Dynamics of summer monsoon active phases and onset over Pakistan

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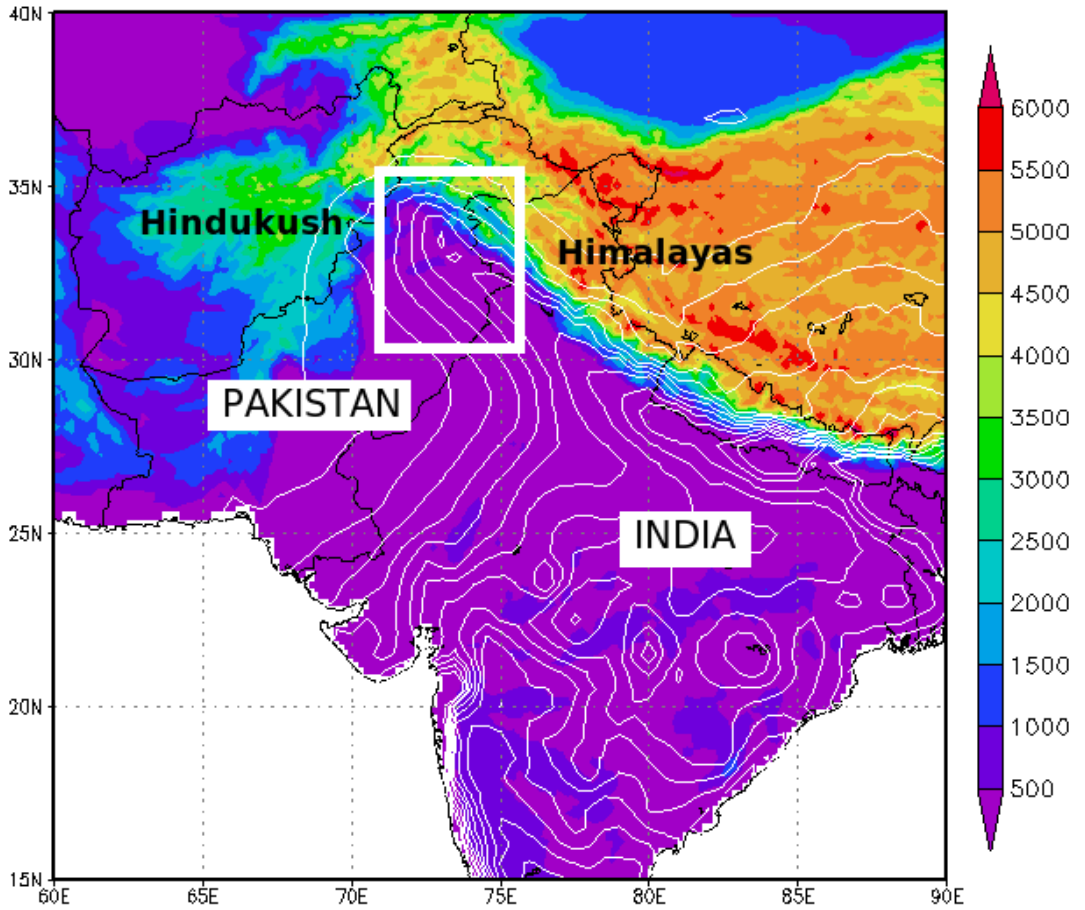
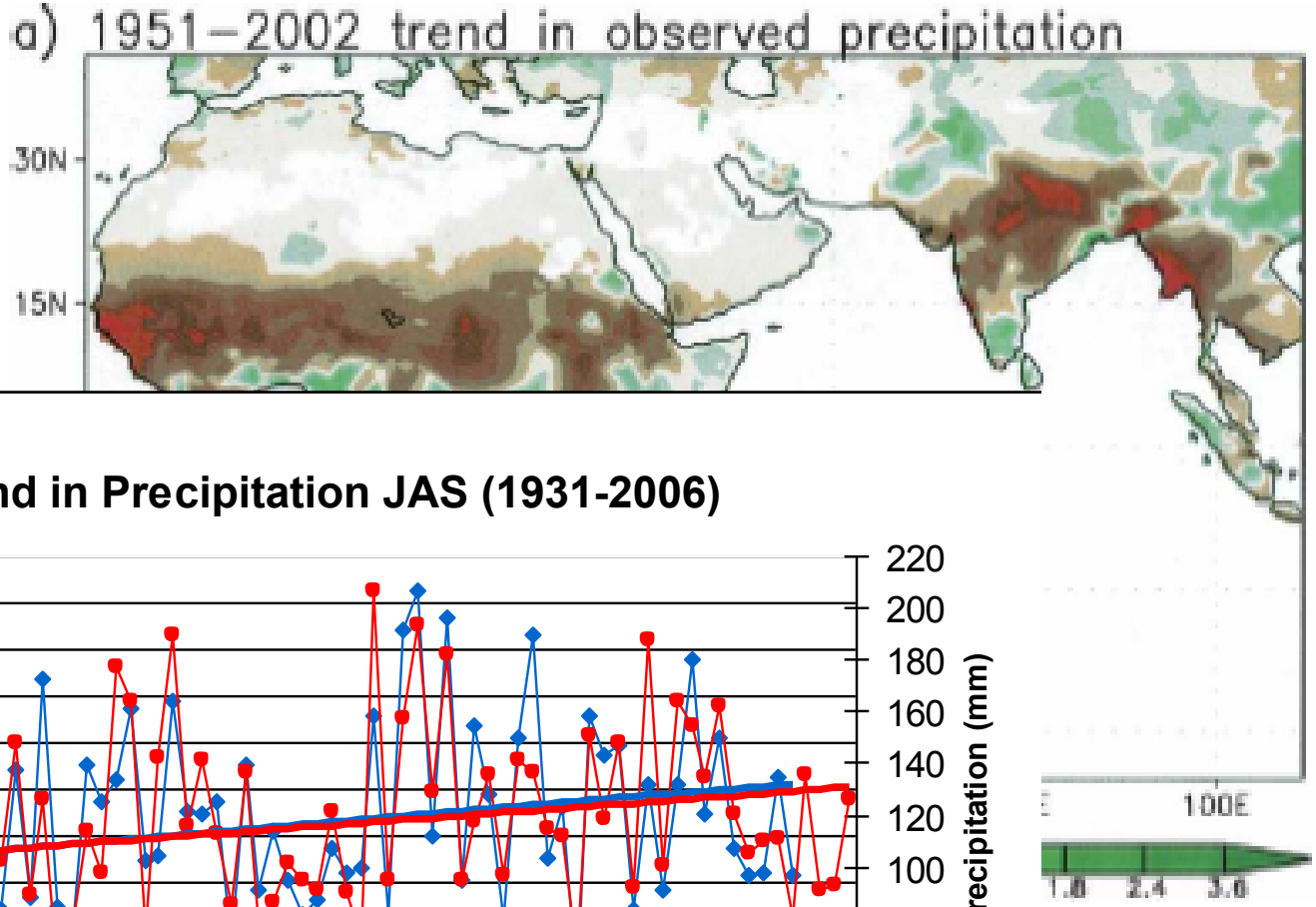
Western Edge of the South-Asian Monsoon (WESAM)

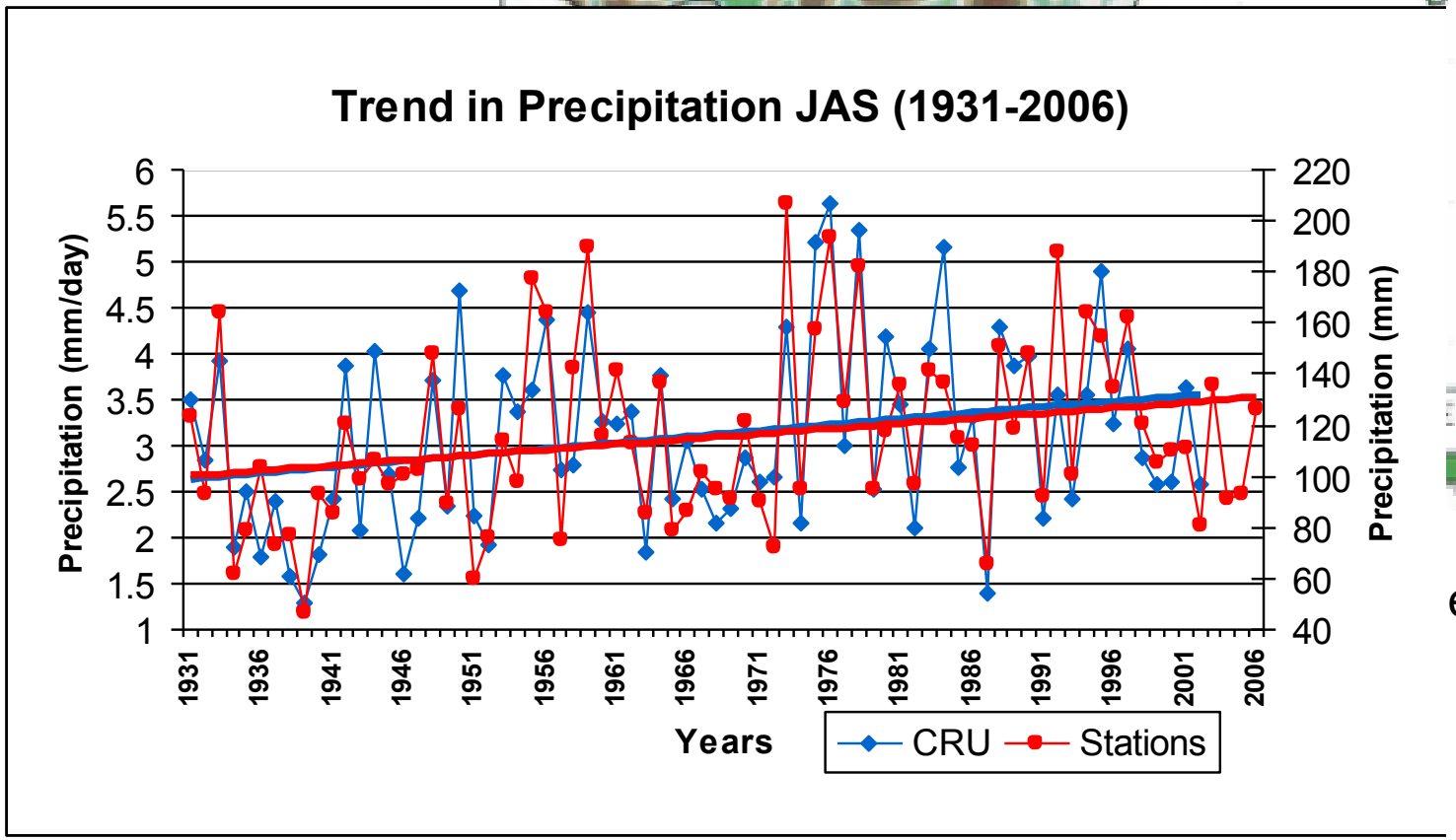
- For the peak monsoon season (77days from 1st of July to 15th of September) Average Station Data
- mean rainfall is 6.1 mm/day
- standard deviation of 8.7 mm/day



The orographic height (shaded unit: m) and summer (JAS) mean rainfall (contour) of WESAM region. The white rectangular box indicates the core monsoon region. The rainfall climatology is calculated for the period of 1950-2000 using CRU TS2.0 data. The contour interval is 1mm/day.

