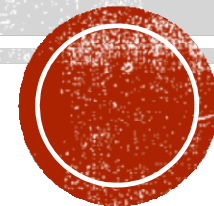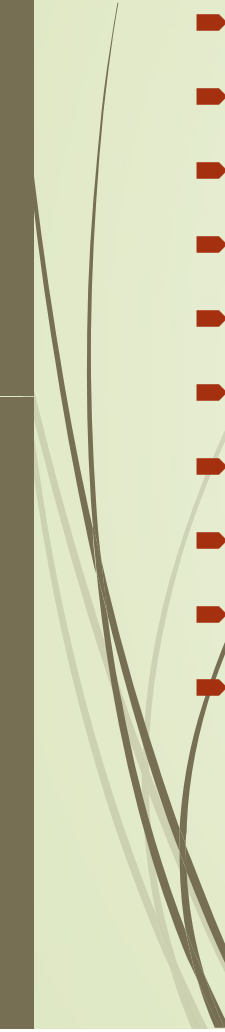# DEMYSTIFYING WDs AND
THEIR LINKS TO CLIMATE CHANGE

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Outline

- The major source of precipitation over Indian subcontinent.

- WDs: The structure

- The large scale forcings

- The thermodynamics

- WDs and Winter hailstorm

- WD index

- WDs and Monsoon interaction (Uttarakhand Disaster)

- Intraseasonal variation of Indian Winter Monsoon
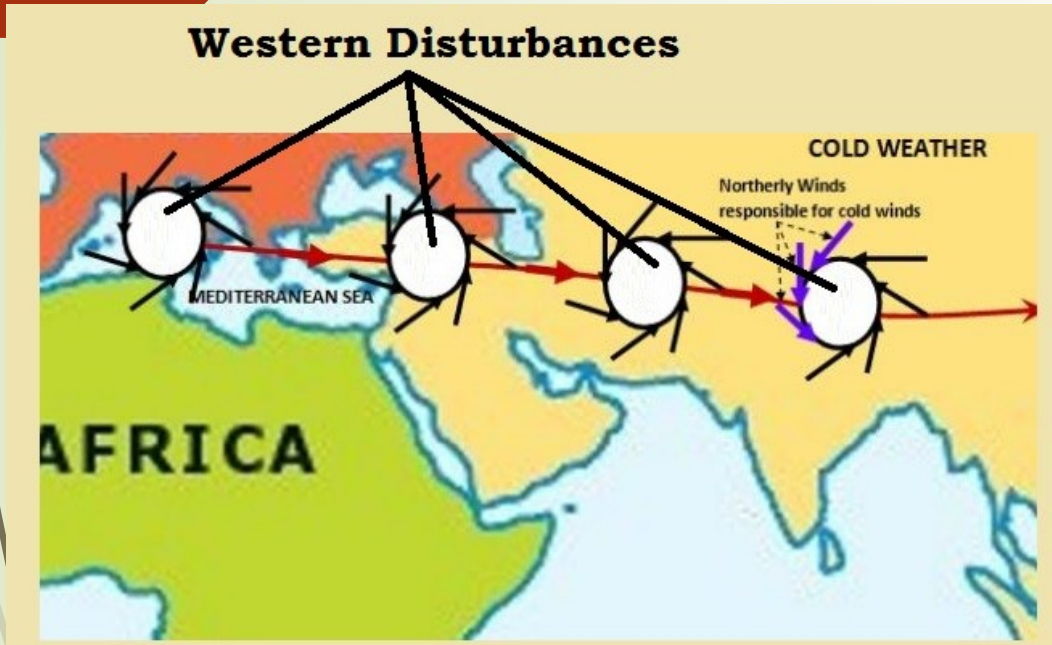
- WDs in Changing Climate

- Etc.

