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Climate Predictability
Part III: Variability of Summer Mean Indian Monsoon Rainfall: Relationship to Circulation and SST

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Climate Predictability

Part I: Predictability of Seasonal Means:

An Introduction to the Role of Boundary Forcing

Part II: The mid-latitude response to tropical Pacific SST:

ENSO forcing of the Pacific / North American region

(Mechanisms partly understood)

Part III: Variability of Summer Mean Indian Monsoon Rainfall:

Relationship to Circulation and SST

Inter-Annual Variability of Mean Summer Indian Monsoon

(Straus, D. M. and V. Krishnamurthy, 2007: The Preferred Structure of the Interannual Indian MonsoonVariability, *Pure appl. geophys.* **164**, 1–16)

To study the variability of seasonal mean JJAS rainfall and circulation over as long a time period as possible requires a homogeneous observationa data set (no big changes in data coverage and quality over time).

- For rainfall, recent data has been made available by the Indian Institute of Tropical Meteorology - both gridded data over India and the all-India land average.

-For the circulation, reanalyses of NCEP or ECWMF are available

Goal is to find link between seasonal mean circulation and rainfall

Reanalysis: A single data assimilation system is used to convert all the archived historical observations (radiosondes, balloons, satellite data into consistent gridded states of the atmosphere.

NCEP Reanalysis: JJAS available from 1948 through 2003

Is it homogeneous in time? No, because available observational data coverage changes with time. *This is particularly true for the divergent component of the horizontal flow. Why?*

Definition of divergent and rotational component of the horizontal flow:

$$
\begin{aligned}
\vec{v} &= \vec{v}_{div} + \vec{v}_{rot} \\
\vec{\nabla} \cdot \vec{v} &= \vec{\nabla} \cdot \vec{v}_{div} \\
\hat{k} \cdot (\vec{\nabla} \times \vec{v}) &= \hat{k} \cdot (\vec{\nabla} \times \vec{v}_{rot})
\end{aligned}
$$

The divergent component is hard to measure, for two (related) reasons:

(1) It is much smaller in magnitude than the rotational component

(2) It is linked to the (un-measurable) vertical velocity via the continuity equation:

$$\vec{\nabla} \cdot \vec{v}_{div} + \frac{\partial \omega}{\partial p} = 0$$

NCEP Reanalysis: JJAS available from 1948 through 2003

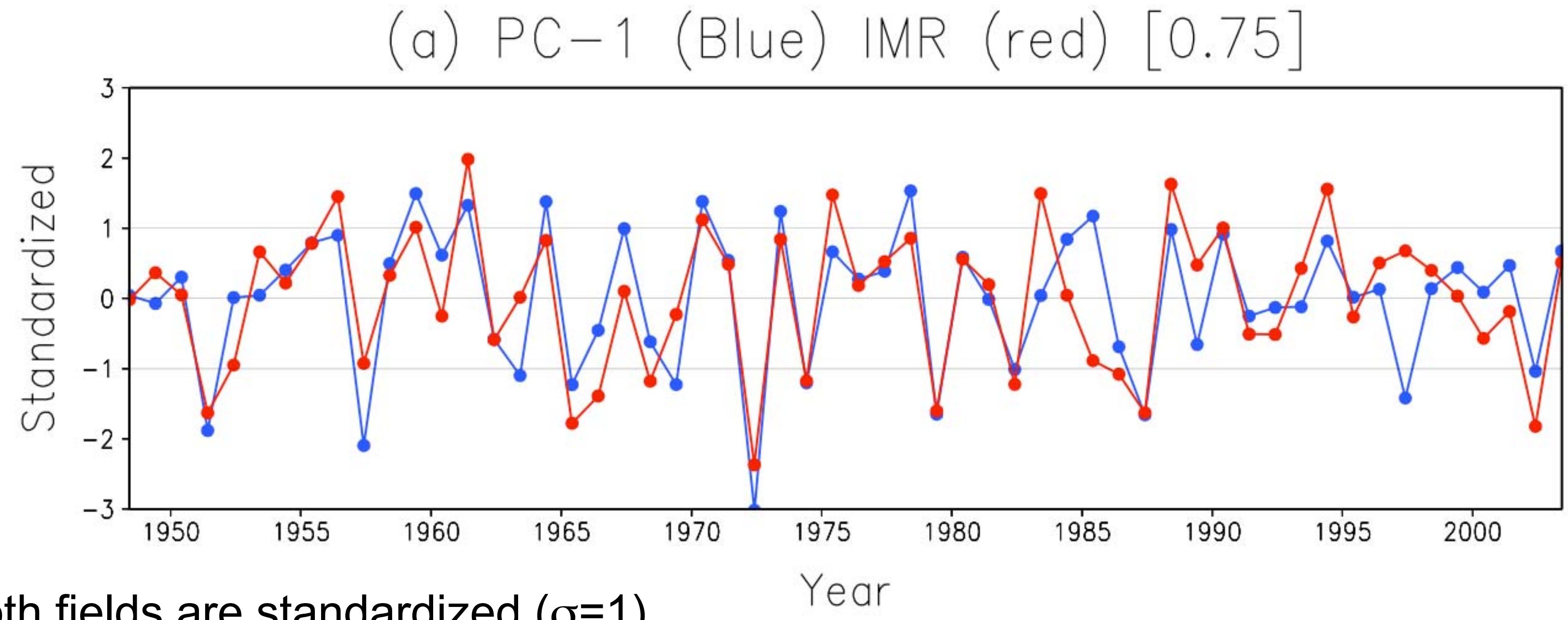
- Use only the rotational component of the seasonal mean winds

