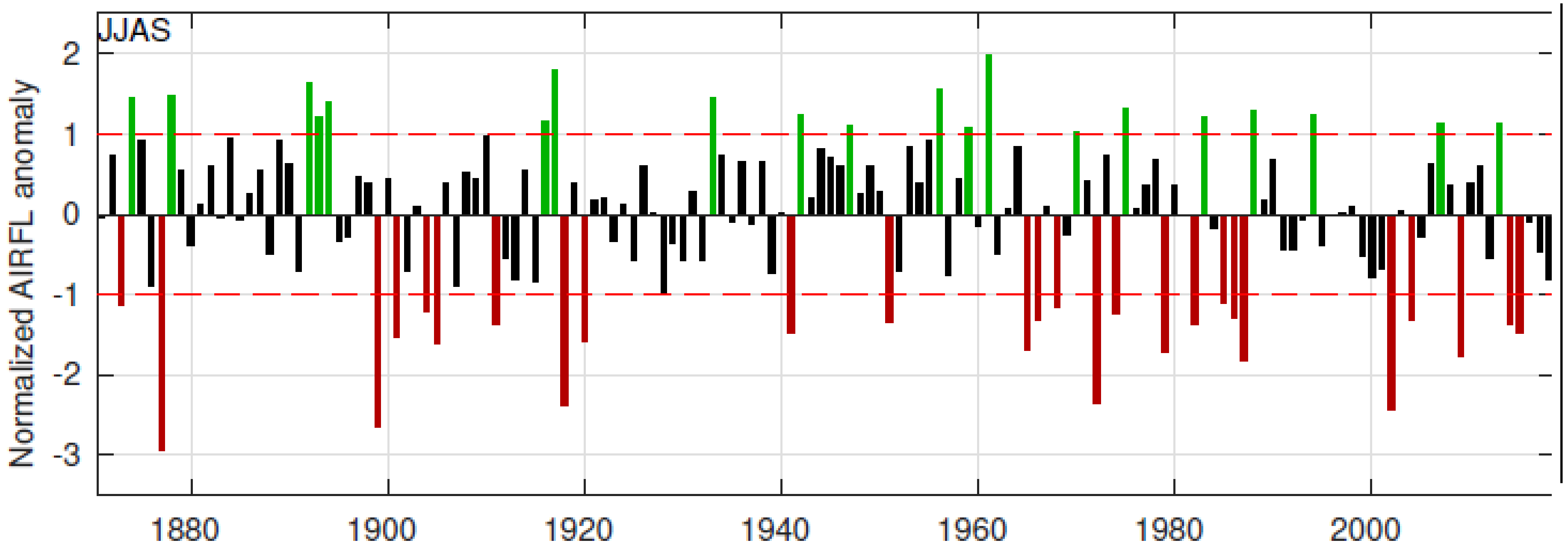
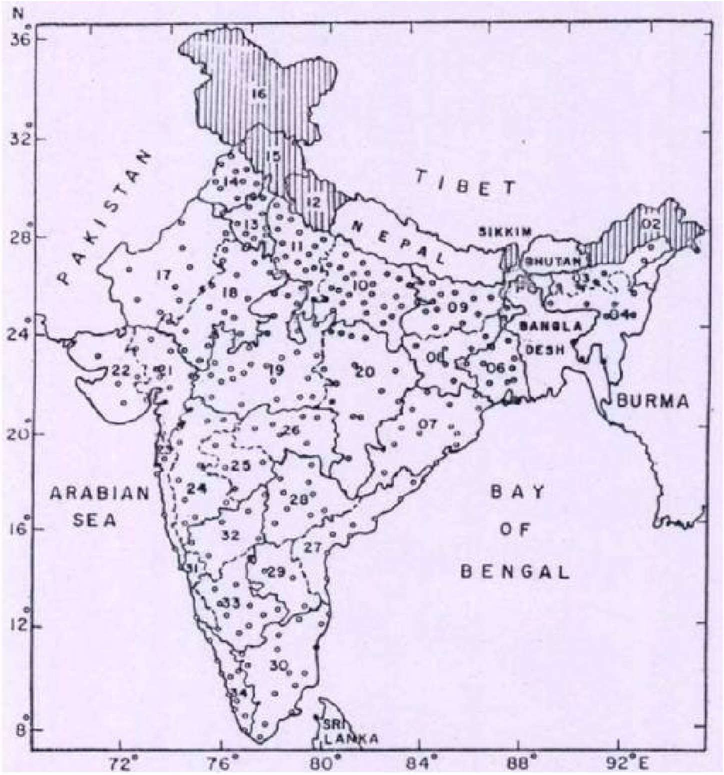
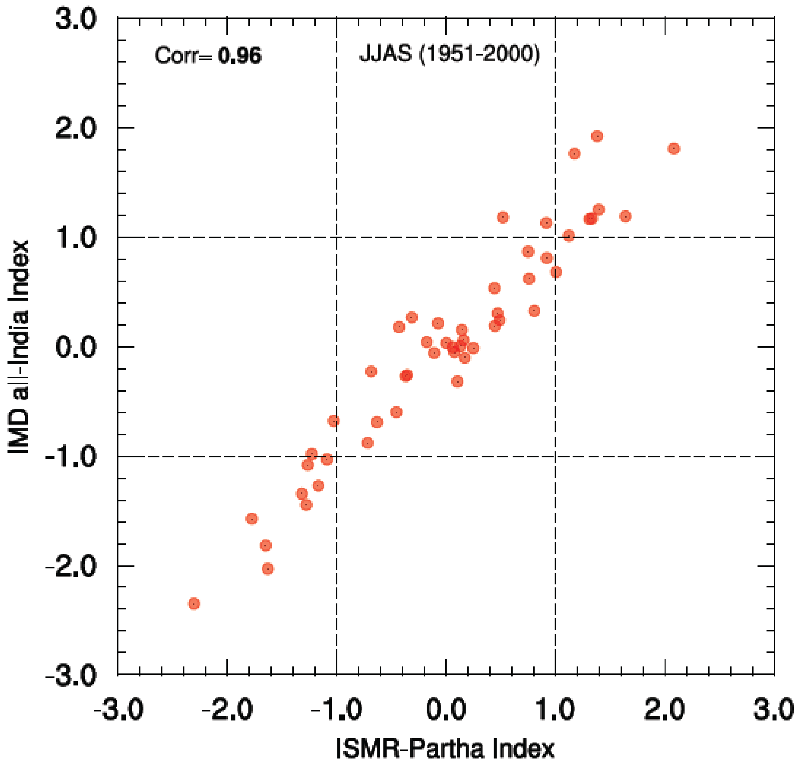
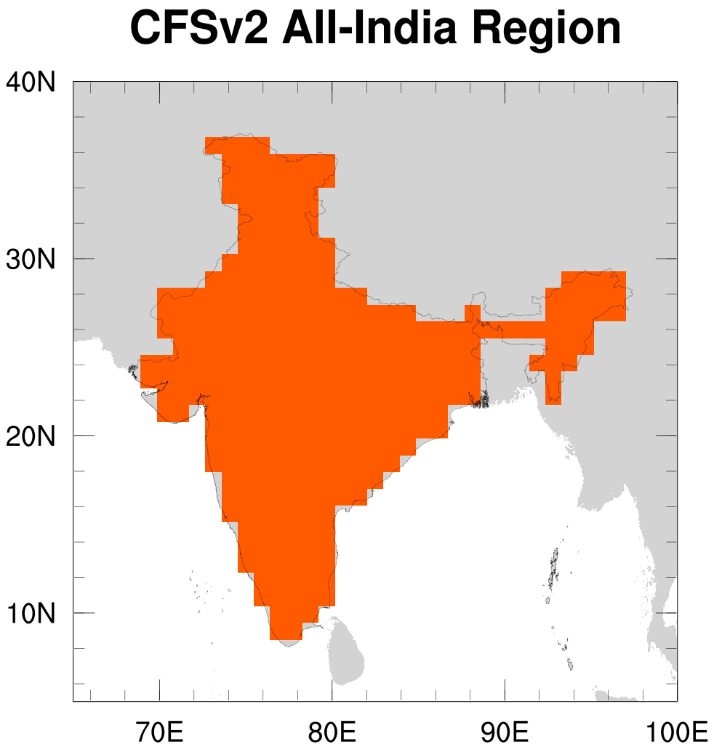
Interannual variation of ISMR

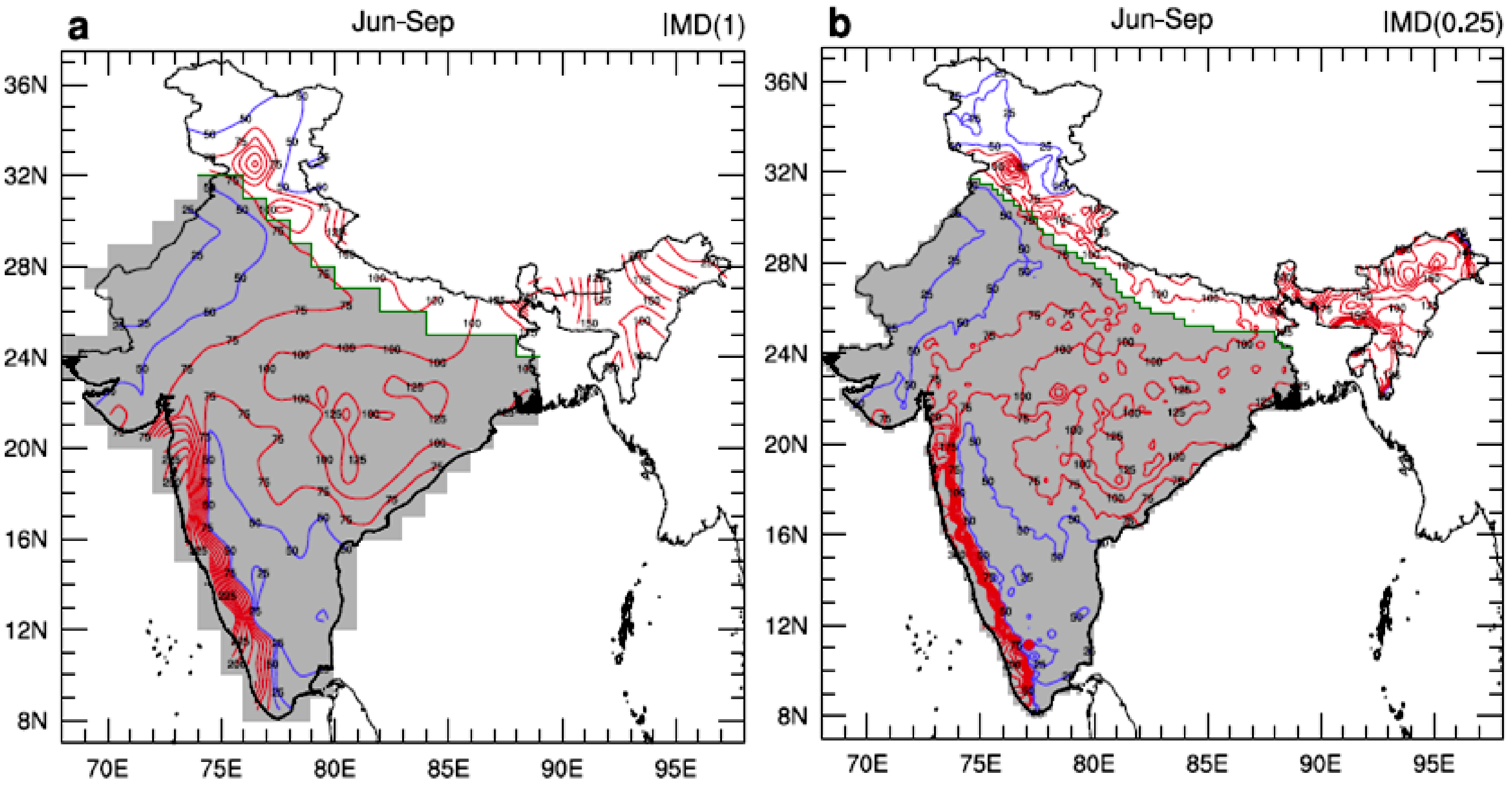



PAKISTAN
TIBET
NEPAL
SIKKIM
BHUTAN
BANGLA DESH
BURMA
ARABIAN SEA
BAY OF BENGAL
SRI LANKA

ISMR-Partha

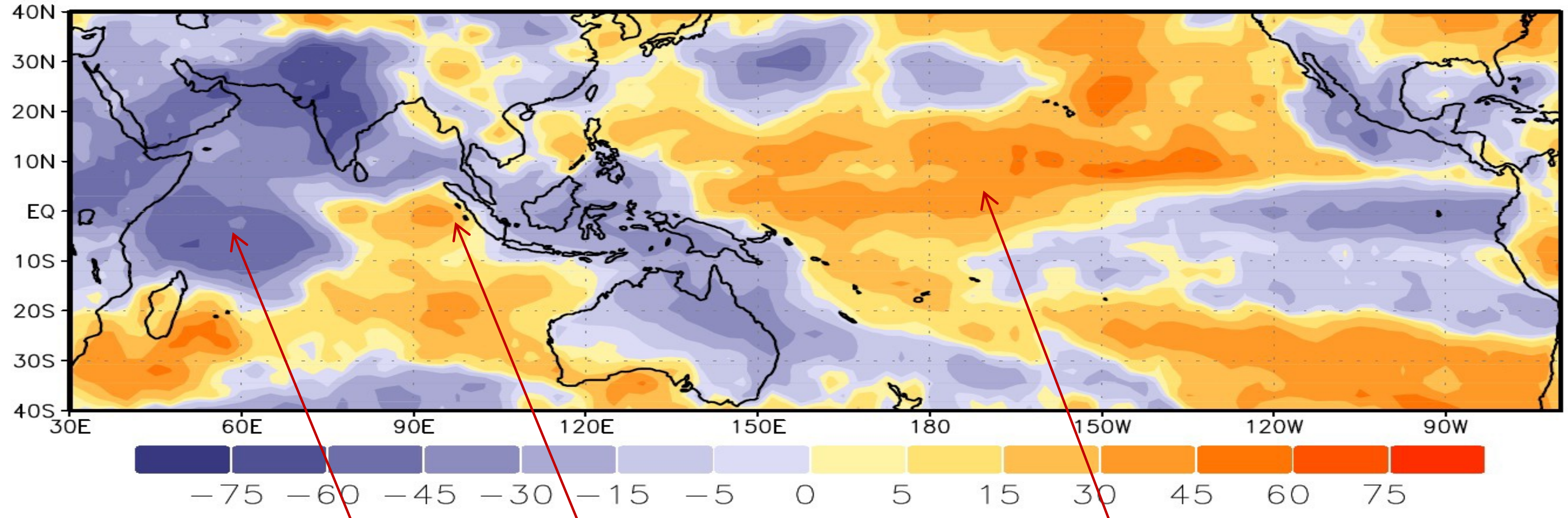

Corr= 0.96
JJAS (1951-2000)
IMD all-India Index
ISMR-Partha Index
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0


