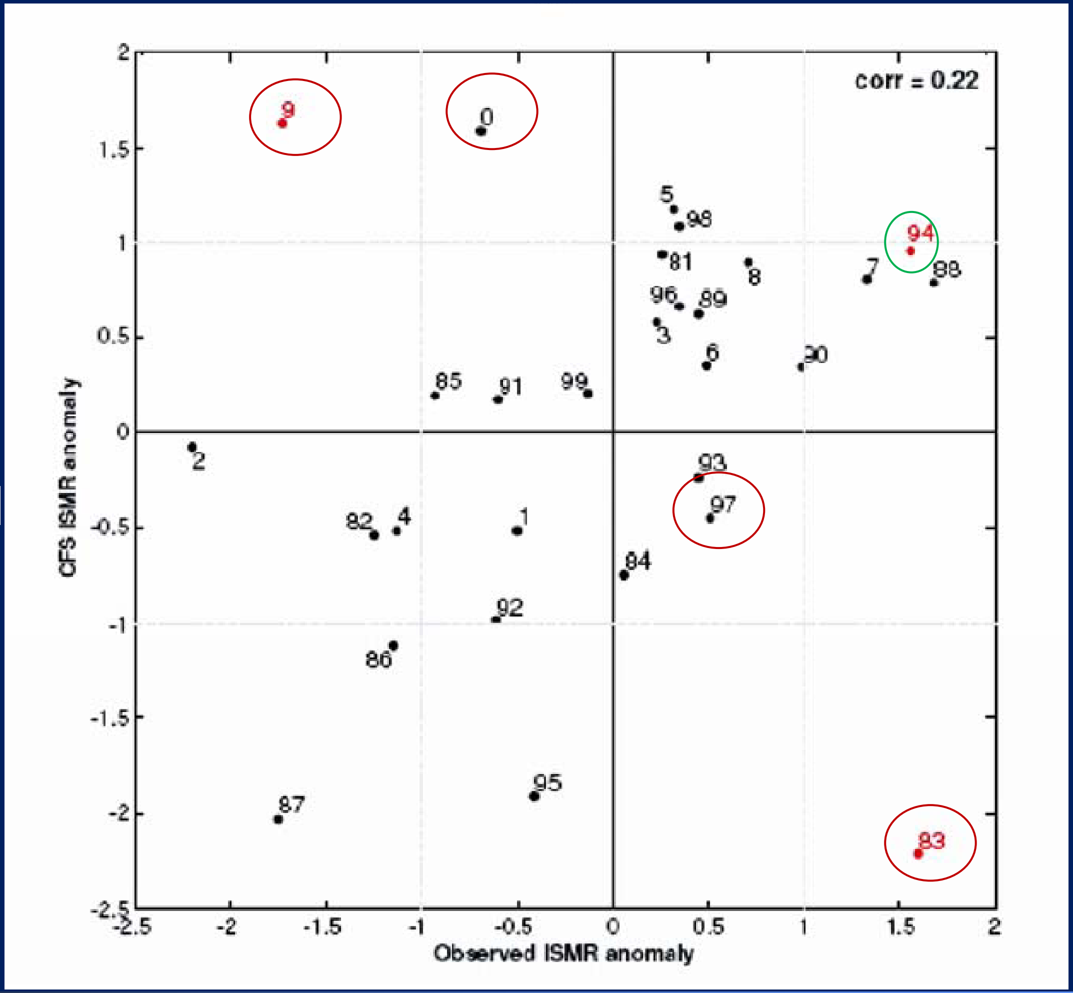
Note positive anomaly predicted for 1994

