Contribution of Lows and Depressions to Summer Monsoon Rainfall

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Mainly Results based on the following two studies

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Analysis of the daily rainfall events over India using a new long period (1901–2010) high resolution (0.25° × 0.25°) gridded rainfall data set

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Active and break events of Indian summer monsoon during 1901–2014

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Points for Discussion

- Contribution of monsoon low pressure systems (LPSs) in the southwest monsoon season rainfall over India and examine association between LPS and interannual Variation of all India summer monsoon Rainfall (ISMR)

- **Association between active and break monsoon events over India and LPS.**

- Association between Monsoon Depressions and extreme rainfall (ER) events over the country.

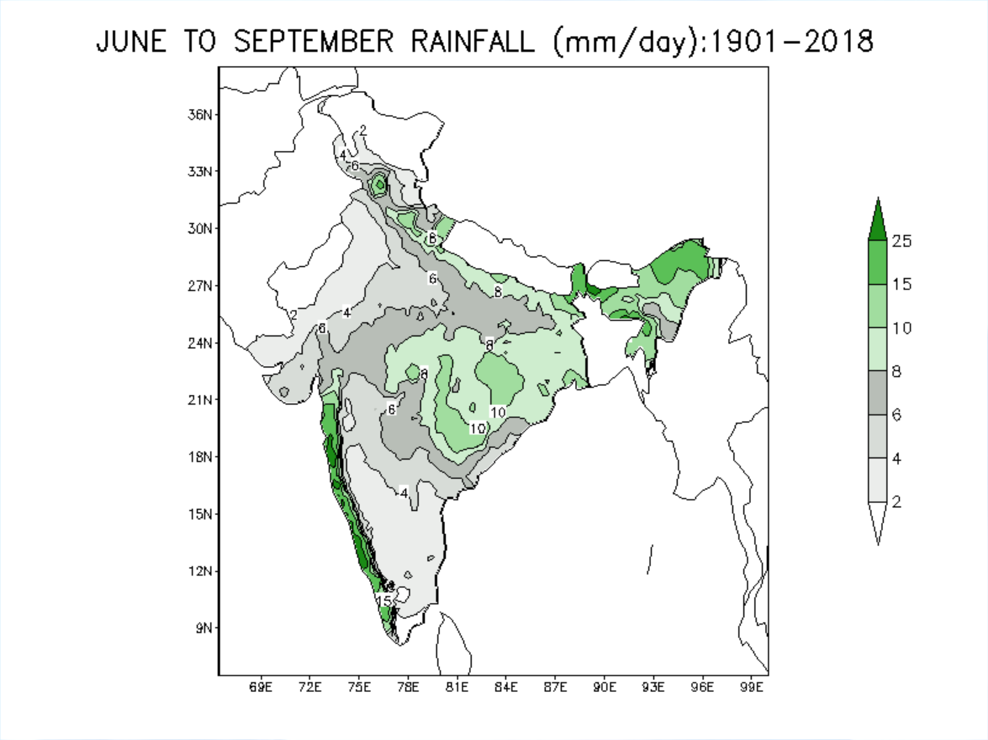
Data Used

- New high spatial resolution (0.25^{o} X 0.25^{o}, latitude X longitude) daily gridded rainfall data set covering a long period of 110 years (1901-2010) over the Indian main land (Pai et al. 2013).

http://imdpune.gov.in/Clim_Pred_LRF_New/Grided_Data_Download.html

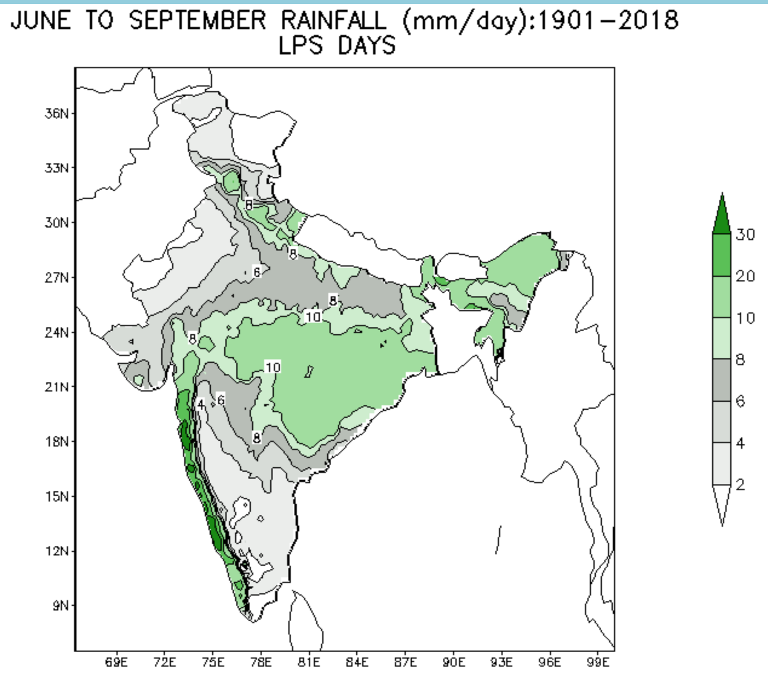
- The daily rainfall records from 6955 rain gauge stations with varying availability periods were used for preparing this data set. Out of these 6955 stations, 547 are IMD observatory stations, 494 are hydro-meteorology observatories and 74 are Agromet observatories. The remaining are rainfall reporting stations maintained by the State Governments.
- Another data set used in this study is the number and days of monsoon depression (MD) during the southwest monsoons season for the period 1901-2010 derived from "Cyclone eAtlas – IMD" published by the India Meteorological Department. **A MD day was defined as the day when a monsoon cyclonic system of intensity equal to or higher than a depression was observed in the surface chart of the Indian monsoon region (0-30^{o}N, 50^{o}E-110^{o}E) for 24hrs from 00UTC of that day.** In addition, the number of monsoon lows for the period 1901-2010 derived from Jadhav and Munot (2004) and that for the period 2001-2010 derived from the daily weather reports over India published by the IMD.

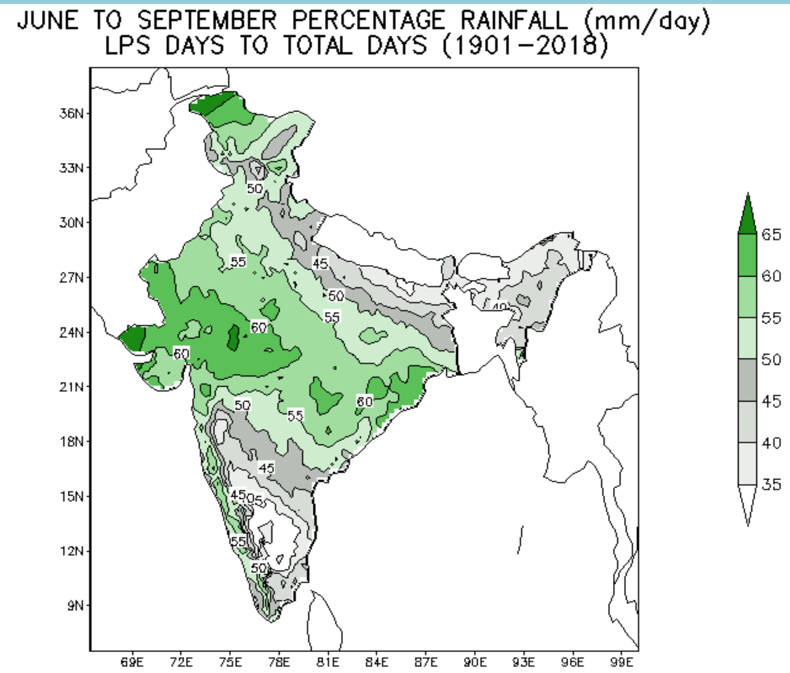
SW Monsoon Rainfall & Topography

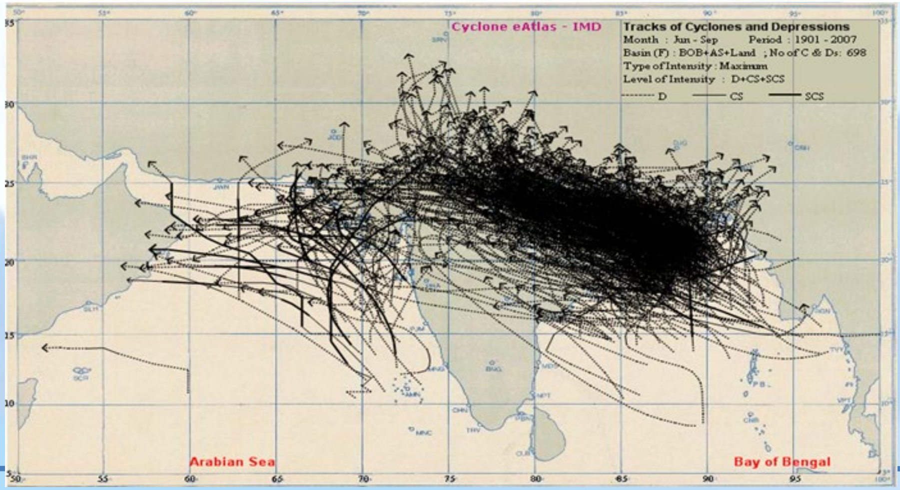


Spatial distribution of rainfall immediately brings out its strong dependence on the orography. The Western Ghats of the peninsula and the great Himalayan arc extending from Kashmir to Assam in the north and hills of Burma and Khasi and Jaintia Hills of Meghalaya have profound effect on the rainfall of India. The heavy orographic rainfall on the windward side of hill ranges of Western Ghats, and the rapid decrease of rainfall on the leeward side of the hills.

