UNIFIED MECHANISM OF ENSO CONTROL ON INDIAN MONSOON RAINFALL

SUNEET DWIVEDI

K Banerjee Centre of Atmospheric and Ocean Studies,

M N Saha Centre of Space Studies

University of Allahabad, Allahabad, INDIA

Motivation

- ❖ **Useful prediction of the seasonal mean ISMR required for benefit of the farmers has remained a challenging problem.**

- ❖ **Predictable component of ISMR variability: slowly varying external forcing like ENSO**

- ❖ **A significant component of IAV of the ISMR can arise from "internal" dynamics of the atmosphere resulting largely from statistics of MISOs.**

- ❖ **Internal IAV of ISMR is considered to have limited predictability (MISOs are not predictable more than 1 month in advance).**

- ❖ **If the "statistics of MISOs" are modulated by ENSO, higher predictability limit could be achieved leading to an improvement in the outlook for South Asian monsoon prediction.**

- ❖ **ENSO influences the South Asian monsoon rainfall through LRS (SRS).**

- ❖ **How the ENSO modulates the statistics of MISOs (active and break spells) and thereby influence the ISMR?**

Outline

- Scientific basis is demonstrated from a nonlinear dynamical perspective.
- 113 years (1901–2013) long time series of the IMD high-resolution daily gridded rainfall data is used.
- Quantitative analysis of modulation of the probability distribution of rain spells.
- Asymmetry in rain spells results from differential frequency of occurrence of “short” and “long” break and active spells.
- El Niño and La Niña events modulate the probability of occurrence of short and long active and break spells during a season in such a way to make the ISMR weak (strong) during El Niño (La Niña) years.
- Role of ‘seasonal’ mode is explained.
- Unified mechanism of ENSO control on the ISMR is proposed.

Scientific Basis

- The basis for such an effort lies in the findings of Mittal et al.[2007]

- They analyzed the conceptual forced Lorenz model to explore the effects of sea surface temperature forcing on the seasonal rainfall.

- ISMR is considered as a quasi-bimodal process in nature

- El Niño and La Niña events are considered as external forcing that tend to modulate the probabilities of active and break spells.

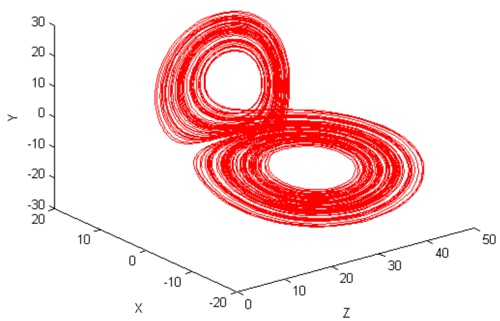
- Insight is gained from low order conceptual models using the nonlinear dynamical system theory

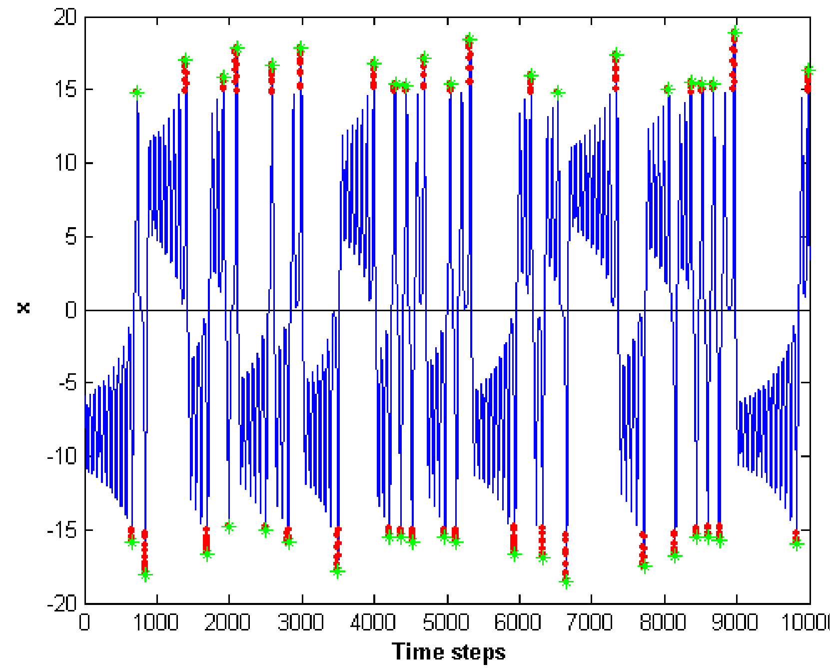
TWO-REGIME MODELS/PROCESSES:

MOMENTOUS DISCOVERY

❖ **We discovered** *Prediction Rules for Regime Changes and Duration in New Regime for the Lorenz and other Two Regime Models*

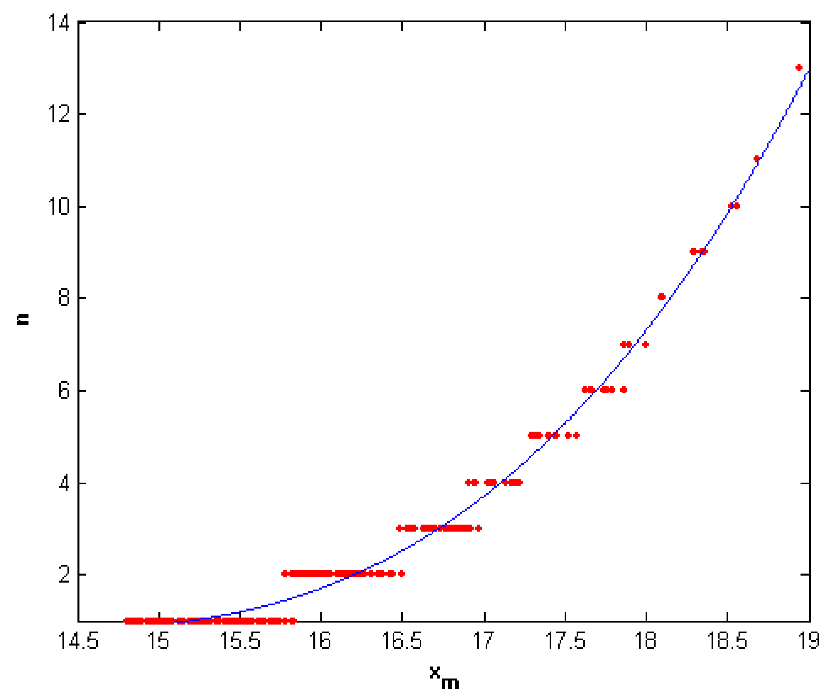
$$\frac{dx}{dt} = -ax + ay$$
$$\frac{dy}{dt} = -xz + rx - y$$
$$\frac{dz}{dt} = xy - bz$$





➢ ***Rule 1: When |x(t)| is greater than a critical value (x_c ~ 14.8) the current regime will end after it completes the current orbit.***

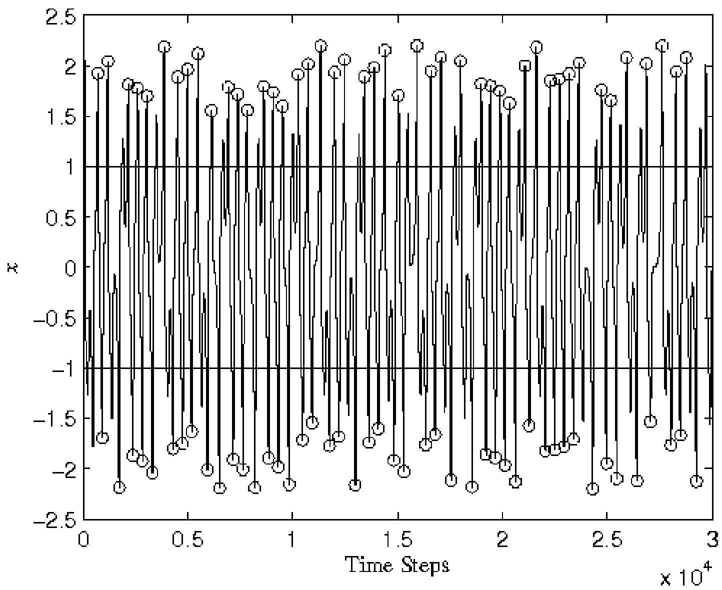
➢ ***Rule 2: The length n of the new regime increases monotonically with the maximum value x_m of |x(t)| in the previous regime.***