The major sources of precipitation over Indian subcontinent
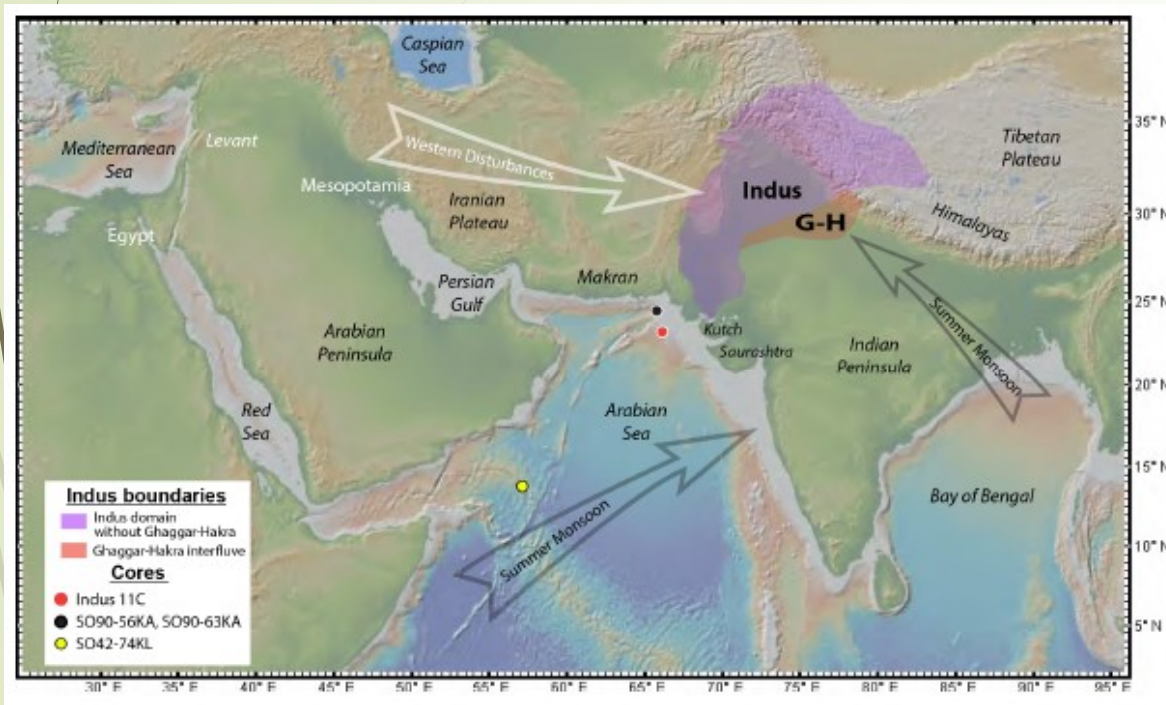
Source: Giosan et al., 2018

➡ The Indian summer monsoonal rainfall over entire Indian land mass during summer.

➡ The **rainfall associated with the WDs over the northern India during winter**.

Western Disturbances (WDs)

Source: Jagranjosh.com

- WDs are in part **extra-tropical cyclones** originating as **mid-latitude frontal systems** and migrating eastward **embedded in the subtropical westerly jet stream** (SWJ) (Mull and Desai, 1947).

- WDs are not just a typical extra-tropical cyclone, but they also have unique characteristics and dynamics.

- The **precipitation associated with WDs** influences the hydrological budget, climatic zones, micro climates, food and water security etc. (Dimri and Chevuturi, 2016).

- The interaction of the WDs with the northwestern **Himalayas orography** (Ramaswamy, 1956) causes their intensification and the subsequent precipitation. This meets the water demands of the northern Indian region and popularly termed as **Indian Winter Monsoon** (Dimri et al., 2014).

WDs: The Structure
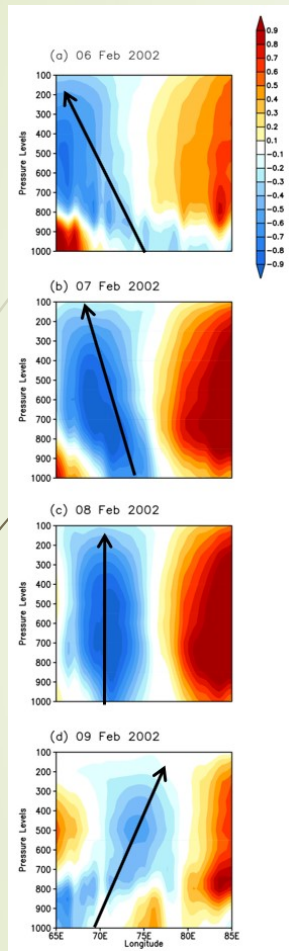
(a) Vertical distribution of geopotential anomaly averaged over latitude (25°N - 40°N) for a WD case (a) to (d).
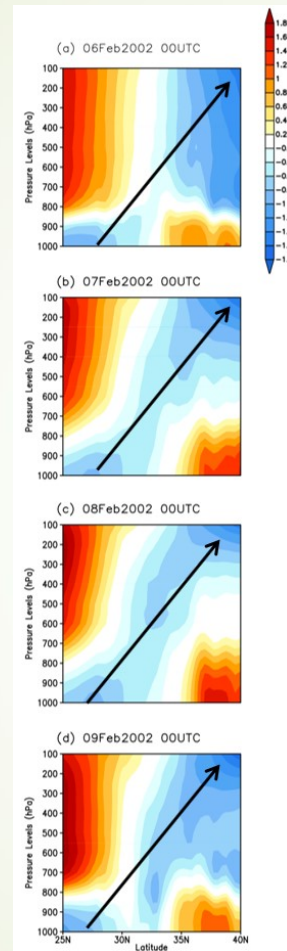
(b) Same as figure on left but with averaged over longitude (65°E - 85°E).

