Third Pole Climate Forum

The third session of the Third Pole Climate Forum (TPCF-3) and meeting of the Third Pole Regional Climate Centre Network (TPRCC-Network) Task Team New Delhi, India3–5 June 2025.

WMO Third Pole RCC Network (In Demonstration Phase)

Hydro-meteorological Extremes and Compound Climate Events in the Himalayas.

Presented by,

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The Himalayas: Climate Change Hotspot

★ **Atmospheric changes:**

- Warming rates exceed the global average; High elevation
- Increased interannual variability of monsoon
- Shift in the track and intensity of WDs
- Change in the rainfall and snow fall contributions
- Increase in extreme rain events

★ **Cryosphere changes:**

- Himalayan glaciers are retreating at rates of 10–60 meters per year
- Rise in the formation and expansion of glacier lakes (>5000)
- Rising trend in frequency and magnitude of GLOF, Avalanches
- Earlier snowmelt reduced water availability in late summer

★ **Hydrological changes**

- New flood prone areas have been emerged.
- Changing precipitation patterns affects streamflow dynamics
- Shift in peak streamflow timing due to earlier snowmelt
- higher short-term runoff due to cloudbursts
- Increase in disaster risk due to compound events


SIKKIM EXPRESS

OF THIS LAND, FOR ITS PEOPLE

WASHED AWAY IN A FLASH

❑ 21 GREF, ITBP lives ❑ 86 RCC base, houses ❑ North Skm Highway

1 month isolation for Chungthang

Teesta River towns put on alert

35% of Joshimath in high-risk zone

TIMES NEWS NETWORK

Dehradun: Approximately 35% of Joshimath, which faced severe land subsidence last year, is situated in a high-risk zone, according to Ranjit Sinha, secretary of the disaster management department. Sinha, and senior officials from Uttarakhand State Disaster Management Authority (USDMA), participated in a public consultation on rehabilitation and recon-

Uttarakhand government has earmarked 25 hectares of land for relocation of affected residents

sons said they were unwilling to relocate elsewhere. The secretary also said no new construction would be permitted in the town until experts verify that the land beneath Joshimath has stabilised. "The district administration will take action if any new construction is reported," Sinha said.

Meanwhile, Joshimath Bachao Sangharsh Samiti

The Newz Radar

Nearly 60 dead in Shimla landslide, other rain-related incidents

The Newz Radar

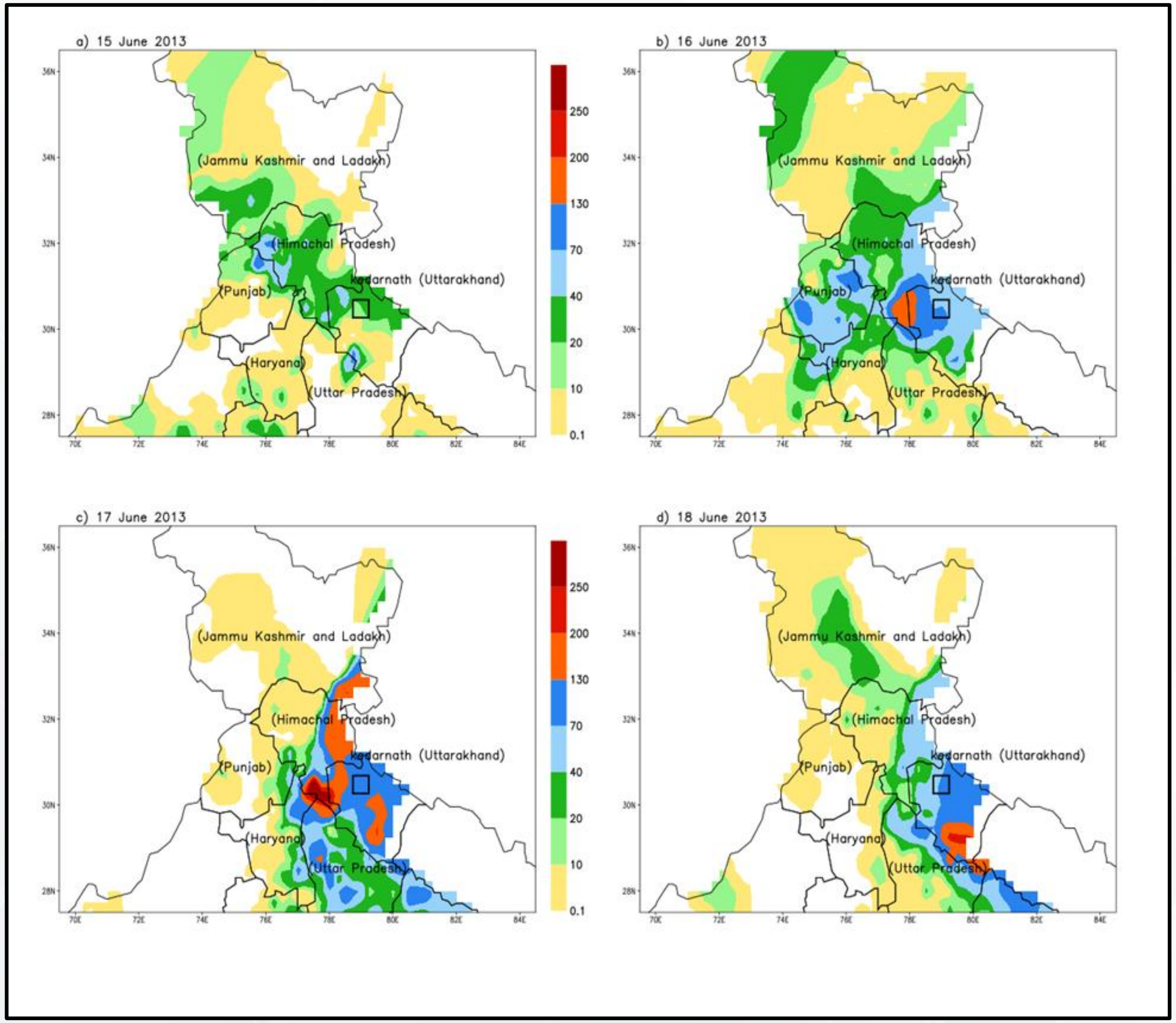
48 still missing in Himachal as one-night torrential rain revives horrific 2023 disaster memories

Extreme Rain events in Subtropical Asia (Himalaya) after 2010

India	Pakistan	Nepal	China
• **Leh** (4-6 Aug 2010) • Kharahar Valley (12 Sept 2010) • **Kedarnath** (16-17 June 2013) • Uttarkashi (2-8 Aug 2012) • Jammu and Kashmir (3-6 Sept 2014) • Tehari garwal (31 July 2014) • Karnaprayag (8 May 2016) • Chamoli (July 2016) • Nandum Arunachal Pradesh (Aug 2018) • Shimla (Aug 2019) • J & K Kishtwar (July 2021) • Kinnur HP (July 2021) • Chamoli (Feb 2021) • Dharmashala (Aug 2022) • Sikkim (Oct 2023) • **Himachal Pradesh** (July 2023)	• Sindh, Punjab, Baluchistan (27-30 July 2010) • Islamabad, Mithi, Sindh (9-11 Aug 2011) • Jacobabad (9 sept 2012) • Pakistan-eastern Afghanistan (31 July-5 Aug 2013) • Karachi (Aug 2015) • Baluchistan (April 2019) • Karachi (Aug 2020) • **Pakistan flood** (Jun-Aug 2022) • Many more ….	• Jure (Aug 2014) • **Nepal (April 2015)** • Central Nepal (11-14 Aug 2017) • Eastern Nepal (11-12 July 2019) • Nepal (Sept 2024)	• South China (31May-3 June 2010) • Yangtze river valley and east China (30 June-6 July 2016) • Yangtze river (Jun-Aug 2020) • Henan 9July 17-22, 2021)