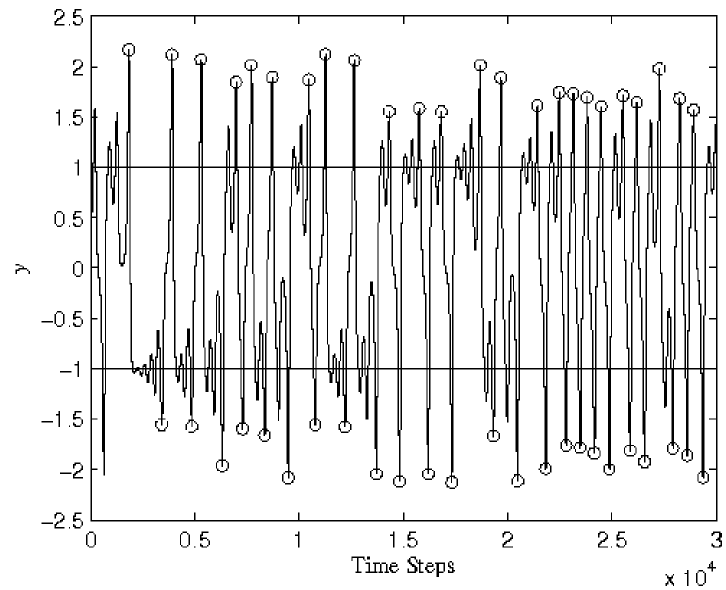


Yadav, Dwivedi and Mittal, J. Atmos. Sci., 62, 2316-2321, 2005

Generic Prediction Rules: Applies to large class of two-regime models/processes

ACT





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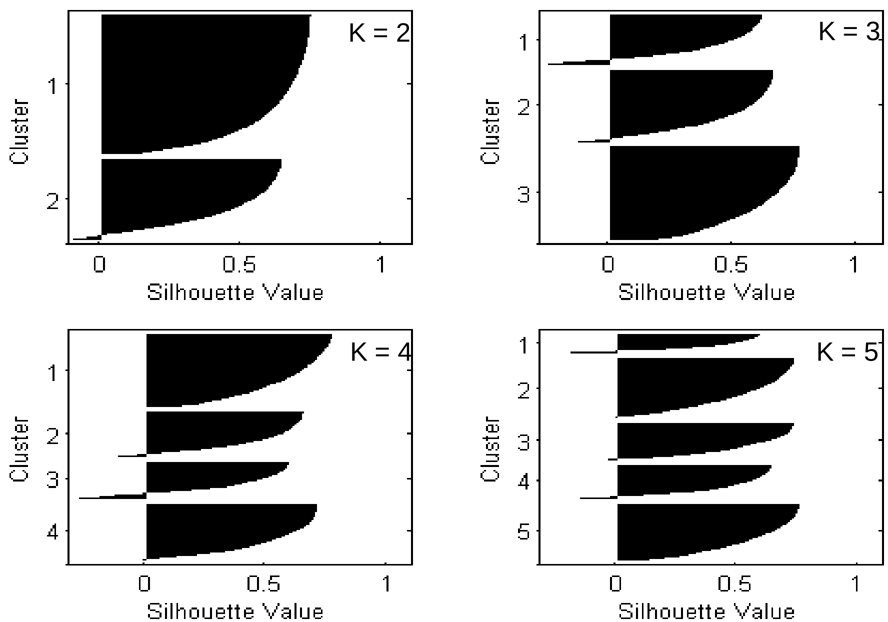


K-mean clustering of the ISO data

❖ **These prediction rules are generic in nature: applicable to even real time processes such as ISO and IOD**

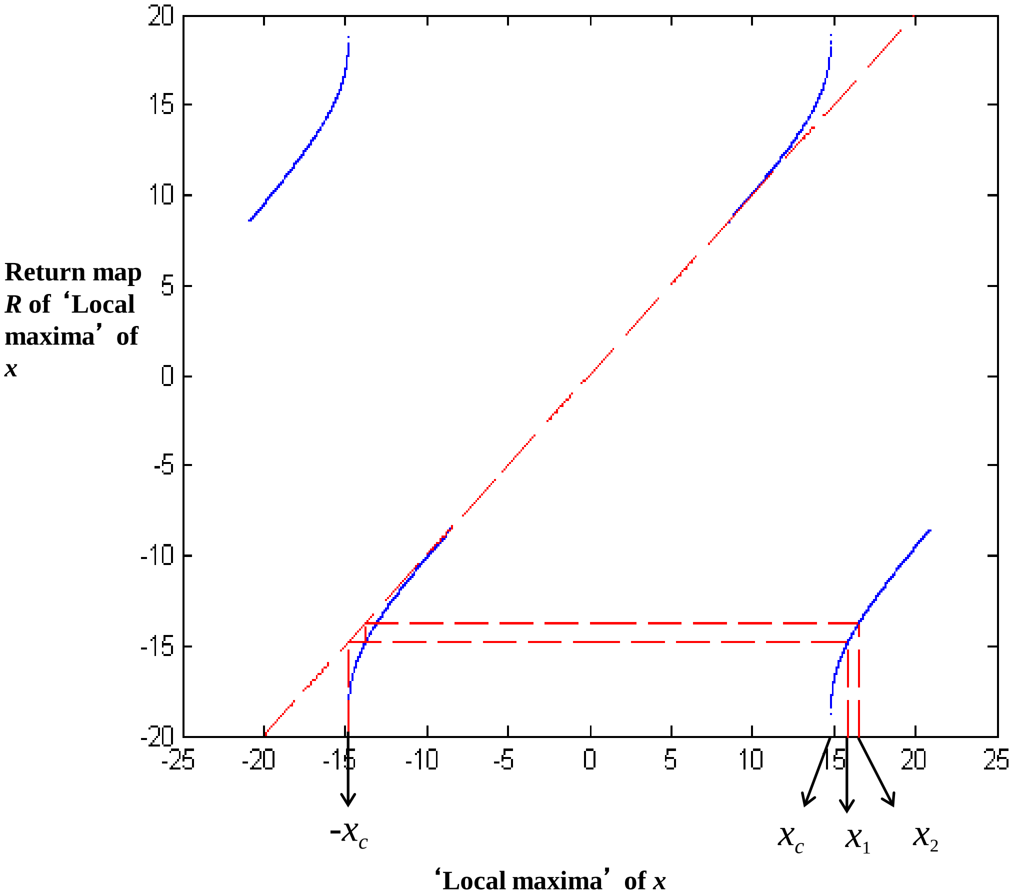
Dwivedi and Mittal, Pure and Applied Geophysics, 169, 755-761, 2012

Probability distribution for Number of Cycles Between Successive Regime Transitions for the Lorenz Model

- Return map for the maximum value of the variable *x* of the Lorenz model with the help of an invariant manifold technique.

- Return map is used to derive the regime transition rules.

- The probability of different regime lengths is estimated for the Lorenz model and forced Lorenz model.



