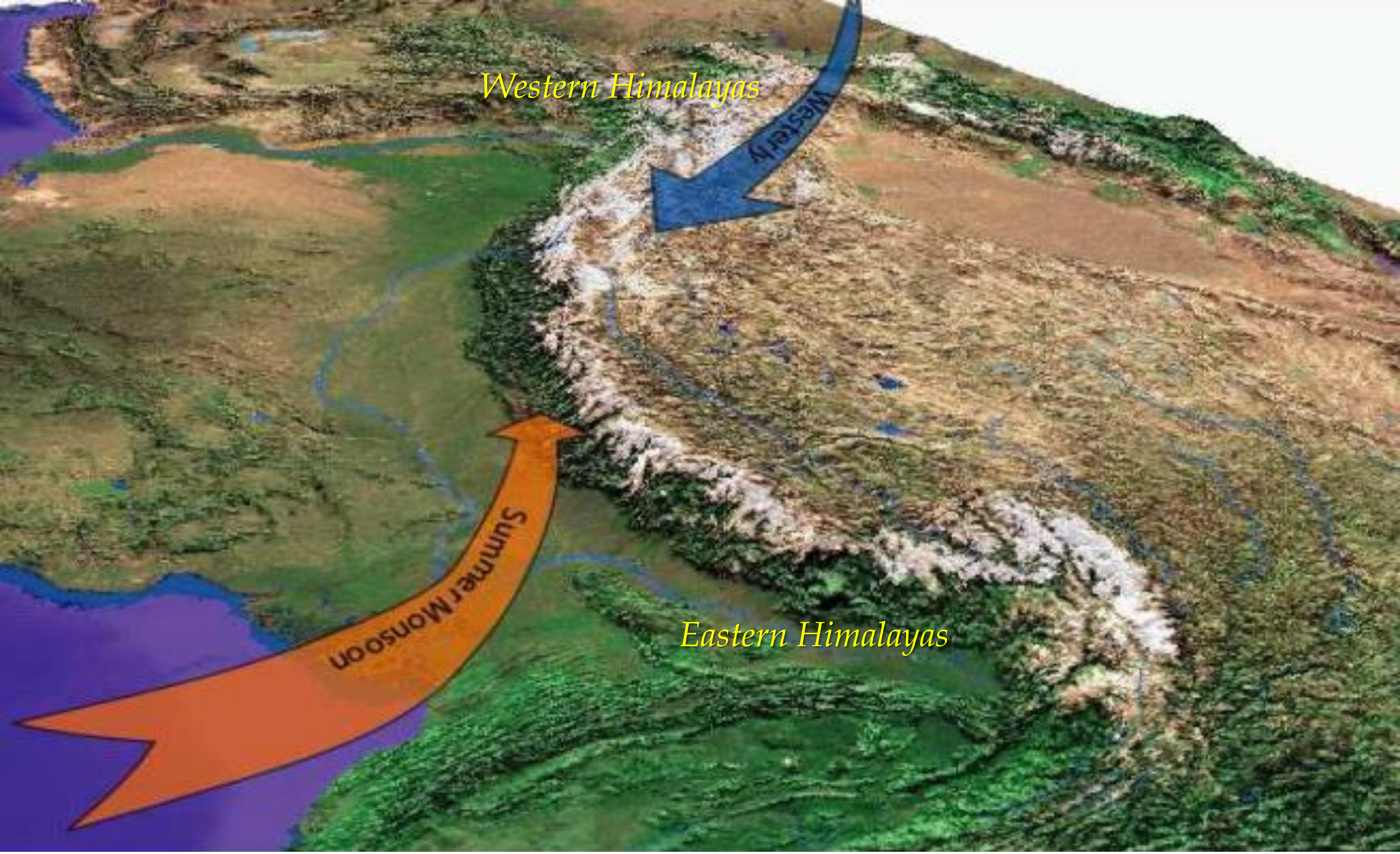
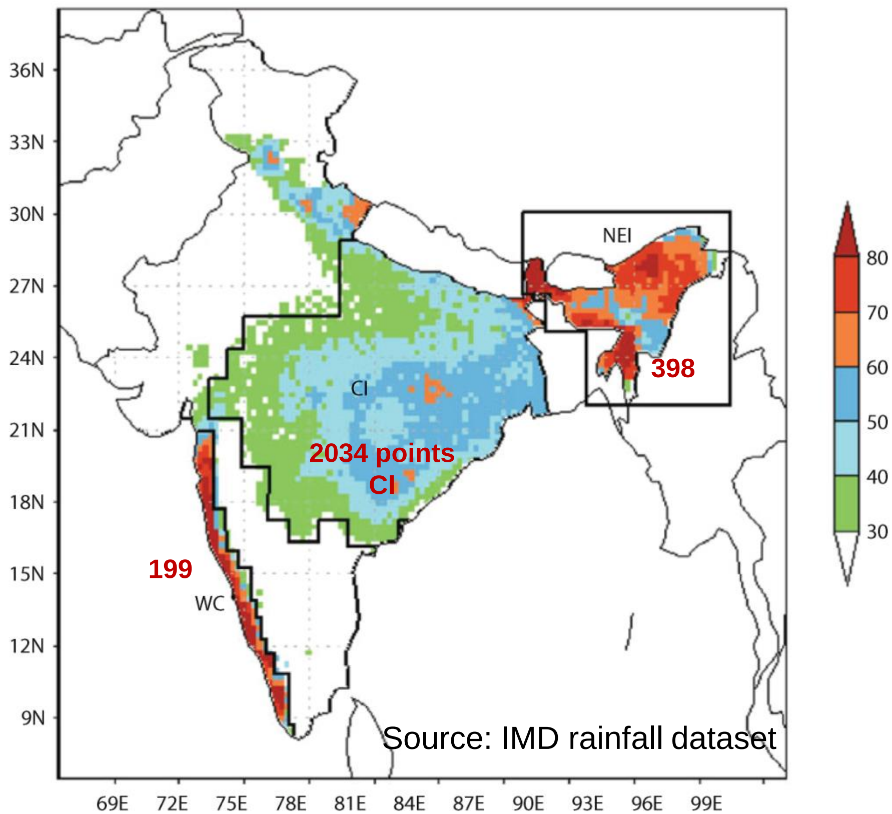


Large-scale dynamics and numerical modelling of Heavy precipitation events in the Himalayan region

Ramesh Vellore, Centre for Climate Change Research,
Indian Institute of Tropical Meteorology, Pune, India.

Science and Training Workshop on Climate Change over the High Mountains of Asia
October 8-12, 2018

Flood vulnerability over mountainous North-east India

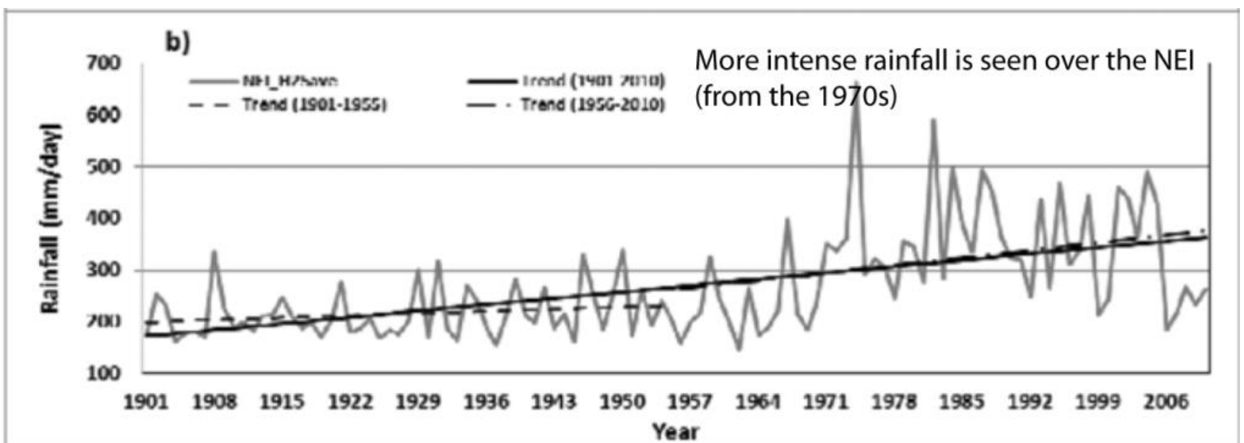


Spatial distribution of mean and frequency and extreme rain events over India during the monsoon season for the period 1901-2010 (Pai and Sridhar 2015)

The spatial domains of WC, CI and NEI enclose 199, 2,034 and 398 grids respectively.

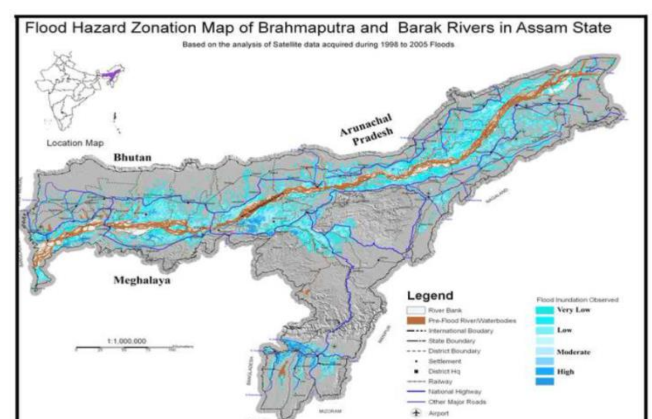
we can see that the grid points within CI received about 30–60 days/season of extreme rain events (64 mm day or more) and most of the grid points within the other two regions (WC and NEI) received ≥ 60 days/season of extreme rain events.

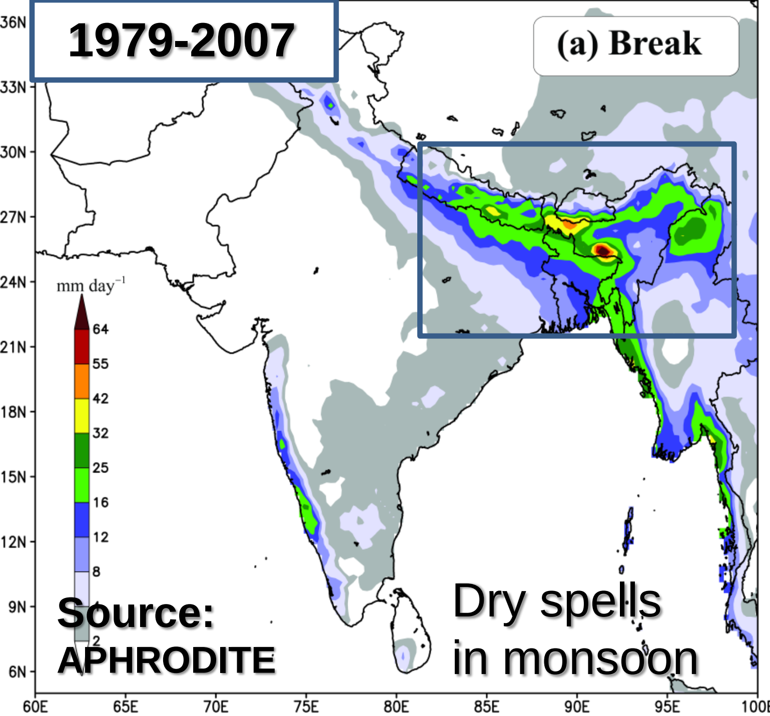
The highest grid point rainfall recorded over NEI during the 1901-2010 period was 939.45 mm.

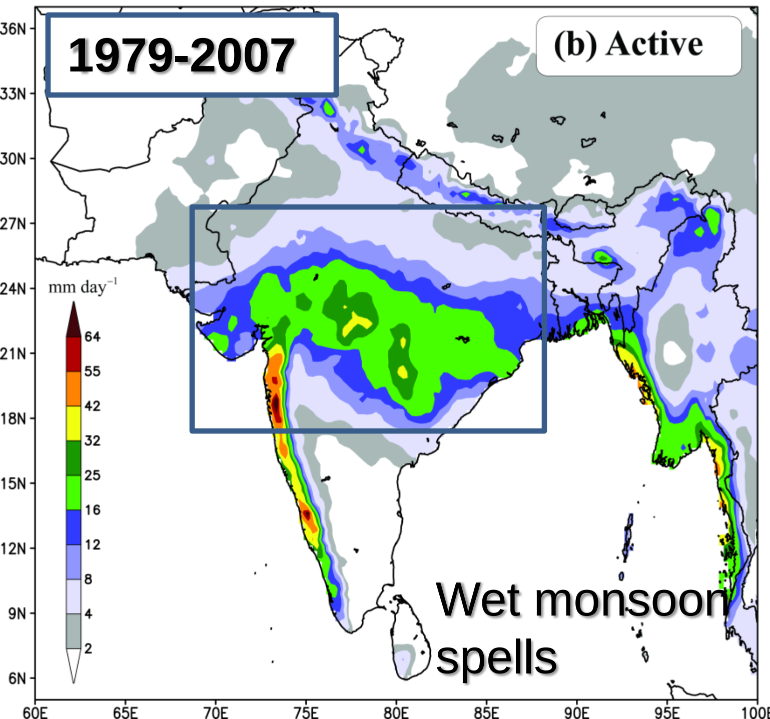


Higher flood inundations are typically observed in the plains of northeast Assam and on the northern side of the mountainous regions in the state of Meghalaya in India.

(Source: NRSA, India) Period: 1998-2005







Nomenclature

Weak/subdued/Break Monsoon

Rainfall over the monsoon-core land region is less than half the normal

Rainfall activity is confined to northeastern parts of India

Weaker wind speeds: Wind speed is up to 12 knots (over the Sea)

Active/vigorous Monsoon

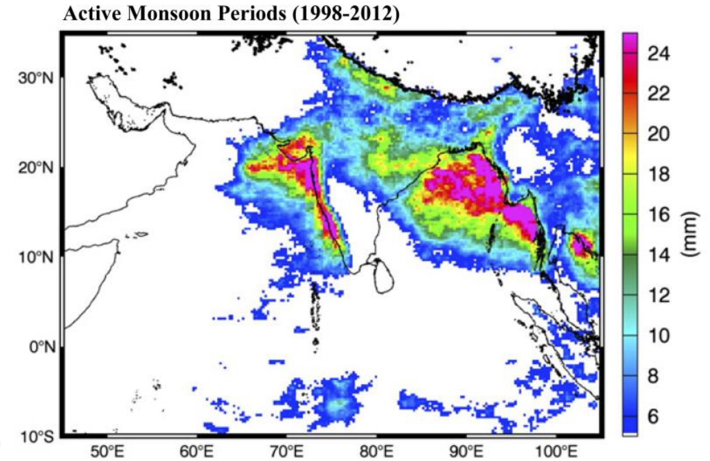
Rainfall is fairly widespread over the land area

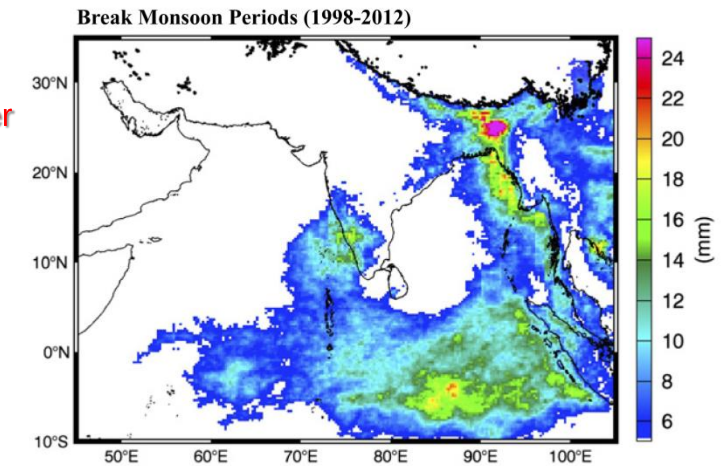
Rainfall 1½ to 4 times the normal

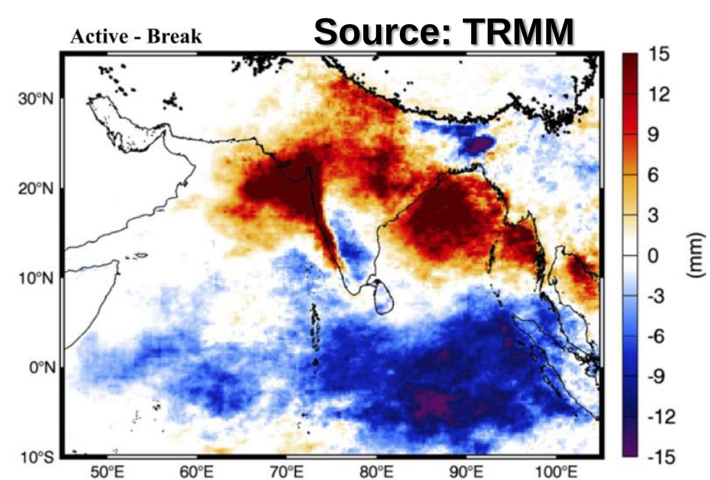
The rainfall in at least two stations should be 5 cm

Stronger wind speeds: Wind speed is between 23 to 32 knots (over the Sea)

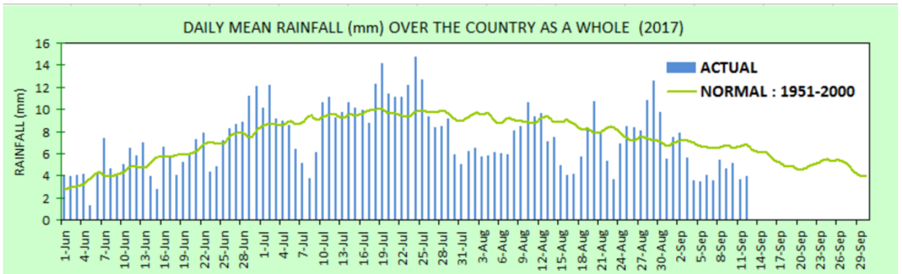
Vigorous monsoon:
Rainfall > 4 times normal
Wind speeds > 32 knots