Extreme Rain Event over Kedarnath during 16-17 June 2013

- During 15–18 June 2013, a steep mountainous catchment of the Mandakini River received continuous rains, very heavy rains occurred on 16–17 June 2013
- Meteorological laboratory of Wadia Institute recorded 325mm rainfall between 15 June (5.00pm) to 16 June (5.00pm)
- Other rain-gauges in Uttarakhand recorded rainfall ranges between 70-370 mm

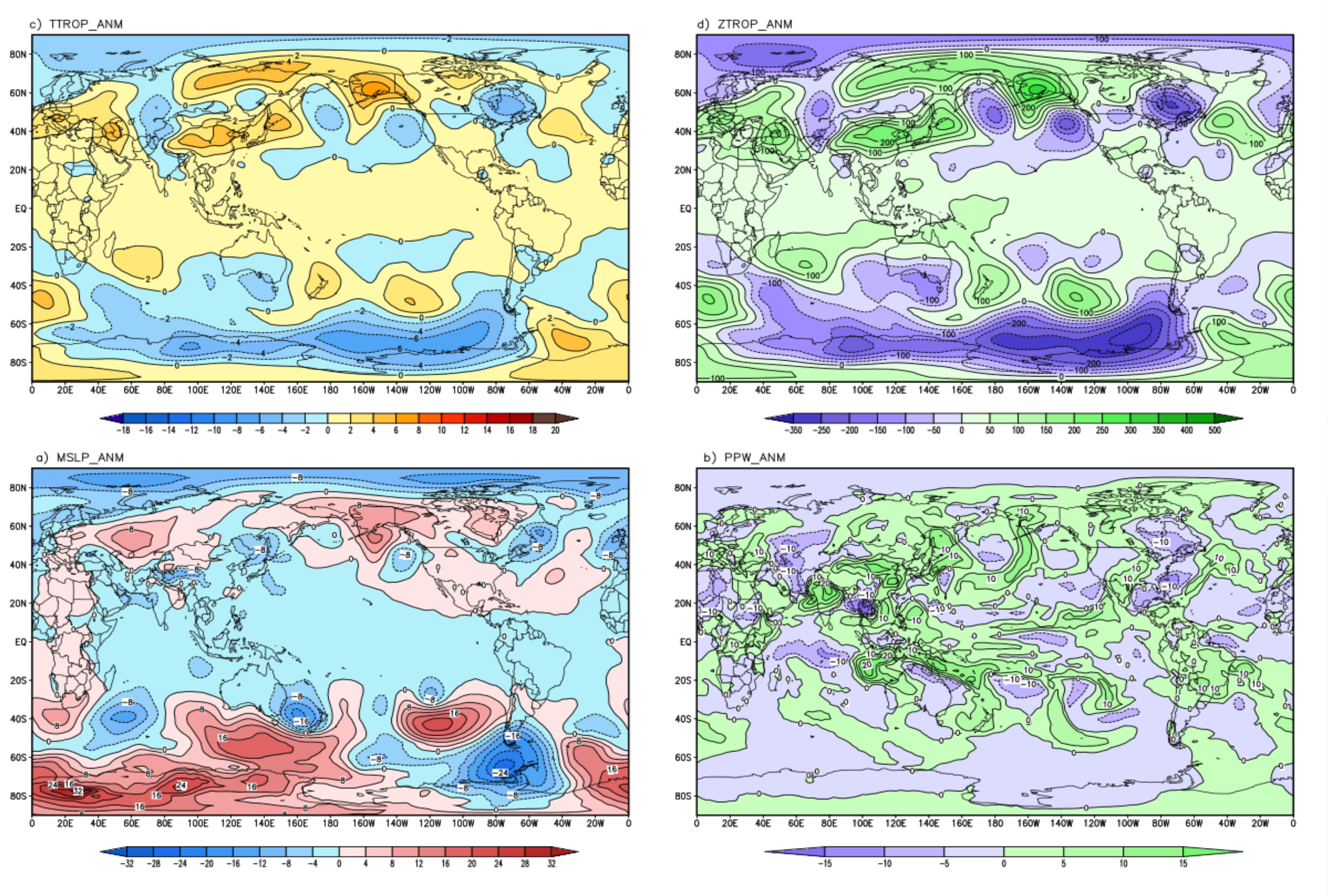


Daily rainfall distribution across part of northern India during 15-18 June 2013

(Ranade & Singh 2021)

Large-scale global and regional thermal structure

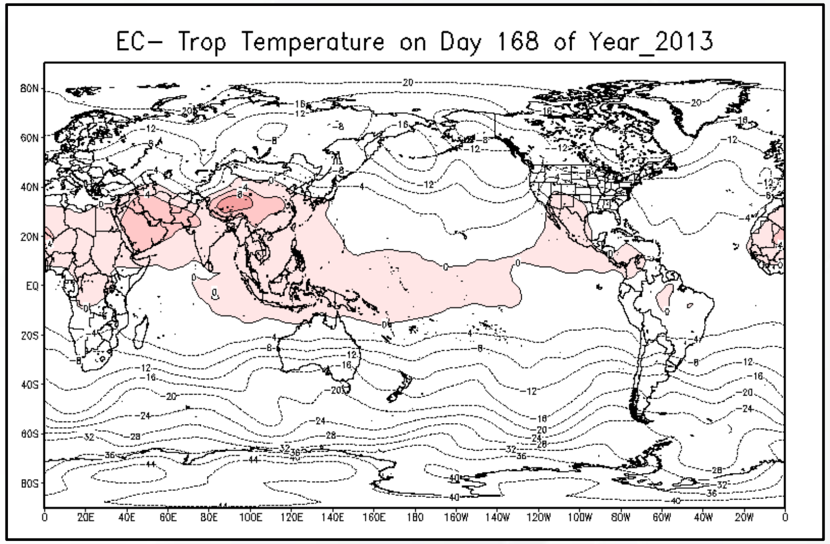
Departure from normal in mslp (a), PW (b), T_{TROP} (c) and Z_{TROP} (d) during 16-17 June 2013