CFSv2 All-India Region
40N
30N
20N
10N
70E
80E
90E
100E



a
Jun-Sep
IMD(1)
36N
32N
28N
24N
20N
16N
12N
8N
70E
75E
80E
85E
90E
95E
b
Jun-Sep
IMD(0.25)
36N
32N
28N
24N
20N
16N
12N
8N
70E
75E
80E
85E
90E
95E

Correlation of ISMR with June-Sept OLR

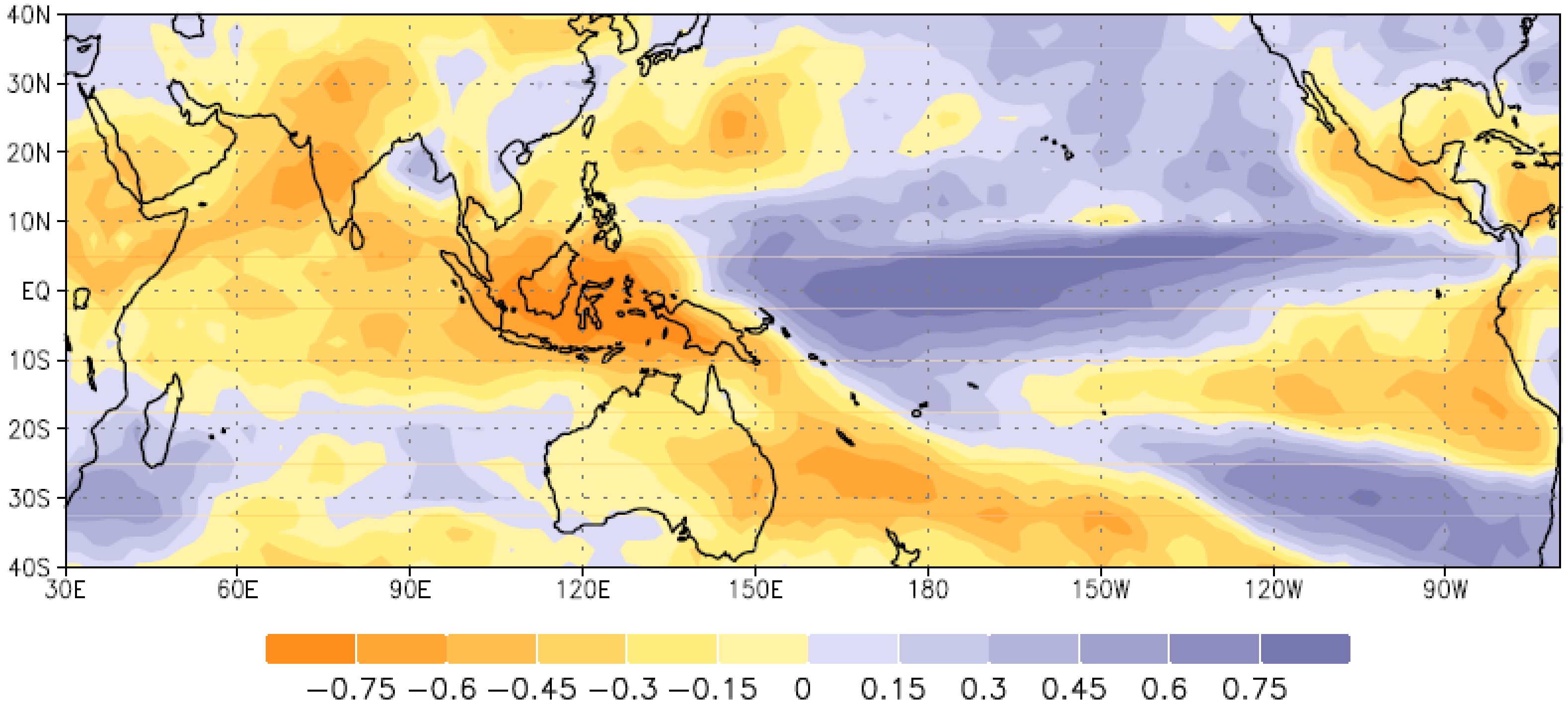


Contours of correlation coefficient x100 are shown

Link with convection over eq. Ind. Ocean

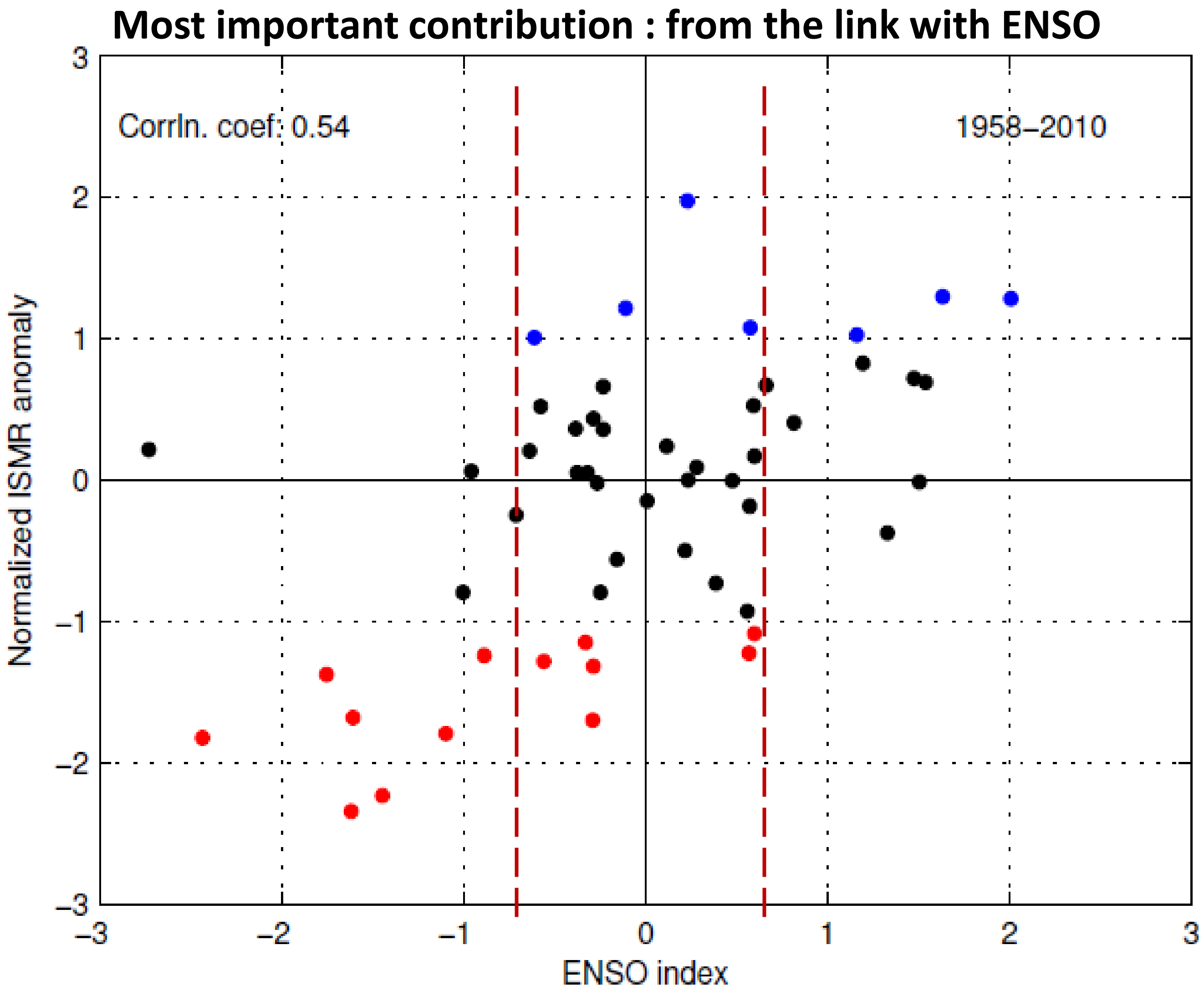
Link with ENSO

Correlation of ENSO index with OLR for JJAS

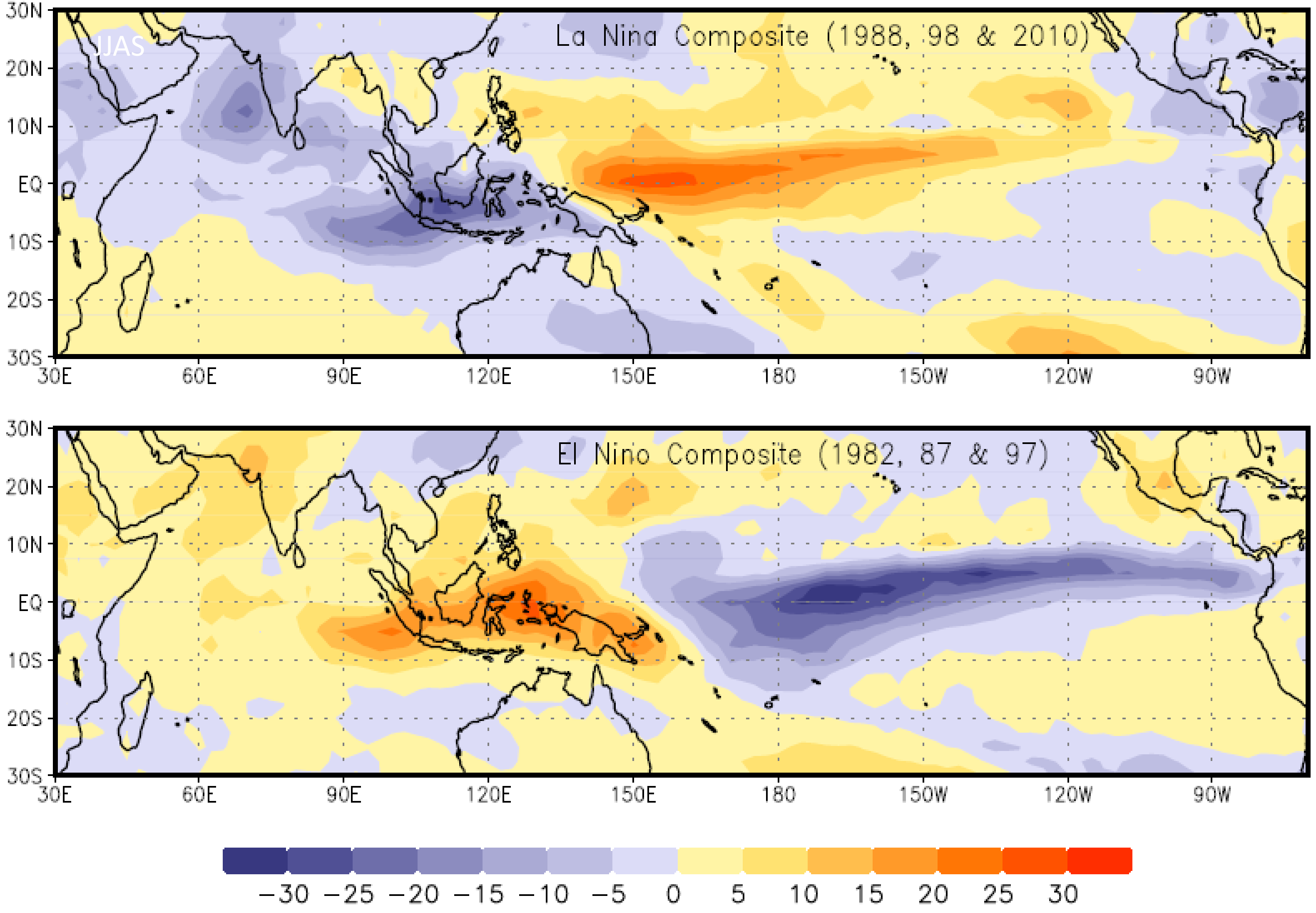


El Nino (La Nina) suppresses(enhances) convection over the entire eq. and north Ind. Ocean i.e. the life line of the monsoon and hence over the Indian region as well.