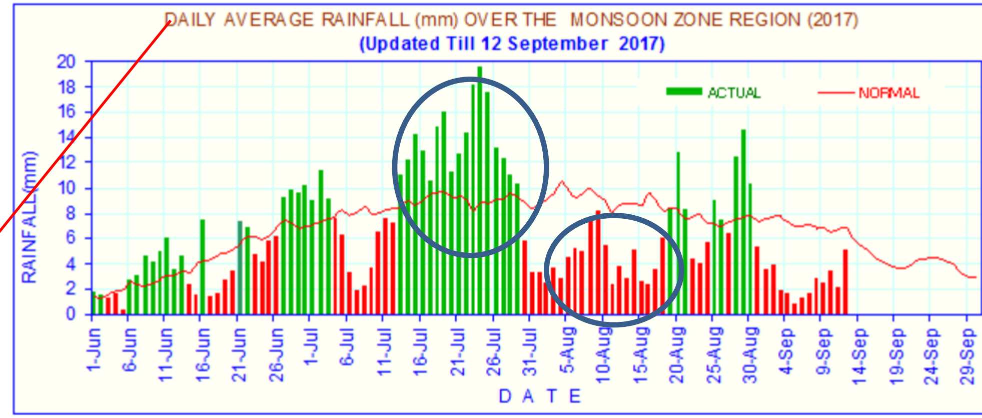


Source: http://www.imd.gov.in/



Daily evolution of 2017 All-India India summer monsoon (AISMR) rainfall

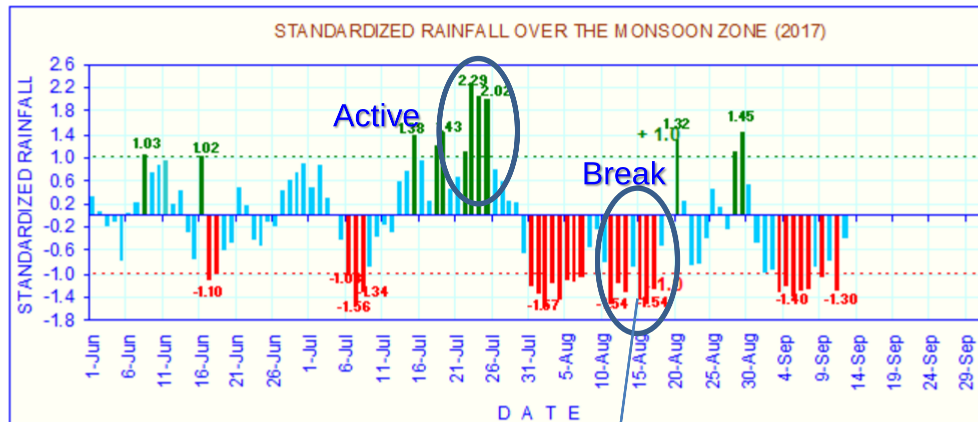
Active (wet) and Break (dry) spells during summer monsoon

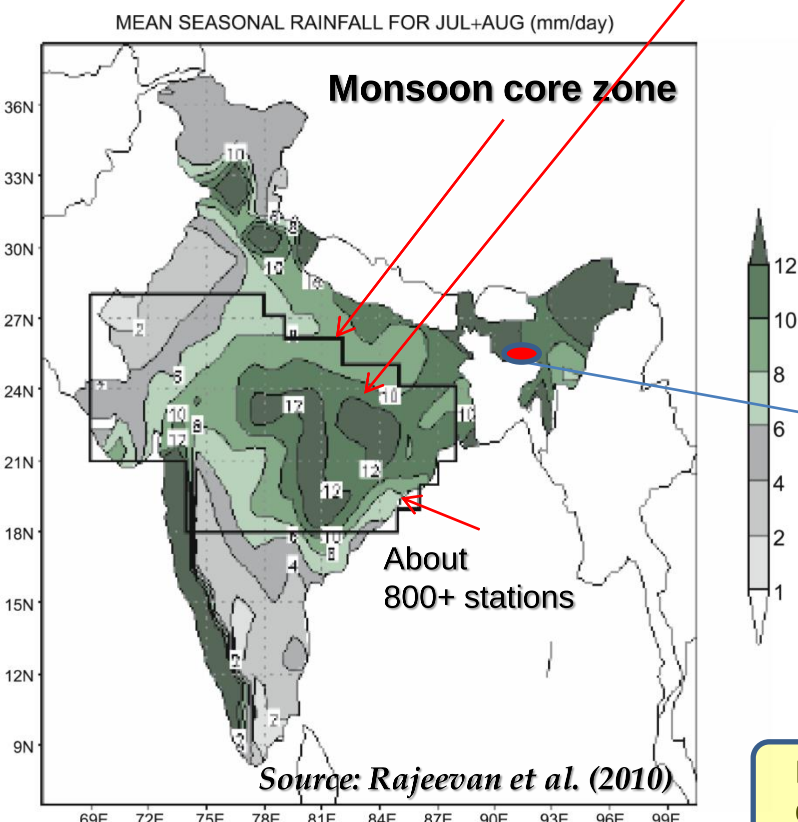


Heavy rain = 6 to 12 cm

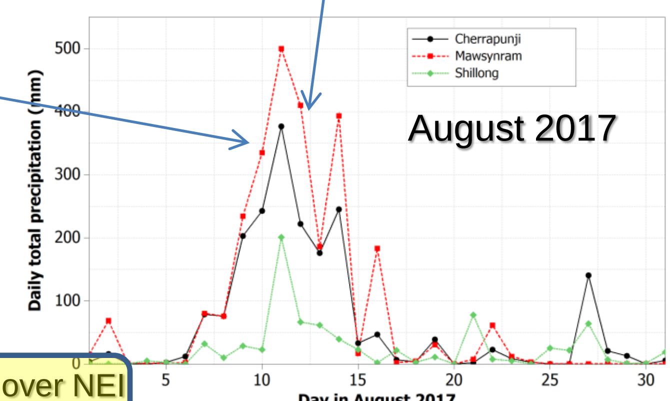
Very heavy rain = 12 to 24 cm

Extremely heavy rain > 24 cm

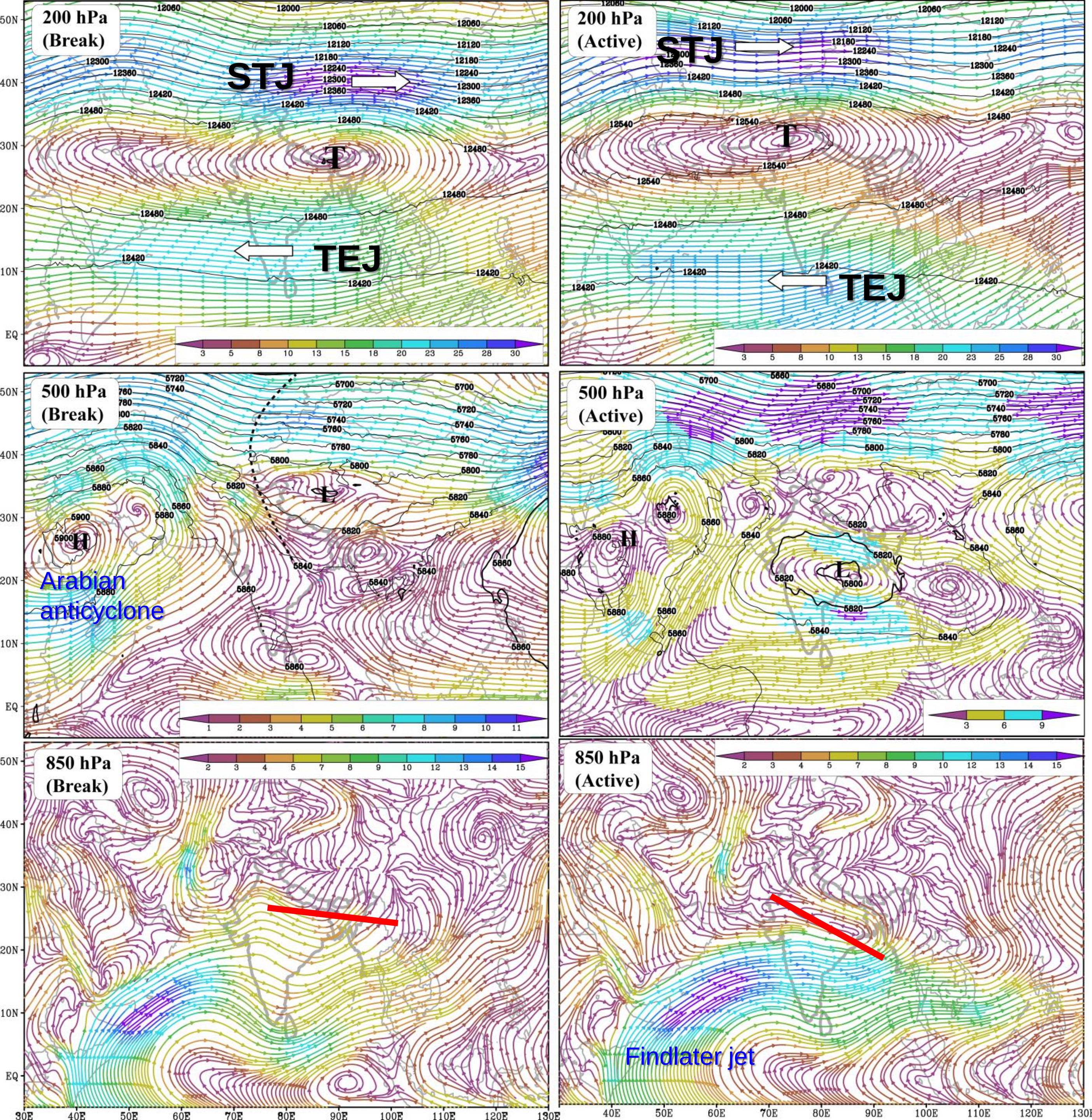




The (active) break spell has been identified as the period during which the standardized rainfall anomaly is less (more) than −1.0 (+1.0), consecutively for three days or more.



Flood-producing rains occur over NEI during break periods



Summer monsoon archetypal circulation patterns

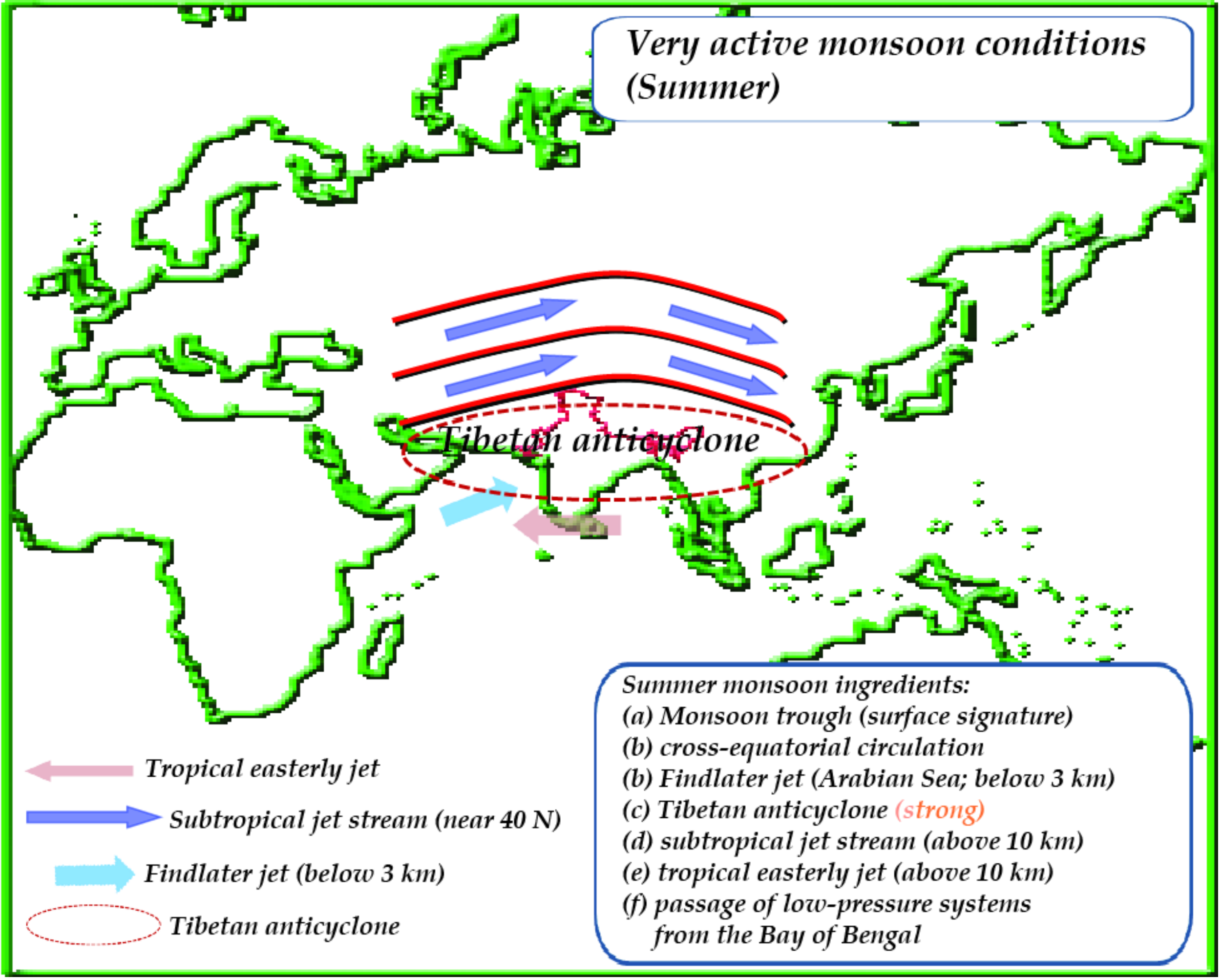
200 hPa
T: Tibetan anticyclone
STJ: Subtropical jet stream
TEJ: Tropical easterly jet

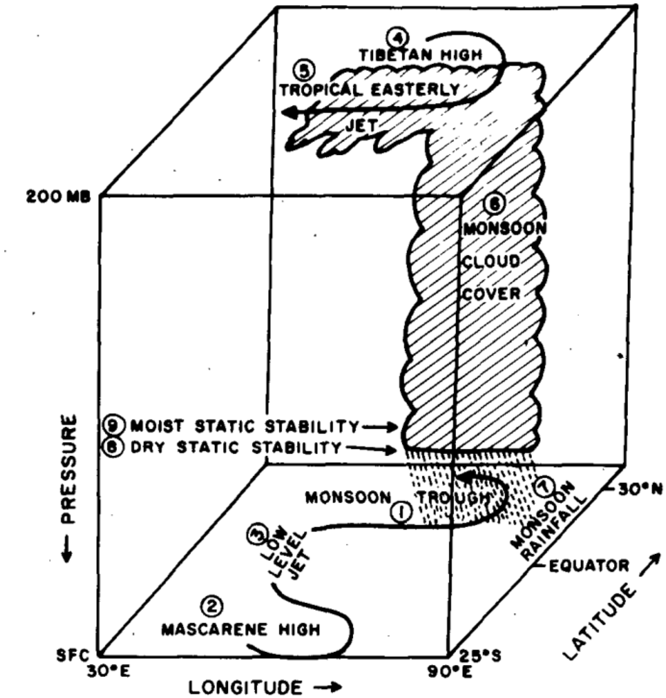
The Himalayas act as a barrier between STJ and TEJ – therefore the positioning of these jets is critical for the Himalayan rainfall.

500 hPa

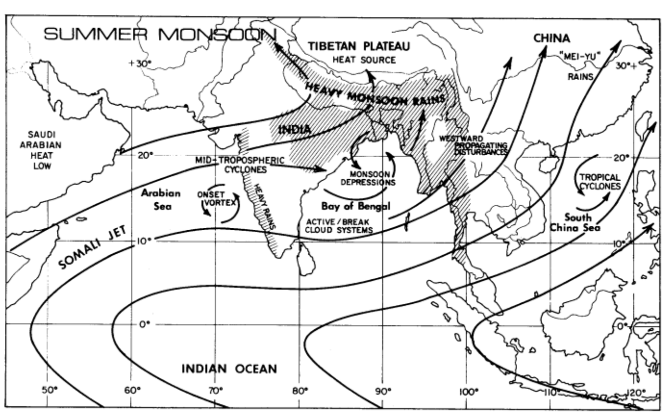
850 hPa

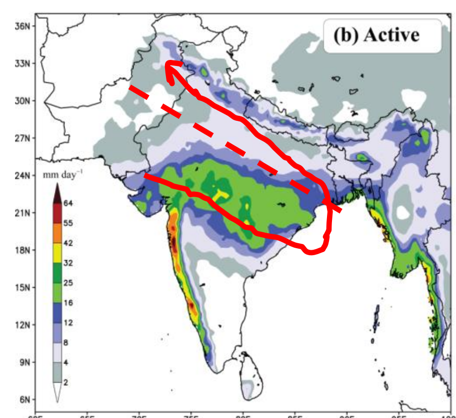
Source: ERA-Interim





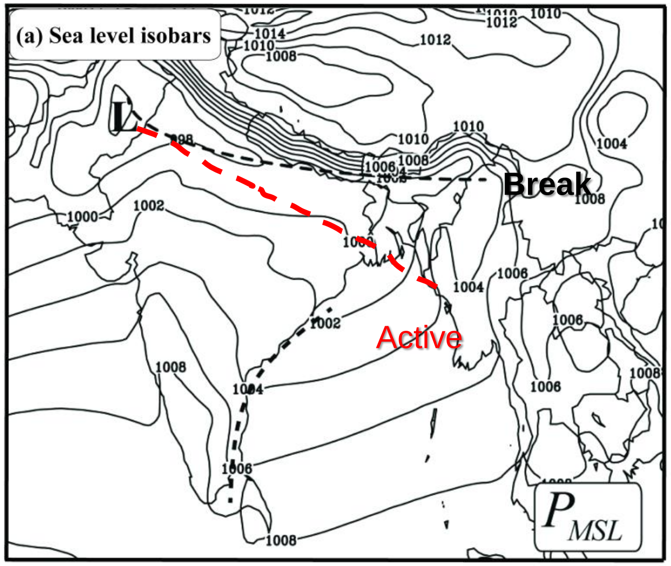
One can refer the condition as vigorous or very active when strong or robust signatures of (a)-(f) are seen

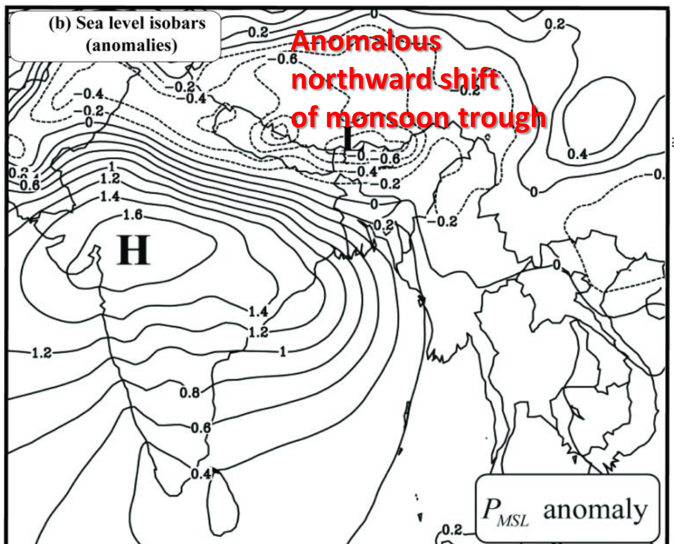


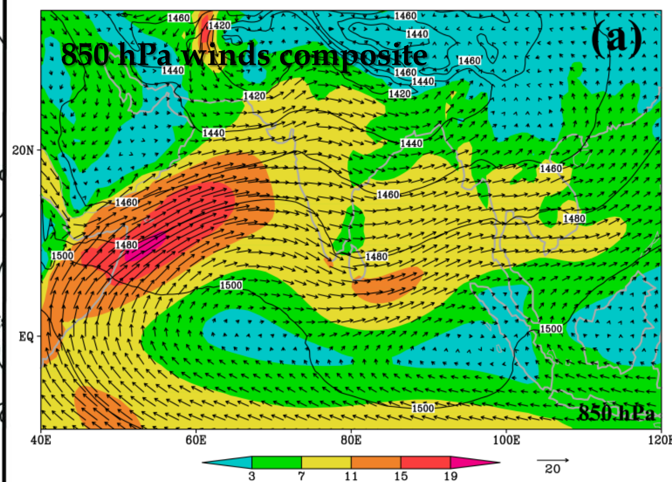


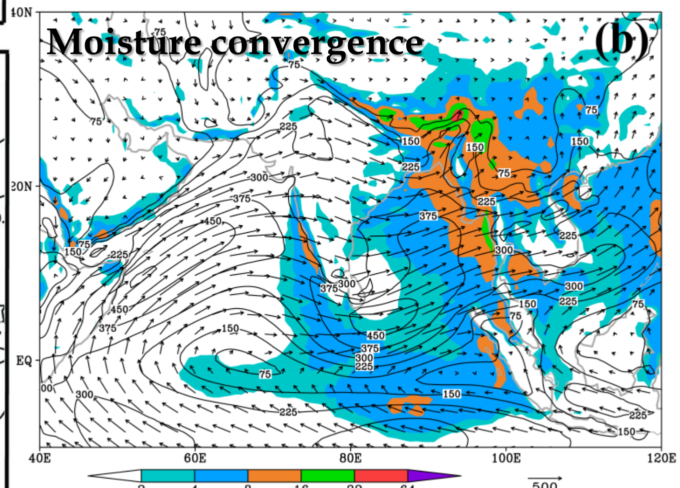
Occurrence of extreme precipitation events in the Himalayas are mostly from the penetrating monsoon circulation from east to west