- Use both 850 hPa and 200 hPa flow in extended Indian region (tropical flow has generally large baroclinic component)

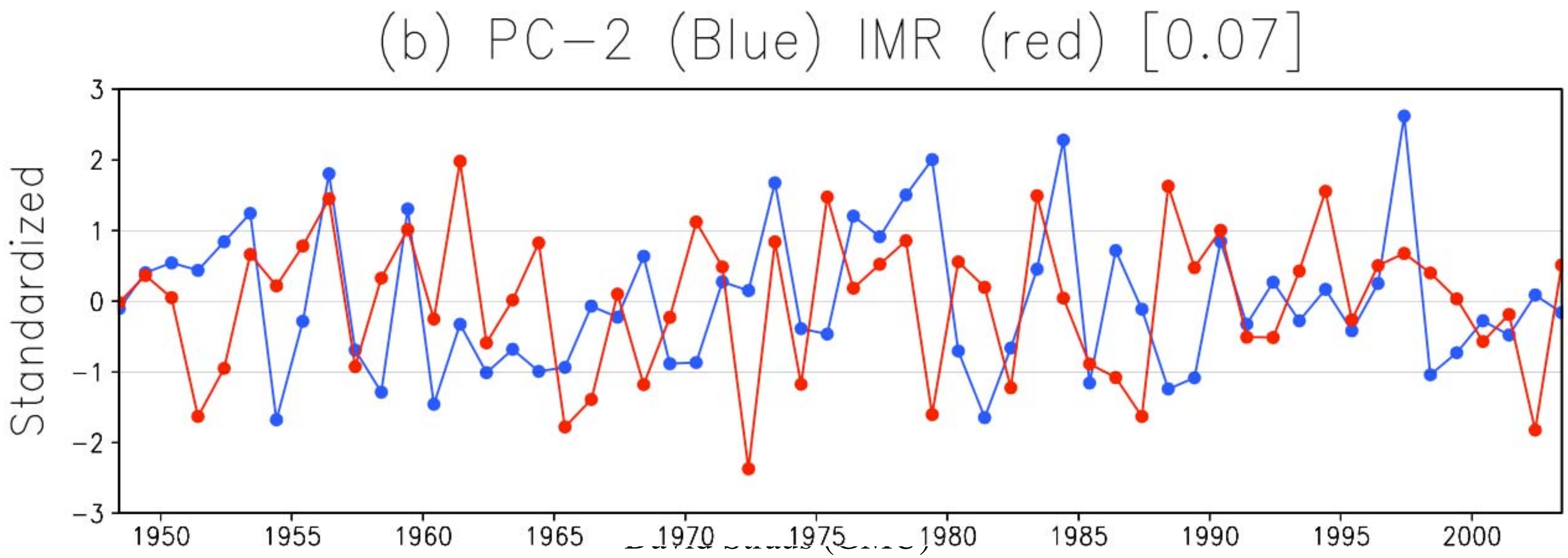
- Remove long-term trend in both seasonal mean rainfall and winds (2 fields with a long term trend will be correlated even if there is no physical connection)