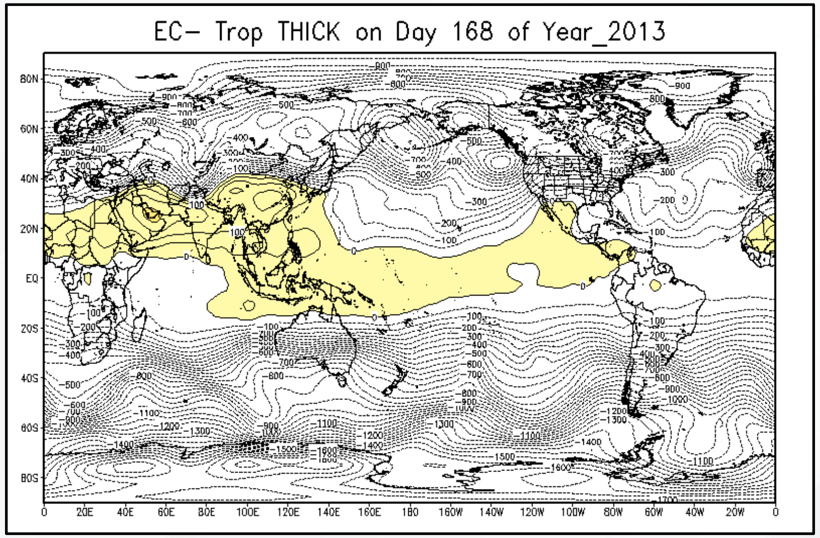


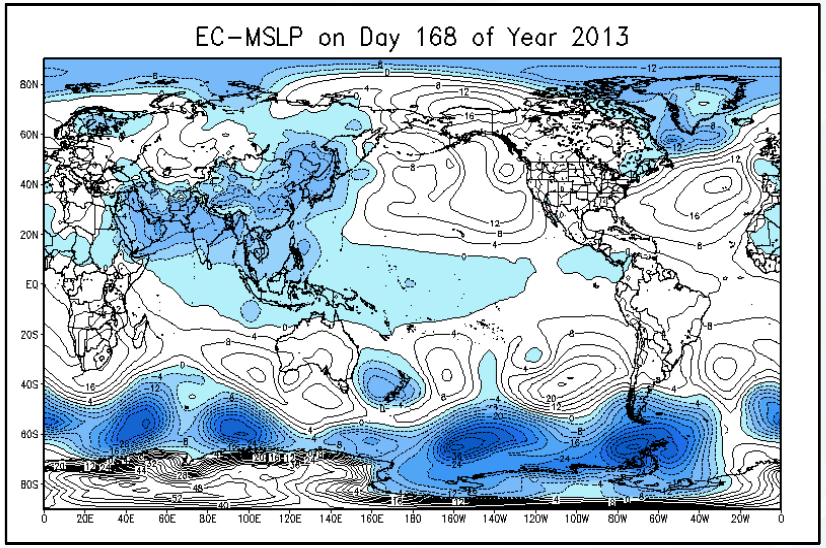
Normal tropospheric temperature and thickness downward slopes from Tibet-China (TBT-CHN) to indicated geographical zones during 16-17 June, and departure-from-normal (DFN) therein during 16-17 June 2013.

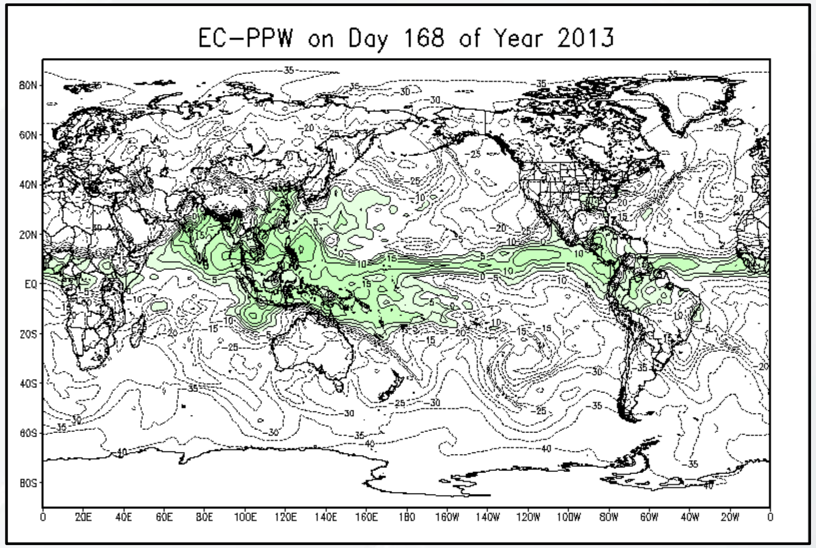
Geographical domains	Tropospheric temperature slope T_{TROP} (ºC)		Tropospheric thickness slope Z_{TROP} (m)	
	Normal	DFN	Normal	DFN
GLB (globe)	8.4	+2.3[1]	291.0	+106.2[1]
NH (north hemisphere)	4.8	+2.0[1]	148.5	+93.0[1]
SH (south hemisphere)	12.1	+2.6[1]	433.4	+119.5[1]
NPL (north polar; 70°-90°N)	18.5	+2.5[5]	698.5	+121.4[1]
NMLat (north mid-latitudes; 45°-70°N)	12.3	+2.0[5]	460.4	+97.9[5]
NSBT (north subtropic; 25°-45°N)	3.1	+1.8[1]	92.1	+81.4[1]
NTP (north tropic; 2.5°-25°N)	-0.2	+2.0[1]	-64.7	+95.3[1]
EQU (equator; 2.5°S-2.5°N)	0.4	+1.8[5]	-79.8	+110.4[5]
STP (south tropic; 2.5°-25°S)	2.0	+2.0[1]	13.1	+92.2[1]
SSBT (south subtropic; 25°-45°S)	12.2	+2.4[1]	453.5	+110.9[5]
SMLat (south mid-latitudes; 45°-70°S)	23.9	+3.6[1]	928.5	+161.2[1]
SPL (south polar; 70°-90°S)	37.5	+4.2[5]	1421.6	+197.0[1]

Analysis of EREs using Equatorially/Globally Conditioned (EC-GC) Meteorological Analysis









Equatorial mean Value (EMV):

- The natural and robust reference;
- Least seasonality;
- Minimum diurnal variation;

Parameter	Equatorial mean value (EMV) (±SD)
Lower Tropospheric temperature (925-700hPa) (c)	15.7 (±0.3)
Mean sea level pressure (mb)	1010.6 (±0.7)
Precipitable water (mm)	44.4 (±2.6)
Geopotential height at 850 hPa (m)	1502.9 (±4.6)
Geopotential height at 600 hPa (m)	4398.5 (±4.1)
Geopotential height at 250 hPa (m)	10931.7(±9.2)

(Ranade & Singh 2021)

Visualization of EREs using Global weather Regime (GWR) charts

- Weathers across the globe are associated with either convergence or divergence, and further, they are either under warm or cool condition. (*Warm and cool is relative to corresponding equatorial mean value)*

- Warm low regime : EC-T_{level} > zero and EC-z_{level} < zero
- Cool low regime : EC-T_{level} < zero and EC-z_{level} < zero
- Warm high regime : EC-T_{level} > zero and EC-z_{level} > zero
- Cool high regime : EC-T_{level} < zero and EC-z_{level} > zero

❖ **Multiple visualizable factors operated in unison**

Intense contrast between north extratropical cool-low-dry regime and monsoon warm-low-moist regime;