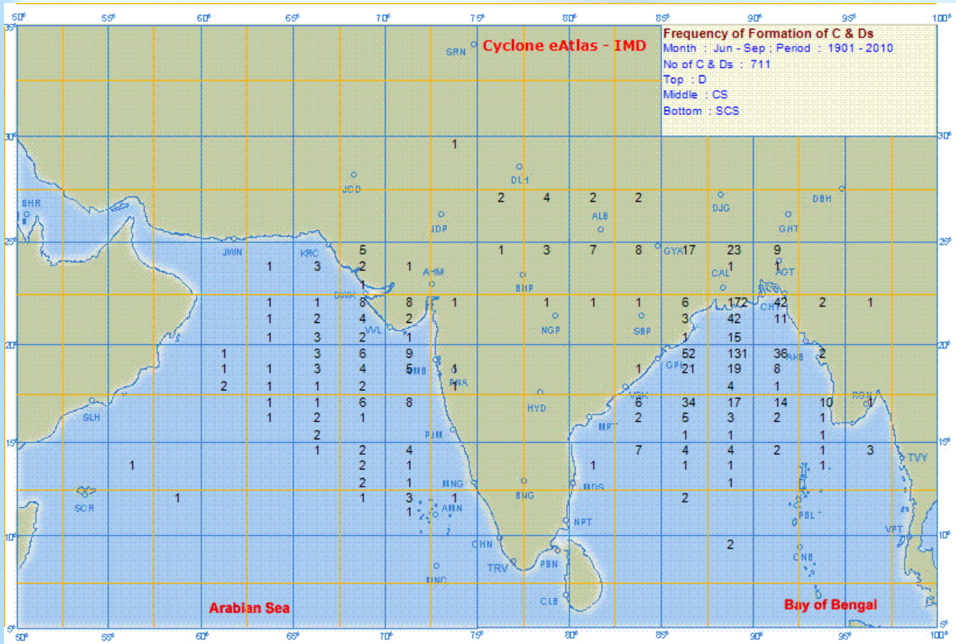
Mean Rainfall and LPS

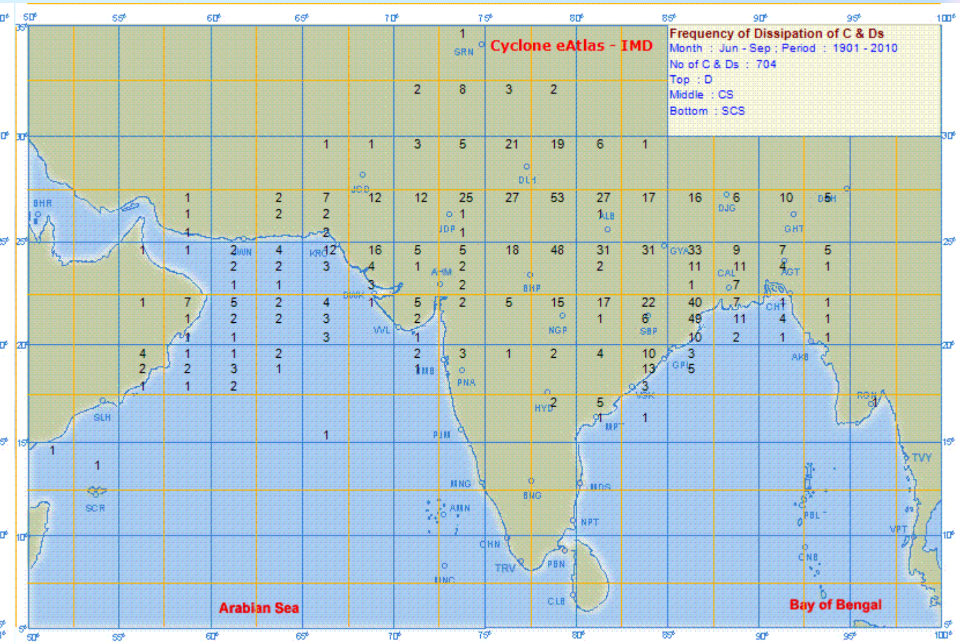




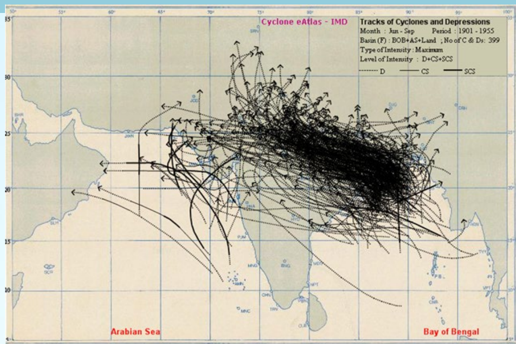


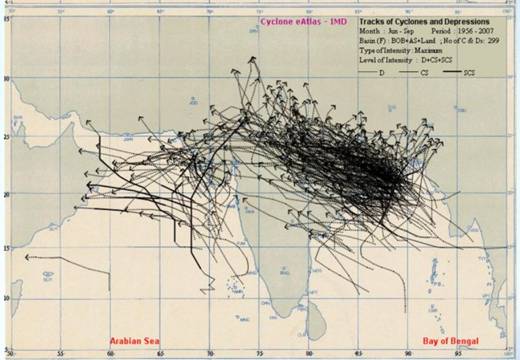
Frequency of Formation and Dissipation of MD and Cyclones: 1901-2010



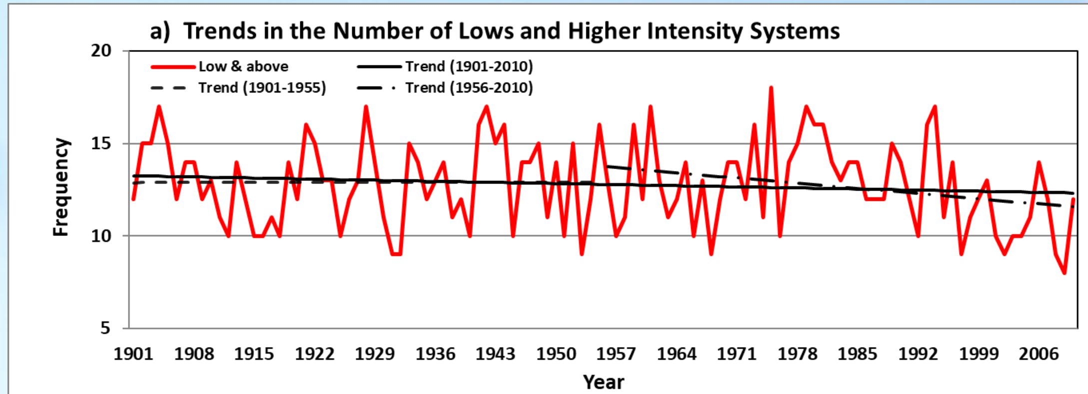


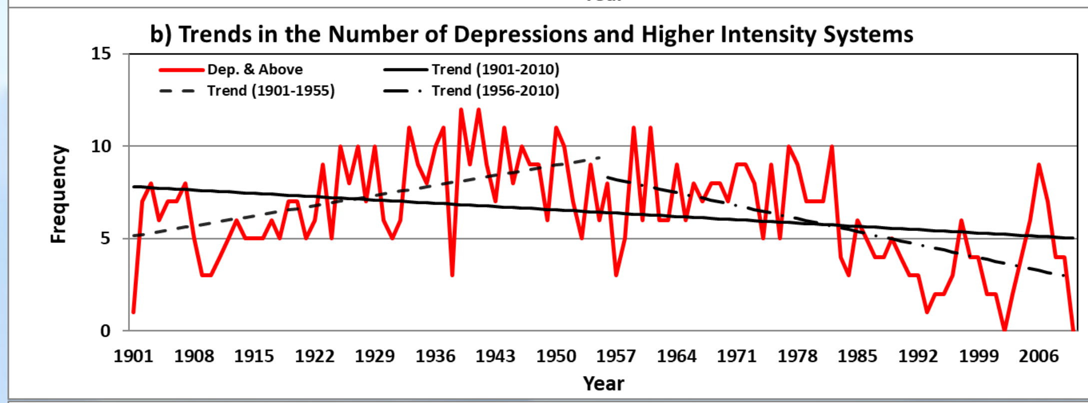
Number of Low Pressure Systems

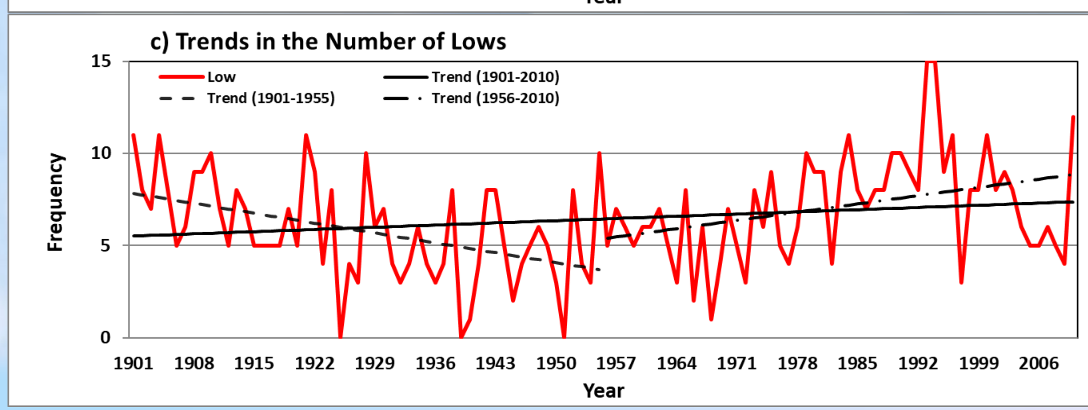




Number of Low Pressure					
	JUN	JUL	AUG	SEP	JJAS
Mean (1901-2010)	1.4	1.8	1.7	1.5	6.4
Sta Dev (1901-2010)	1.1	1.3	1.4	1.2	2.9
Number of MDs and stronger systems					
Mean (1901-2010)	1.3	1.5	1.8	1.7	6.4
Sta Dev (1901-2010)	1.1	1.3	1.3	1.1	2.8