However, loud false Alarms 1997, 1983, 1999

ISMR anomaly predicted by CFS1 versus observed 1982-2009

Obs.Droughts: Predicted negative ISMR anomaly for 5 out of 6

Obs. Excess rfl Predicted - Positive ISMR anomaly for 4 out of 5



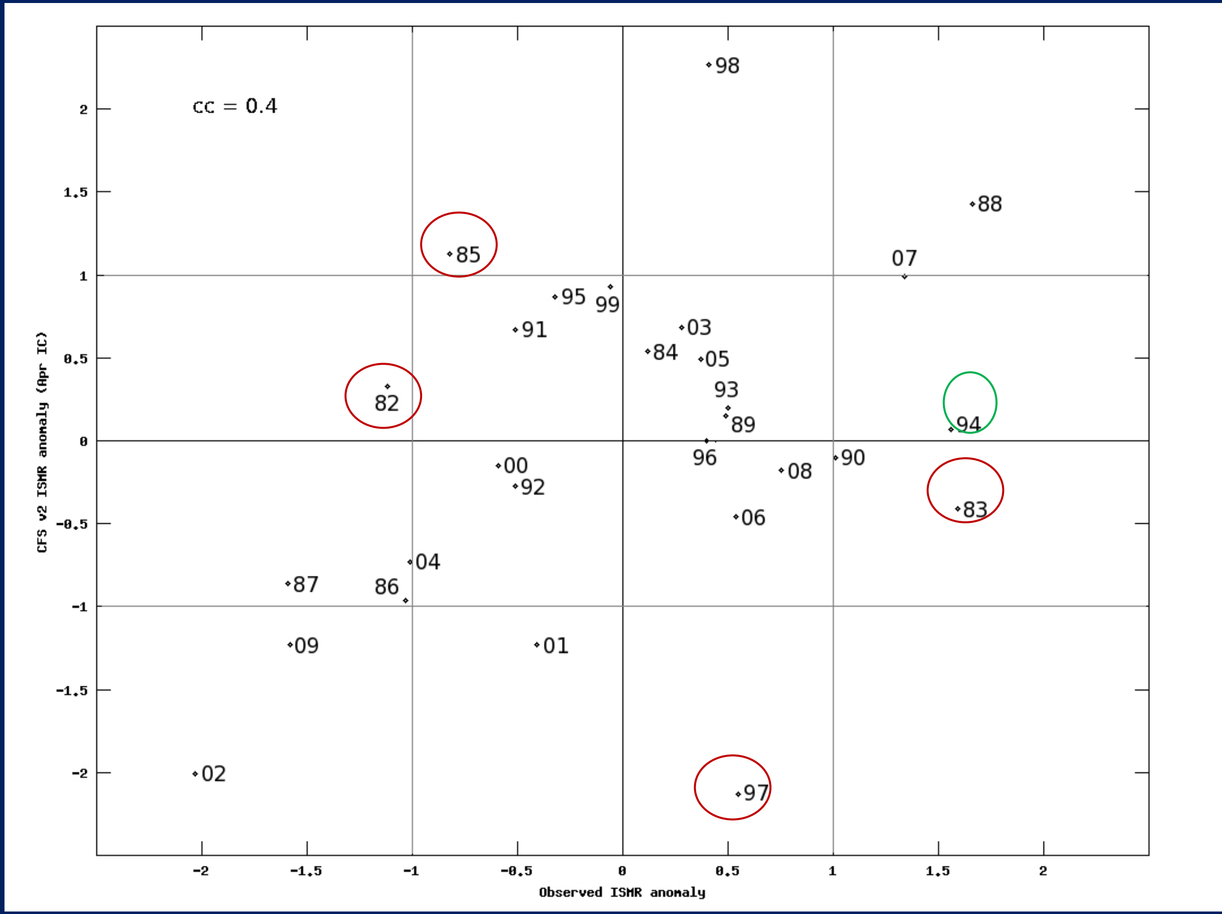
Large errors: 1983, 2000, 2009

Note 1997 is also in the wrong quadrant

Janakiraman et. al 2011

ISMR anomaly predicted by CFS2 versus observed 1982-2009

Obs. Droughts: Predicted -negative ISMR anomaly for 4 out of 5
Obs. Excess rfl Predicted - Positive ISMR anom for 3 out of 4



Large errors: 1983, 1997, 1982, 1985

Mohit Ved et. al. 2012

Correlation between predicted and observed ISMR (Raj 12)

	Mean rainfall (cm)	Coefficient of variation CV (%)	Correlation coefficient 1960–2005
Observed	82.9	11.9	1
ECMWF	93.2	4.5	0.37
IFM-GEOMAR	79.8	5.7	0.34
MF	45.0	8.2	0.34
HadGEM2	80.0	12.2	0.39
CMCC-INGV	91.0	5.4	0.39
ENSEMBLES MME	75.8	5.7	0.45
DEMETER MME (1960-2001)	76.0	4.3	0.28

Note: Marked improvement over DEMETER. C.C. varies only from 0.34 to 0.39 for different models. The observed ISMR is that from IMD. We get very similar results if the ISMR from the IITM website is used.