Mittal, Dwivedi and Yadav, Physica D, 233, 14-20, 2007

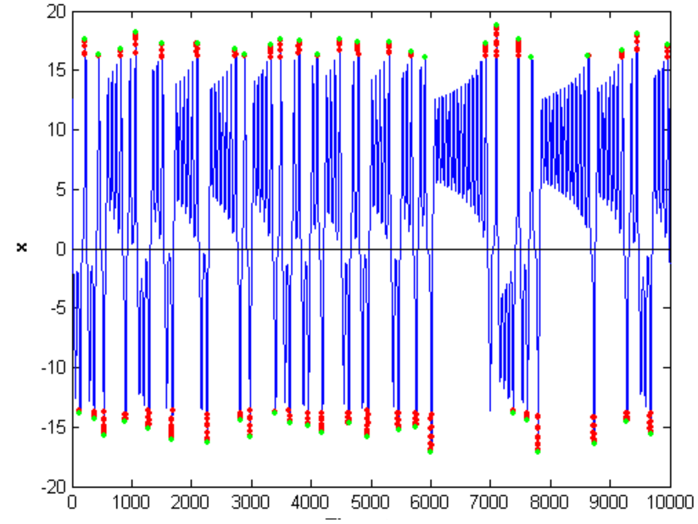
- ❖ **Forced Lorenz Model:** introduced by Palmer to explore the effect of eastern pacific SST on JJAS mean monsoon rainfall)

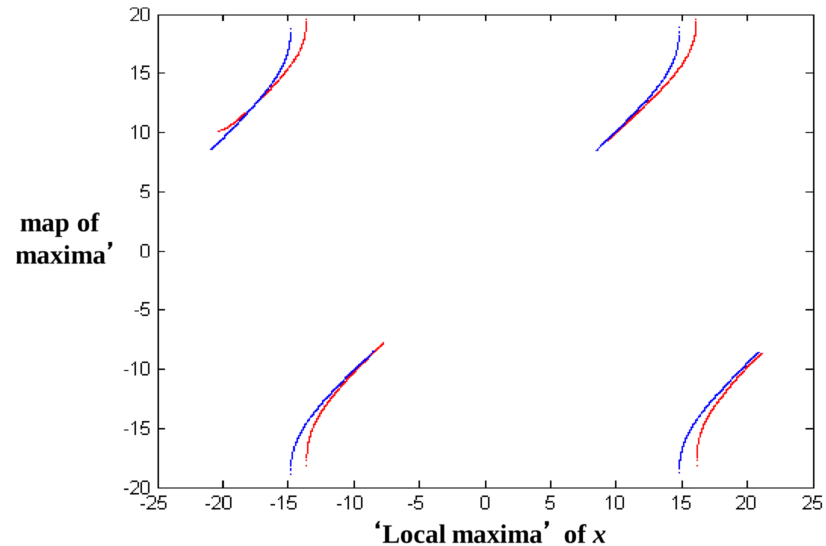
$$\frac{dx}{dt} = -ax + ay + F_x$$

$$\frac{dy}{dt} = -xz + rx - y + F_y$$

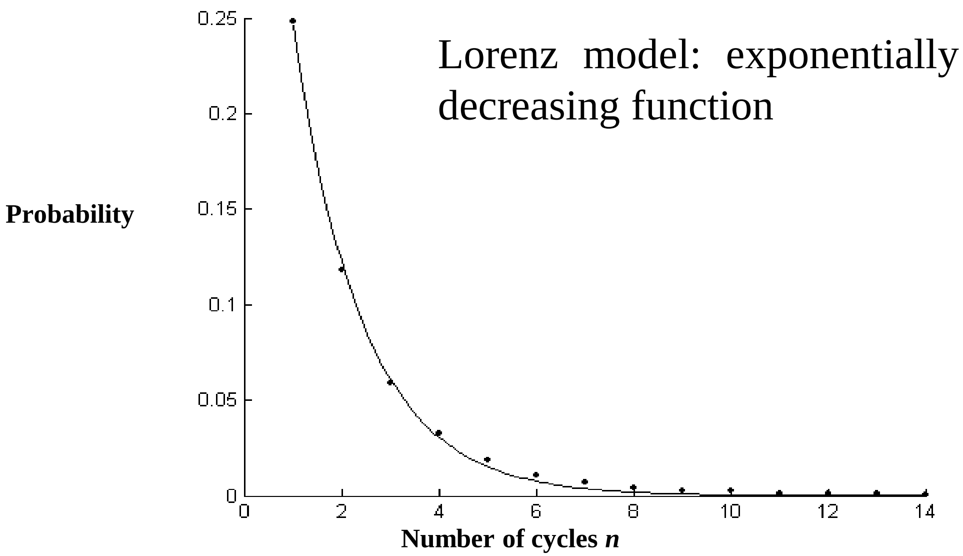
$$\frac{dz}{dt} = xy - bz + F_z$$

with $F_x = aF$, $F_y = -F$, $F_z = 0$ and $F = [-1.5\ 1.5]$





- ❖ **Probability distribution for residency time in a regime**



Mittal, Dwivedi and Yadav, Physica D, 233, 14-20, 2007

Effect of (+ve) Forcing:

- probabilities of duration in positive and negative regimes are no longer equal. What can we learn? Interpretation??

Hypothesis:

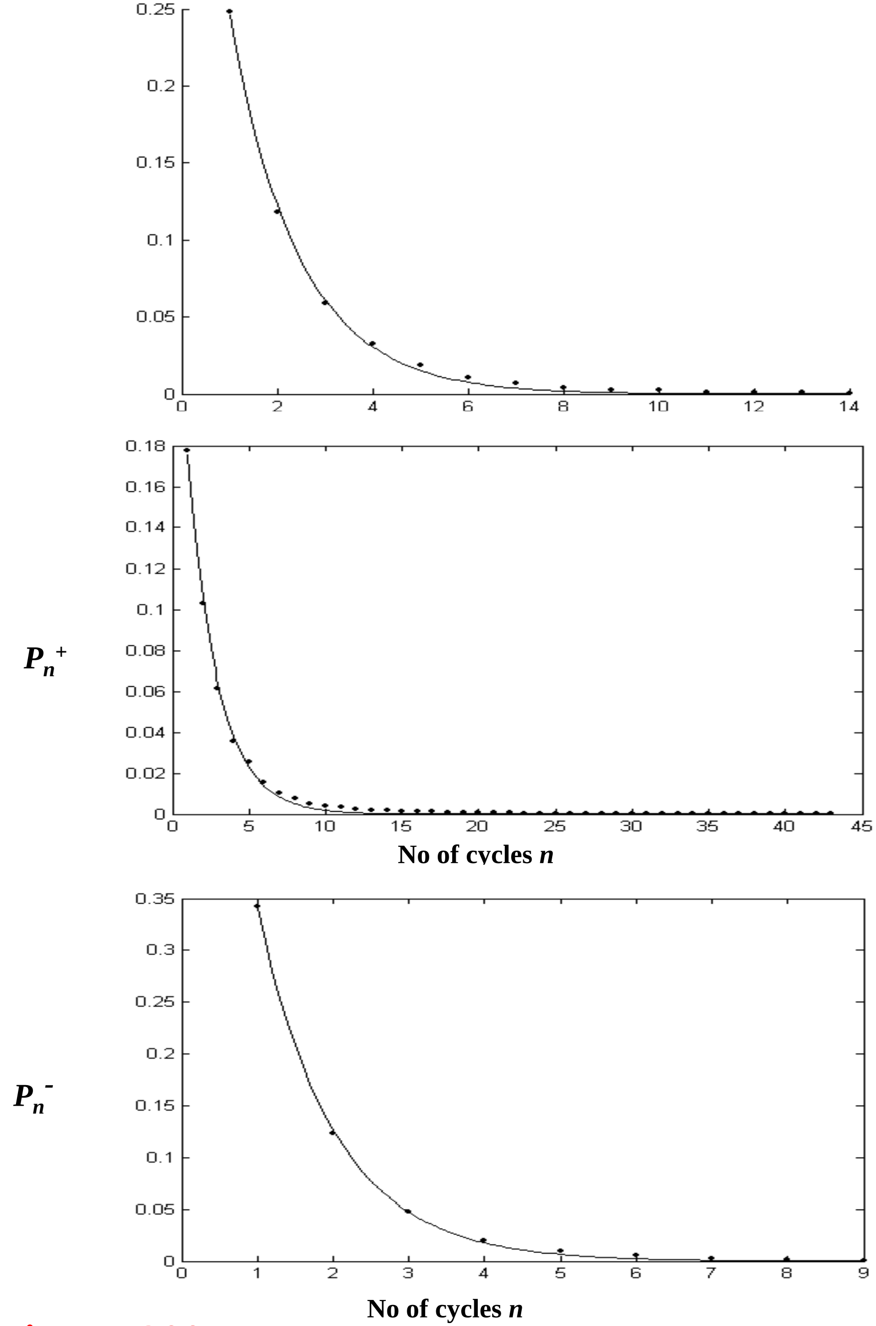
• generally: negative correlation between El Nino index and Indian Seasonal Mean Rainfall.