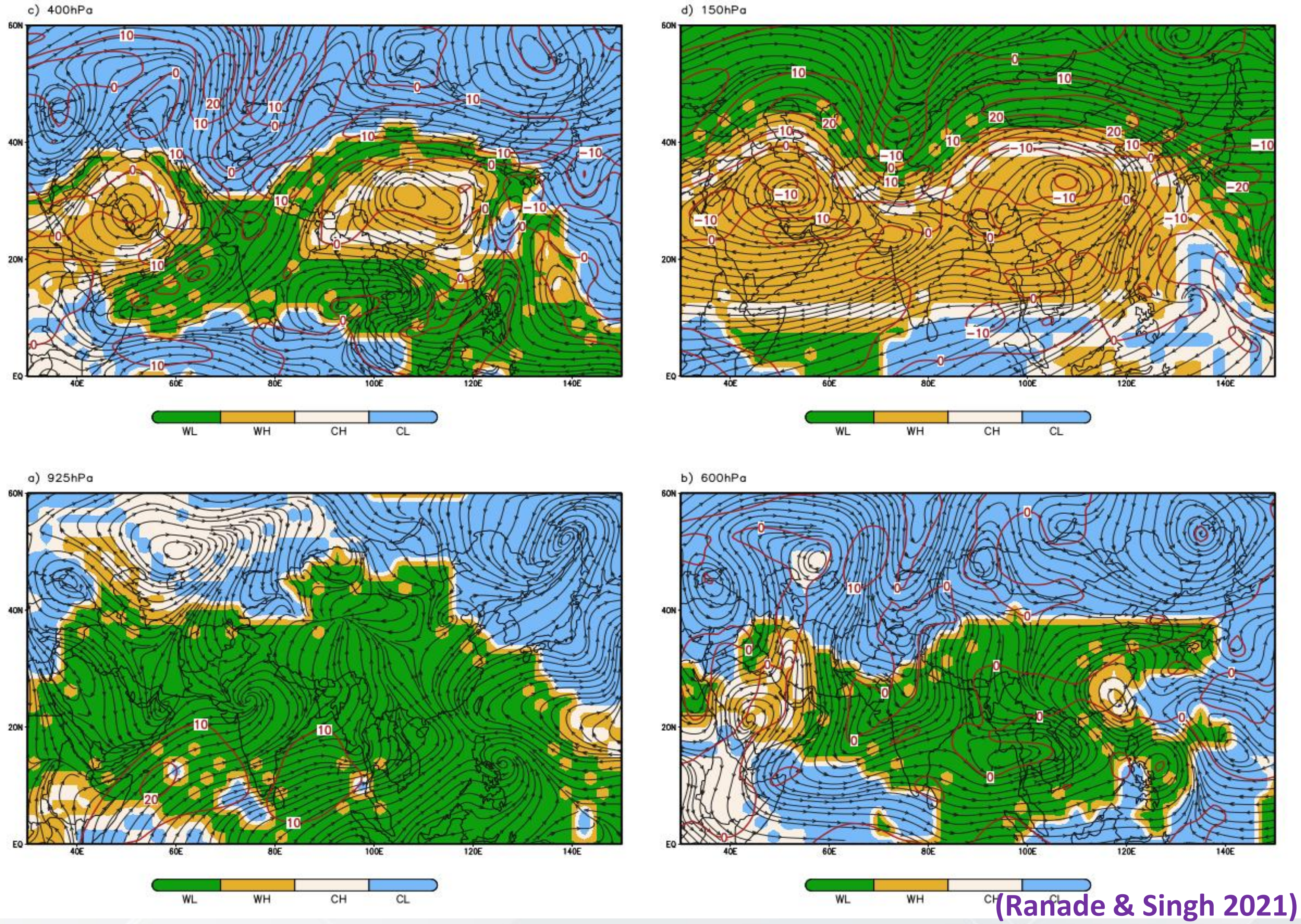
Squeezing of warm-moist monsoon flows exiting from western slopes of Himalaya;

Forced lifting of moist airs due to orography;

Upward pumping of excessive accumulated moist airs due to intense convergence over northwestern India.

Intense suction of airs from lower levels due to intense upper tropospheric divergence over the Tibet-China sector

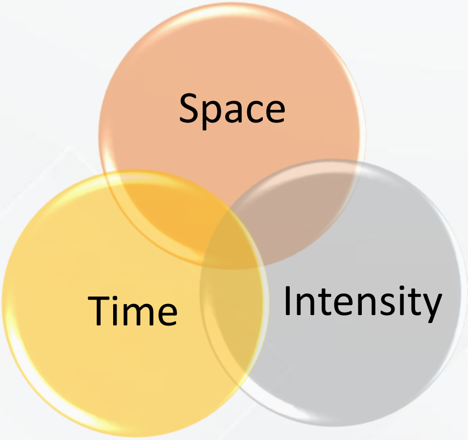
Regional distribution of GWR, streamlines and GC-W during 0600UTC 16 June – 0600UTC 17 June 2013 at 925, 600, 400 and 150-hPa.



(Ranade & Singh 2021)

What type of rainfall field does the monsoon circulation creates over the Indian region?

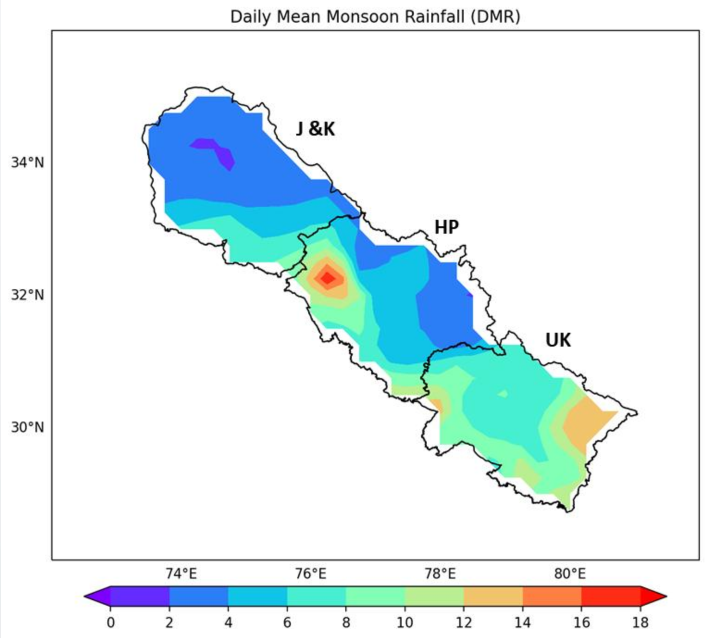
Stationary?
Spatially variable?
Normally? or
Extremely?