(Source: Dimri and Chevuturi, 2016)

- The **vertical tilt of low-pressure region of the WD** shifts towards the west during the early stage of development of the WD, which shifts towards the east as the WD propagates and subsequently dissipates (Dimri and Chevuturi, 2016 and Hunt et al., 2019) (Fig. a).

- A clear and consistent northerly shift in the vertical dimension is seen during evolution of the WD (Fig. b).

- This suggests that the low at different pressure levels during a **WD has a northwesterly tilt** in the early days of the WD, which becomes northerly as the WD arrives at WHs and propagates to become a north-easterly tilt as the WD travels further eastward.

- This movement describes the motion of the WD over the course of its **life cycle of origin-evolution-propagation-deterioration**.
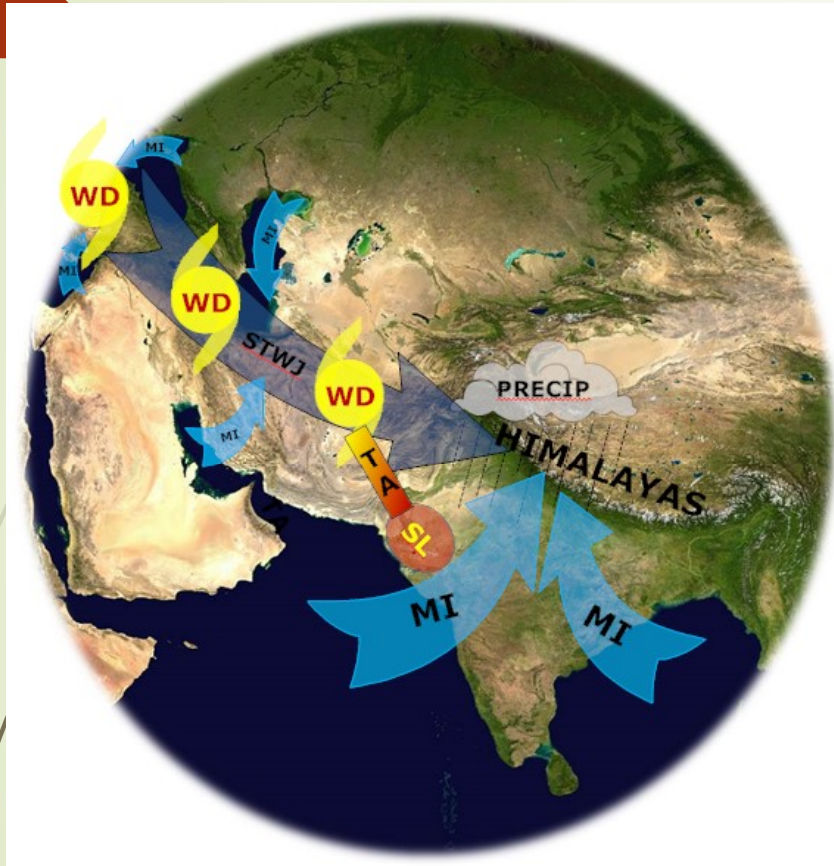
WDs: The large scale forcings

Fig. Conceptual model of WDs. (MI = Moisture incursion, PRECIP = Precipitation, SL = Surface low, STWJ = Sub-tropical westerly jet, TA = Westward tilted axis in vertical, WD = Upper air western disturbance).
(Source: Dimri and Chevuturi, 2016)

- The WDs are defined by two synoptic characteristics; an **upper tropospheric depression in the SWJ** and the pre-existing surface low (Singh and Kumar 1977).