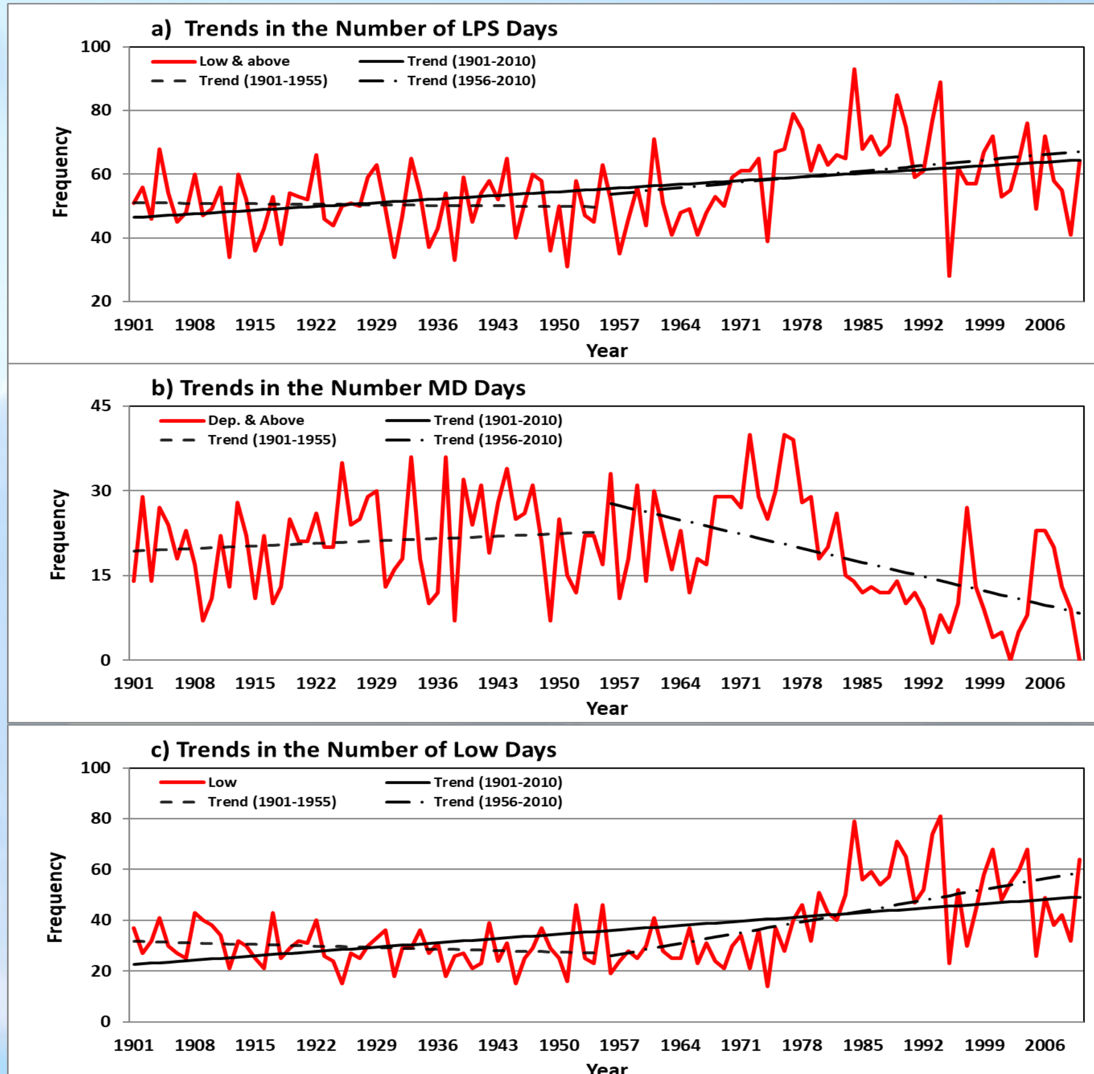


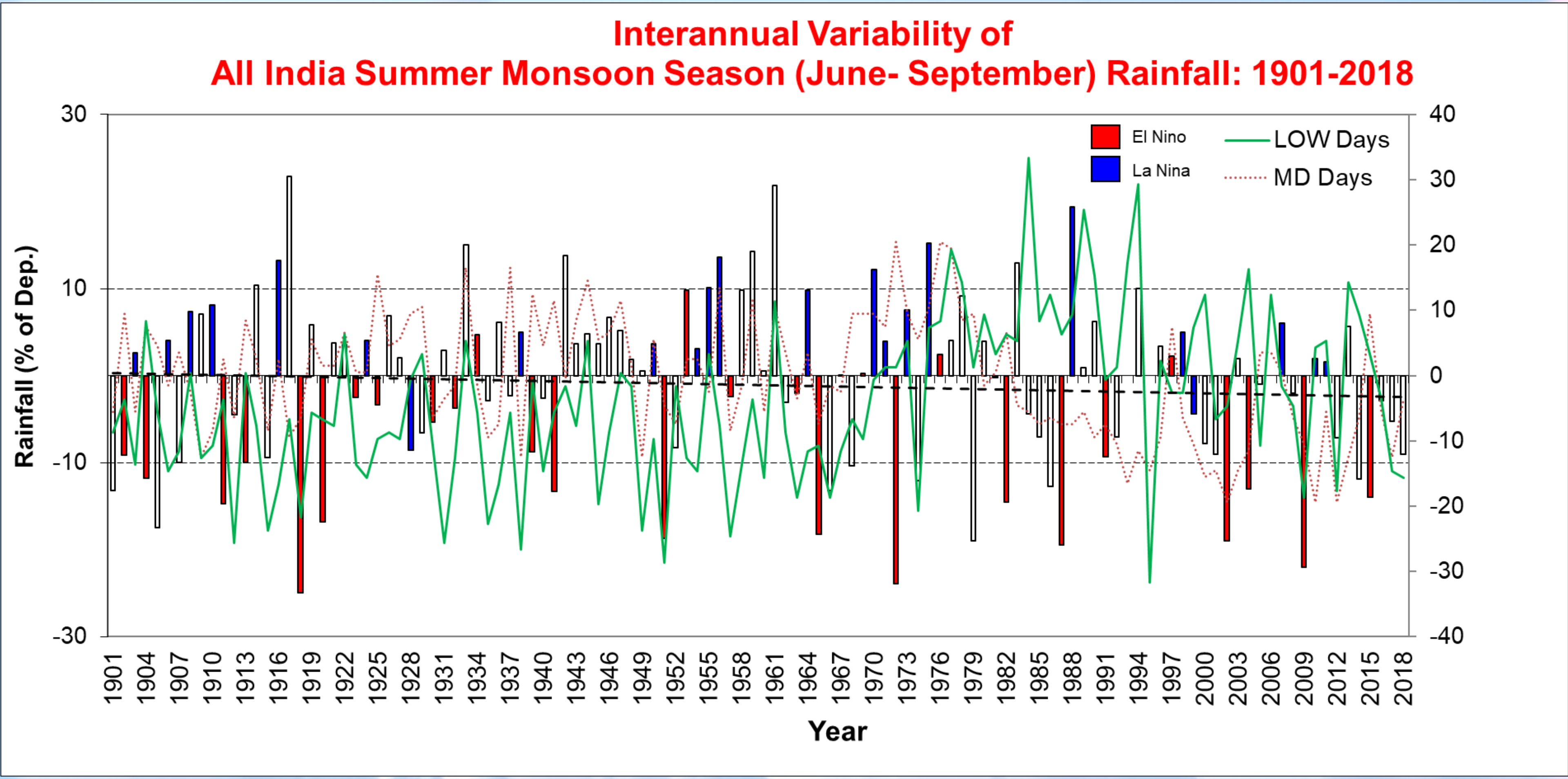




Interannual Variability & Trends of LPS days: 1901-2010

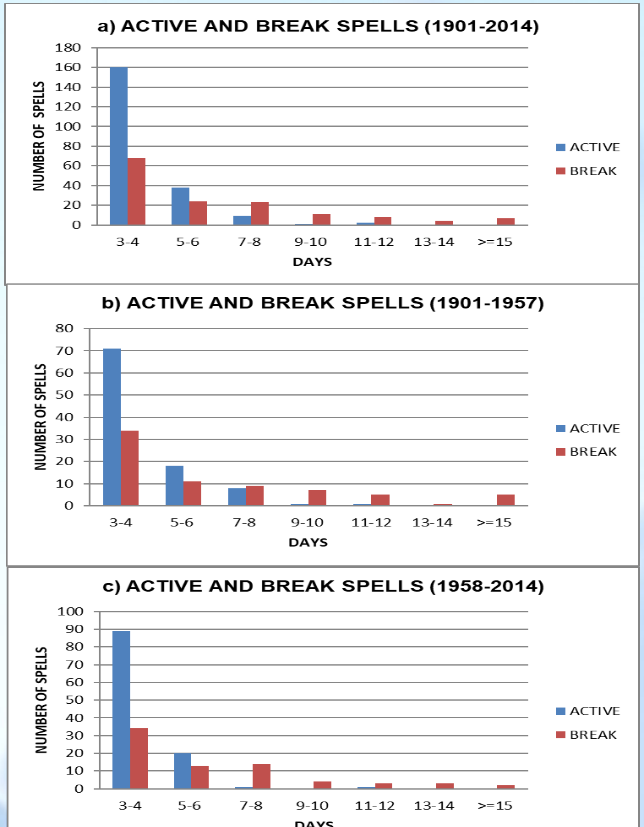
Number of Low Pressure Days					
	JUN	JUL	AUG	SEP	JJAS
Mean (1901-2010)	6.3	8.8	10.9	10.0	35.9
Sta Dev (1901-2010)	4.4	4.9	5.4	5.6	14.6
Number of Days of MDs and stronger systems					
Mean (1901-2010)	3.9	4.7	5.4	5.6	19.5
Sta Dev (1901-2010)	3.2	4.1	4.6	4.4	9.2

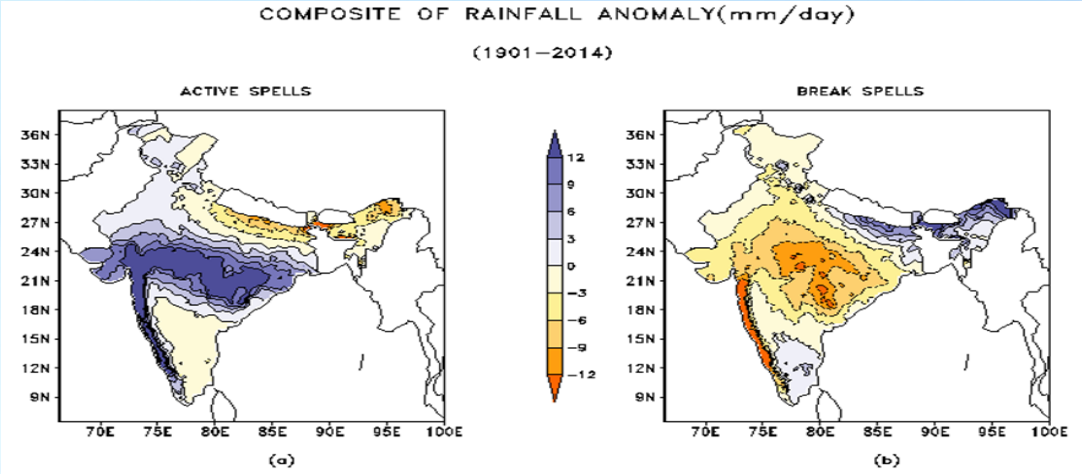


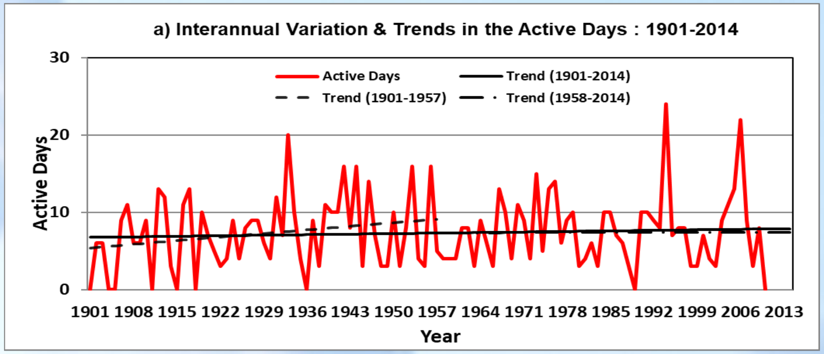


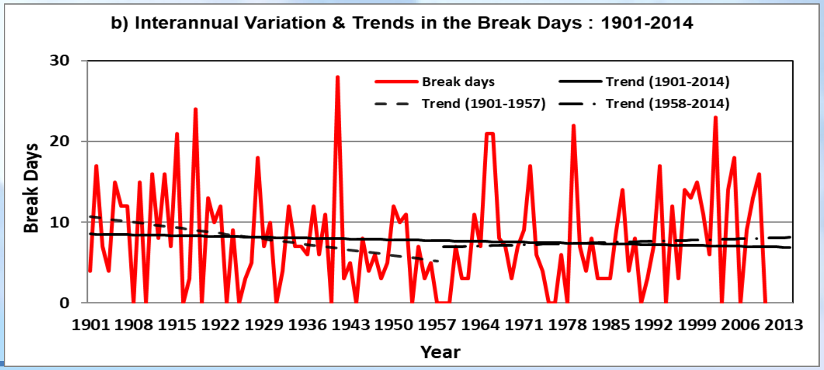
C.C. ISMR Vs Low Days = 0.04　　**C.C. ISMR Vs MD Days = 0.13**

Active and Break Monsoon Events





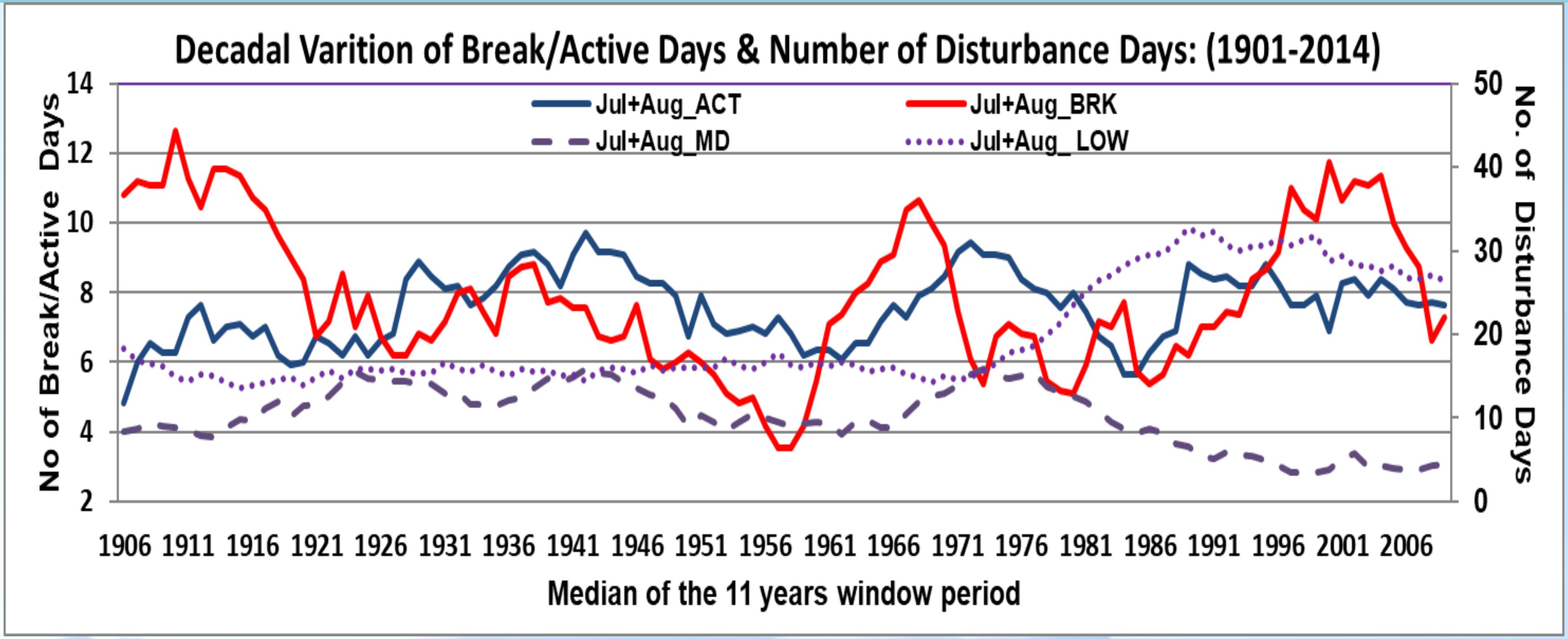




Increase in the active spells by about 12% in the in the second half, mainly in the short duration (3-6 days) spells.

