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Targeted Training Activity: Seasonal Predictability in Tropical Regions to be followed by Workshop on Multi-scale Predictions of the Asian and African Summer Monsoon

4 - 15 August 2008

Indian Summer Monsoon Rainfall and Its Link with ENSO and the Indian Ocean

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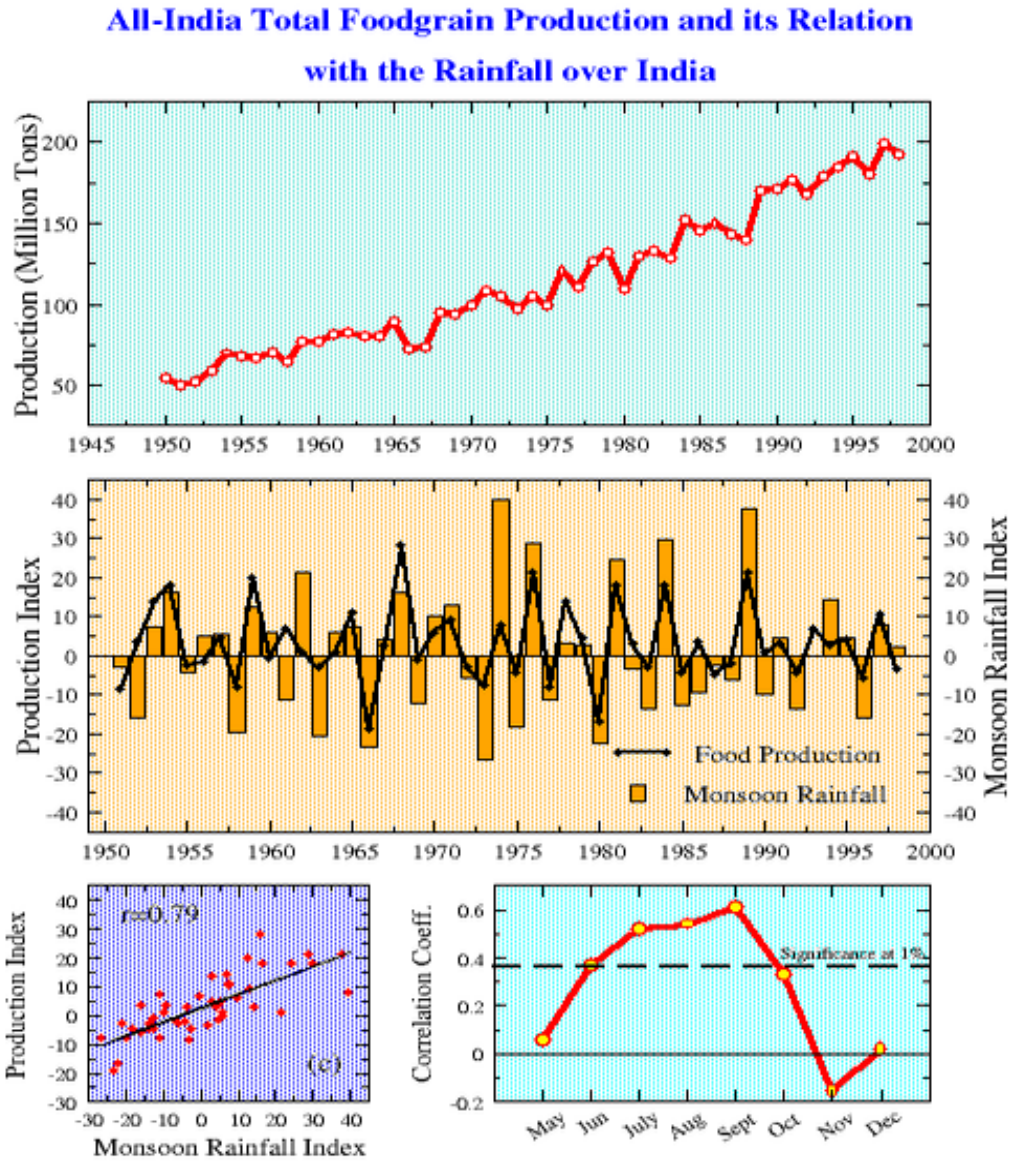
Indian Summer Monsoon Rainfall and Its Link with ENSO and the Indian Ocean

Mark A. Cane

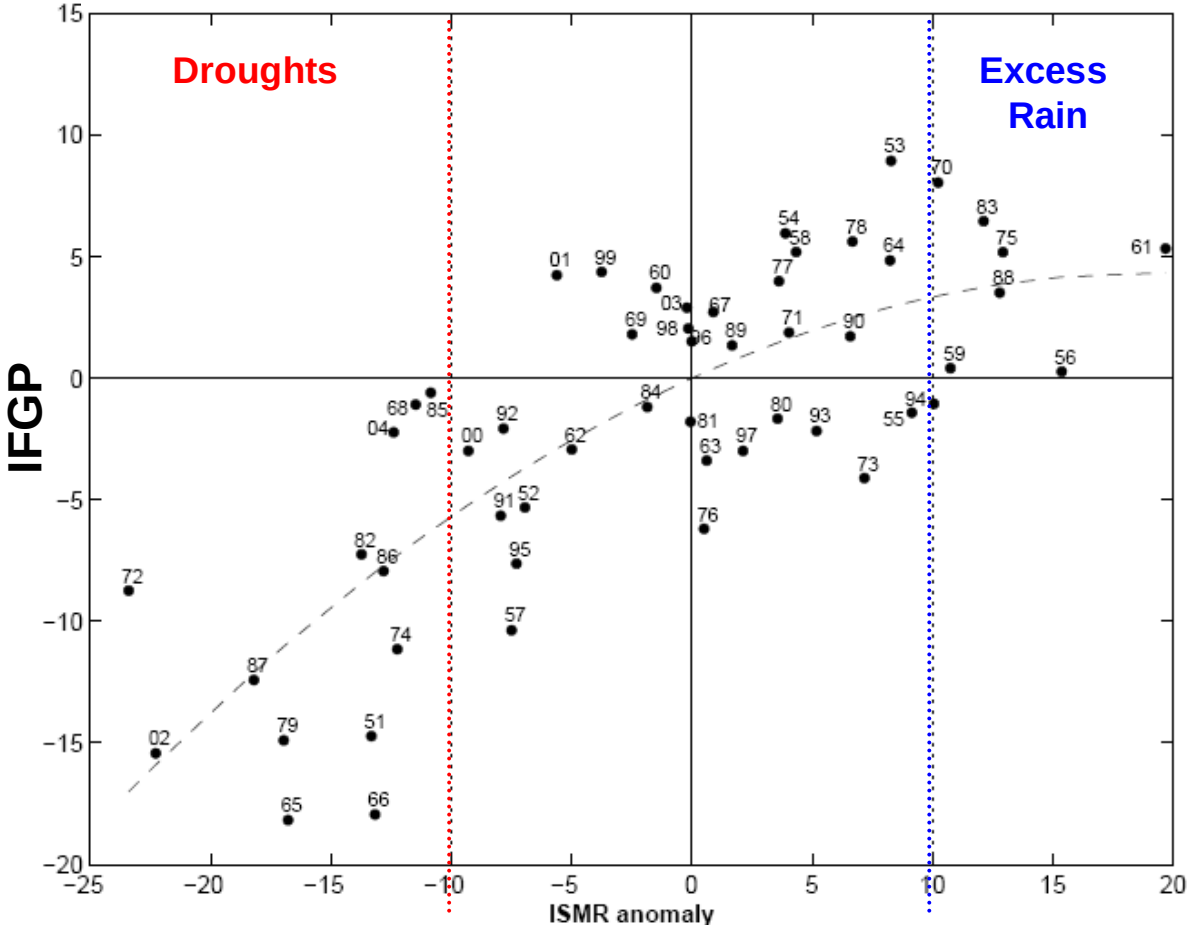
Lamont-Doherty
Earth Observatory of
Columbia University

with **Chie Ihara**,
Yochanan Kushnir, Victor
de la Pena; **K. Krishna
Kumar**, B. Rajagopalan,
M. Hoerling, G. Bates;
S. Gadgil, P.A. Francis

Total Foodgrain Production in India and its Relation to Indian Rainfall



Indian Food Grain Production vs Rainfall (ISMR)

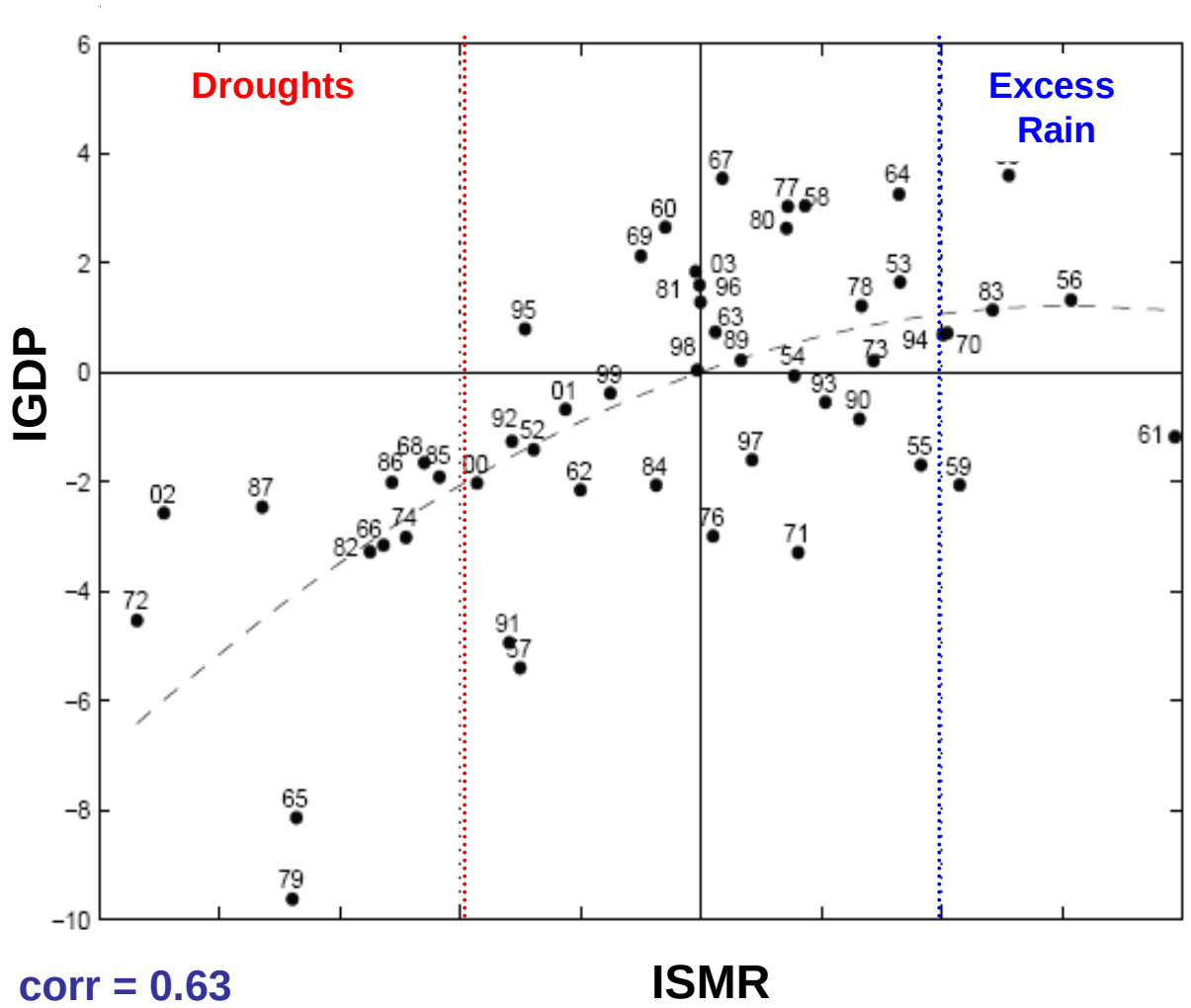


corr = 0.76

ISMR

Gadgil & Gadgil, 2007

Indian Gross Domestic Product vs Rainfall (ISMR)