- The **tilt of the low pressure system in the vertical axis** can be attributed to the evolution of WD from west of India in the upper atmosphere and the stationary surface low seen over the India.

- These **wave-like disturbances** interact with the orography of the Himalayan terrain to generate instability conditions over the northern Indian region and so form the winter storms.

- The **orographic lifting**, along this steep relief in addition to moisture incursion from the Arabian Sea, supports the development of convective available potential energy (CAPE) leading to storm development and resulted in **heavy rainfall**.

WDs: The thermodynamics
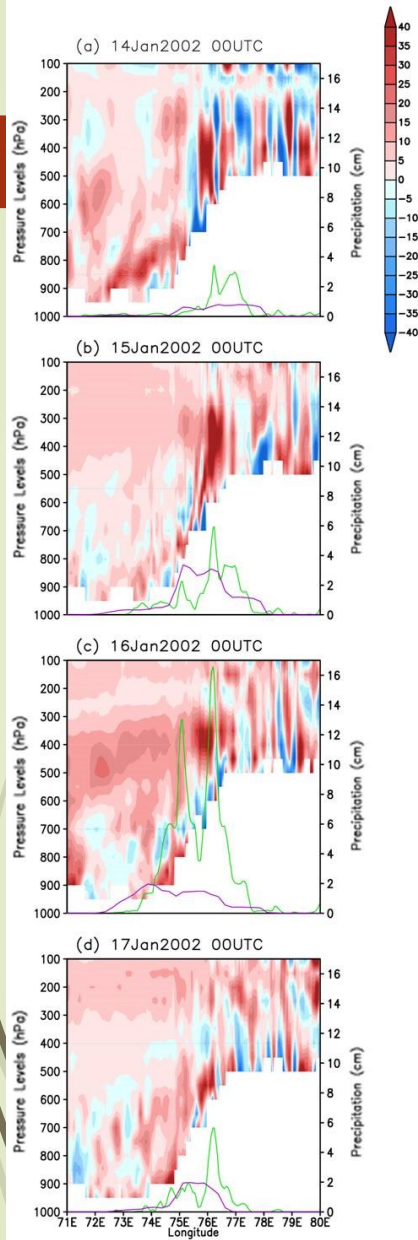
Vertical cross section of vorticity ($\times 10^5$ s^{-1}, shaded), model precipitation (cm/day; green line) and observed precipitation (cm/day; purple line) along 33°N for the WD case study (16-17 Jan, 2014)

(Source: Dimri and Chevuturi, 2016)

➡ Intensification of cyclonic circulation is associated with increased positive vorticity, which in turn will intensify the WD and hence **increase associated precipitation**.

➡ The **positive vorticity** is closely associated with the maxima of precipitation.

➡ The distribution of **vorticity along the rising topography** of the Western Himalayan region causes the orographic forcing producing the precipitation by the WDs.

WD Index (WDI)
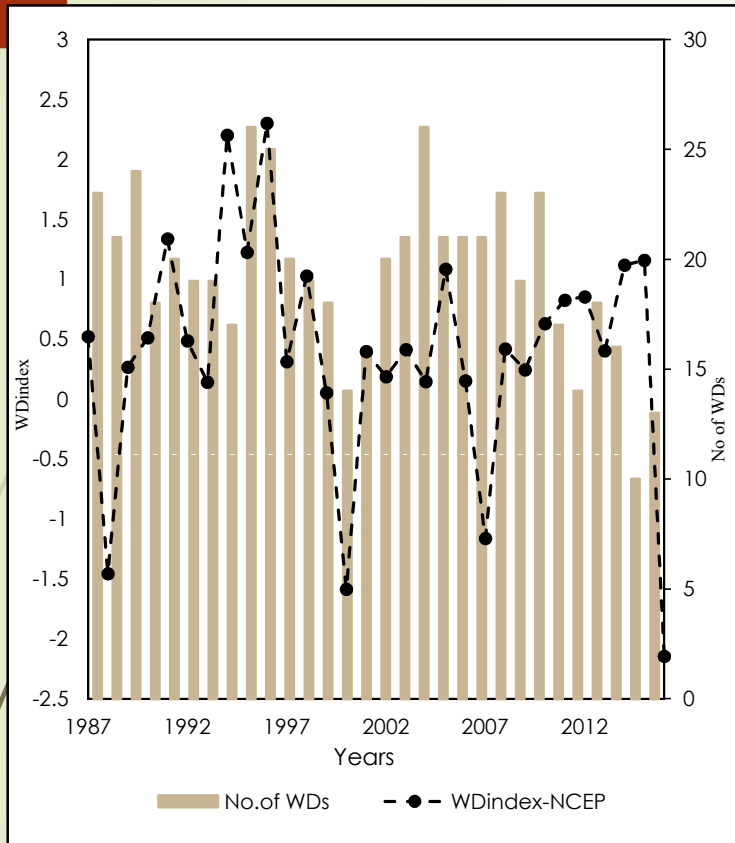
Time series of WDI and number of WDs. WDI is plotted as lines. The bar graph shows the number of WDs.