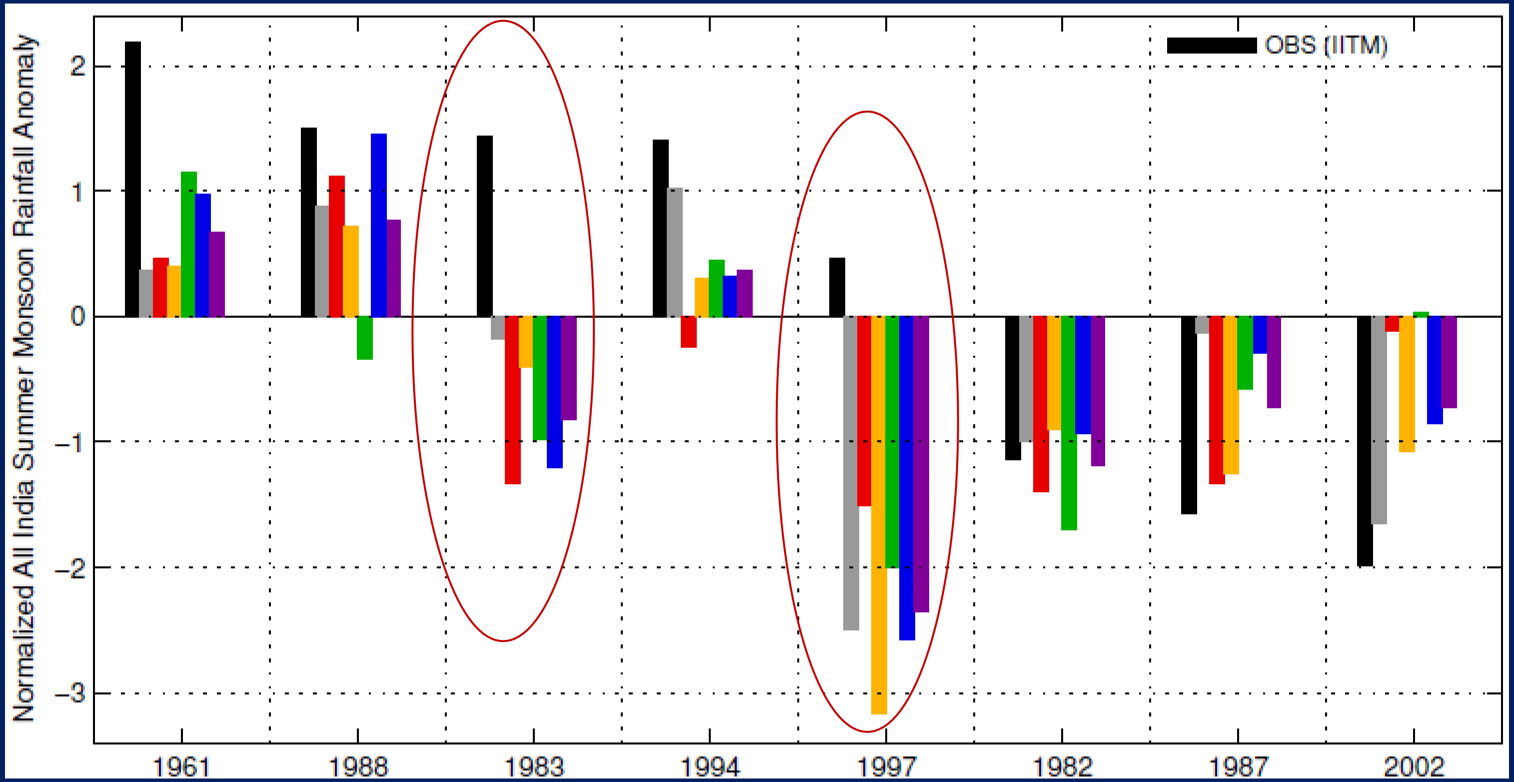
I consider next the retrospective predictions by these five models for some special years.

Correlation between predicted and observed ISMR		
Model Ensembles	1960-2005	1960-2005 (without 1983,97)
MME	0.48	0.64
	(1982-2009)	Without 1983,97
CFS2 AprilIC	0.40	0.56
CFS2 MayIC	0.32	0.53