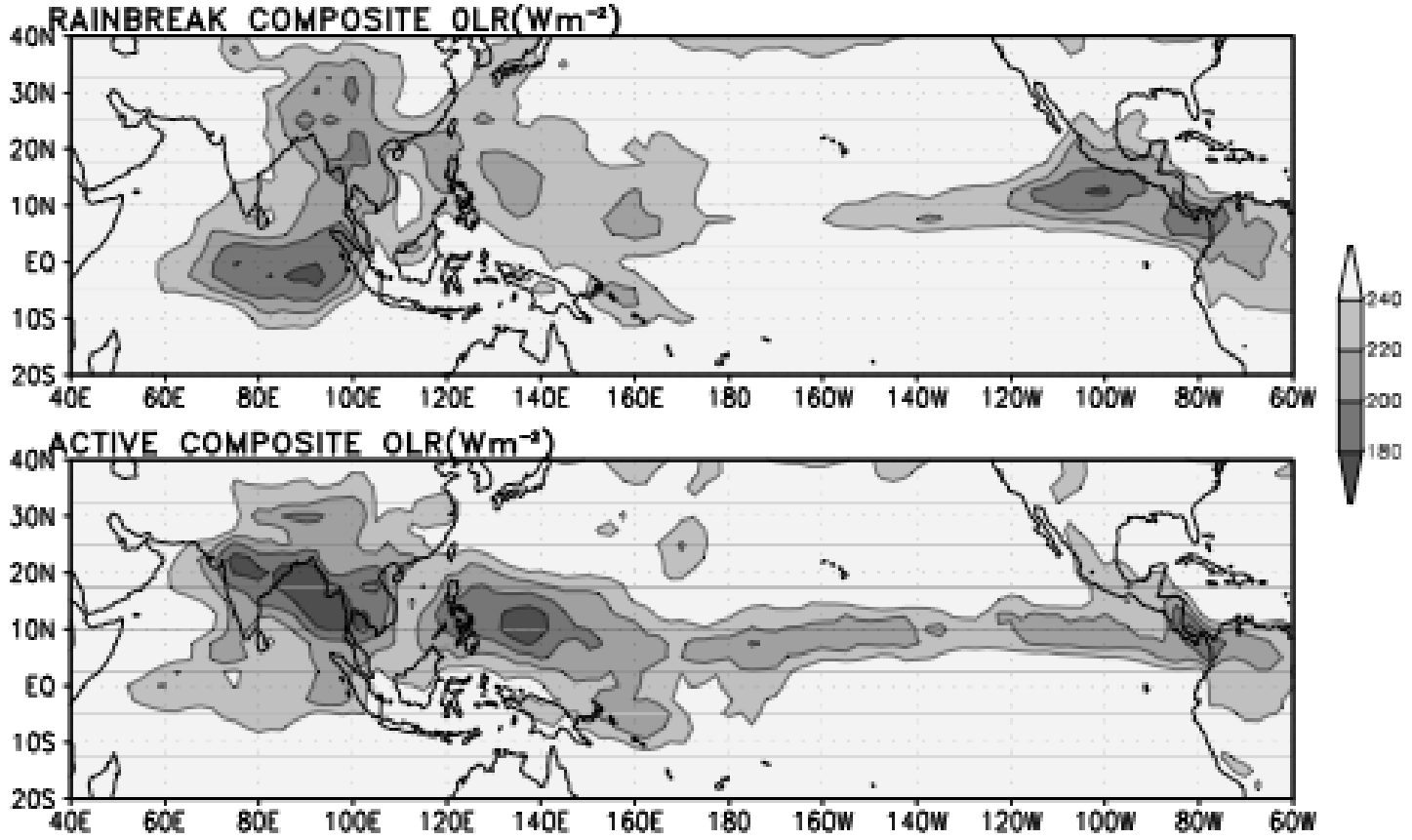
corr = 0.63

Gadgil & Gadgil, 2007

Composite OLR Patterns

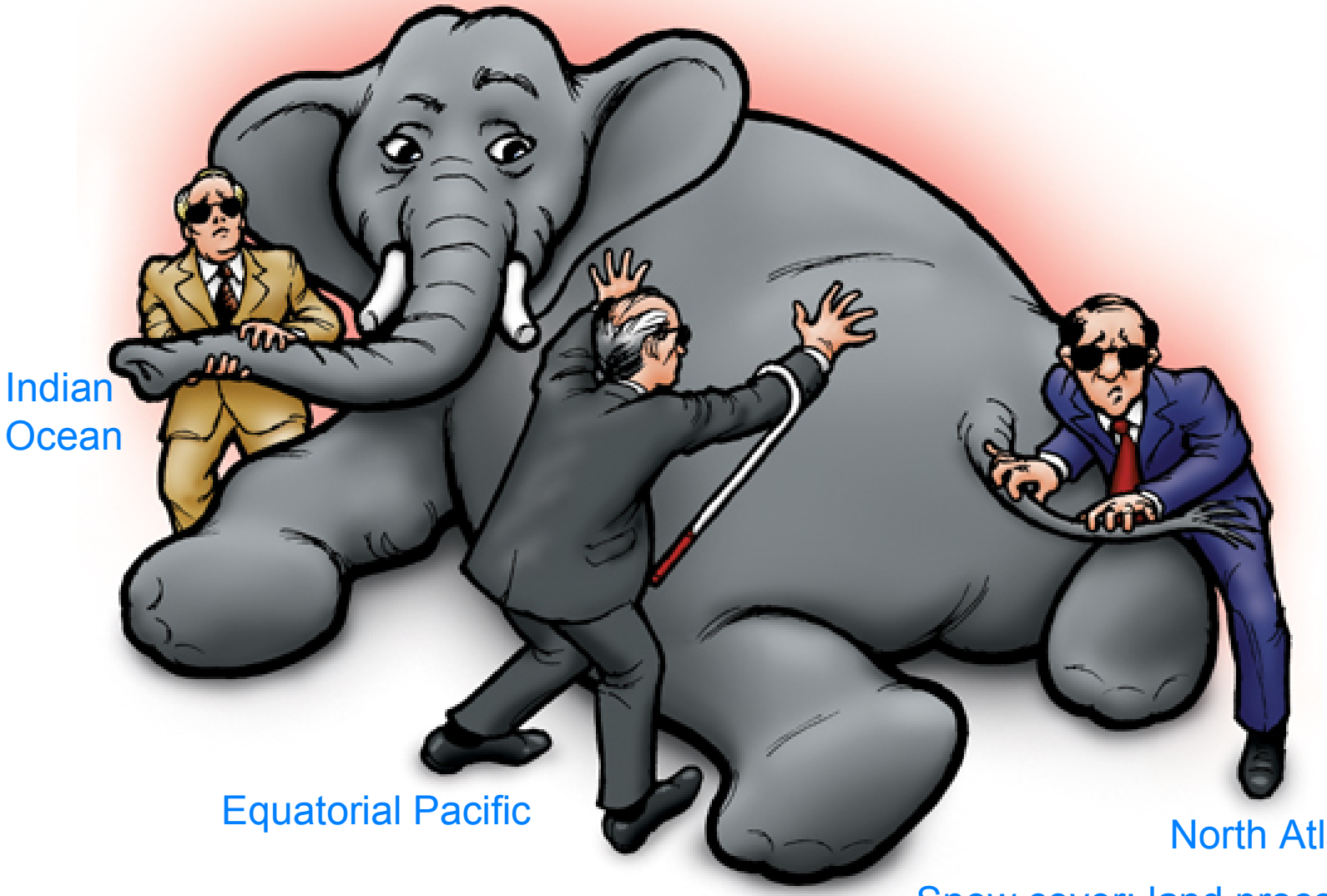
Monsoon Break

Monsoon Active



after Gadgil & Joseph, 2003

Sources of Monsoon Variability?



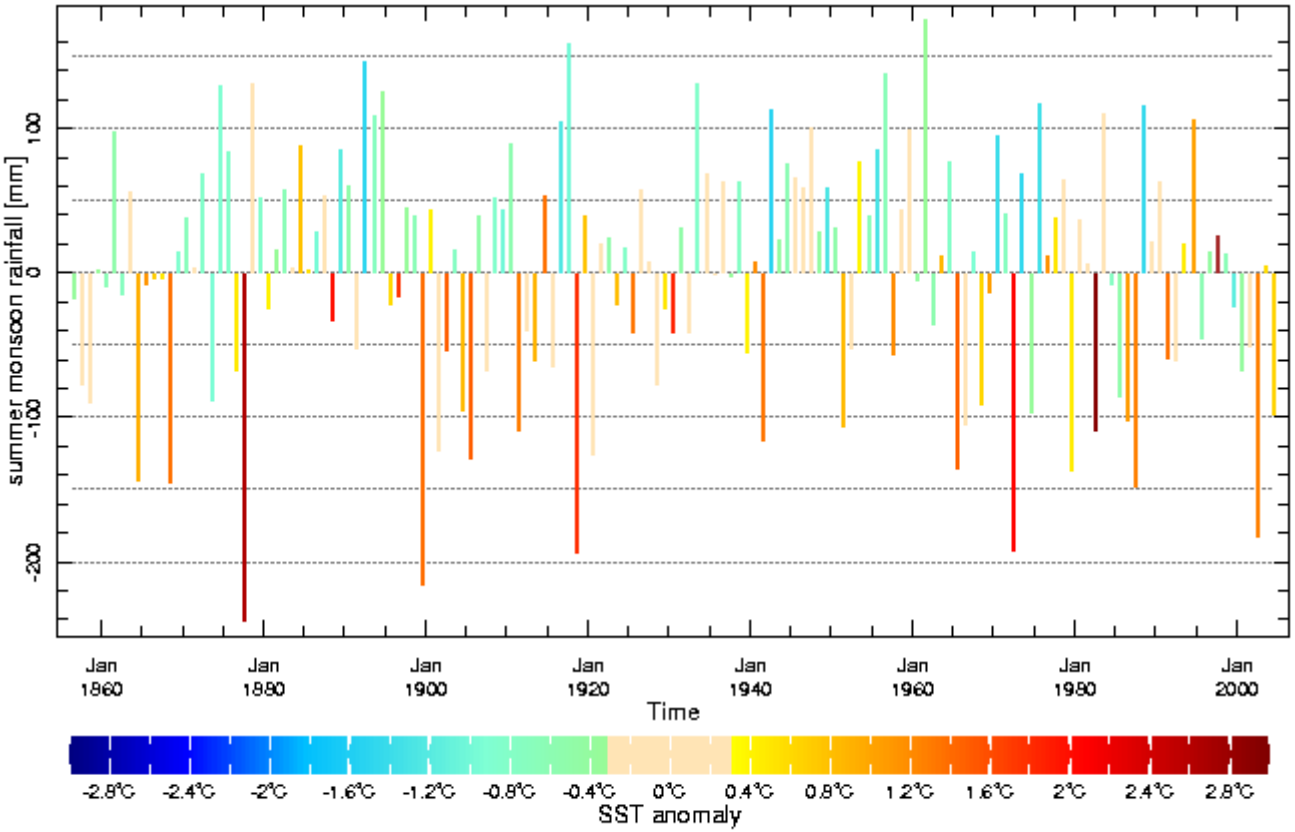
Indian Ocean

Equatorial Pacific

North Atlantic

Snow cover; land processes

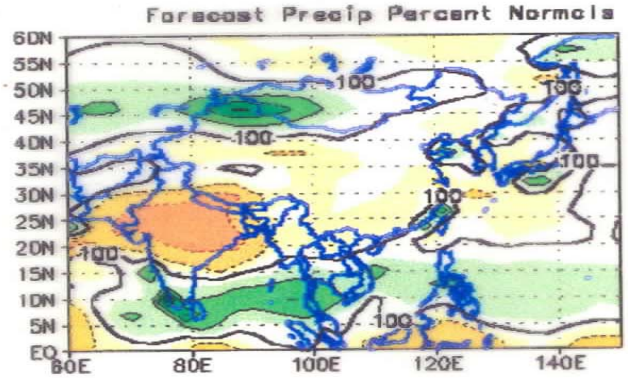
The India Rainfall - ENSO connection



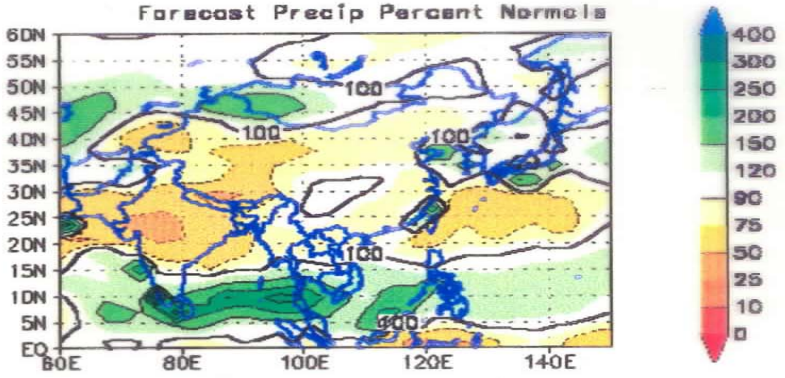
Rainfall Data: Indian Institute of Tropical Meteorology (IITM).
SST Data: Kaplan NINO3 index from Optimal Smoother analysis of MOHSST5 monthly sea surface temperature anomalies.

The International Research Institute for Climate and Society

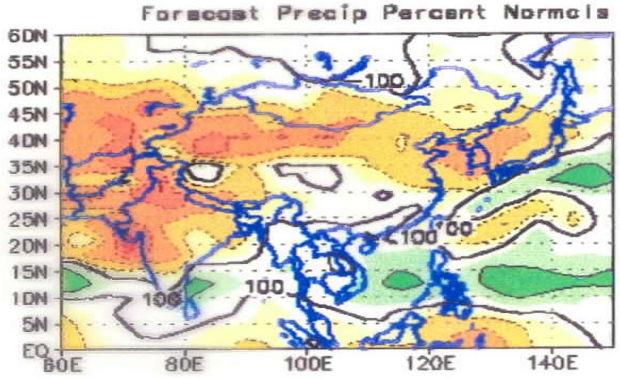
NCEP FORECAST PRECIP
for JUN–JUL–AUG 1997



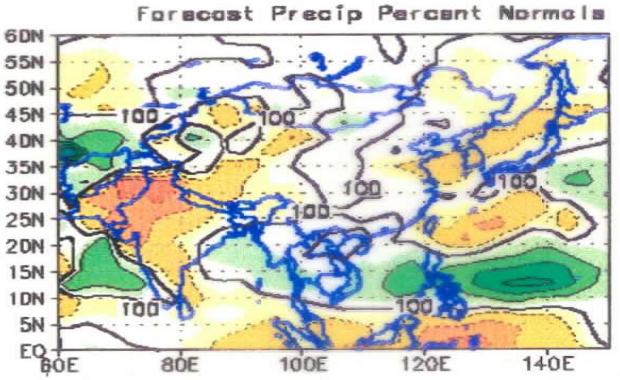
NCEP FORECAST PRECIP
for JUL–AUG–SEP 1997



ECHAM FORECAST PRECIP
for JUN–JUL–AUG 1997



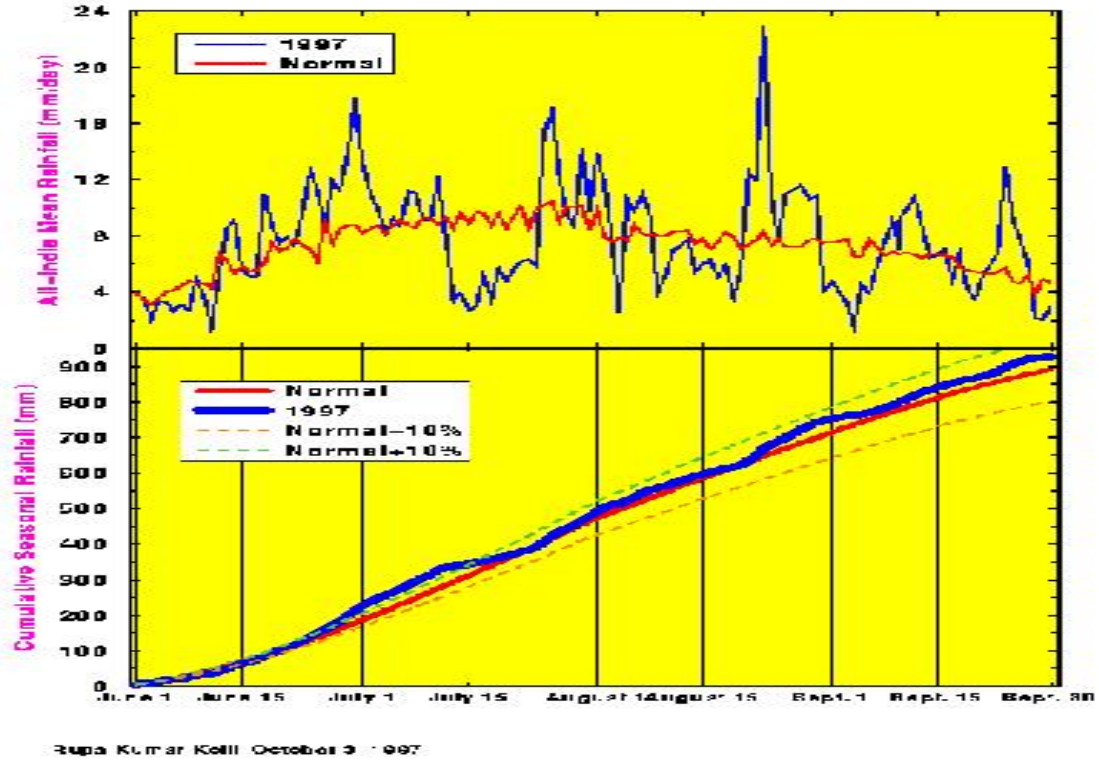
ECHAM FORECAST PRECIP
for JUL–AUG–SEP 1997



I

IRI The International Research Institute for Climate and Society

EVOLUTION OF 1997 INDIAN MONSOON



These pictures are based on the real-time reports from about 100 to 170 stations well-spread over India, as published in the Daily Weather Summaries issued by the India Meteorological Department.

