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# Deviation of South-Asian Summer Monsoon Onset with associated Trends of Anthropogenic Black Carbon over Pakistan

Muhammad Latif and Vanisa Surapipith

Department of Meteorology, COMSATS Institute  
of Information Technology, Islamabad, Pakistan

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- We'd like to thank NOAA for providing integrated OLR daily data, and NCEP-NCAR for temperature, geopotential height, winds, specific humidity daily data sets, and FNL-Reanalysis as input to WRF.
- We also acknowledge Pakistan Meteorological Department, Islamabad, for providing daily station rainfall data.

# Introduction

- South Asian Summer Monsoon (SASM) is one of the most fascinating meteorological phenomena in nature that affects all the socioeconomic aspects of the region (Kim et al. 2012; Turner and Annamalai 2012).
- Over the Indian mainland, the monsoon enters first over the southern tip of the Indian peninsula (South Kerala) around 31 May (Ananthakrishnan and Soman 1988). It then progresses northward and culminates over the central Pakistan around mid of July (Ding and Sikka 2006).
- The whole monsoon circulation over most of the south Asian region generally fades away by mid of October (Zeng and Lu 2004).

# Monsoon onset over Pakistan

- The onset of summer monsoon over Pakistan is of paramount importance for the agricultural productivity of the region.
- The cultivation of different crops in monsoon-dependent regions largely depends on the amount of seasonal rainfall and the commencement of monsoon rains (Sadiq and Qureshi 2010).
- Therefore, an early or delayed onset may have serious effects on crop growth and yield, even if the mean rainfall remains normal during whole summer season (Simon et al. 2006; Raju et al. 2005).
- According to Chaudhry (1992), Pakistan receives nearly 55–60 % of its total annual rainfall during the summer monsoon season.
- A little variability in monsoon onset and rainfall may adversely affects the Gross Domestic Product (GDP) of the country, as agriculture sector accounts for 24 % of GDP in Pakistan (IUCN 2009). Thus, the study of monsoon onset and the associated dynamical mechanism is important for the country.

# Monsoon Onset Index

- Ananthakrishnan and Soman (1988) objectively defined the monsoon onset for Kerala using daily mean rainfall data obtained from dense rain-gauges network.
- Soman and Krishnakumar (1990, 1993) have critically examined the SASM onset and associated climatological structure of the atmospheric fields over Kerala based on rainfall, winds, relative humidity, and Outgoing Long-wave Radiations (OLR) composites analysis.
- Fasullo and Webster (2003) developed Hydrologic Onset and Withdrawal Index (HOWI) to define the SASM onset and withdrawal in terms of vertically integrated moisture transport over the Arabian Sea.
- Puranik et al. (2013) proposed Monsoon Onset Forecast Index (MOFI) to predict the SASM onset over Kerala using OLR and kinetic energy as proxies.
- Wang et al. (2009) objectively determined the SASM onset over Kerala making use of Objective Circulation Index (OCI).
- Taniguchi and Koike (2006) found that the criterion of low-level wind speed for defining the SASM onset is more appropriate than the moisture transport.



# This work

- the climatological and year-wise monsoon onset dates are calculated over Core Monsoon Region of Pakistan (CMRP) using the observational daily rainfall and Precipitable Water (PW) data sets by employing Precipitation Index (PI) and Normalized Precipitable Water Index (NPWI) techniques.

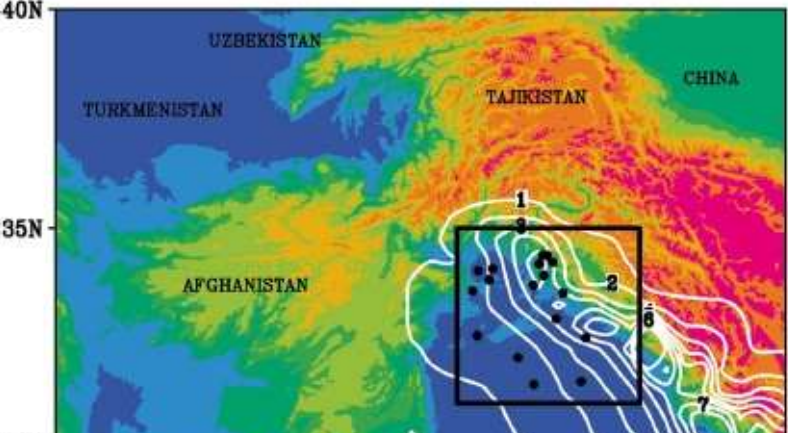
# Three observational data sets

- (1) daily rainfall data (1961–2007) of 17 meteorological stations in the core monsoon region over Pakistan;
- (2) Asian Precipitation-Highly Resolved Observational Data Integration Towards Evaluation of Water Resources (APHRODITE), version APHRO\_V1101 for Monsoon Asia (MA: 60°E-150°E, 15°S-55°N), with spatial resolution of 0.5°×0.5°, from 1961 to 2007;
- (3) The daily PW data at 1°×1° horizontal grid resolution from NASA Water Vapor Project-MEaSURES (NVAP-M), archived at ASDC, NASA Langley Research Center (from 1988 to 2007).