The break and active days were identified using the criteria suggested by Rajeevan et al. (2010) but using IMD high resolution (0.25° X 0.25°) gridded daily rainfall data

Decadal Variation of Break/ Active Days of LPS days



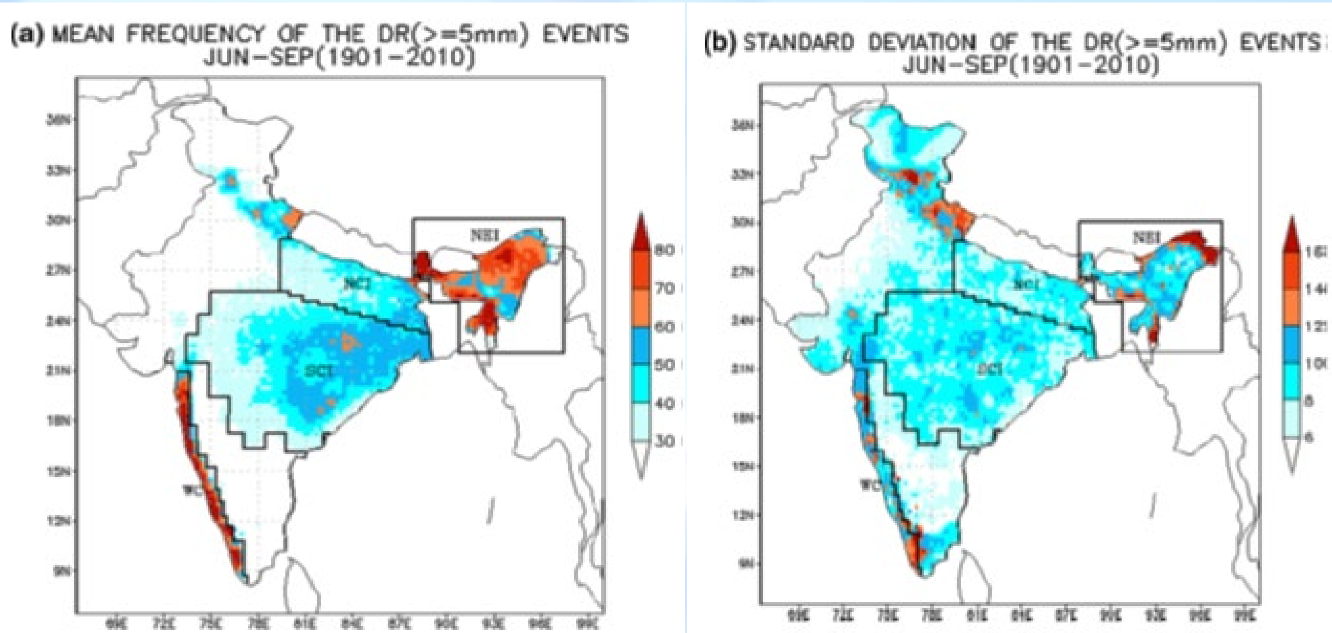
Decadal variations of break days showed an out phase of relationship with MD days.

Relatively stronger in phase relationship between MD days and active days till around early 1980s which reversed later due to sudden decrease in the MD days.

Post early 1980s, both the active & break days were in the increasing phase, which was also coincided with the sudden and significant increase in the number of days of monsoon lows (LOW).

The LOWs, which generally have short life helped in the occurrence of active spells of short duration. Thus, post early 1980's, the increase in the active days covering short duration active spells caused by the significant increase in the LOW days compensated the decrease in the active days covering relatively long duration active spells caused by the MD days. This lead to the out of phase relationship between MD days and the active days post early 1980s

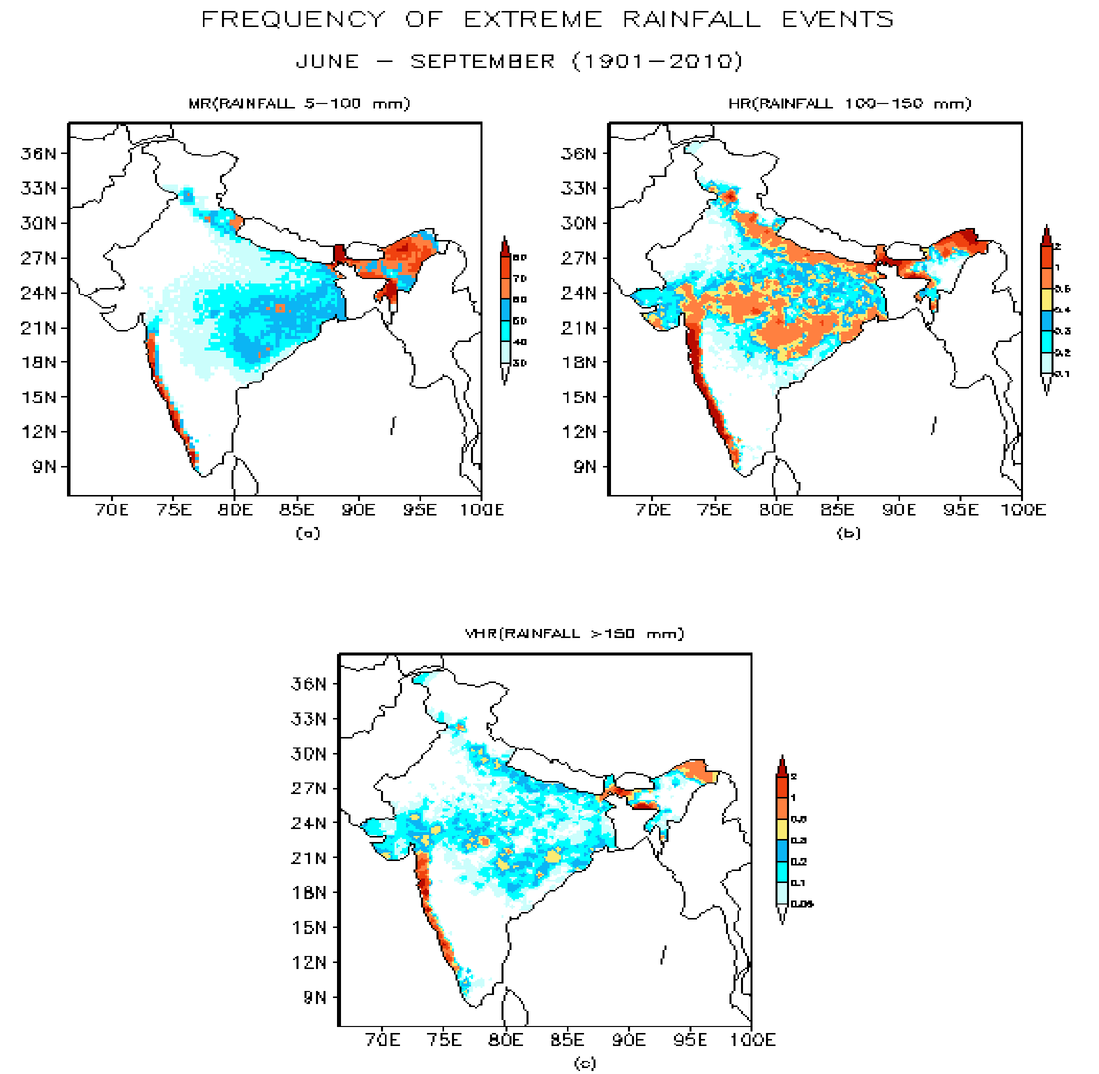
Results: Mean and SD of ER Frequency: Domains of Regions Under Study



- Extreme rainfall (ER) events are defined as rainfall events with ≥5mm.
- ER events were classified into three categories;
  - Moderate rainfall (≥5mm to 100mm) or MR events,
  - Heavy rainfall (≥100mm to 150mm) or HR events and
  - Very heavy rainfall (≥150mm) or VHR events.

Over CI, the occurrence of ER events was highest in the eastern half of the region, which is the area most impacted by the monsoon low pressure systems (monsoon lows, depressions etc.) that form in the Head Bay or neighbourhood. The monsoon low pressure systems that form over the Bay of Bengal, in general, move westward to northwest wards along the monsoon trough or northwards and then re-curve. However, some of these systems weaken over the eastern half of the CI. Over WC & NEI, where the orography plays an important role, the frequency of ER events was much higher over most of the areas.

Frequency of MR, HR & VHR Events

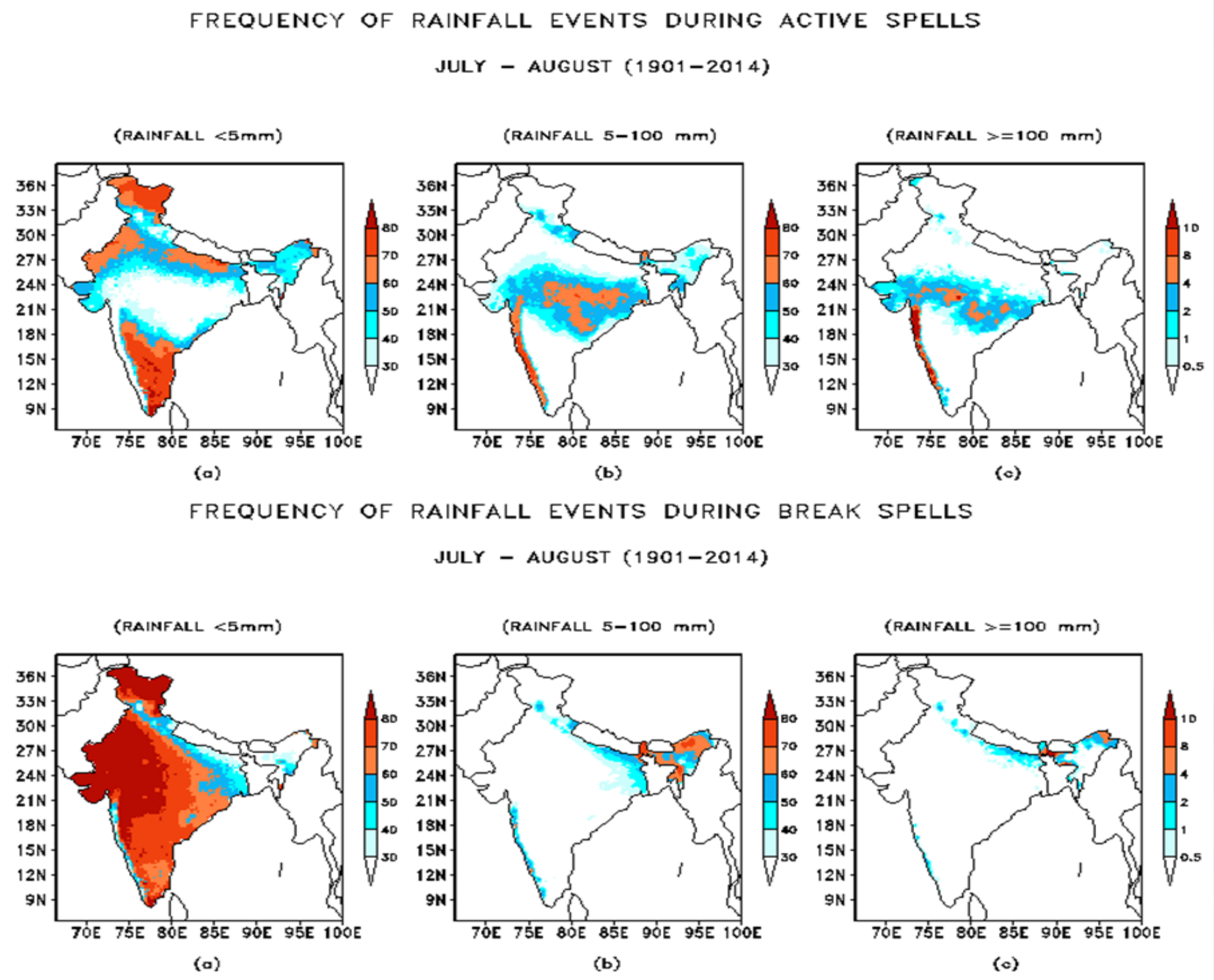


The spatial distribution of the HR & VHR events (figures 2b & 2c) show that most areas of WC received HR & VHR events relatively more compared to other areas of the country but with nearly same frequency