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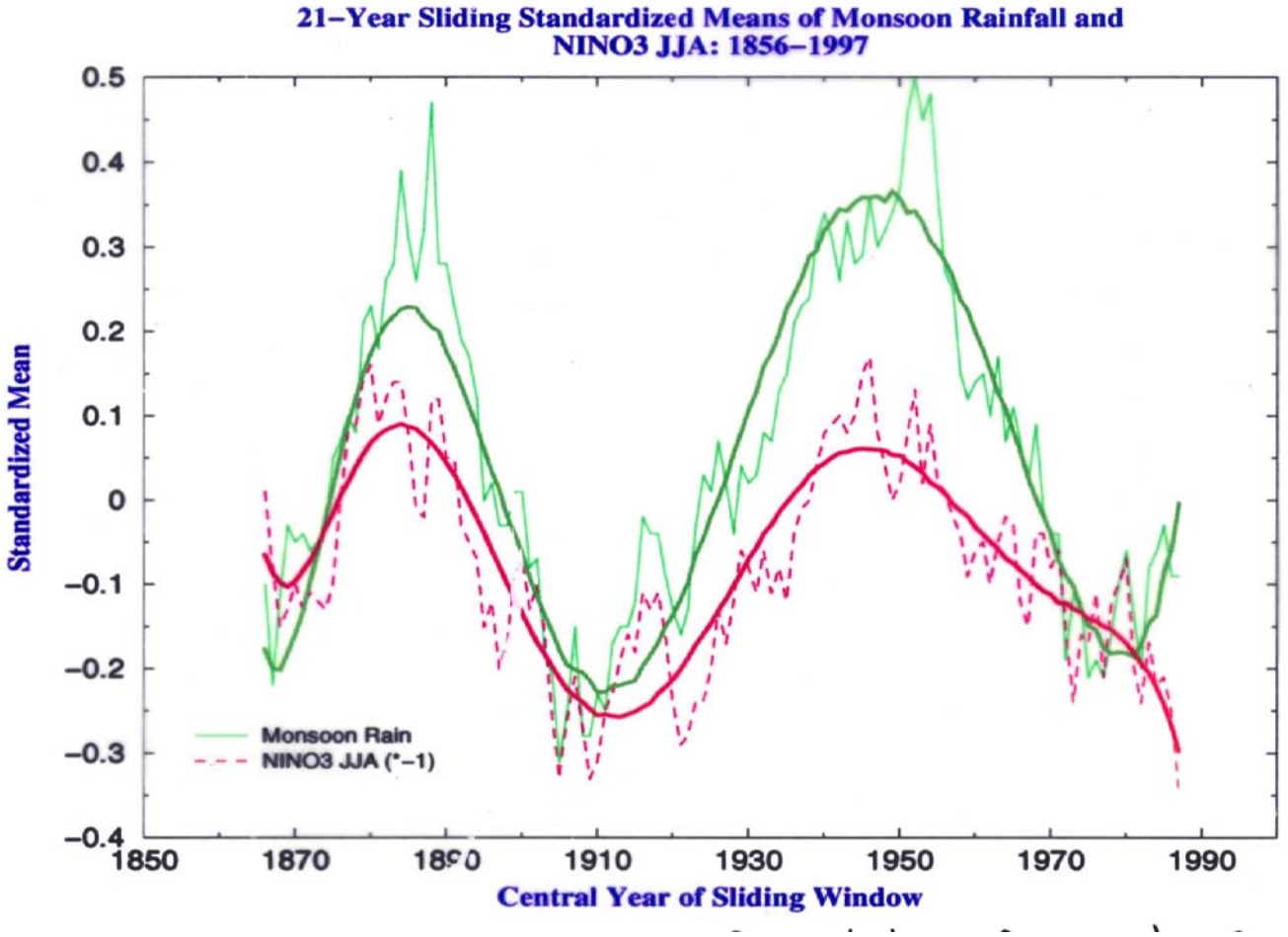
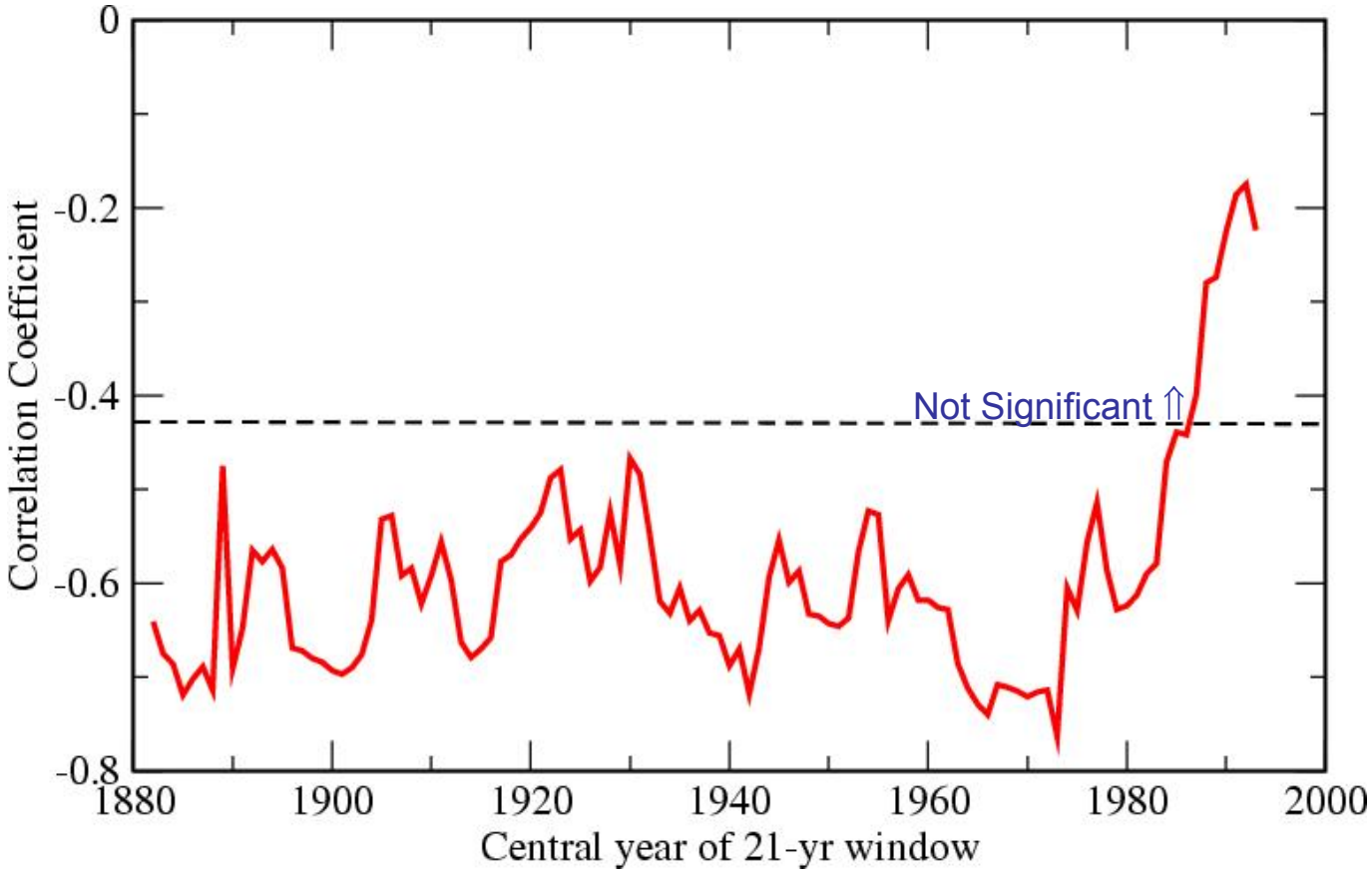
Low-frequency co-variability of Monsoon Rainfall and ENSO



from K. Kumar, Rajagopalan & Cane

Science, 1999

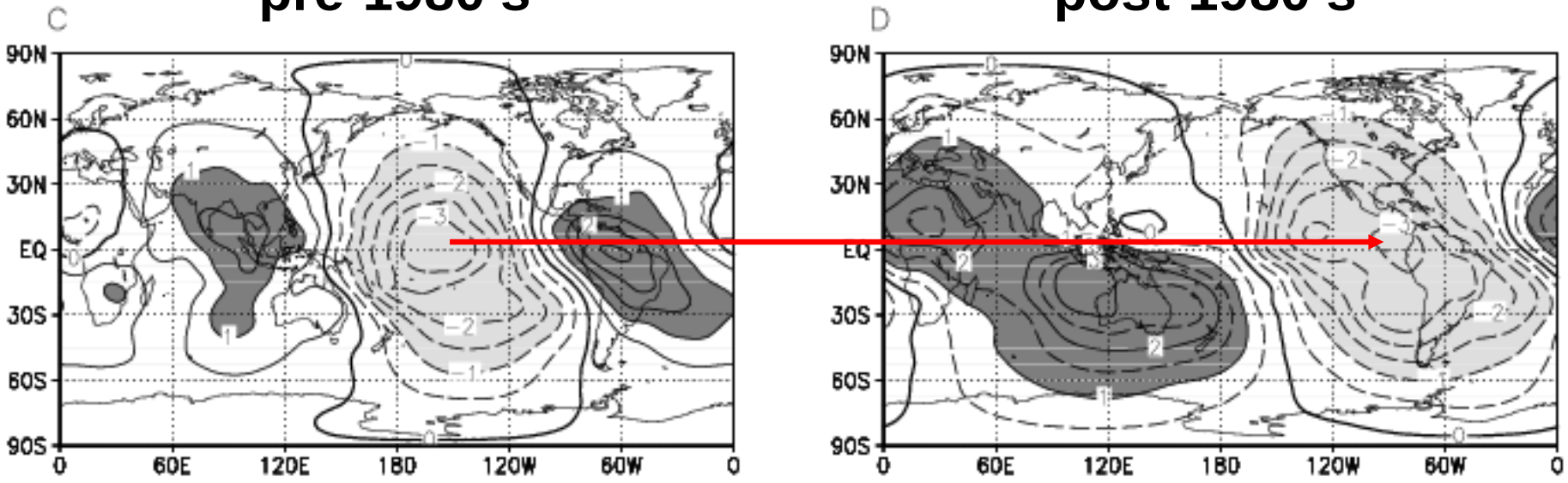
21-Yr Sliding Correlation between Indian Monsoon Rainfall and NINO3 (JJAS)1871-2002



from K. Kumar, Rajagopalan & Cane
Science, 1999

Relation between Indian Monsoon Rainfall and the Composites of 200mb Velocity Potential for El Niño Events

pre-1980's | **post-1980's**



Walker circulation moves to the east

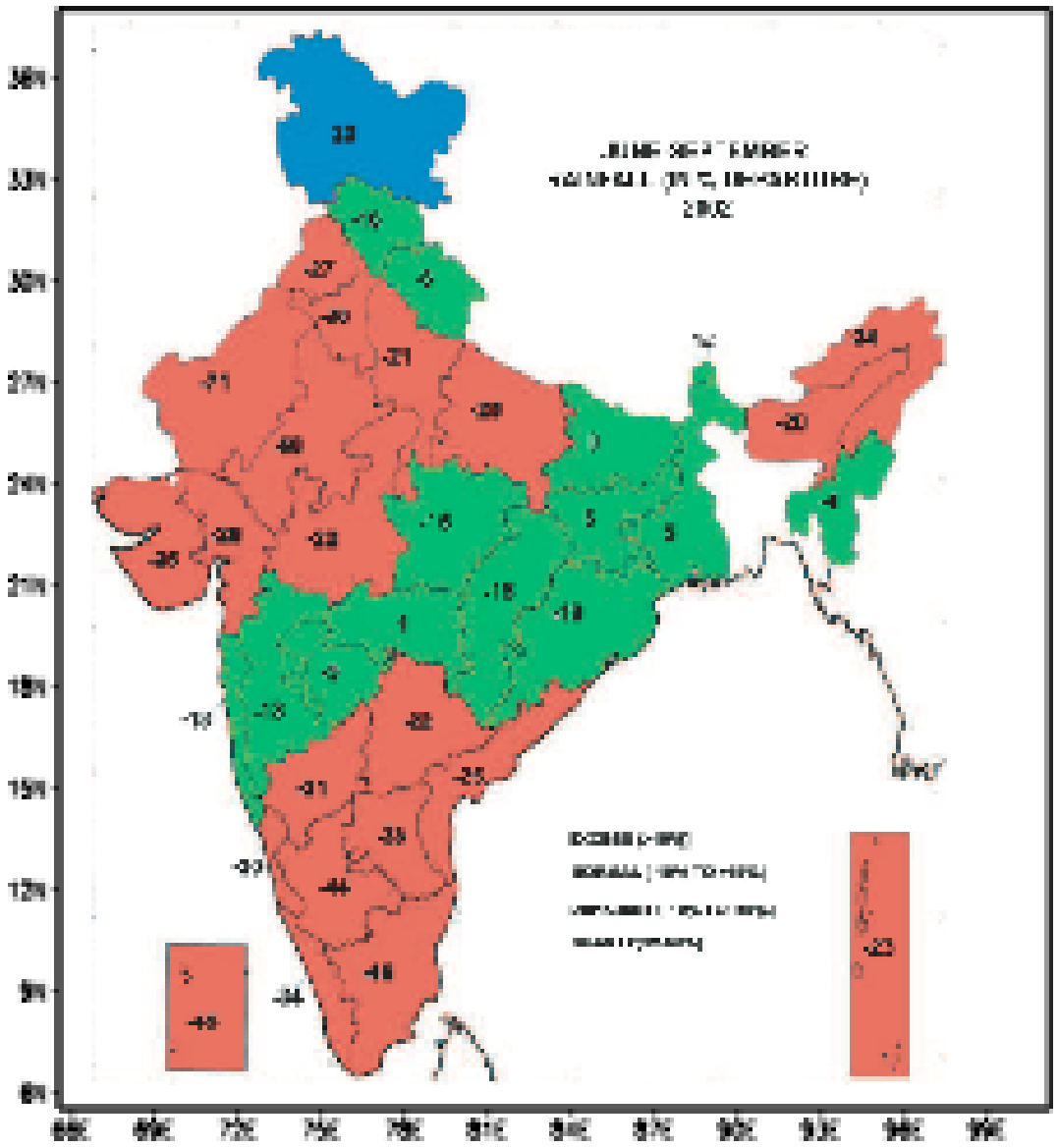
Krishna Kumar et al., Science (1999) offer possible explanations:

- Enhanced land-sea gradient over the Indian region as a consequence of recent global/Eurasian warming helps monsoon to be normal despite stronger El Nino occurrences in recent decades

- South-eastward shifts in ENSO related east-west Walker Circulation anomalies leave Indian region out from under the subsidence

We will return to the second idea later on…

RAINFALL (IN % DEPARTURE)
JUNE TO SEPT 2002



Gadgil et al 2007

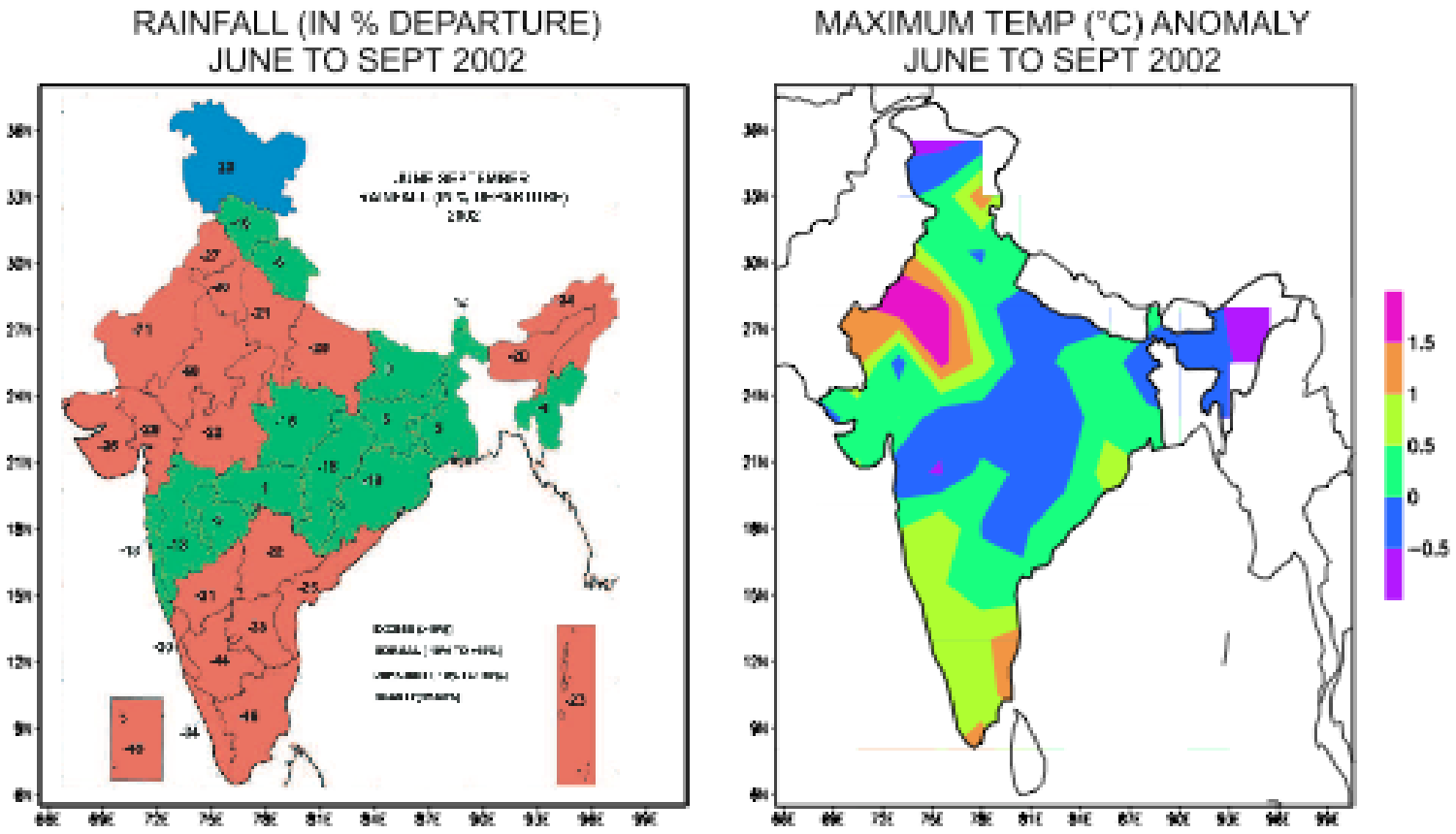


Figure 5: Anomalies of the rainfall (left) and maximum temperature (right) for the summer monsoon of 2002 (June to September).