Composite of monsoon-breaks

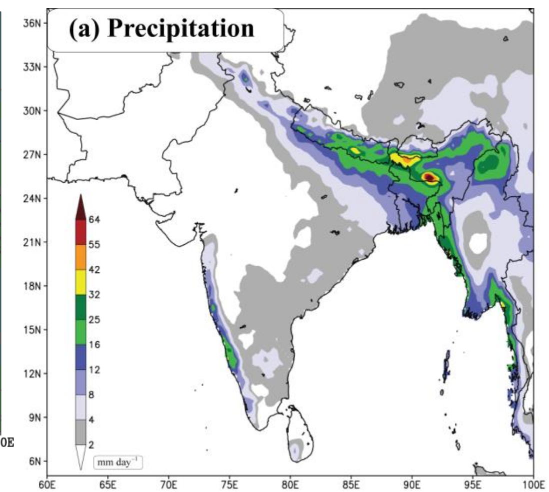


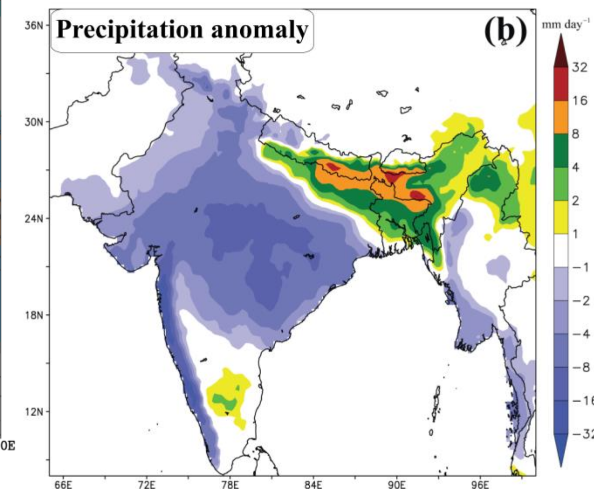






(1979-2007)

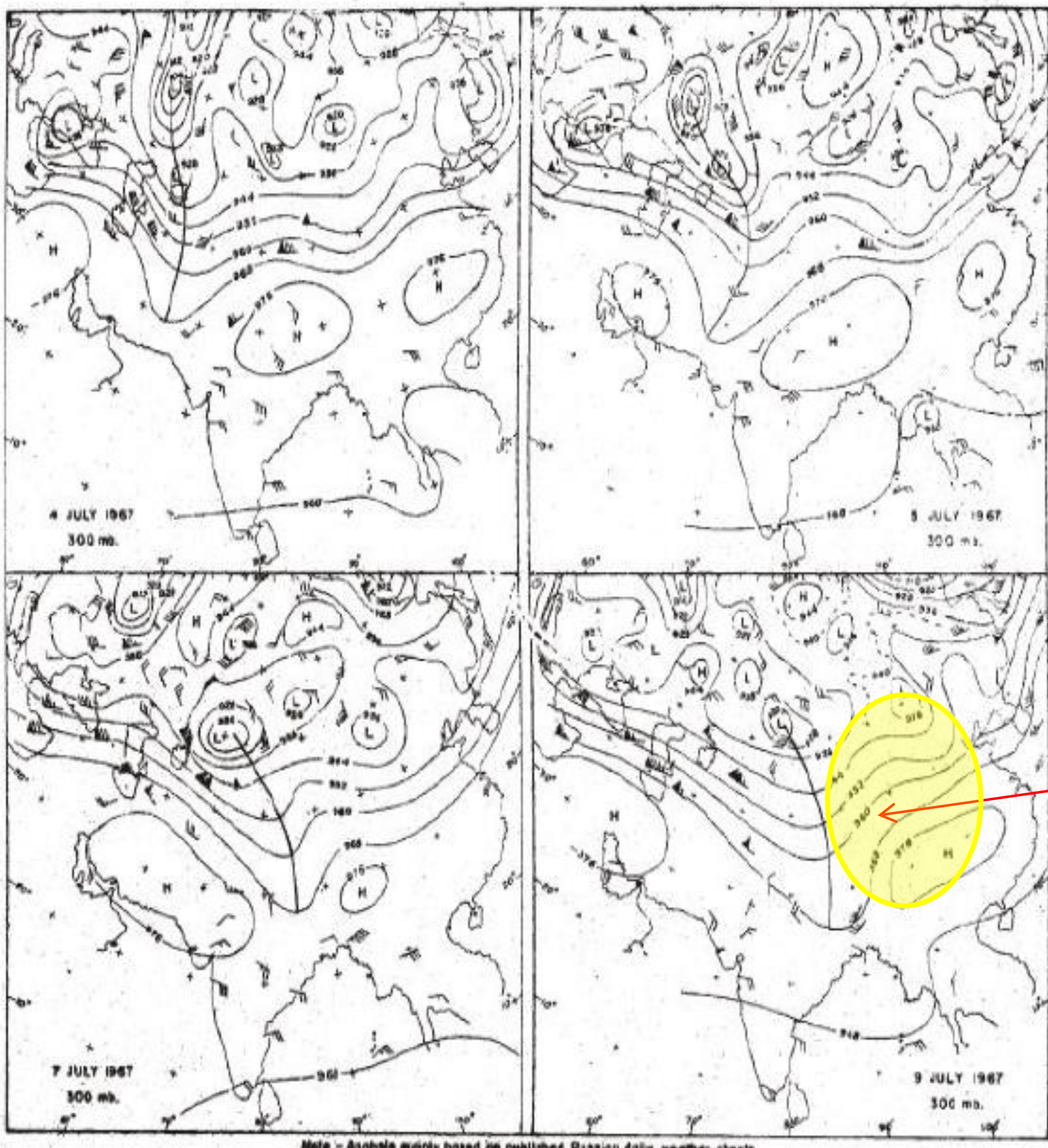




Source: APHRODHITE (0.25°× 0.25°)

Source : ERA-Interim (0.75°× 0.75°)

Monsoon Breaks: Extratropical circulation interactions

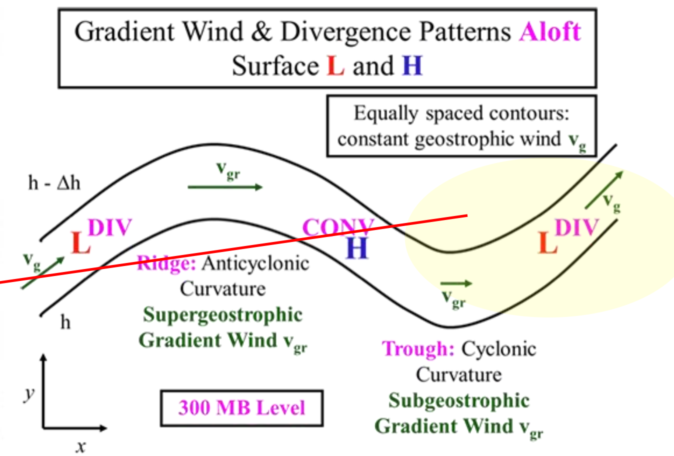


(Source: Rao 1976)

Extratropical interactions with monsoon circulation are envisioned with the passage of trough in westerlies during 'break'

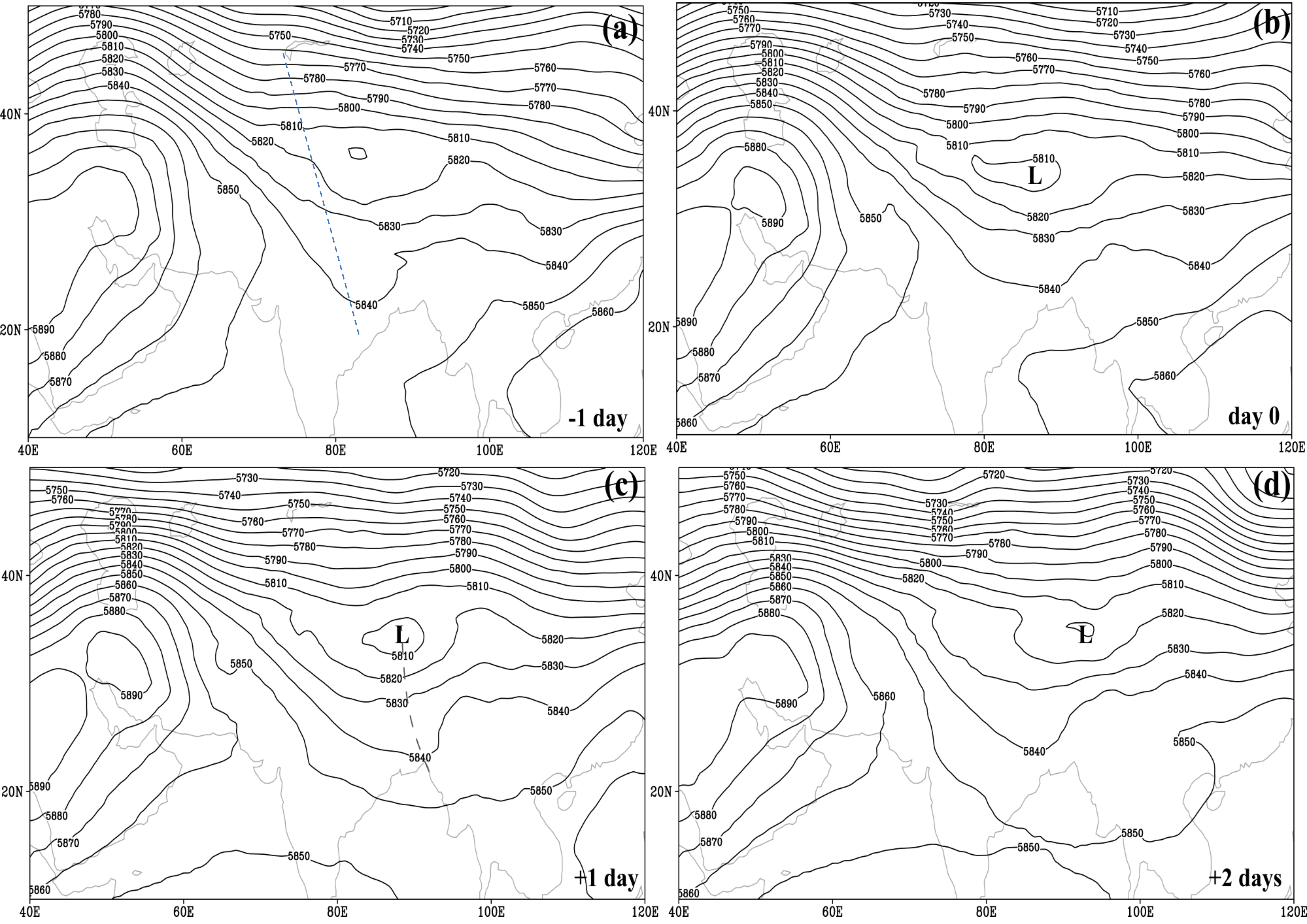
Large amplitude troughs protrude into Indo–Pakistan area at 500 hPa and aloft.

Viewed as: The upper level divergence causes heavy rainfall over and near the Himalayas.

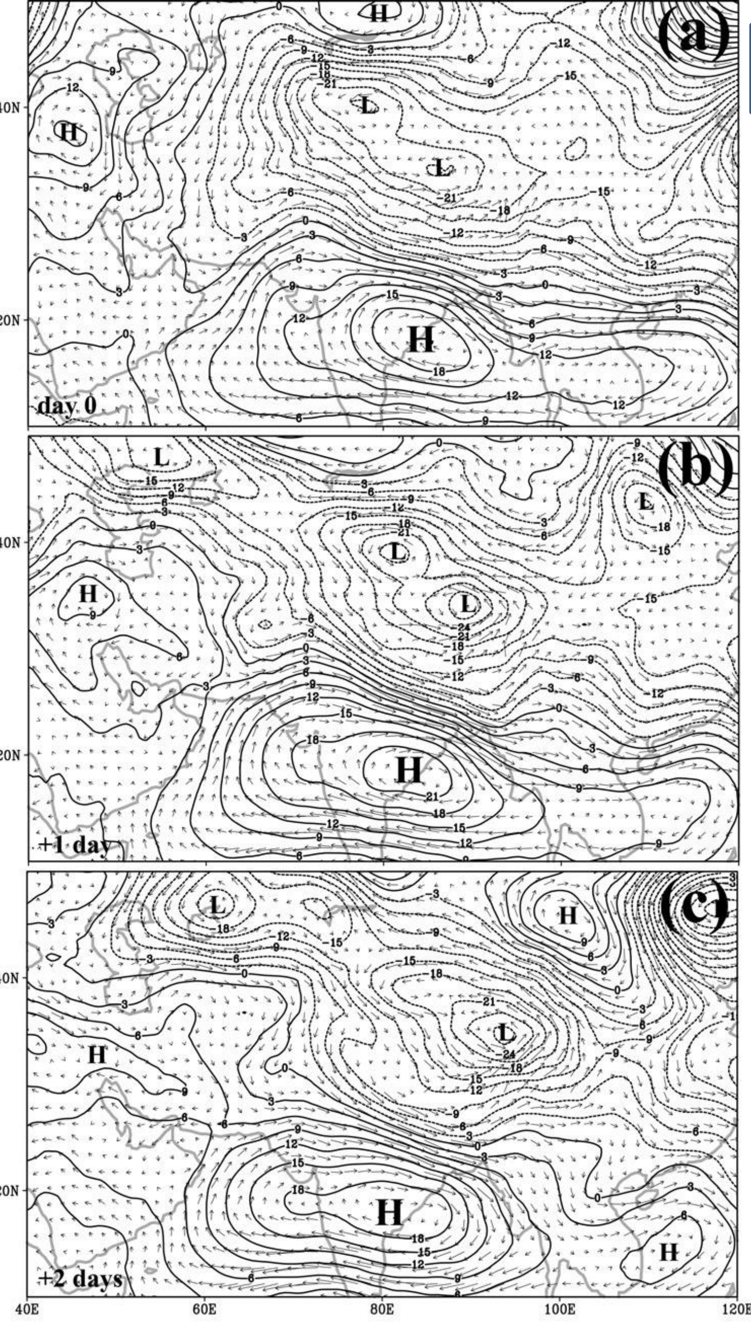


- Upper level divergence on large-scale
- Rainfall more confined over the central-eastern Himalayas

Mean 500 hPa circulation during break periods



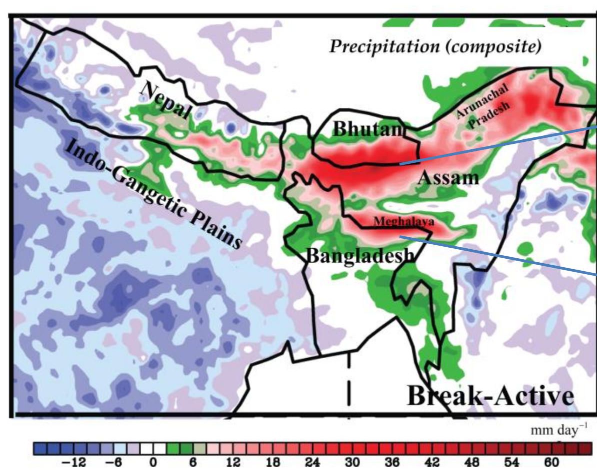
Monsoon-mid-latitude interactions – break cycle



Time evolution of anomalous 500 hPa wind and geopotential height during break cycle

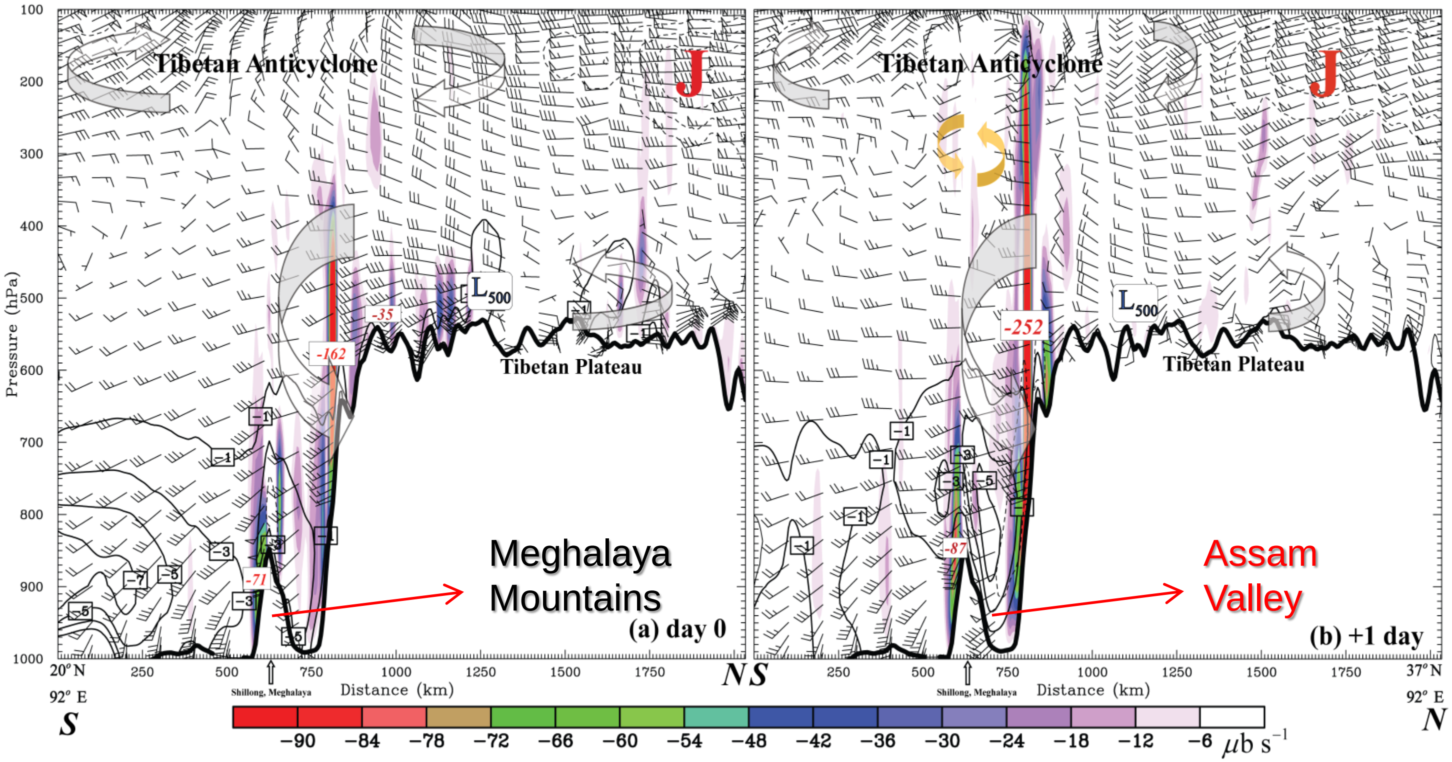
During monsoon-break periods, foothill-locked monsoon trough (surface), extratropical forcing from the perturbations associated with the mid-tropospheric circulation, and the eastward moved Tibetan anticyclone (200 hPa) – these 3 elements stacked in vertical to provide a three-dimensional closure for deep vertical circulation near the central-eastern Himalayan foothills.

