CHANGING MONSOON INTRASEASONAL VARIABILITY AND ITS ASSOCIATION WITH EXTREME EVENTS OVER INDIA

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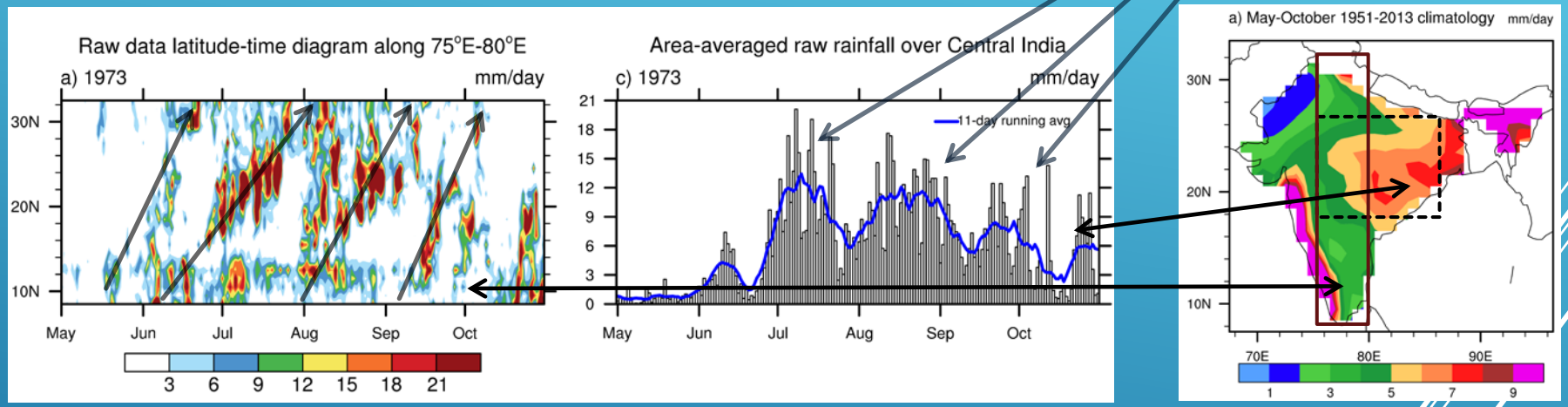
INTRASEASONAL VARIABILITY (ISV):

- ISV: Active (wet) and break (dry) episodes of enhanced and decreased precipitation over India.



- Broadband spectrum with periods between 10 and 90 days.
- Preferred periods of variability: 10-20 days and 30-60 days.
- **Intraseasonal oscillations (ISO):** the 'building blocks' of monsoon ISV (e.g. Goswami 2012).

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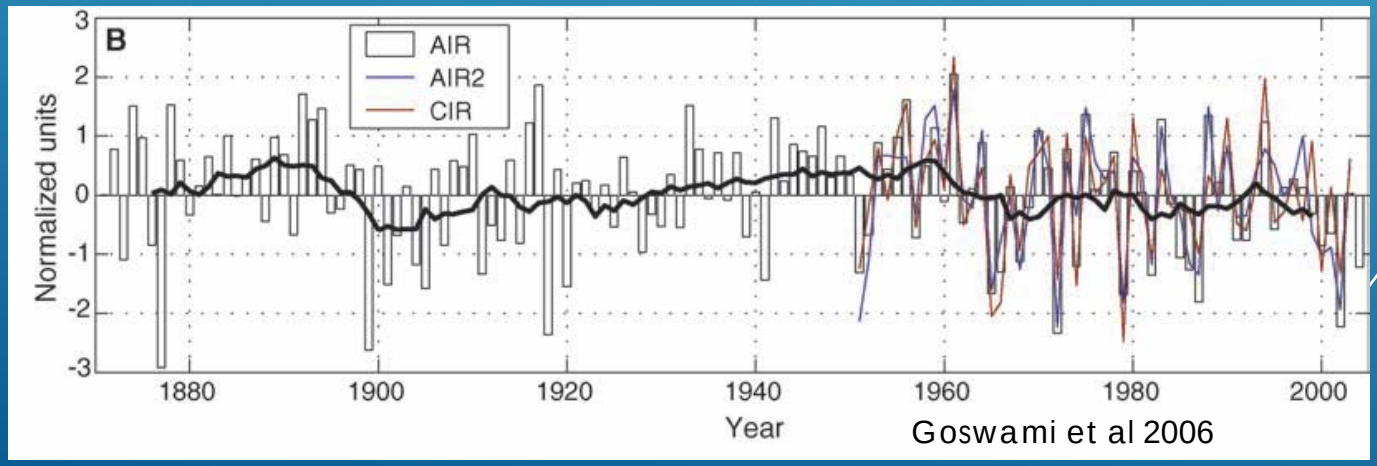
- ISV can have an impact on the seasonal total rainfall (Lawrence & Webster, 2001; Rajeevan et al 2010).
- Nature of ISV: predictability of seasonal mean Indian summer monsoon rainfall (ISMR) (Charney & Shukla 1981; Webster et al 1998).
- Higher ISV can lead to poorer predictability of seasonal mean (Waliser et al 2003).
- **Is there any change in intensity of monsoon ISV in the recent decades?**
- ISMR has not shown any long-term trend.



Goswami et al 2006

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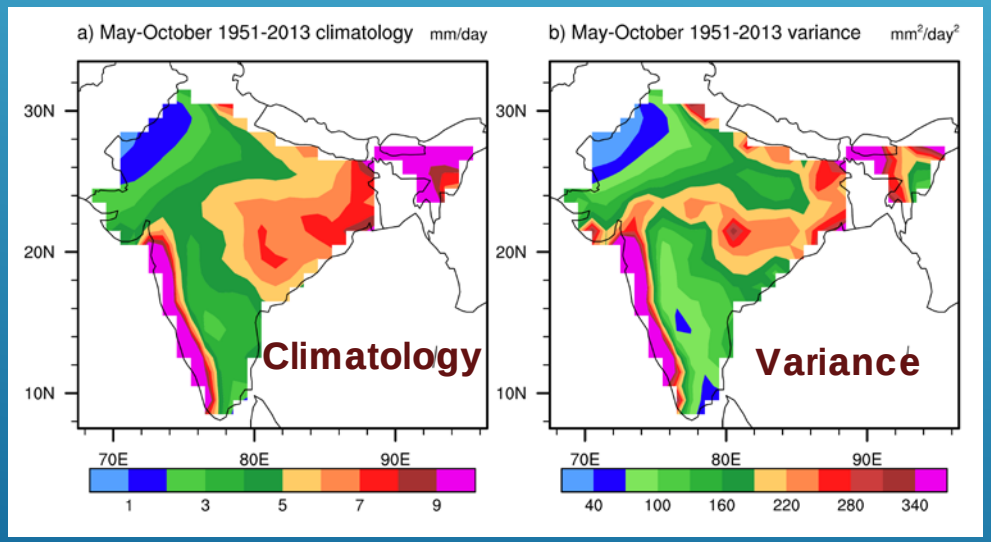
DATASET:

- We used daily gridded rainfall data (1º x 1º) over India for 1951-2013 from the India Meteorological Department (IMD) (Rajeevan et al 2006).
- This dataset is based on quality controlled daily rainfall measured at 2,140 stations, well distributed over India, and has been extensively used to understand monsoon behaviour.