Gadgil et al 2007

Another idea, from Gadgil et al 2003,2004…

EQUATORIAL INDIAN OCEAN OSCILLATION: EQUINOO

- **WHEN CONVECTION IS ENHANCED OVER THE WEIO, IT TENDS TO BE SUPPRESSED OVER EEIO &VICE VERSA**
- **EAST-WEST SEA LEVEL PRESSURE GRADIENT ANOMALIES ALONG THE EQUATOR ARE CONSISTENT**
- **⇒ ANOMALIES OF ZONAL COMPONENT OF SURFACE WIND ALONG THE EQUATOR: EQUINOO (EQWIN)**

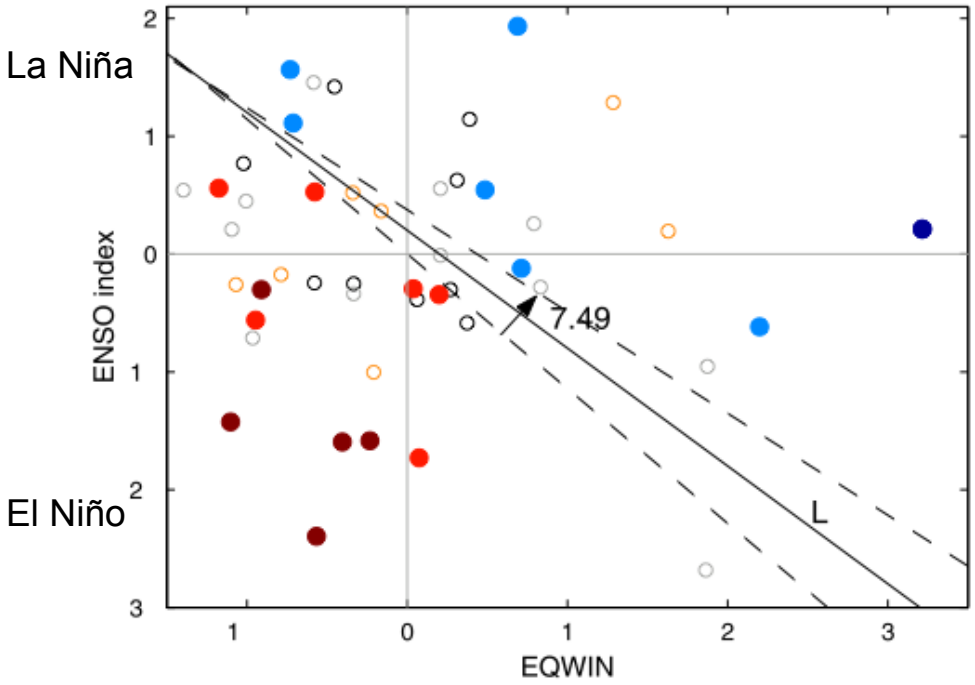


Figure 4. Each season during 1958–2003 is shown on the phase plane of the June to September average of the ENSO index (negative of Nino 3.4 index) and EQWIN. The corresponding ISMR anomaly (normalized by the standard deviation) is represented with different symbols: large dark blue (red) closed circles for values above (below) 1.5 (−1.5), blue (red) closed circles for values between 1 (−1) and 1.5 (−1.5), small black (orange) open circles for values between 0.25 (−0.25) and 1 (−1) and small gray open circles for values between −0.25 and 0.25.

From Gadgil et al, GRL, 2004

●,● Good Monsoon years

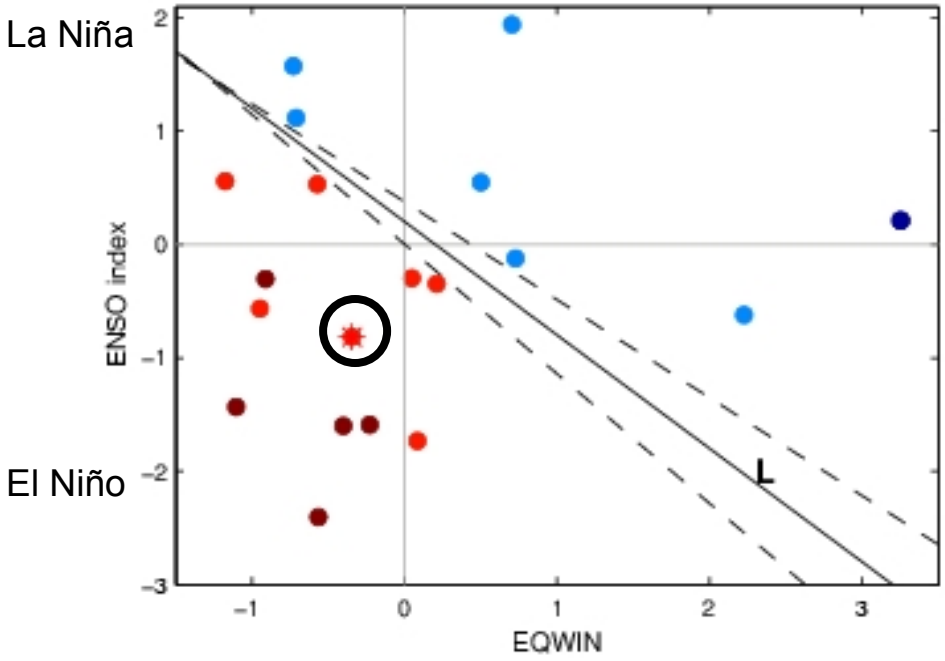
●,● Poor Monsoon years

Gadgil et al 2003,2004:

Negative wind anomalies in the equatorial Indian Ocean are associated with increased ISMR

Gadgil et al 2003,2004:

Negative wind anomalies in the equatorial Indian Ocean are associated with increased ISMR



●,● Good Monsoon years

●,● Poor Monsoon years

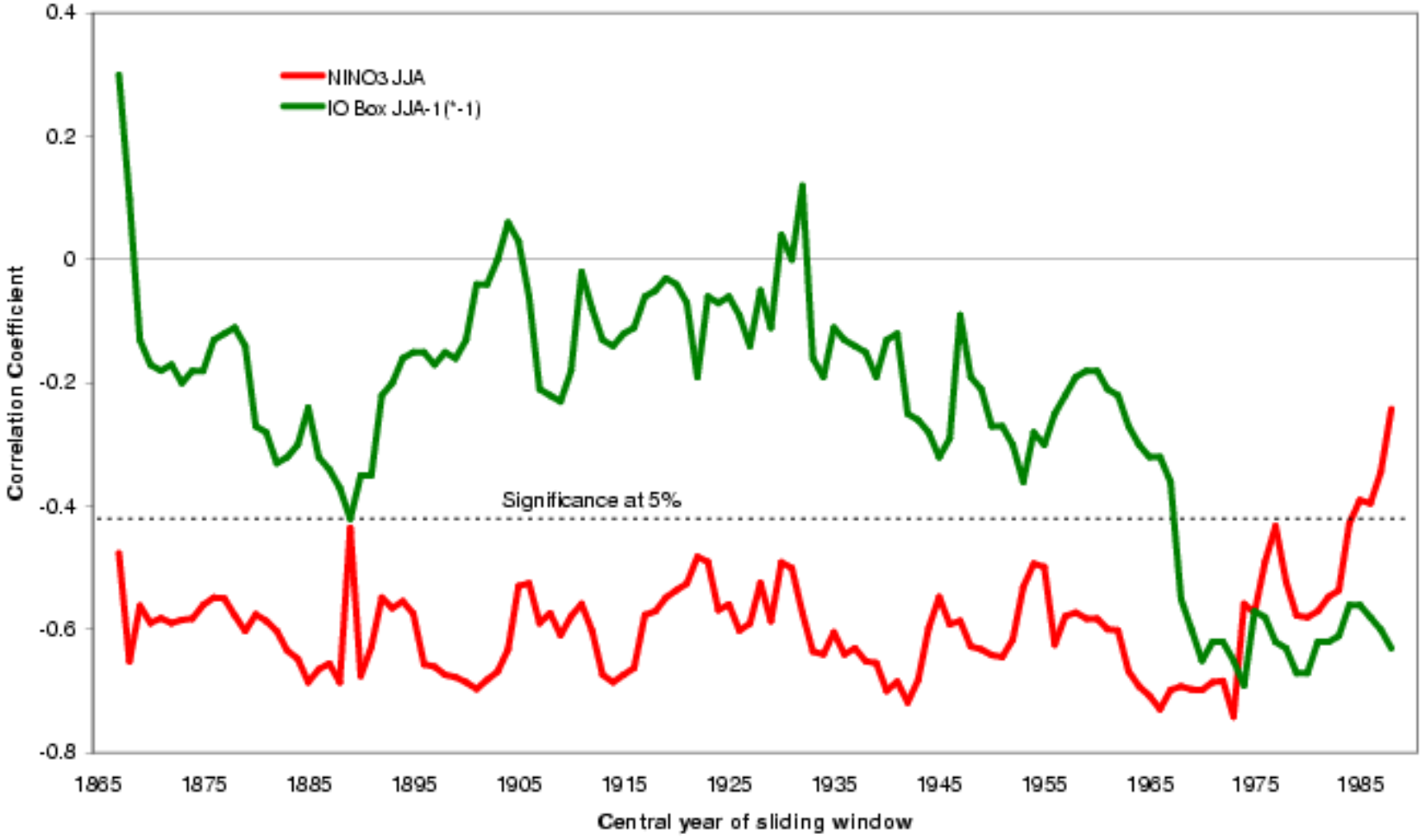
✡ 2004

1958 - 2004

after Gadgil et al, GRL, 2004

21-Year Sliding Window Correlations between Monsoon Rainfall and JJA SST

(1) NINO3 (2) IO Box (×-1)



Follow-up:

1) **Zonal wind index (EQWIN), SST Dipole Mode index (SSTDMI) and ISMR** (Ihara et al, *Int. J. of Climatology,* 2007)

2) **Indian Ocean SST anomalies and ENSO evolution** (Ihara et al, *J. Climate*, 2008)

Data Sources: 1881 to 1998

Zonal wind anomalies: COADS (also, Kaplan wind analysis)
SST anomalies, NINO3 : Kaplan et al. (1998)
ISMR: Sontakke et al. (1993)

Indices:

EQWIN: zonal wind anomalies averaged over [60-90E, 2.5S-2.5N]
SSTDMI: SSTa difference between [50-70E, 10S-10N] and
[90-110E, 10S-0]

Methods: Linear Regression, Contingency Tables

Definition of Categories

		NINO3(JJAS)		
		La Niña(33%)	Neutral(33%)	El Niño(33%)
ISMR	Above (33%)			
	Normal(33%)			
	Below(33%)			

Contingency tables

El Niño

ISMR	EQWIN: Below(50%)	EQWIN: Above(50%)	
Below(33%)	13	12	25
Normal+Above	13	1	14
	26	13	39

P-value
0.001

La Niña

ISMR	EQWIN: Below(50%)	EQWIN: Above(50%)	
Below+Normal	4	12	16
Above(33%)	9	14	23
	13	26	39

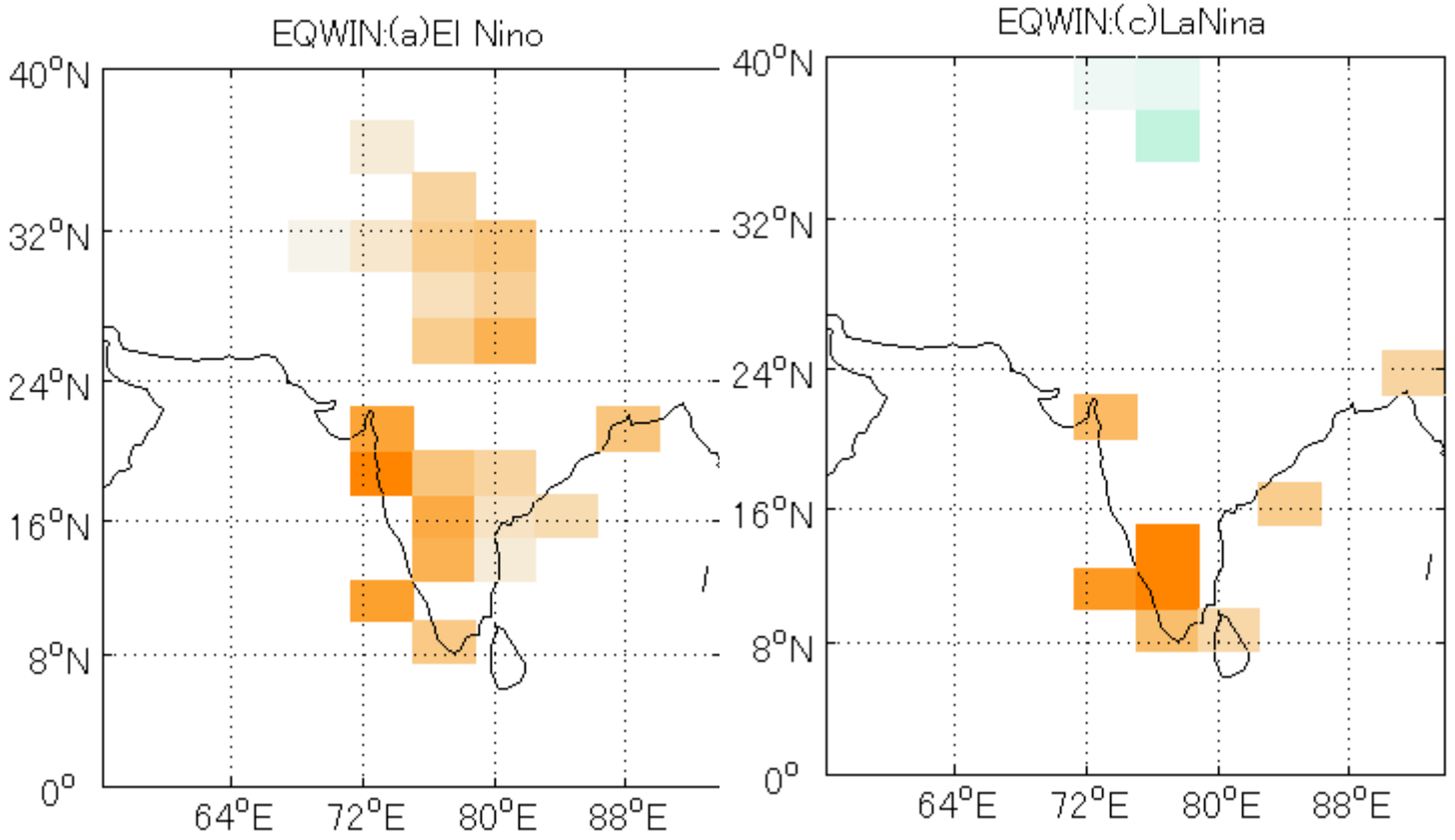
P-value
0.28

Normal

ISMR	EQWIN: Below(50%)	EQWIN: Above(50%)	
Below(33%)	3	8	11
Normal(33%)	10	8	18
Above(33%)	7	4	11
	20	20	40

P-value
0.20

Composites of the mean JJAS rainfall



El Ni–o events with co-occurring negative EQWIN minus those events that co-occur with positive EQWIN

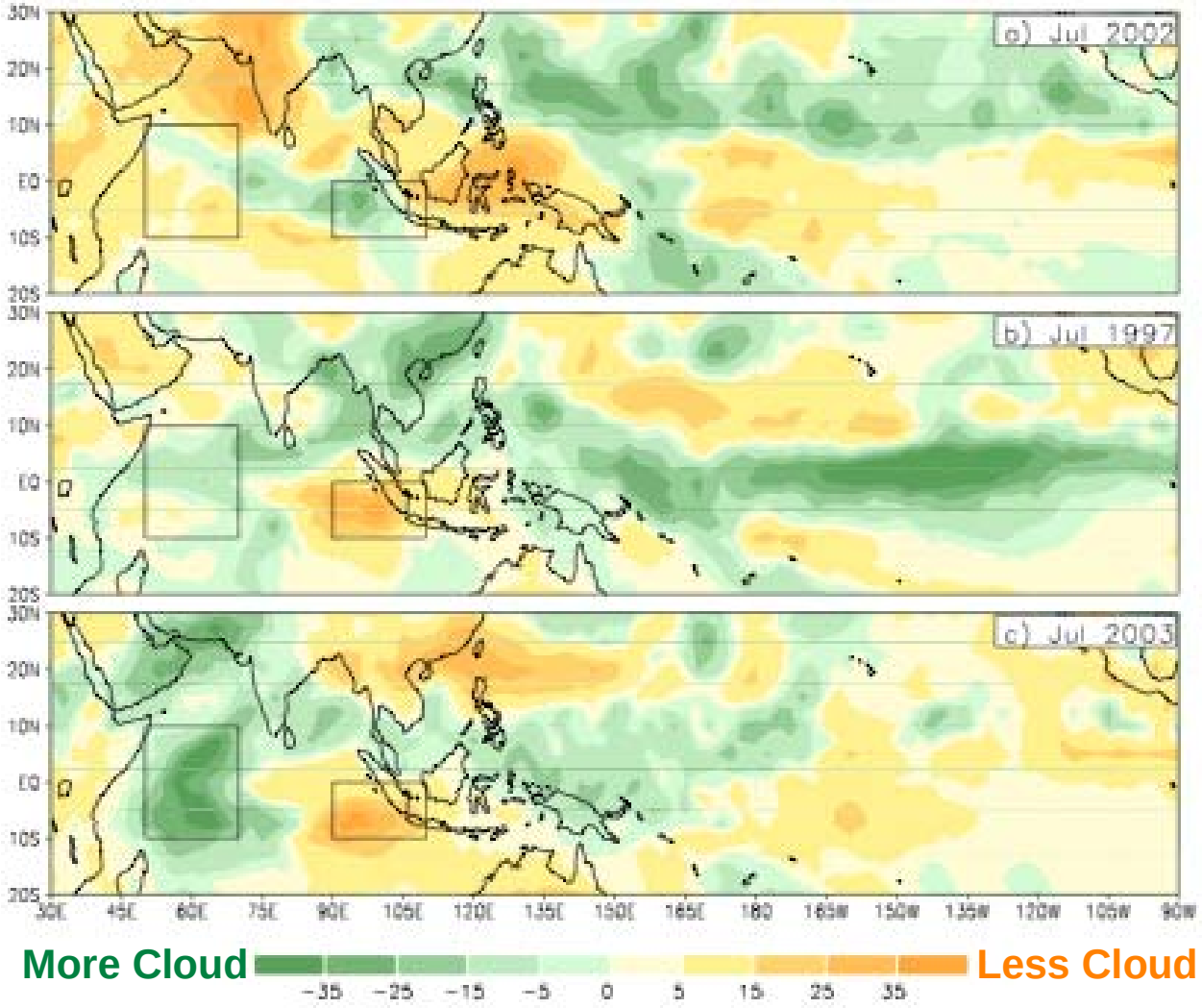
La Ni–a

July OLR Anomalies (W/m^2)

Drought

Normal

Normal



2002

1997

2003

Gadgil et al 2007

Conclusions, part 1

- There is a significant association between zonal wind anomalies at the equatorial Indian Ocean(EQWIN) and ISMR during El Niño years but not during La Niña and neutral years.
- We could not find any associations with SSTDMI.