Parameters of EREs
- Location
- Frequency
- Rainfall Intensity
- Area Extent
- Rainwater
- Duration

✓ Large-scale extreme rain events (LS-EREs):

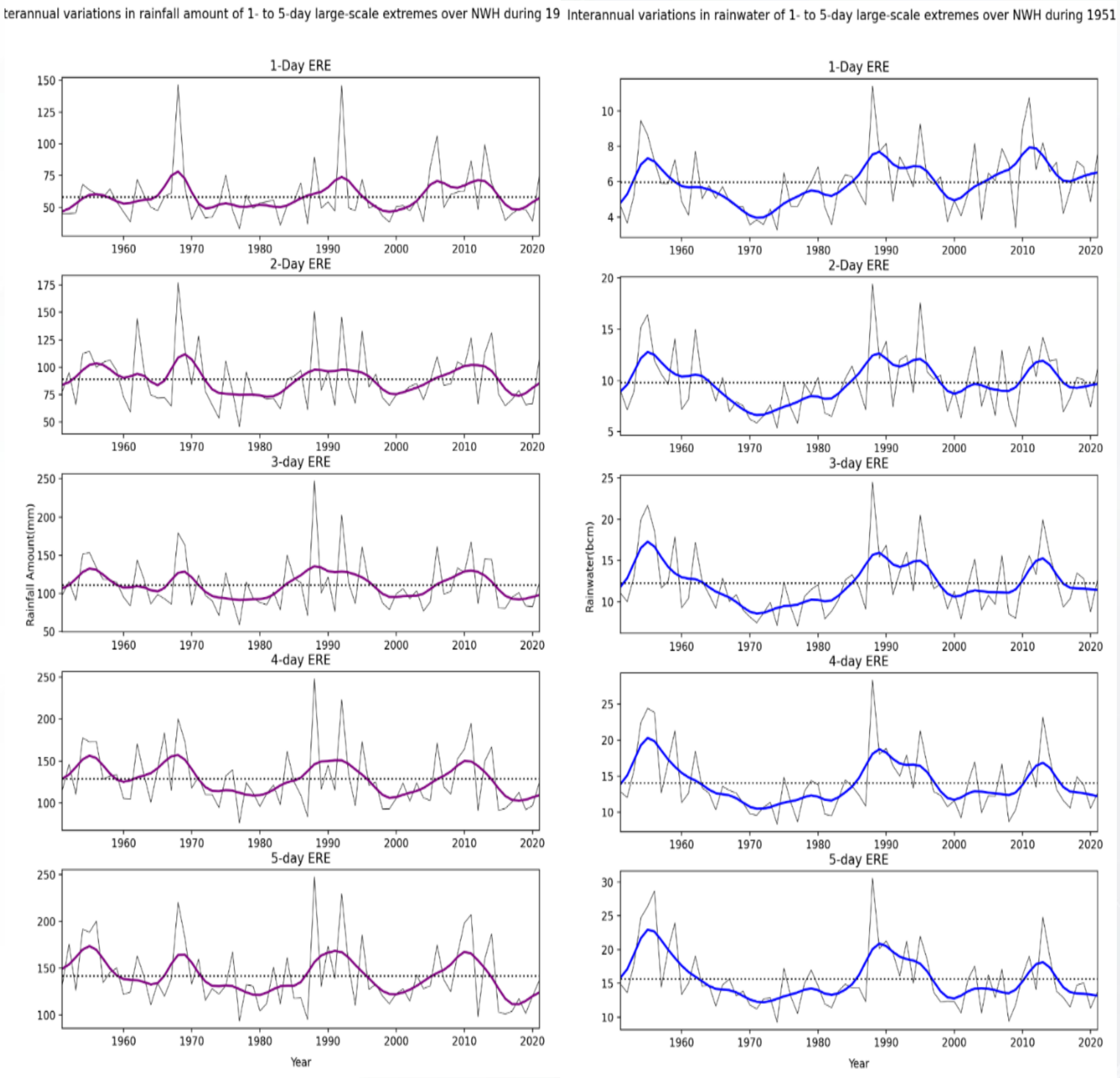
- Large-area is under wet condition for the consecutive days cause severe flooding.
- The rainfall amount of LS-EREs demarcates the area of infiltration excess runoff likely to cause flash flood, severe soil erosion and deep water logging.
- Areal extent of LS-EREs demarcate the area of saturation excess runoff likely to adversely affect standing agricultural crops and normal human activities on large-scale



Spatial variation in Daily Mean monsoon rainfall (DMR) across NWH

Large-scale Extremes over NW Himalaya

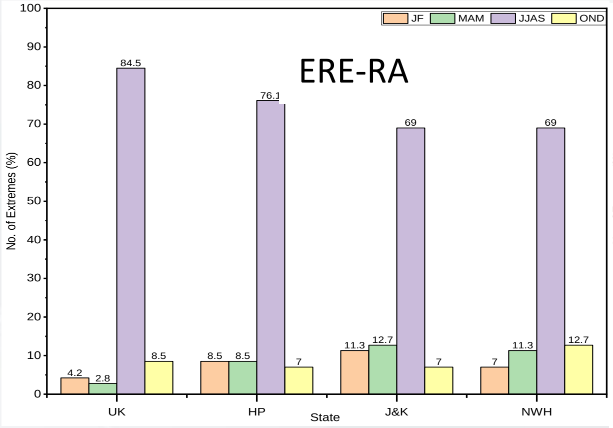
Interannual variations in RA and RW of LS-EREs

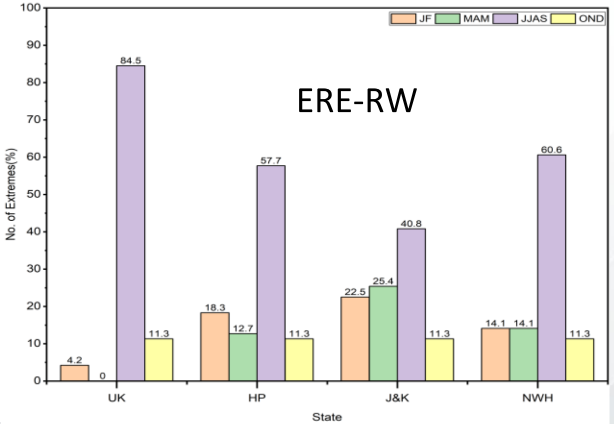


Recent 20 years (2001-2021) changes in parameters of large-scale EREs compare to past 51 years (1951-2000)