Motivation





e to September

Background

1. The core region of WESAM lies over north central Pakistan. For the peak monsoon season (77days from 1st of July to 15th of September), mean rainfall is 6.1 mm/day with standard deviation of 8.7 mm/day in the averaged station observation data used in this study

2. The south Asian monsoon (SAM) exhibits clear alteration of Active (wet) and Break (dry) phases within a season. The northward propagating intraseasonal oscillations (ISO) with 10-20days and 30-60days periods are found to be responsible for the active and break phases of SAM. (e.g. Krishnamurthy and Shukla, 2000)

3. In previous studies on the ISV of SAM, different criteria are used for identification of breaks and active phases (AP). Webster et al. (1998) considered spells of convection and 850 hPa zonal winds over a larger scale region (65-95°E, 10-20°N), Goswami and Ajaya Mohan (2001) defined AP on the basis of the strength of the 850 hPa wind at the single grid-point 15°N, 90°E, Krishnan et al. (2000) defined break phases as days with positive Outgoing Longwave Radiation (OLR) anomalies over northwest and central India

Station Data:

1. The daily rainfall data of 11 meteorological stations which lies in the core WESAM region (32-35° N, 71-76° E) is used.

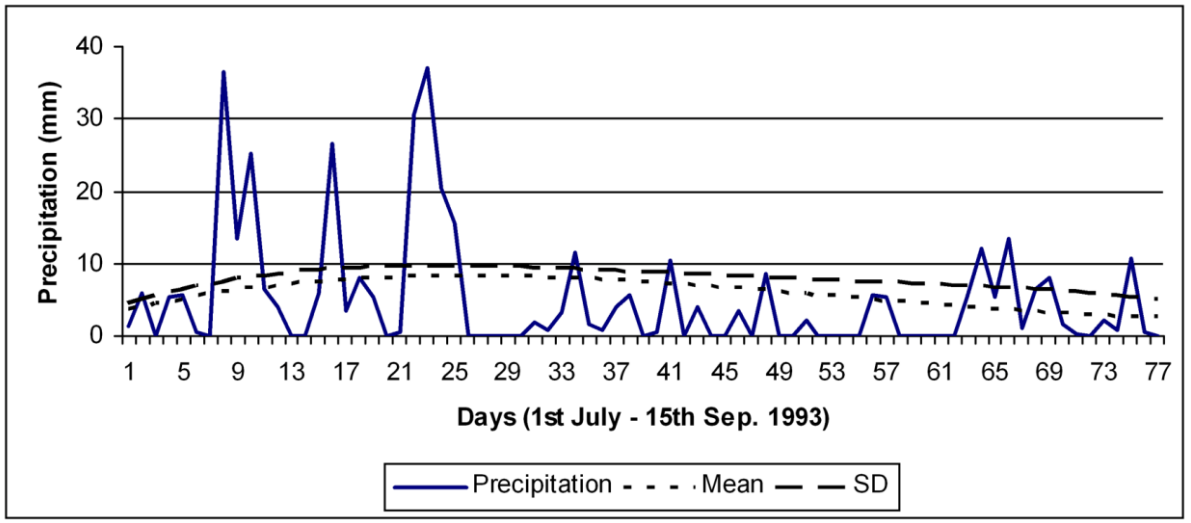
2. To avoid influence of seasonal monsoon onset and retreat, 77 days of peak monsoon season (1st July~15th September, JAs) were chosen for 28 years (1979-2006)

3. The EOF analysis showed that the stations used to define the rainfall index also have homogeneous pattern of their primary variability.

Active Phases Definition:

1. The normalized rainfall time series is defined by averaging the daily rainfall over this core WESAM region and standardizing the daily rainfall time series by subtracting its daily long term normal (1979-2006) and dividing by its daily standard deviation (SD).

2. The daily long term normal and standard deviation were normalized by fitting a 4th degree polynomial. The APs are identified as the periods during which the normalized rainfall anomaly is more than 0.6 times the standard deviation (70~120% of daily mean rainfall climatology), consecutively for three days or more. In this way 45 active phases (167 days) were identified.



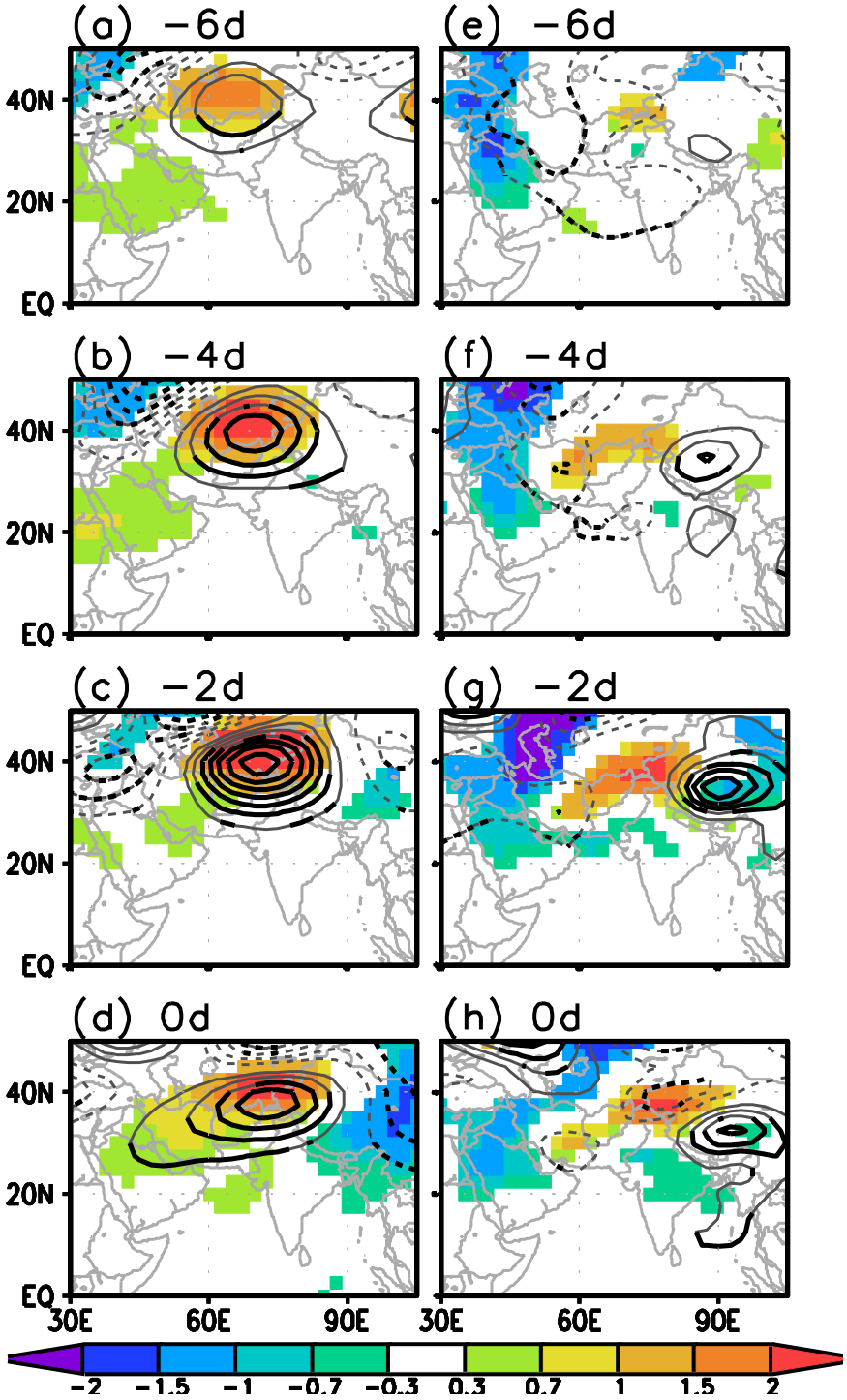
The daily precipitation of average of 11 stations from 1st of July to 15th of September, 1993 and normalized climatological (1979-2006) daily mean and standard deviation.