(Source: Midhuna et al., 2020)

- The **WDI is defined using the seasonal mean value of geopotential height anomaly** (averaged over the area of 25°N 60°E to 40°N 80°E) at 850 and 200 hPa. The value at 850hPa is subtracted from 200hPa. Then it is divided by standard deviation to construct standardized WDI.

- **WDI increases with number of WDs** in almost all the years except in few years.

- This is because **WDI may depend upon intensity of WDs**. The poor correlation is found between WDI and no. of WDs due to the fact that not all WDs are strong enough to create large dip in upper troposphere geopotential height which leads to more precipitation over the region. Only 5% of WDs lead to heavy precipitation (Hunt et al. 2018).

WD Index (WDI)
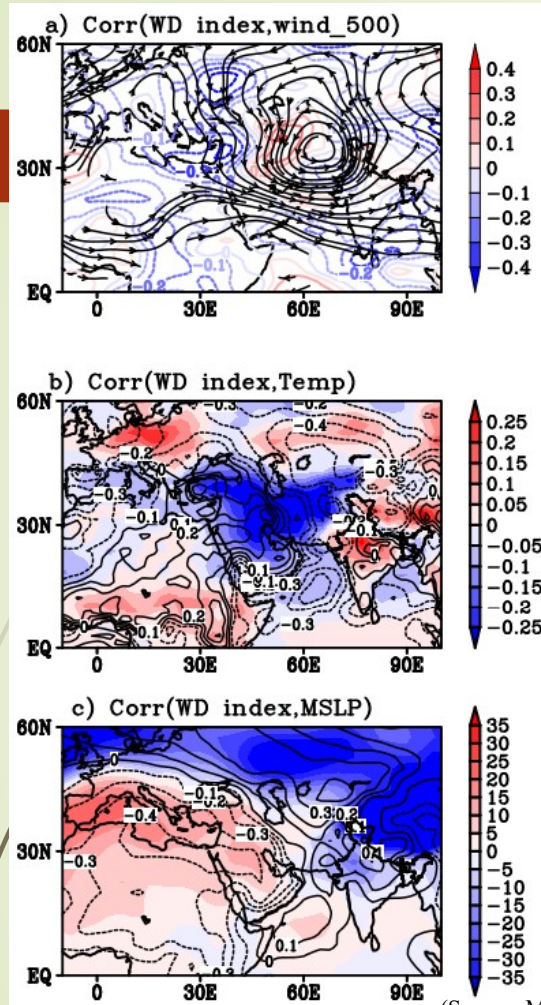
(Source: Midhuna et al., 2020)

Spatial pattern of correlation between WDI and a) 500hPa wind (streamlines in m/s), blue contour line corresponds to negative correlation and red contour line corresponds to positive correlation b) 2m temperature (shaded in degree C) c) Mean Sea Level Pressure (MSLP, shaded in meter) for WD minus DJF days averaged during 1986-2016. The positive correlation is shown in black solid contours and negative correlation is shown in broken line contours.

- **500hPa wind is positively correlated with WDI** over the Hindukush and Sulaiman ranges (Fig. a). That explains about the sustaining of WD over this area. A negative correlation is noted over rest of the region. This suggests a divergence of mass from the rest of the region.

- Colder temperature is observed over northwest regions of Indian subcontinent. In northern part of India **warmer temperature is found which is negatively correlated with WDI**. This suggests cold air incursion towards India during the propagation and passage of WDs.

- MSLP patterns indicate higher pressure over west of Indian subcontinent and lower pressure over India and northern latitudes. The low-pressure area seen over northern part of India are associated with ascending/converging air masses which leads to showers over the region. **MSLP shows positive correlation with WDI** over this region.