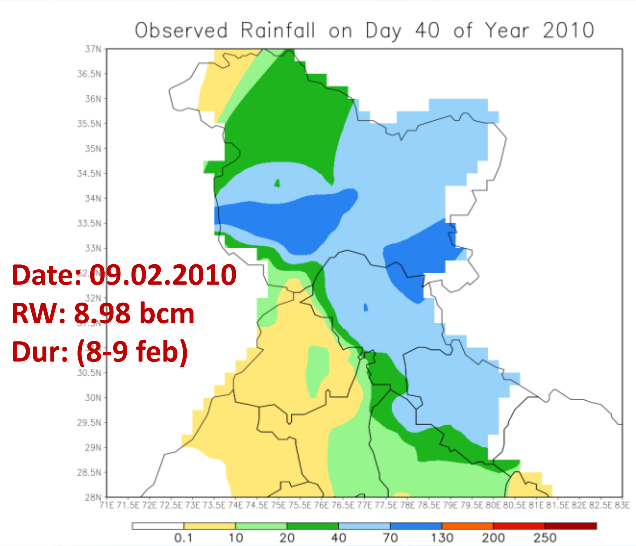
Duration of EREs	NWH			State_UK			State_HP			State_JK		
	ERE-RA		ERE-RW	ERE-RA		ERE-RW	ERE-RA		ERE-RW	ERE-RA		ERE-RW
	RA (%)	AE (%)	RW (%)	RA (%)	AE (%)	RW (%)	RA (%)	AE (%)	RW (%)	RA (%)	AE (%)	RW (%)
1-day	7.5	28.2[10]	15.94[5]	23.2[5]	15.6	34.5[1]	-1.4	0.7	-4.7	16.2[5]	21.4[5]	23.3[5]
2-day	-0.2	31.1[5]	3.46	14.7[10]	9.2	25.9[1]	-10.3[10]	-0.7	-6.7	7.9	11.3	12.5
3-day	-3.2	43.8[1]	0.95	12.5[10]	14.9	25.3[1]	-14.2[5]	8.9	-9.9	6.1	13.8	9.6
4-day	-5.8	20.2	-3.37	13.2[5]	0.1	21.7[5]	-17.6[5]	-0.5	-16.2[5]	0.5	20.5[5]	7.7
5-day	-3.8	14.9	-6.88	10.7[10]	0.6	19.8[5]	-18.8[1]	10.9	-19.9[5]	-0.2	23.3[5]	6.4

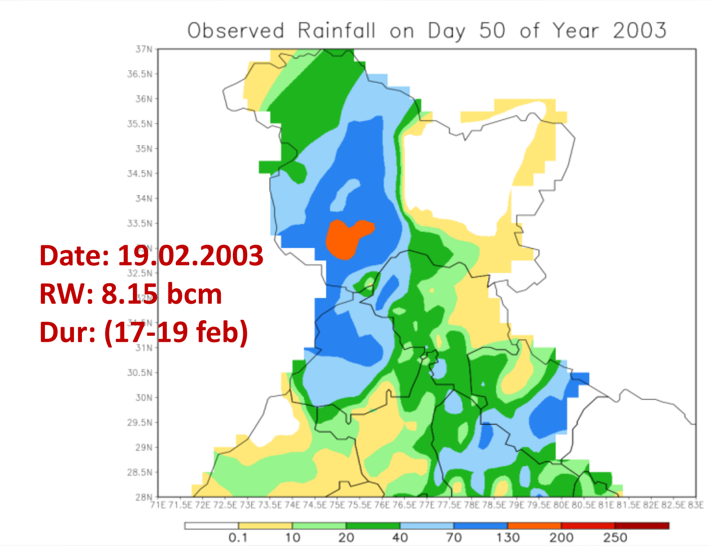
Seasonal distribution of LS-EREs

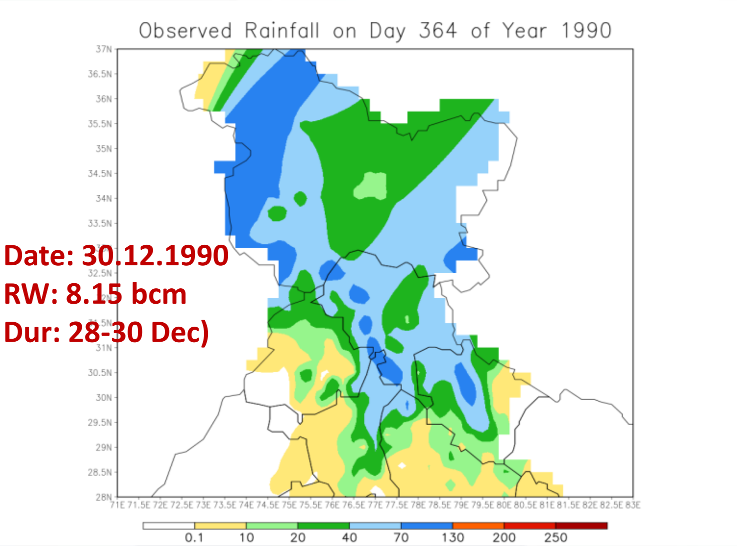




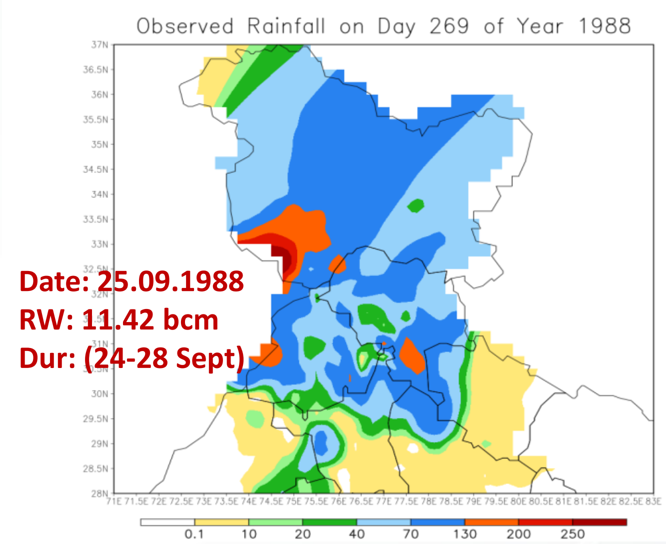
Winter Season Most Extreme ERE-RW over NWH