Evolution of temperature and geopotential height anomalies

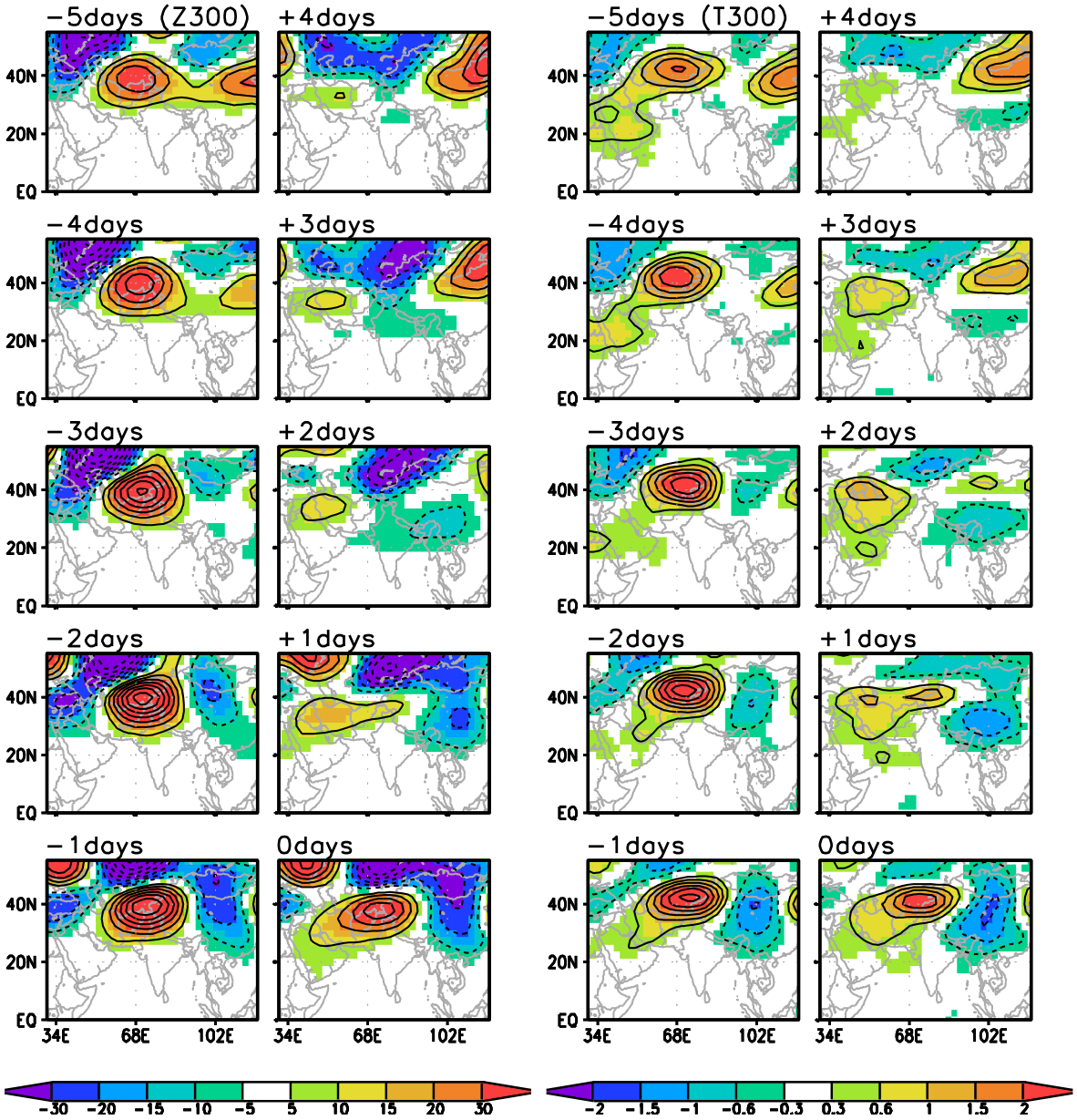
(a) 300hPa geopotential height composite anomaly (contour) and temperature anomaly (shading) at 6 days before active phase (AP). The composite values with 95% significance are shown as thick contours and shaded.

(b), (c), (d) same as (a) except for 4days, 2days, and 0days before AP

(e)-(h) same as left panels except for 850hPa level. Contour interval is 10 and 5 for 300hPa and 850hPa geopotential heights, respectively.



Upper tropospheric anomaly : the earliest signal (~week before)



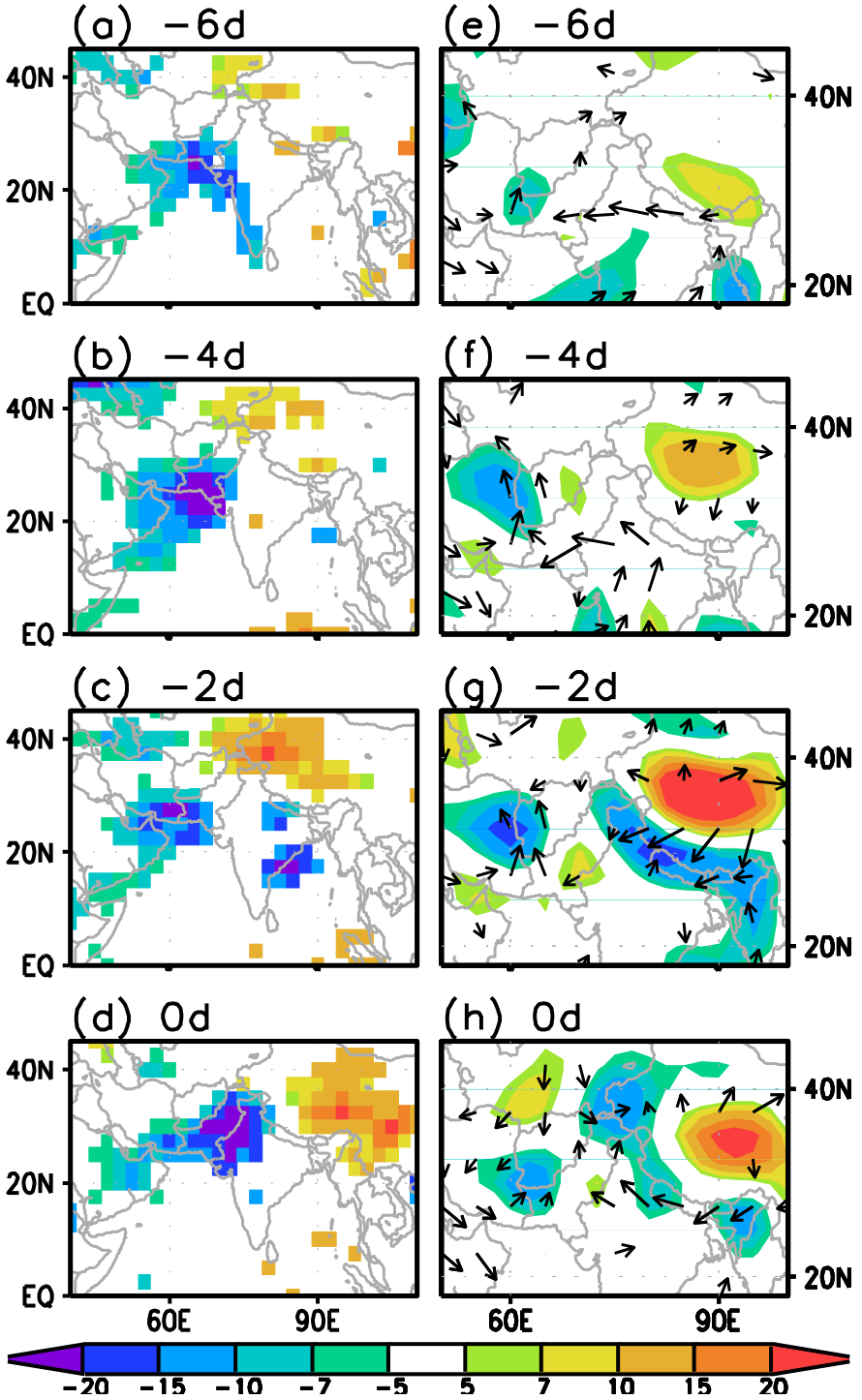
Warm anticyclone develops until the beginning of event.

As soon as event occurs, the anomalous anticyclone collapses.

OLR and Low-level winds

Same as in previous figure except for OLR and 850hPa winds. Shadings in right panels are divergence (× 5.0 × 106) of 850hPa wind anomaly.

The wind anomalies with 95% significance are plotted as vector.