- NCEP-NCAR reanalysis used for computing the wind shear and meridional temperature gradient over Indian region.

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EXTRACTING ISO MODES:

- Applied multichannel singular spectrum analysis (MSSA) to the May-October (184 days long) data over India for each year (Ghil et al 2002).
- MSSA is able to automatically identify oscillatory modes.
- Requires no detailed knowledge of individual subsystems nor a suitable phase definition for each of them.
- Extension of the familiar EOF analysis but includes temporal lags of spatial data to obtain space–time patterns of variability.
- Diagonalize the lag-covariance matrix. Obtain **ST-EOFs and ST-PCs: Describes space-time patterns**.
- **Eigenvalues → power in the modes.**

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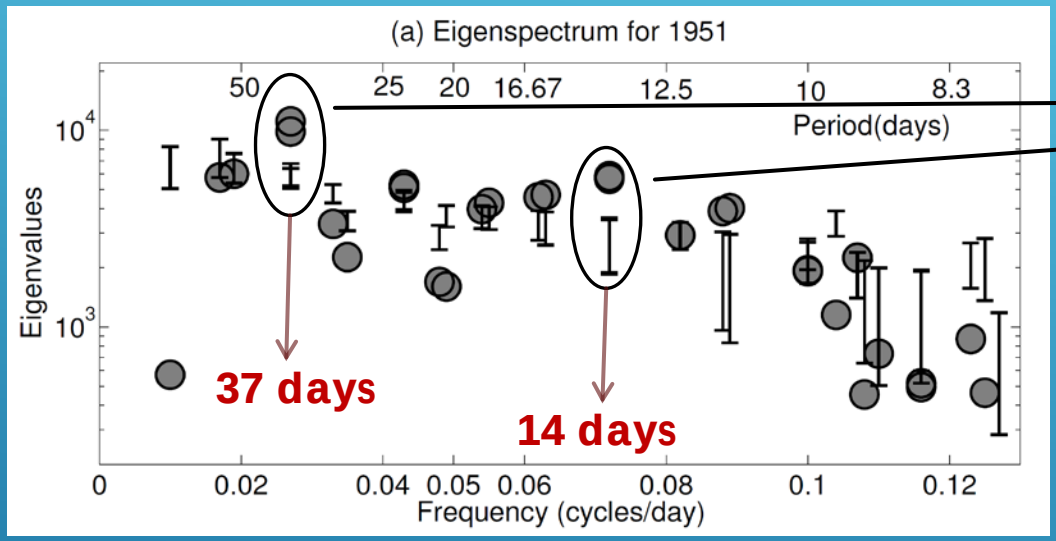
- Oscillation: Two consecutive ST-PCs with nearly equal eigenvalues are in phase quadrature.
- Several 'significant' oscillatory modes; periodicities within 10-60 days: Nature of broad spectrum in monsoon ISOs.



First two significant oscillatory pair

- Spatio-temporal characteristics of these 'significant' modes?
- Reconstruction of the part of the time series associated with a single mode (or several) is done by convolving the corresponding ST-PC with ST-EOF (and combining them).