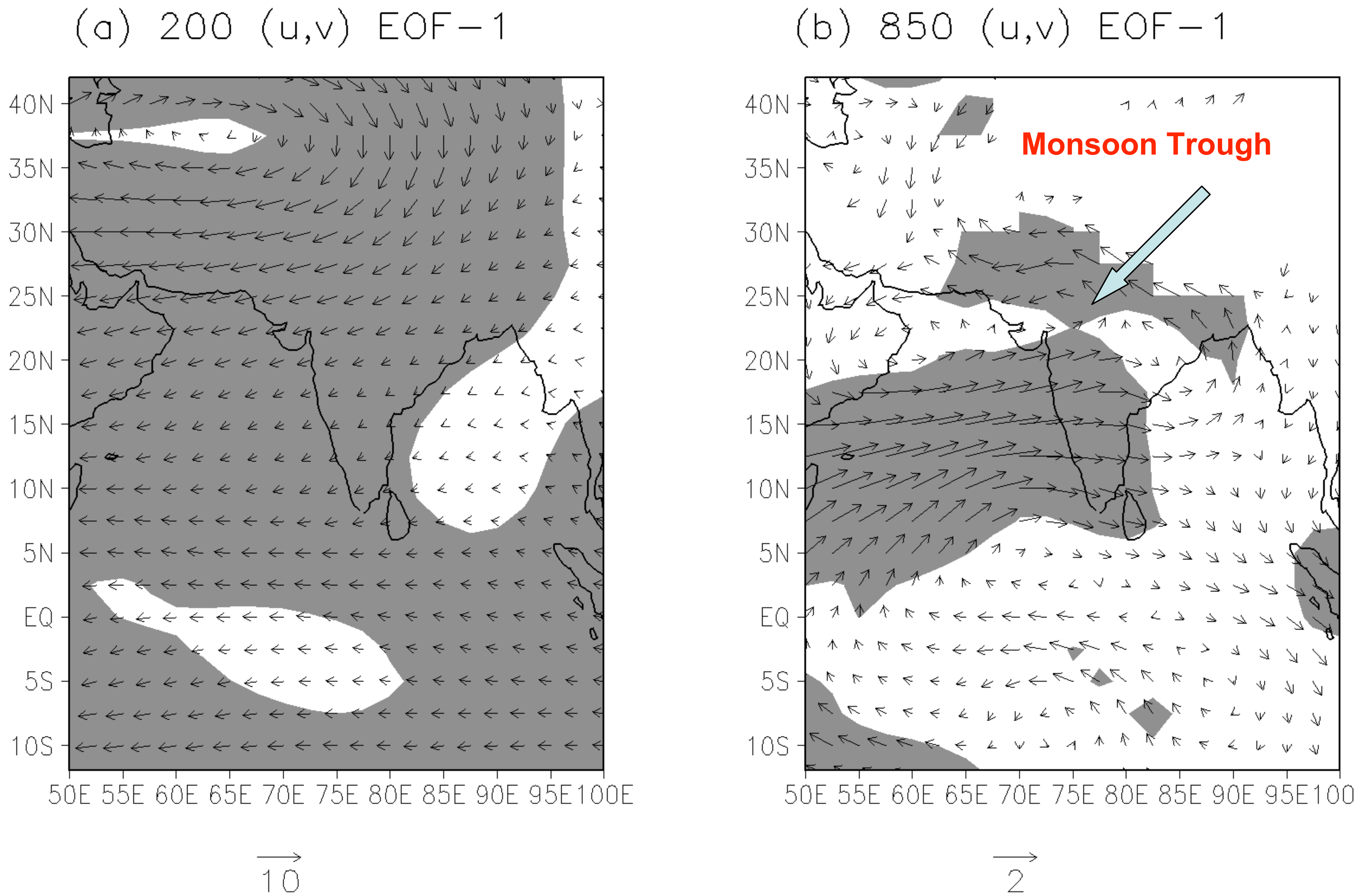
- Carry out a principal component analysis on both levels of winds together - that is the input field is the combined (u,v) at two levels. The percentage of explained variance of the first three modes is: 25%, 15%, 10%