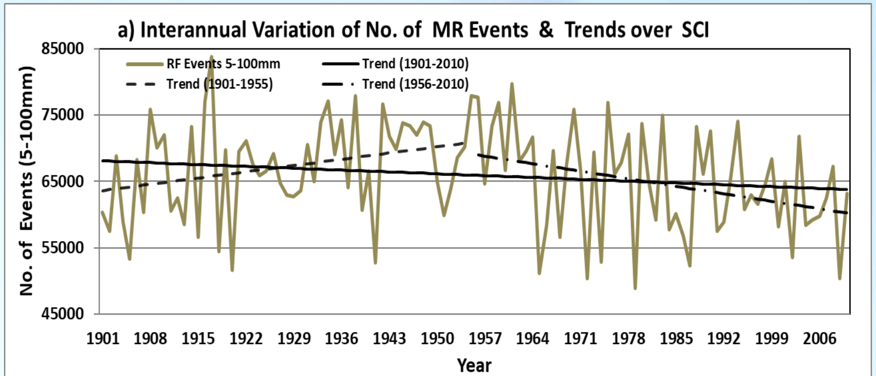
Over NEI, the maximum frequency of HR and VHR events occurred over northern parts of SHWB, Meghalaya & neighbouring Assam, and highlands of Arunachal Pradesh

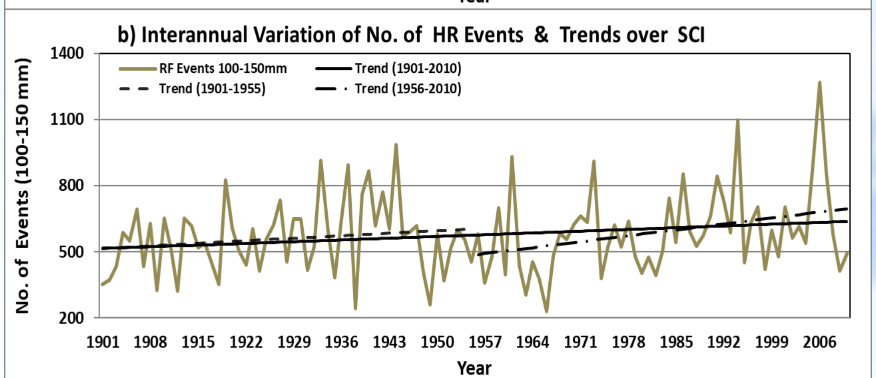
Over CI, there are two distinct zones of maximum frequency of HR & VHR events. First zone is along the foothills of Himalayas and the second is the much broader zone in the southern part of the central India extending from east Gujarat in the west to north Odisha and neighbouring Gangetic west Bengal in the east. These two zones correspond to the opposite zones where the maximum rainfall belt shifts between active and break monsoon conditions

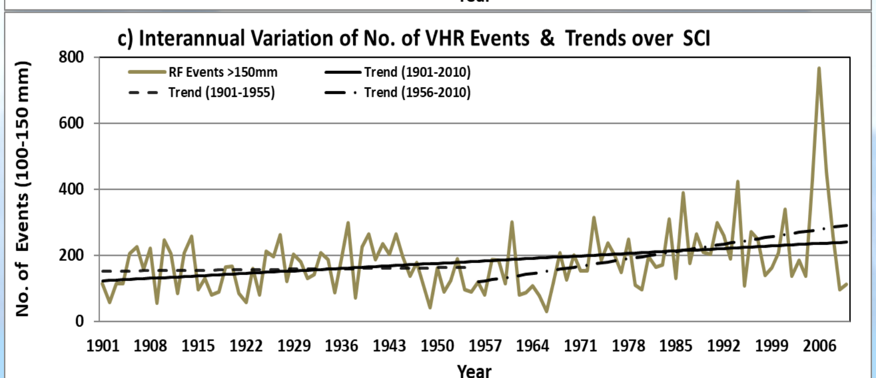
ER events: Active Vs Break Monsoon

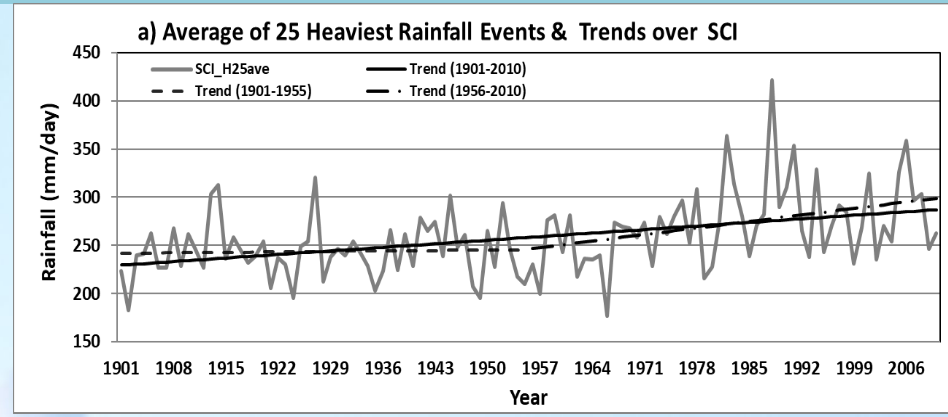


Trends in the Frequency and Intensity of ER Events over South Central India





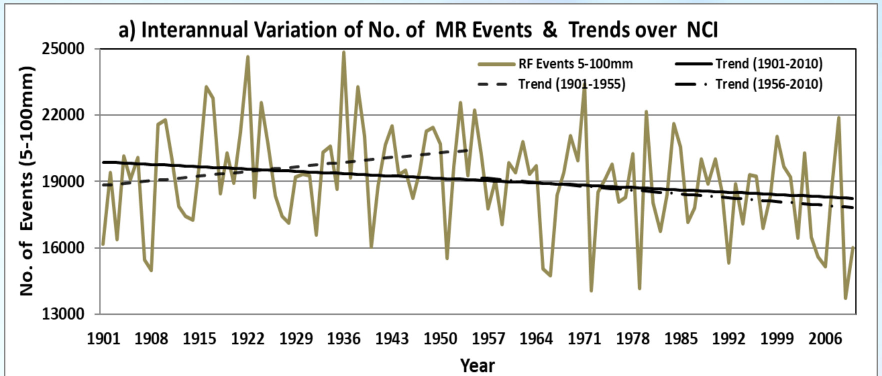


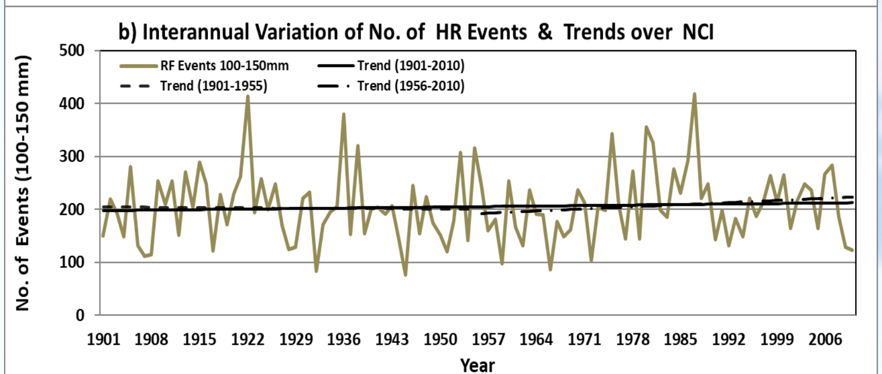


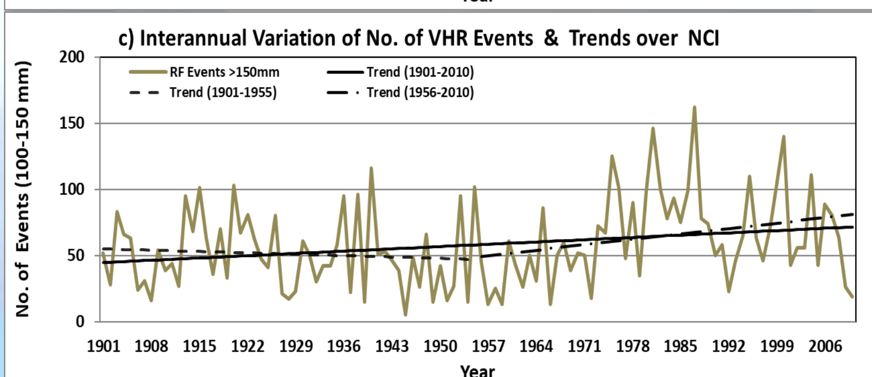
Trends in the Rainfall Over SCI

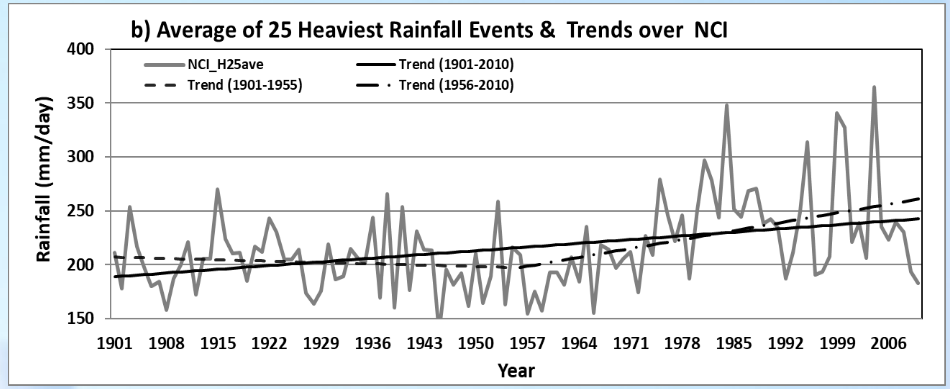
Trends/ decade in	Rainfall Categories	Period		
		1901-2010	1901-1955	1956-2010
Area Averaged Rainfall (mm/day)	≥0 mm	-0.02	0.16*	-0.10
Aggregated number of grid point events over the region (number)	≥5mm	-373.94	1368.2*	-1546.45*
	5mm-100mm	-395.96	1349.8*	-1616.74**
	100-150mm	11.24*	16.35	38.48*
	≥150mm	10.78**	2.08	31.80**
Average of 25 heaviest rainfall events (mm/day)	≥5mm	5.28**	0.69	9.67**

Trends in the Frequency and Intensity of ER Events over North Central India





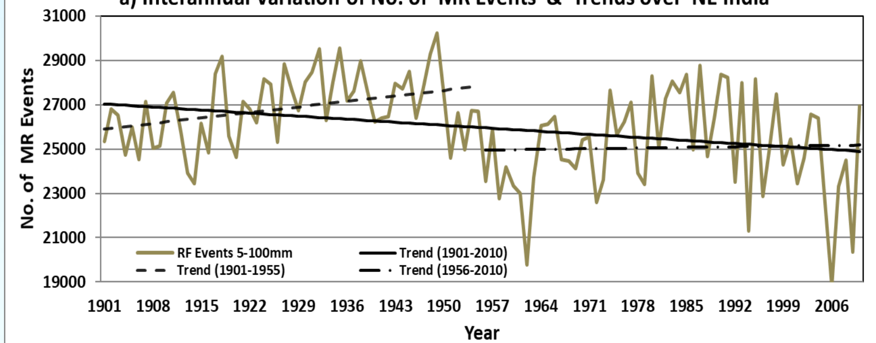




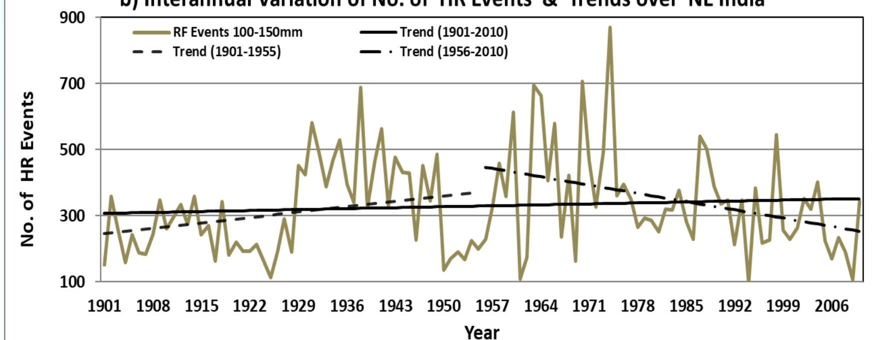
Trends in the Rainfall Over NCI

Trends/ decade in	Rainfall Categories	Period		
		1901-2010	1901-1955	1956-2010
Area Averaged Rainfall (mm/day)	≥0 mm	-0.06	0.09	-0.05
Aggregated number of grid point events over the region (number)	≥5mm	-145.77*	296.41	-235.29
	5mm-100mm	-149.60*	298.67	-246.83
	100-150mm	1.36	-0.79	5.70
	≥150mm	2.46**	-1.47	5.84*
Average of 25 heaviest rainfall events (mm/day)	≥5mm	4.92**	-1.76	11.75**