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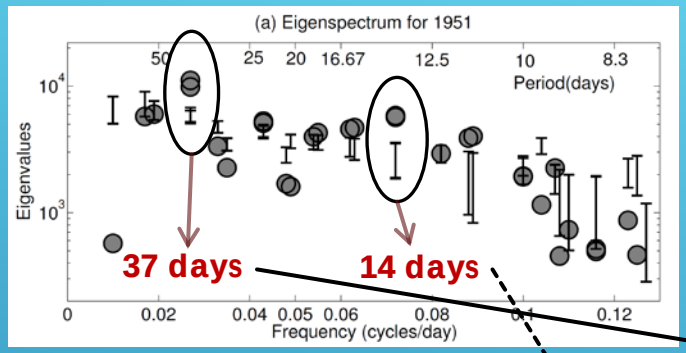
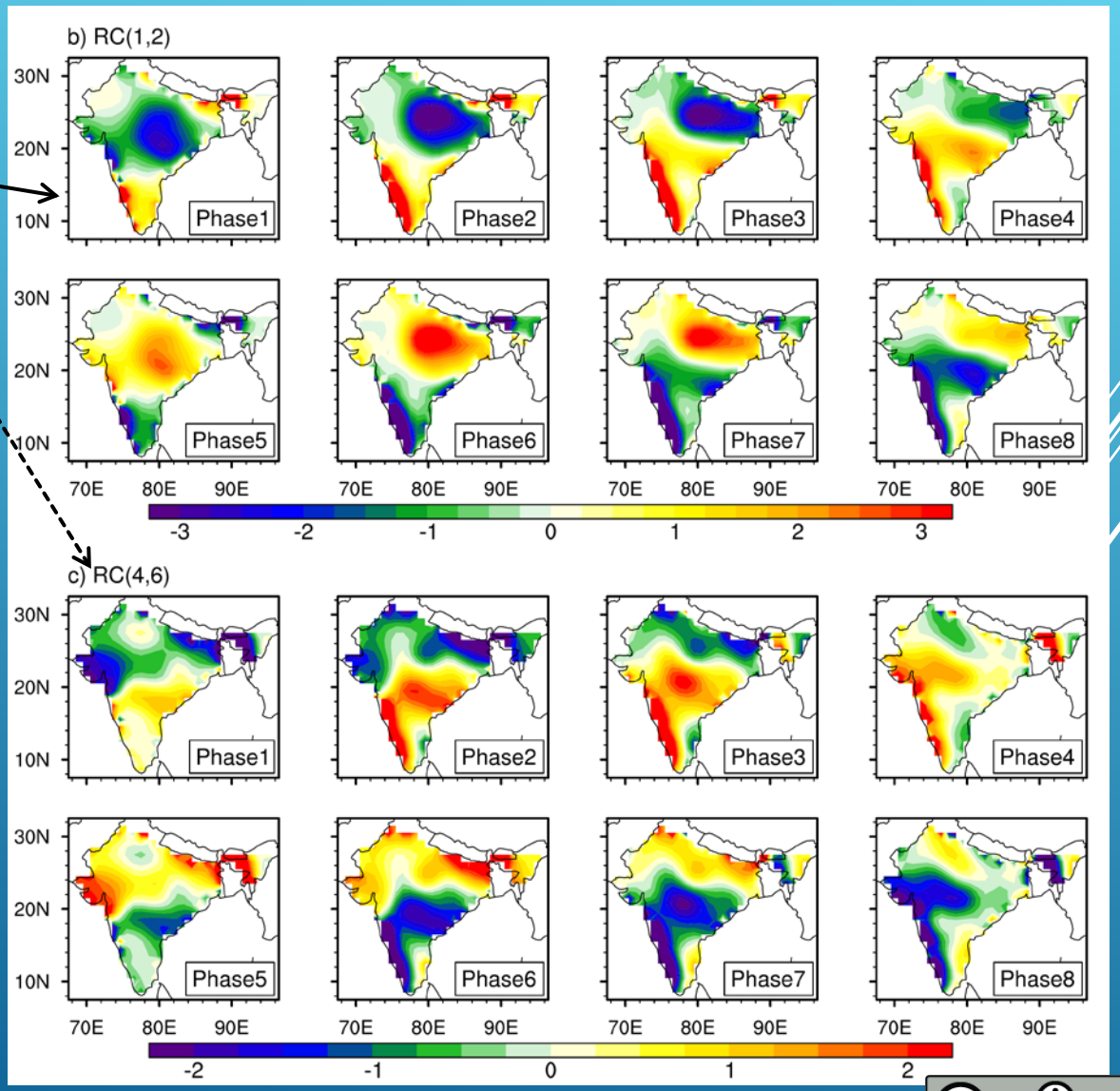
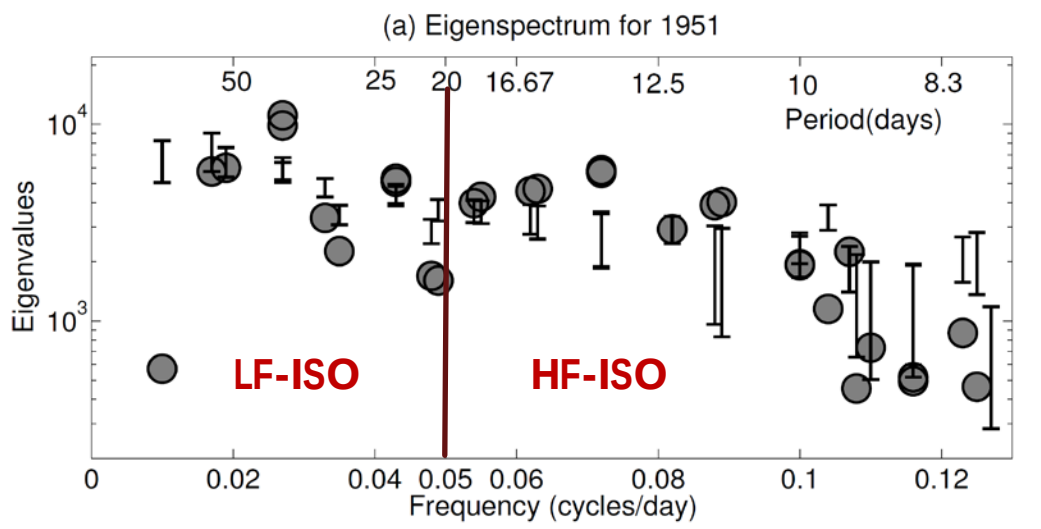


1951 as an example:

- Modes 1 and 2: Periodicities of 37 days. Replicates the typical active-break cycle.
- Modes 4 and 6: Periodicities of 14 days. North-westward propagation.





- Divide the significant oscillatory modes for each year into two scales: low- (20-60 days) and high-frequency (10-20 days) scale.
- Reconstructed parts associated with each low- and high-frequency intraseasonal scale: low-frequency ISO (LF-ISO) and high-frequency ISO (HF-ISO).
- The sums of the variances explained by the significant eigenmodes in low- and high-frequency scales represent the intensities of LF-ISO and HF-ISO.

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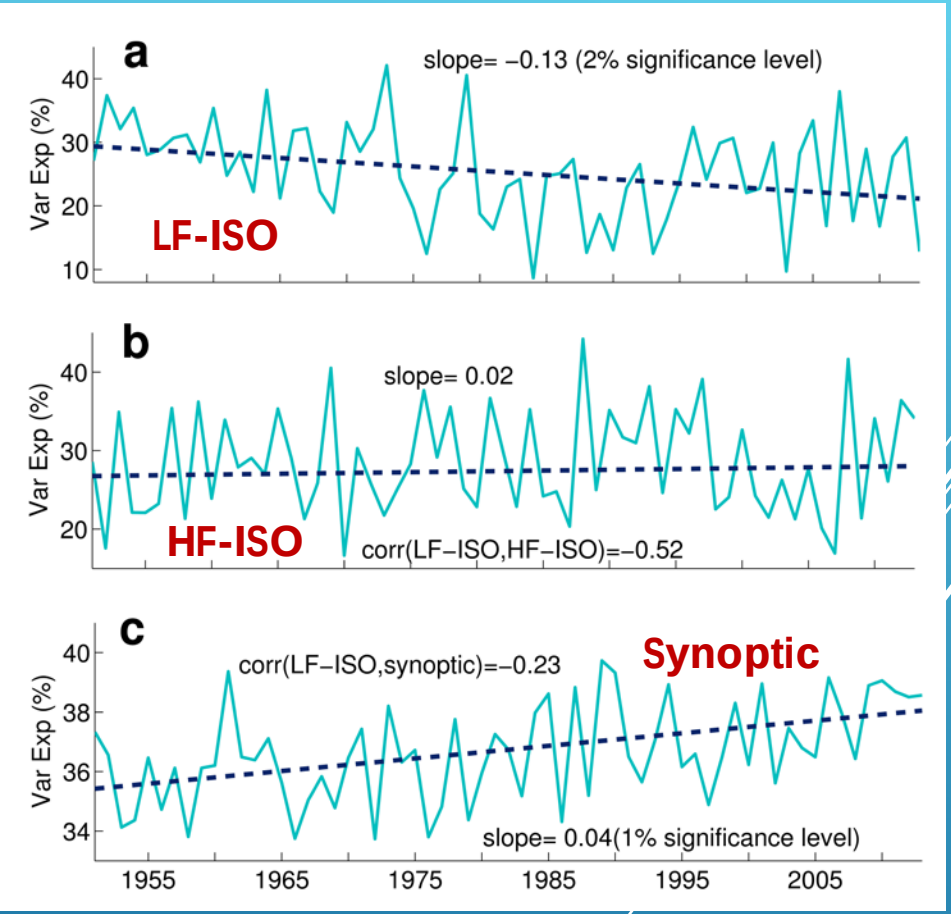
WEAKENING OF LOW-FREQUENCY ISO:

- A significant decreasing trend in the LF-ISO intensity with HF-ISO variance remaining almost constant for the entire time period.
- Increasing trend in synoptic-scale (3-9 days filtered) variability: rising trend in frequency of weak LPS in recent decades (Jadhav and Munot 2008; Ajaymohan et al 2010)



(a) LF-ISO, (b) HF-ISO, (c) Synoptic

Trends are evaluated using Theil-Sen estimator, and Mann-Kendall test is used to determine the significance of the trends.