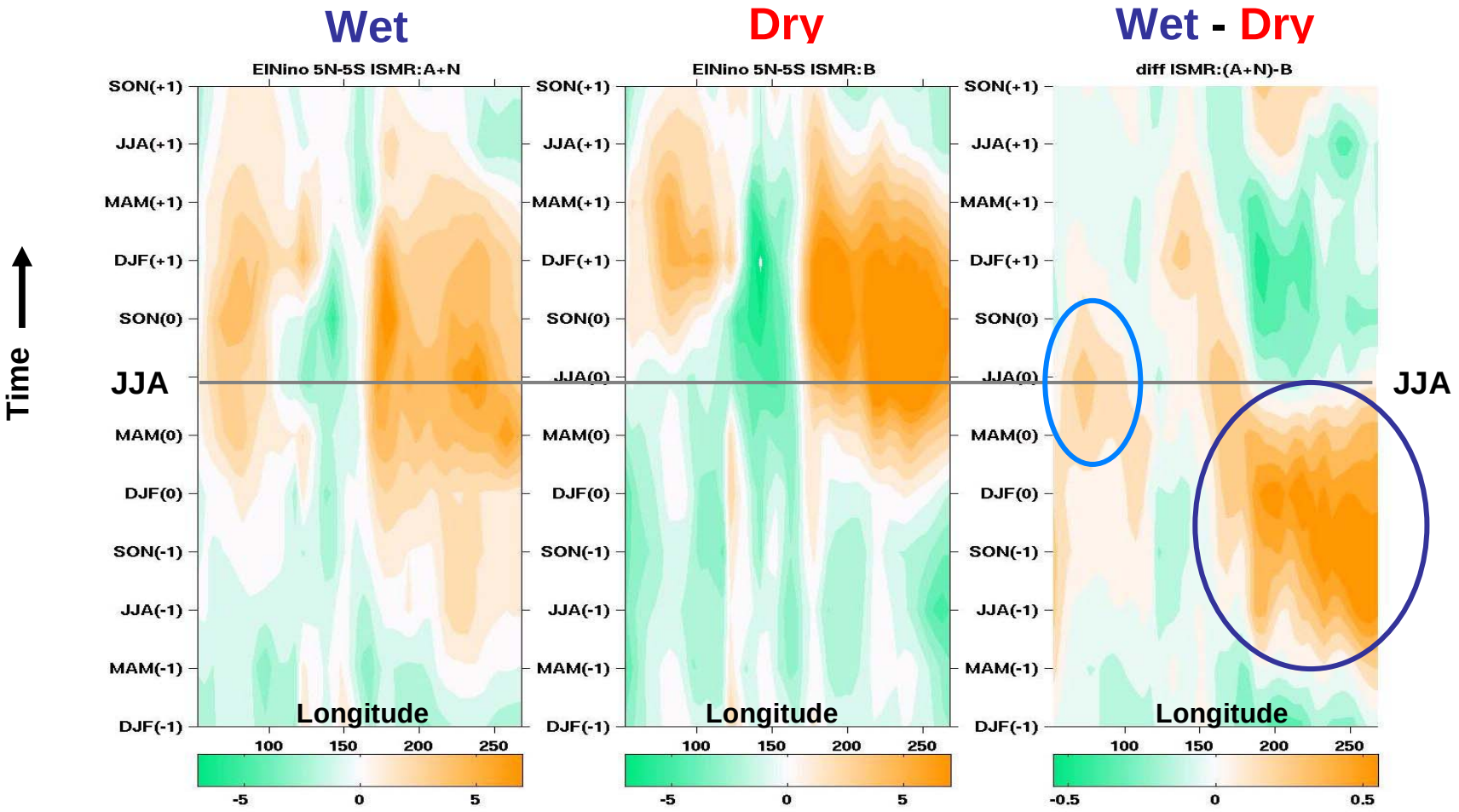
Causality?

- Is the Indian Ocean impacting the monsoon, or
- are EQWIN and ISMR both responding to the same forcing?

- Either way JJAS EQWIN is not predictive

We look at the seasons before JJAS:

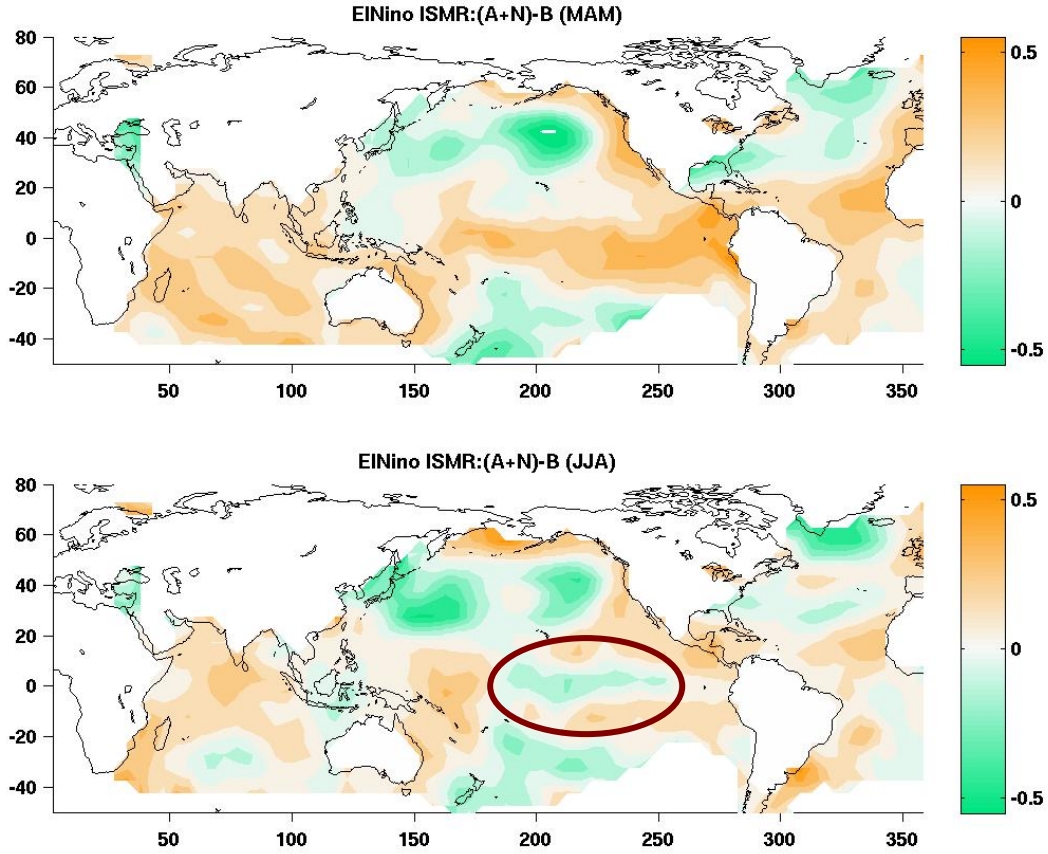
Evolution of equatorial SST [5S-5N] during El Niño



El Niño starts earlier in wet years (cf Shukla & Paolino 1983)

And Indian Ocean warms by the monsoon season

Composite SST anomalies during El Niño:
Wet - Dry years [ISMR (A+N)-B]

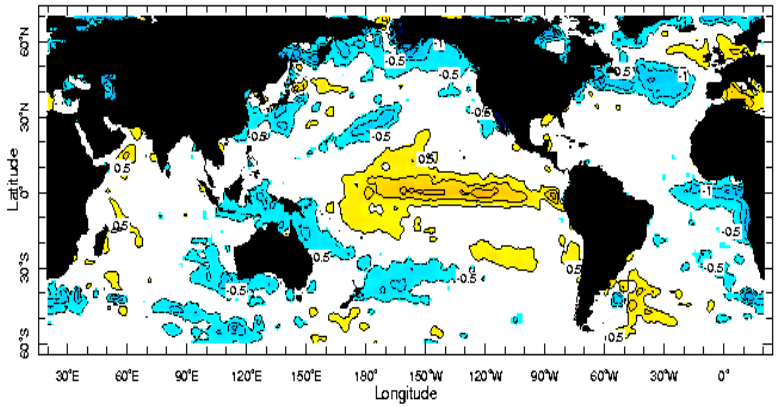


In dry years the SSTA is greater in the central Pacific
In wet years it is more to the east

Sea Surface Temperature Anomalies in 1982 & 1997

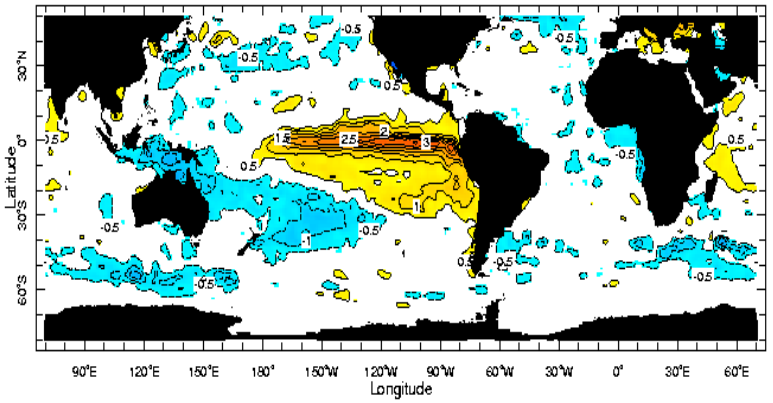
Monsoon Rainfall: -13%

JJA 82



Jun-Aug 1982

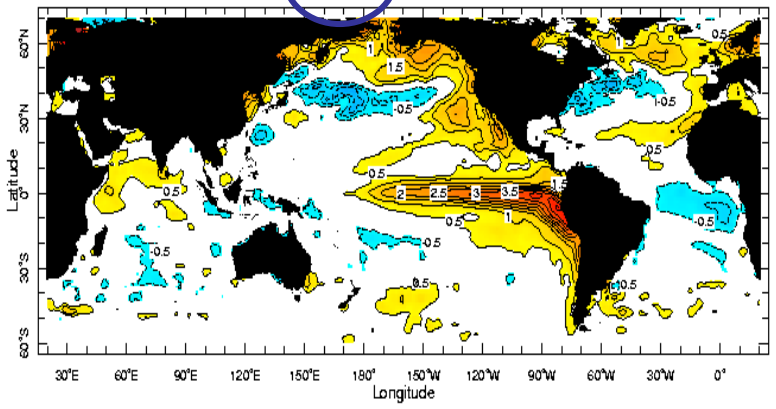
SON 82



Sep-Nov 1982

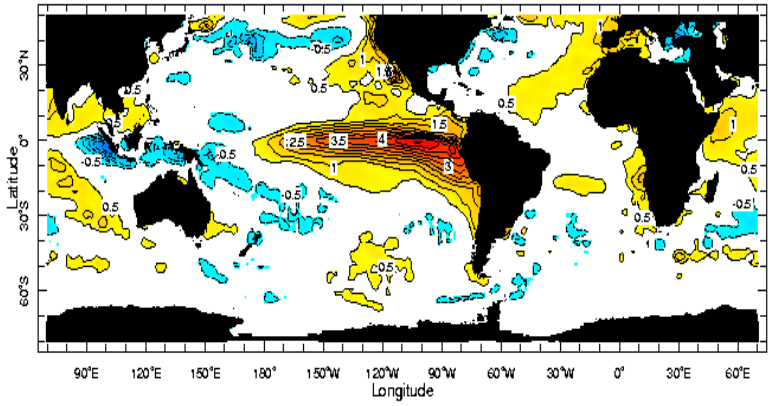
Monsoon Rainfall: +2%

JJA 97



Jun-Aug 1997

SON 97

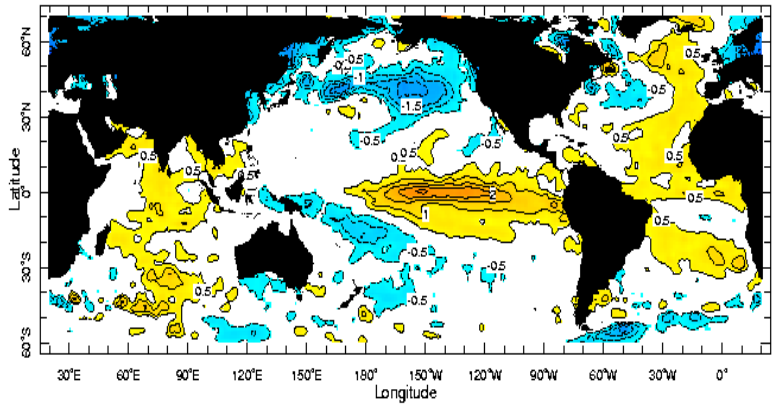


Sep-Nov 1997

Sea Surface Temperature Anomalies in 1987 & 2002

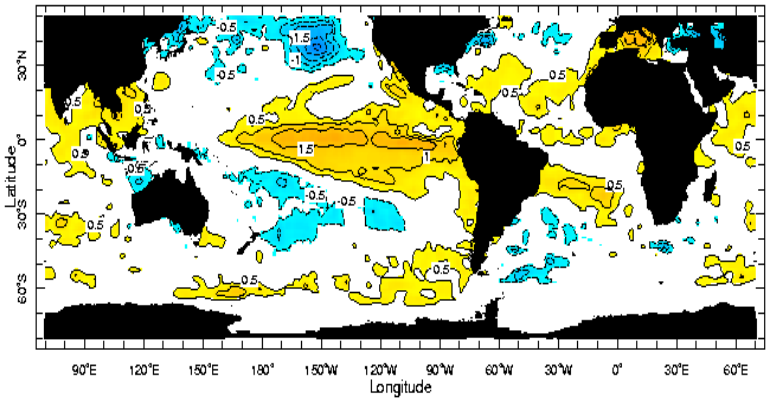
Monsoon Rainfall: -18%

JJA 87



Jun-Aug 1987

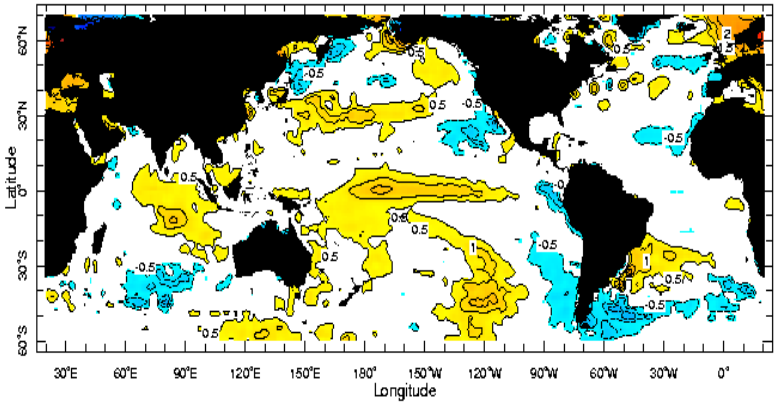
SON 87



Sep-Nov 1987

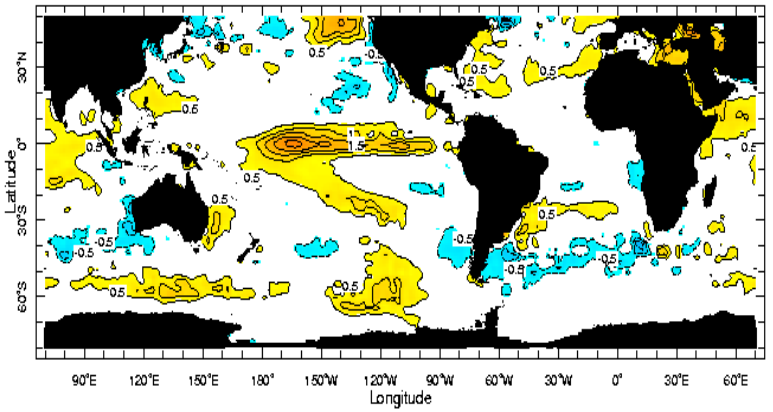
Monsoon Rainfall: -19%

JJA 02



Jun-Aug 2002

SON 02



Sep-Nov 2002

Contingency Tables show that

Only during El Niño years is the association between IOSST/WPSST and ISMR significant.

