Multidecadal variability in the Indian summer monsoon and its connection with global sea surface temperature

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Objectives:

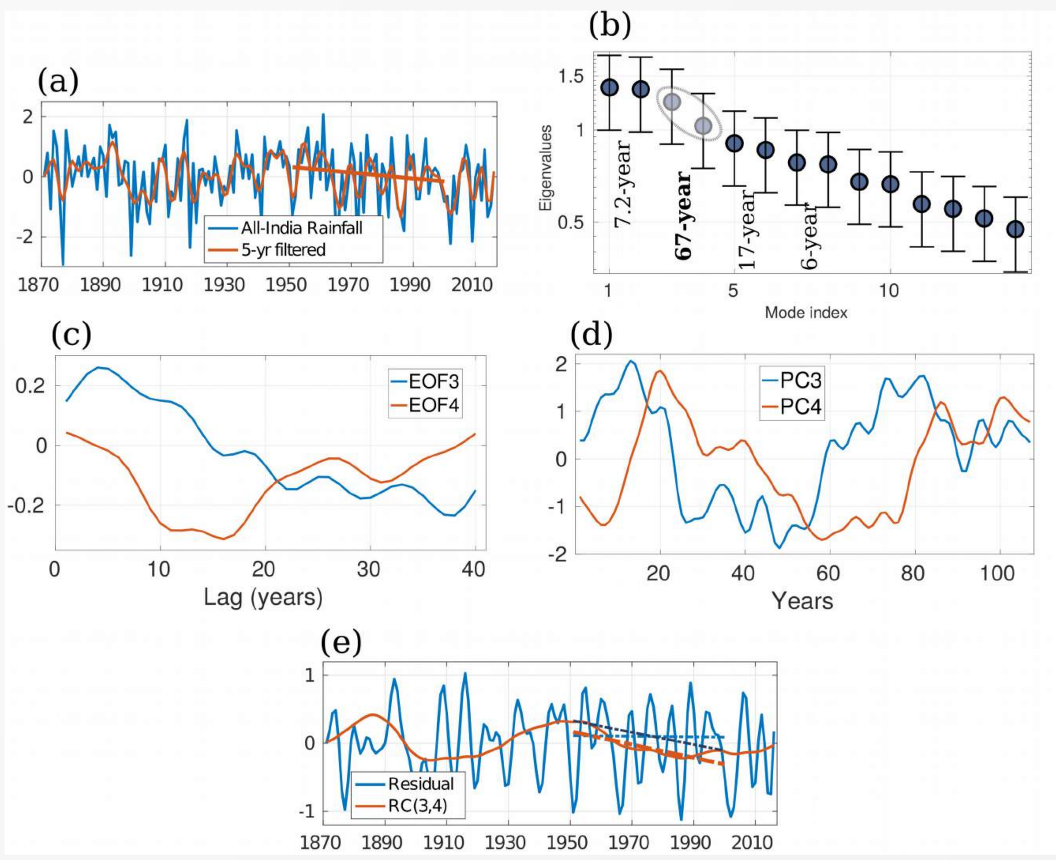
- Investigate whether **Indian Summer Monsoon Rainfall (ISMR)** possesses a multidecadal/**ultra low-frequency (UL)** mode of variability using observed rainfall data.
- Does this mode modulates seasonal *rainfall intensity* over India?
- Is the *recent decrease in ISMR* explained by this mode?
- What drives this mode? Is there any *connection with the global sea surface temperature (SST)* variability?
- Aim to establish a *physical mechanism* between the two phenomena: ISMR and global SST in multidecadal scale.

Data:

- All-India monthly rainfall data from 1871—2016 obtained from Indian Institute of Tropical Meteorology (IITM) *(Parthasarathy et al., 1994)*.
- We also use India Meteorological Dept. (IMD) gridded rainfall data from 1901—2014 *(Pai et al., 2014)*.
- Monthly SST from HadISST during 1871—2016 *(Rayner et al., 2003)*.
- NCEP/NCAR Reanalysis-1 data (1948—2016) *(Kalnay et al., 1996)*.