Principal components of modes 1 and 2 (blue), along with all-India rainfall (red)

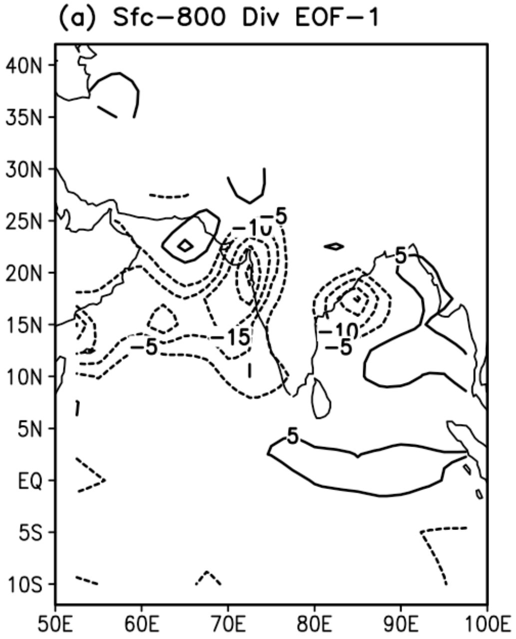


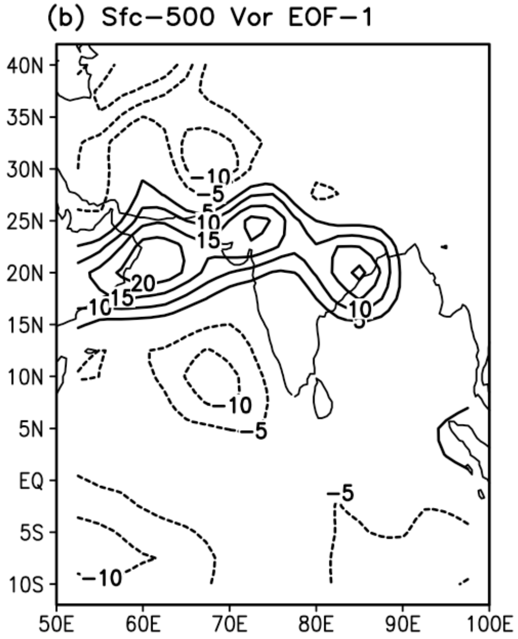
both fields are standardized (σ=1)

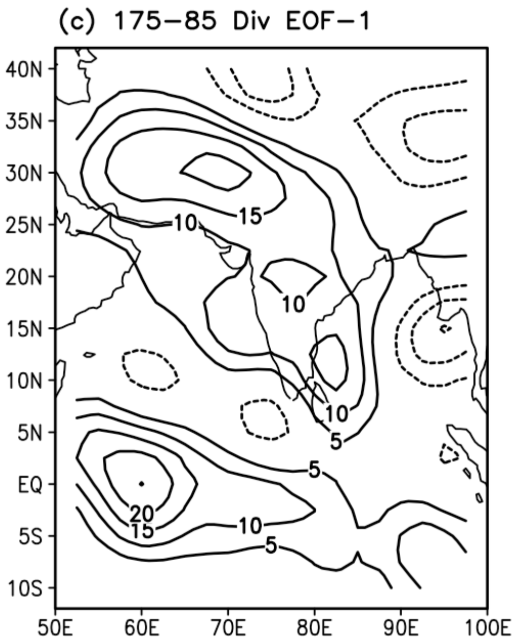




Composite differences of full horizontal winds for 200 hPa (a) and 850 hPa (b). Composite differences are defined as the difference between the mean of all (7) years for which PC-1 > σ and the mean of all (12) years for which PC-1 <- σ . Shading denotes 10% significance using a two-sided t-test. Reference vectors show the magnitude (in m/sec) in each case.