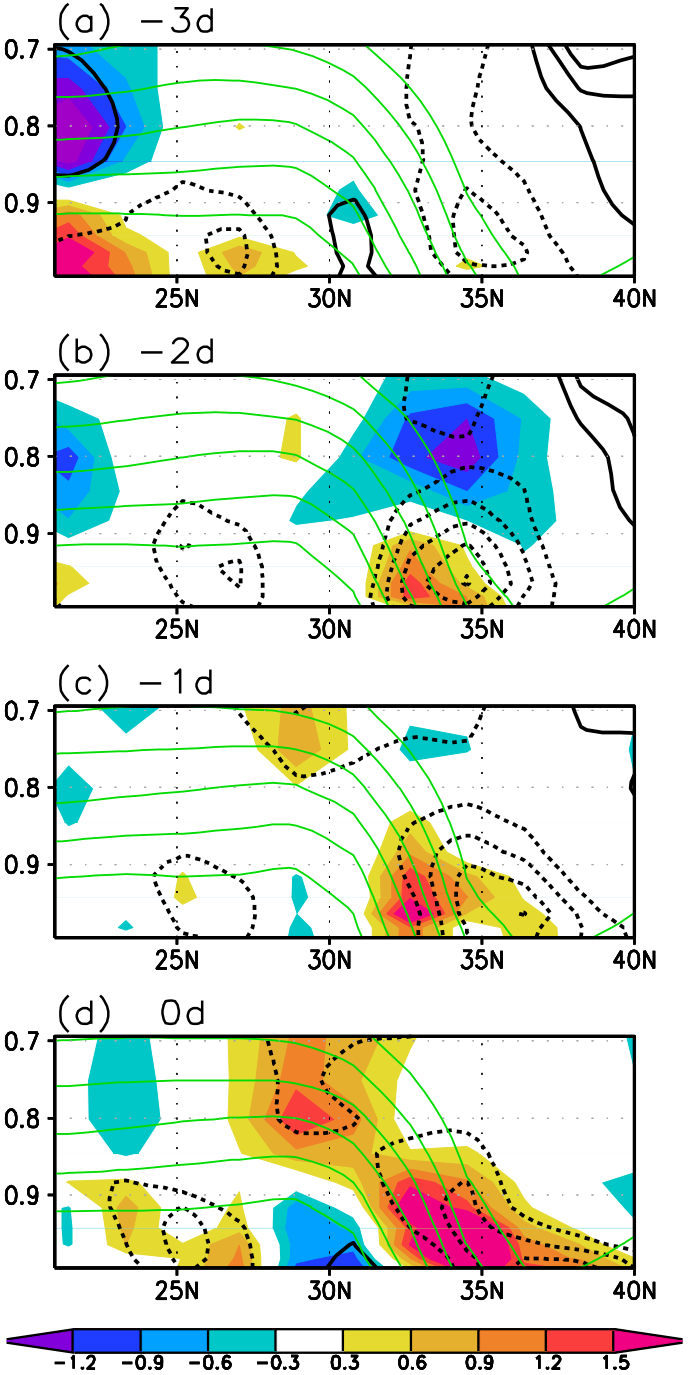
Vertical structure

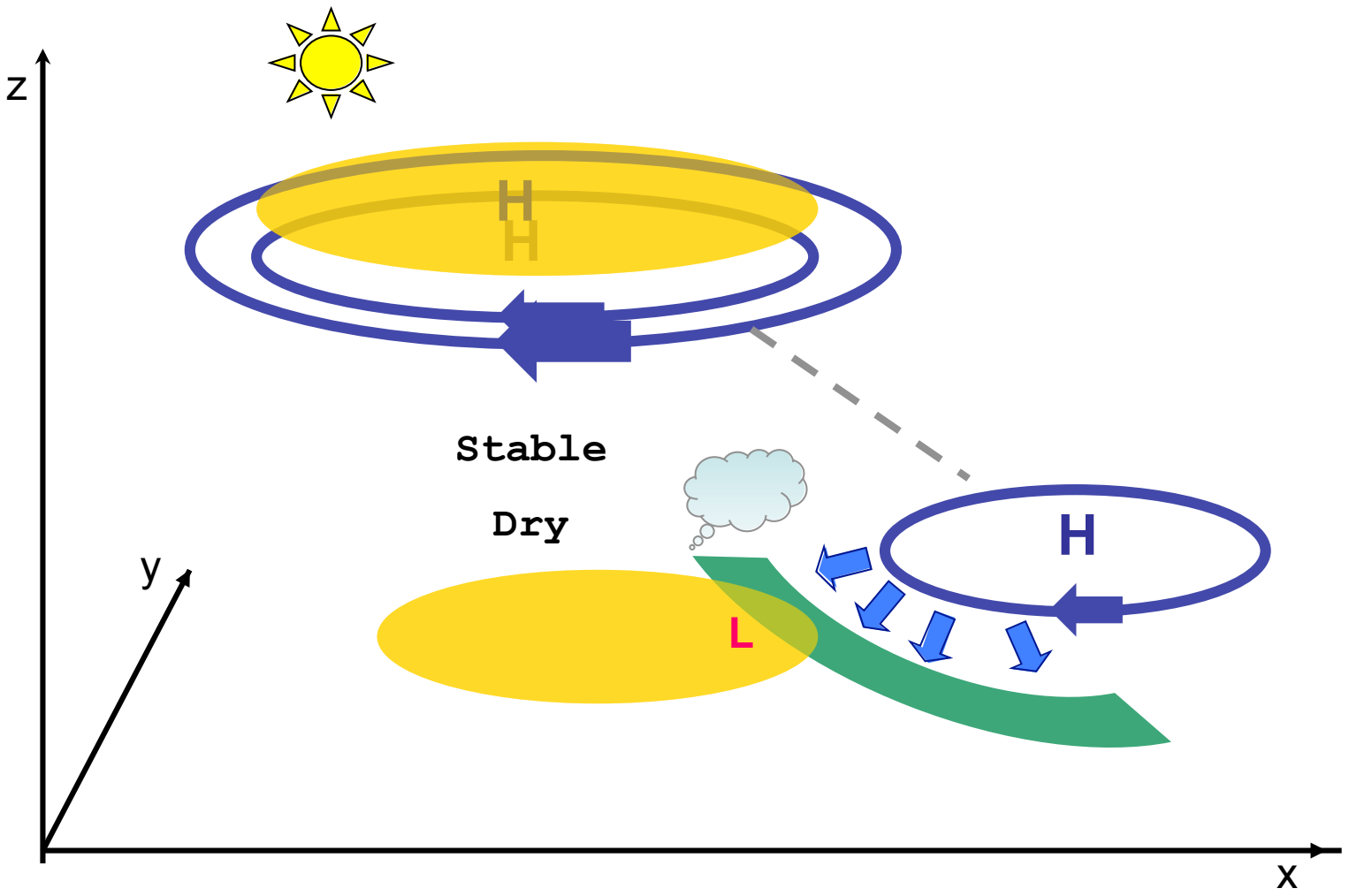
(a) Vertical (sigma level) cross-section of zonally averaged (71E-75E) composite anomalies of:

- moisture flux convergence (shaded; 1.0×10^5 g/kg s^{-1})
- horizontal wind divergence (thick lines; $\times1.0 \times 10^5$)
- mixing ratio (thin green lines; g/kg) at 3 days before AP.

The grid points with insignificant values (less than 95%) are omitted in the zonal average.

(b), (c), (d) same as (a) except for 2 days, 1 days, and 0 days before AP. Contour interval of divergence is 0.2. Contours of mixing ratio drawn are 16, 14, 12, 10, 8, and 6 g/kg from south to north direction. The moisture flux convergence values with 95% significance are plotted.



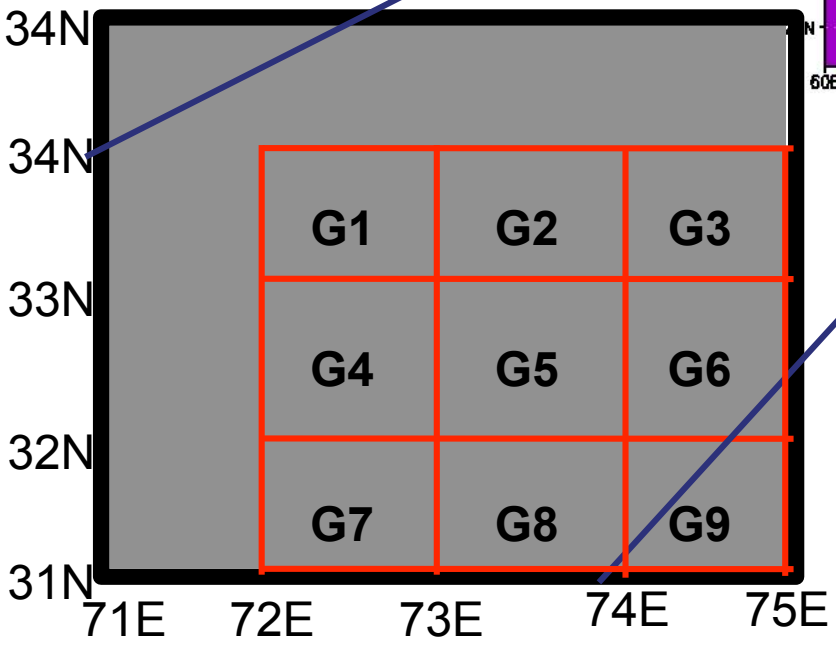

z
H
H
Stable
Dry
H
L
y
x

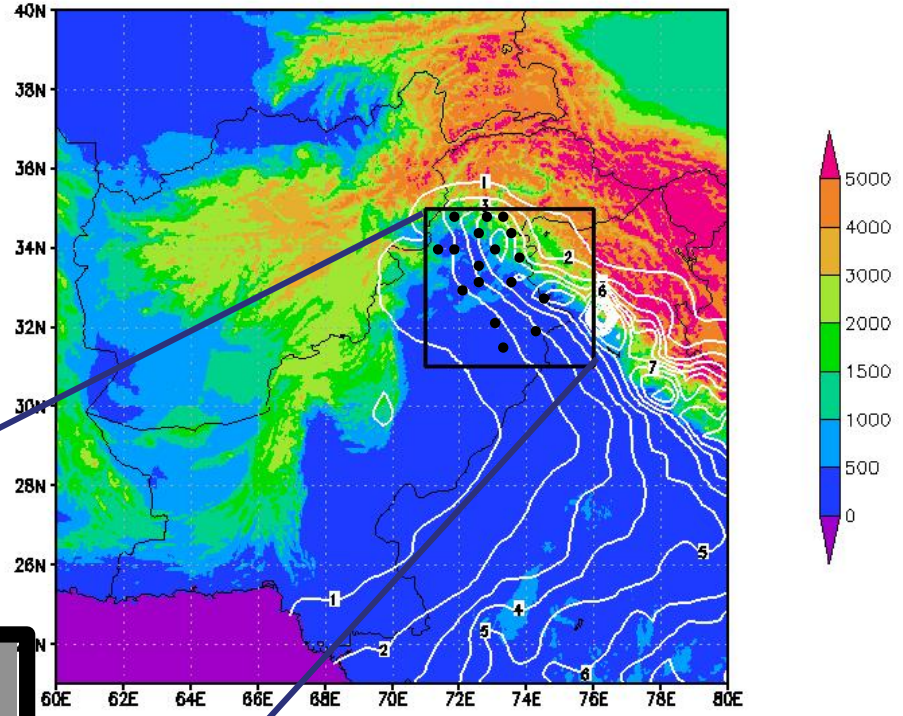
Monsoon onset over Pakistan

Study Domain

- Core Monsoon Region (main box)

  (71-75°E, 31-35°N)
- Precipitation Index (PI) and PI threshold based criterion





Black dots in the core region shows location of PMD stations

Data used...

- Daily rainfall station data – 17 Meteorological stations, 1961-2007, obtained from Pakistan Meteorological Department (PMD)

- APHRODITE (version APHRO-V1101)- daily dataset, 0.5°x0.5° grid resolution, 1961-2007.

- Daily Precipitable Water (PW) data- 1º × 1º horizontal grid resolution, 1988-2009, obtained from NASA Water VApor Project (NVAP)-M, archived at Atmospheric Science Data Center (ASDC), NASA Langley Research Center.

- NCEP/NCAR reanalysis- daily dataset at 1º × 1º resolution, 1961-2007, standard pressure levels.