Observed ISMR from IITM data

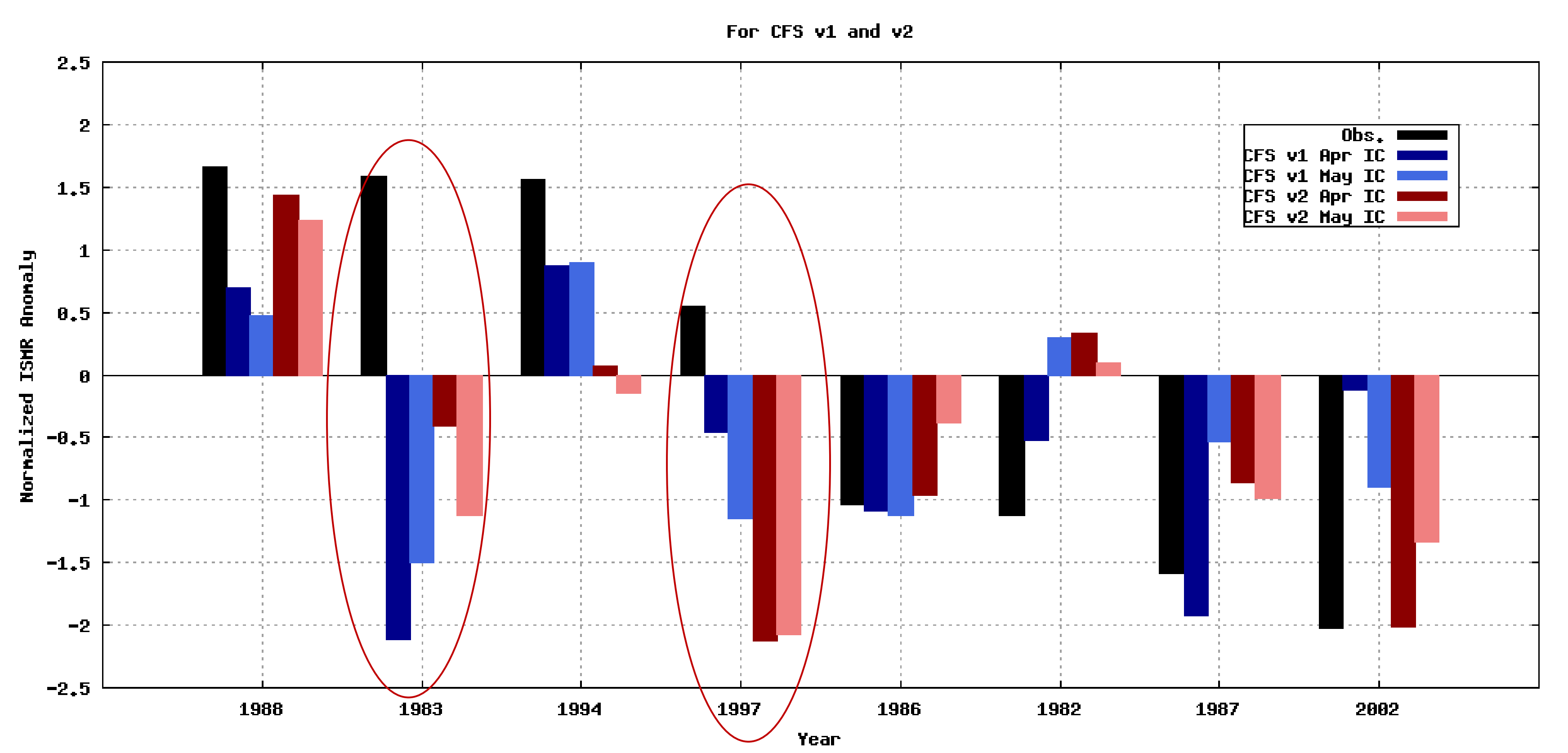
If the predictions for 1997 and 1983 are improved, the correlations would be enhanced substantially.

ENSEMBLES: some special years



Note : All models predict the observed sign of ISMR anomaly for the excess monsoon of 1961, and