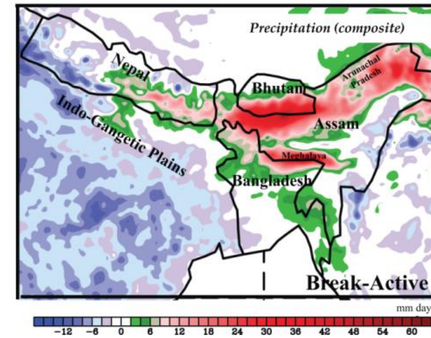
Flood vulnerablity : central-eastern Himalayas (Brahmaputra River basin)

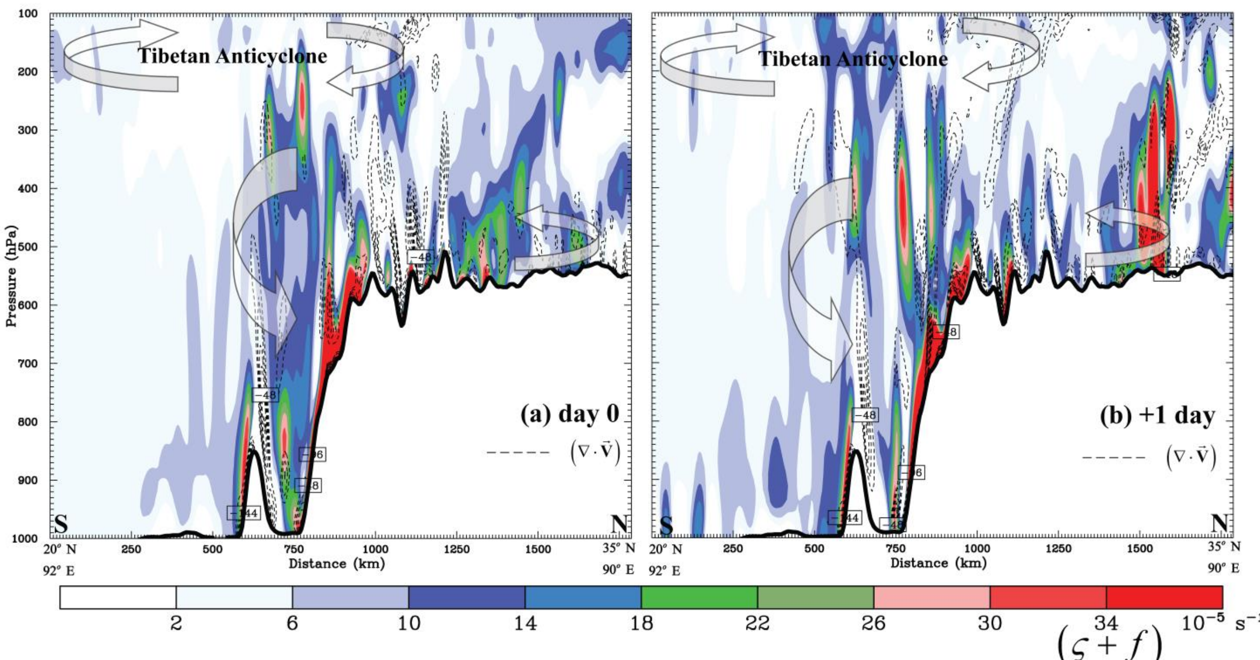


Conceptualized as Monsoon-extratropical interaction

orographic precipitation enhancements

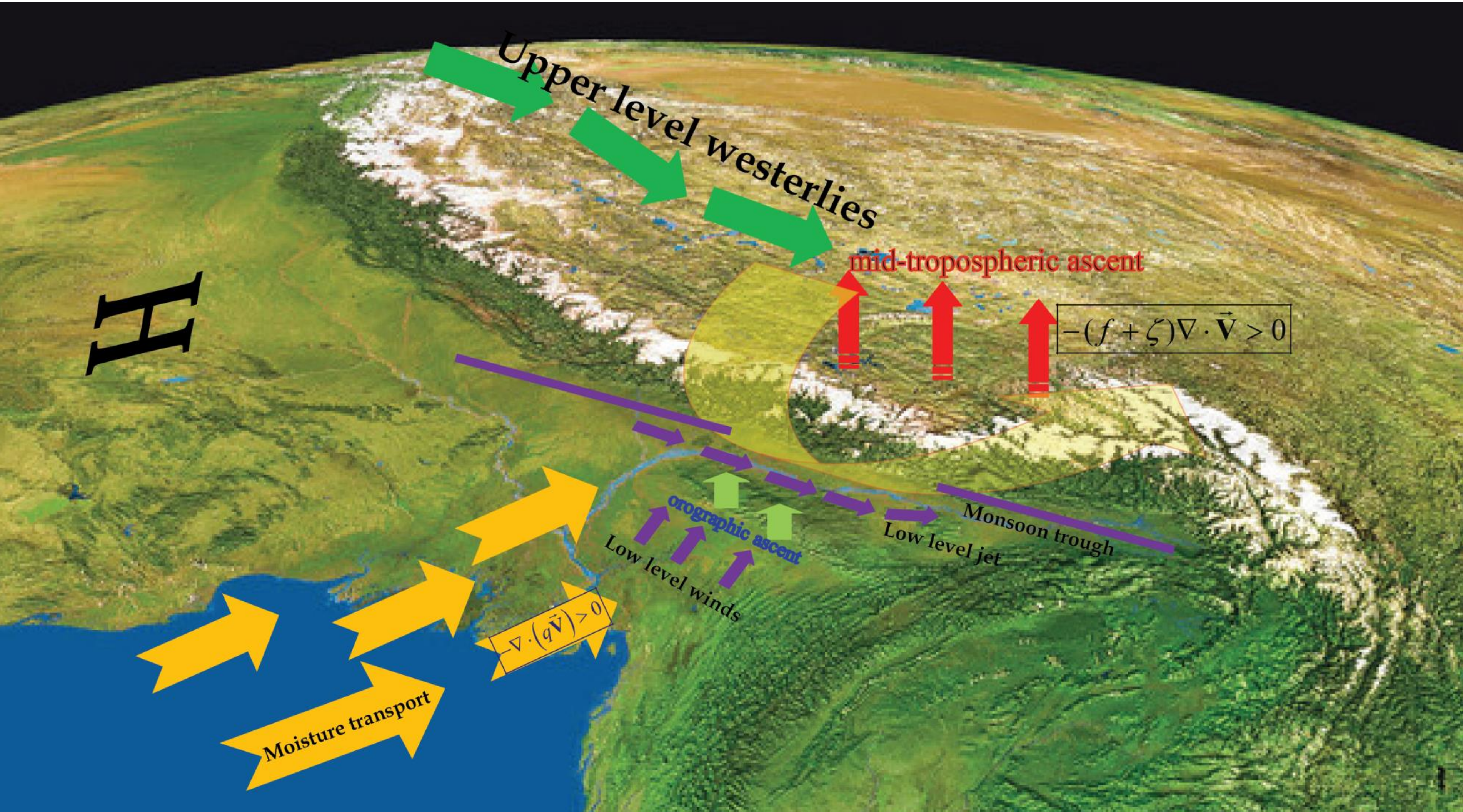






Anomalous enhancement of precipitation over the CEH foothills is induced by dynamical interactions between southward intruding mid-latitude westerly troughs and the regional monsoon circulation anomalies in the mid-tropospheric levels, which lead to mid-level convergence, strong mid-tropospheric ascent and vorticity stretching over the CEH foothills.

Large-scale dynamics during breaks



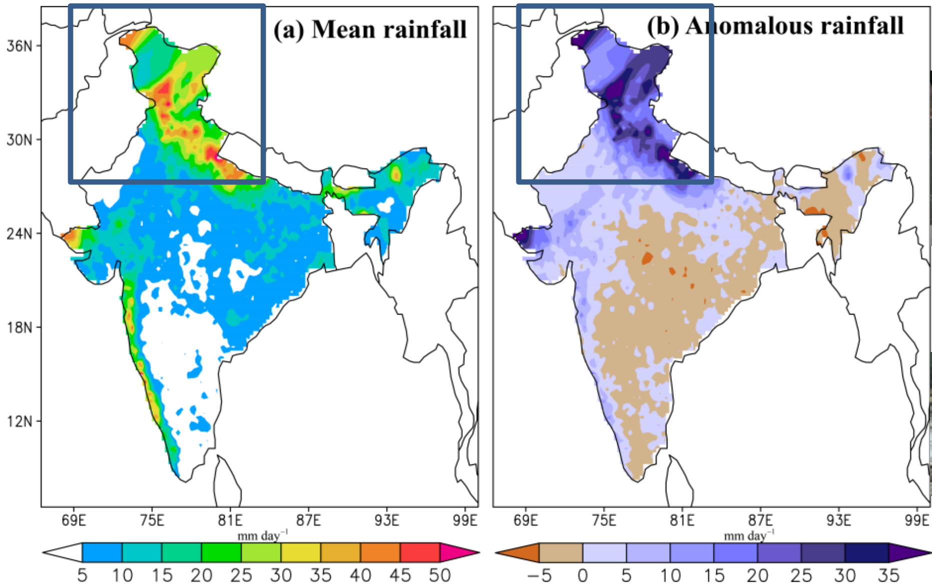
Clim Dyn
DOI 10.1007/s00382-013-2024-1

On the anomalous precipitation enhancement over the Himalayan foothills during monsoon breaks

Ramesh K. Vellore · R. Krishnan · Jayant Pendharkar · Ayantika Dey Choudhury · T. P. Sabin

Vellore et al. (2014)

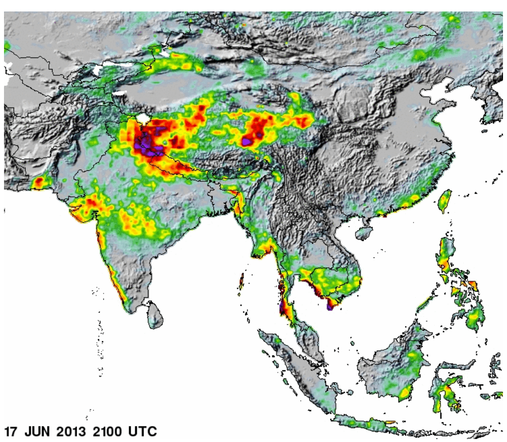
Extreme rain events in the Western Himalayas - Occurs in conjunction with moderately active periods & slow moving upper level circulation

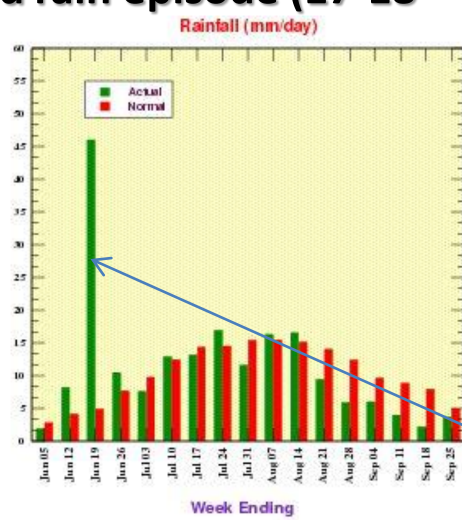


Maximum rainfall amount (mm) occurred within the box region encompassing 28°N–35°N and 75°–85°E and the day of the occurrence of the extreme event

No.	Day of the extreme event	Maximum rainfall (mm)
1	12 Aug 1979	344
2	8 Jul 1980	332
3	17 Jul 1980	217
4	29 Sep 1981	334
5	6 Jun 1982	415
6	13 Sep 1982	364
7	20 Sep 1983	357
8	11 Jul 1986	267
9	22 Jul 1988	264
10	9 Aug 1988	283
11	24 Sep 1988	408
12	25 Sep 1988	269
13	26 Sep 1988	285
14	27 Sep 1988	220
15	28 Aug 1989	252
16	10 Jul 1990	305
17	21 Jul 1992	272
18	11 Jul 1993	415
19	12 Sep 1993	277
20	16 Aug 1994	321
21	9 Sep 1994	241
22	10 Sep 1994	347
23	4 Sep 1995	360
24	5 Sep 1995	424
25	23 Aug 1996	231
26	2 Aug 1997	235
27	17 Sep 2005	207
28	16 Sep 2006	214
29	31 Jul 2008	460
30	20 Sep 2008	351
31	25 Jul 2009	301
32	16 Aug 2011	234
33	**17 Jun 2013**	**367**
34	**18 Jun 2013**	**229**

A classic example- Uttarakand rain episode (17-18 June 2013)





Large-scale dynamics: Monsoon-extratropical circulation interactions

Several dry subtropical regions are affected by extreme precipitation and flooding. These regions include Middle East, Northwestern Africa, Southwestern North America, southern Africa, South America, the Himalayas, and Australia (e.g. Wright, 1997; Knippertz et al., 2003; Knippertz and Martin, 2005, 2007a; Seluchi and Marengo, 2000; Hart et al., 2010; Hong et al., 2011; Favors and Abatzoglou, 2013; Martius et al., 2013; Vellore et al., 2016).

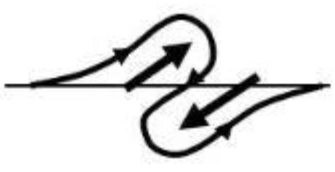
These extreme precipitation events have all in common to result from the interaction between the extratropical and tropical circulations.

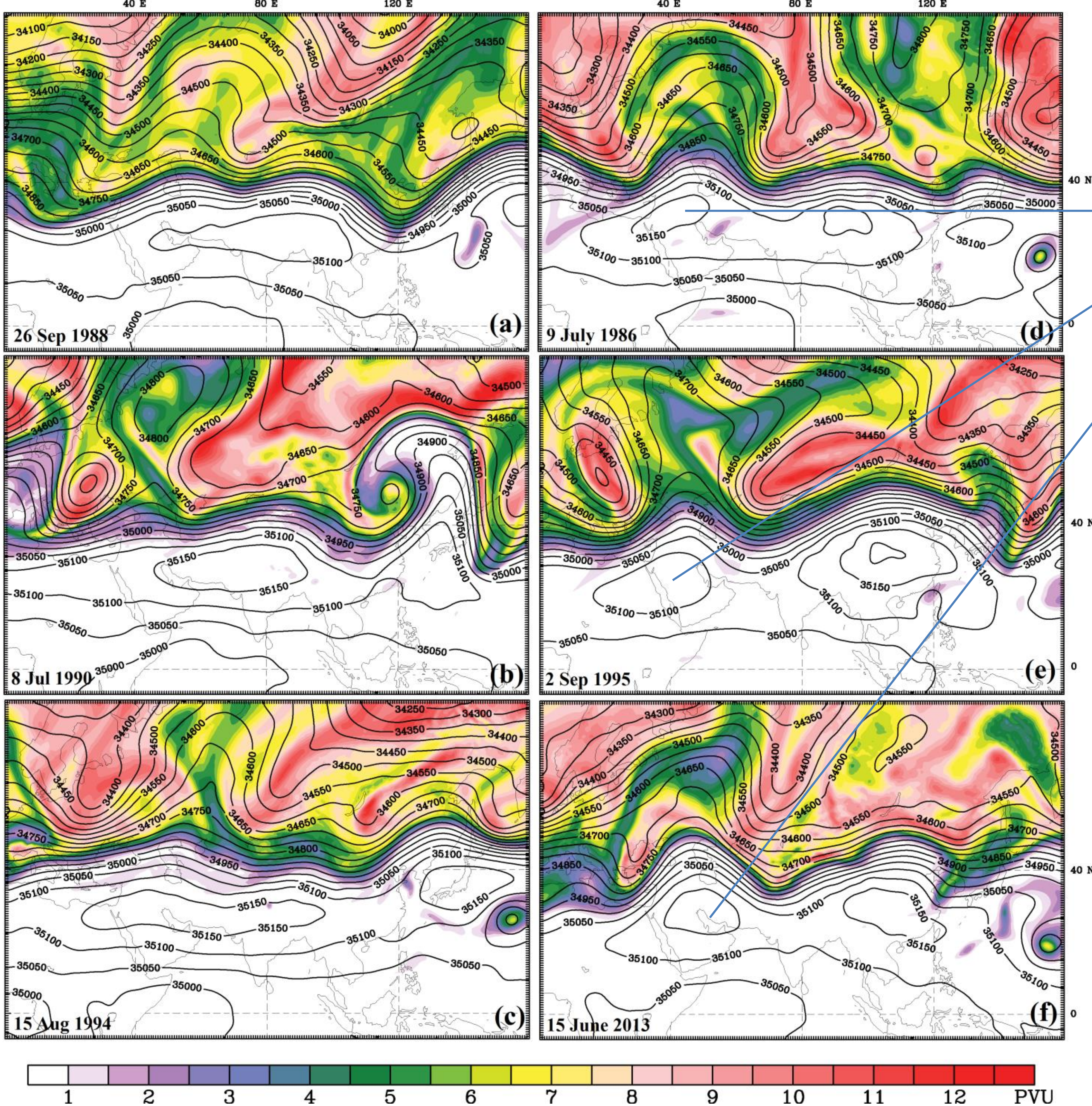
- *Tropical-extratropical interactions are often preceded by wave trains that propagate from the extratropics toward the tropics*

- *The combination of potential vorticity (PV) reduction through latent-heat release and negative PV advection can lead to rapid ridge amplification (upstream) – as a result anticyclonic wave breaking occurs along with the intrusion of an upper-level trough far into low latitudes*

- *The mid-latitude upper level trough interacts with the tropical circulation in the form of monsoonal lows – provides a corridor for poleward excursion of tropical moisture.*