Objective Criterion

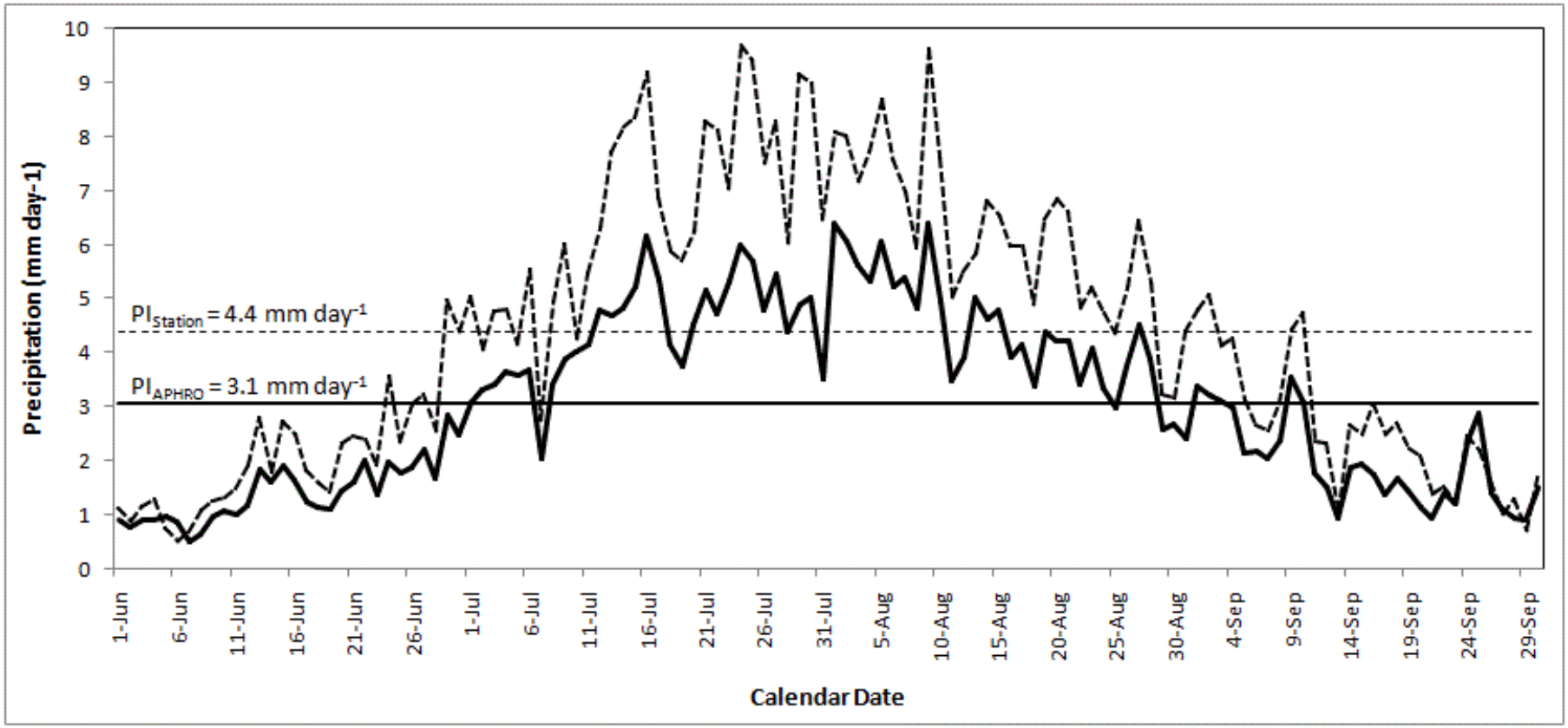
- Precipitation Index made both for station (17) and APHRODITE daily area average precipitation
- Precipitation index threshold = 4.4 mm/d (station), 3.1 mm/d (APHRODITE)
- *Monsoon onset date is the first date the threshold is met for 3 consecutive days after June 1.*
- Normalized Precipitable Water Index (NPWI) is calculated as:

$$NPWI = \frac{(PW - PW_{min})}{(PW_{max} - PW_{min})}$$

Where PW_{max} and PW_{min} are the 22 years average of the annual maximum and minimum daily PW data respectively.

- *If 5-grid cells out of 9 fulfill threshold (0.168; Golden Ratio) criterion for 3 consecutive days after 1st of June, the monsoon onset is declared.*
- large-scale circulation anomalies and the thermo. structure of the atmosphere leading the onset, NCEP/NCAR reanalysis daily data (2.5º × 2.5º), standard pressure levels, 1961 to 2007.

PI time series to calculate PI threshold values

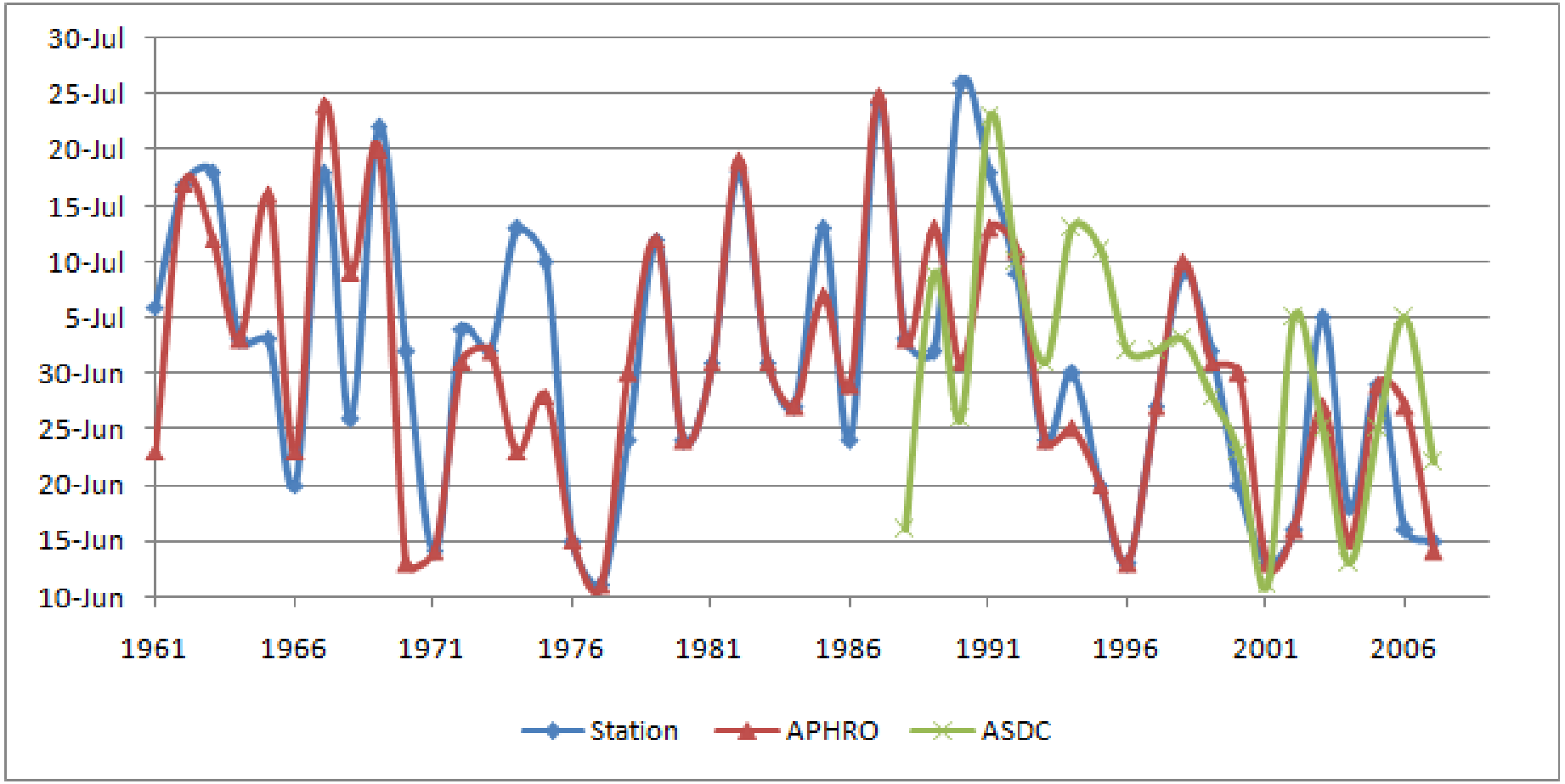


Climatological (1961-2007) area-averaged daily APHRODITE (thick line) and PMD station (dotted line) precipitation indices in millimeters per day for the core monsoon region over Pakistan.

Station		APHRODITE		PW-ASDC	
Years	Onset Dates	Years	Onset Dates	Years	Onset Dates
1961	6JUL	1961	23JUN		
1962	17JUL	1962	17JUL		
1963	18JUL	1963	12JUL		
1964	3JUL	1964	3JUL		
1965	3JUL	1965	16JUL		
1966	20JUN	1966	23JUN		
1967	18JUL	1967	24JUL		
1968	26JUN	1968	9JUL		
1969	22JUL	1969	20JUL		
1970	2JUL	1970	13JUN		
1971	14JUN	1971	14JUN		
1972	4JUL	1972	1JUL		
1973	2JUL	1973	2JUL		
1974	13JUL	1974	23JUN		
1975	10JUL	1975	28JUN		
1976	15JUN	1976	15JUN		
1977	11JUN	1977	11JUN		
1978	24JUN	1978	30JUN		
1979	12JUL	1979	12JUL		
1980	24JUN	1980	24JUN		
1981	1JUL	1981	1JUL		
1982	18JUL	1982	19JUL		
1983	1JUL	1983	1JUL		
1984	27JUN	1984	27JUN		
1985	13JUL	1985	7JUL		
1986	24JUN	1986	29JUN		
1987	24JUL	1987	25JUL		
1988	3JUL	1988	3JUL	1988	16-Jun
1989	2JUL	1989	13JUL	1989	9-Jul
1990	26JUL	1990	1JUL	1990	26-Jun