all but one for 1994. However, none models predict the sign of the observed ISMR anomaly for 1997 and 1983.

CFS1 and CFS2:some special years



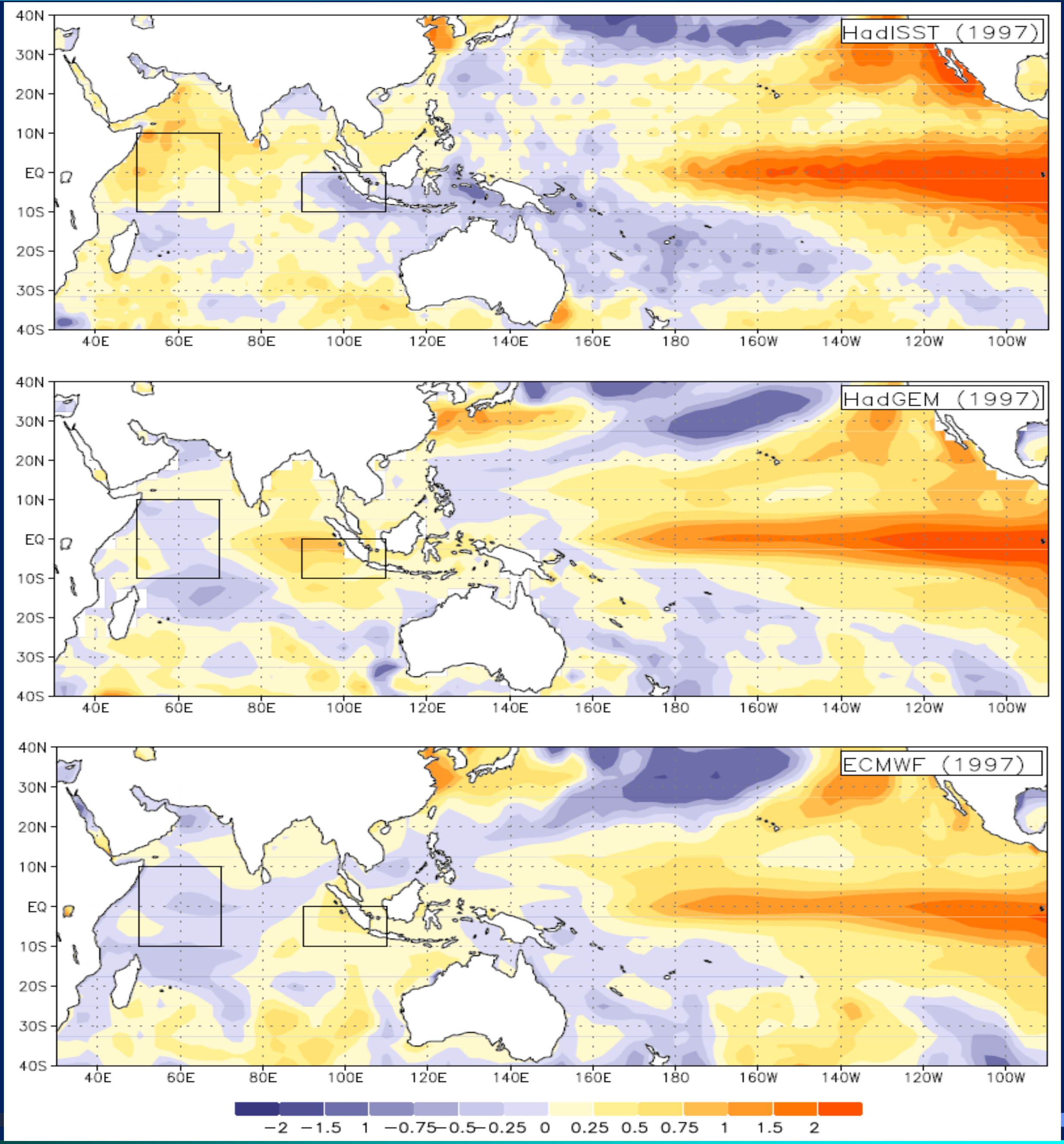
CFS2 gets the El Nino season of 1982 wrong, and almost normal ISMR in 1994 for which CFS1 prediction is reasonable.