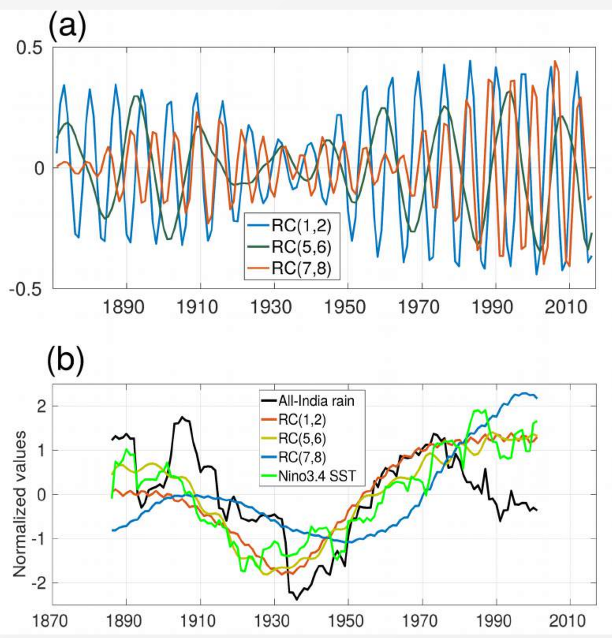
Extracting ISMRUL:

- June—September mean rainfall used. *Mean = 848.2 mm, Std dev = 83.5 mm*.
- Normalize 146-year long time series. 5-year low-pass filter (Chebyshev type-I) applied to eliminate very high-frequency fluctuations.
- **Singular spectrum analysis (SSA)** applied to the data *(Ghil et al., 2002)*.
- SSA has become a very useful tool to diagnose short and noisy time series:
- *Data-adaptive approach*. SSA diagonalizes a lag-covariance matrix to produce empirical orthogonal functions (EOFs) and principal components (PCs).
- Oscillation is present if two eigenvalues are almost equal and EOFs and PCs are in phase quadrature.
- Reconstruction components (RCs) representing the oscillations are obtained by convolving corresponding EOFs and PCs.



- *Decreasing trend in ISMR during 1951—2000* as documented in many studies.
- ***Modes 3 and 4 capture a 67-year periodic oscillation***.
- RC(3,4) shows multi-decadal variability (***ISMRUL***).
- Shows increasing trend in recent few years.

Other dominant modes:

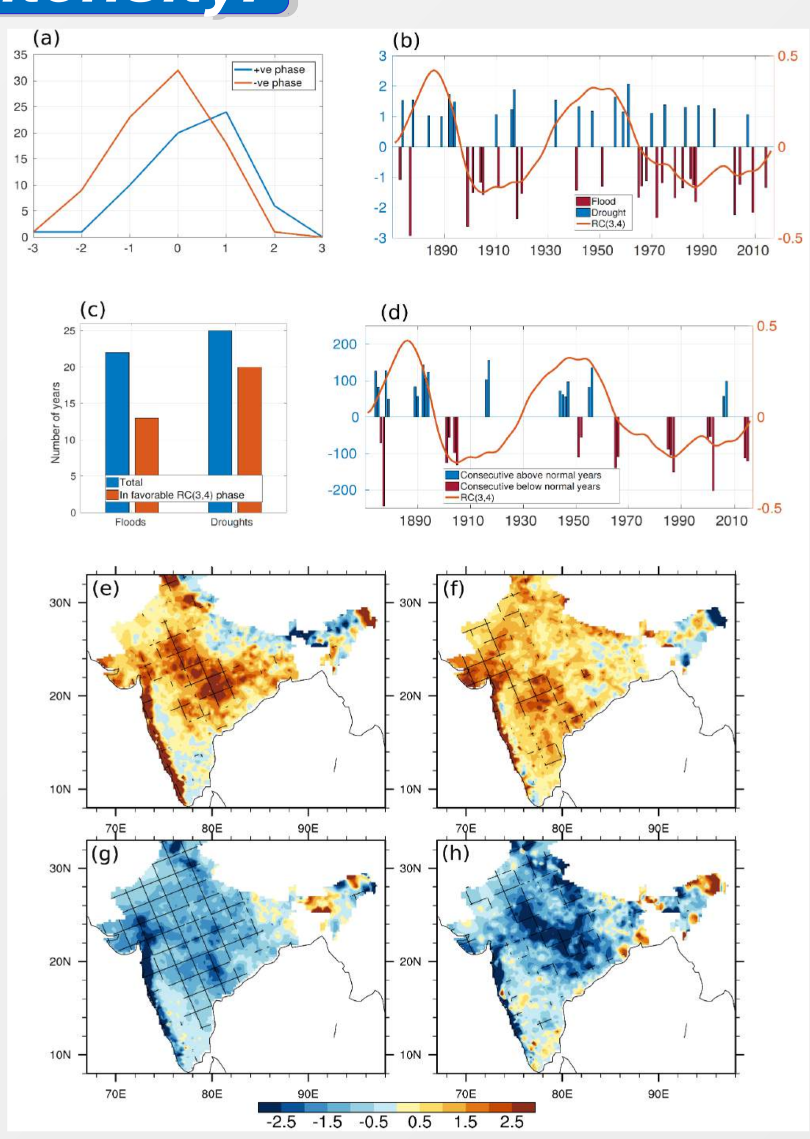


- First two modes exhibit 7.2-year cycle.
- Modes 5 and 6 show a 17-year oscillation.
- Modes 7 and 8 capture a 6-year cycle.
- Epochal patterns of these modes and Nino-3.4 SST shows coherence.

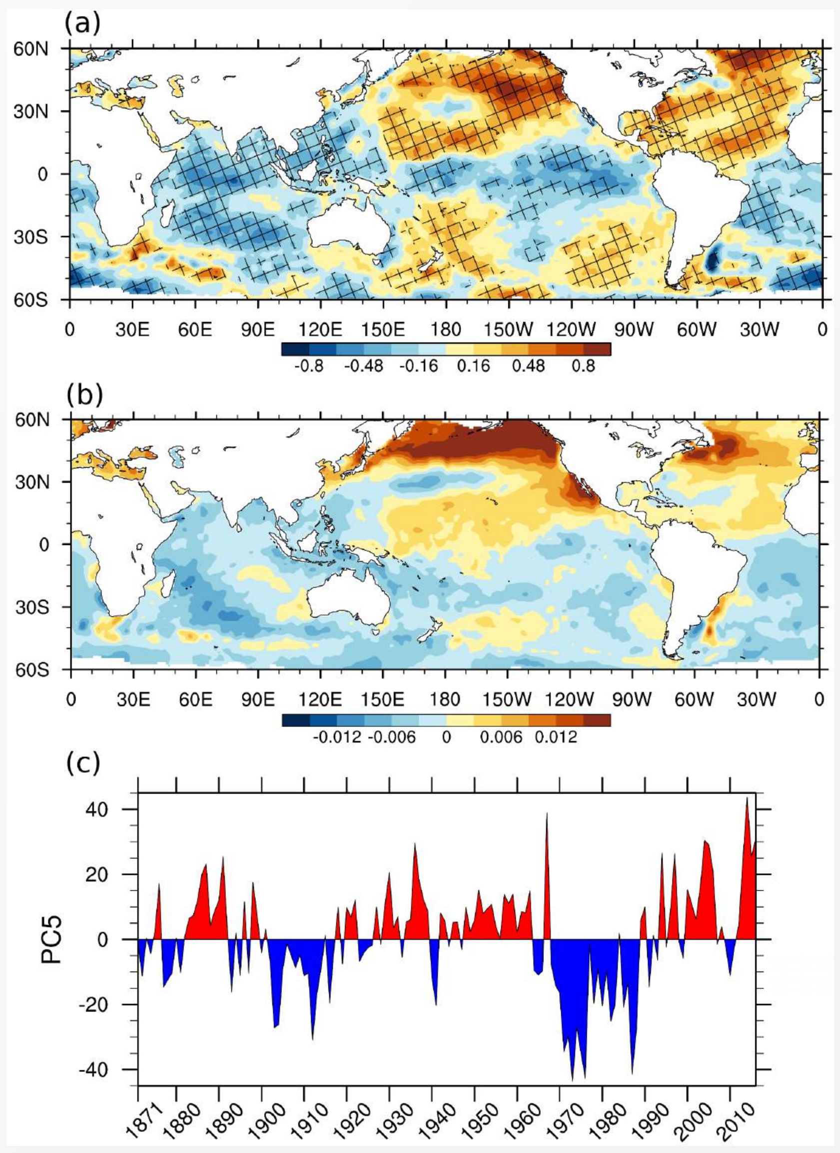
ISMRUL and rainfall intensity:

- Rainfall over India in ISMRUL +ve (62 cases, 873mm) and –ve (84 cases, 828 mm) phases are different.
- *60% of total flood years and 80% of total drought years are in favourable ISMRUL phase.*
- Consecutive years of above/below normal rainfall are modulated by ISMRUL.