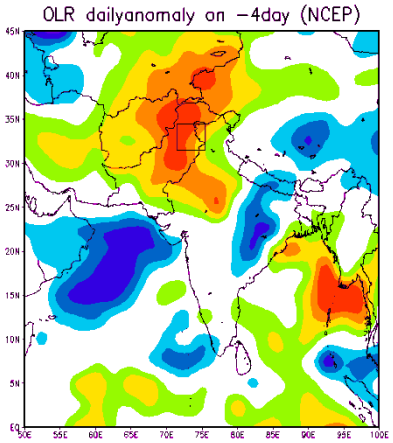
Station		APHRODITE		PW-ASDC	
Years	Onset Dates	Years	Onset Dates	Years	Onset Dates
1991	18JUL	1991	13JUL	1991	23-Jul
1992	9JUL	1992	11JUL	1992	10-Jul
1993	24JUN	1993	24JUN	1993	1-Jul
1994	30JUN	1994	25JUN	1994	13-Jul
1995	20JUN	1995	20JUN	1995	11-Jul
1996	13JUN	1996	13JUN	1996	2-Jul
1997	27JUN	1997	27JUN	1997	2-Jul
1998	9JUL	1998	10JUL	1998	3-Jul
1999	2JUL	1999	1JUL	1999	28-Jun
2000	20JUN	2000	30JUN	2000	23-Jun
2001	13JUN	2001	13JUN	2001	11-Jun
2002	16JUN	2002	16JUN	2002	5-Jul
2003	5JUL	2003	27JUN	2003	25-Jun
2004	18JUN	2004	15JUN	2004	13-Jun
2005	29JUN	2005	29JUN	2005	25-Jun
2006	16JUN	2006	27JUN	2006	5-Jul
2007	15JUN	2007	14JUN	2007	22-Jun
				2008	7-Jun
				2009	19-Jul
SD	**13**	**SD**	**11**	**SD**	**12**
Ave	**2-Jul**	**Ave**	**1-Jul**	**Ave**	**30-Jun**
Median	**2-Jul**	**Median**	**1-Jul**	**Median**	**2-Jul**

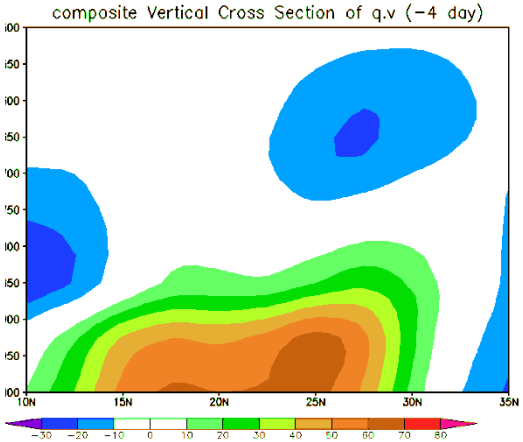
Comparison of station, APHRO and ASDC onset dates

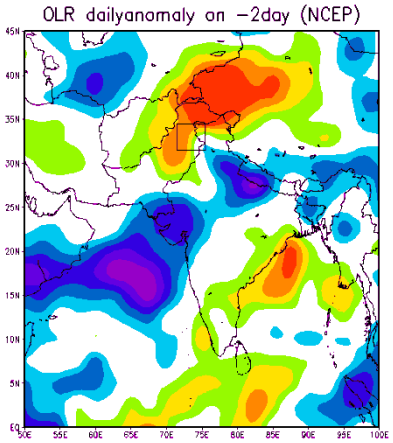


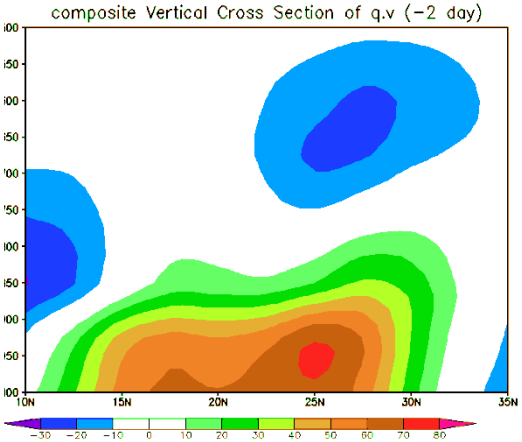
Mean composite of OLR

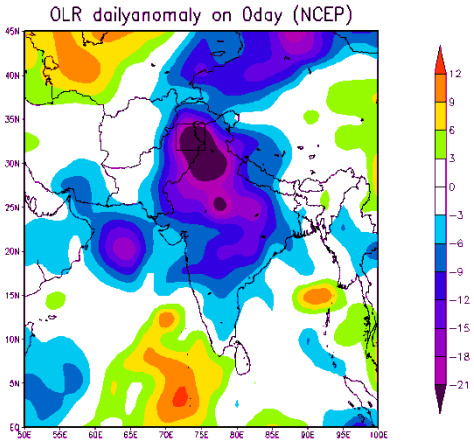
and moisture transport (meridional component); zonal average (70-76°E)