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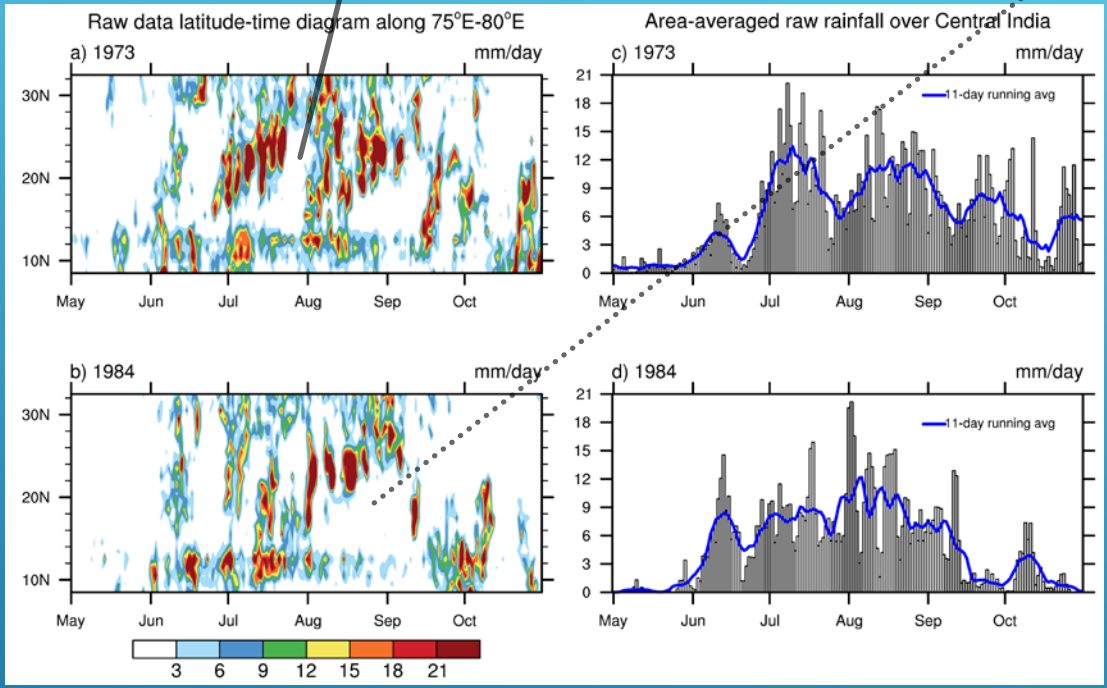
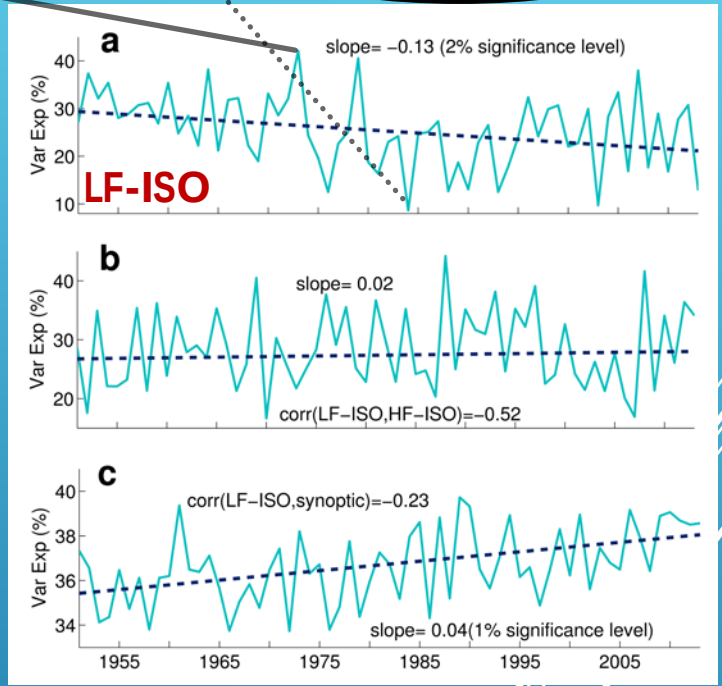
Strong LFISO features

Weak LFISO features

An index to calculate ISO intensity!!





- Amplitude and distribution of LF-ISO related rainfall strongly vary from year-to-year.
- Clear understanding of the causes behind this interannual changes in ISO intensity is not yet achieved, but is required for better prediction.