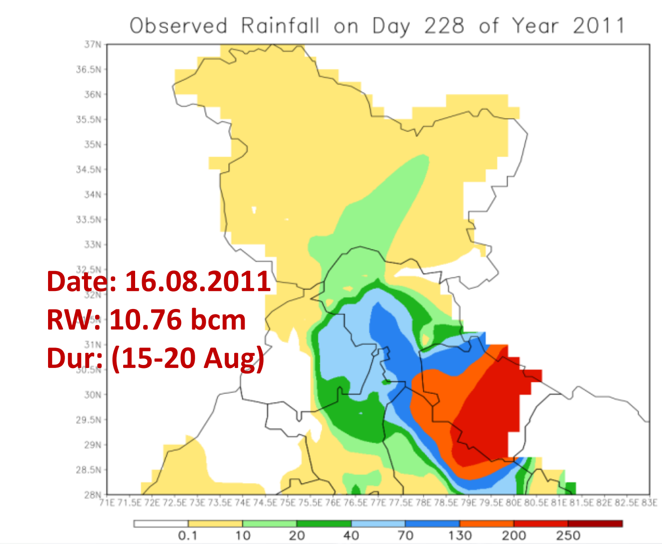


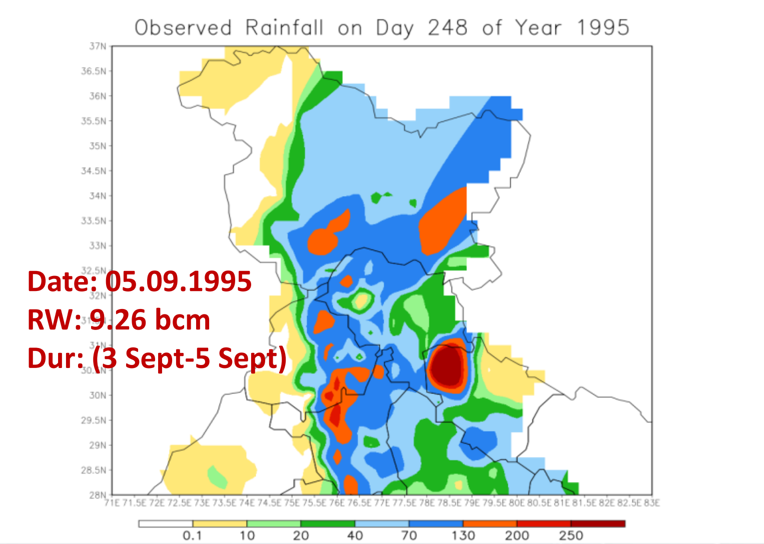




Monsoon Season Most Extreme ERE-RW over NWH

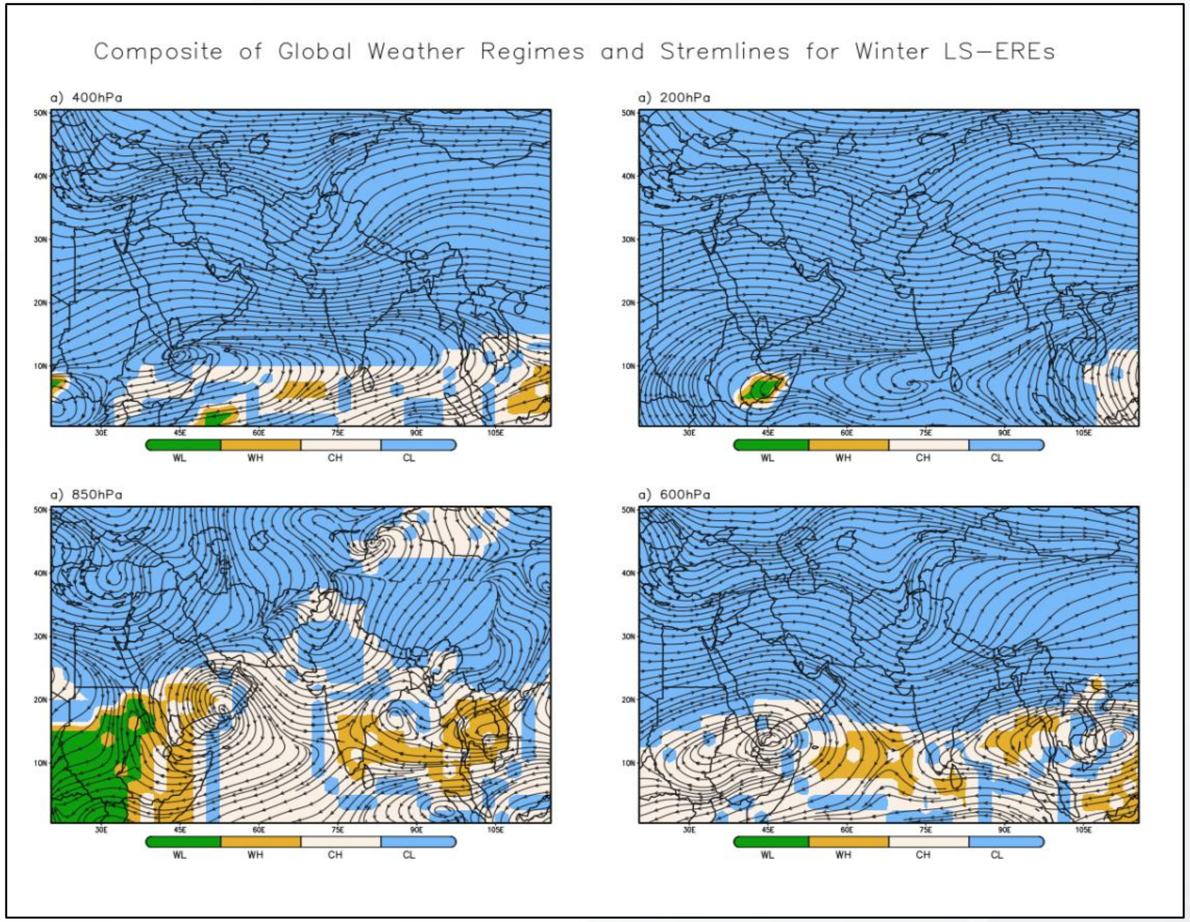




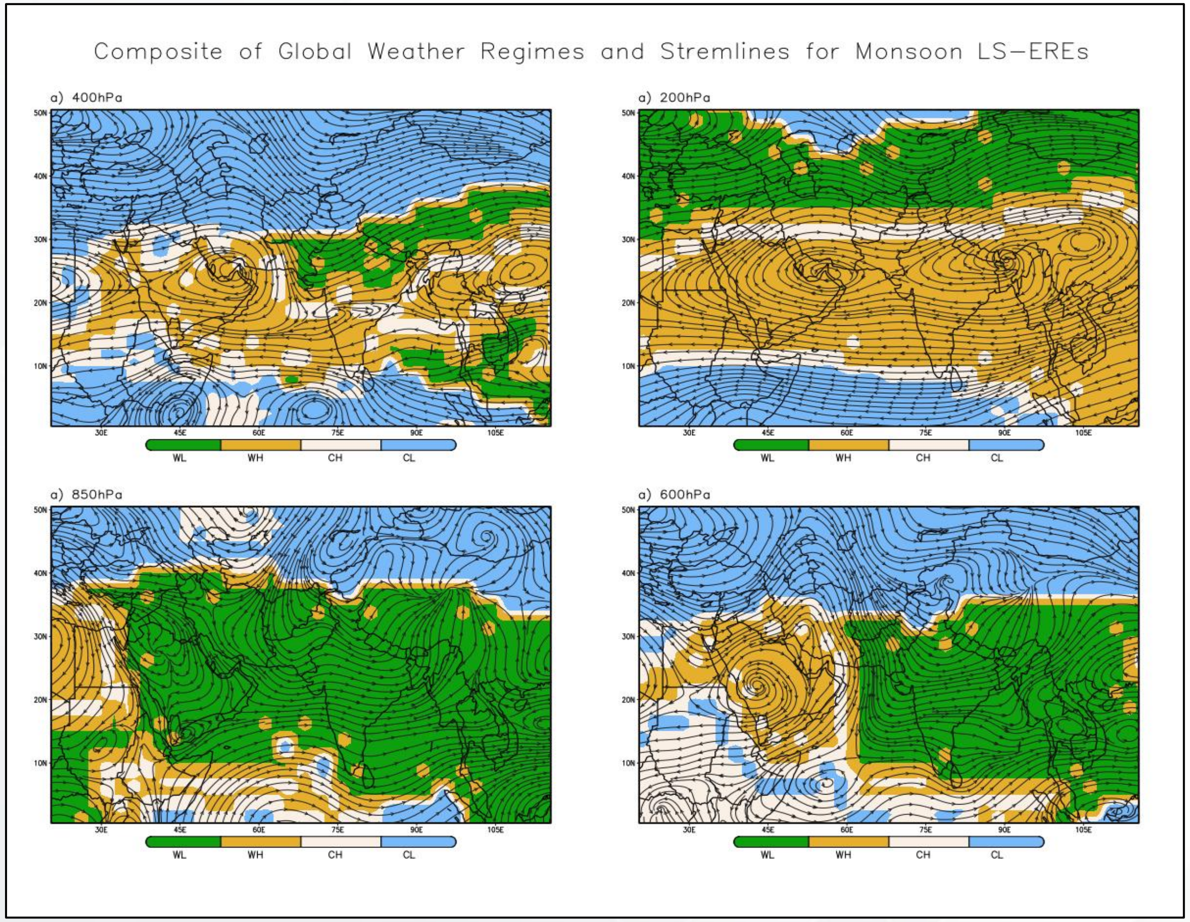


Composites of Global Weather Regimes (GWR) and streamlines

Winter-EREs



Monsoon-EREs



Warm Low	Warm-high	Cool-high	Cool-low
$EC\text{-}T_{level} > 0$ and $EC\text{-}Z_{level} < 0$	$EC\text{-}T_{level} > 0$ and $EC\text{-}Z_{level} > 0$	$EC\text{-}T_{level} < 0$ and $EC\text{-}Z_{level} > 0$	$EC\text{-}T_{level} < 0$ and $EC\text{-}Z_{level} < 0$

Typology of Compound events observed in Himalayas

Simultaneous/Concurrent Events *(within hours)*

- Heavy rain + snowmelt + glacier outburst → flash flood e.g. Chamoli (Feb 2021)
- Cloudburst + landslide → Debris flow e.g Ladakh (Aug 2010)
- Drought+ heatwave *e.g Indo-Gangetic foothills (May-June 2022)*

Successive/Consecutive Events *(over days to week)*

- Successive heavy rainfall events → flood e.g. Himachal Pradesh (July 2023)
- Rainfall-Induced Glacier lake Outburst Floods → Flash flood e.g Kedarnath (June 2013)
- Monsoon rainfall followed by seismic activity → landslides e.g. Nepal (April 2015)
- Intense Western Disturbance causing snowfall → Avalanche e.g. Siachen (Feb 2016)

Precursor-driven events *(prolonged prior state over months)*

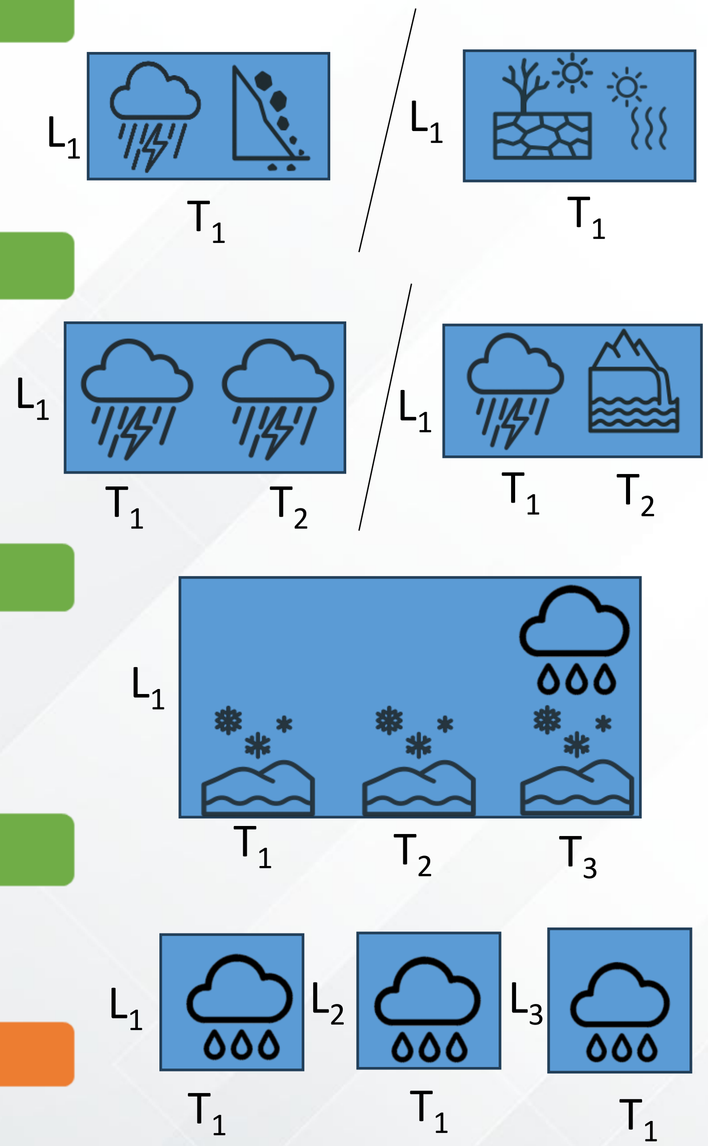
- Precipitation over extensive snow cover → flood *e.g. Beas basin-HP (spring 2021)*
- Rainfall on steep saturated soil → landslide or debris flow e.g. Kinnur, Hp (July 2021)
- Prolonged warm spell/heatwave over snow cover area → flash flood e.g. HP (April-may 2023)

Spatially connected Events *(different but adjacent regions)*

- Large-scale extreme rain events → regional flooding *e.g. UK and HP (July 2023)*
- *Synoptic Scale western disturbance → Avalanches e.g Kashmir, Siachen, Kargil (feb 2019)*

Anthropogenically triggered