• shift of focus from seasonal mean rainfall to the statistics of lengths of active and weak spells.

• La Nina year: the probabilities of longer active spells should increase whereas those of shorter active spells should decrease.

• the probabilities of shorter break spells increase whereas those of longer break spells decrease.

• El Nino years: opposite



Mittal, Dwivedi and Yadav, Physica D, 2007

- **Weakening ENSO-Monsoon correlation**

Proposal

- **instead of looking at the correlation between the seasonal mean ISMR and ENSO events, the emphasis should be towards estimating the influence of the El Niño and La Niña events on the frequency (occurrence) of intraseasonal active and break spells of the ISMR.**

El Niño and La Niña years during 1901-2013

- HadISST SST anomalies in the Niño 3.4 region [5° N-5° S, 120° W-170° W]
- An El Niño (La Niña) event is said to occur if the Niño 3.4 SST anomalies averaged over the June-July-August [JJA] months of a year exceed 0.5° C (-0.5° C).
- A total of 22 El Niño years and La Niña years, respectively, were identified using the abovementioned definition during 1901-2013.

El Niño years	1902, 1904, 1905, 1914, 1915, 1919, 1926, 1930, 1940, 1941, 1951, 1957, 1963, 1965, 1972, 1982, 1987, 1991, 1997, 2002, 2009, 2012
La Niña years	1909, 1910, 1916, 1924, 1933, 1938, 1942, 1945, 1950, 1954, 1955, 1956, 1964, 1970, 1971, 1973, 1975, 1985, 1988, 1998, 1999, 2010

Active and Break Spells of ISMR

- Rainfall Dataset: high-resolution (0.25^{o}x0.25^{o}) IMD daily gridded rain gauge data analyzed into regular grid boxes over the Indian subcontinent for 113 years (1901-2013).

- Time series: area averaging JJAS rainfall anomaly over the core monsoon region [13786 data points (122 each year for 113 years)].

- Break Spells : period during which the rainfall anomaly normalized by its standard deviation is less than -1.0, consecutively for three days or more.

- Active Spells: periods during which the rainfall anomaly normalized by its standard deviation is more than +1.0, consecutively for three days or more.

- Number of break spells during:
    - El Niño years: 56
    - La Niña years: 43
    - Normal years: 143

Methodology:

- Number of break spells of each duration (i.e. of 3 days, 4 days, 5 days, etc.) is divided by the total number of break spells to obtain probability corresponding to that break spell length.

- Break spells are classified into two categories, namely, short break spells and long break spells.

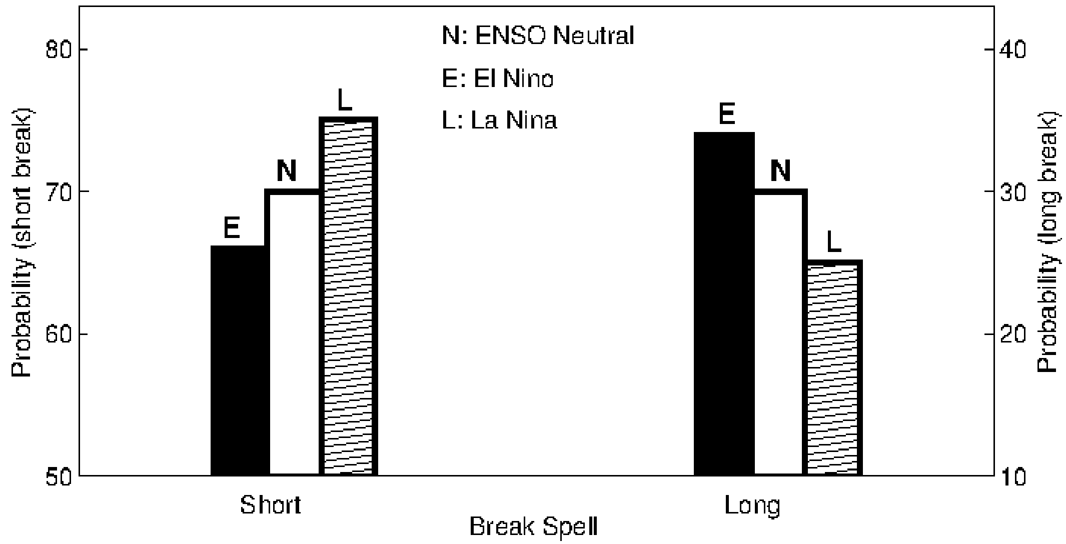
- Break spell duration of 3-7 days: Short break spells

- Break spell duration greater than 7 days: long break spells

Dwivedi et al., GRL, 2015

Probability (in % age) of break spell duration

Category	ENSO neutral years	El Niño years	La Niña years
Short break spells (3-7 days)	70	66	75
Long break spells (>7 days)	30	34	25



- These probabilities reveal interesting facts.
- During El Niño years, probability of shorter break spells decreases whereas the probability of longer breaks increases.
- On the other hand, during the La Niña events, the probability of longer breaks decreases whereas that of shorter breaks increases.

Dwivedi et al., GRL, 2015

Active Spell Duration

- Number of active spells during:

  - El Niño years: 42
  - La Niña years: 77
  - Normal years: 196

- duration of break spells on an average longer than active spells (for example, longest break spell is of 22 days as compared to longest active spell of 12 days).

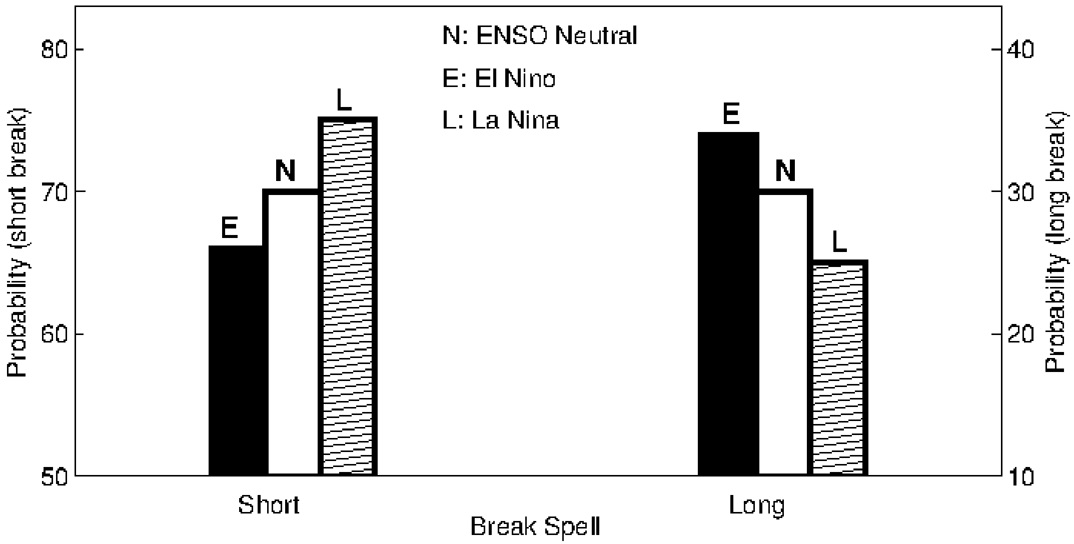
- Breaks tend to have a longer life-span than active spells: almost 80% of active spells last 3-4 days, only 40% of the break spells are of such short duration.