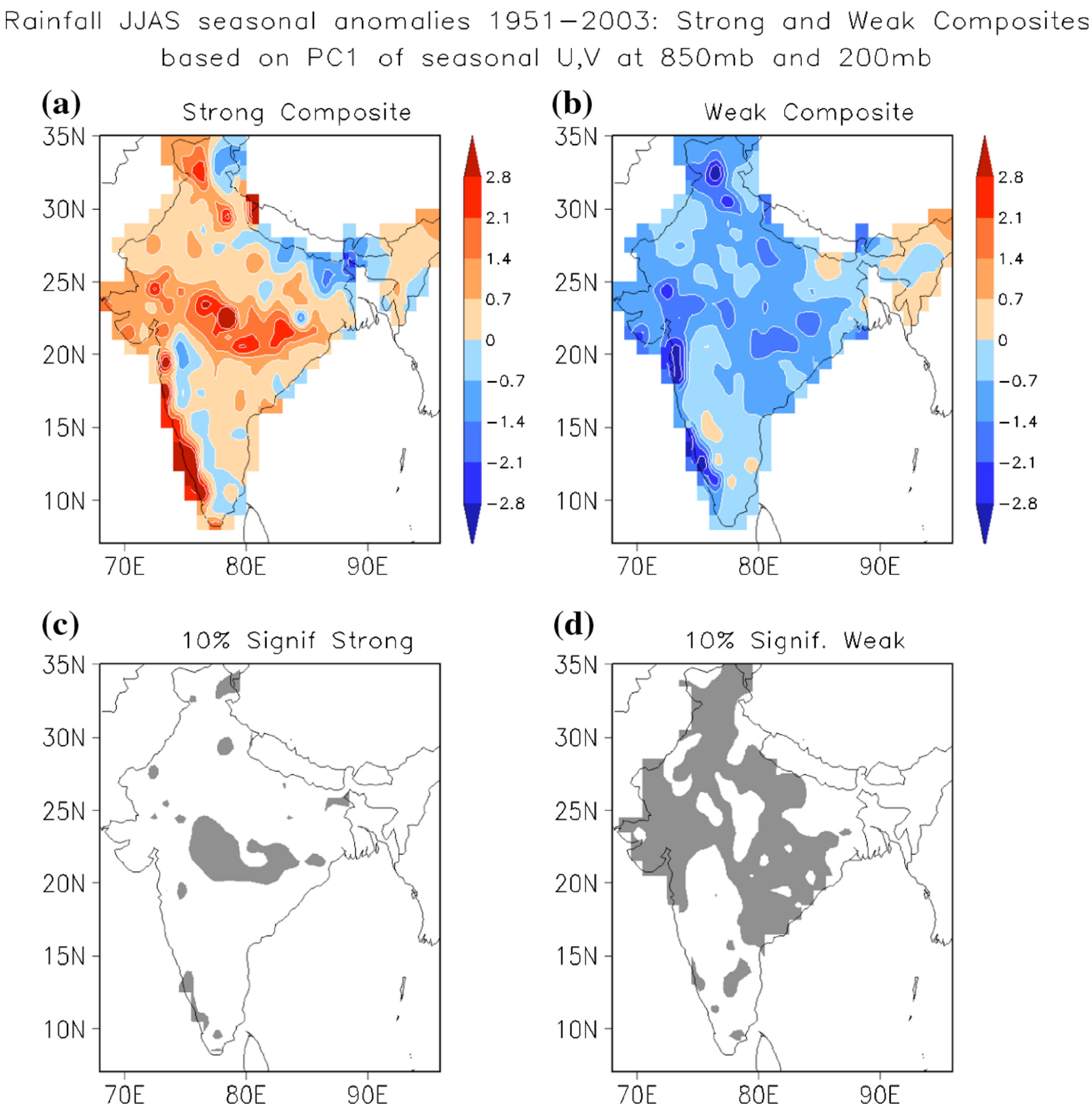


Composite differences of mass-weighted vertical integral of:
(a) Divergence (from the surface to 800 hPa),
(b) vorticity (from the surface to 500 hPa), (c) divergence (from 275–85 hPa).