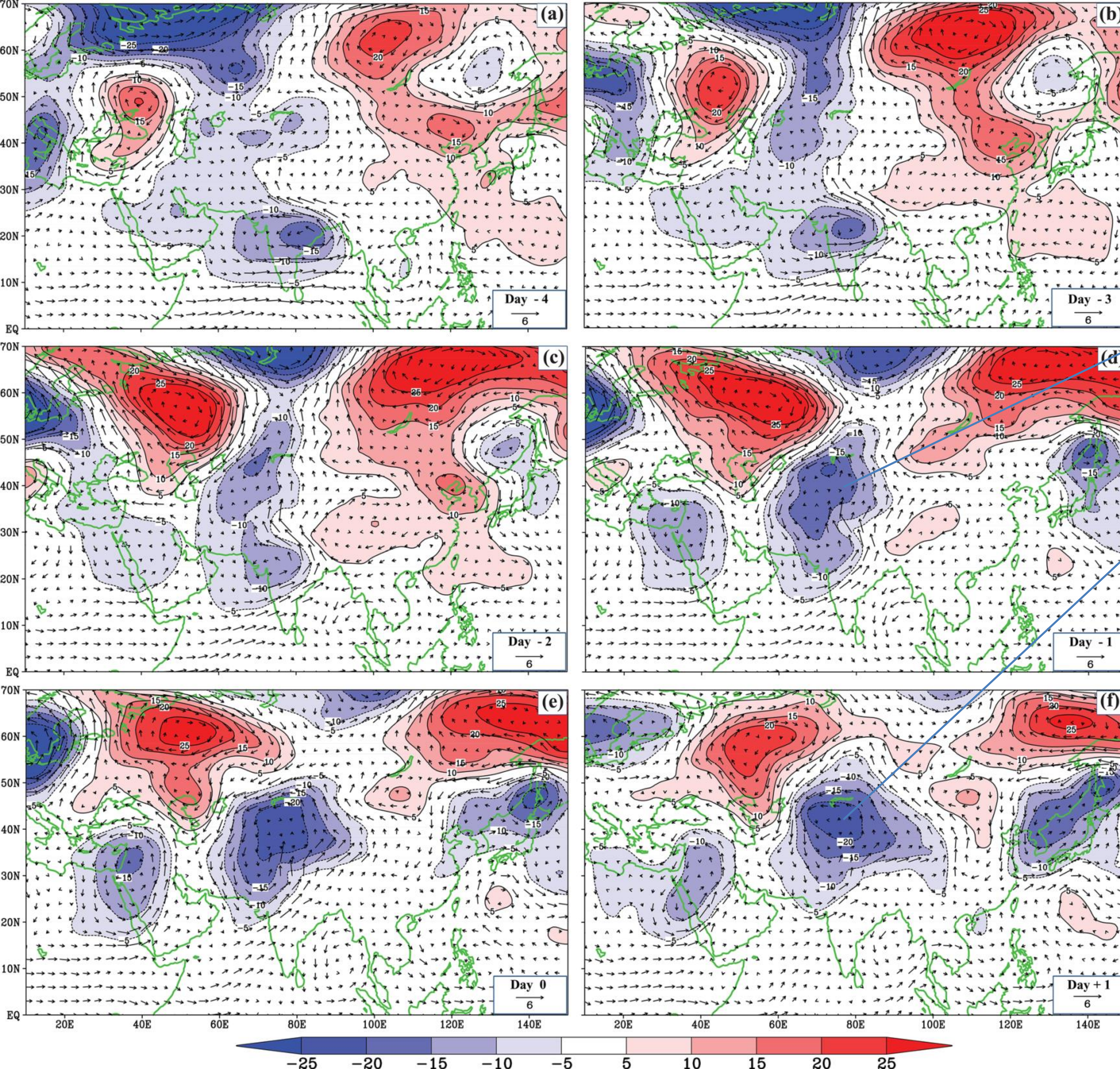
- When the wave amplitude reaches a critical level
- Irreversible overturning of isentropic potential vorticity





Splitting of anticyclone

Montgomery stream function (contours; divided by acceleration due to gravity; units in meters) and potential vorticity (shaded; 1 PVU = 10^{-6} $m^2\ s^{-1}\ K\ kg^{-1}$) on the isentropic surface θ = 350 K a few days prior to extreme precipitation events in the WEH region valid on (a) 26 September 1988, (b) 8 July 1990, (c) 15 August 1994, (d) 9 July 1986, (e) 2 September 1995, and (f) 17 June 2013 (source: ERA-Interim reanalysis).

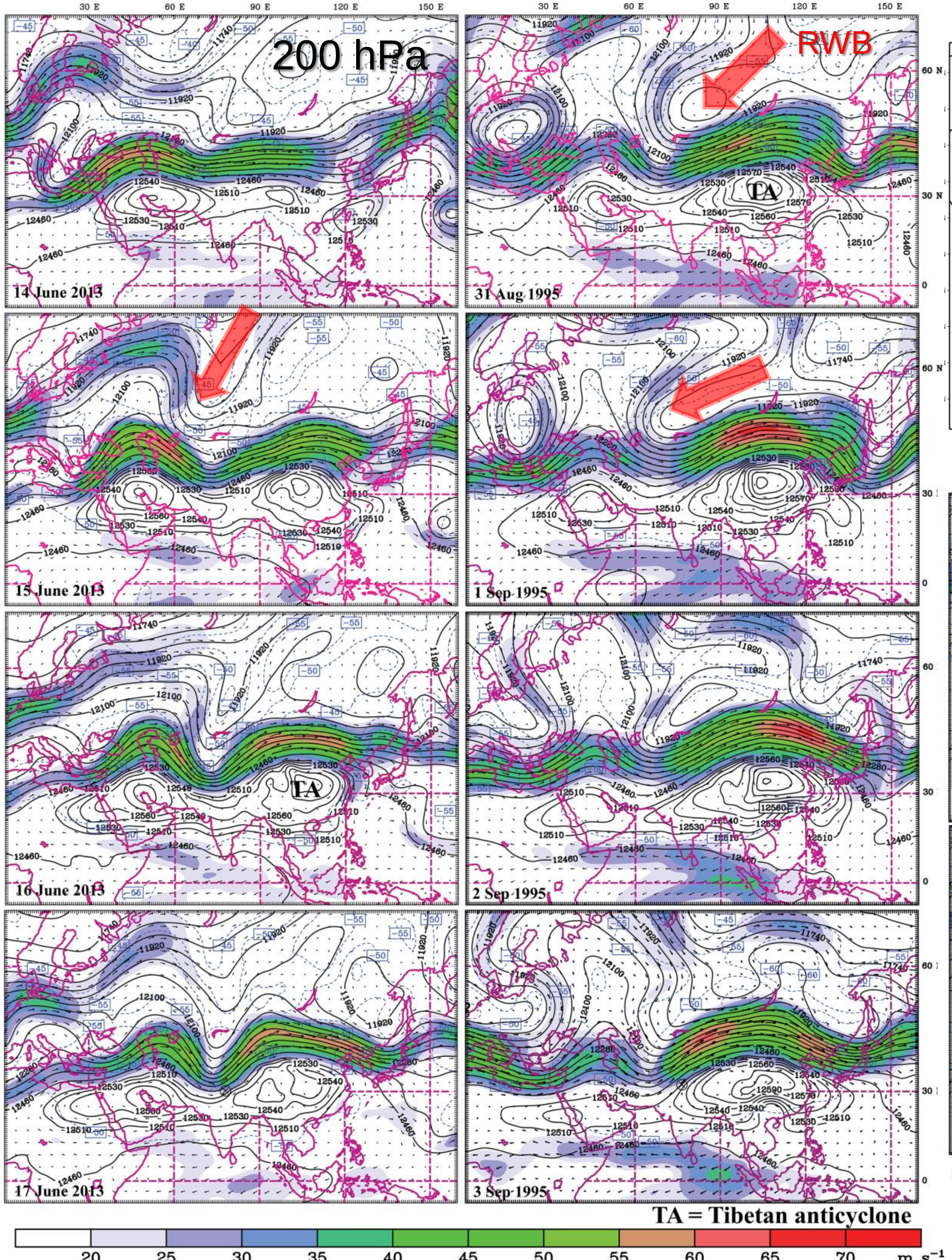


A composite map of daily anomalous circulation fields (horizontal winds–vectors; and geopotential height–*shaded*; units in meters) at 500 hPa

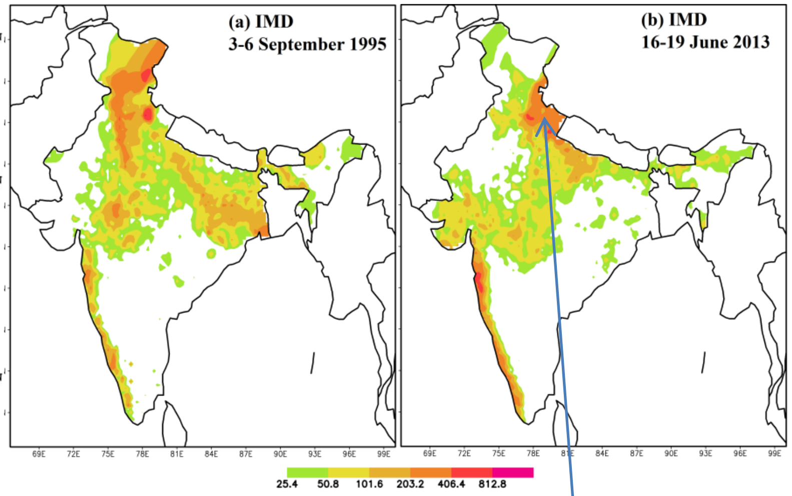
Source of Mid-level Vorticity

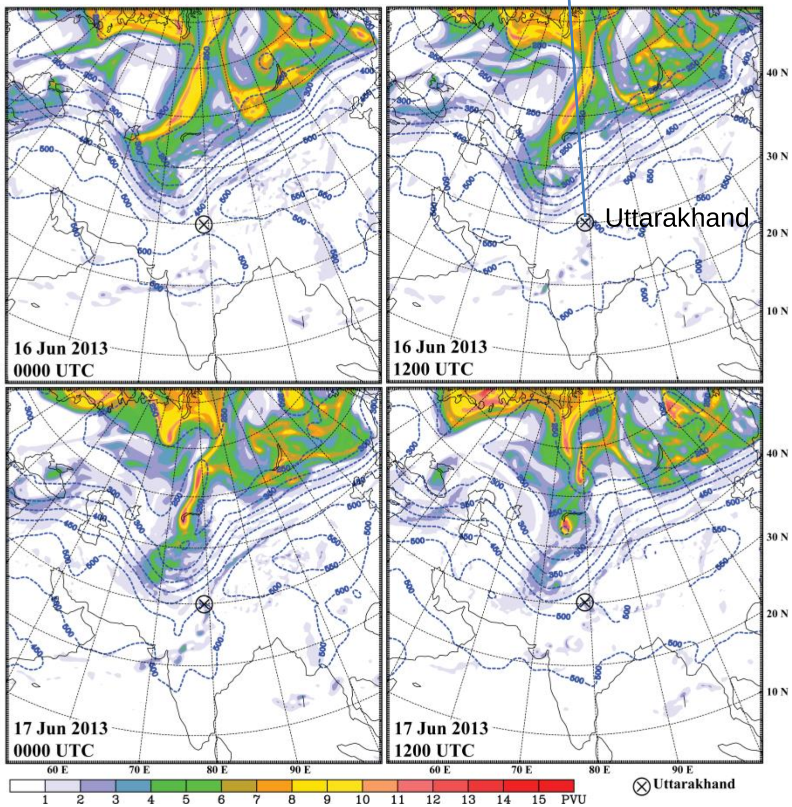
Isentropic PV

Anticyclonic Wave breaking

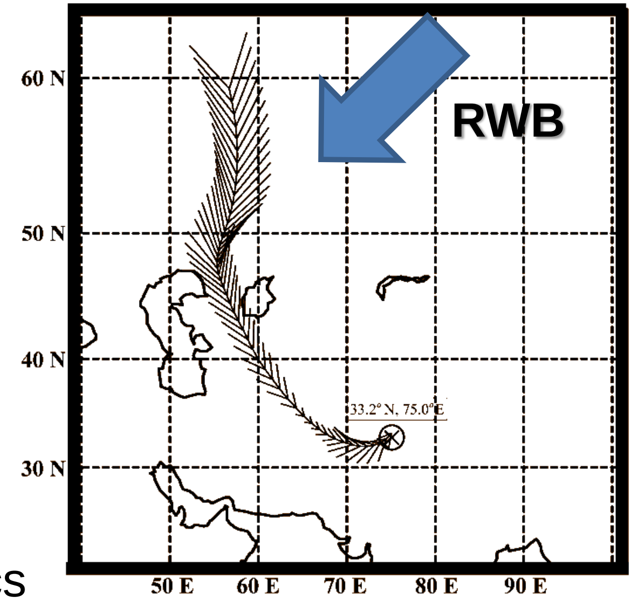


Rainfall (IMD)



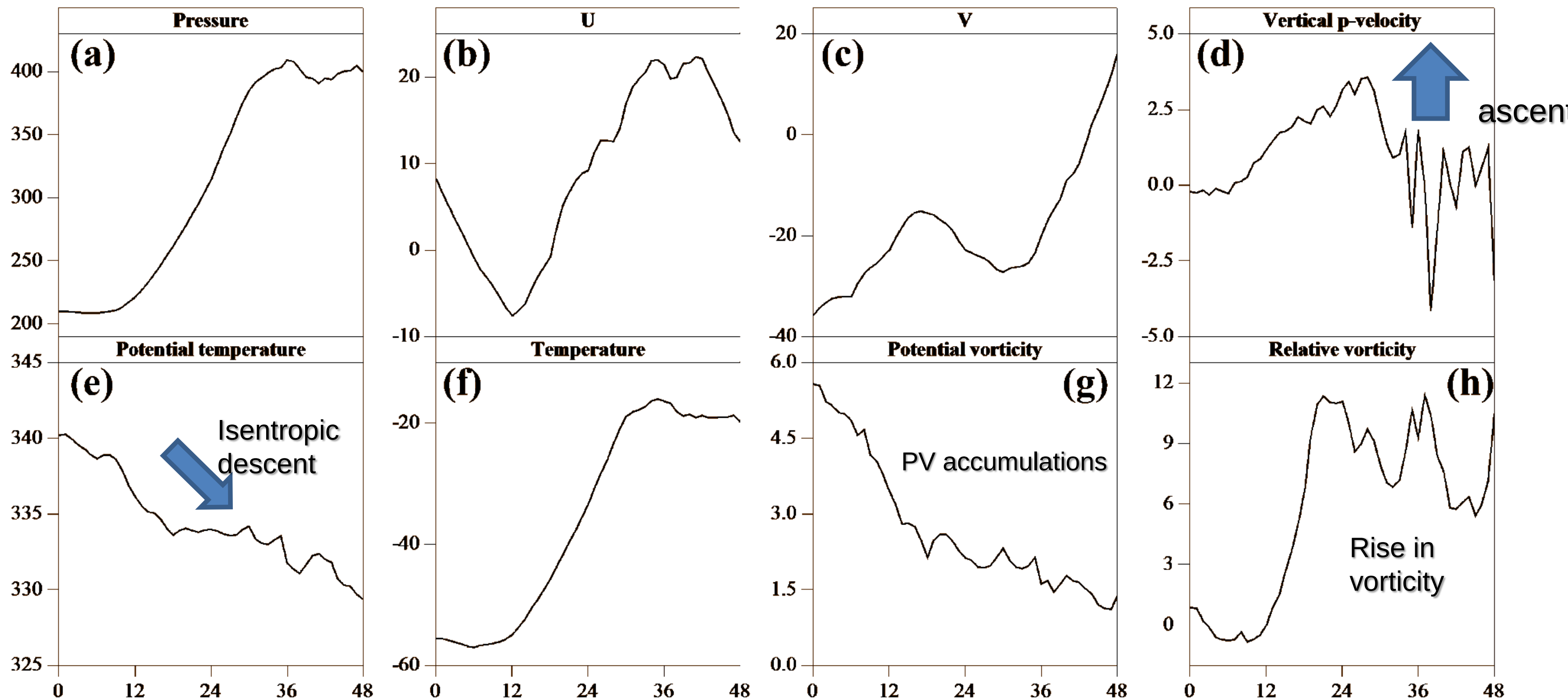


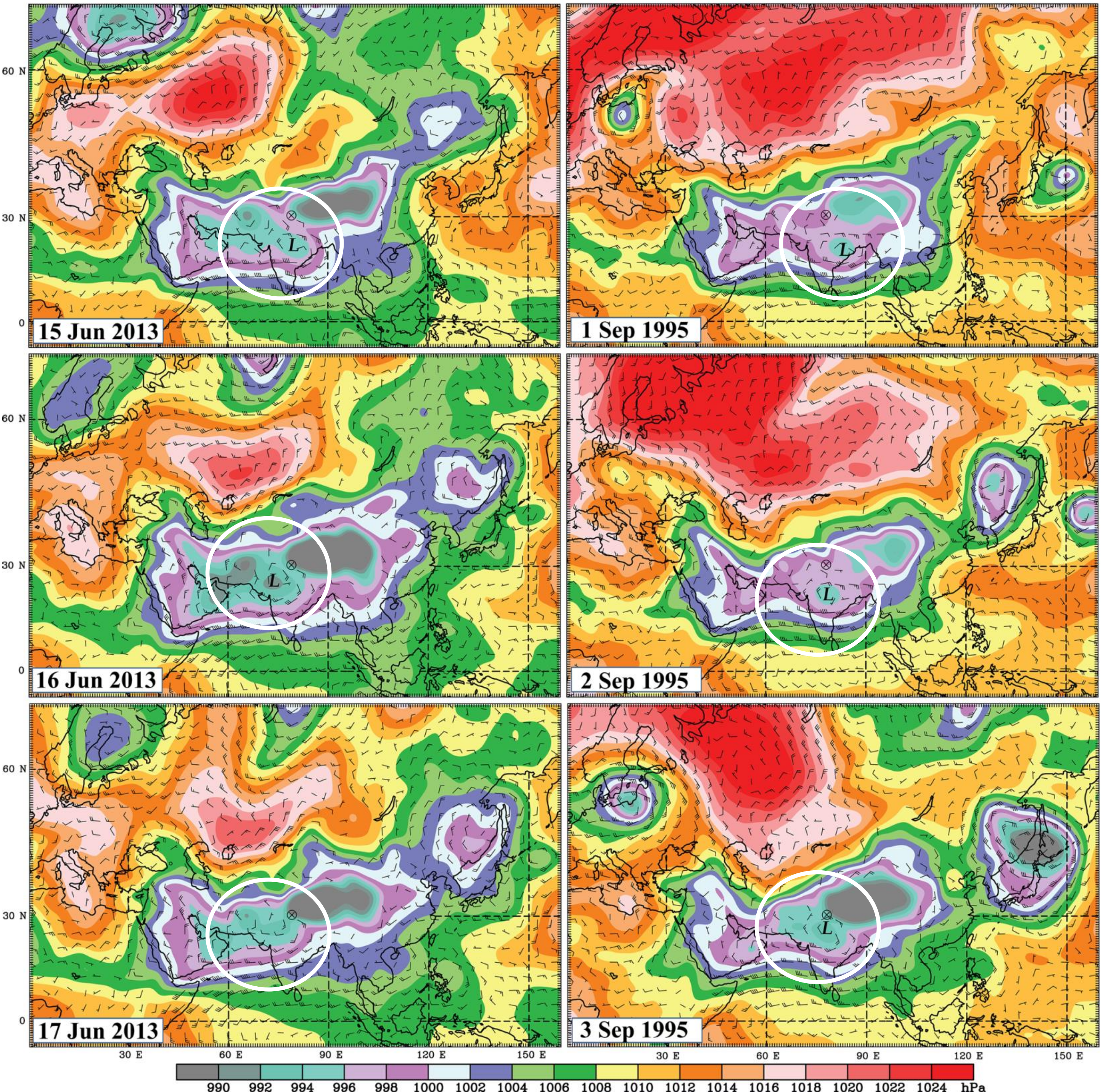
Isentropic potential vorticity (θ= 330 K)



Parcel backtrajectory reaching 33.2ºN and 75ºE (into the trough; north of Uttarakhand). The x axis indicates time in hours, starting from 0000 UTC 15 June 2013 (0h) and ending at 0000 UTC 17 June 2013 (48h). Wider to narrower arrows indicate regions of parcel descent