ENSO index =negative of normalized SST anomaly of Nino3.4. Hence positive values of ENSO index favourable for the monsoon



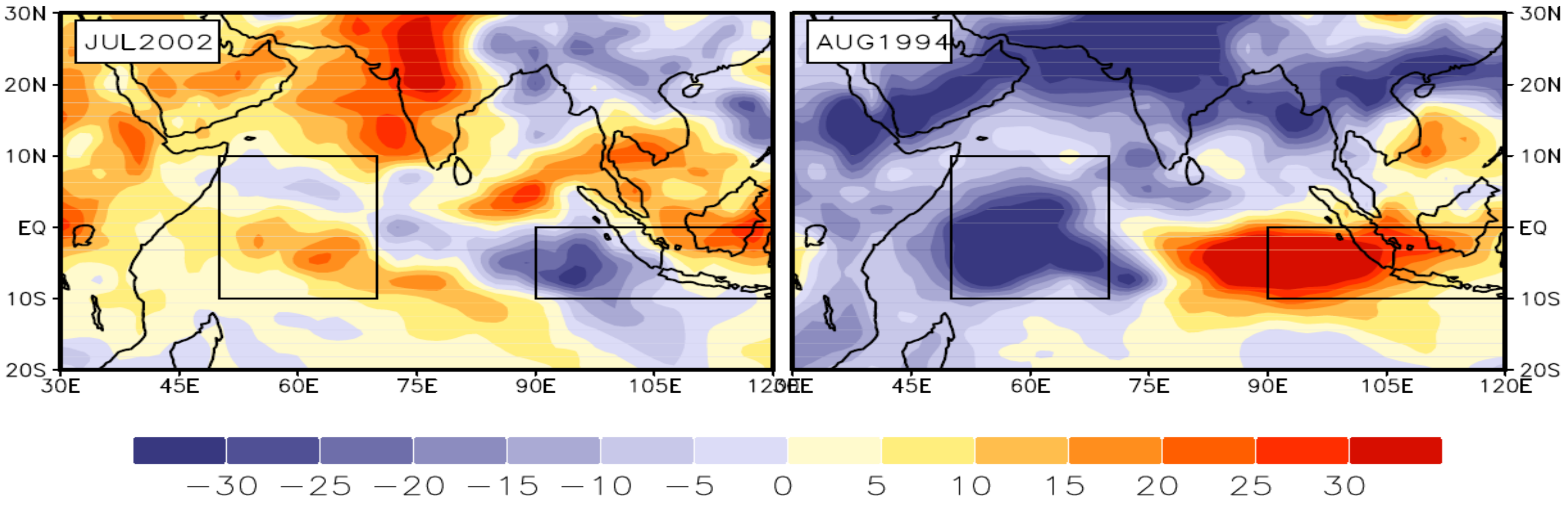
No droughts for ENSO index>0.6; no excess rfl seasons for index<-0.8 but several extremes for intermediate values (one-sided prediction)



JJAS
La Nina Composite (1988, 98 & 2010)
El Nino Composite (1982, 87 & 97)
30N
20N
10N
EQ
10S
20S
30S
30E
60E
90E
120E
150E
180
150W
120W
90W
−30 −25 −20 −15 −10 −5 0 5 10 15 20 25 30

We found in 2004 that in addition to ENSO, another mode, which is the equatorial Indian Ocean Oscillation (EQUINOO) also plays an important role in interannual variation of the monsoon.

OLR anomalies



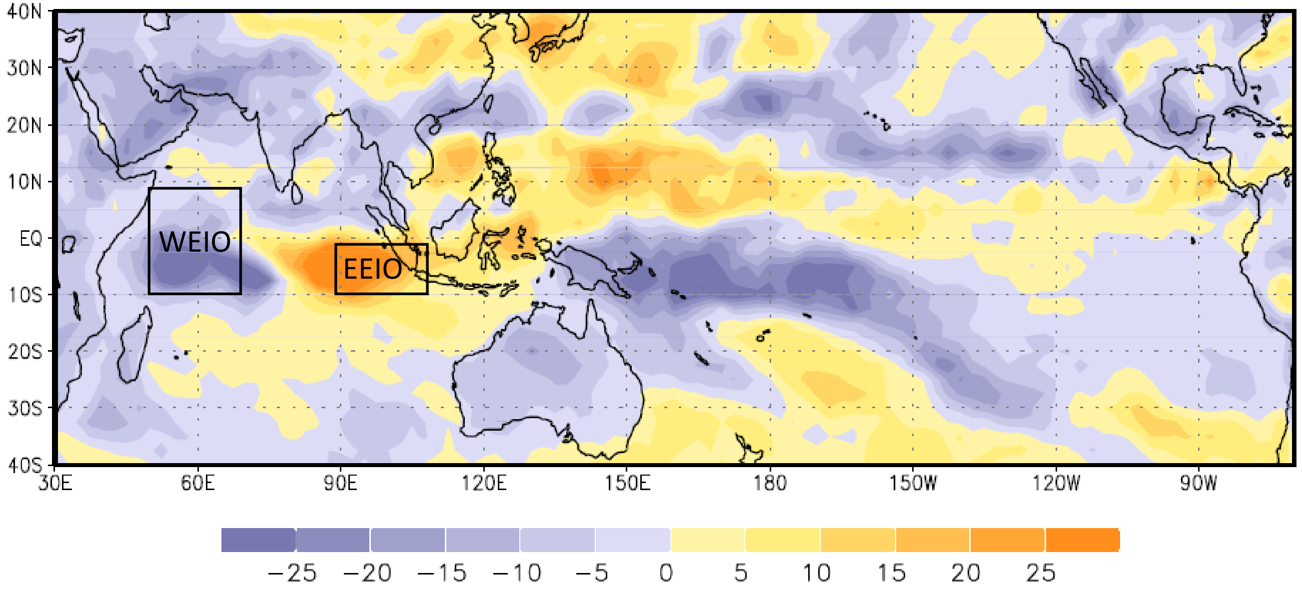
July 2002: negative phase

August 1994: positive phase

Equatorial Indian Ocean Oscillation (EQUINOO)

OLR anomaly patterns

August 1994

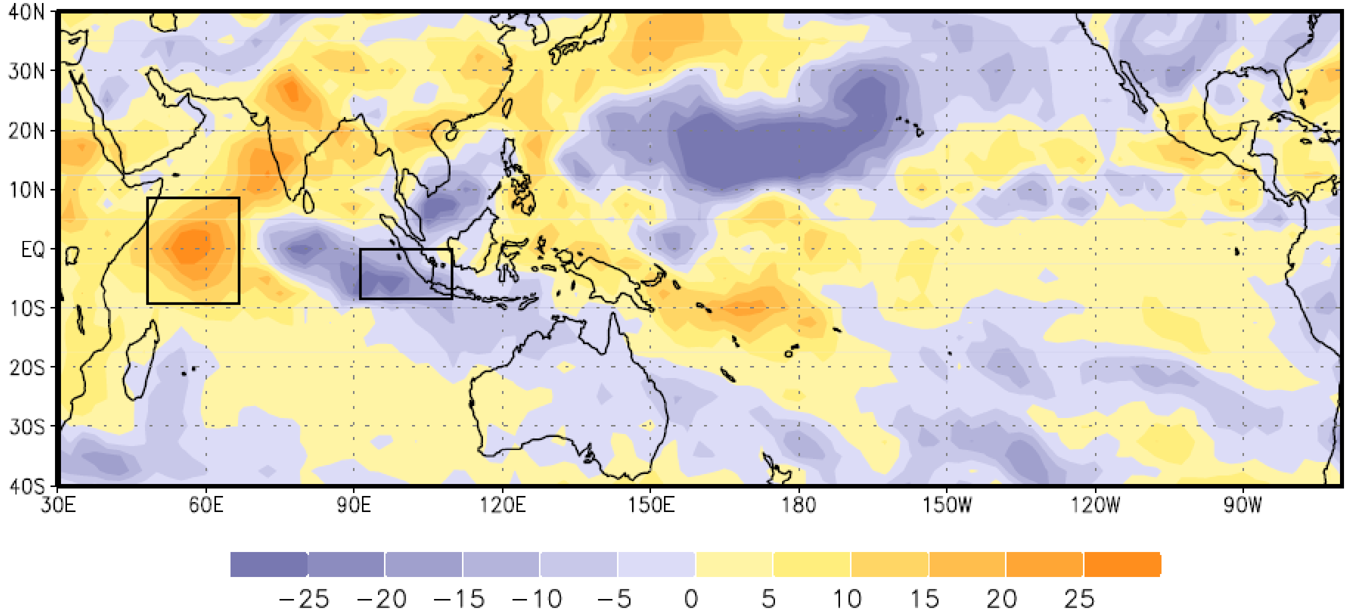


Positive phase

Atmospheric component of the coupled Indian Ocean Dipole (IOD) mode.

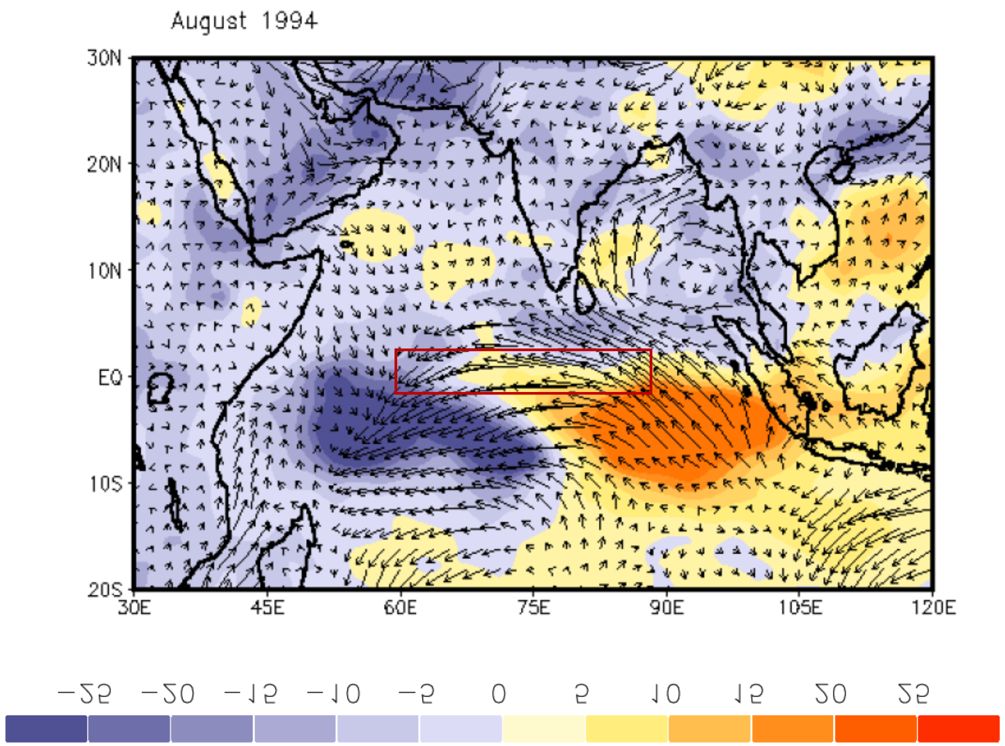
WEIO,EEIO Regions defined in the IOD paper of Saji et. al.

August 1986



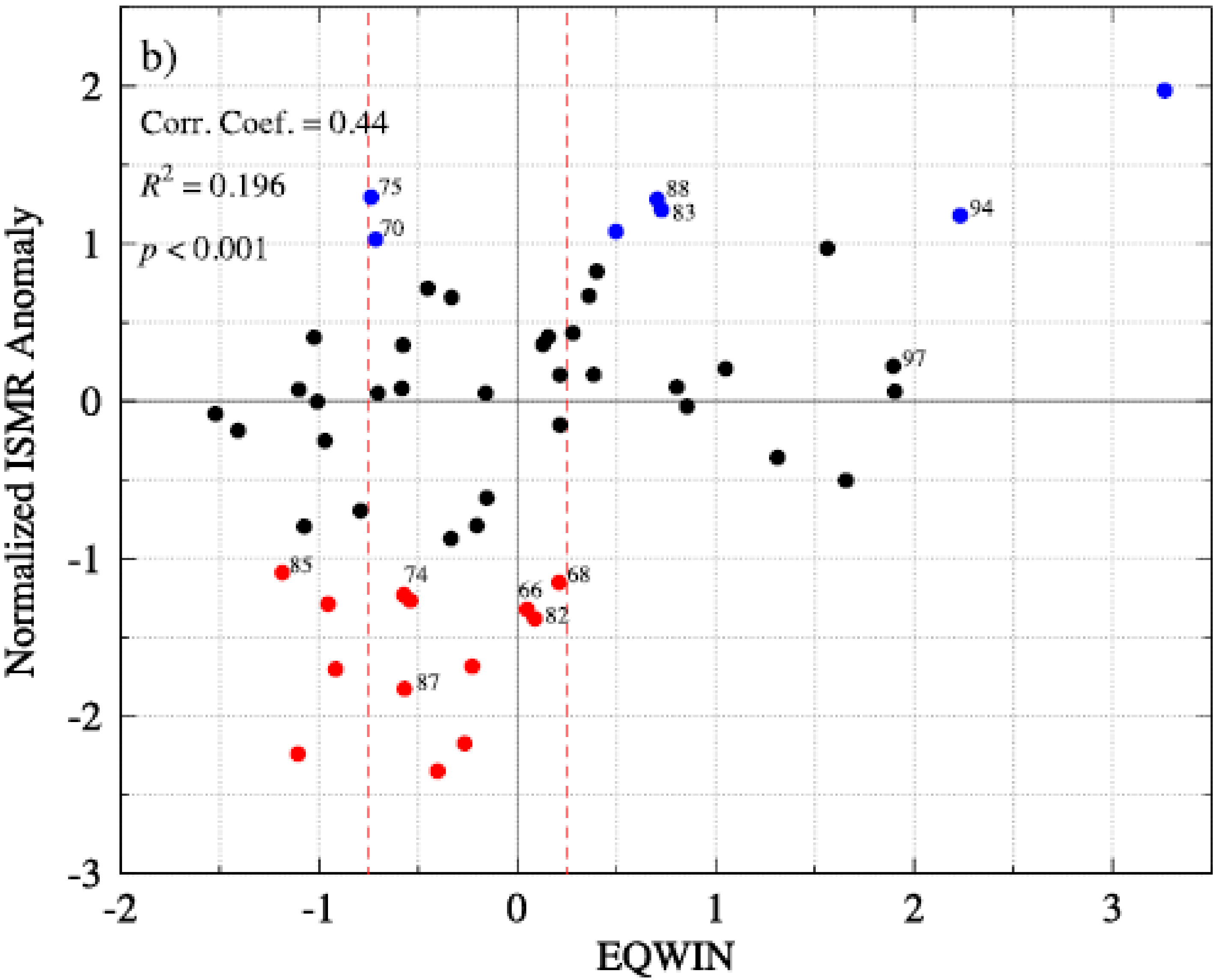
Negative phase

- We use EQWIN an index of EQUINOO, defined as the negative[1] of the anomaly of the surface zonal wind averaged over 60^0E-90^0E:2.5^0S-2.5^0N, normalized by its standard deviation.