WDs and Winter hailstorm
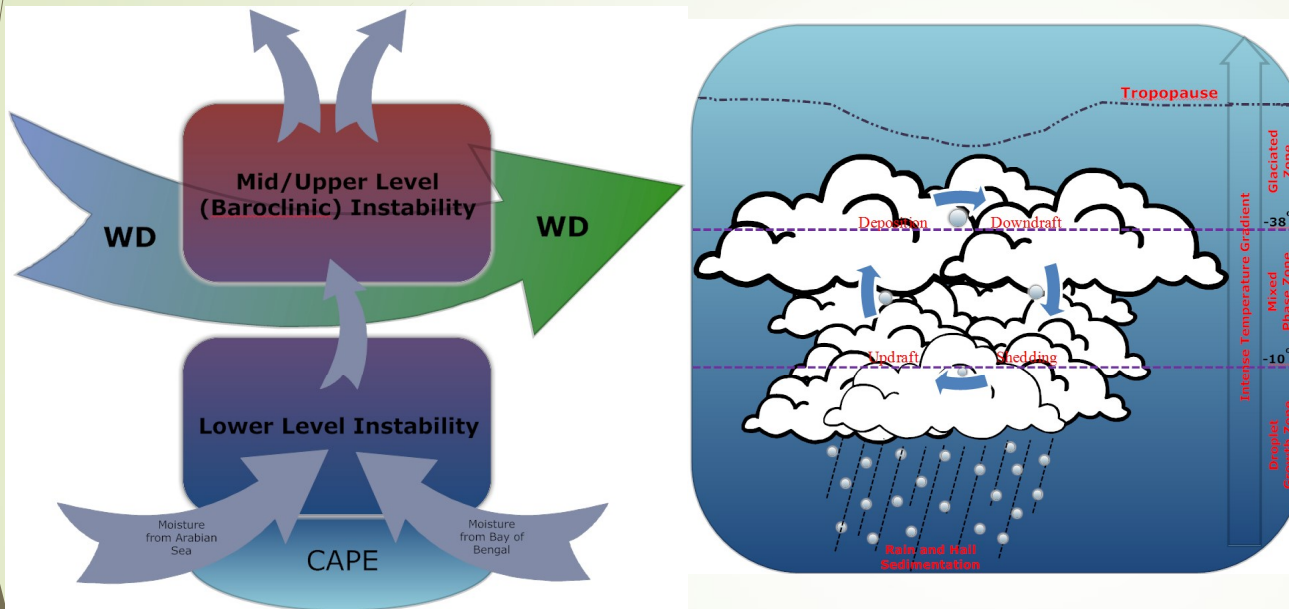
Conceptual model of the winter hailstorm.
(Source: Chevuturi and Dimri, 2015)

- **Lower level convection** is enhanced by **CAPE** development, due to increased moisture incursion and temperature conditions.

- **Upper level instability** is formed due to presence of **WD causing tropopause lowering** and incursion of colder stratosphere into troposphere.

- **Instability develops multiple cloud cells** which is conducive for **hail formation**.