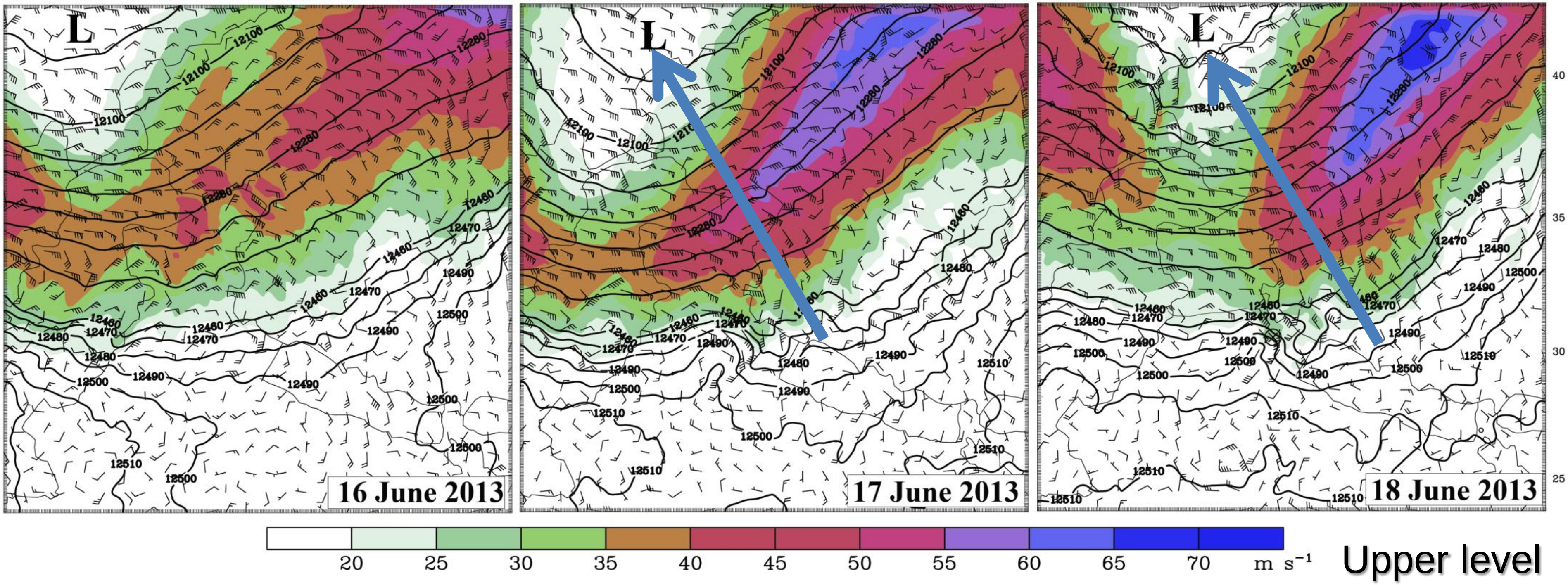
Hourly parcel diagnostics



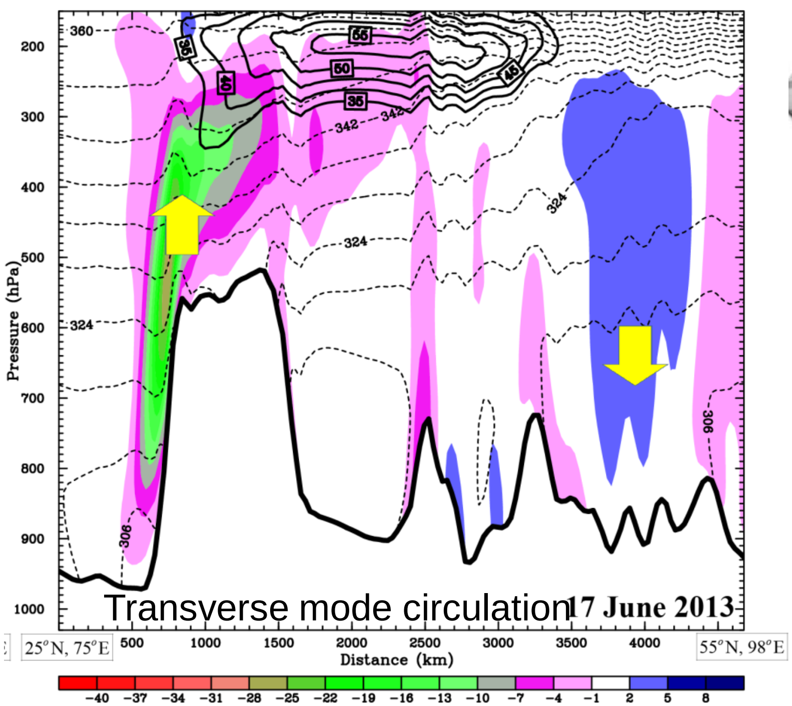


Extreme precipitation over the Western Himalayas has concurrence with northwestward moving monsoon lows

850 hPa winds
Sea level pressure (shaded)

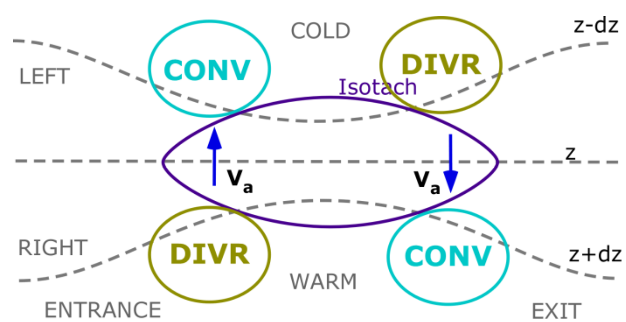


Upper level ageostrophy



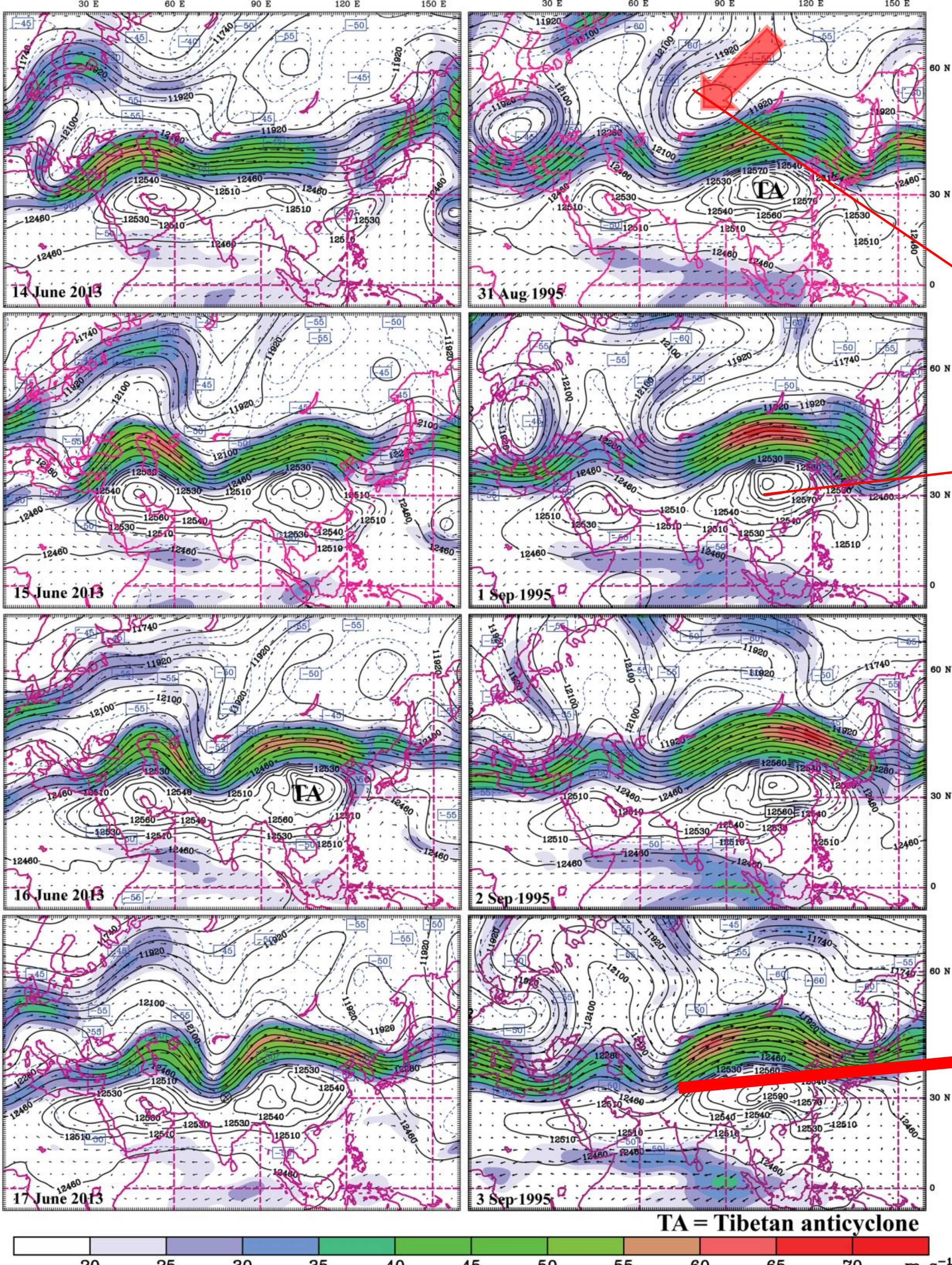
Transverse mode circulation

Jet entrance region dynamics is important

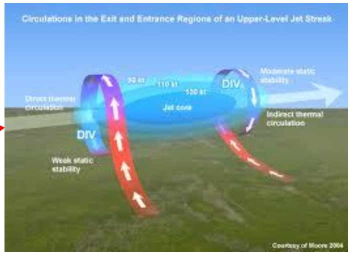


Thermally direct Circulation (entrance region)

Sequence of dynamical processes Vellore et al. (2016)

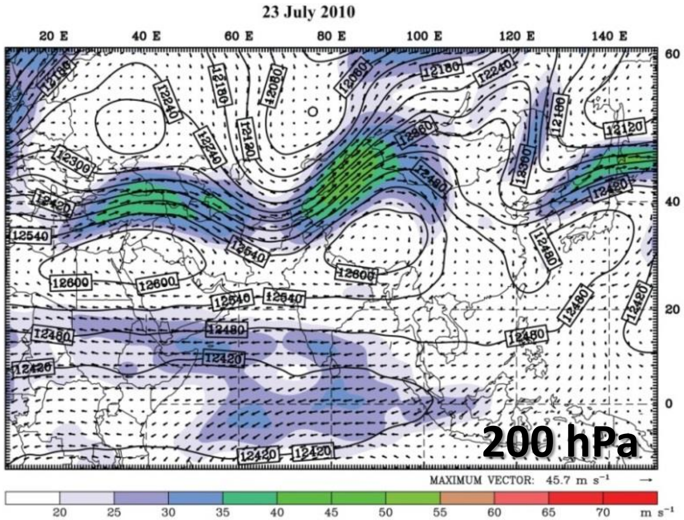


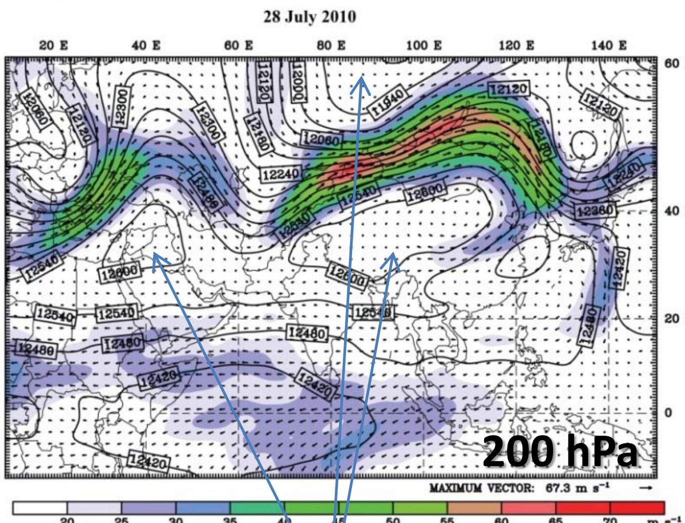
- Monsoon conditions are relatively not stronger as compared to active-monsoon periods.
- Upper level circulation commence with extratropical Rossby wave breaking signatures
- Splitting of Tibetan anticyclone (TA)
- Deeper equatorward penetrating large-amplitude troughs
- Interactions with monsoon circulation in phase with passage of low pressure systems from Bay of Bengal
- Jet acceleration & secondary circulation dynamics in concert with orographic ascent of air along the foothill region

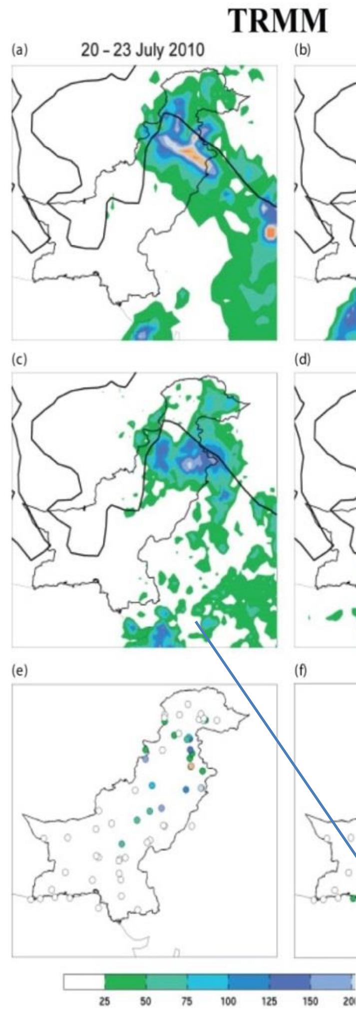


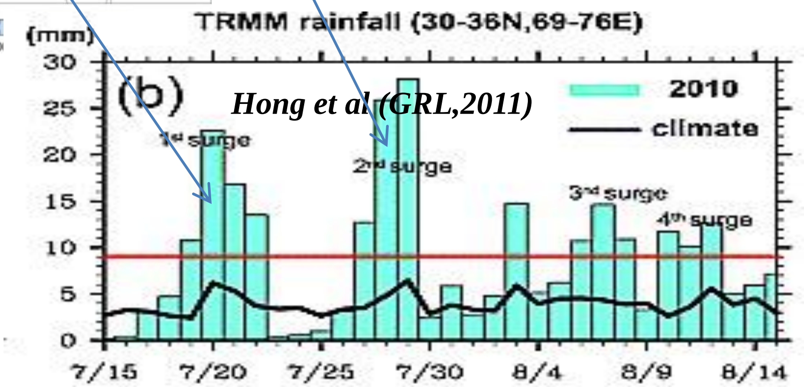
- Extreme rainfall over the western Himalayan foothills

Another classic example : Pakistan floods in July 2010







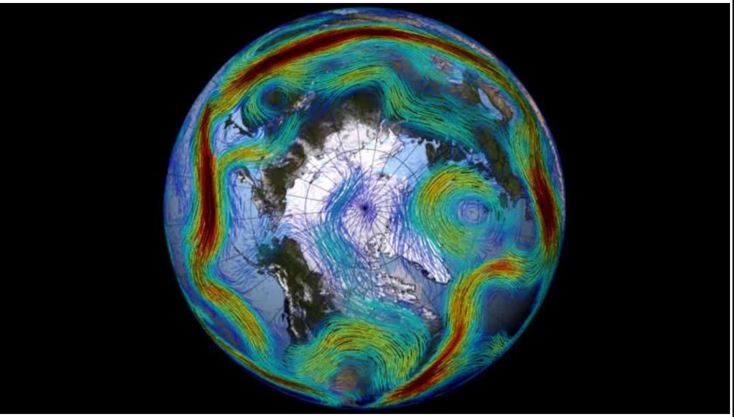


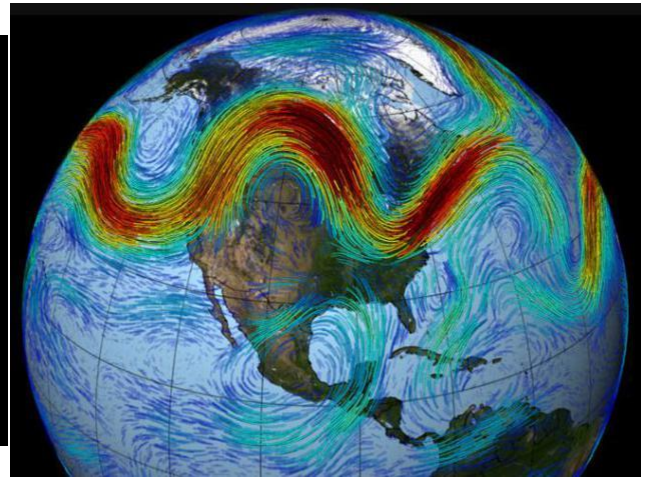
Hong et al (GRL,2011)

Upper air circulation signals have similarities with extratropical wave breaking and splitting of Tibetan anticyclone

Atmospheric blocking events associated with high geopotential heights and surface temperatures over Eastern Europe were present during consecutive many flood situations (2010-12) over Pakistan

Eurasian summer 2010
Pakistan floods 2010

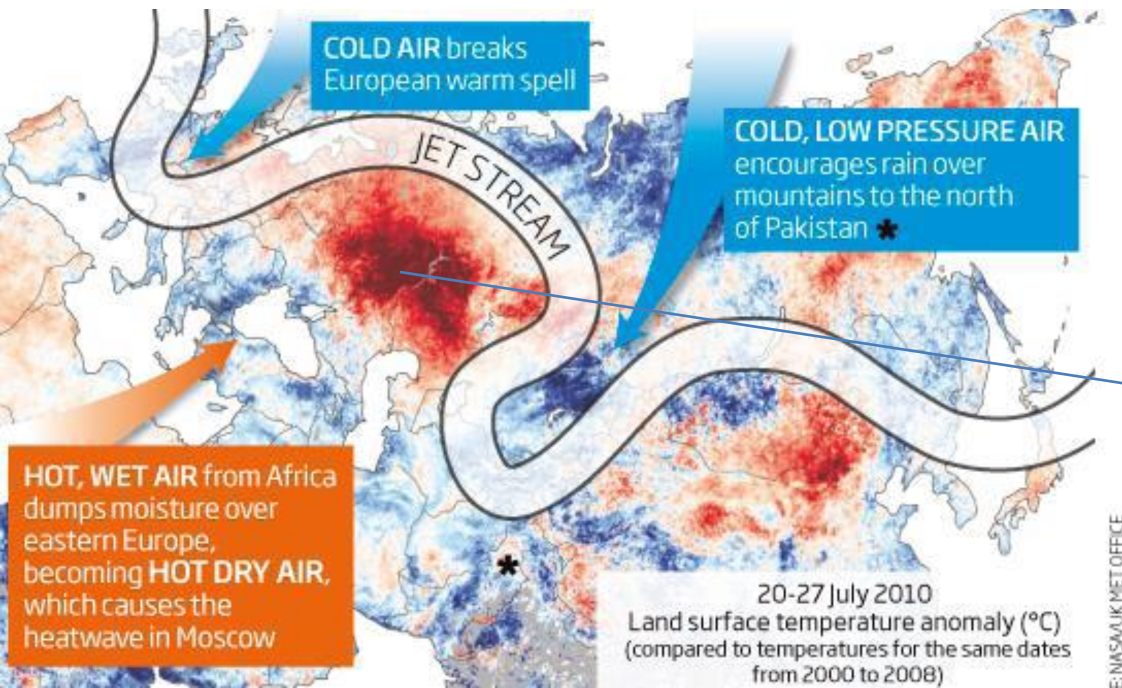




Extreme events:
A jet stream changing?