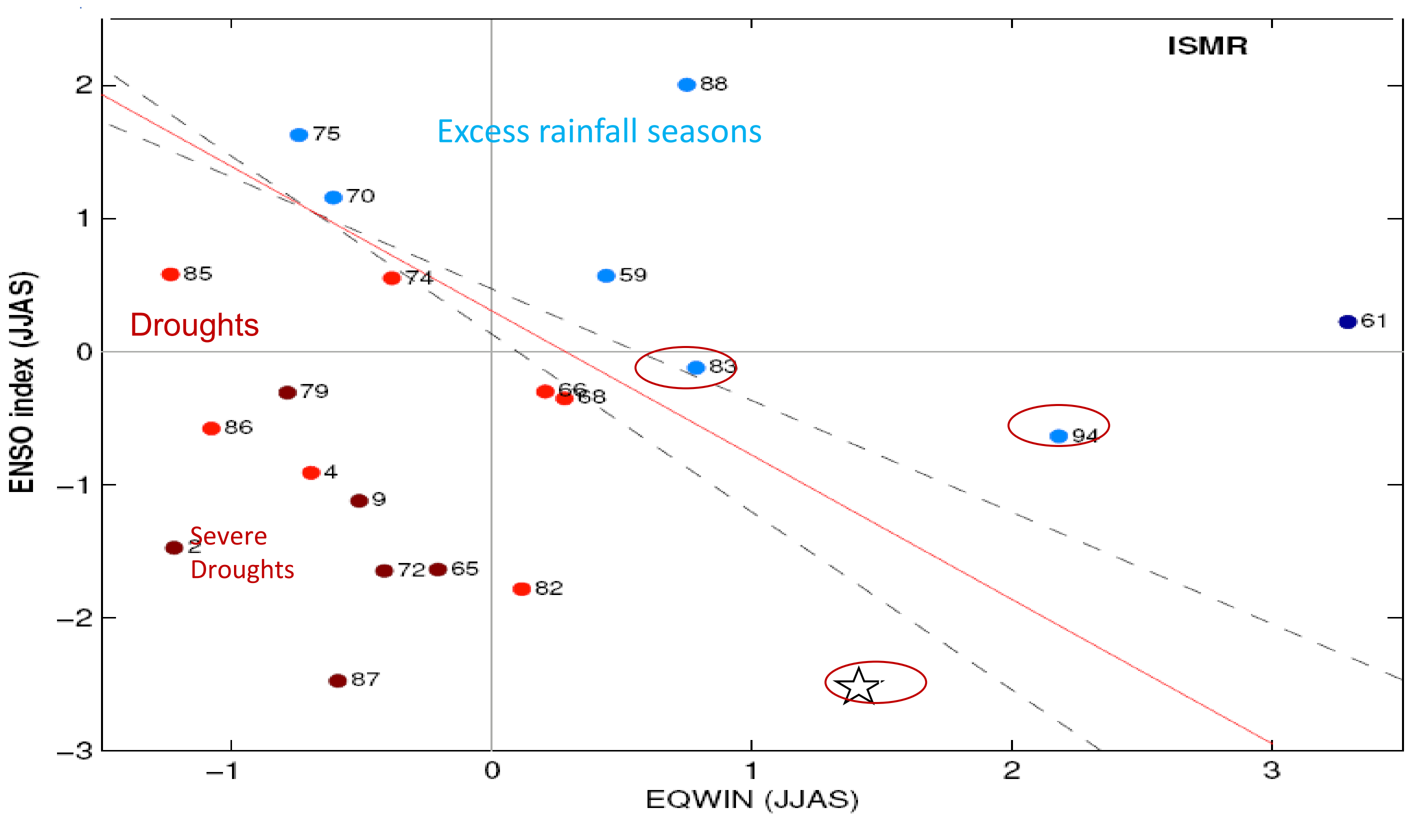


EQWIN=2.03

- [1]negative (so that positive values of EQWIN imply favourable for the monsoon),

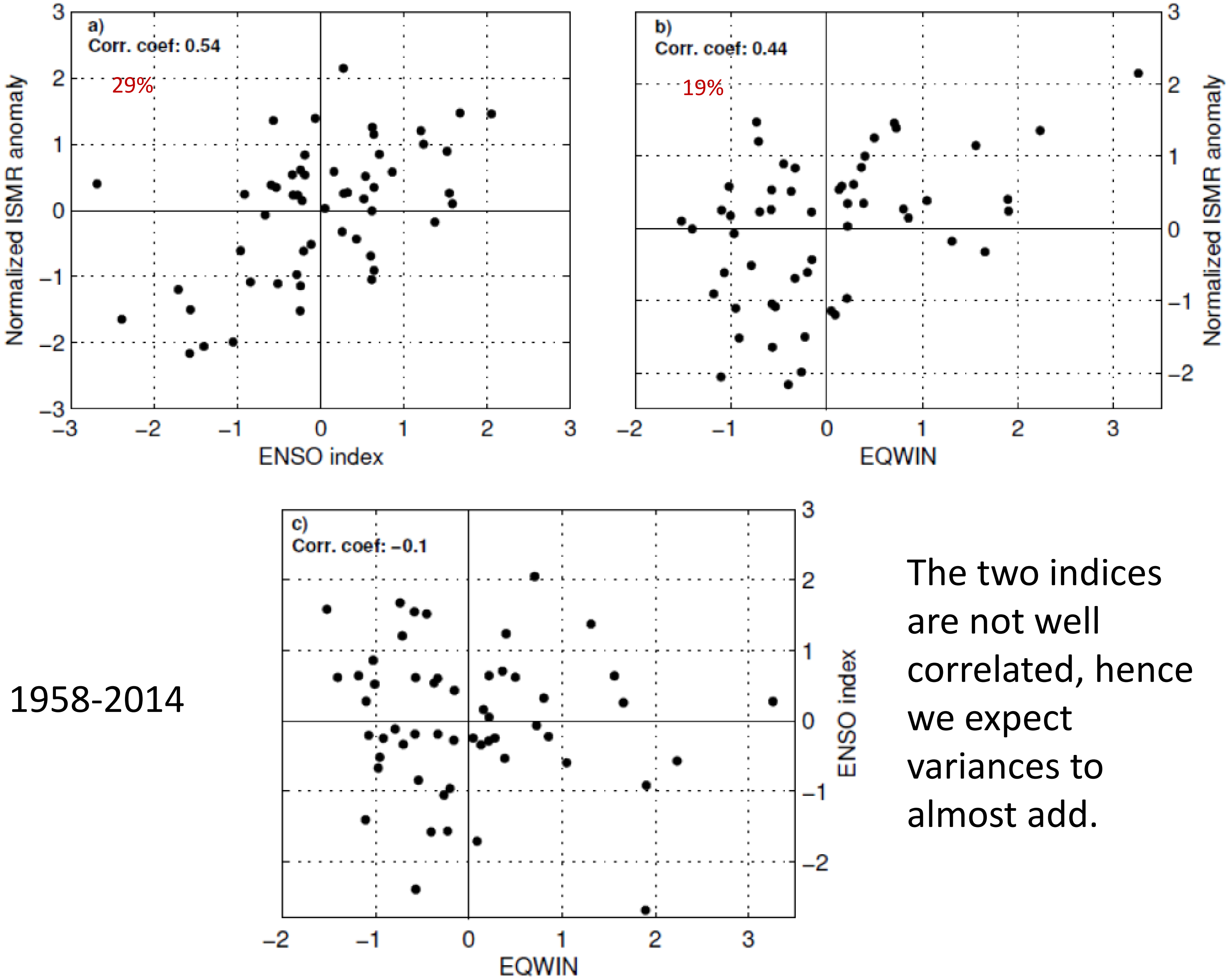

b)
Corr. Coef. = 0.44
$R^2 = 0.196$
$p < 0.001$
75
70
88
83
94
97
85
74
66
68
82
87
2
1
0
-1
-2
-3
-2
-1
0
1
2
3
Normalized ISMR Anomaly
EQWIN

Strong association of ISMR extremes with ENSO& EQUINOO



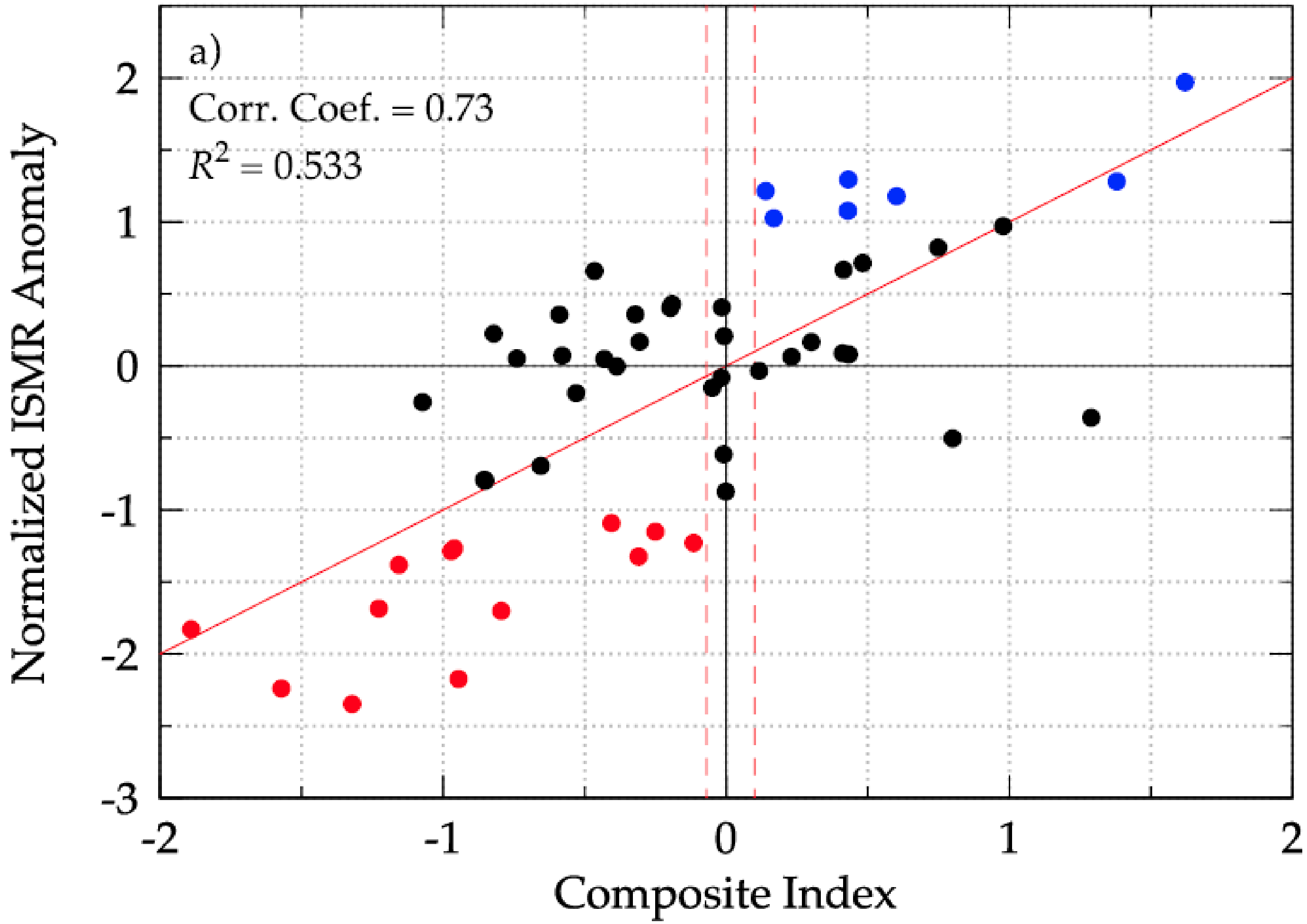
No droughts if the ENSO index &EQWIN values imply that the point is above the line and no excess rainfall seasons if it is below.