Years with unacceptably large errors

- **1997: the observed ISMR anomaly was positive but all the models of ENSEMBLES, MME and CFS1 & CFS2 predict deficit ISMR. Furthermore, drought is predicted by 4 out of 5 ENSEMBLES, MME, CFS1 (May I. C.) and CFS2 (with April and May I. C.).**
- **All the models simulate a stronger than observed El Nino, particularly over the central Pacific, which is expected to have a large negative impact on ISMR. Furthermore, the SST anomalies over the equatorial Indian Ocean predicted by the models are of smaller magnitude than observed.**

SST

Obs

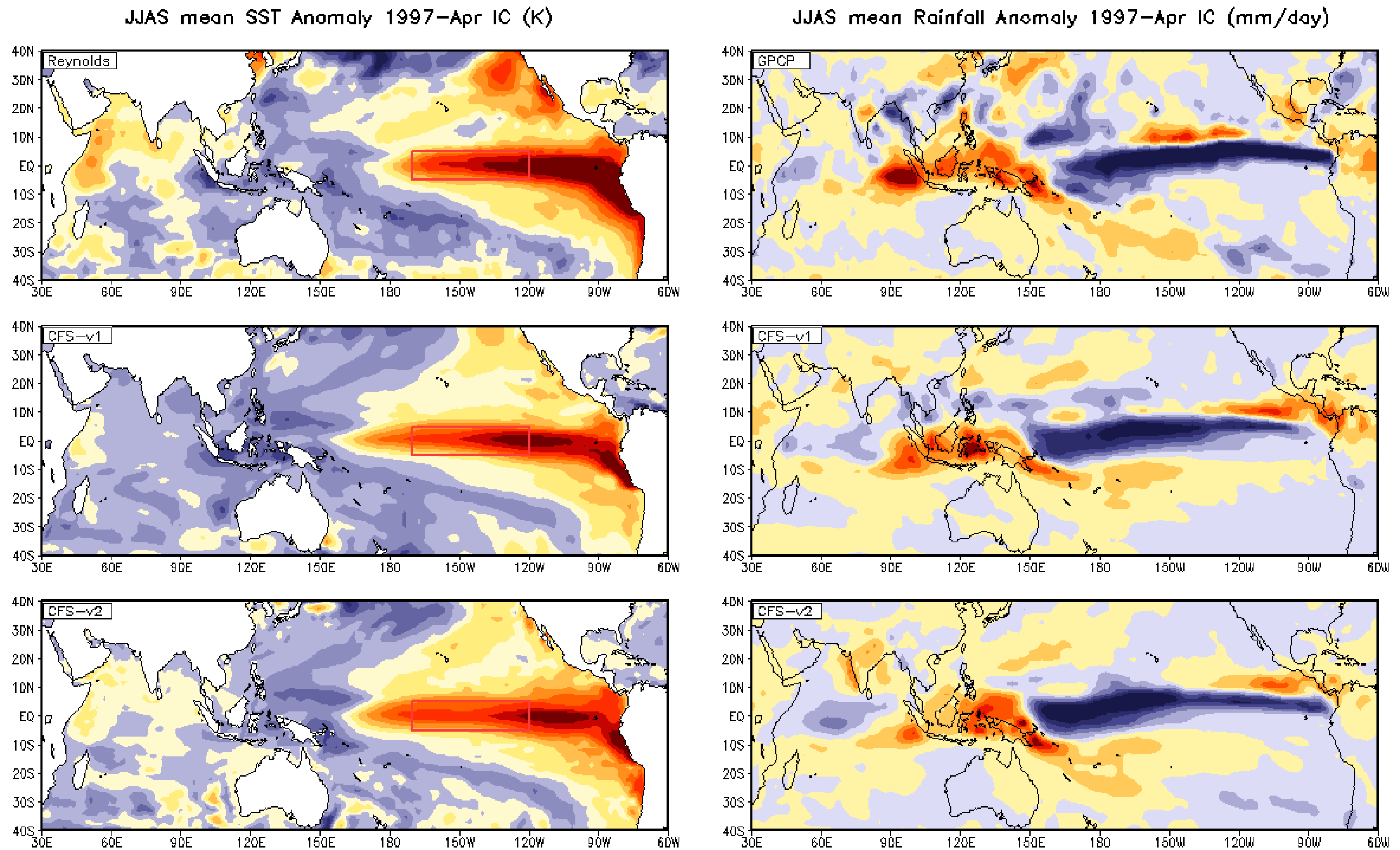


HADGEM

ECMWF

after Francis et. al 2012

CFS1,2:1997



after Mohit Ved et. al. 2012

The SST anomaly pattern and positive EQUINOO appears to be better simulated by CFS models.

- **In some cases (HadGem, ECMWF) a reverse SST anomaly pattern relative to the observed is predicted over the equatorial Indian Ocean, with cold anomaly over the western and warm anomaly over the eastern equatorial Indian Ocean. CFS1,2 and Meteo-France predict the correct SST anomaly pattern over the equatorial Indian Ocean but the magnitude is smaller than observed. The other two models i.e. CMCC and IFM-GEOMAR predict warm anomalies over the western and eastern parts. Thus it is not surprising that all the models predict deficit ISMR in response to the strong El Nino.**
- **Consequently, the MME also predicts an absence of SST anomalies over   the equatorial Indian Ocean, strong anomalies over the central Pacific and a drought over the Indian region for 1997(Raj.12).**
- .

1983 : For the excess monsoon season of 1983, all the five models of ENSEMBLES, MME as well as CFS1 and CFS2 predict deficit ISMR, with most predicting a drought.

The El Nino retreated from the central Pacific halfway though the summer monsoon of 1983. Also, the zonal SST gradient as well as EQUINOO became very favourable in August-September. However, the MME predicted that the SST anomalies (and hence rainfall anomalies) characterizing the El Nino, persisted over the central equatorial Pacific through the season. The large error in 1983 with a large deficit predicted instead of the observed excess, has been attributed to error in the prediction of the timing of the retreat of the El Nino of 1982-83 from the central Pacific (Raj. 12).

- It is interesting that 1983 and 1997 were problem cases also in the AMIP type runs with AGCMs. Thus incorporation of coupling does not seem to have had the salutary effect that was expected.
- Since the impact of positive IOD events such as those of 1997 is well known, it is critical that the models are able to predict the occurrence of such events.
- An important question that arises is:

Are the models such as HAD GEM, ECMWF etc. capable of generating predictions of positive IOD events and the links of the positive EQUINOO phase to the monsoon?

The answer is provided by the retrospective predictions for 1994

Marked improvement from AGCMs – 1994:

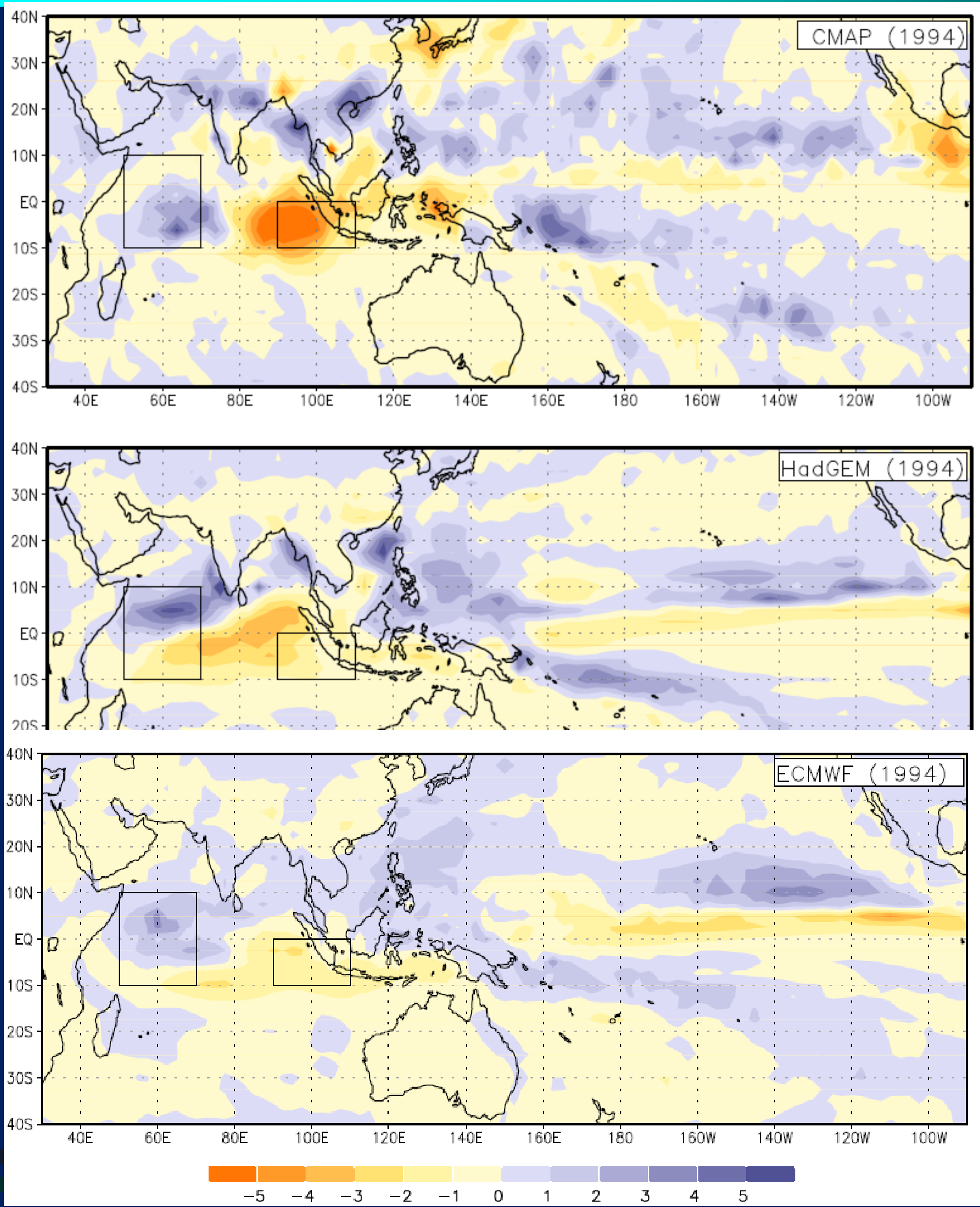
- Whereas almost no models in AMIP simulated a positive ISMR anomaly for the excess monsoon season of 1994, the vast majority of the coupled models considered here, have done so.
- We find that all the models predict the correct sign of the anomalies over the western and eastern equatorial Indian Ocean i.e. a positive phase of the IOD. However, the ENSEMBLES models and CFS2 predict SST anomalies with a smaller magnitude, whereas CFS1 with a larger magnitude than observed. The local response of a positive EQUINOO is also predicted by all the models.