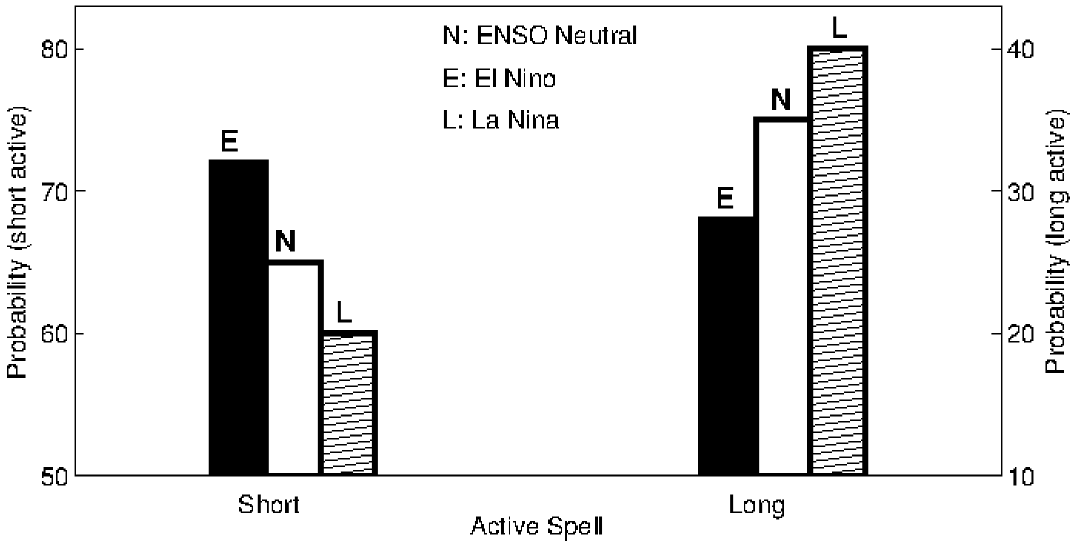
- Active spells with duration of 3-4 days: short active spells

- Active spells with duration greater than 4 days: long active spells

Probability (in % age) of active spell duration

Category	ENSO neutral years	El Niño years	La Niña years
Short active spells (3-4 days)	65	72	60
Long active spells (>4 days)	35	28	40





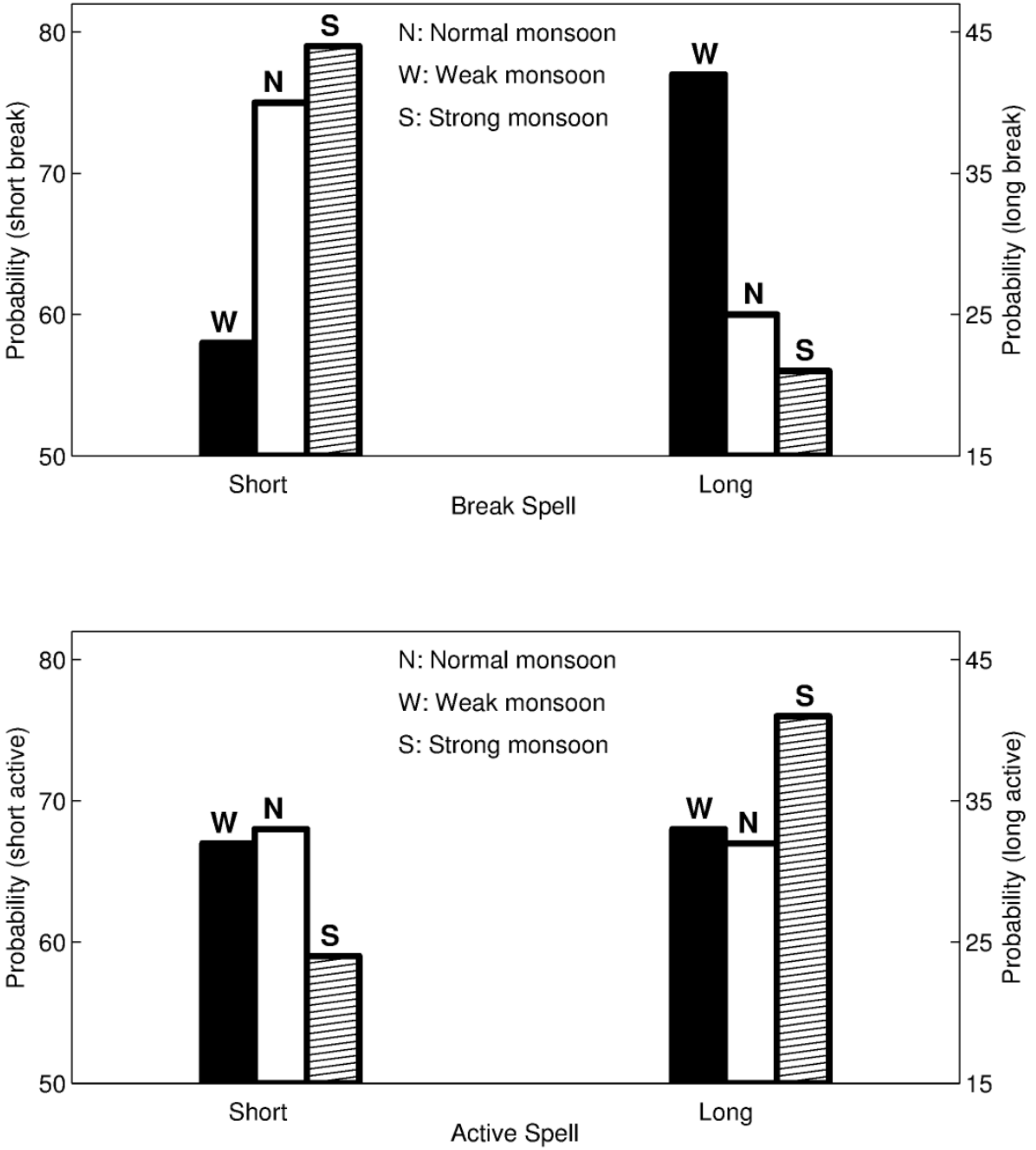
- El Niño years: shorter active spells become more frequent whereas longer active spells become less frequent.
- On the other hand, the frequency of longer active spells increases whereas that of shorter active spells decreases during La Niña events.

- To put the results in perspective, a similar probability analysis for strong and weak monsoon years is carried out.
- Strong monsoon years: JJAS rainfall over the core monsoon region is greater than one standard deviation above the mean.
- Weak monsoon years: JJAS total rainfall over the core monsoon region remains less than one standard deviation below the mean.