Gadgil et. al 2003,2004



1958-2014

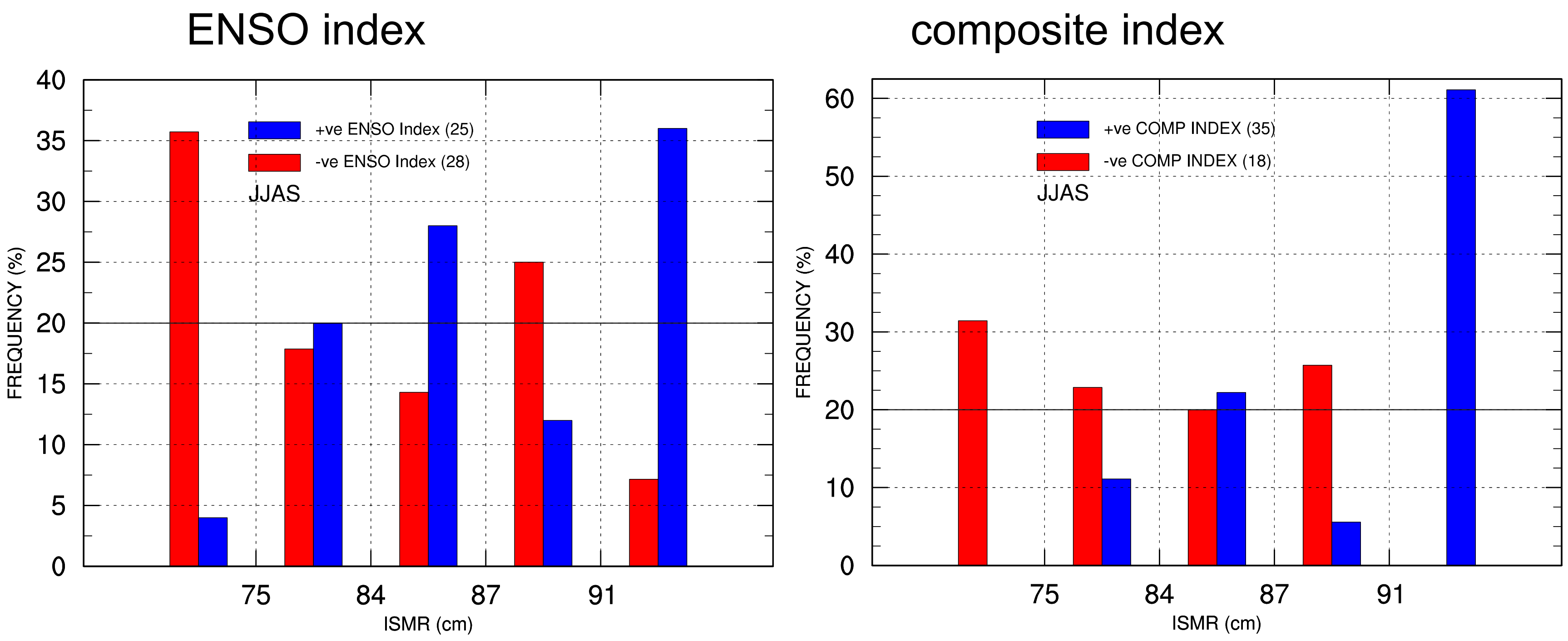
The two indices are not well correlated, hence we expect variances to almost add.



Sajani et. al 2016

During JJAS the ENSO index and EQWIN are very poorly correlated, so the variances add and a composite index explains over 53% of the variance of ISMR.
Hence need prediction of ENSO as well as EQUINOO for prediction of ISMR

Association: Frequency distributions of ISMR for different signs of ENSO index and composite index



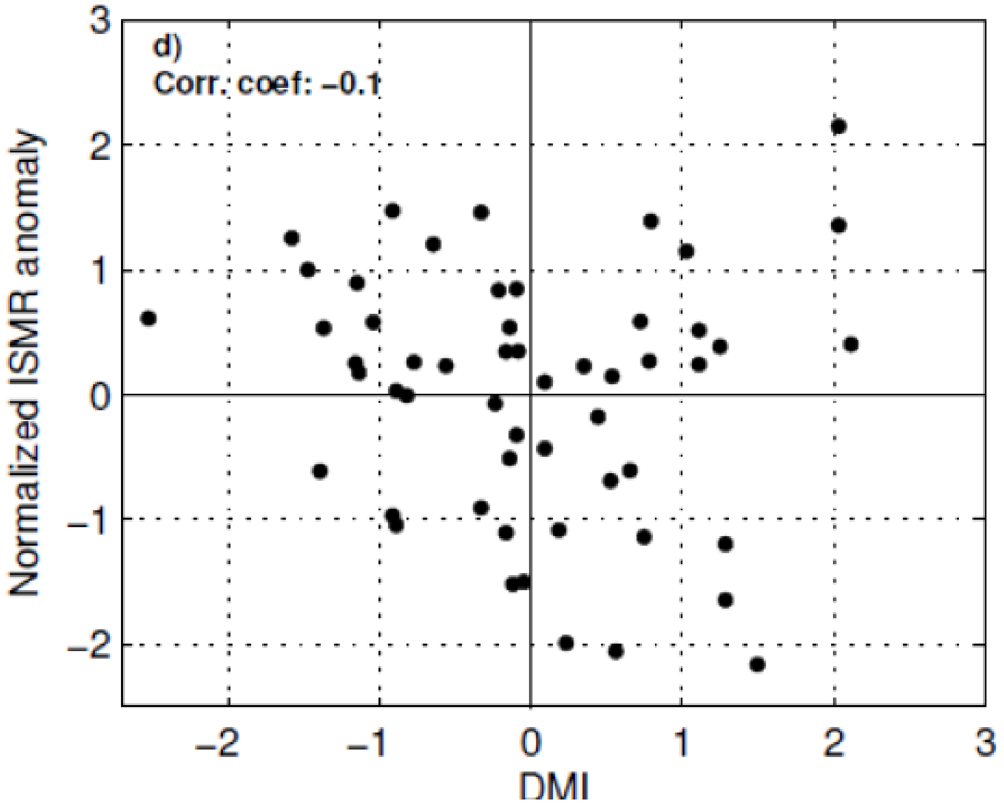
Classes chosen such that each with 20% chance for climatology

Thus there are two modes, each of which plays a very important role in determining the interannual variability of ISMR

1 El Nino Southern Oscillation (ENSO) which is a strongly coupled mode for which we use Nino SST indices:
2. EQUINOO: atmospheric component of the coupled mode called Indian Ocean Dipole Mode, which however, is not strongly coupled to the oceanic component.

Index commonly used for IOD is

DMI=SST anom (WEIO)-SST anom (EEIO), normalized by the standard deviation.



While ISMR is well correlated with EQWIN, ISMR is not well correlated with DMI.

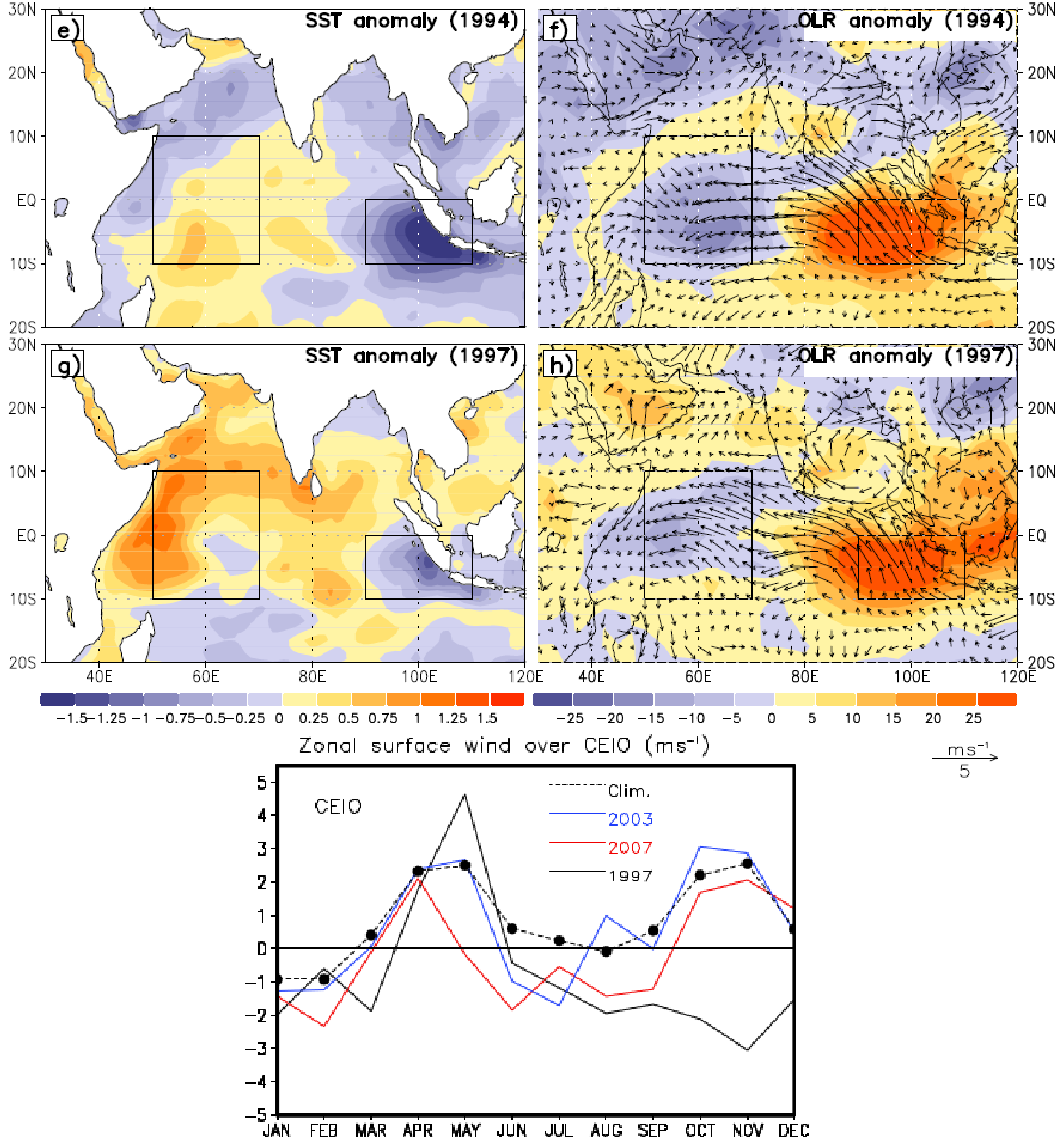
However, strong positive phase of IOD (pIOD events) such as 1994 and 1997are associated with strong positive phase of EQUINOO. Also the first step in the triggering of pIOD event is the genesis of positive phase of EQUINOO.

Relationship of the variation of ISMR over the entire range with simultaneous values of the indices : Association

Ihara, C., Kushnir, Y., Cane, M. A. and De la Peña, V, (*Int. J. Climatol.*, 2007)

analysed the data from 1881-1998 and showed that the linear reconstruction of ISMR on the basis of both ENSO index (taken to be NINO3) and EQWIN has a stronger correlation with the observed ISMR than the NINO3 alone.

Value addition with EQUINOO

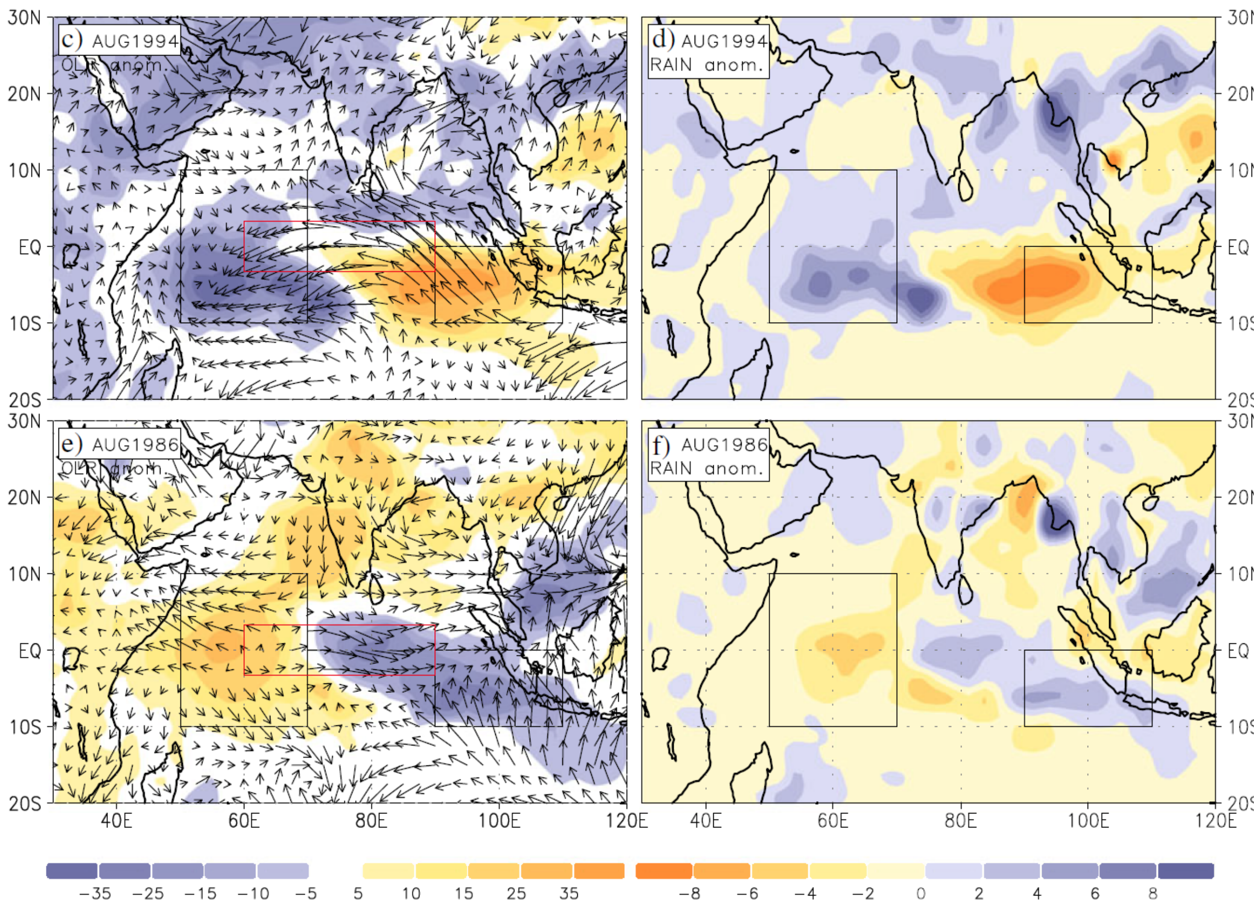


- **Note that pIOD events such as of 1994 and 1997, are characterized by a positive phase of EQUINOO.**
- **The positive EQUINOO phase is associated with easterly anomalies of the surface wind over the central equatorial Indian Ocean.**

- **Climatologically the zonal wind is rather weak during the summer monsoon. Hence difficult to asses anomalies accurately.**
- **OLR is a more robust and reliable measure.**
- **So in the satellite era we use an index for EQUINOO based on OLR.**

The index based on OLR, viz., EQUINOLR is defined as

EQUINOLR = OLR anomaly (EEIO)- OLR anomaly (WEIO); normalized by the standard deviation.