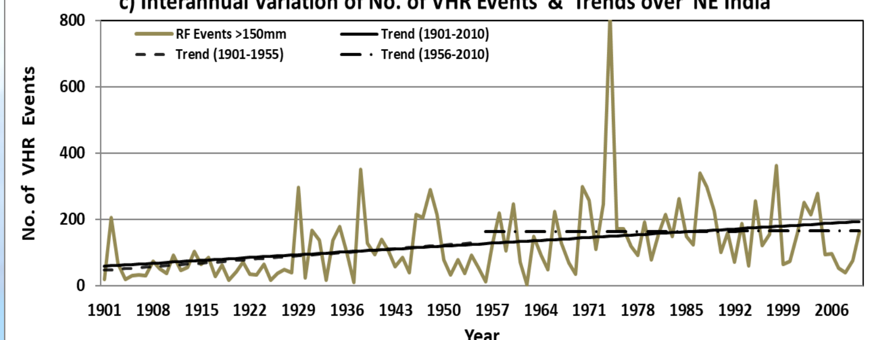
Trends in the Frequency and Intensity of ER Events over northeast India



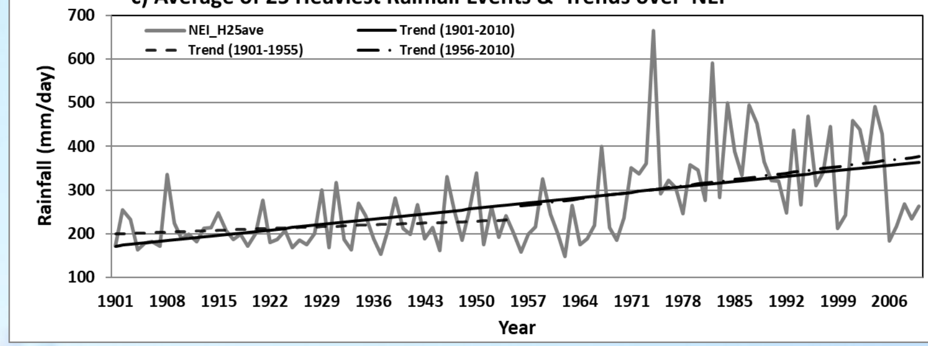
a) Interannual Variation of No. of MR Events & Trends over NE India



b) Interannual Variation of No. of HR Events & Trends over NE India



c) Interannual Variation of No. of VHR Events & Trends over NE India

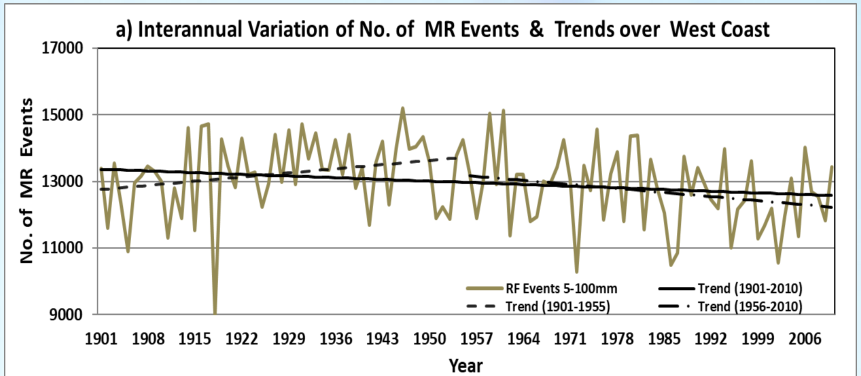


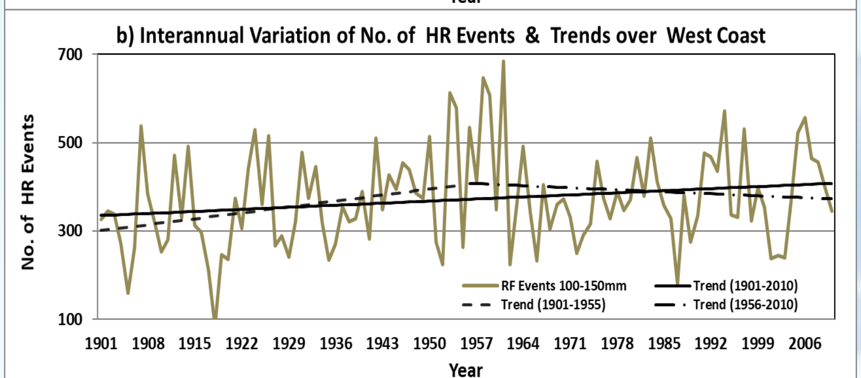
c) Average of 25 Heaviest Rainfall Events & Trends over NEI

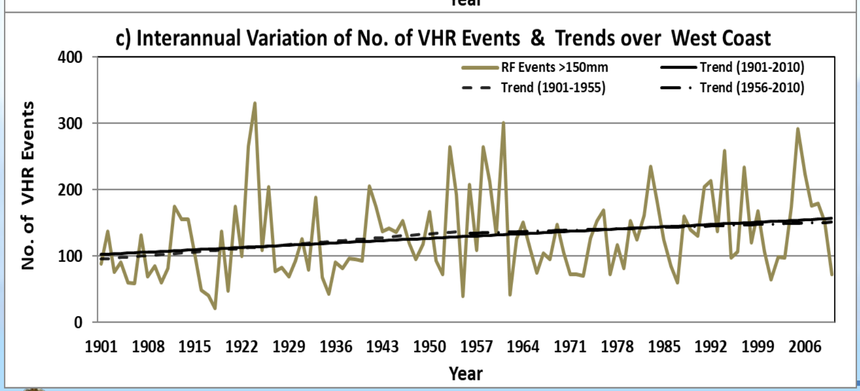
Trends in the Rainfall Over NEI

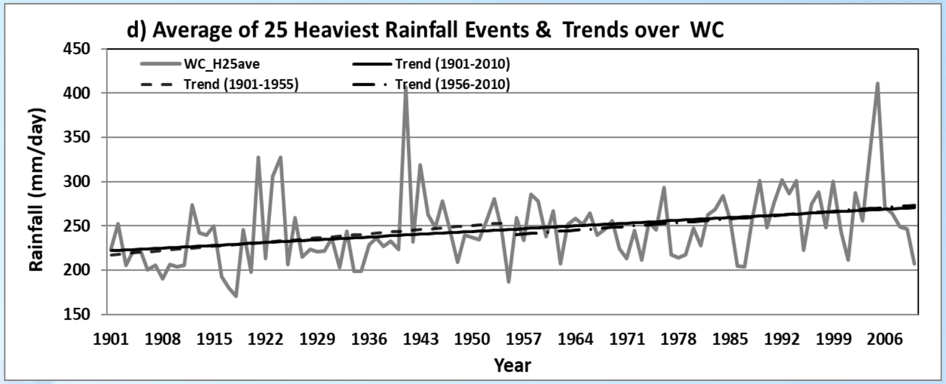
Trends/ decade in	Rainfall Categories	Period		
		1901-2010	1901-1955	1956-2010
Area Averaged Rainfall (mm/day)	≥0 mm	-0.11*	0.31**	-0.27
Aggregated number of grid point events over the region (number)	≥5mm	-179.9**	395.3**	6.2
	5mm-100mm	-196.3**	356.3**	41.7
	100-150mm	4.1	23.5*	-35.7**
	≥150mm	12.3*	15.5*	0.2
Average of 25 heaviest rainfall events (mm/day)	≥5mm	17.60**	5.97	20.93*

Trends in the Frequency and Intensity of ER Events over west coast





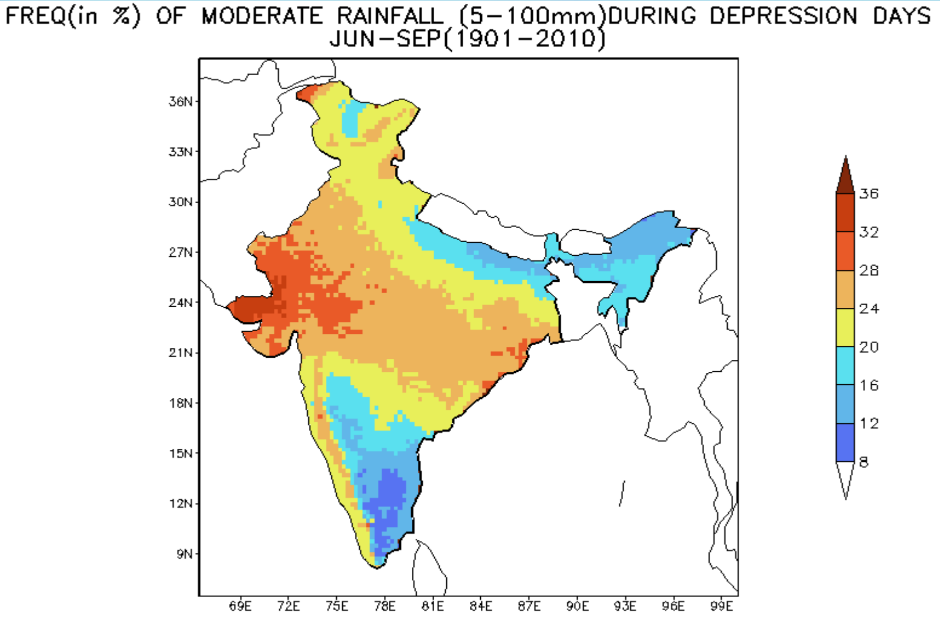


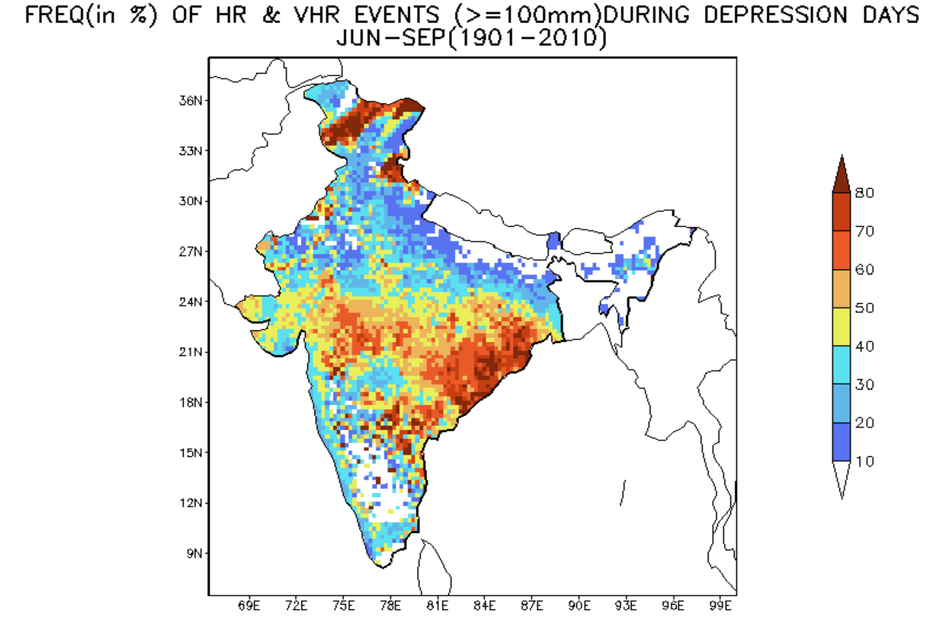


Trends in the Rainfall Over WC

Trends/ decade in	Rainfall Categories	Period		
		1901-2010	1901-1955	1956-2010
Area Averaged Rainfall (mm/day)	≥0 mm	0.05	0.45*	-0.27
Aggregated number of grid point events over the region (number)	≥5mm	-60.8	205.6*	-177.7
	5mm-100mm	-72.4*	178.6	-174.3
	100-150mm	6.7*	19.2*	-6.5
	≥150mm	5.0**	7.8	3.0
Average of 25 heaviest rainfall events (mm/day)	≥5mm	4.49**	6.74	6.12*

Composite Frequency Maps During MD days:
Percentage of Frequency of ER Events During the Season