Strong Monsoon years	1908, 1916, 1917, 1919, 1926, 1933, 1934, 1942, 1944, 1945, 1946, 1955, 1956, 1959, 1961, 1973, 1975, 1977, 1978, 1983, 1990, 1994, 2003, 2011, 2013
Weak Monsoon years	1901, 1902, 1905, 1911, 1913, 1915, 1918, 1920, 1928, 1939, 1941, 1951, 1965, 1966, 1968, 1972, 1974, 1979, 1982, 1985, 1986, 1987, 1991, 2000, 2002, 2004, 2009

Probabilities during Strong and Weak Monsoon years

- Strong monsoon years: probability of short break spells increases
- Weak monsoon years: probability of long break spells increases
- Frequency distribution similar to those during La Niña (El Niño) years, indicating that the El Niño (La Niña) facilitates the frequency distribution required for making the south Asian monsoon weak (strong).



Dwivedi et al., GRL, 2015

Separating out and demonstrating the influence of the El Nino on the ISMR

Weak but non El Niño years: Break spell duration during those weak monsoon years, which were not forced by the El Nino events

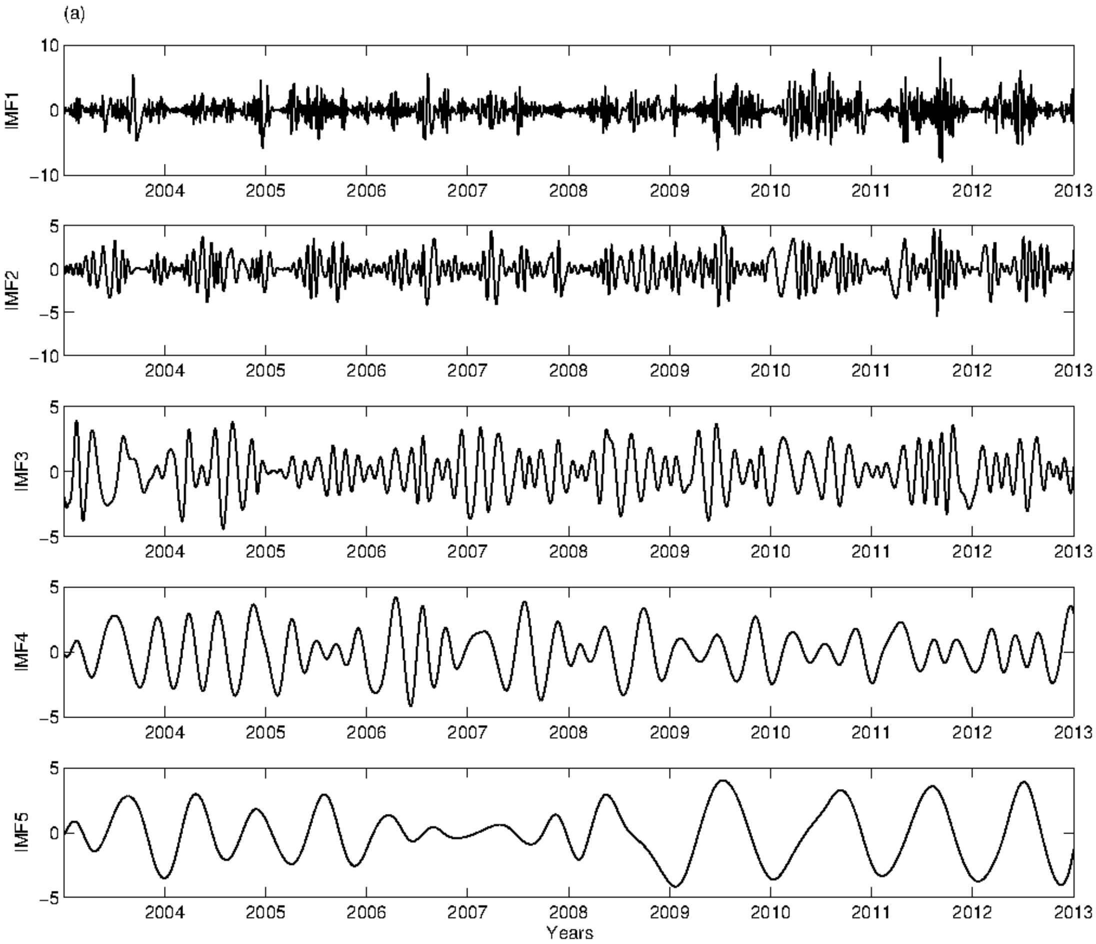
Strong but non La Niña years: Strong monsoon years which were not forced by the La Niña events

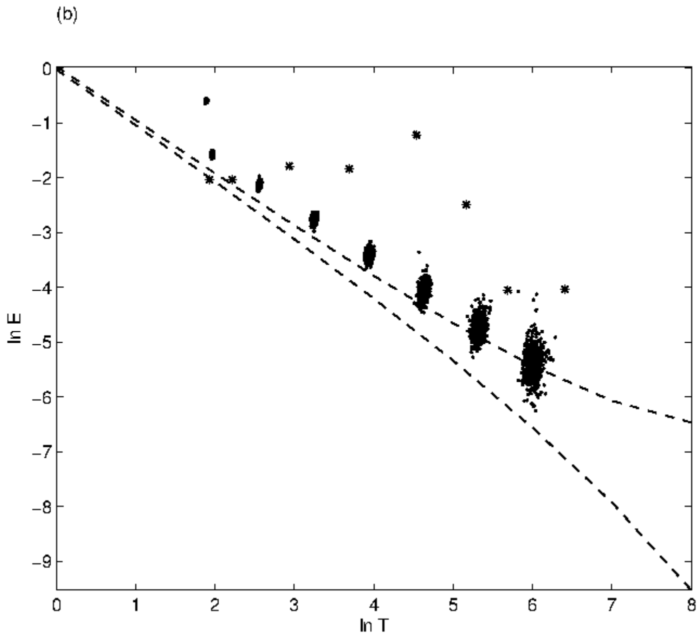
Category	ENSO neutral years	El Niño years	La Niña years	Weak Monsoon years	Strong Monsoon years	Weak but non El Niño years	Strong but non La Niña years
Short break spells (3-7 days)	70	66	75	58	79	62	76
Long break spells (>7 days)	30	34	25	42	21	38	24

- ***Weak but non El Niño years: probability of longer (shorter) breaks decreases (increases) as compared to their respective values during weak monsoon years, thus confirming the role of the El Niño on causing longer breaks.***
- ***'Strong but non La Niña years': probability of longer (shorter) breaks increases (decreases) as compared to their respective values during strong monsoon years, thus confirming the role of the La Niña on causing shorter breaks.***

IMFs of Rainfall Time Series

To gain insight regarding how ENSO modulates the probabilities of short and long break and active spells, the rainfall time series is decomposed into intrinsic mode functions (IMFs) using the empirical mode decomposition technique.





The IMFs of the rainfall time series represent physically meaningful and statistically significant modes of Indian monsoon variability.