A note on new indices for the equatorial Indian Ocean oscillation

P A Francis[1,*] and Sulochana Gadgil[2]

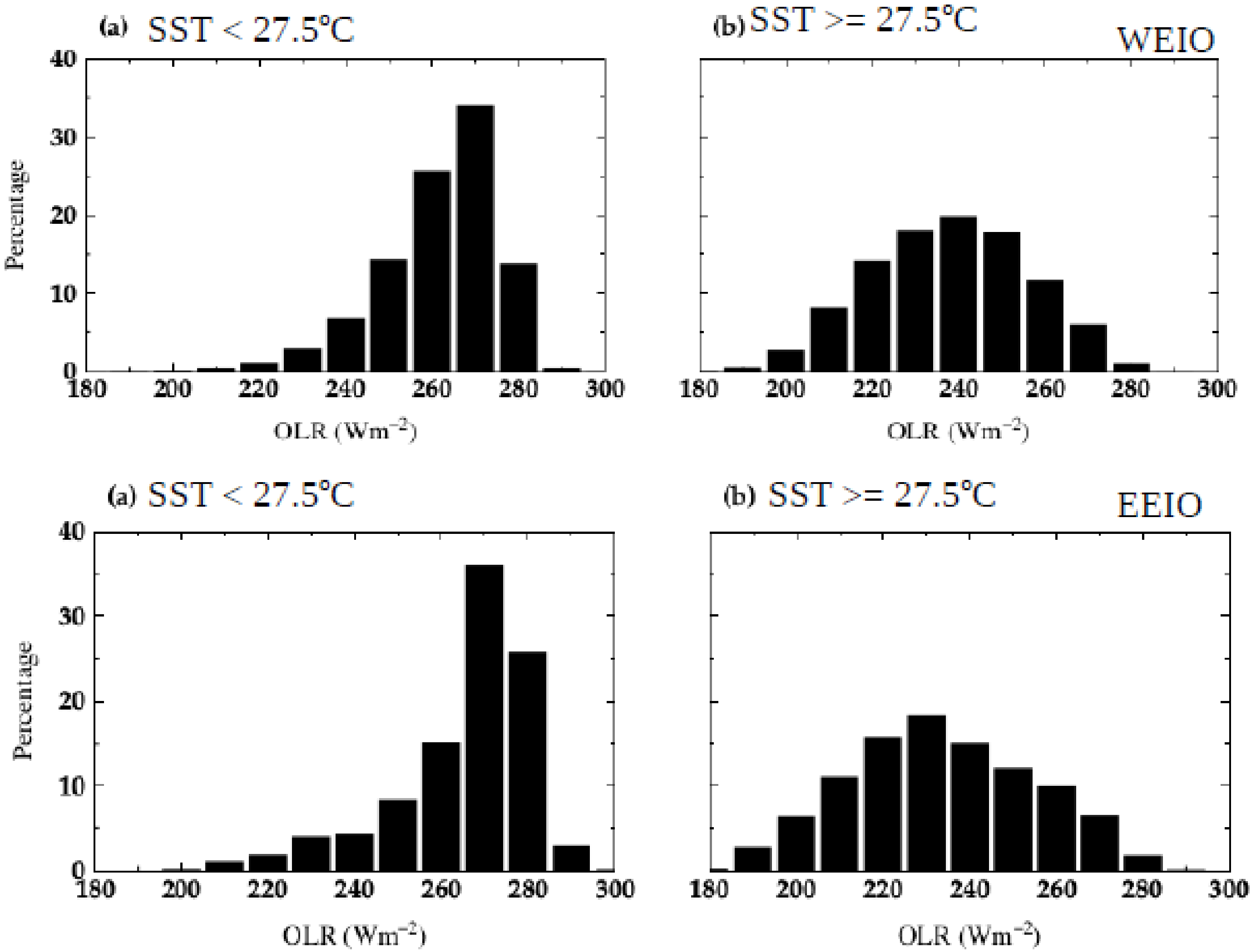
J. Earth Syst. Sci. **122**, No. 4, August 2013, pp. 1005–1011

- Note that, what we have here is an association, and not a prediction.
- However, such associations with ENSO made the launch of IRI possible, after the phenomenal success in understanding and predicting ENSO.
- Hence, useful, if we can predict ENSO and EQUINOO indices for these periods.
- However, while ENSO predictions from models appear to be reasonable*, coupled models are not able to predict the evolution of EQUINOO as yet and almost no model can simulate its links with ISMR.

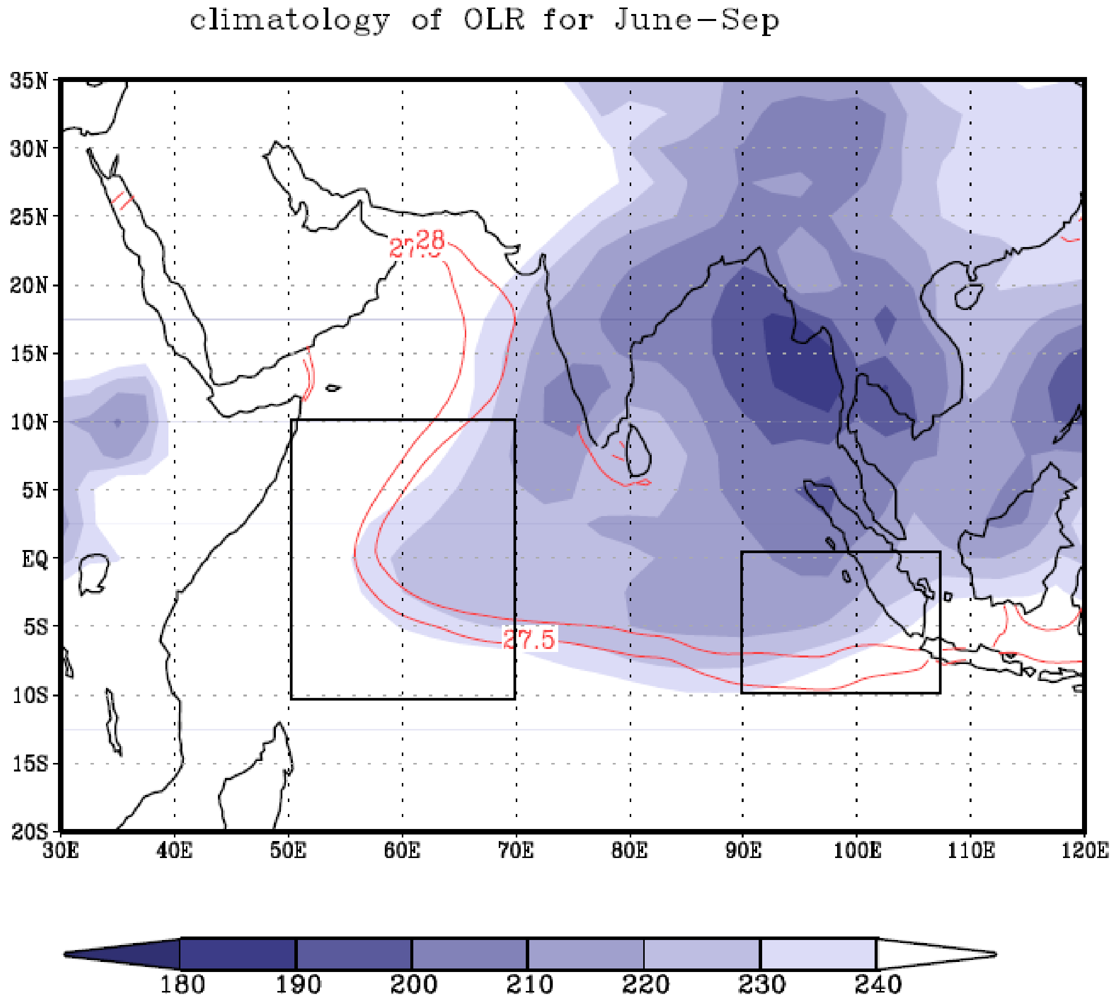
- * Not good enough for evolution of Nino3.4 SST anomalies in 2012,2014

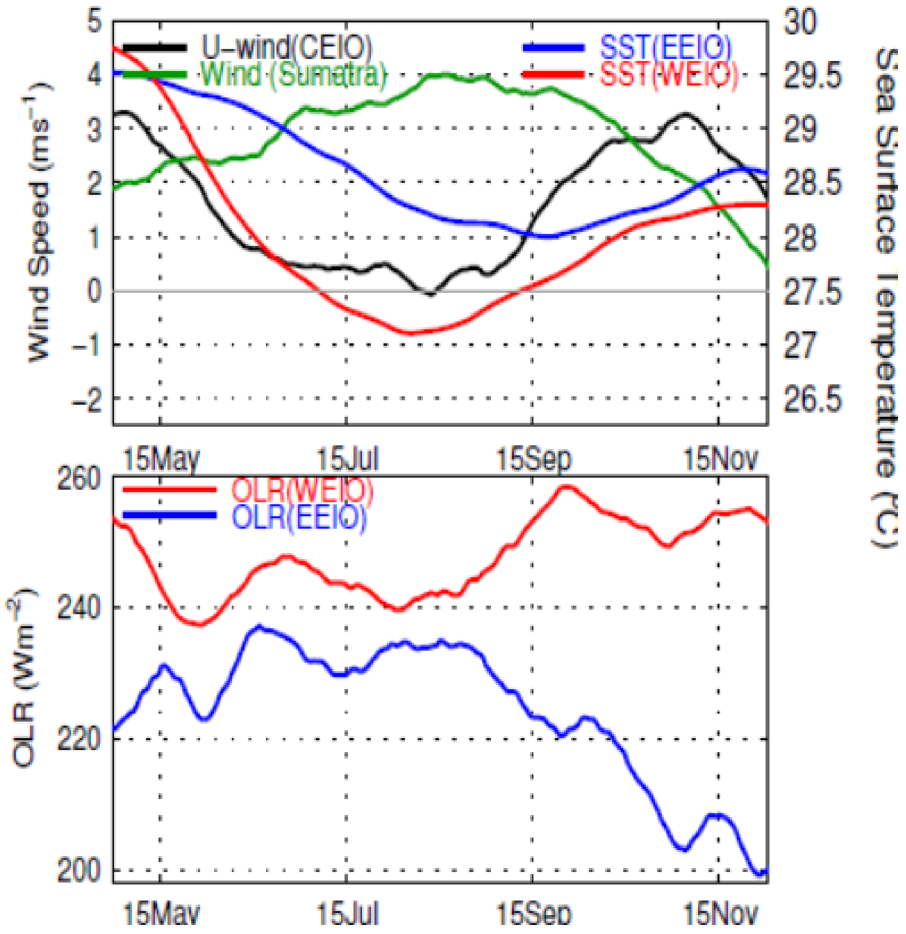
Some background:

For organized convection over tropical oceans, SST has to be above a threshold of about 27.5C.



Frequency distribution of the of the OLR of WEIO (top) and EEIO (bottom) for June, July, August & September months during 1982-2018





Note that climatologically EEIO(OLR)<WEIO(OLR) throughout May-November .
So, negative phase of EQUINOO implies intensification of climatology where as positive phase is associated with weakening or reversing the east-west climatological OLR gradient. Similarly positive IOD is associated with weakening or reversing the east-west climatological SST gradient