Contour interval is 1.0 x 10^{-4} kg/(m^2 s) in (a) and (c), 1.0 x 10^{-3} kg/(m^2s) in (b). Zero contour omitted.

The time mean vorticity integrated over the lower half of the atmosphere is a measure of the presence of cyclonic monsoon disturbance.

Figure 2b suggests a storm path from the Bay of Bengal westward across India and into the Arabian Sea, consistent with the Monsoon trough seen at 850 hPa in the leading EOF, and consistent with the lower level divergence in Figure 2a. The upper level divergence suggests deep convection over the equator (which is confirmed by the vertical velocity composites, not shown), and the presence of upward motion over the higher elevations of Pakistan.

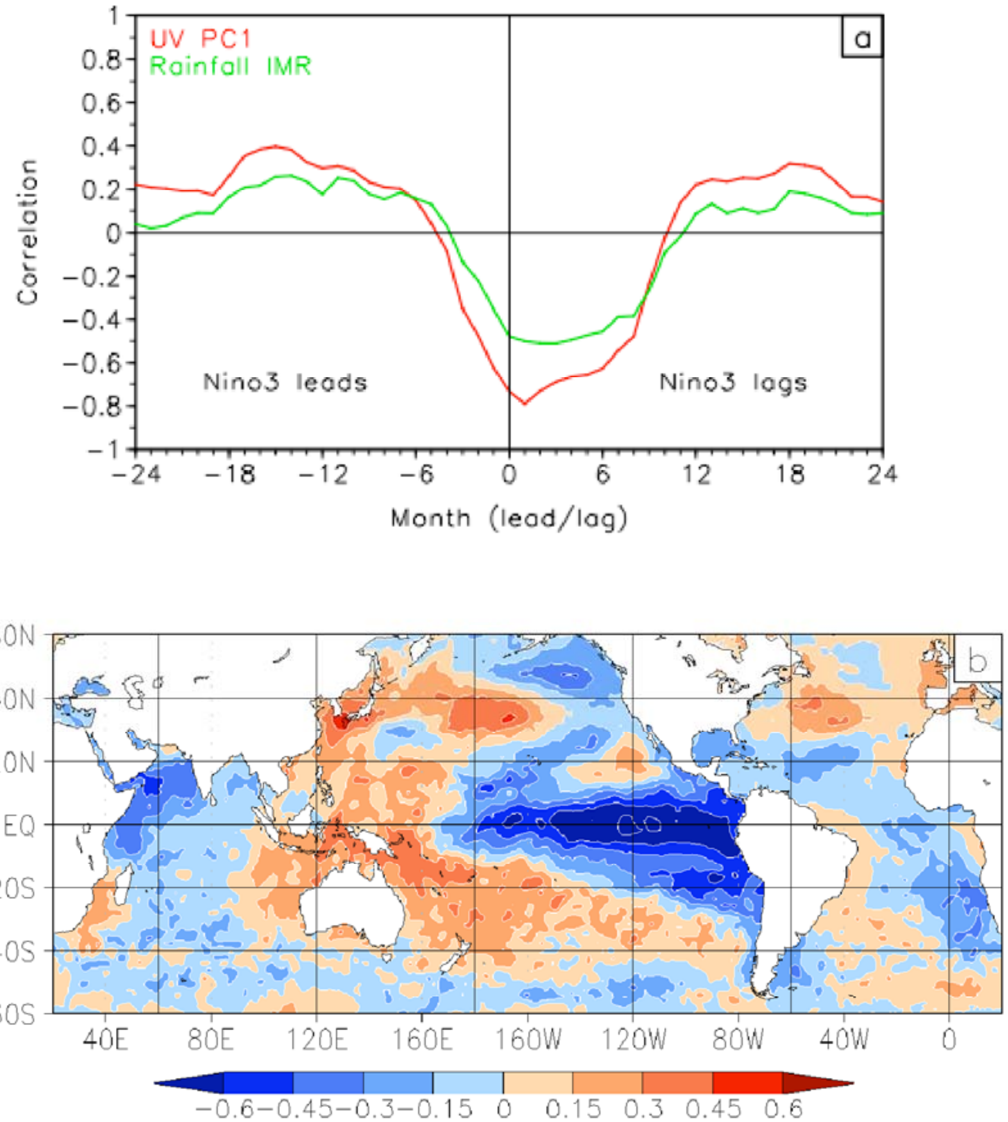


Rainfall JJAS seasonal anomalies 1951–2003: Strong and Weak Composites
based on PC1 of seasonal U,V at 850mb and 200mb
(a)
Strong Composite
(b)
Weak Composite
(c)
10% Signif Strong
(d)
10% Signif. Weak
35N
30N
25N
20N
15N
10N
70E
80E
90E
2.8
2.1
1.4
0.7
0
−0.7
−1.4
−2.1
−2.8

The strong composite shows enhanced rainfall along India (20N–25N), along the west coast, and to the north. The sign of the anomaly is generally the same over all of India. The weak composite shows generally reduced rainfall over the same regions, with the anomaly again being of predominantly one sign.

The structure of both composites is similar to the map of composite rainfall shown by KS, based entirely on the seasonal mean IMR for the extended period 1901–1970. The composite maps look quite different, however, from the difference map of intra-seasonal active phase composite and break phase composite rainfall anomalies shown by KS

(KS = KRISHNAMURTHY, V. and SHUKLA, J. (2000), Intraseasonal and interannual variability of rainfall over india, J. Climate 13, 4366–4377.