WDs and Monsoon Interaction
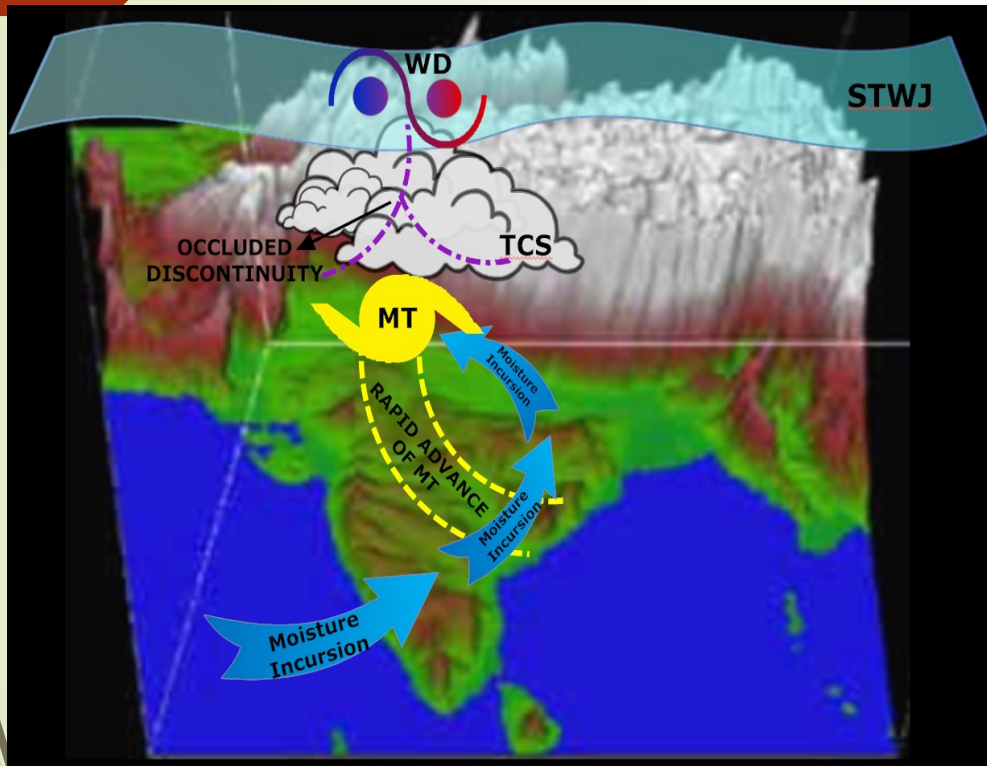
Conceptual model of the Pulsatory Extension of the
Monsoon towards Himalayas.
(Source: Chevuturi and Dimri, 2016)

- Natural disaster in the form of flash floods due to **extreme precipitation** occurred at Uttarakhand **(Kedarnath), India, on 16–17 June 2013** because of the interaction between WDs and Monsoon system.

- The early migration of the **monsoon trough (MT)** towards northern India and its interaction with an incoming **WDs** formed a **transient cloud system (TCS)** that led to extreme precipitation over Uttarakhand.

- The formation of the TCS was attributed to the rapidly advancing "**Pulsatory Extension of the Monsoon system (PET)**" towards northern Indian in the early monsoon period.

- PET was caused by the formation of an **occluded discontinuity** or front over north India.

Intraseasonal variation of Indian Winter Monsoon
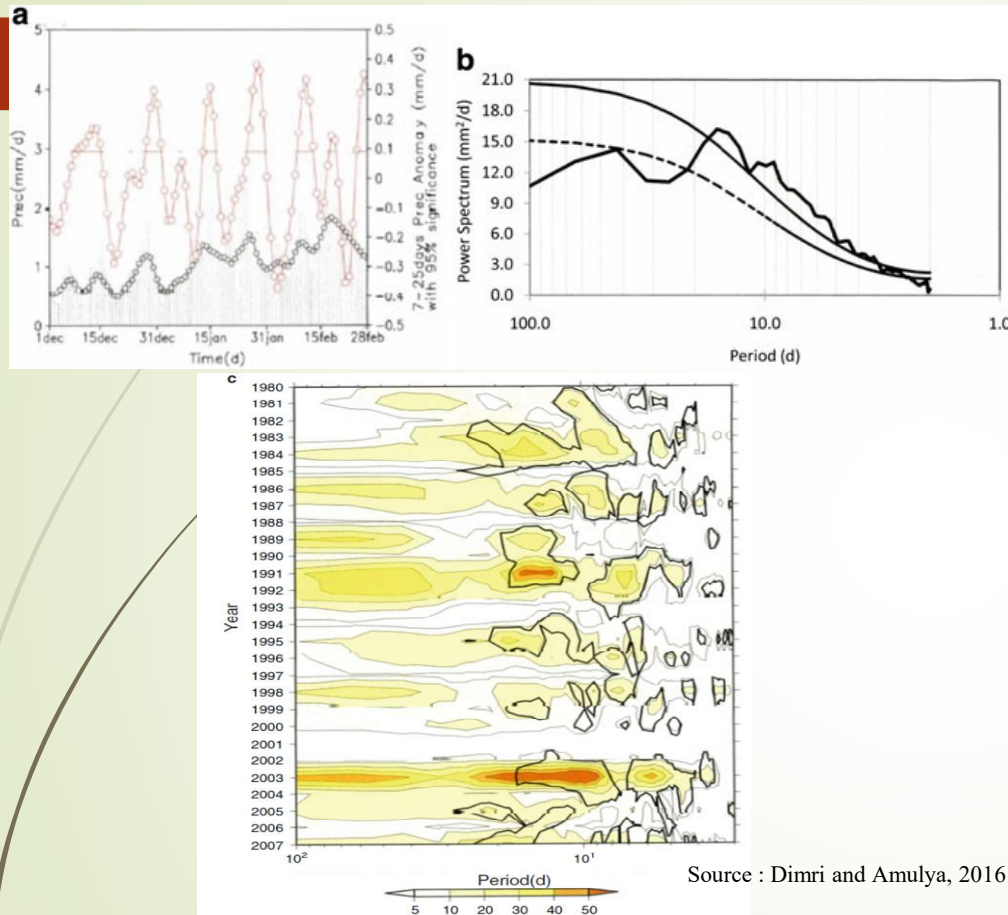
Source : Dimri and Amulya, 2016