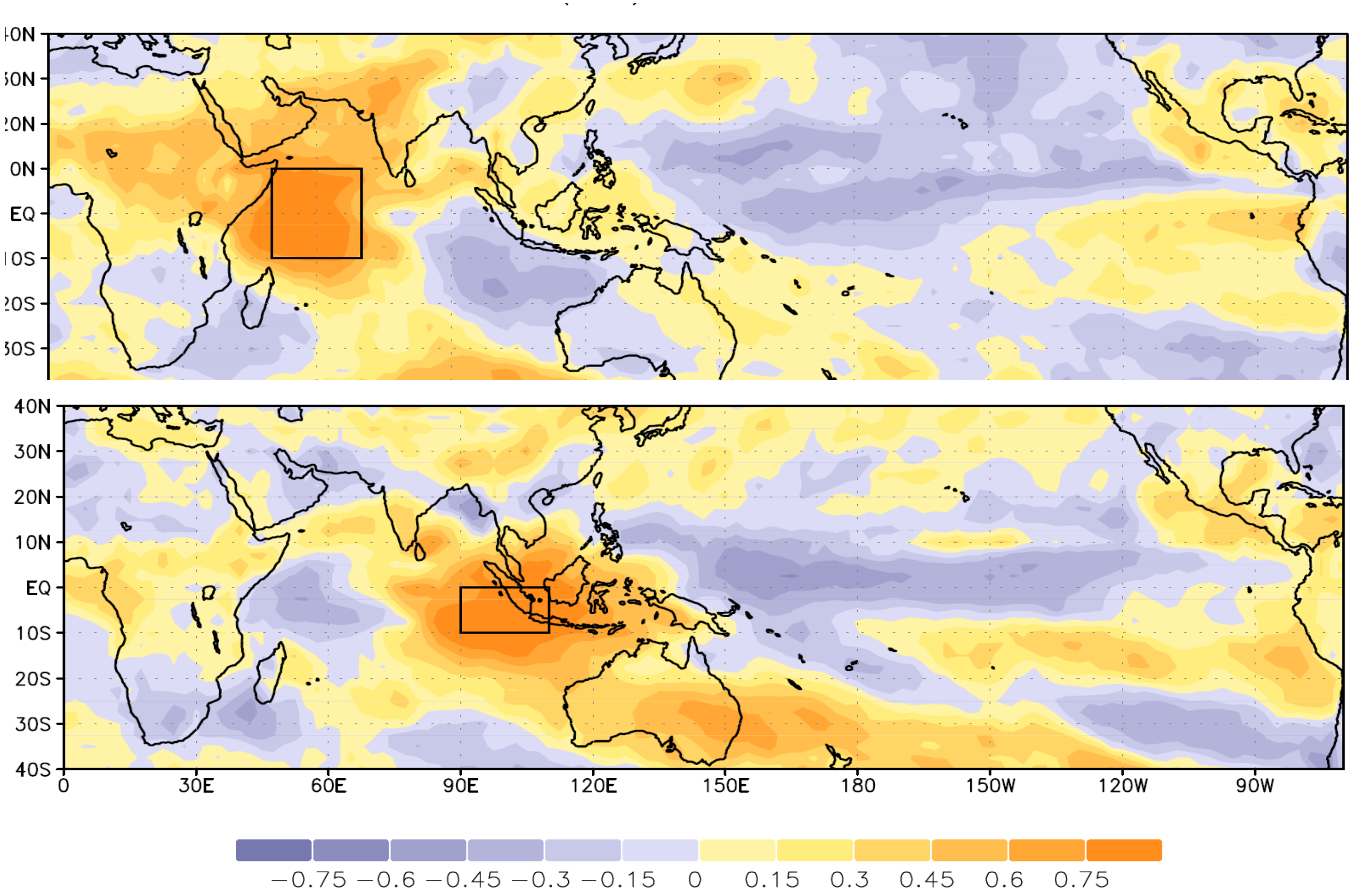
Competition between convection over EEIO and WEIO

The OLR over WEIO (EEIO) is negatively correlated with OLR of EEIO (WEIO) on daily, monthly and seasonal scales because there is a competition between the convection over these regions, with the convection being enhanced (suppressed) over the WEIO (EEIO), when it is suppressed (enhanced) over the EEIO (WEIO) the region.

Corr of JJAS OLR

With WEIO (OLR)

With EEIO (OLR)



Hence if convection over one of these regions is suppressed by some factor, that over the other region gets enhanced.

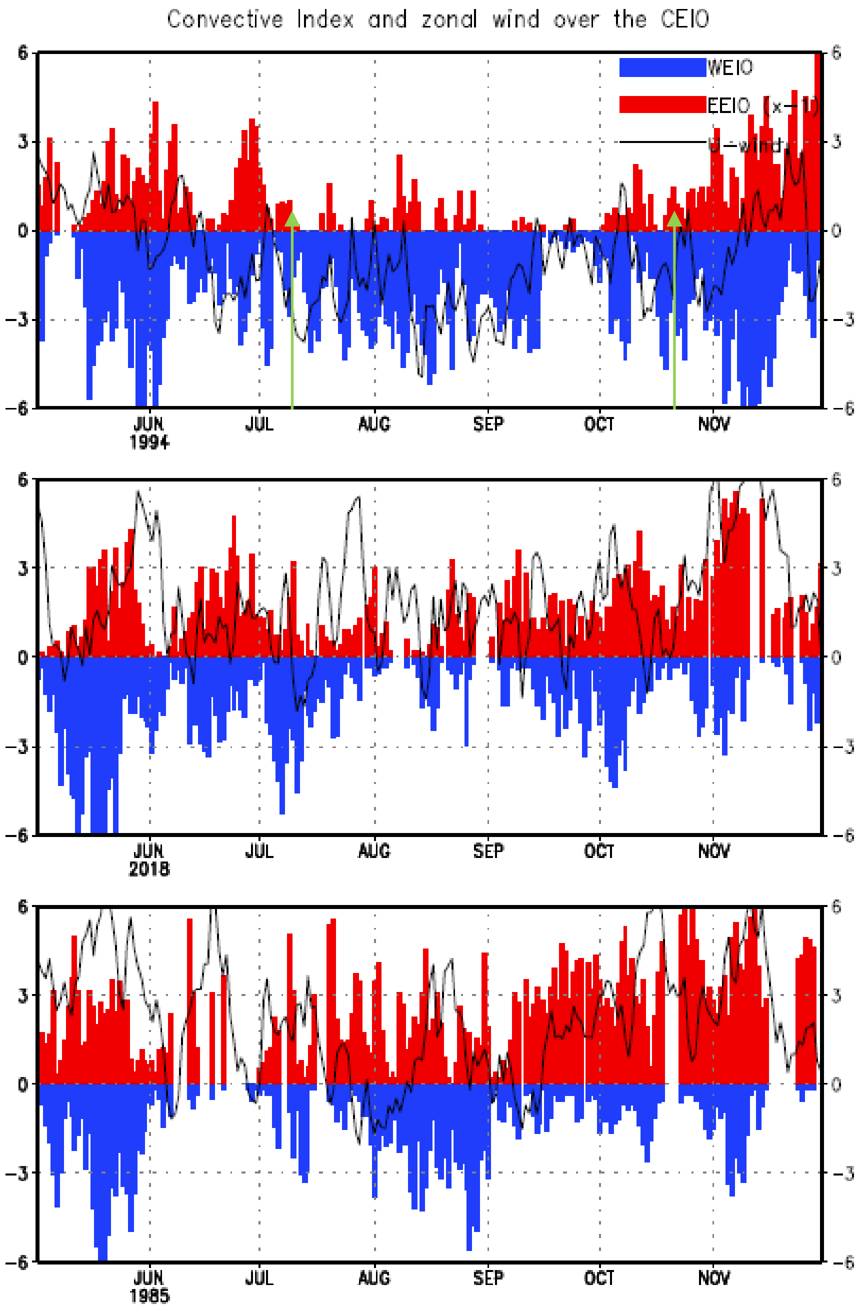
It should be noted that even when the monthly OLR is lower over EEIO, convection does occur on some days over WEIO, provided the SST is above the threshold; the lower OLR of EEIO arises from higher propensity of convection over EEIO.

A useful measure of convection over a region such as WEIO or EEIO on the daily scale is

CI= Sum of (200Wm^{-2}-OLR) over all the grids for which OLR<200Wm^{-2}

CI is thus a measure of the area over which the convection occurs as well as its intensity

Positive EQUINOO in association with pIOD event 1994



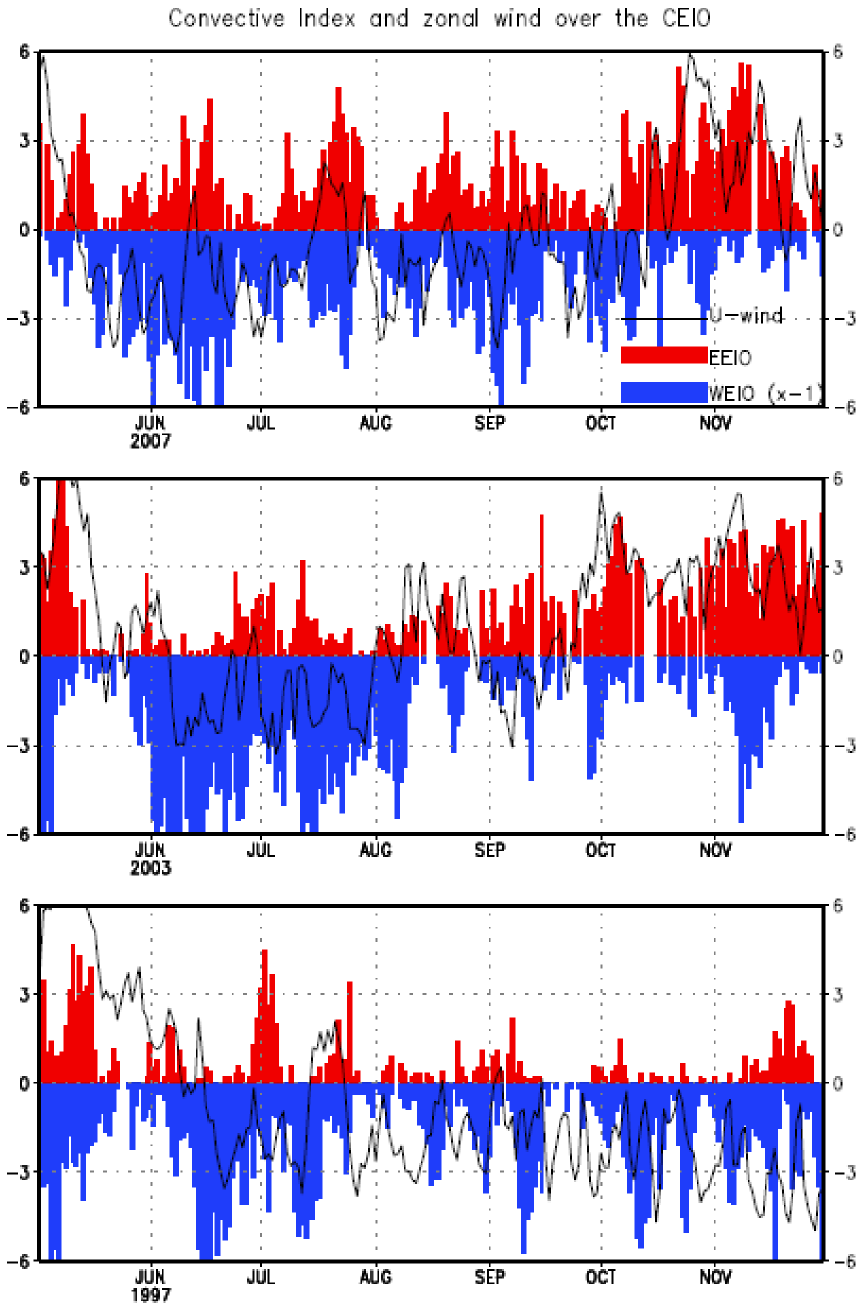
Convection over EEIO suppressed continuously from mid July to mid-October. Wind over CEIO easterly from June-October

2018: EQUINOO for JJAS close to zero: Neutral case

Convection over EEIO as well as WEIO intermittently/ Wind primarily westerly varying in magnitude

Negative EQUINOO

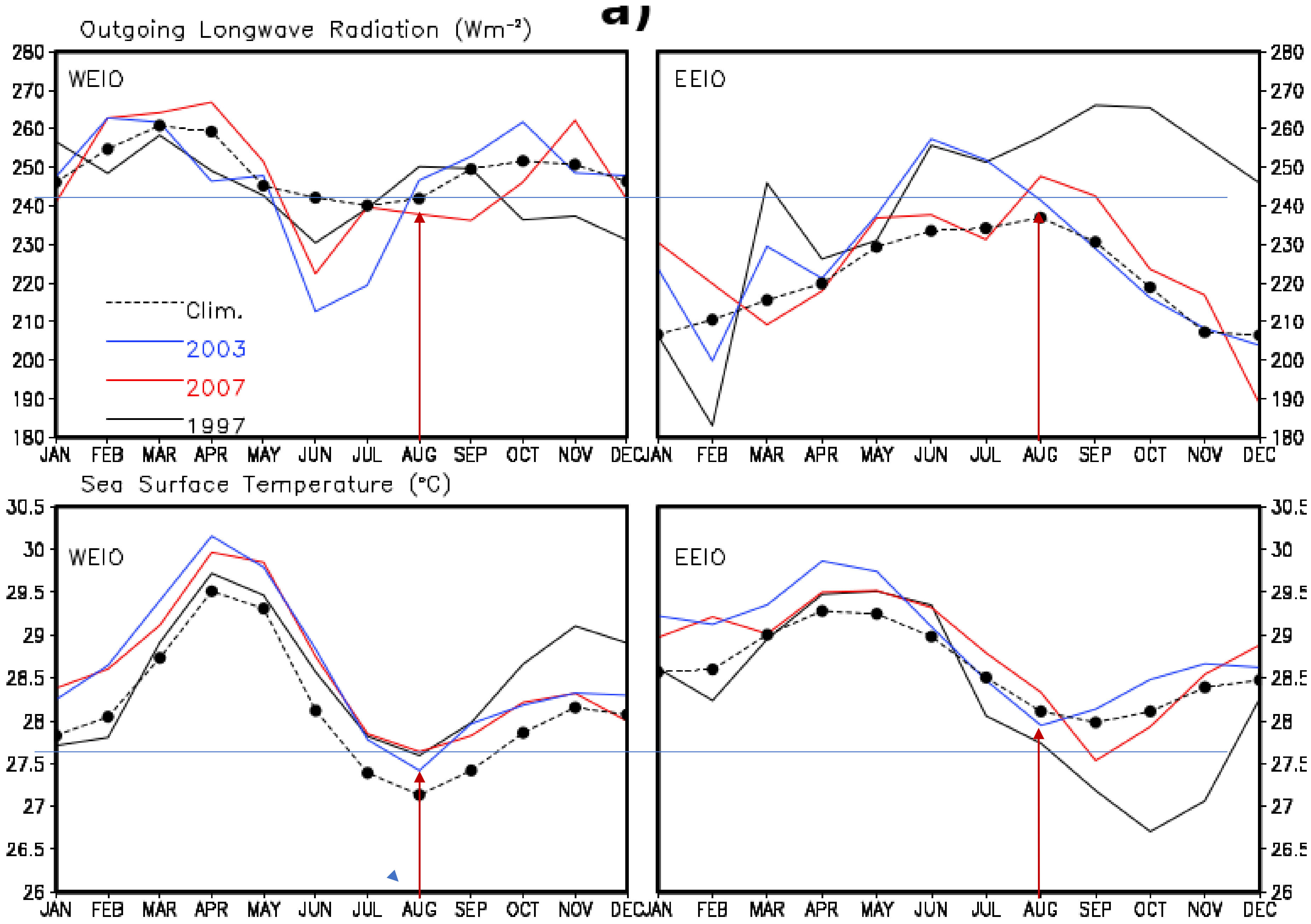
Convection over EEIO sustained, Wind almost always westerly varying in magnitude



2007: positive phase throughout the season

2003: positive phase only June to early August

1997: positive throughout the season: pIOD event



In June-July 2003
SST of WEIO and EEIO above 27.5C but OLR of WEIO much lower than 240 while that of EEIO above 240.
Aug 2003:
WEIO: SST<thresh OLR>240;EEIO: SST continues warm and OLR of EEIO goes below 240:abortion of the positive phase

In 2007 for WEIO
SST> 27.5 and OLR <240 throughout
For EEIO SST> 27.5, except Sept. OLR a little bit >240 only in Aug, Sept

Genesis

- Genesis of the positive phase of EQUINOO involves suppression of convection over EEIO, enhancement of convection over the WEIO and associated changes in the circulation pattern.
- Francis et al (2007) had shown that all the positive IOD events in the period 1982-2004 are preceded by the occurrence of a severe cyclone over the Bay of Bengal during April/May.