Not significant during La Niña or Neutral years.

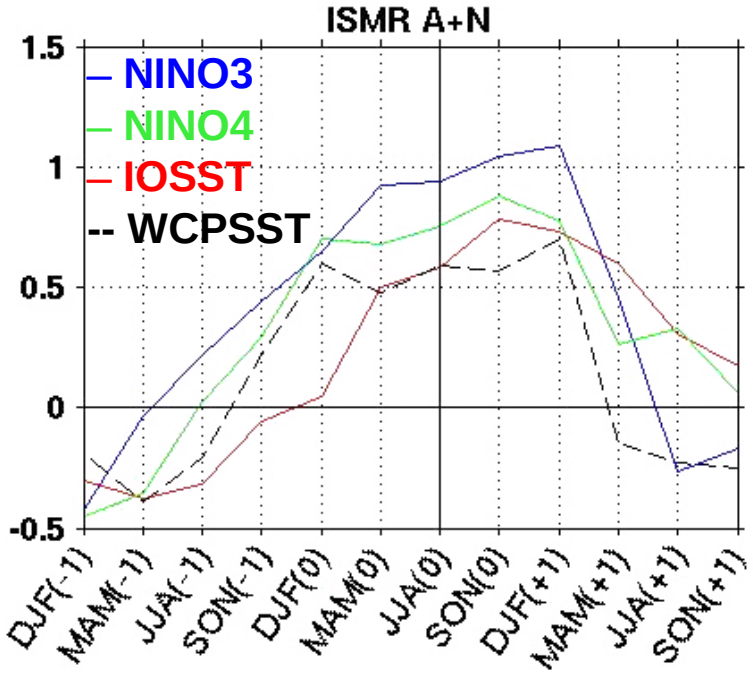
But ENSO influences Indian Ocean SST....

New Indices:

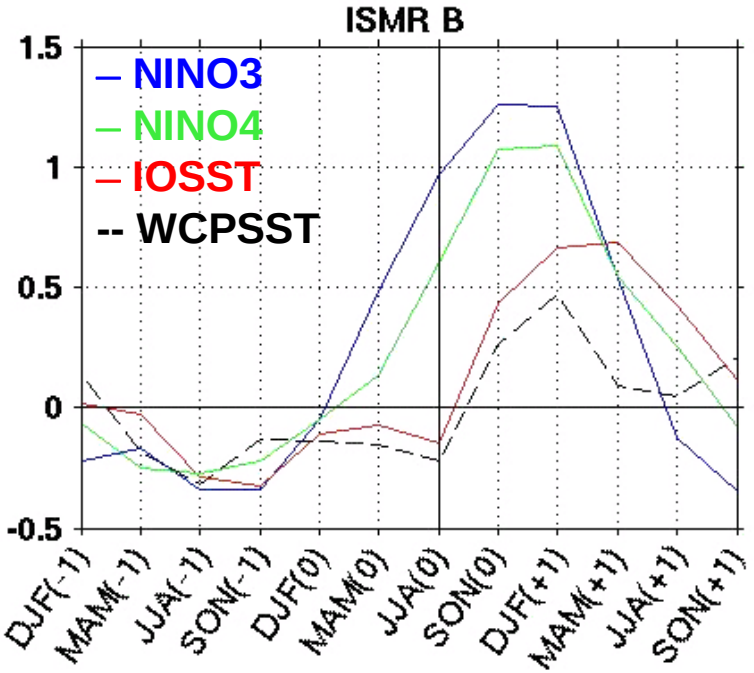
IOSST: SSTa averaged over [70E-90E, 5S-10N]
WCPSST: Western Central Pacific SSTa [160-175E, 10S-0]

Composites of indices for a 3 year interval

ISMR Wet



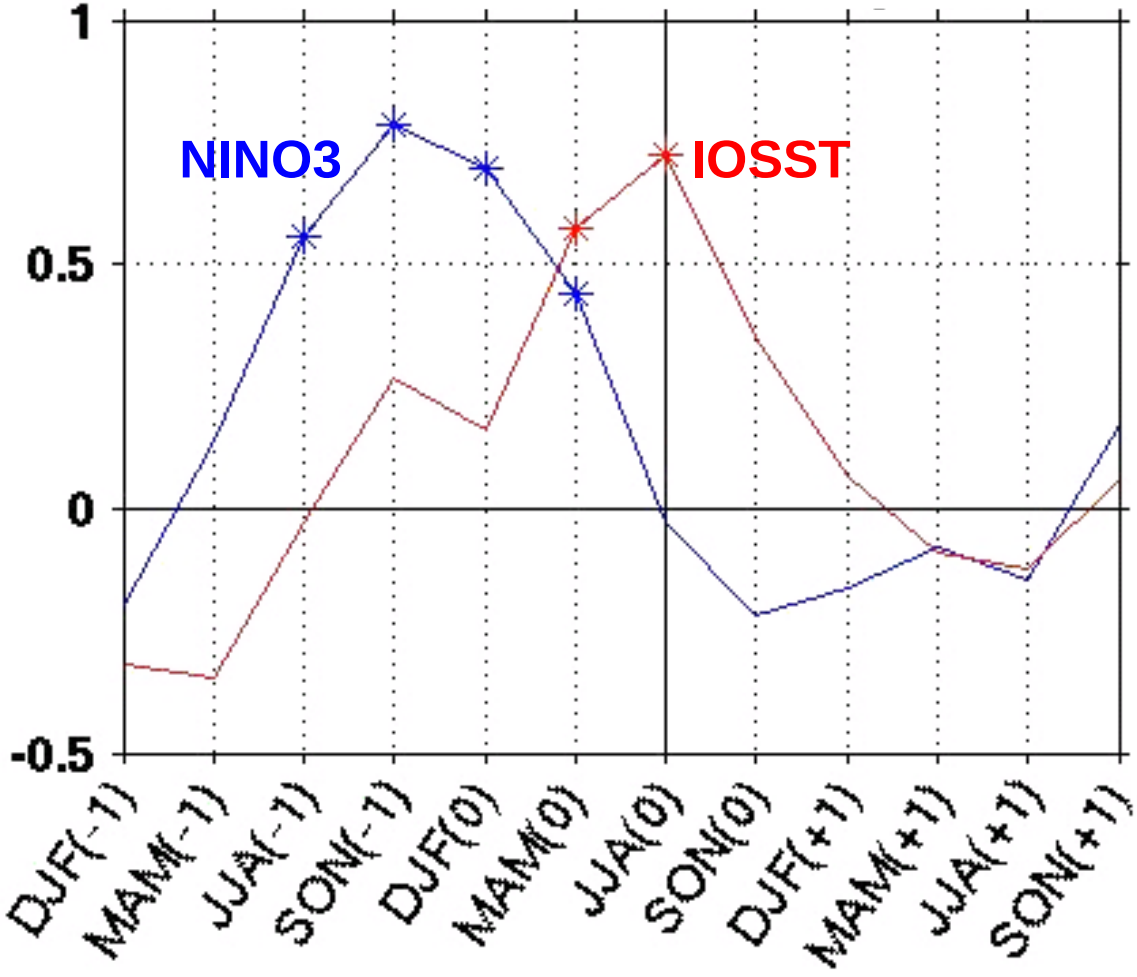
ISMR Dry



ISMR Wet: El Niño starts about 3 seasons before monsoon, Indian Ocean warm

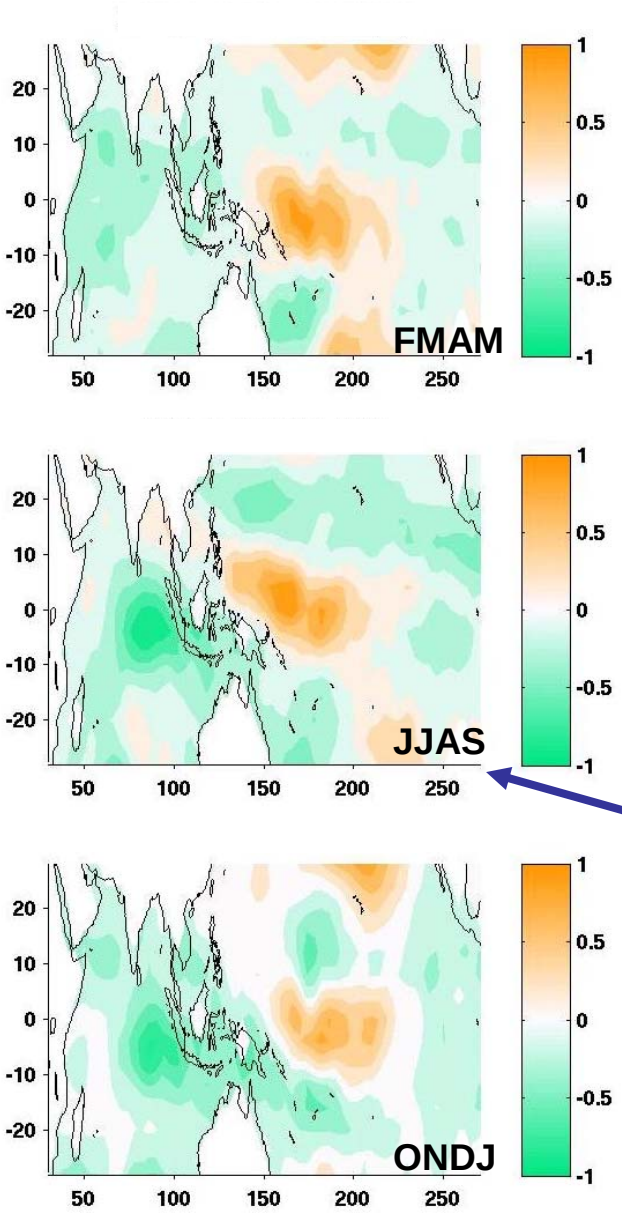
ISMR Dry: El Niño develops later, Indian Ocean cold

Evolution: Wet - Dry



Wet = A+N, **Dry** = B * = significant at 90%

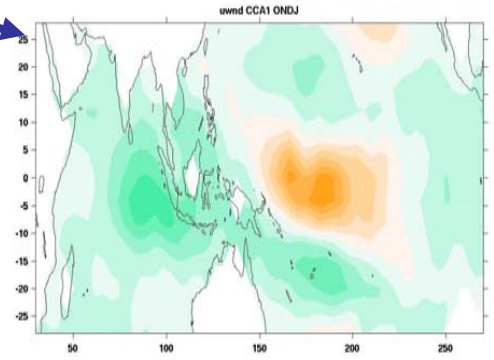
Composite El Niño Zonal Wind Anomalies when ISMR is above normal (A+N)



When ISMR is A+N:

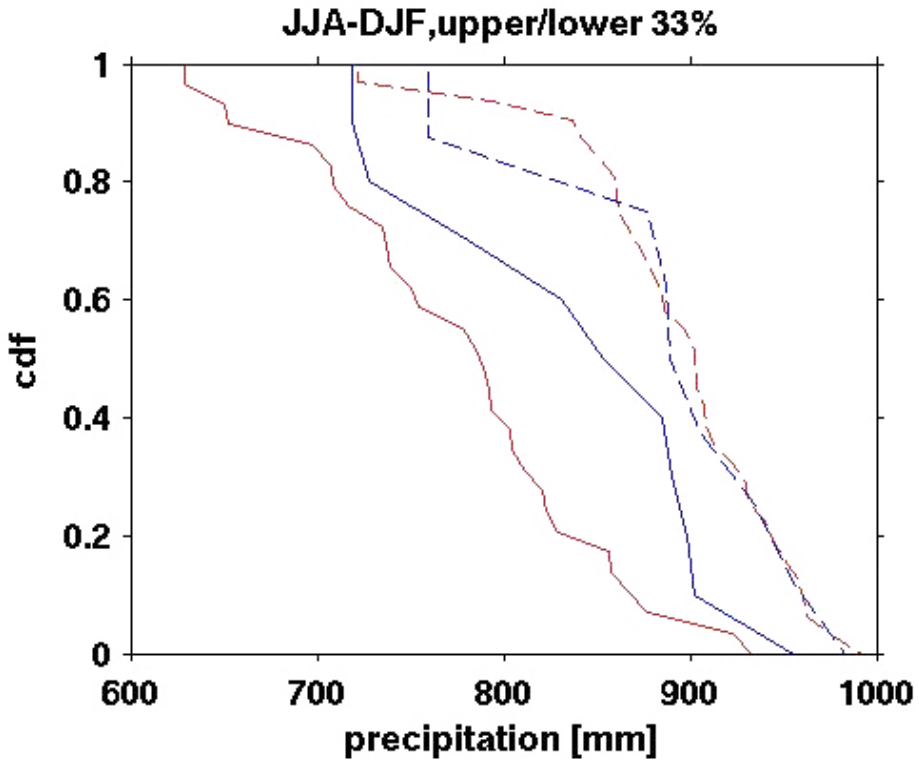
Composite of the monsoon season (JJAS) resembles the canonical ONDJ pattern - the mature phase of El Niño.

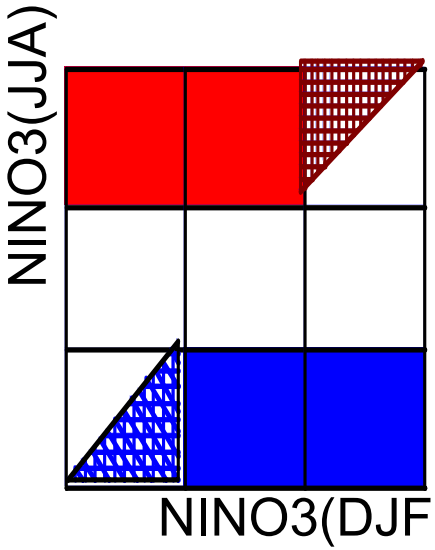
The state of the Indian Ocean is a season ahead.



Canonical El Niño ONDJ (Mature phase)

Cumulative density function of ISMR

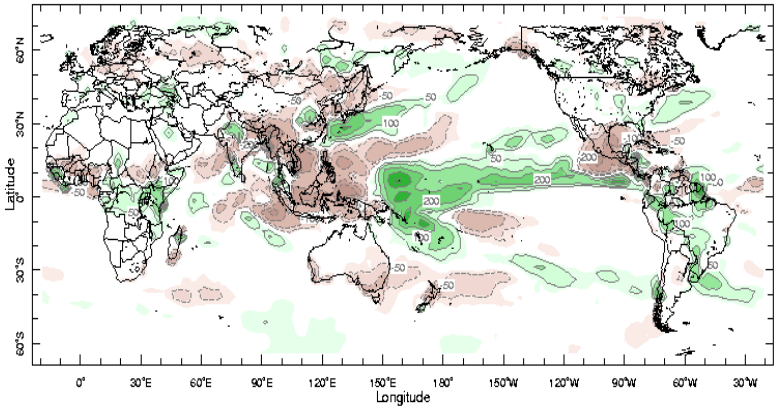




Precipitation Anomalies: JJA

Monsoon Rainfall: -13%

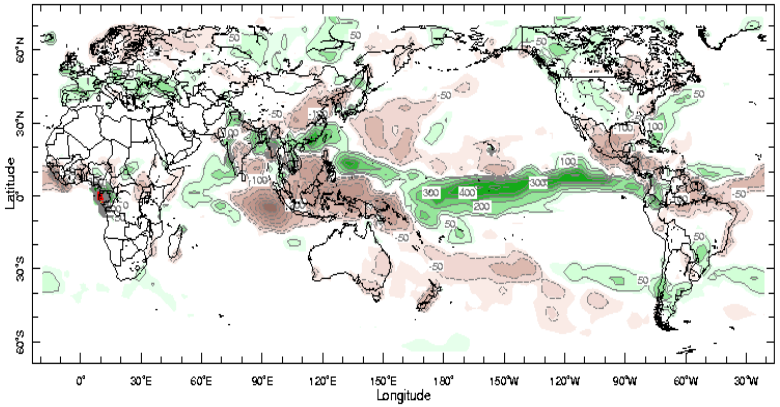
1982



Jun-Aug 1982

Monsoon Rainfall: +2%

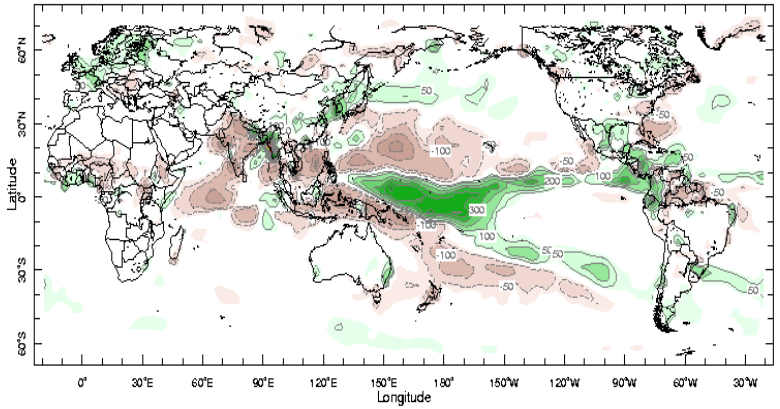
1997



Jun-Aug 1997

Monsoon Rainfall: -18%

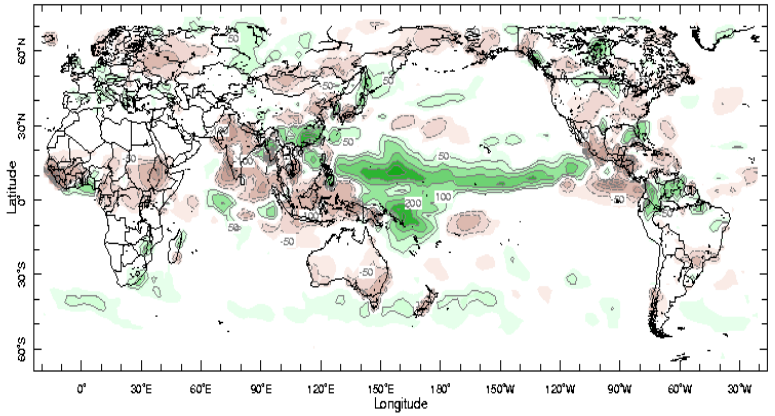
1987



Jun-Aug 1987

Monsoon Rainfall: -19%

2002



Jun-Aug 2002

Conclusions, part 2

- During protracted El Niño, Indian Ocean is warmer and ISMR tends to be wetter.
- During rapid rising El Niño, Indian Ocean is not warm enough and the usual ISMR - El Niño relation holds.
- These associations are not significant during La Niña.