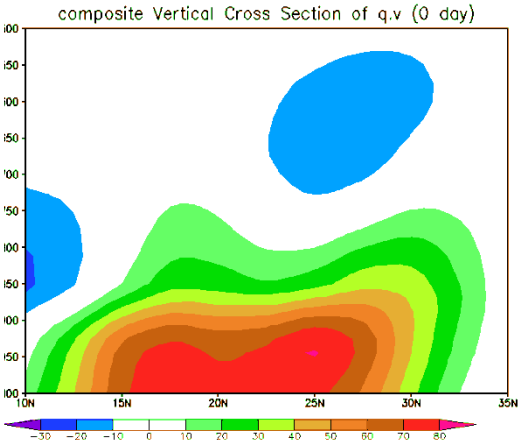




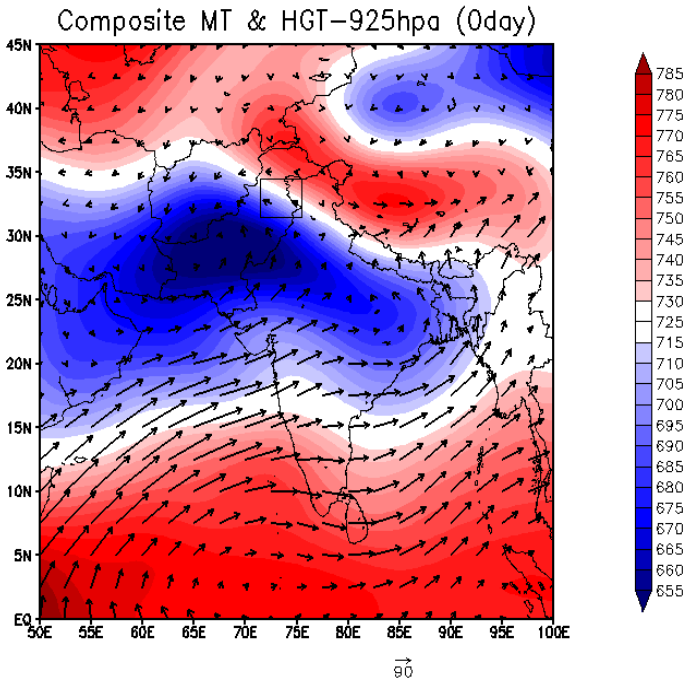


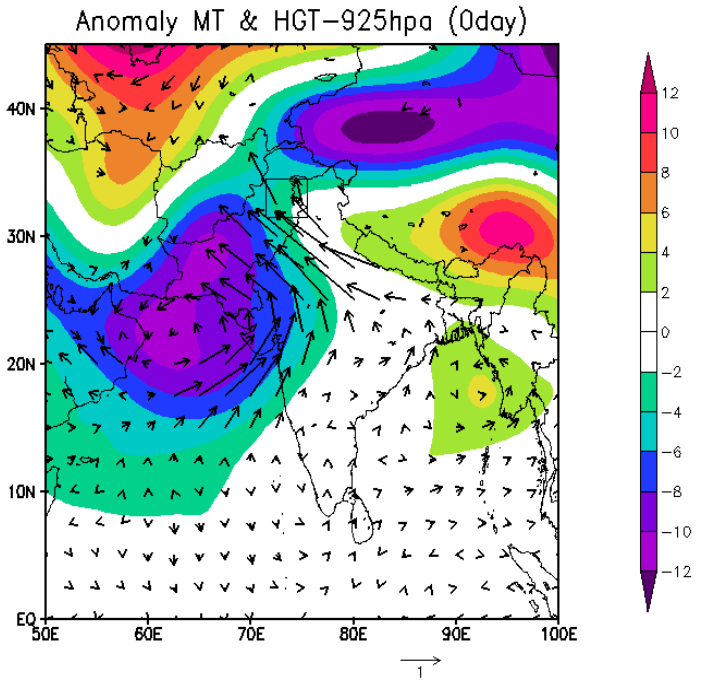






Moisture Transport & HGT 925 hPa composite anomaly



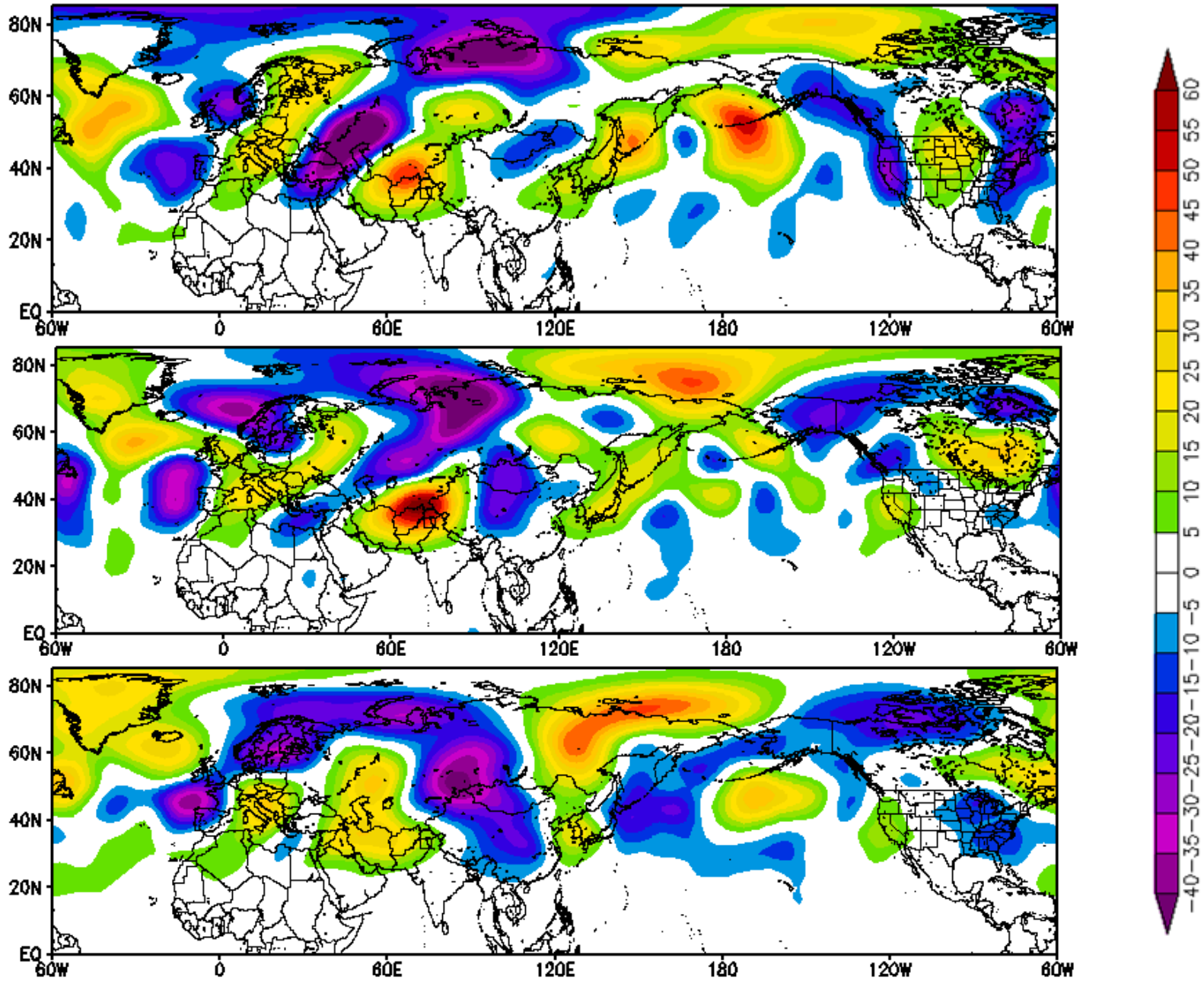


HGT 300 hPa composite anomaly

- 4 Day

- 2 Day

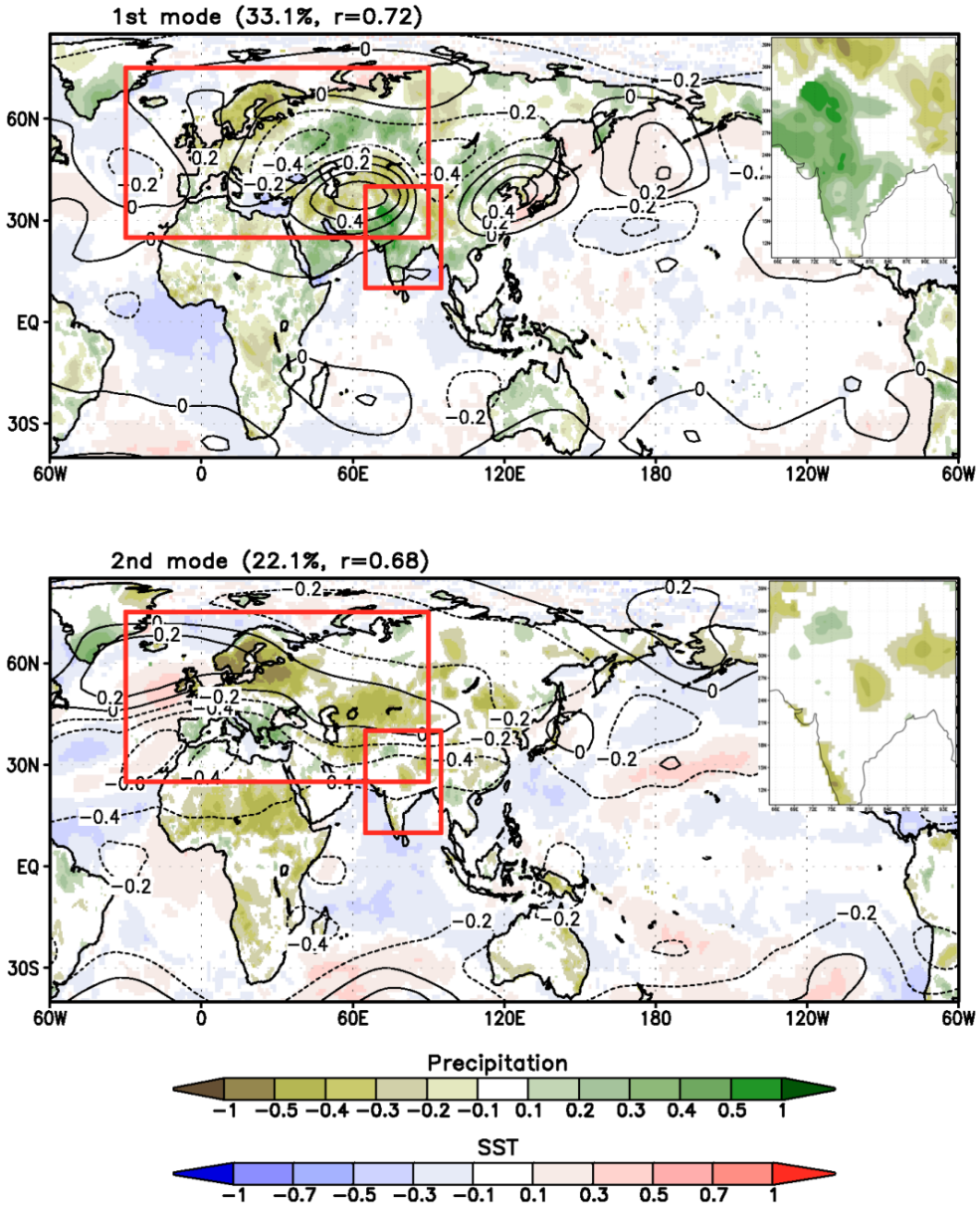
- 0 Day



The leading (upper panel) and second (lower panel) modes of CMCA heterogeneous correlation maps, between 200 hPa geopotential heights (contour interval 0.2) over Eurasia (bigger rectangle) and precipitation over south Asia (smaller rectangle)

The correlation of the EC of the leading mode of 200 hPa geopotential heights with CGT index is **0.78**

The correlation of the EC of the second mode of 200 hPa geopotential heights with SNAO index is **0.7**



Summary

1. Robust precursors of AP can be found in the upper tropospheric circulation. About a week before the AP starts, a positive temperature anomaly in the upper troposphere (300hPa) appears in the northwest of core region. This anomaly slowly moves eastward and becomes stronger until the beginning of AP. Together with the temperature anomaly; a positive geopotential height anomaly also develops at the same position

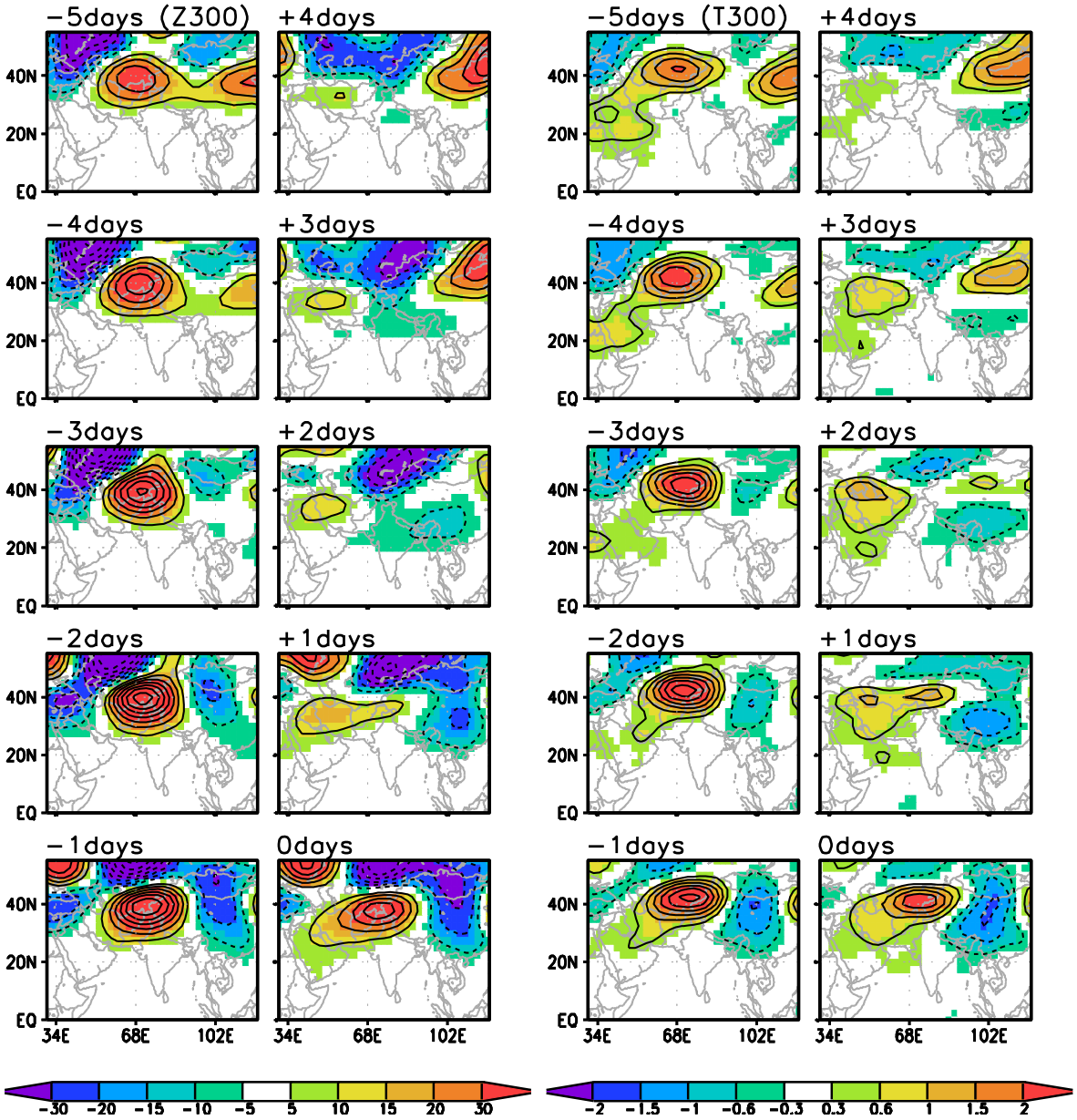
2. Upper level anomaly and local land surface thermal feedback intensifies a baroclinic structure yielding lower level divergent flow near the Tibetan plateau while WNSAM region keeps stable and dry.