Dwivedi et al., GRL, 2015

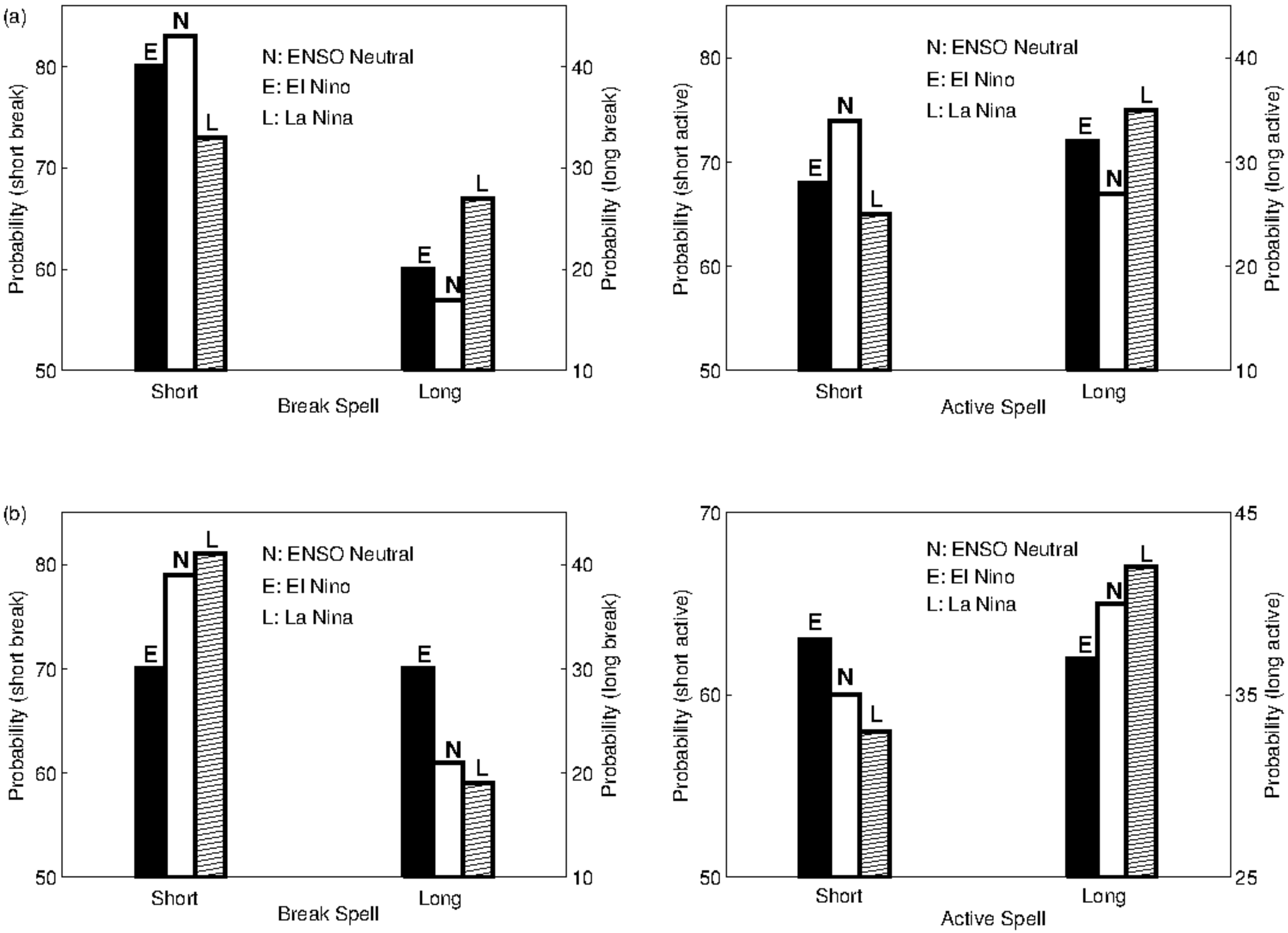
Time period (T) and the Fraction of Explained variance (FEV) of the IMFs during ENSO-Neutral years, El Niño years, and La Niña years

IMF	ENSO-Neutral		El Niño		La Niña	
	T (in days)	FEV (%)	T (in days)	FEV (%)	T (in days)	FEV (%)
1	7 ± 3	13.90	7 ± 3	14.66	7 ± 3	12.95
2	9 ± 3	14.21	10 ± 4	14.16	9 ± 3	13.26
3	18 ± 6	16.61	20 ± 8	20.46	18 ± 8	20.87
4	39 ± 12	15.59	42 ± 15	14.03	38 ± 18	21.07
5	96 ± 31	32.89	112 ± 27	35.64	82 ± 33	22.39
6	171 ± 49	8.47	197 ± 32	5.95	163 ± 42	13.29
7	311 ± 106	2.02	364 ± 53	2.47	311 ± 81	2.78

- IMF1: a synoptic mode, IMF2 to IMF4: known monsoon subseasonal oscillations, namely, the 10–20 day oscillations and the 40 day oscillation.
- **A hitherto unknown "seasonal" mode in the IMF5 is unraveled.**
- These are fundamental modes of the Indian monsoon and a combination of them determines the seasonal mean ISMR in a given year.
- How ENSO changes the characters of these modes has not been quantified so far.
- Neat separation in the behavior of subseasonal and seasonal mode: ENSO modulates probabilities of short/long break/active spells through modulation of seasonal mode.

How the seasonal mode is modulated by the ENSO and in turn modulates the statistics of the MISOs?

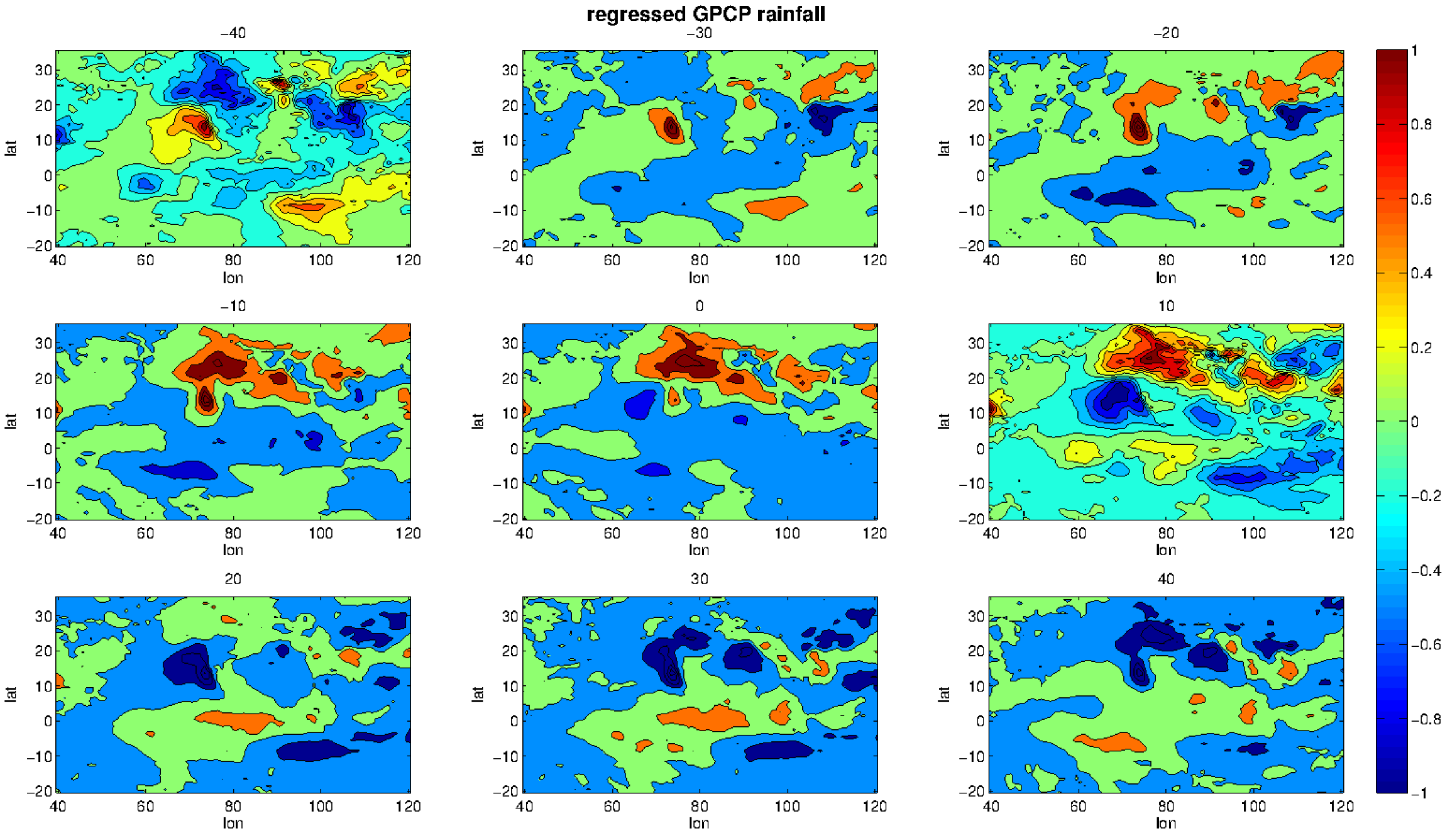
- Rainfall time series is reconstructed with IMF1–IMF4 and the statistics of short and long break and active spells is collected.
- No significant difference in probabilities is noted in this case.
- When IMF5 is added: reconstruction with IMF1–IMF5: probabilities of short and long breaks show similar character like the original time series.



clearly established: seasonal mode is responsible for modulating the subseasonal modes to create the desired distribution for the probabilities of the short and long break and active spells.