Rain

OBS

HAD-Gem

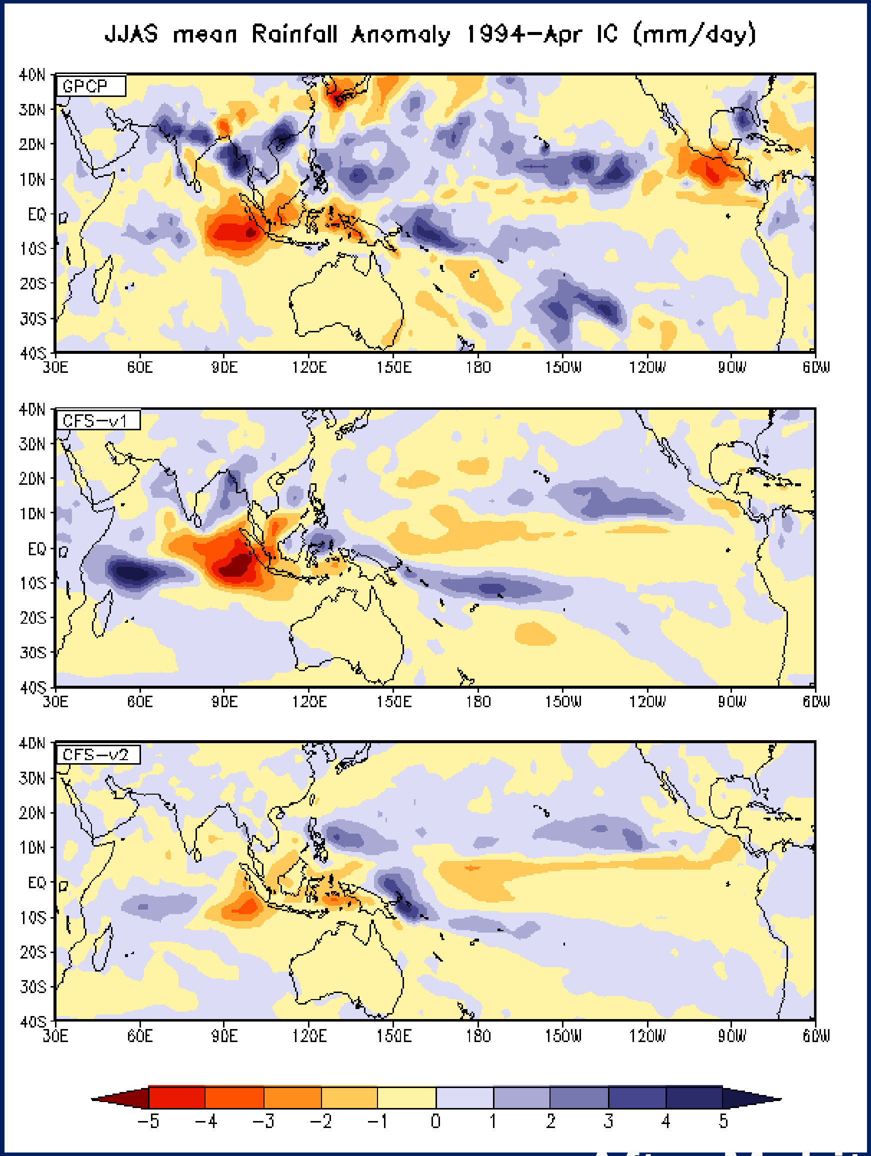
ECM WF



1994

Weaker El Nino in association with weaker SST anomalies over eq. Pacific and weaker EQUINOO than observed, in association with weaker SST anomalies over eq. Indian Ocean

CFS1,2 (April I. C.) : 1994



After Mohit Ved et. al. 2012

- They also predict weaker SST and rainfall anomalies over central equatorial Pacific. With the reduced impact of El Nino, a positive anomaly of ISMR is predicted by almost all the models.

- A realistic pattern of the SST anomalies, but with a smaller magnitude than observed, is a scenario we considered in the experiment under SPIM in which AGCMS were forced with SST derived by assuming that April persist. Thus the positive ISMR anomaly predicted by most of the coupled models is consistent with the positive ISMR anomalies simulated by the AGCMs in that case.

Case of 1994

- Thus all the models predicted the observed SST anomaly pattern over the equatorial Indian Ocean, associated with the IOD event, although most predict the magnitude to be smaller than observed. All the models simulated weaker than observed SST anomalies over the central Pacific and a weaker EL Nino.
- The correct prediction of the sign of the ISMR anomaly by almost all the models can be attributed to the reasonable prediction of the IOD event.

Lessons learnt:

- It appears that the prediction of the transition from El Nino (e.g.1983) and the pattern as well as strength of the mature phase (e.g. 1997) needs to be improved.
- It has been proposed that El Nino plays an important role in triggering of an IOD event via suppression of convection over EEIO. It is believed that the IOD event was triggered before the monsoon of 1997 because the transition to El Nino occurred much earlier. Thus, it is intriguing that an IOD event was not predicted by the models in 1997. Whether the transition phase to El Nino was realistically predicted has to be examined. Why the models were able to predict the SST anomaly patterns over IO in 1994 but not in 1997 , has to be understood.

Summary

- The impact of seasonal rainfall on agriculture and GDP is highly nonlinear with the impact of negative ISMR anomalies much larger than that of positive ISMR anomalies of similar magnitude. A reliable prediction of the non-occurrence of droughts is expected to be very useful.
- The SST-rainfall relationship over Nino 3.4 as well as warm oceans such as the tropical West Pacific, is well simulated by atmospheric and coupled versions of the models of IPCC-AR4.
- On the whole, the models are able to predict the correct sign of the ISMR anomaly for most of the ISMR extremes. However, almost all fail to do so for the excess monsoon season of 1983 and the strong El Nino season of 1997.

- Analysis of these cases suggests that poor skill in prediction of some facets of the two important modes ENSO and EQUINOO leads to the large errors in all the models in some years. A surprising conclusion is that prediction of some facets of ENSO needs to be improved for better monsoon forecasts.
- It is also necessary to understand and model the evolution of EQIUNOO and IOD and, in particular, special attention has to be given to accurate prediction of the triggering of IOD events.
- It is also important to predict the impact of the ENSO on EQUINOO and thereby on the Indian monsoon.

Thank you