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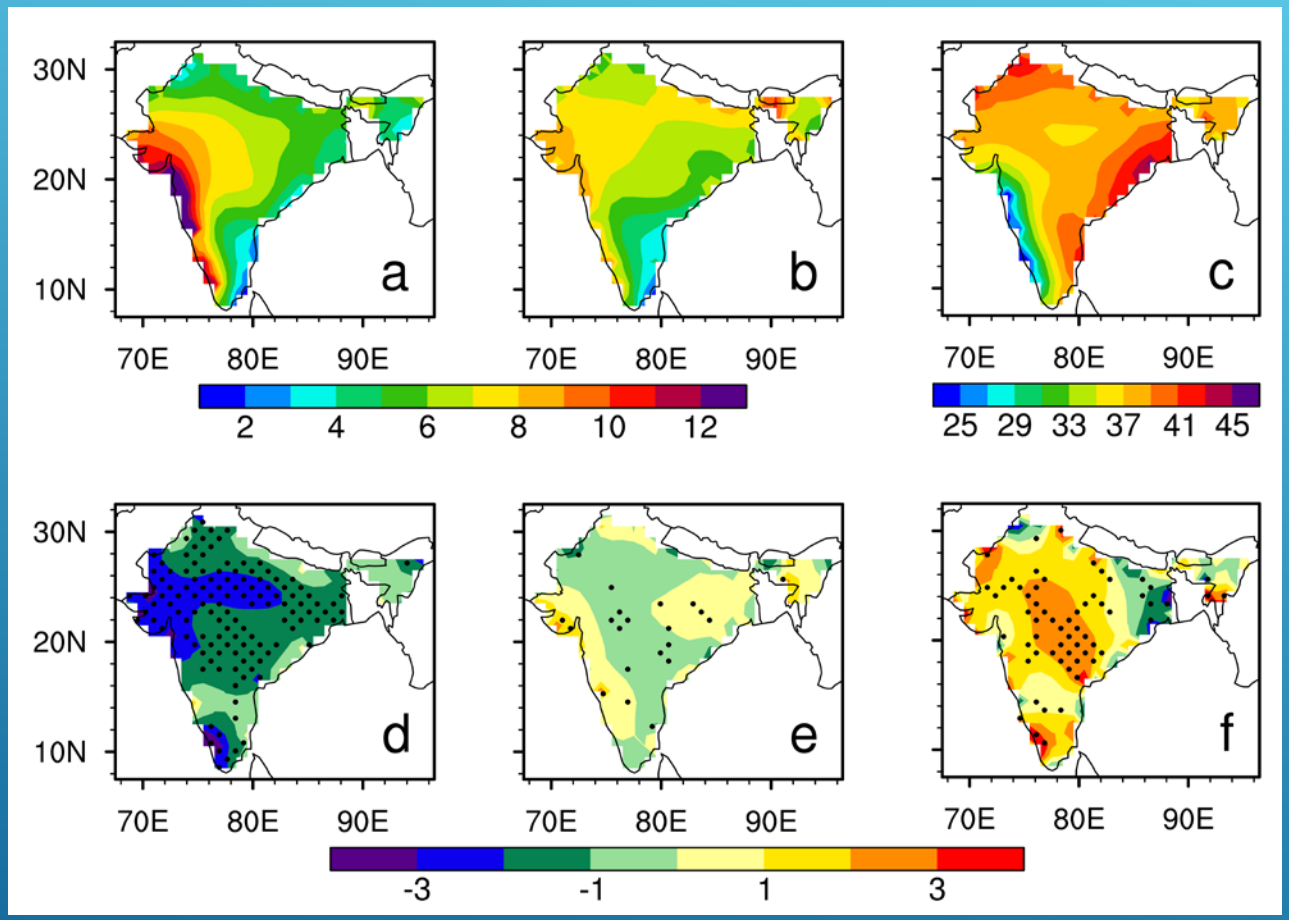
WHERE ARE THE CHANGES SEEN?:

LF-ISO **HF-ISO** **Synoptic**



For 1951-1980 period

Post-1980 minus pre-1980

Spatial distribution of the percentage of the total daily-variance explained (Stippling indicates regions where the null hypothesis of equal means in pre-1980 and post-1980 period can be rejected at 10% significance level.)

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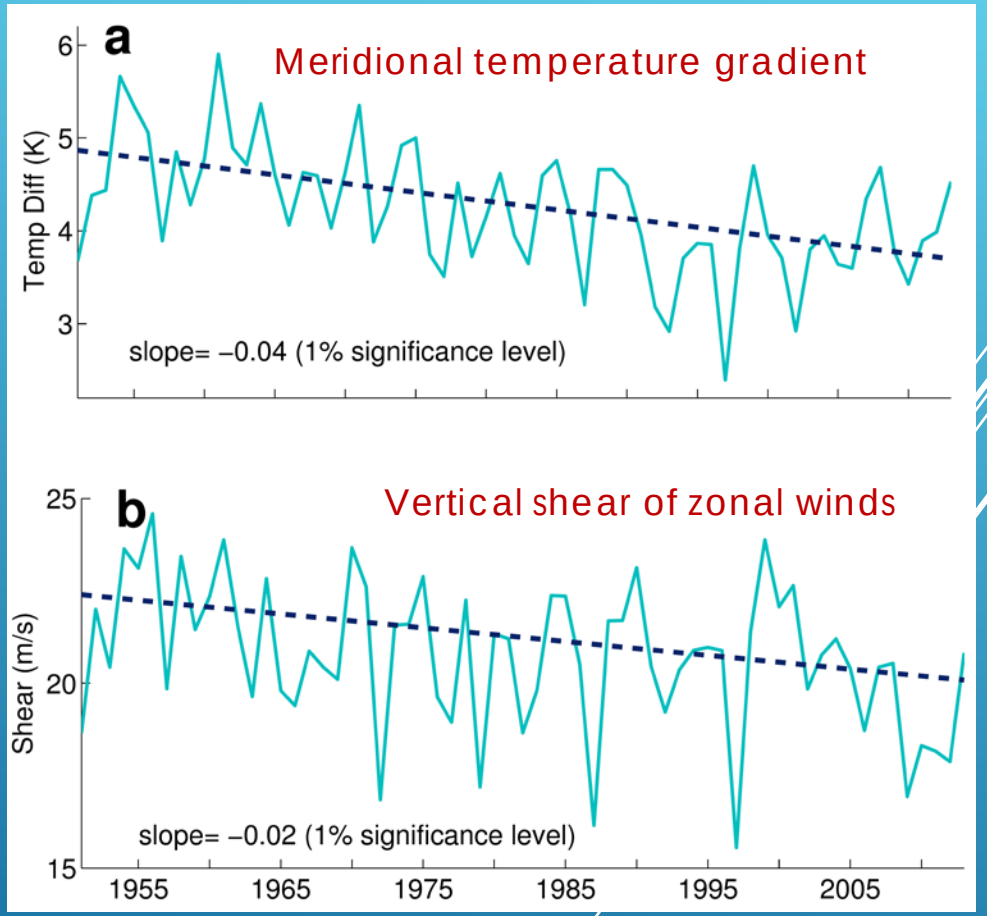
FACTORS?

- Decreasing trend of upper-tropospheric meridional temperature gradient over the monsoon region.
- Weakens the tropical easterly jet via thermal wind balance.
- Easterly shear plays an important role in northward propagation of convection (Jiang et al 2004).



(a) Meridional temperature gradient, (b) Absolute value of vertical shear of zonal winds ($U_{200hPa} - U_{850hPa}$).