How does the ENSO make the period of the seasonal mode to increase during El Niño years while decrease during La Niña years?

The lead-lag regression of the IMF5 with the GPCP daily rainfall indicates that it is associated with seasonal northward migration of the tropical convergence zone.



How does the ENSO make the period of the seasonal mode to increase during El Niño years while decrease during La Niña years?

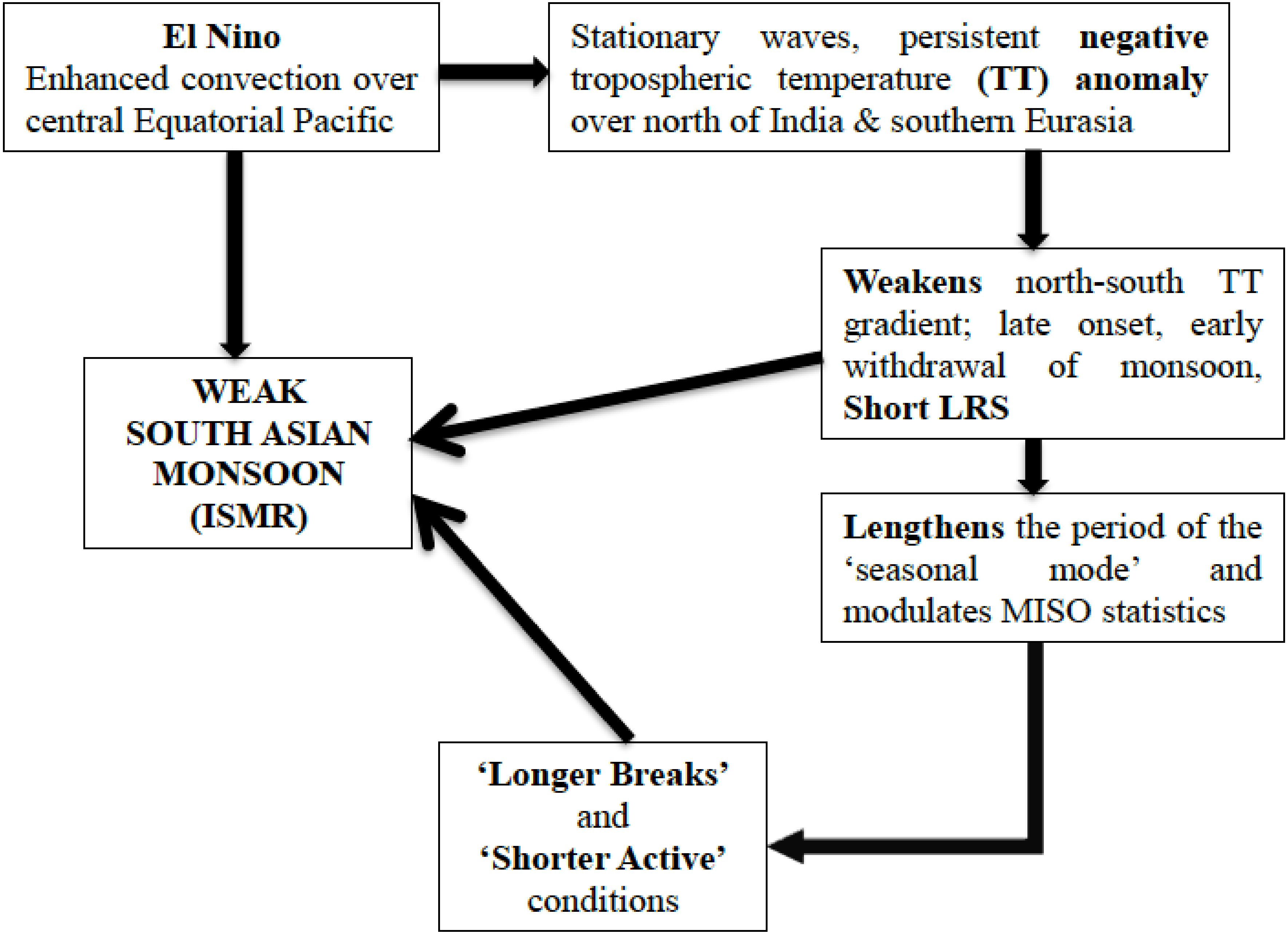
- Deviation of the South Asian monsoon seasonal cycle with sharp "onset" and slow "withdrawal" from a smooth seasonal cycle seems to give rise to this oscillation on the seasonal time scale.

- Also, it may be recalled that the ENSO influences the onset and withdrawal of monsoon through modulation of the north-south gradient of the tropospheric temperature over the region.

- The onset is delayed, while the withdrawal is advanced by an El Niño, thereby shortening the length of the rainy season (LRS).

- A La Niña does the opposite, lengthening the LRS.

- A mechanical manifestation of the shortening of the LRS is an increase in the period of the seasonal mode, while the lengthening of the LRS leads to a decrease of the period of the seasonal mode.



Dwivedi et al., GRL, 2015

Conclusions

- Large-scale tendency of the ENSO to weaken (strengthen) the ISMR by shortening (lengthening) of the LRS also leads to lengthening (shortening) of the period of the seasonal mode, which in turn modulates the probability of occurrence of short and long break and active spells in a way required for a further reduction (increase) of the ISMR, thereby providing a unifying and comprehensive mechanism of ENSO control on South Asian monsoon rainfall.
- Contribution to the ISMR coming from statistics of MISOs represents the internal ISMR variability and is generally considered unpredictable one season in advance and thereby limiting the predictability of the ISMR.
- We estimate this internal ISMR variability from the interannual variance of the seasonal mean anomalies reconstructed from subseasonal modes with periods between 11 and 98 days.
- It is found that statistics of the MISOs contribute to approximately 15% of the ISMR variability.
- Our discovery that the statistics of MISOs is neatly modulated by the ENSO indicates that this part of internal ISMR variability is predictable.

Conclusions

- Our finding therefore provides basis for optimism that the ISMR has higher potential predictability than estimated previously and brightens the prospect for improved skill of seasonal prediction of the ISMR.

- We would require the coupled climate models for seasonal prediction to simulate the space-time characteristics of the MISOs as well as their interannual statistics with fidelity.

- The implications are enormous for the Indian subcontinent where the ISMR variability has a great socioeconomic impact, particularly in the backdrop when it has now become possible to predict El Niño and La Niña events at least 4–6 months in advance with useful accuracy using dynamical models.

S. Dwivedi, B. N. Goswami, and F. Kucharski (2015), Unraveling the missing link of ENSO control over the Indian monsoon rainfall, Geophys. Res. Lett., 42, doi:10.1002/2015GL065909.

THANK YOU FOR YOUR PATIENCE