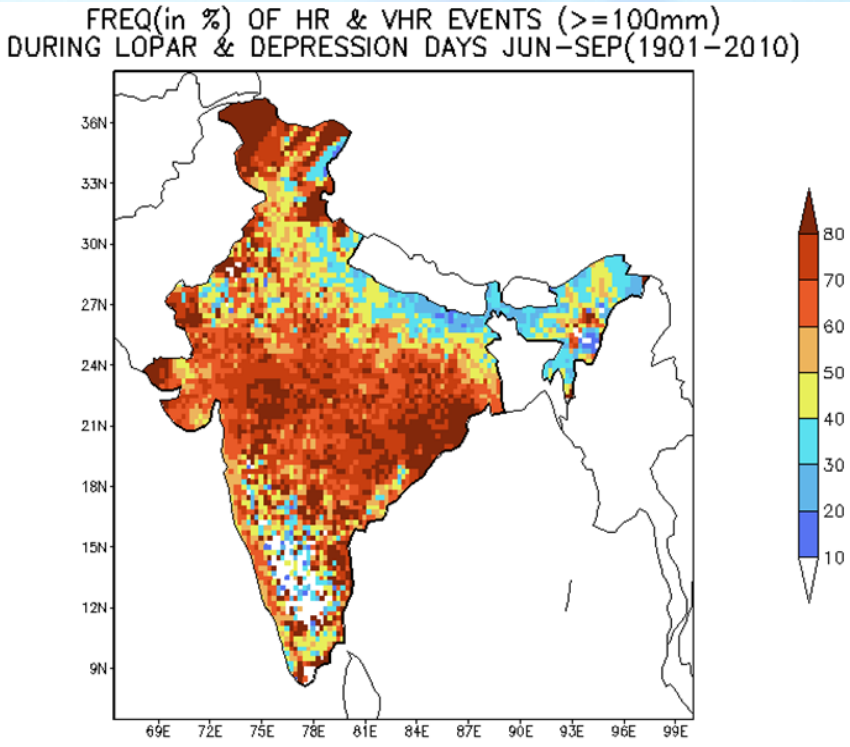




The percentage mean frequency maps of MR events showed that over most parts of the country about 45-65% (20-40%) of the MR events were associated with the LPS days (MD days). Over northeast, areas along the foot hills of Himalayas and southeast Peninsular region only about 30-45% (8-20%) of the MR events were associated with the LPS days (MD days).

over most areas of the eastern part of the monsoon trough zone, about 60-90% of the CHR events during the season were associated with the MD days. Over many areas of central parts of monsoon trough zone, the contribution of MD days to CHR events was about 40-70%. Over western part of the monsoon trough region and along the west coast, less than 40% of CHR events were associated with MD days. On the other hand, along the foothills of Himalayas, less than 20% of CHR events were associated with the MD days.

Contribution of LPS in The occurrence of the CHR events

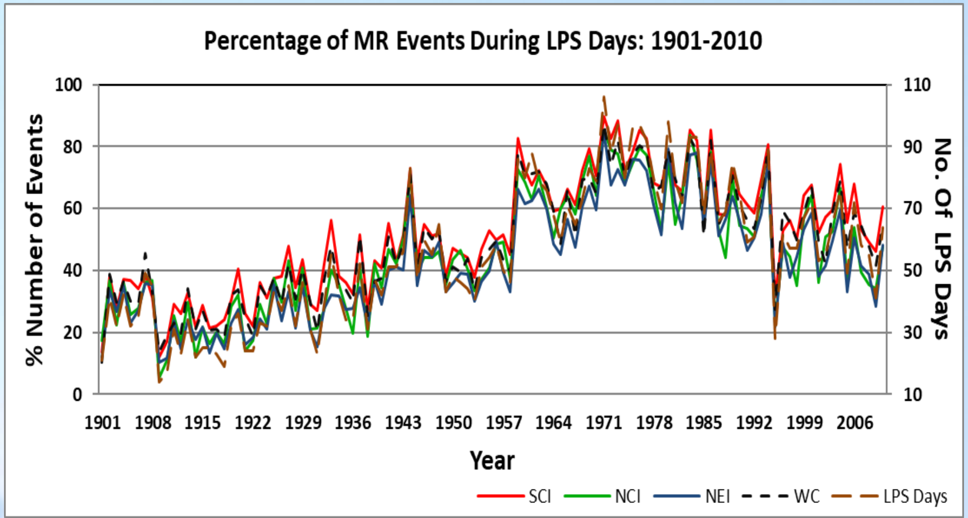


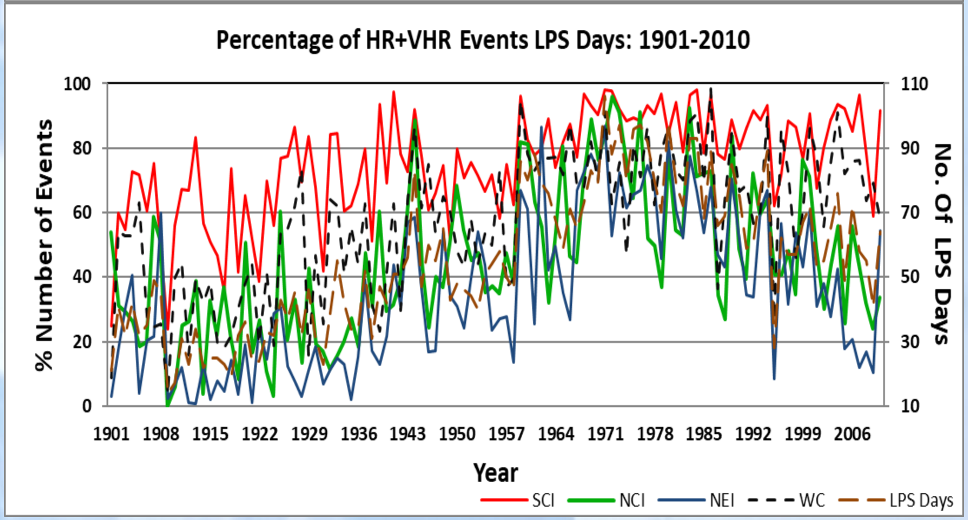
About 70-90% of the CHR (HR +VHR) events over most areas of the monsoon trough zone region and north India occurred during the monsoon season were related to the LPS days. This is the same zone that along with the areas close to the foothills of Himalayas and along the west coast of the country receive climatologically higher frequency of CHR events. But most areas in the WC received only about 50-70% of the seasonal CHR events during LPS days indicating that 30-50% of the CHR events occurred over the season over these areas were not associated with the LPSs. Similarly, over most areas along the foothills of Himalayas (except in the western end), only about 20-40% of the CHR events occurred over the season were associated with the LPSs.

Thus it is clear that whereas MDs and stronger systems contribute most of the CHR events over eastern part of the monsoon trough zone, systems weaker than MDs contribute most the CHR events over western part of the monsoon trough zone.

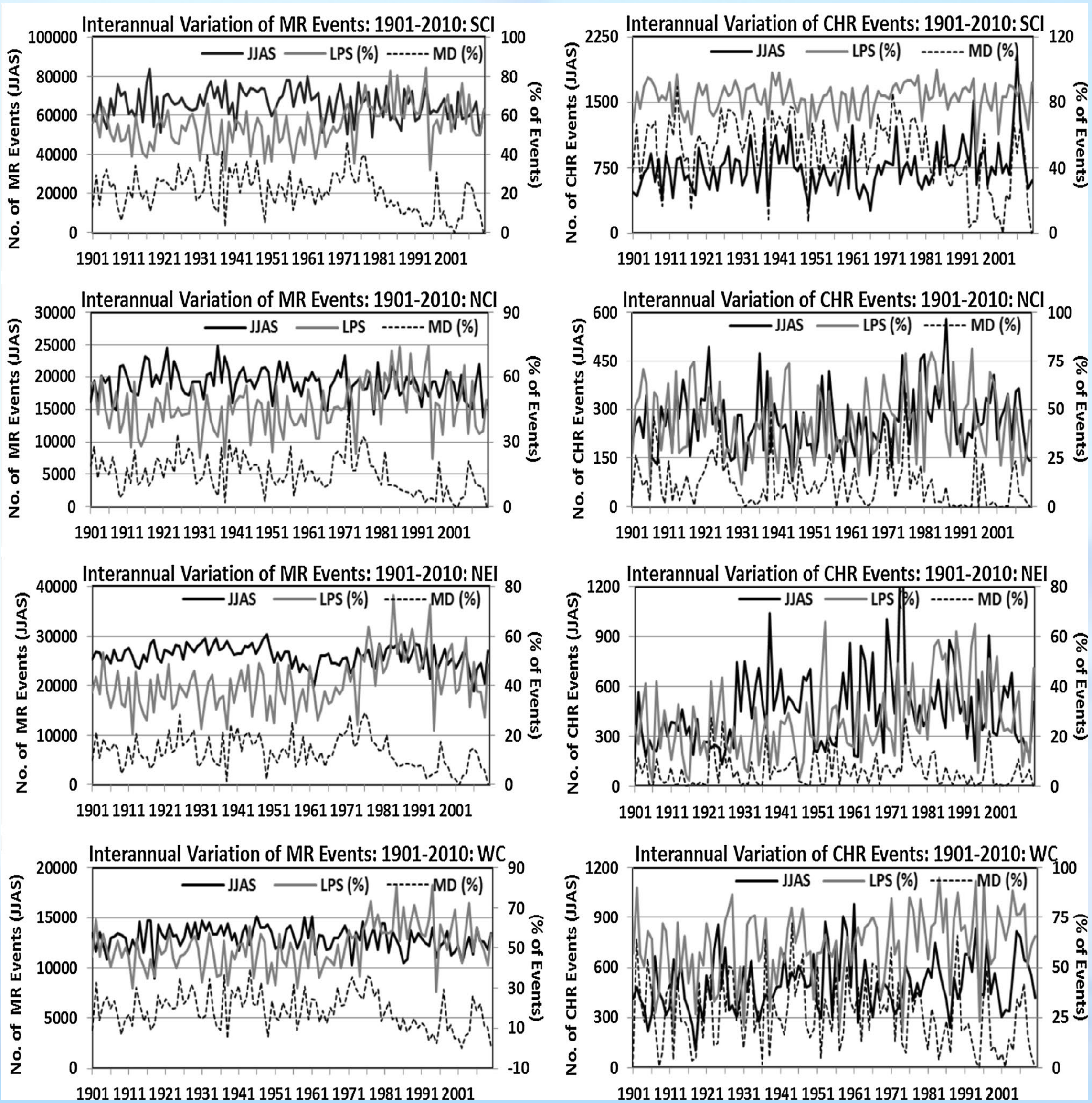
Association between increasing trends in LPS days and CHR events over CI

- Post 1970, in spite of significant decreasing trend in the MD days, increasing trends were observed in the contribution of LPS to the total CHR events over all the four regions.
- This was due to the significant increasing trend in the LOW days (magnitude wise higher than the decreasing trend in MD days) observed post 1970.
- During the data period, the LPS associated CHR events more or less followed the total CHR events over all the four regions (except WC during the second half). (see next slide)
- Thus the significant increasing trends in the HR and VHR events over CI (SCI and NCI) and decreasing trend in HR events over NEI during the recent period (1956–2010) seems to be primarily due to the increasing trend in the monsoon lows.
- Increased moisture content in the atmosphere associated with the global warming trend might have also helped.





Impact of LPS on the interannual variability of the ER events



- **Strong in phase relationship in the inter-annual scale was observed between LPS/MD days and associated MR events as well as CHR events over all the four regions.**
- **The C.C.s of LPS (MD) days with the associated MR events for the period 1901-2010 over the four regions were in the range of 0.87-0.96 (0.92-0.96) and highly significant.** The association of the MR events was strongest for WC and weakest for NCI
- **The C.C.s of LPS (MD) days with the associated CHR events for the period 1901-2010 over the four regions were in the range of 0.54-0.61 (0.52-0.81).** The association of CHR events was strongest for SCI in respect of both the LPS and MD days and weakest in respect of LPS (MD) days for NCI (NEI)
- **This indicates regional difference in the impact of LPS days particularly of MD days on the occurrence of CHR events.**

Reasons for the Regional Difference in the CHR (HR & VHR) events Associated with LPS

During monsoon season, in an average about 13 LPSs (form over the India monsoon region and majority of them form over the head Bay of Bengal or central India. The strong moisture convergence associated with these systems cause CHR events initially over eastern parts of the central India. Subsequently these systems mostly follow a northwest ward track along the quasi-stationary monsoon trough across central India (most of these area comes under SCI) causing active monsoon conditions and CHR events over the region during its life span of about 3–6 days.