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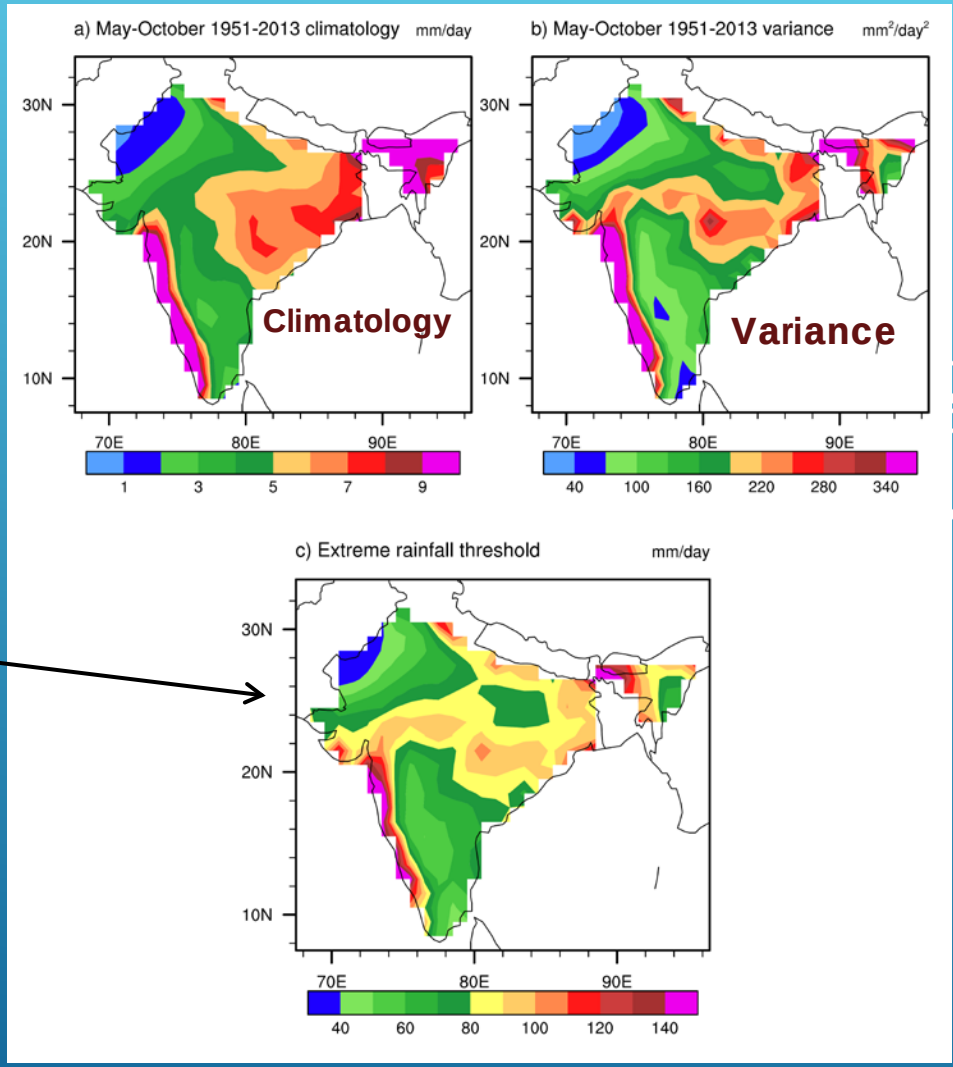
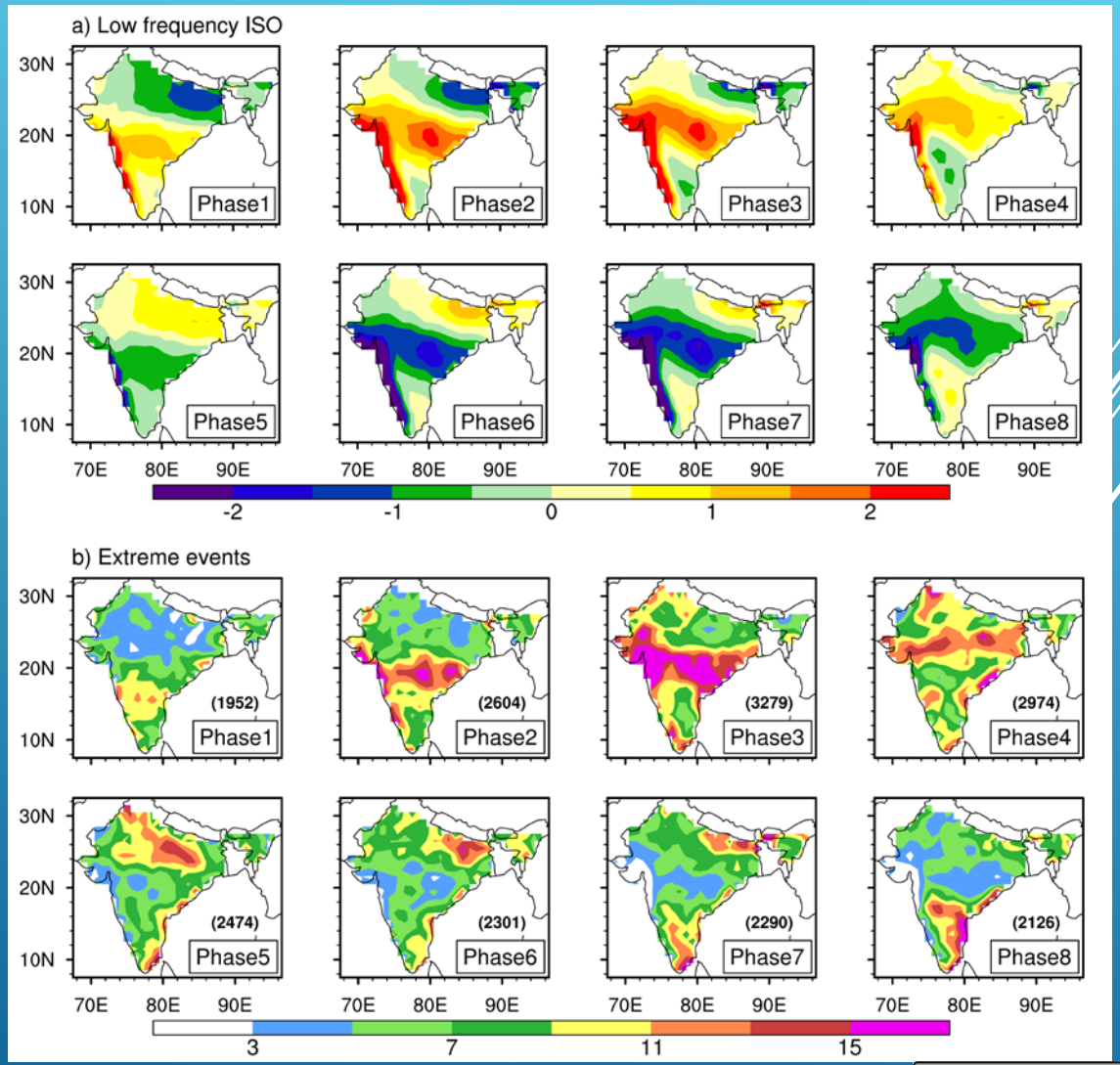
EXTREME EVENTS:

- Large spatial variability in climatological mean and variance of May-October daily mean rainfall.
- We set 99.5th percentile value at each gridpoint based on May-October data for 1951-2013 to define the threshold of an extreme event.