(e) Shows rainfall in flood years in +ve ISMRUL phase.
(f) Shows rainfall in flood years in -ve ISMRUL phase.
(g) Shows rainfall in drought years in -ve ISMRUL phase.
(h) Shows rainfall in drought years in +ve ISMRUL phase.



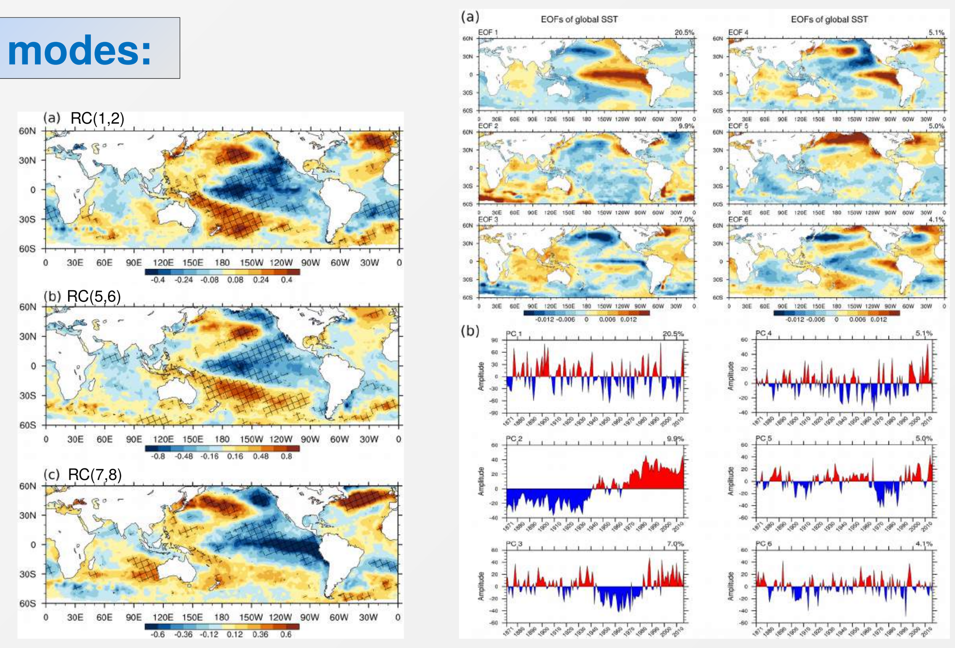
ISMRUL and global SST:



- Regression coefficients of global SST (June—September mean) with ISMRUL shows *horseshoe-like pattern over northern Pacific* (panel (a)).

Conventional PC analysis with global SST.
- EOF5 explains 5% of the total variability (panel (b)).
- Similar patterns as the in panel (a) (pattern correlation of 0.45*)
- Resembles North Pacific Gyre Oscillation.
- PC5 shows multidecadal variability: shifts during 1890s, 1920s, 1970s, and 1990s (panel (c)).