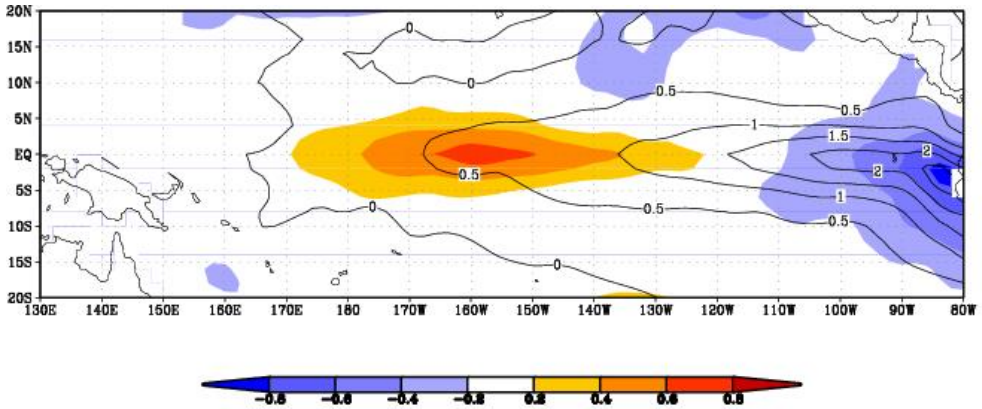
Causality is not clear.

- Role of the Indian Ocean?

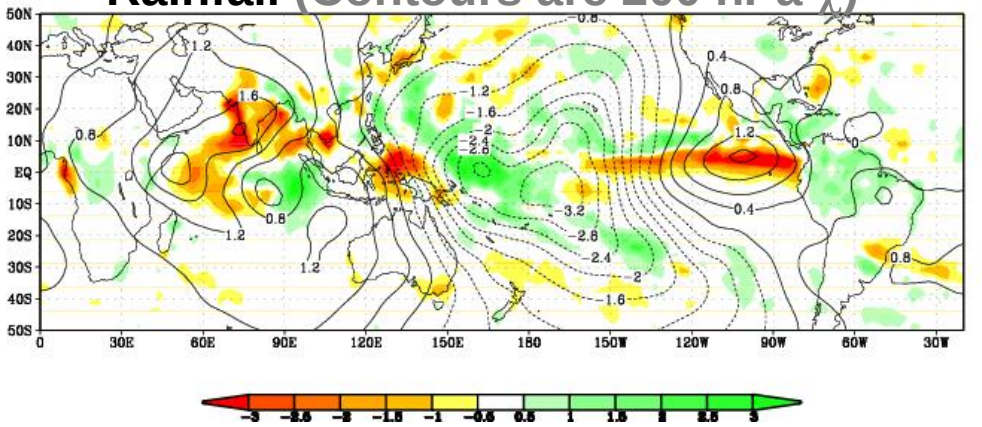
Lets return to the idea of an eastward shift…

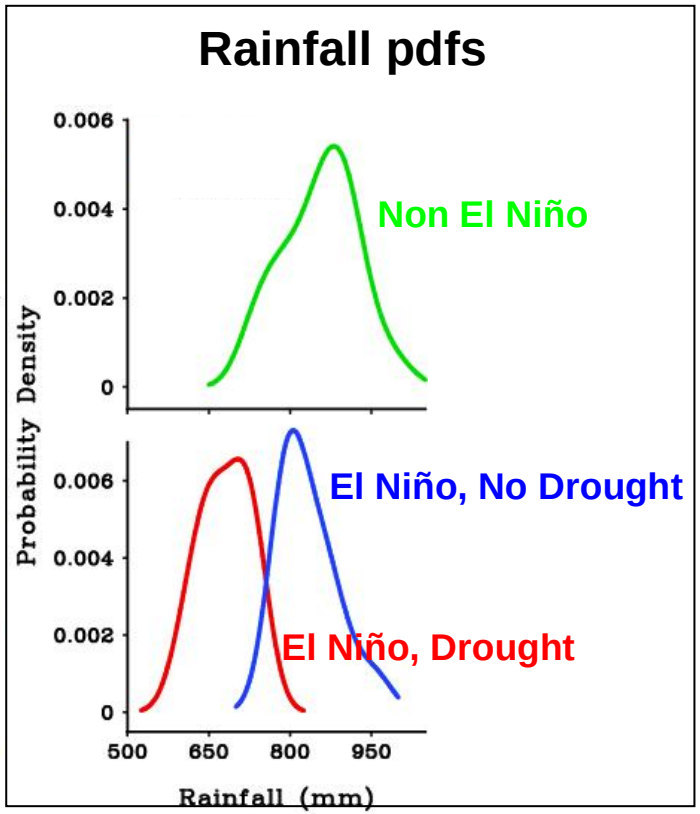
Composite JJAS difference pattern:
Very Dry - Wet El Nino years

SST (Contours are wet year SST)



Rainfall (Contours are 200 hPa χ)

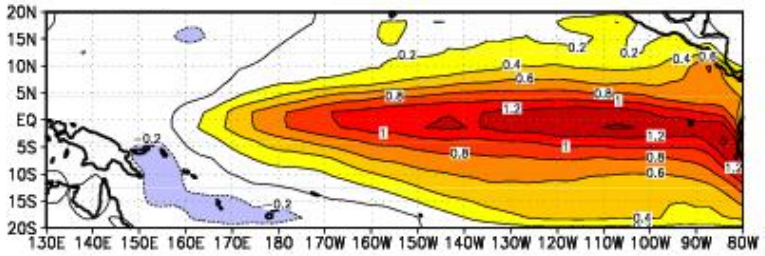




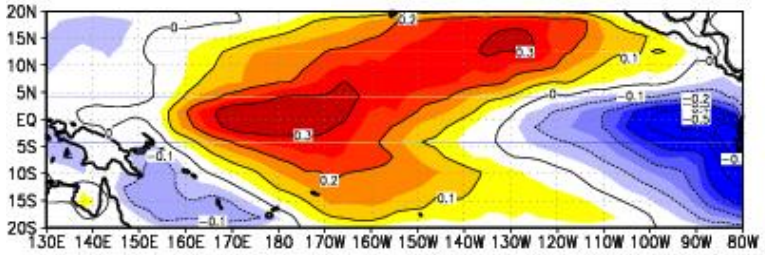
K. Kumar et al, 2006 *Science*

Leading patterns of tropical Pacific SST anomalies

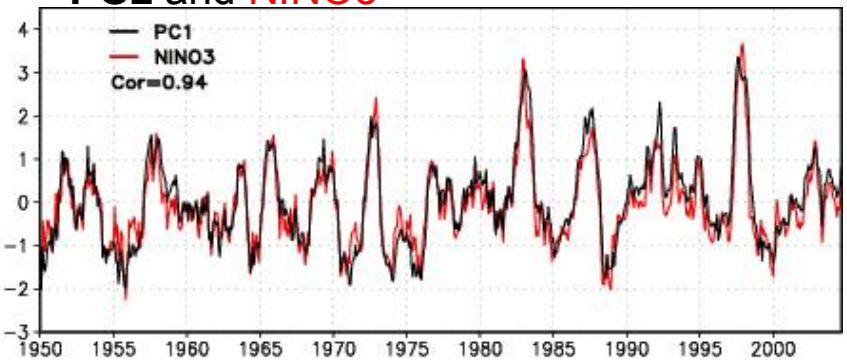
EOF1 (51%)



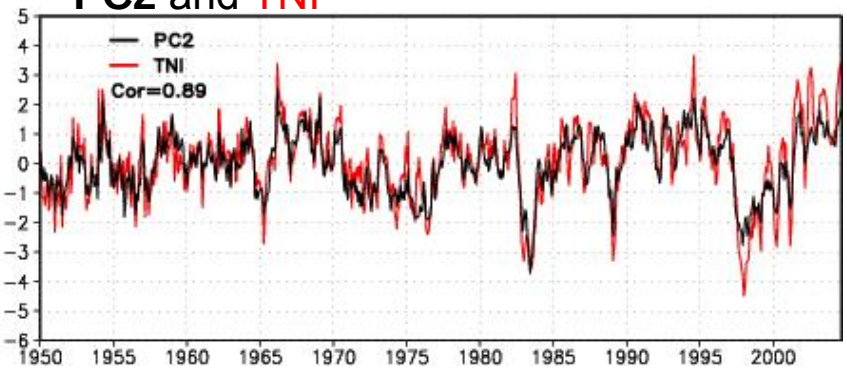
EOF2 (11%)



PC1 and NINO3

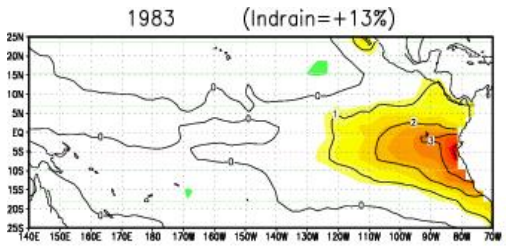


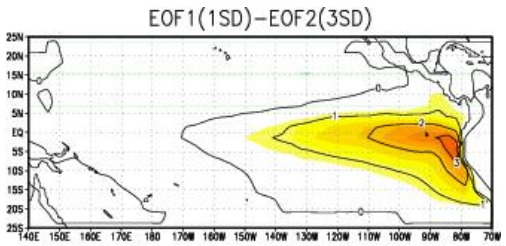
PC2 and TNI

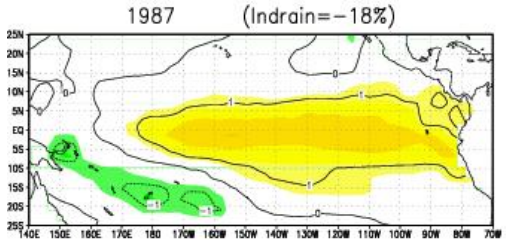


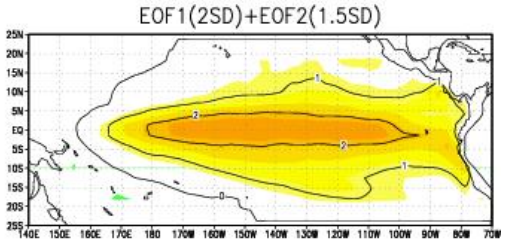
K. Kumar et al, 2006 *Science*

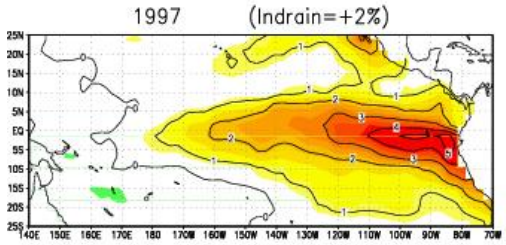
Ability of EOF1 and EOF2 to nearly reproduce the SSTs patterns associated with some of the recent El Nino events that have had different impact on Indian Monsoon

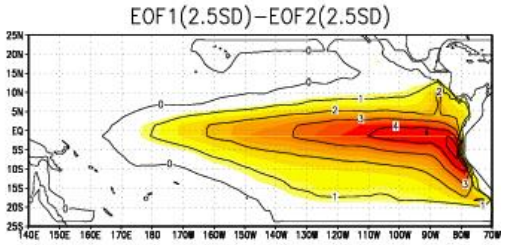


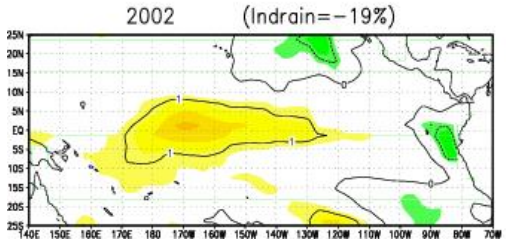


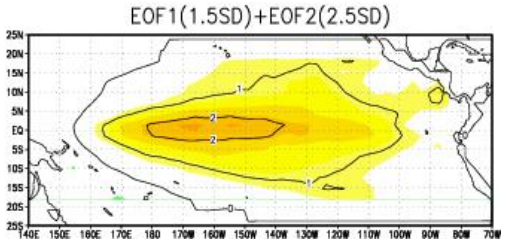












Idealized AGCM Experiments

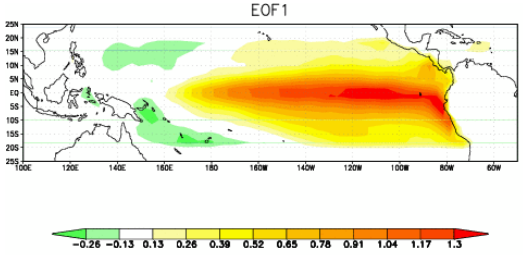
CCM3 (T42, 18 vert levels)

3 sets of 10-member ensemble runs for (1) EOF1
(2) EOF1+EOF2 and (3) EOF1-EOF2 are performed by ramping the magnitude of SST anomaly patterns from 0 to 3σ at a rate of 0.2σ per year
(in all 16x3x10=480 years).

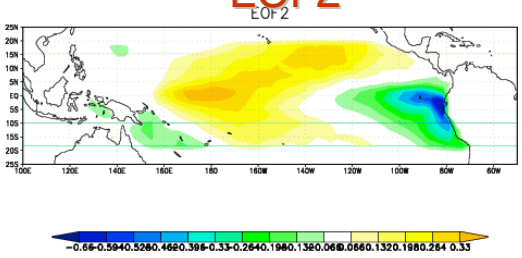
Runs initiated from 1st November and continued for 14 months until the end of December. The first two-months of simulations discarded.