- Road widening + monsoon rain → landslides
- Dam release + flood → downstream flash flood
- Deforestation + rainfall → flood



Challenges in Study and forecast of compound events

⚠ **Observational gaps**:

- Sparse high resolution meteorological data especially above 4,000 m .
- Lack of long-term data of compound events.
- Inadequate glacial lake and snowpack monitoring.
- Lack of real-time cryo-hydro monitoring.

⚠ **Complexity in definition and detection:**

- Climate Modulators/drivers simultaneously act at global, regional and local-scale
- Lack of standardized thresholds for joint occurrence.
- Difficult to isolate the role of individual drivers

⚠ **Modelling challenges:**

- Requirement of fully coupled model (atmosphere-cryosphere-hydrology)
- limitations in capturing localized terrain induced interactions
- Limitations in capturing successive extreme event sequences

Conclusions and Way Forward:

- Subtropical Himalya extreme events are short lived and mostly occur along the boundary of warm-low-moist and cool-low-dry regime.
- Anomalous changes in the global atmospheric temperature structure have triggered short period abrupt change in general and monsoon circulations.
- Frequency and intensity of Compound events in the Himalayas are increasing in response to amplification of cryo-hydro coupling under accelerated regional warming and topographic sensitivity.
- Existing single-hazard frameworks are inadequate to capture synergistic triggers and nonlinear cascading effects of compound events.
- Effective Prediction and mitigation require integrated framework of observations, modelling, cross-border cooperation, interdisciplinary collaborations and robust early warning systems.
- 3-D visualization of real-time and forecasted weather will become increasingly important to translate complex atmospheric information and insights to communities and decision makers.

Thank You...