More meandering?

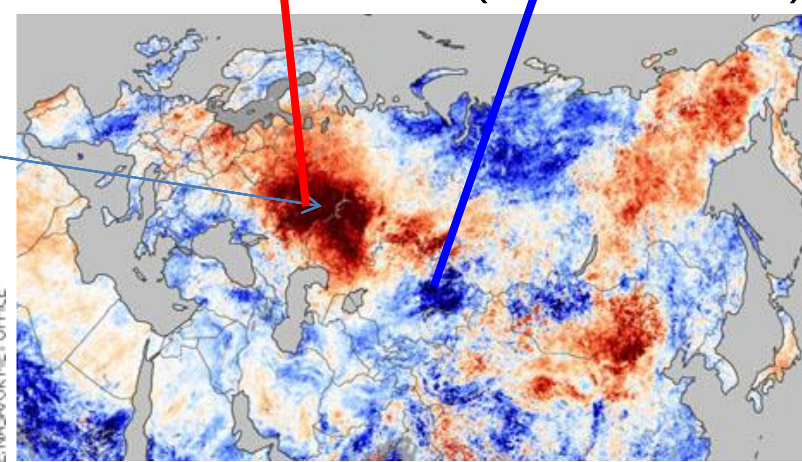
(source: Dim Coumou)

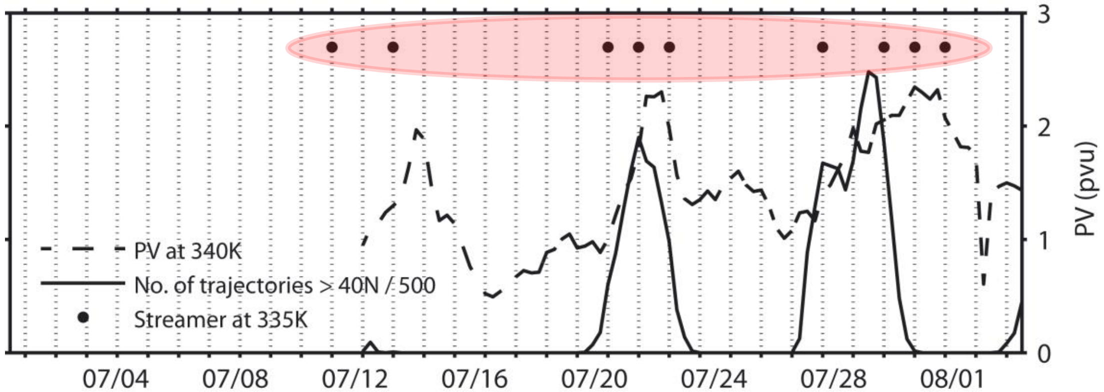


Pakistan flood 2010

Russian heat wave

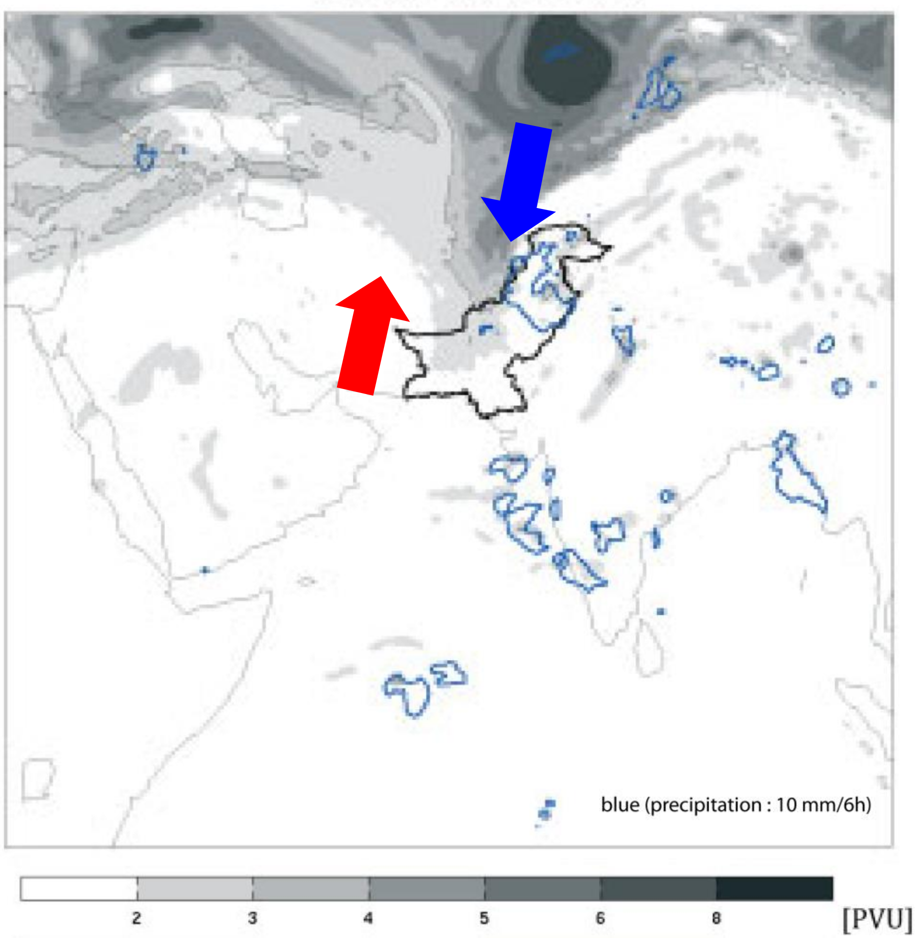
Surface temperature (source: NASA)





objectively identified wave-breaking events on 335 K (dots)

20100722 00UTC



Area mean PV (60◦E–70◦E, 30◦N–40◦N, dashed line)

Martius et al. (2013)

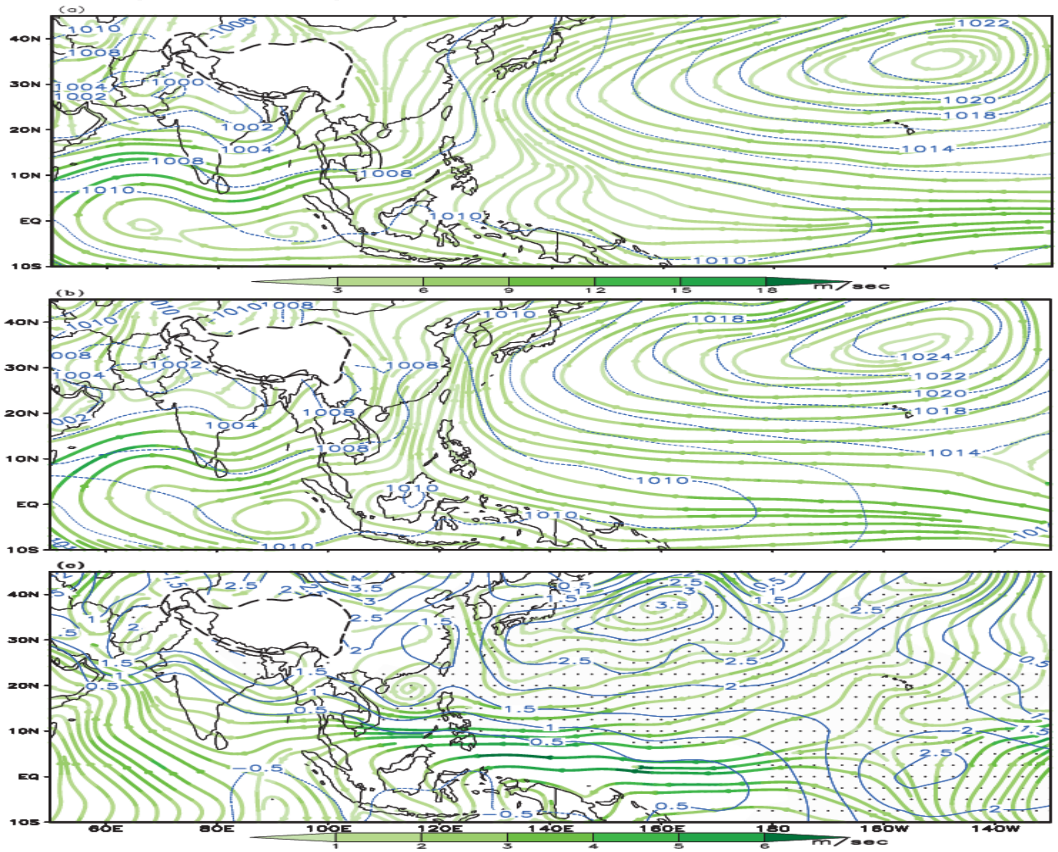
Precipitation was organized and invigorated by upper-level positive PV anomalies that reached Pakistan from the extratropics.

Monsoonal low-level flow features (heat-lows, Indian monsoon depression) were central for the transport and convergence of moist air into northeastern Pakistan

Moisture was transported towards northeastern Pakistan both from the Arabian Sea and the Bay of Bengal.

A long-lived (persistent for about two months) blocking pattern over Europe and Russia and penetration of extratropical PV and concurrent interactions with monsoon surges and La Nina contribution indirectly to the flooding (Hong et al. 2011)

JJAS MSLP (blue contours) and Wind at 850 hPa (Stream-lines)



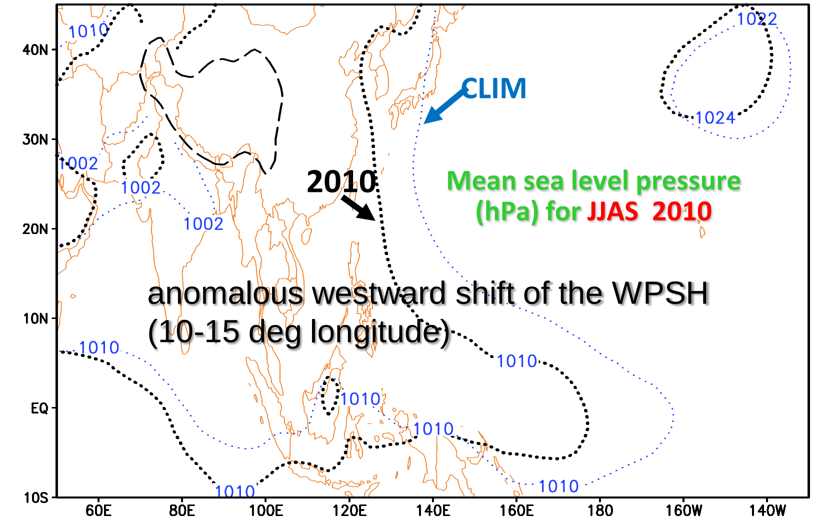
2010 Summer monsoon season observed series of devastating flood events over NW Indo-Pak region.

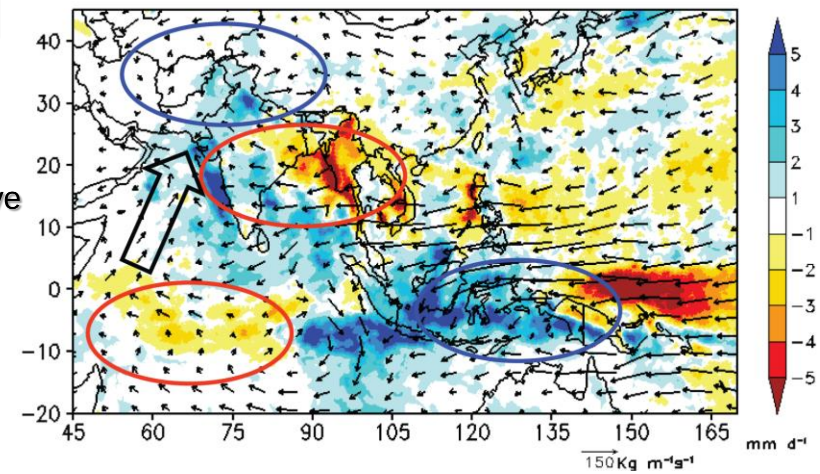
Houze et. al., (2011) attributed these flood events to Mesoscale convective system (MCS) with deep oceanic convection character in a high humid environment with emphasis on cloud systems producing the floods.

Priya et al. (2015) indicates that the tropical Indo-Pacific SST anomalies are an important factor in determining the heavy precipitation over northwest Pakistan and adjacent Indian region

Large-scale seasonal features influencing these north-west Indo-Pak flood events during a typical La Nina year.

Mujumdar et al. (2012) focused on tropical influence in the evolution of extreme events over sub-tropical south-Asia.





Observation
TRMM (Rainfall) & NCEP (Moisture Transport)

Simulations & observations - Inferences

- Monsoon-extratropical interactions understandably provide intense Himalayan rainfall. However, subtleties in the strengths of monsoon and extra-tropical circulations govern the region of intense rainfall over the Himalayas.
- Moderately active monsoon conditions associated with low-pressure system passages provide support to intense rainfall over the western part of the Himalayas. The interactions between monsoon-equatorward penetrating midlatitude circulations provide a closure for deep circulation in the vertical, and further orography also lends a big hand in amplifying the precipitation amounts.
  - Examples: Uttarakhand rain episode in June 2013 and Pakistan floods in July 2010
  - Floods over the Indus Basin.
- Break monsoon conditions provide support to intense rainfall over the central-eastern part of the Himalayas (northeastern states of India) predominantly from the monsoon-extratropical interactions, i.e., not significantly due to orographic effects.
  - During monsoon-breaks, the rain amounts in northeastern part of India is about 3 times the rain amounts obtained during active monsoon conditions in this region.
  - Floods in Assam and over the Brahmaputra River Basin.

Clim Dyn
DOI 10.1007/s00382-013-2024-1

On the anomalous precipitation enhancement over the Himalayan foothills during monsoon breaks

2014

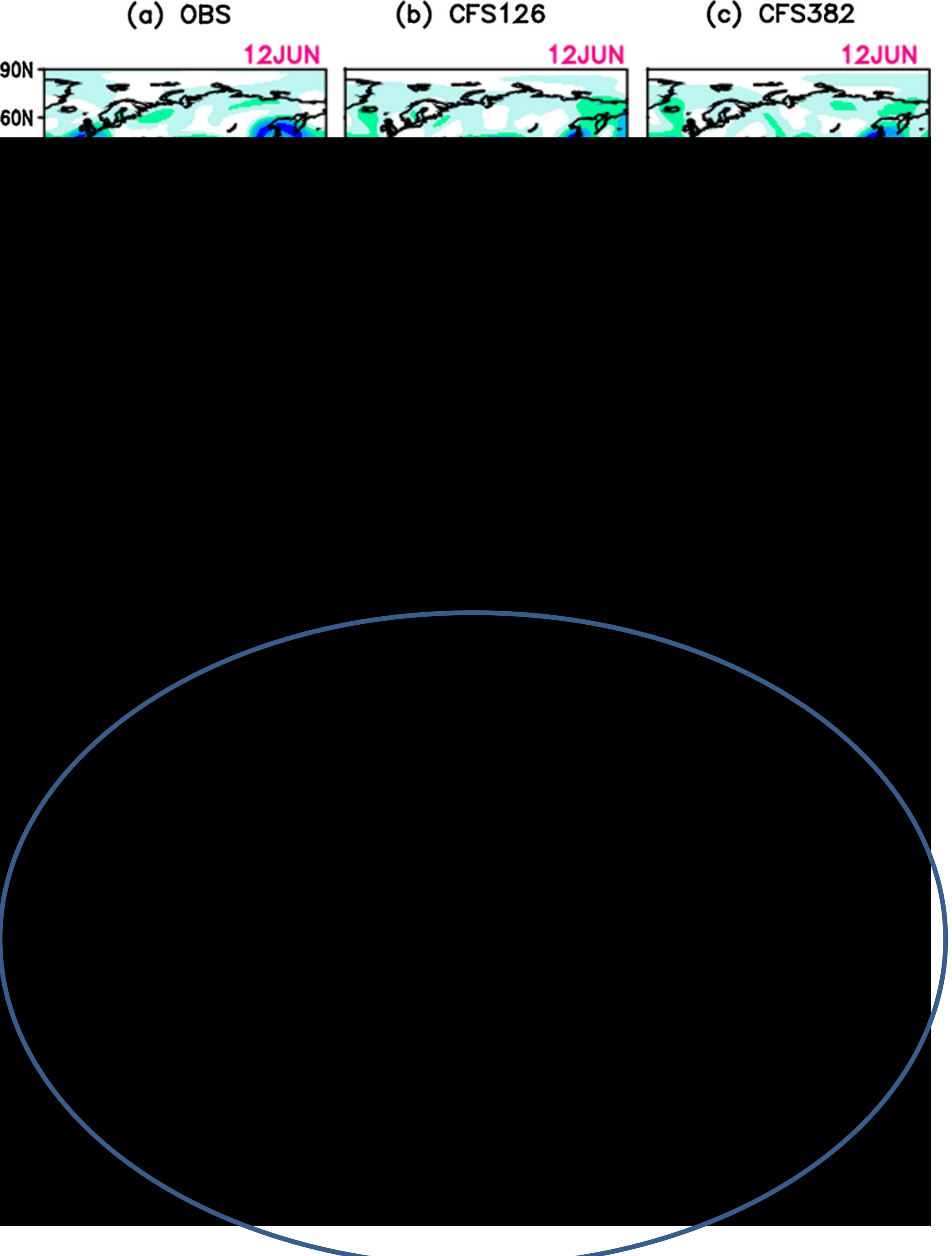
Ramesh K. Vellore · R. Krishnan · Jayant Pendharkar · Ayantika Dey Choudhury · T. P. Sabin

Clim Dyn
DOI 10.1007/s00382-015-2784-x

Monsoon-extratropical circulation interactions in Himalayan extreme rainfall

2016

Ramesh K. Vellore [1] · Michael L. Kaplan [2] · R. Krishnan [1] · John M. Lewis [2,3] · Sudhir Sabade[1] · Nayana Deshpande[1] · Bhupendra B. Singh[1] · R. K. Madhura [1] · M. V. S. Rama Rao [1]

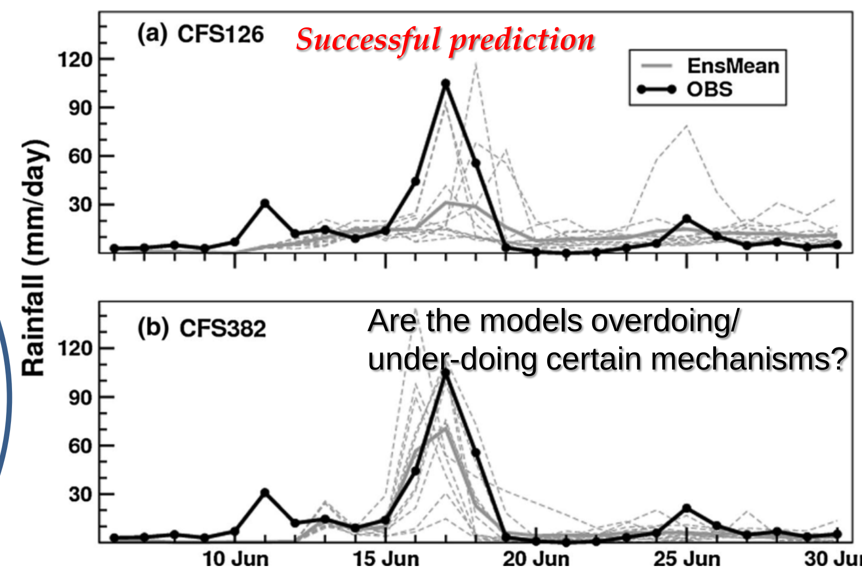


Joseph et al. 2014

Predictability of extreme events:

Upper level wave breaking, trough deepening and jet accelerations at the subtropical/extra-tropical latitudes are rather critical for interaction with the moist-laden monsoon circulation to result in extreme precipitation events over the western Himalayas (in concert with the orographic lift)

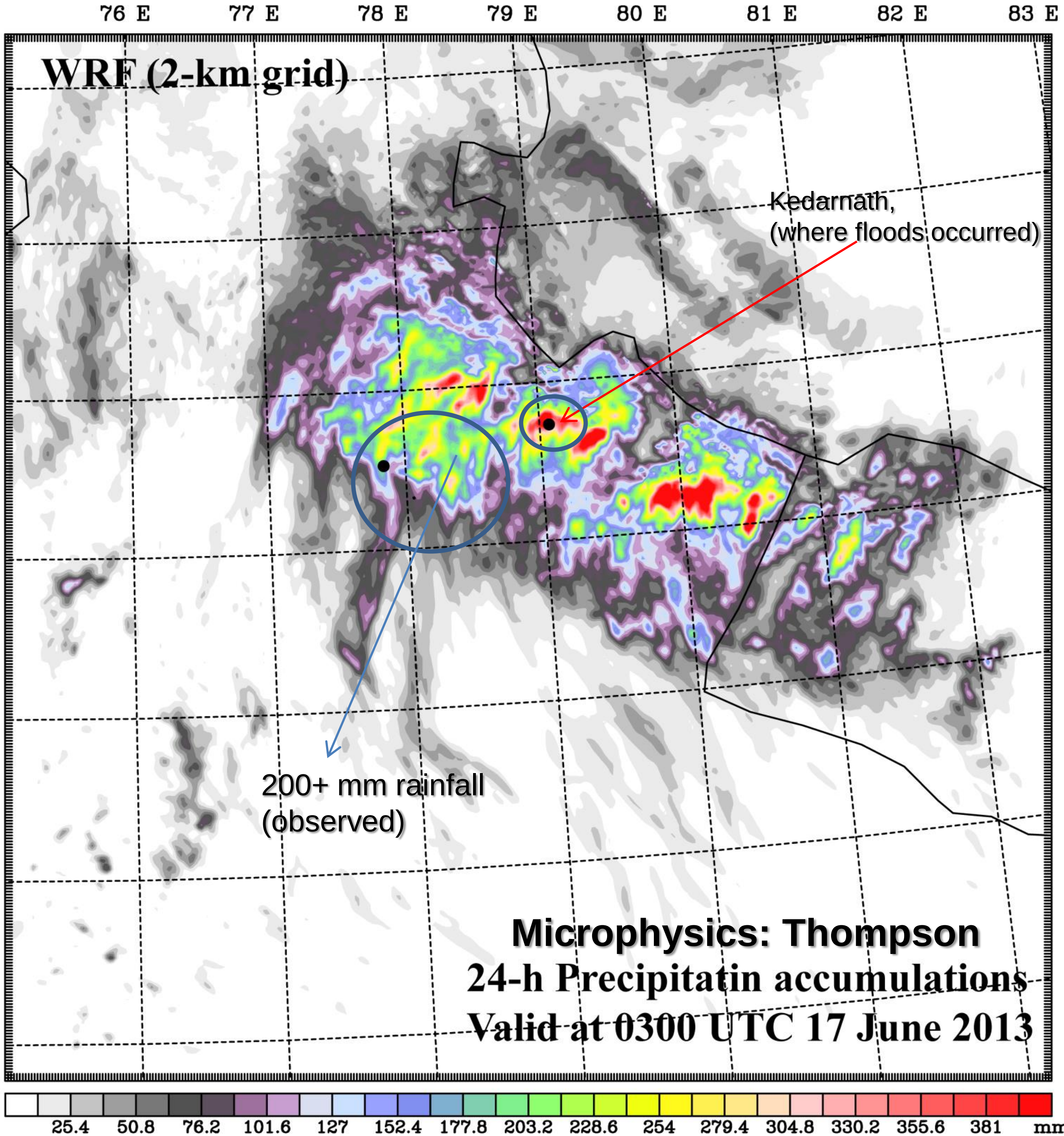
Susmitha Joseph, A.K.Sahai, S. Sharmila, S. Abhilash, N. Borah, R. Chattopadhyay, P.A. Pillai, M. Rajeevan, Arun Kumar: North Indian heavy rainfall event during June 2013: diagnostics and extended range prediction, Climate Dynamics (2014)



Extended range prediction of Uttarakhand rainfall event by CFS126 and CFS382 from 05 June initial condition. Rainfall values are averaged is 78°–80°E and 29°–31°N.

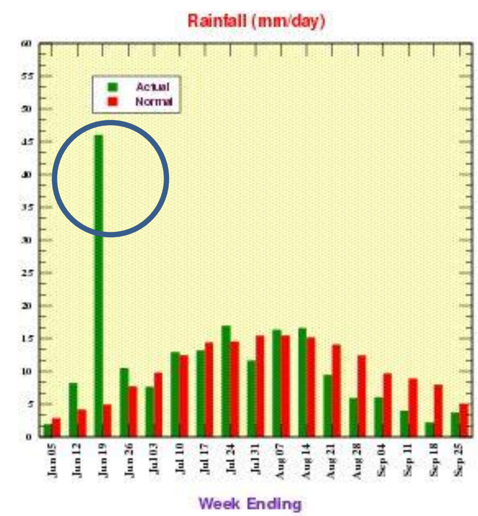
Attribution: Orography

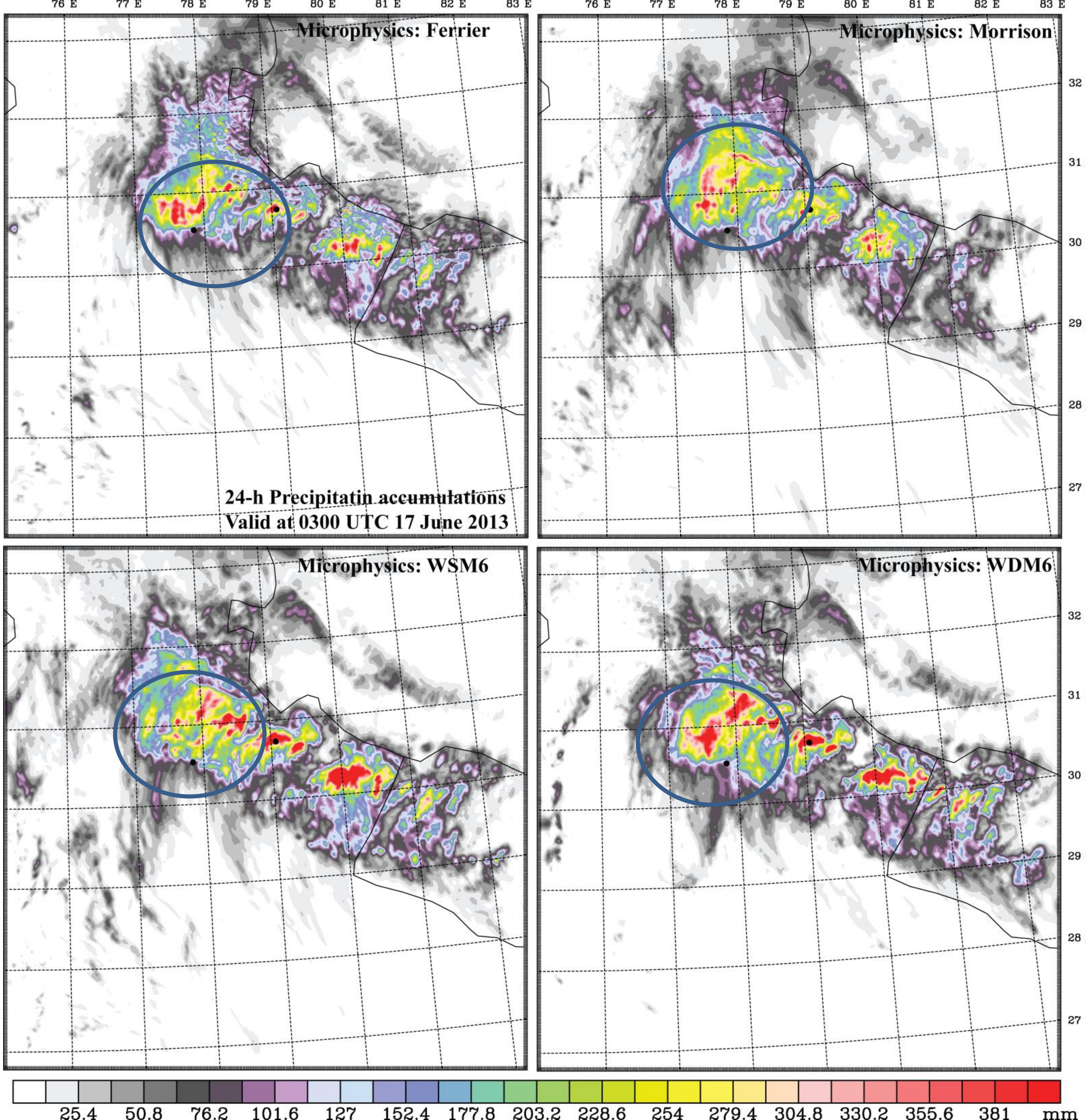
High-resolution WRF simulation of Uttarakhand rain event during June 2013



Bright side:

Simulations are able to capture precipitation structures well

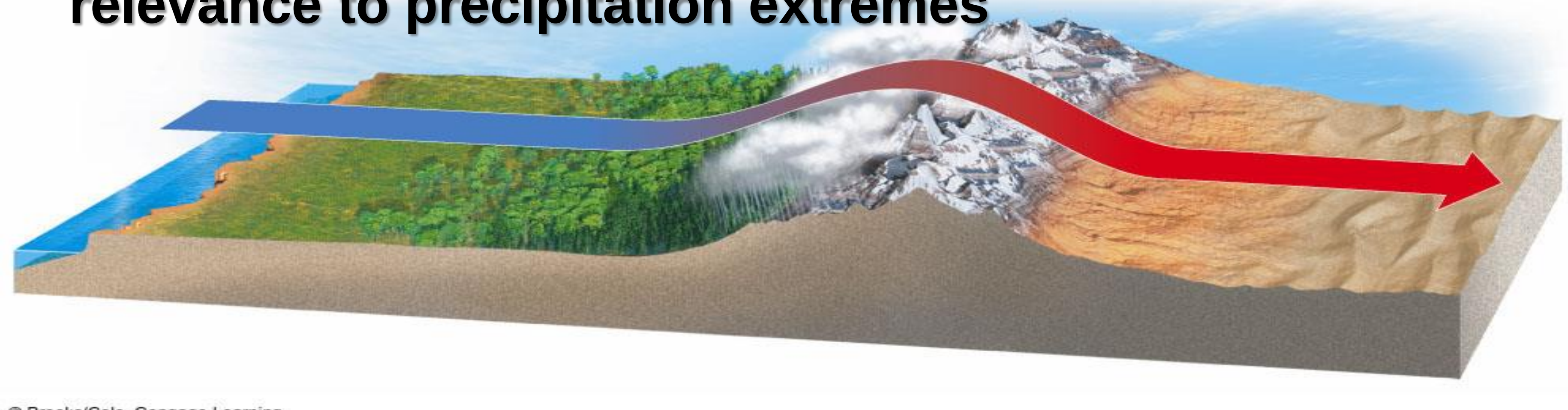




Mystery still lies
in the choice of
representation
of physics in models

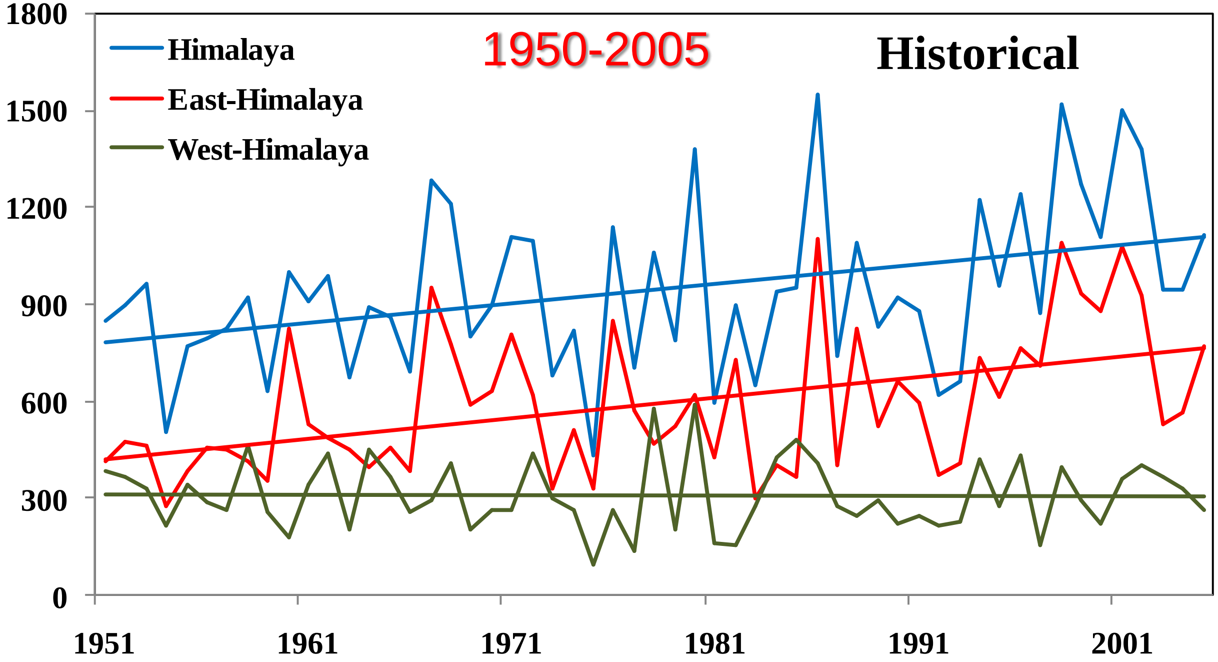
Way to future

- **Future changes in precipitation extremes in a warming climate**
  - **Are Uttarakhand and Pakistan type of calamitous floods going to be frequent in future?**
- **Future changes in monsoon circulation and extratropical circulation and their interaction relevance to precipitation extremes in the Himalayas.**
  - **Polar amplification**
  - **Jet stream intensity**
- **Changes in the large-scale teleconnections and their relevance to precipitation extremes**

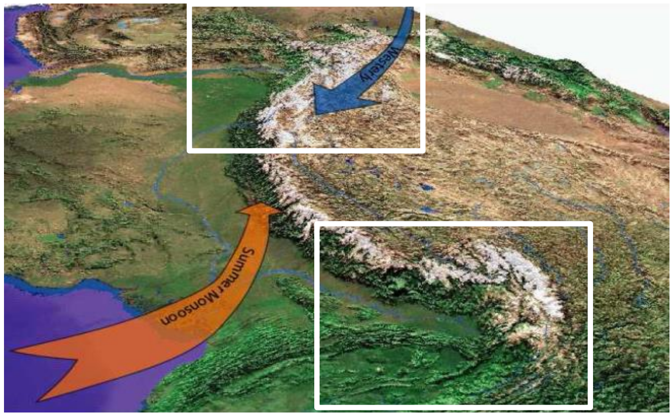


Thank you

LMDZ4-simulated over the Himalayas

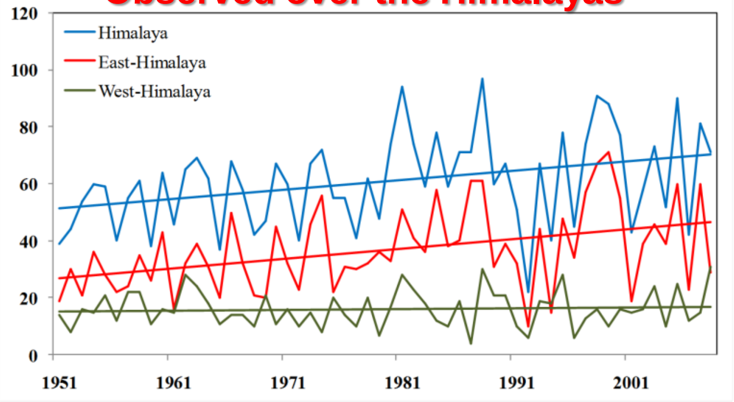


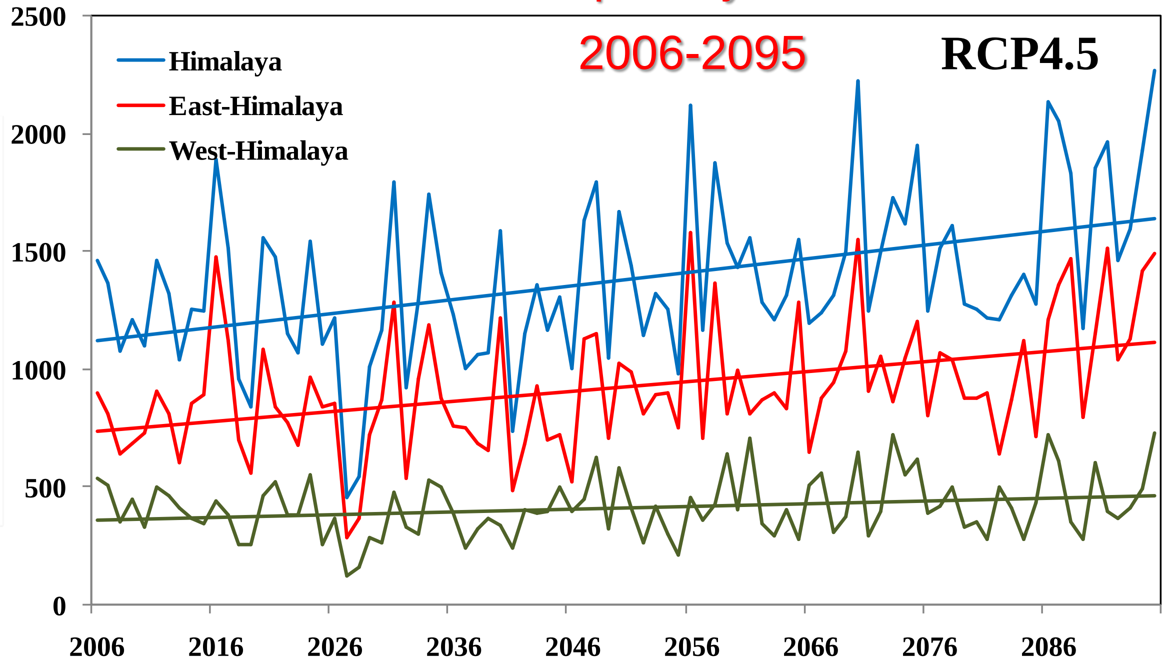
Courtesy:
T. P. Sabin



Propensity of monsoon-breaks

Observed over the Himalayas





Overview

- An overview of rainy and dry spells during the summer monsoon
- Perspectives of large-scale dynamics to extreme precipitation over the Himalayas
- Numerical modeling of a heavy precipitation event