UV PC1
Rainfall IMR
a
Correlation
Nino3 leads
Nino3 lags
Month (lead/lag)
b
60N
40N
20N
EQ
20S
40S
60S
40E
80E
120E
160E
160W
120W
80W
40W
0
−0.6 −0.45 −0.3 −0.15 0 0.15 0.3 0.45 0.6

The association of the leading EOF with the global distribution of seasonal mean SST can be assessed from Figure 6b, which shows the point-wise temporal correlation of SST with PC-1. (A correlation of absolute value greater than 0.30 is significant at the 2% level.)

The familiar ENSO pattern is predominant in Figure 6b, along with a region of strong correlation in the Northwest Pacific. The significant negative correlation in the western Indian Ocean is indicative of two possible ways in which the atmosphere forces the ocean: (i) Strong monsoon winds lead to evaporative cooling, and (ii) the winds force enhanced coastal upwelling.

Webster – Yang	U850 – U200 (0–20N 40–110E)	0.52	1958–1995
Monsoon–Hadley	V850 – V200 (10–30N 70–110E)	0.64	1958–1995
Westerly Shear	U850 – U200 (5–20N 40–80E)	0.68	1958–1995
PC-1 (GM)	(U,V) 850 (20S–30N 40E–100E)	0.62	1958–1997
PC-4 (S)	(U,V) 850 (20S–40N 60–120E)	0.60	1958–1997
(this paper)	(Ur,Vr) 850, 200 (12S–42N 50–100E)	0.75	1948–2003

Monsoon Indices. Various monsoon indices and their correlation with IMR for JJAS seasonal means.

A. WEBSTER-YANG defined originally in Webster and Yang (1992); statistics above from WANG and FAN (1999).
B. Monsoon-Hadley defined originally in GOSWAMI et al. (1999); statistics above from WANG and FAN (1999).
C. Westerly shear defined by WANG and FAN (1999).
D. PC-1 from EOF analysis presented in GOSWAMI and AJAYA-MOHAN (2001).
E. PC-4 from EOF analysis presented in SPERBER et al. (2000)

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