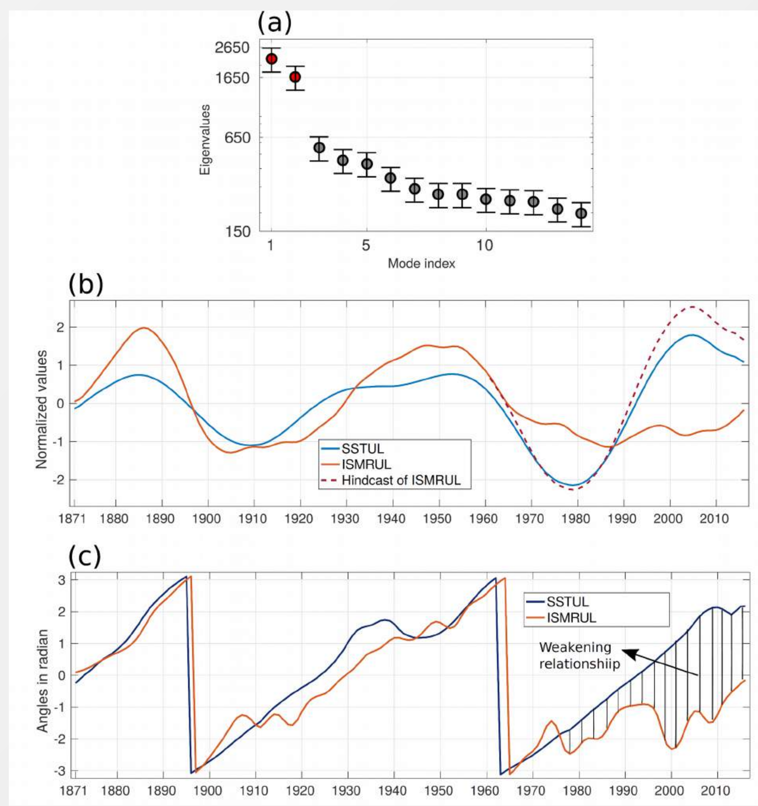
Other modes:



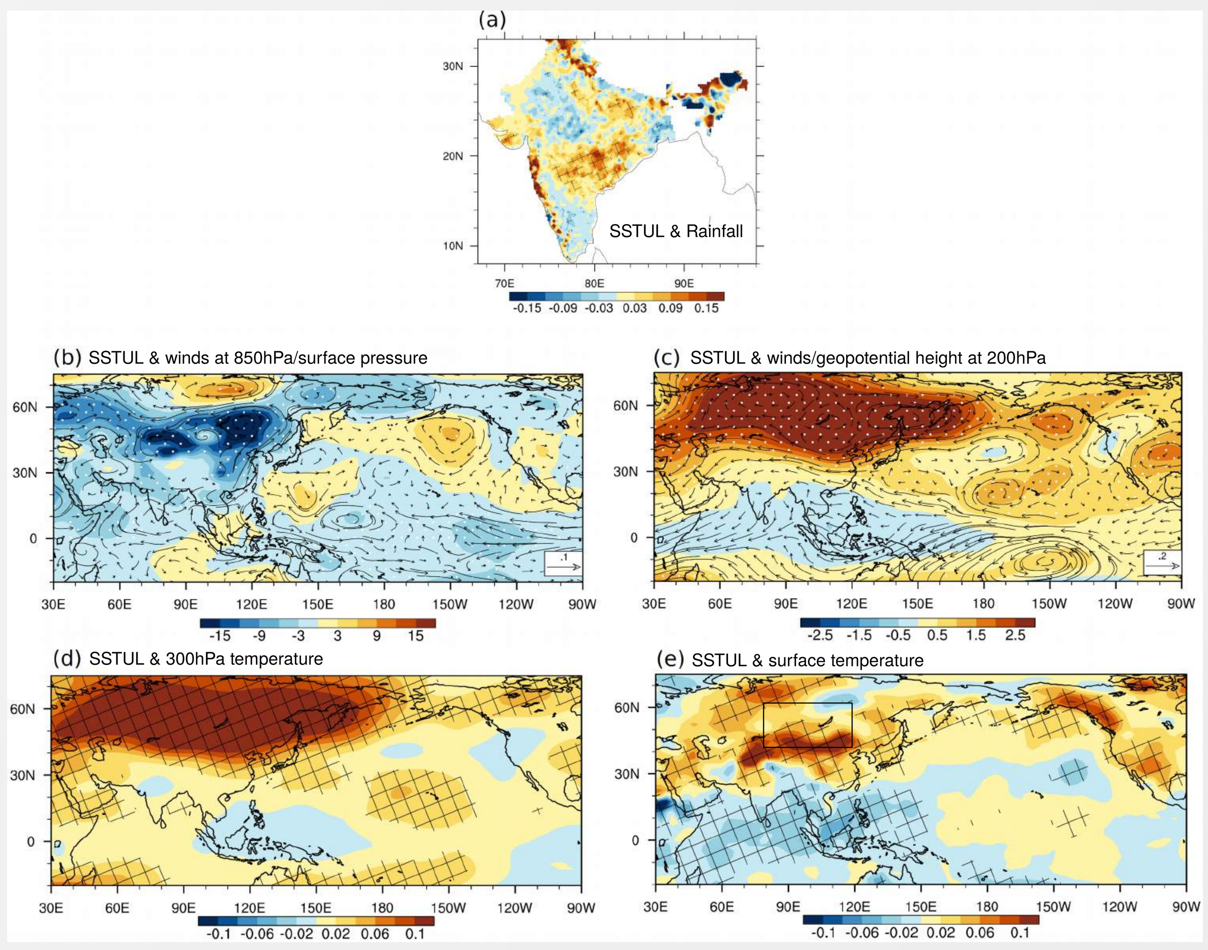
ISMRUL and SSTUL:

Perform SSA on the SSTPC5 time series.
- First two modes show oscillatory pattern with periodicity of 67 years,
- RC associated with these two modes represents ultra low-frequency mode in SST (***SSTUL***).
- Correlation coefficient (ISMRUL, SSTUL) = 0.45*.
- Correlation value is stronger (0.85*) for 1871—1975.

Calculate phase angle of ISMRUL and SSTUL.
- Angle is calculated as $\tan^{-1}(Y'(t)/Y(t))$, Y(t) is ISMRUL or SSTUL.
- Strong correspondence between the two with ISMRUL lagging 2-3 years, especially till 1980s.
- Decoupling between ISMRUL and SSTUL in the last few decades occurred with a weakening ENSO-Monsoon relationship *(Kumar et al., 1999)*.



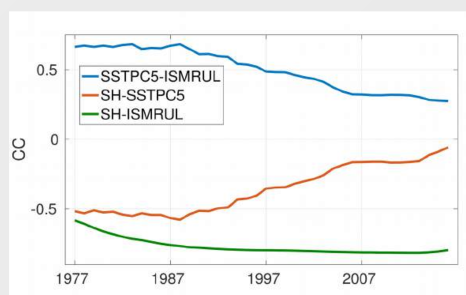
Possible mechanism:



We analyse 1948—1975 data (regression coefficients)
- Rainfall over central India is associated with SSTUL.
- *Lower surface pressure* over the Siberian High (SH) is seen with anti-clockwise low level winds.
- Similar patterns as seen in North Pacific Oscillation (NPO) *(Rogers 1981)*.
- *Increased geopotential height and atmospheric temperature* over SH.
- This alters *meridional temperature gradient* over the Indian domain, changes *tropical easterly jet* intensity by thermal wind balance.
- Stronger easterly jet is associated with more rainfall over India.

- Correlation values between unfiltered SH surface pressure, SSTPC5 and ISMRUL suggest strong relationship between the fields (1948—1975).
- Relationship between SST and SH weakened after 1980s.
- Relationship between SST and ISMR weakened after 1980s.

	SH	SSTPC5	ISMRUL
SH	1	-0.51*	-0.53*
SSTPC5	-0.51*	1	0.67
ISMRUL	-0.53*	0.67*	1



Conclusions:

- Using longest available rain-gauge data, *multidecadal mode in ISMR (ISMRUL)* is identified by a data adaptive approach (SSA).
- ISMRUL significantly *modulates* the occurrences of flood/above normal rainfall or drought/below normal rainfall events over India.
- A *horseshoe-like pattern in northern Pacific*, resembling NPGO, also shows oscillation in similar timescale (*SSTUL*). ISMRUL and SSTUL are strongly associated. Relationship weakened after 1980s.
- A *mechanism* is presented: SSTUL is associated with changes in atmospheric conditions over north-central Asia, thereby altering tropical easterly jet intensity. This changes favourable conditions for rainfall over India.

Reference:

Karmakar, N., Chakraborty, A. and Nanjundiah, R. S. “Influence of a global sea surface temperature mode on ultra-low frequency variability in the Indian summer monsoon rainfall”, Submitted to Q. J. Royal Meteorol. Soc.

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