Associated with the formation LPSs over the Bay and their movement along the normal tracks also strengthens monsoon flow and produce conducive conditions for CHR events along the windward side of the Western Ghats.

On the other hand, while passing through its normal tracks, the moist monsoon winds get diverted towards system with maximum moisture convergence occurring in the forward left sector of the systems resulting CHR events over the region. This causes reduction in the moisture supply to NEI by resulting in conditions less conducive for deep convective activity and reduced CHR events over the region. Once crossed over to land, LPSs start weakening due to interaction with the land surface. As a result, in most cases, the LPSs reaching over northwest India are weaker than MD and contribute to most of the CHR events over these areas. At the same time, in spite of low contribution of the LPSs/MDs to the CHR events (≤44/12 %), higher climatological frequency of CHR events over NCI and NEI can be attributed to the break monsoon conditions.

Thank you

Conclusions

- Significant long term trends in the number and intensity of the ER events were observed in all the 3 geographical regions under study (CI, NEI and WC). However, the signs and magnitude of the trends in the frequency of the ER events differed from region to region.
- Over all the 3 regions, the trends in the intensity of ER events (average of 25 highest rainfall events) were significant & increasing during the second half and the total period
- Over CI, significant decreasing trend in MR events and significant increasing trends in the HR and VHR events were observed during the second half in consistent with earlier studies.
- Over NEI, significant increasing trends were observed in the frequency of all the 3 categories of ER events during the first half. During the second half, only significant trend was observed in the HR events (decreasing at 99% level) over NEI.
- Over WC, the increasing trends in the frequency of all the 3 categories of ER events during the first half with significant trend only In HR events. In the second half, no significant trends were observed in all the categories of ER events.

Conclusions

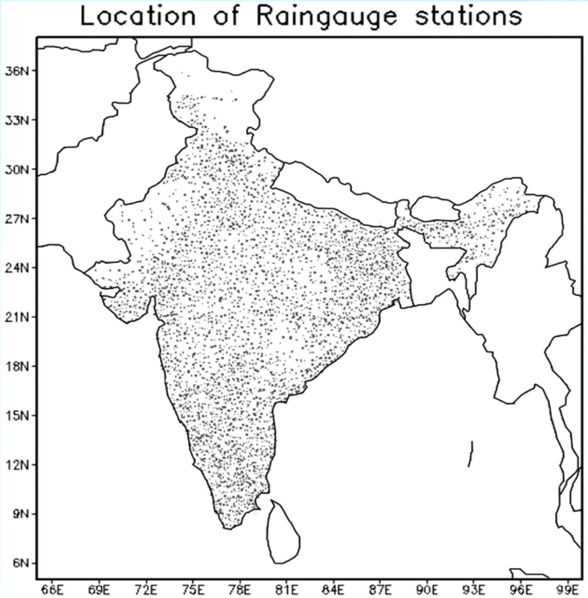
- About 20-40% of MR events over CI & WC and about 10-20% of MR events over NEI were associated with the MD days
- About 40-80% of HR & VHR events over south CI and about 20-50% of HR & VHR events over WC were associated with the MD days. This was only about 10% over NEI.
- The % of ER events associated with the MD days over all the regions showed decreasing trend in associated with the decreasing trend in the MD days.
- The increasing trend in the HR and VHR events during the season over CI in spite of decreasing trend in the frequency of MDs is due to the increasing trend in the frequency of Lows.
- The disaster potential (flood risk) over CI during the recent years have increased due to significant increasing trends in the frequency (areal coverage) of HR and VHR events as well as the intensity of ER events over CI during the recent period.
- On the other hand, the disaster potential over NEI & WC has increased in terms of the intensity of the rainfall events.

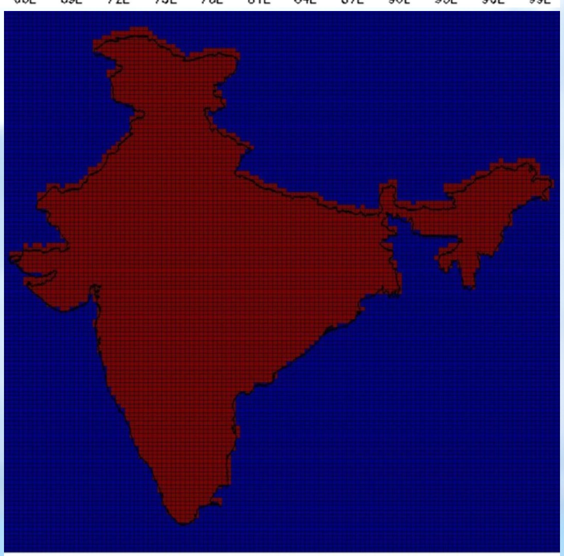
Factors that influence the rainfall pattern over India during the SW Monsoon Season

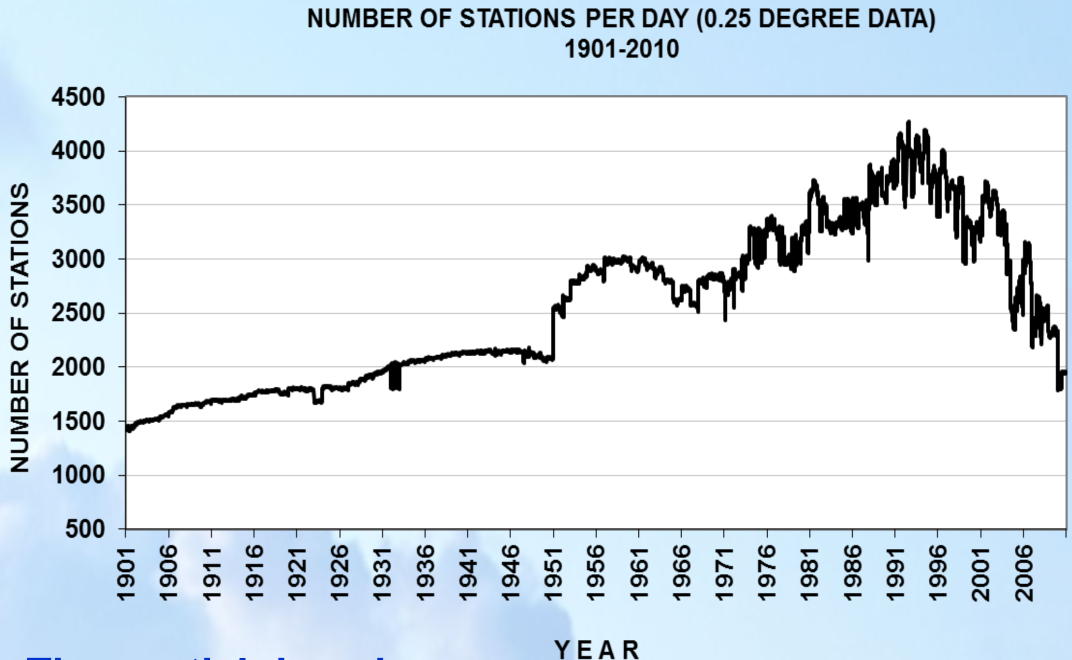
- Orographic lifting across the mountain slopes and
- Dynamical lifting caused by the surface convergence and/or upper-level divergence due to changes in the atmospheric conditions.
- The changes in the atmospheric conditions is caused by the changes in the location and intensity of following components of the monsoon, which have important role in varying the lifting of the moist air across the region.

- Semi-permanent systems such as Seasonal Heat Low (HL), Monsoon Trough (MT), Tibetan Anticyclone (TA), Tropical Easterly Jet (TEJ) and Low-Level Jet (LLJ) or Somali jet, which have profound impact on the overall strength of the monsoon circulation
- Transient synoptic systems such as troughs, upper air cyclonic circulations, lows, depressions, cyclones etc. over Indian monsoon region and west pacific (their intensity and track) that cause an increase in moisture convergence over the Western Ghats.
- Monsoon intra seasonal Oscillation (MISO) that cause northward propagation of monsoon trough. MISO can occur associated with or without the Madden Julian Oscillation (MJO), which is a traveling convective pattern that propagates eastward and is the largest element of the intraseasonal (30- to 90-day) variability in the tropical atmosphere.

Data Used







The spatial domain:

6.5°N to 38.5°N (129 points) & 66.5°E to 100°E (135 points)

The temporal domain:

1st January, 1901 to 31st December, 2010.

Grid Resolution: 0.25°X 0.25°

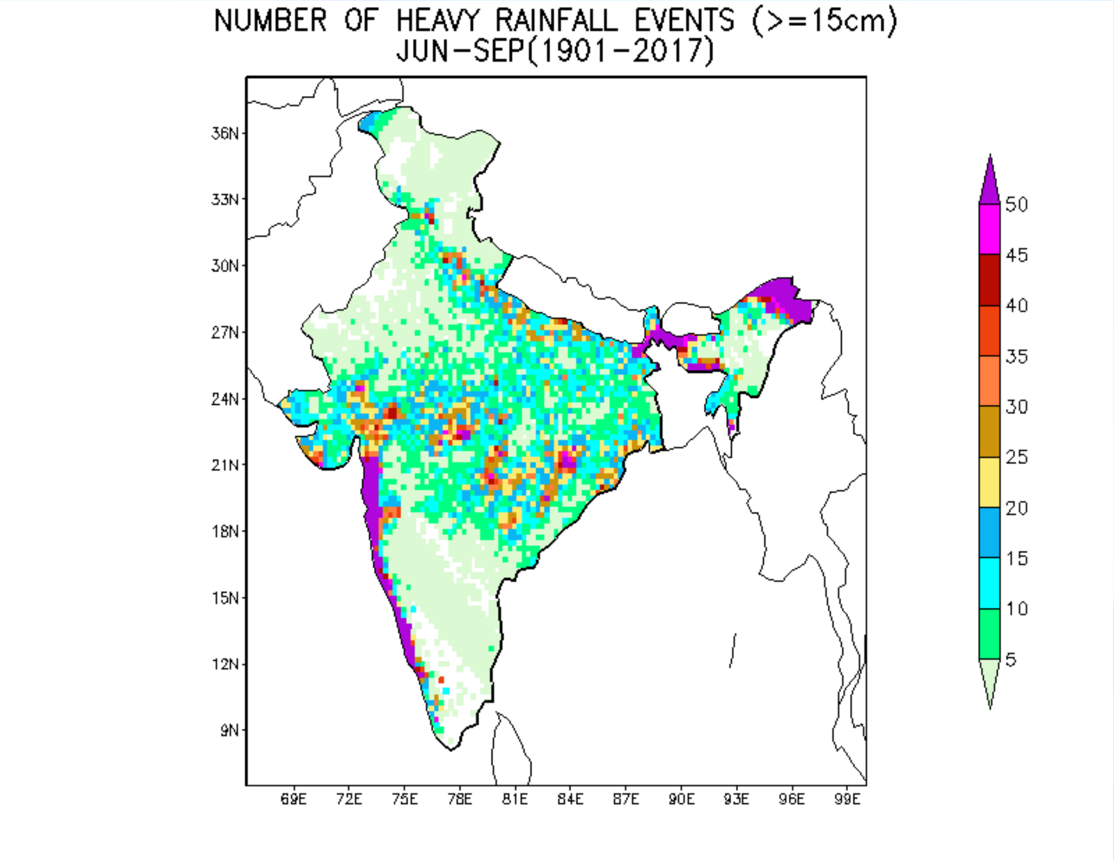
No of grid points in the main land: 4964

Data Used

Low pressure (Low) and Monsoon Depression (MD) information for the period 1901-2019

A LOW (MD) day was defined as the day when a monsoon low pressure system (LPS) of intensity lower (equal to or higher than) a depression was observed in the surface chart of the Indian monsoon region (0-30^{o}N, 50^{o}E-110^{o}E) for 24hrs from 00UTC of that day. When there are 2 or more LPSs observed on the same day, the count will be made towards system with stronger intensity.

All India summer monsoon Rainfall for the period 1901-2019.



NUMBER OF HEAVY RAINFALL EVENTS (>=15cm)
JUN-SEP(1901-2017)
36N
33N
30N
27N
24N
21N
18N
15N
12N
9N
69E 72E 75E 78E 81E 84E 87E 90E 93E 96E 99E
50
45
40
35
30
25
20
15
10
5