ASSOCIATION WITH LF-ISO:

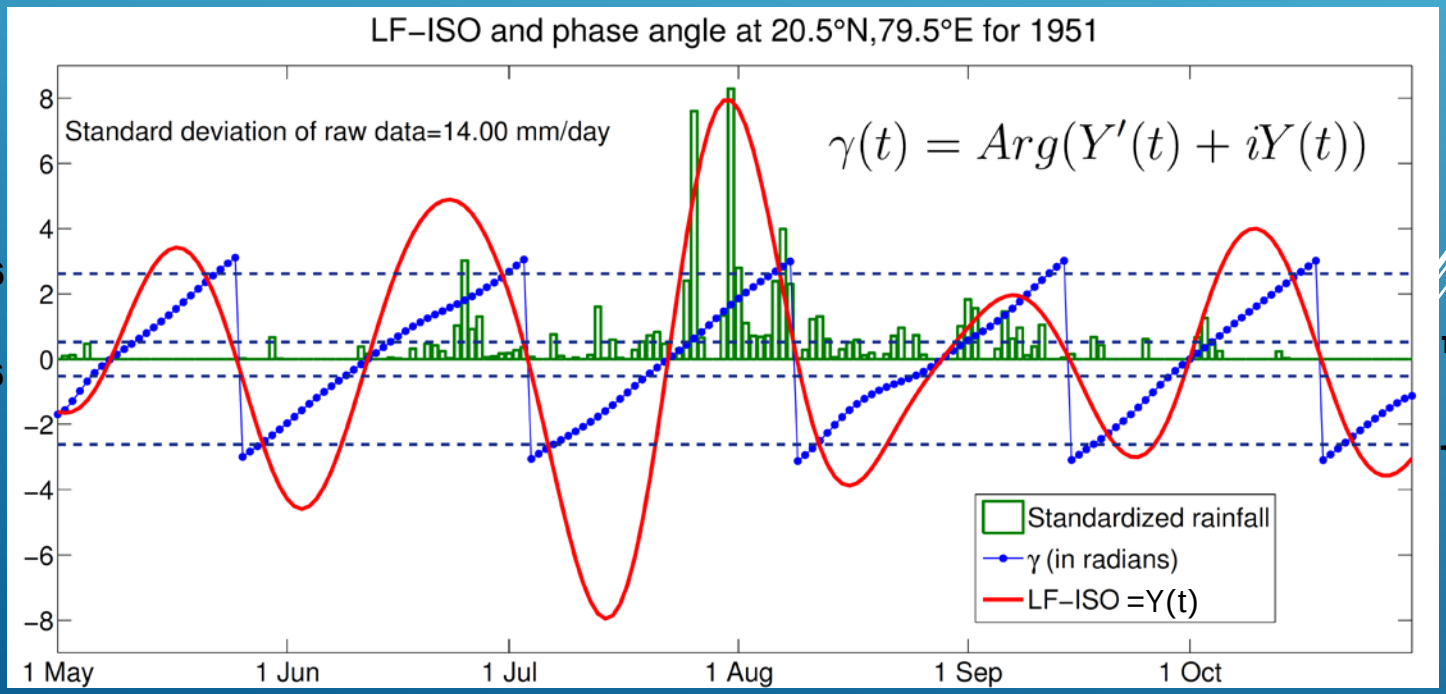
- Phase composite structures of LF-ISO and the number of extreme events occurring in a particular phase composite:
- Extreme events are inclined to occur in places where LF-ISO is positive.
- Extreme rain events are preferentially located in the monsoon lows or large-scale convergence zone, and propagates poleward as the LFISO progress.



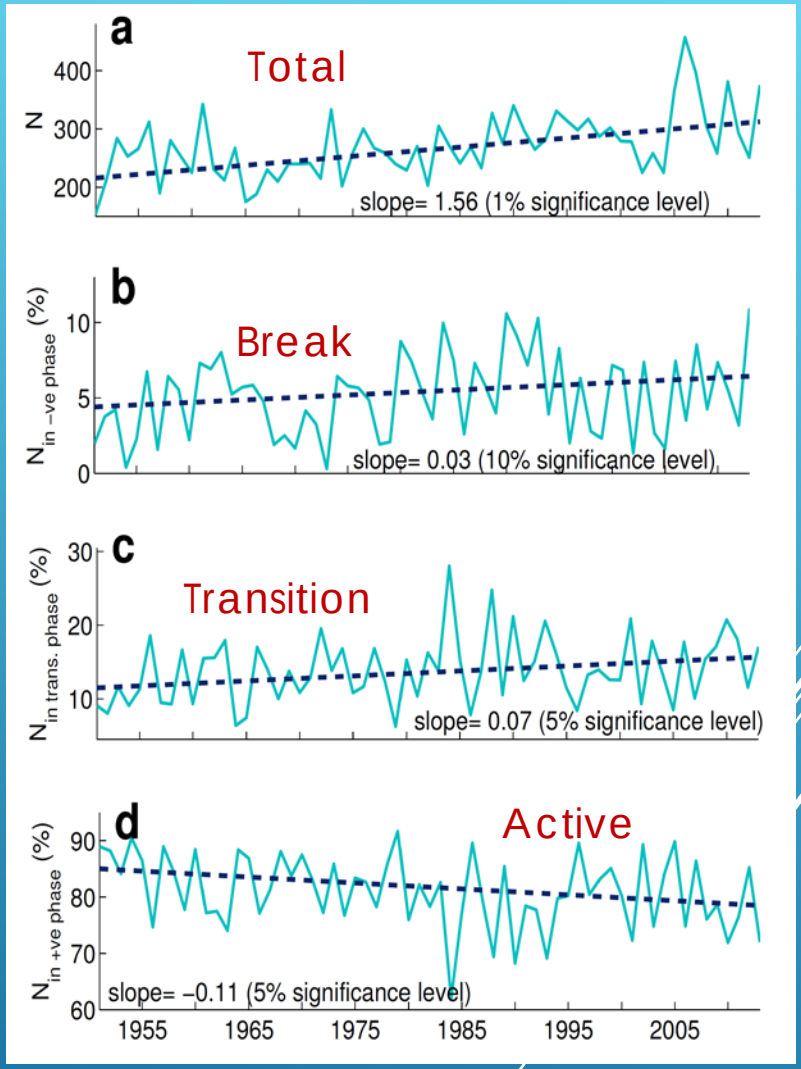
EXTREME EVENTS IN ACTIVE/BREAK PHASES:

ACTIVE/BREAK PHASES OF ISO:

- Based the oscillatory behaviour of the reconstructed ISOs, we defined the **active** (if γ lies in $(\pi/6, 5\pi/6)$), **break** (if γ lies in $(-5\pi/6, -\pi/6)$) and **transition** phases (otherwise) using the ISO time series.