Proposed Mechanism:

- The strong convection over the Bay associated with the severe cyclones suppresses convection over the EEIO, which leads to enhancement of convection over the WEIO.
- Associated with this, equatorial wind anomalies become easterlies, enhancing the convergence over the WEIO.

- **Further, intense meridional pressure gradient in the eastern part of the Indian Ocean can intensify the upwelling favourable alongshore winds off the west coast of Sumatra, leading to cooling of EEIO and a weakening of the eastward SST gradient.**

FEEDBACK

- **Weakening of eastward gradients in convection and SST across the equatorial Indian Ocean in the summer monsoon lead to weaker westerlies. Associated with this, equatorial wind anomalies become easterlies, enhancing the convergence over the WEIO. This feedback can further enhance the convection over the WEIO and keep the EEIO convection suppressed, leading to the initiation of a positive EQUINOO with easterly anomalies over the central equatorial Ocean.**

- **The cyclones are relatively short lived and the suppression of convection over the EEIO associated with these cyclones does not last for more than a few days.**
- **However, with the establishment of convection over WEIO and associated positive atmospheric feedback, convection over the EEIO can remain suppressed for several weeks over the EEIO leading to a positive phase of the EQUINOO so that the conditions favourable for development of the positive IOD continue for a longer period.**
- **We believe this is the mechanism for sustenance of the positive phase of EQUINOO in June and July 2003 and 2008.**
- **How could the positive phase be sustained in the latter part of the season in 2007?**

What led to the termination of the positive phase in 2003?

- **Air-sea fluxes is the primary factor determining the SST of WEIO (Vinayachandran, Deep Sea Res.). So with development of convection SST decreases rapidly from May to August climatologically.**
- **With enhanced convection in 2003, SST of WEIO decreased more rapidly and went below the threshold in August and convection was suppressed thereafter.**
- **SST of EEIO also decreased but the SST anomaly was close to zero during June-August and EEIO remained warmer than WEIO.**
- **Convection over EEIO was suppressed during June-July, but with suppression of convection over WEIO in August, it flared up and the positive EQUINOO phase was aborted.**
- **This did not happen in 2007 as the SST of WEIO never crossed the threshold.**

- **There was prolonged convection over the WEIO in 2007 from mid-May to end of September, despite there being no strong positive IOD event. Even though there was intense convection, SST anomalies of WEIO remained positive and SST remained higher than 27.5 C throughout the season. This was associated with deeper than normal isothermal layers in the WEIO.**

- **Effy et al *(personal communication, 2019)* have shown that higher mixed layer temperature of WEIO during June/July 2007 was maintained as a result of less efficient vertical processes. They showed that this was due to the deepening of isothermal layers with the arrival of two downwelling Rossby waves from the EEIO; one as a direct response of easterly wind burst and another reflected from the eastern boundary when the downwelling Kelvin wave (triggered by the westerly wind burst in the first half of April) encountered the eastern boundary.**

Summer Monsoon 2019

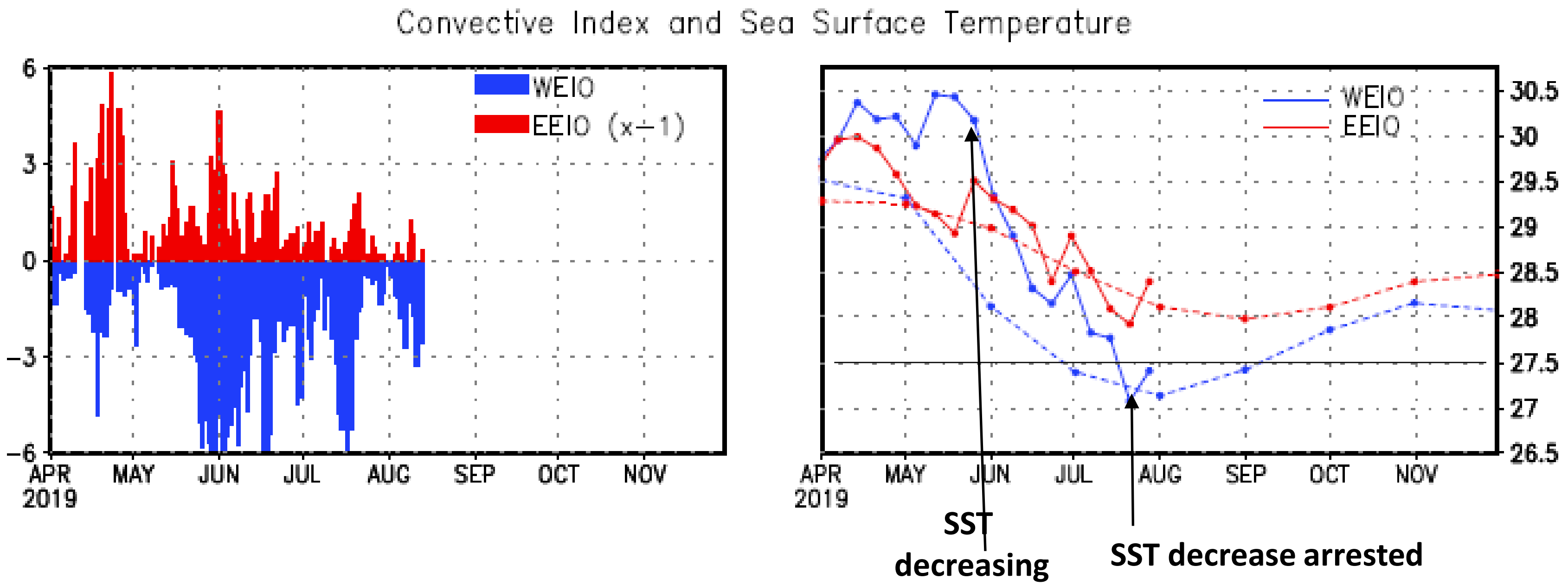
The convection over EEIO first got suppressed with the very severe cyclone 'Fani', over the Bay in early May, and remained subdued until last week of June and was even further suppressed in July while convection over WEIO increased in June and was sustained until end of July.

In addition to the active convection over WEIO, the El Nino also must have contributed towards suppression of convection over EEIO. From June to mid-July, SST of EEIO was slightly higher than that of WEIO but both were above the threshold, so clearly dynamical factors played a role in suppressing convection of OLR of EEIO.

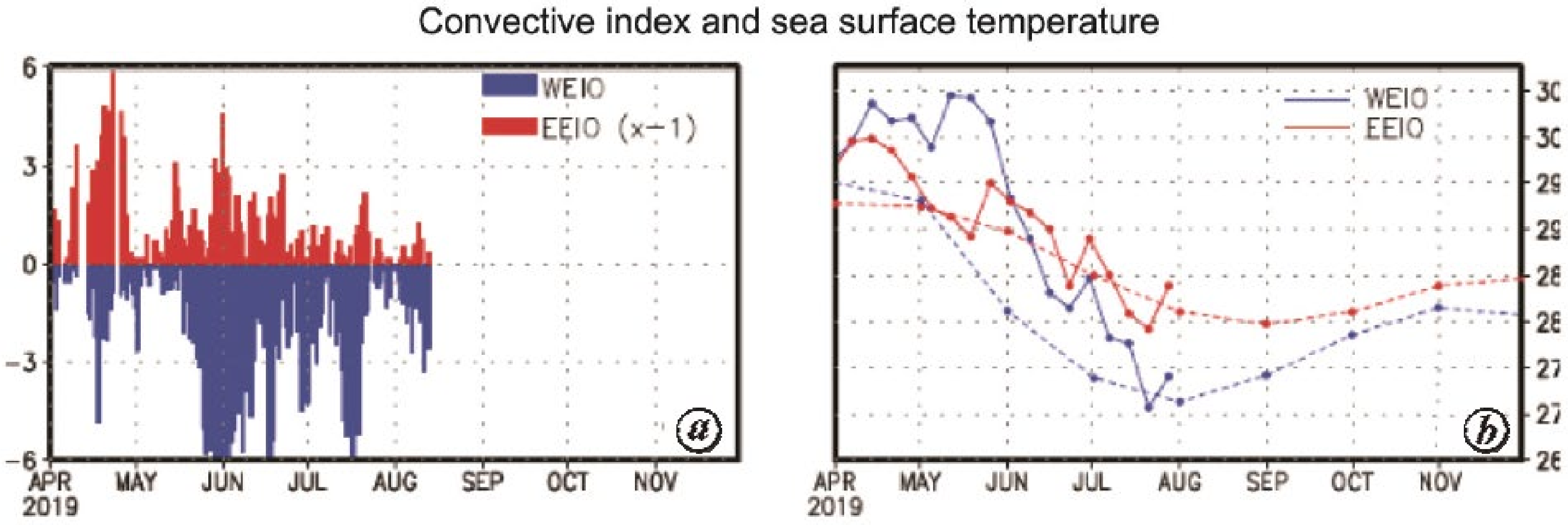
During June-July when the convection was sustained over WEIO, the SST decreased rapidly. However, this decrease was arrested towards end of July and the SST began to increase again (lack of convection?).

Summer Monsoon 2019

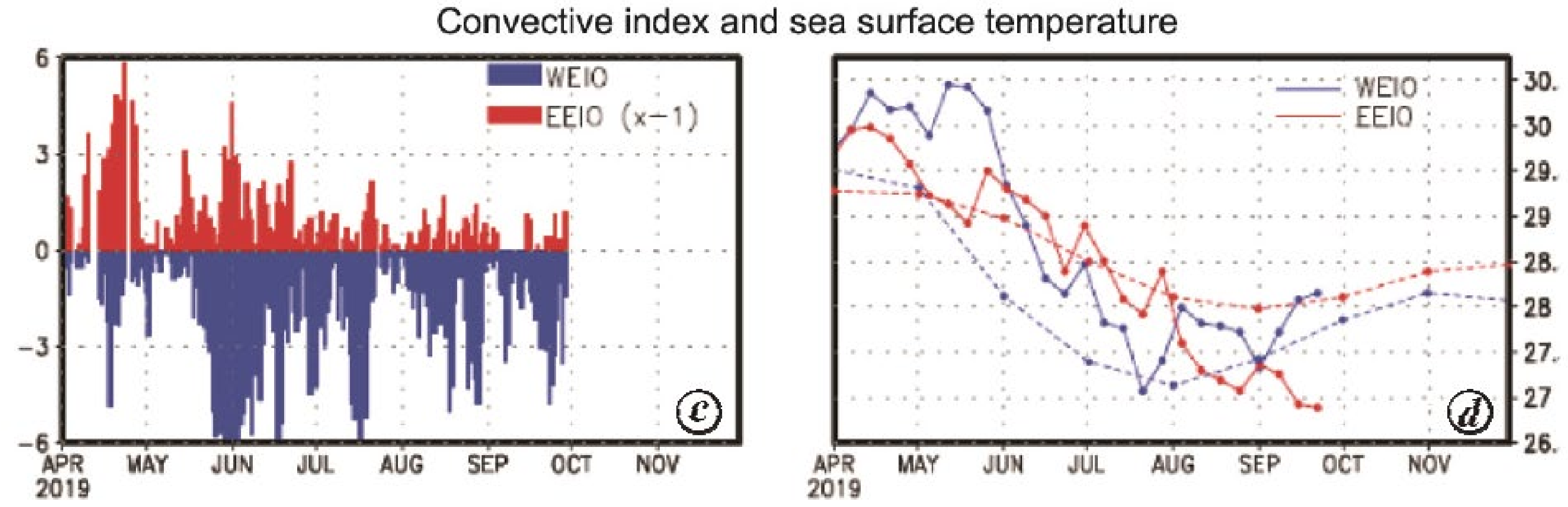
In the paper



Summer Monsoon 2019: validation of educated guess



In the paper



By September

Challenges ahead for prediction of the interannual variation of the monsoon

Major success story of atmospheric and oceanic sciences towards the end of the 20th century:

Understanding the ENSO phenomenon and development of models which can predict it.

At present there is reasonable skill in predicting the El Nino Southern Oscillation over the Pacific.
However, very few models can simulate the phase of the EQUINOO and almost no model can simulate the link of EQUINOO to the monsoon.

Need deeper understanding: Suggestions

Run atmospheric models with observed SST, ocean models with observed atmospheric conditions and simple coupled systems

Thank you