3. The anomalous wind from the low level anticyclone forms a convergence zone along the foothills of Himalayas and this convergence zone expands toward the core region as the warming of core region enhances, which accumulates moisture from the south near the surface of the core region

4. South Asian summer monsoon intraseasonal oscillations seem to be less important in the AP of WESAM than the midlatitude circulation and land-surface feedbacks.
5. The mean monsoon onset date is 1st of July and CGT seems to play a role in the monsoon onset over Pakistan

Thanks for the attention !

Upper tropospheric anomaly : the earliest signal (~week before)



Warm anticyclone d
evelops until the
beginning of event
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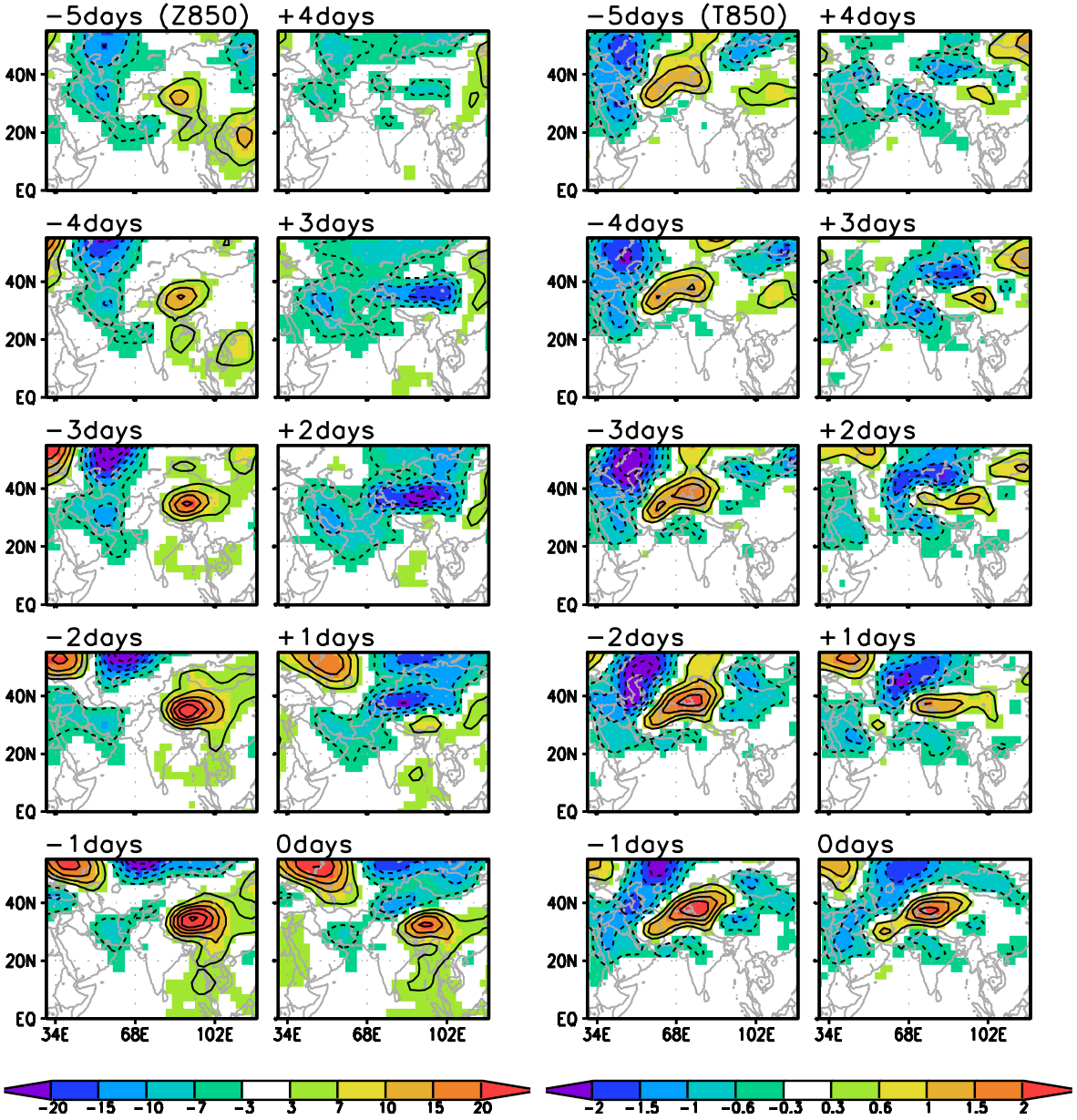
As soon as event o
ccurs, the anomalo
us anticyclone col
lapses.

Lower tropospheric anomaly : follows upper level but eastward tilt in height field



Anticyclone over Tibet an plateau develops.

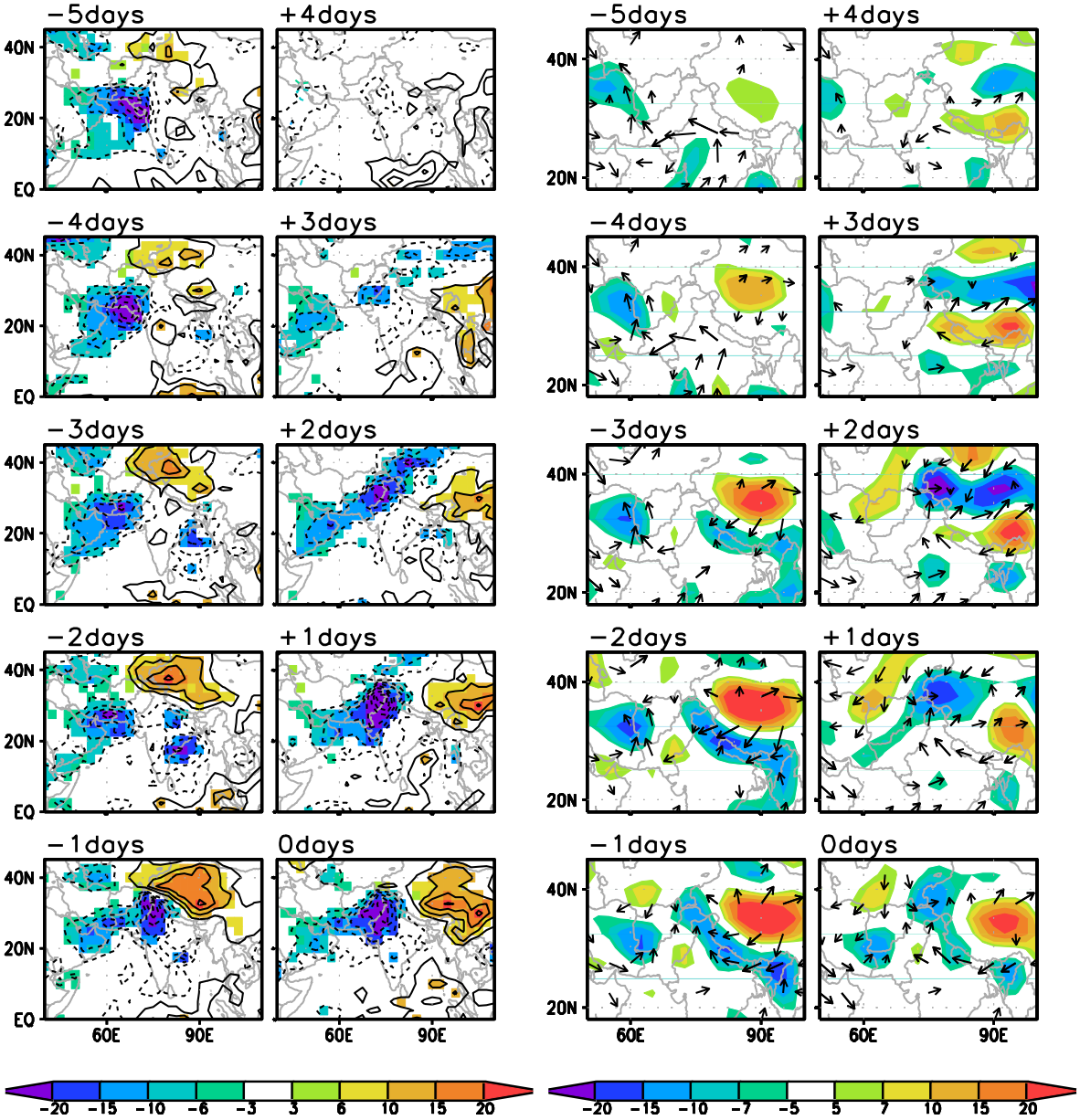
Warm area resemble to pography. (effective h eating of atm due to h igh altitude)

Column mean heating en hances relate circulat ion anomaly

But, upper atmosphere is warmer - stable

As soon as event occur s, the anomalous antic yclone collapses.

OLR & 850 wind/divergence



Positive OLR due to stable atm. - surface heating - later, heat low forms

Clouds over Arabian sea : pre-condition?/moisture source?

Sudden shift at -1,0dy

Strong divergence develops at Tibetan Plateau – convergence band along the Himalaya – causes low level convergence at core region.