- Decreasing trend in percentage of extreme events occurring in active phase.
- Increasing trends in percentage of extreme events during break and transition phases.
- ➔ Almost 7% of the total extremes are now occurring in break/transition phases instead of active phase!!!



(a) Total extremes. Percentage of extremes in (b) negative (break) phase, (c) transition phase and (d) positive (active) phase of LF-ISO.

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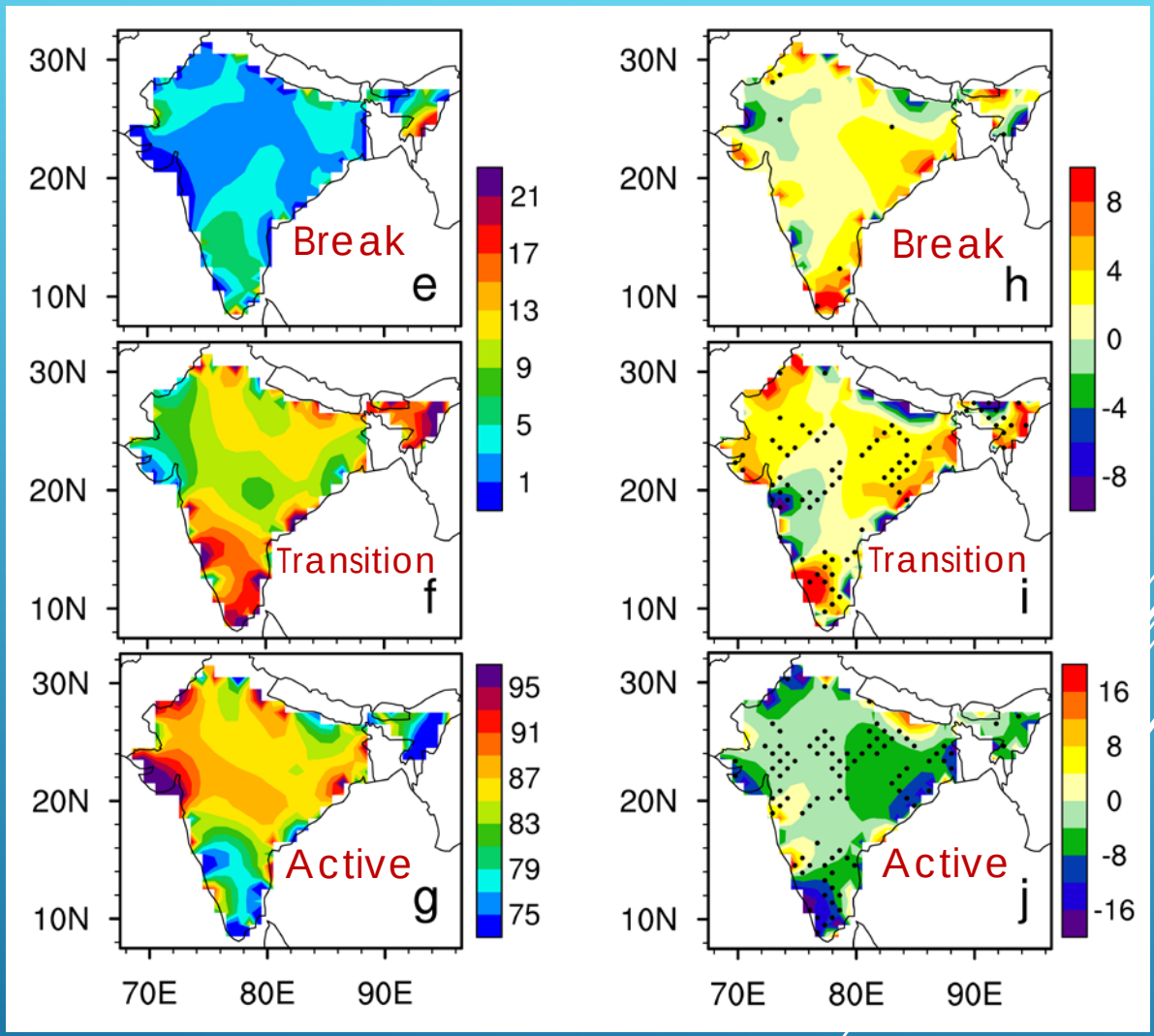
- Percentage of extreme events occurring in the break and transition phases shows an increase over Gangetic plain, eastern coast and southern part of India during post-1980 period.

(Stippled regions are hardly present in (h) because of very few non-zero values in either of the epochs at each gridpoint. The results are, in this case and also in (i) and (j), suggestive but not conclusive, and a larger dataset may be needed to bring out this difference more significantly.)



Percentage of the extremes during 1951-1980 in (e) negative (break) phase, (f) transition phase and (g) positive (active) phases of LF-ISO, respectively. (h-j) Post-1980 minus pre-1980 for the same.

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CONCLUSIONS:

- Extracted and examined the strength of ISO modes in Indian monsoon rainfall.
- A significant decreasing trend in the relative strength of low-frequency ISO.
- Synoptic variability has increased significantly, mainly over central India.
- A tendency towards redistribution of preferred time of extreme events within intraseasonal timescale.

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DISCUSSIONS:

- Monsoon circulation over Indian region has weakened because of reduced land-sea thermal contrast in recent decades (Zveryaev 2002), which may be attributed to spatially uneven effects of greenhouse gases (Zuo et al 2012) or human-influenced aerosol emissions (Bollasina et al 2011)
- A **weakening of the 30-60 days ISO in lower-tropospheric zonal wind** over the Indian subcontinent, the northern Arabian Sea and the Bay of Bengal in recent decades has been observed (Zveryaev 2002).
- Fitful occurrence of these short spatial and temporal scale extreme events would make it more difficult to capture in medium- and long-range forecasts.

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ACKNOWLEDGEMENT:

- The high-resolution gridded daily rainfall data we use here has been developed by the India Meteorological Department (IMD) for the period 1951 to 2013 [Rajeevan et al 2006]. The dataset can be obtained by contacting the National Climate Centre, IMD, Pune (ncc@imdpune.gov.in).
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REFERENCE:

- Nirupam Karmakar, Arindam Chakraborty, & Ravi S. Nanjundiah, "**Decreasing intensity of monsoon low-frequency intraseasonal variability over India"**, *Environ. Res. Lett.* 10 (2015) 054018 (http://dx.doi.org/10.1088/1748-9326/10/5/054018).