Climatological SSTs prescribed outside of ENSO region

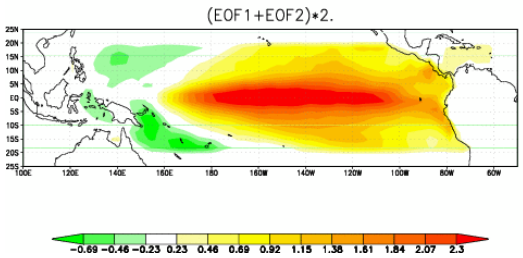
EOF1



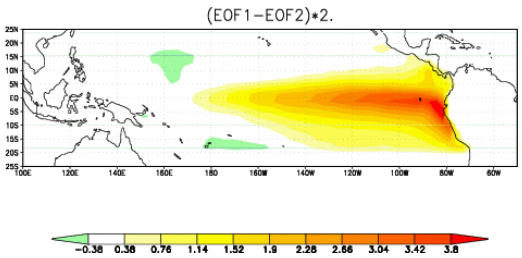
EOF2



EOF1+EOF2



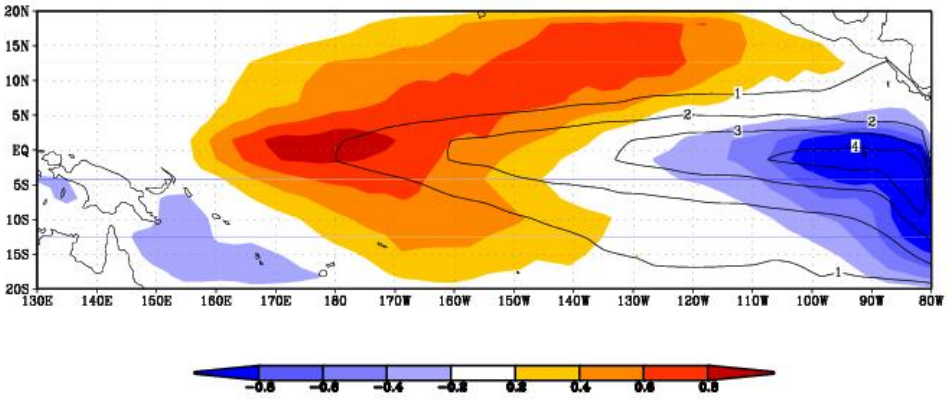
EOF1-EOF2



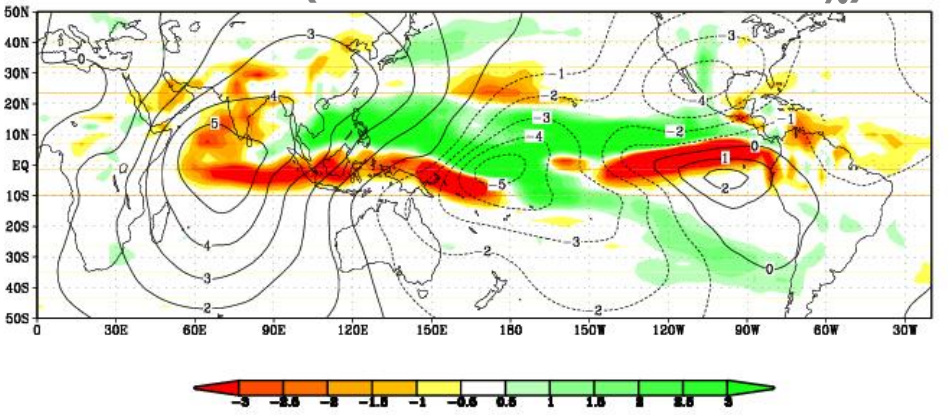
Control Expt: 150 yrs run is made with monthly evolving Climatological SSTs globally

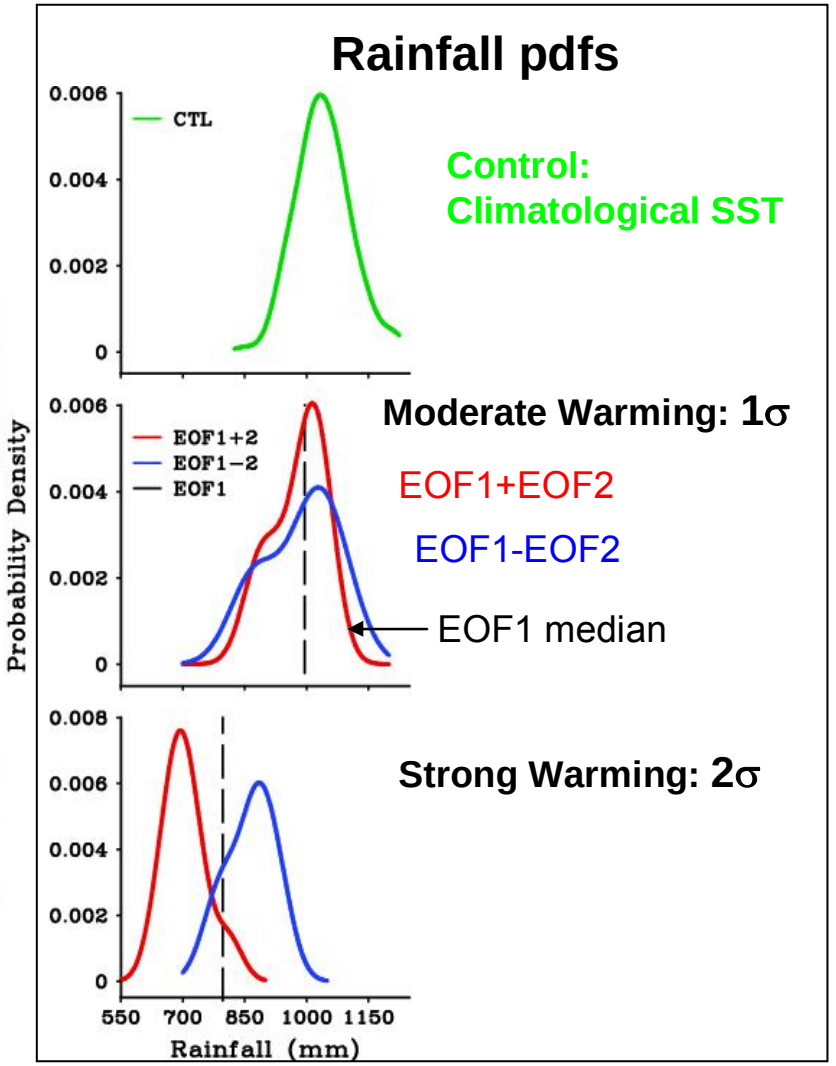
AGCM experiments composite:
Central - Eastern SSTa El Niño years

SST (Contours are wet year SST)



Rainfall (Contours are 200 hPa χ)





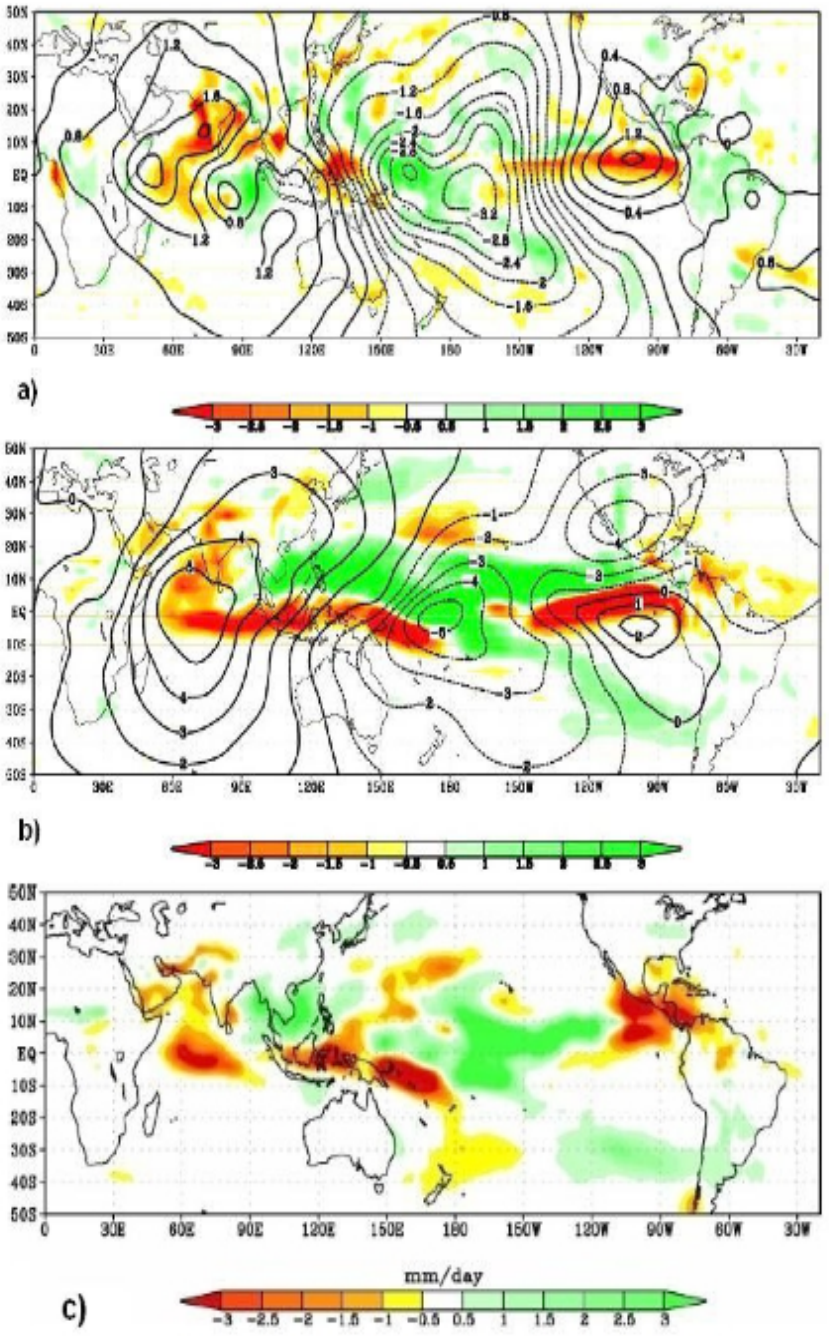
Climatological SSTs elsewhere; 1σ, 2σ ensembles

K. Kumar et al, 2006 *Science*

Severe Drought - Drought Free Composites

Mean rainfall (shading)

200 hPa velocity potential (contours)



Observed

Experiments with Central Pacific - Eastern Pacific SSTAs

POGA Simulations

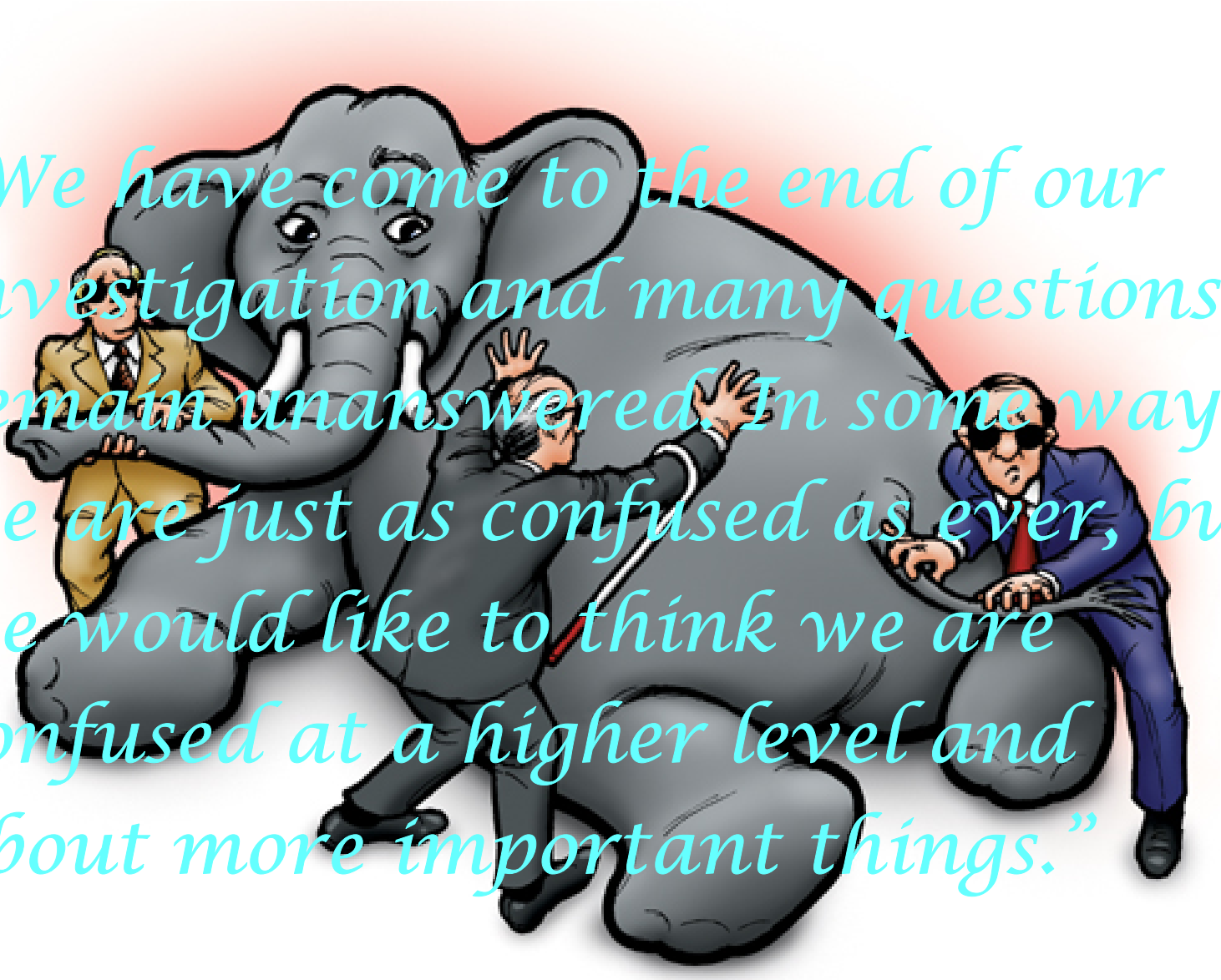
Gadgil et al 2007

Conclusions, part 2

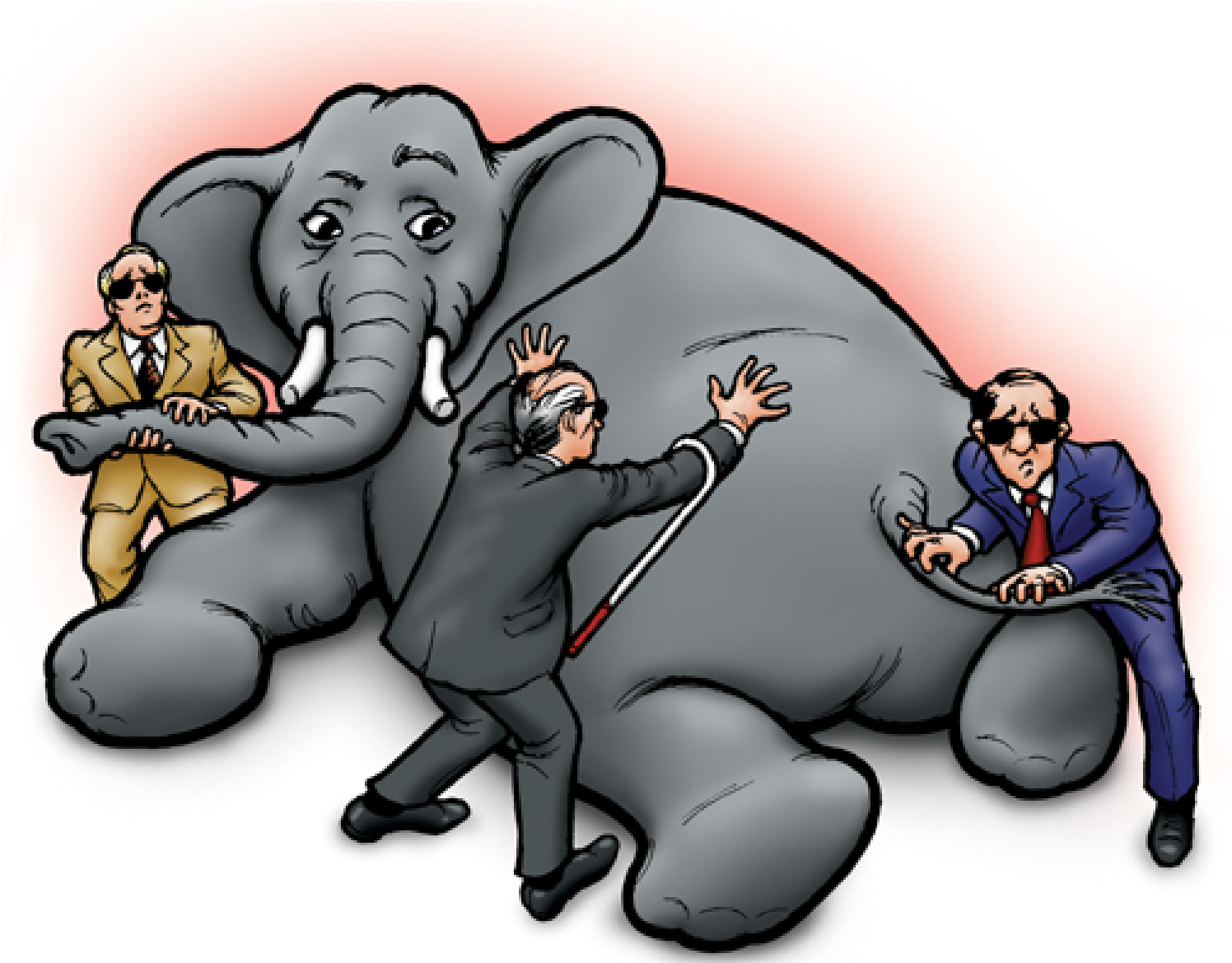
- During protracted El Niño, Indian Ocean is warmer and ISMR tends to be wetter.
- During rapid rising El Niño, Indian Ocean is not warm enough and ISMR - El Niño relation holds.

Conclusions, part 3

- The pattern of El Niño SST anomalies matters.
- Wet ISMR if SST anomaly is further east.
- How does this fit with conclusions above?
- **Role of the Indian Ocean?**



"We have come to the end of our investigation and many questions remain unanswered. In some ways we are just as confused as ever, but we would like to think we are confused at a higher level and about more important things."



Thank you