(a) Based on 28 years (Dec 1979, Jan, Feb 1980 to Dec 2006, Jan, Feb 2007) of data, time-series of WHDP climatology (bar; left axis), pentad precipitation climatology (black line with open circles; left axis), and 7–25-day filtered precipitation anomaly (red line with open circles; right axis). The line of 95 % signifi cance is also shown and the period above this corresponds to climatological active phases. (b) The 28-winter (DJF) ensemble spectrum of the WHDP time series from 15 Nov. to 15 Mar. (120 days). A red noise spectrum (dashed curve) and its 95 % level of signifi cance (solid curve) are also shown. (c) Interannual variation in the WHDP spectrum from 1980–2007. The thick black solid line shows the 95 % level of significance.

- The **Intraseasonal Oscillation (ISO)** on sub-monthly timescales with active and break peaks is observed (a). 140 active and 119 break peak phases are identified.

- Using the fast Fourier transform (FFT), A pronounced periodic ~**16-day peak** with a 95% statistical significance is identified (Fig. b).

- The 28 years' power spectrum of IAV of the WHDP showing approximately a **16-day** period scale in each year (Fig. c).

WDs in the Changing Climate

The global hydrological cycle is expected to accelerate with increased CO_2 as the warmer atmosphere can hold more water (Zahn and Allan 2013). Thus regions where the precipitation is strongly dependent on ocean moisture uptake will **experience stronger precipitation events** (Gimeno et al. 2013).

- Based on Coupled Model Intercomparison Project Phase 3 (CMIP3) experiments, Meehl et al. (2007) revealed possible **increased future storm activity**; however, the more recent CMIP5 simulations show a **decline in Northern Hemisphere storm activity** (Chang et al., 2012). These results indicate towards the uncertainties in the model results.

- The climate drivers and topography presented within the model environment along with the snowfall amounts are **likely to be more uncertain** (Dimri and Chevuturi, 2016).

- Ridley et al. (2013) have provided a comprehensive overview of the **increase in WD frequencies** up to 2100, and associated snowfall (37%) is also predicted to increase over the region.

- Madhura et al. (2014) also indicate an **increase in the frequency of the WDs** due to the mid-tropospheric warming trends in recent decade over the west-central Asia.

- The WD frequency has a strong relationship with **model resolution**: higher resolution models produce significantly more WDs, and a disproportionately high fraction of extreme events (Hunt et al., 2019).

Mechanism of enhanced WDs in Changing Climate

Contours of surface air temperature trend (ºC per decade) during (1961–2006) overlaid on the Tibetan and Himalayan orography. The shaded scale represents surface elevation in meters

(Source: Madhura et al., 2015)

Time-series meridional temperature difference (30 ºN– 35ºN minus 50ºN–55ºN) (K) averaged over the Eurasian longitudes (20ºE–100ºE) for the DJFMA season a 500 hPa, b 200 hPa, c Map showing the difference of baroclinic instability index (C) between the second half (1980–2011) and the first half (1948–1979)

▶ The **warming trends** in excess of 0.5 ºC per decade over the west-central Tibetan Plateau and Himalayas (Fig. 1).

▶ The **meridional temperature gradient (MTG) index** is a good indicator for **baroclinic eddy activity**. The increasing trend of MTG index in the middle and upper-troposphere (5% significance level) provides corroborative support for enhanced baroclinicity in the region during the recent decades.

▶ The **enhanced baroclinicity favours enhanced activity of WDs** and extreme precipitation events over the WH in recent decades.

A.P. Dimri · Amulya Chevuturi

Western Disturbances - An Indian Meteorological Perspective

THANK YOU