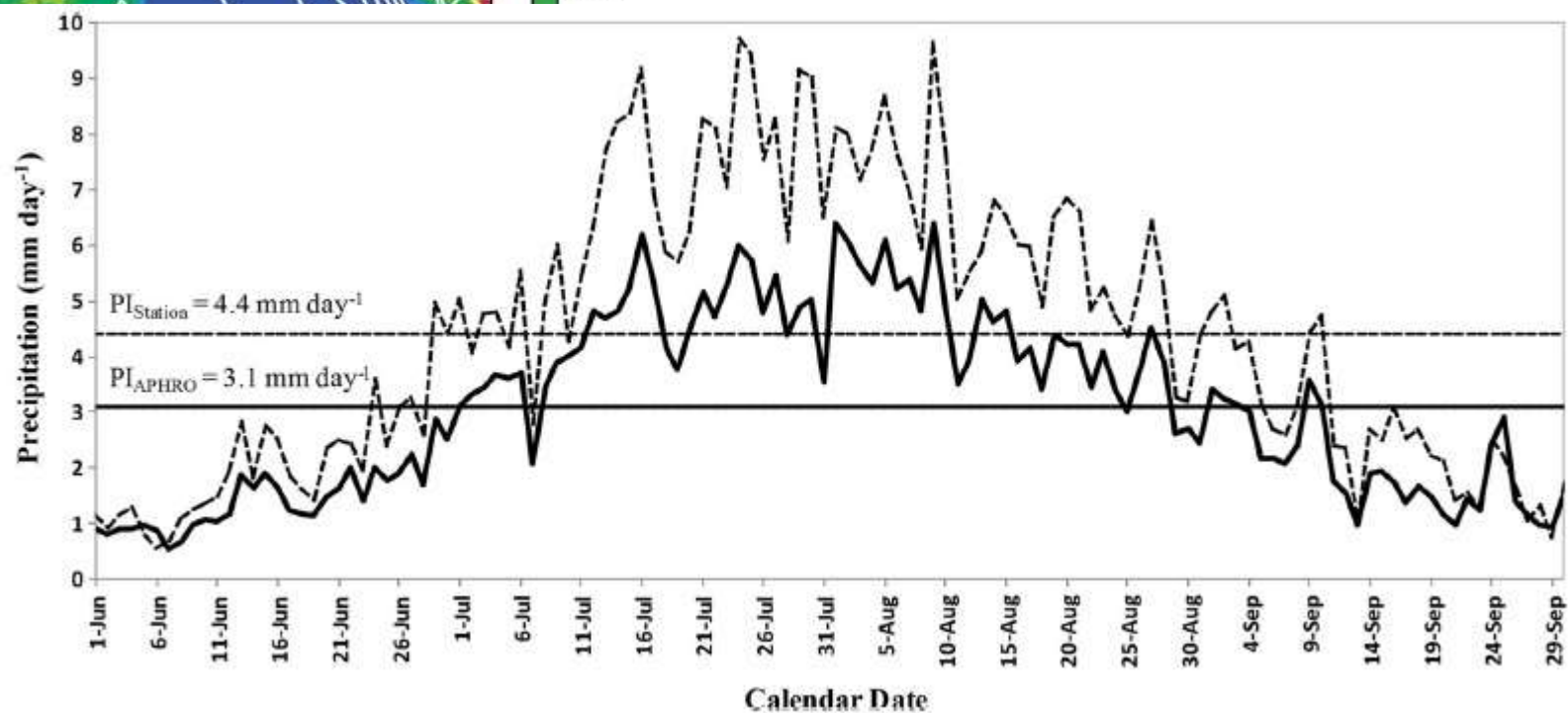
# Precipitation Index (PI)

- A PI is computed by area (31-35°N, 71-76°E) averaging APHRODITE daily rainfall (while selecting the rectangular box, some part of India is also included in the area averaging) and similarly averaging all the stations daily rainfall in the core region.
- Then the PI threshold is defined following Higgins et al. (1997), as the mean of daily PI climatological rainfall from 1 June to 30 September

# Core Monsoon Region Pakistan (CMRP)



Climatological (1961–2007) area-averaged daily APHRODITE (thick line) and daily station averaged (dotted line) rainfall indices in millimeter/day for the CMRP. Horizontal straight lines shows PI threshold for APHRODITE and station data sets



# Normalized Precipitable Water Index (NPWI)

- nine-grid cells (31-34°N, 72-75°E each 1°×1°) were selected from the core monsoon region.
- NPWI is then calculated on each grid cell as follows;

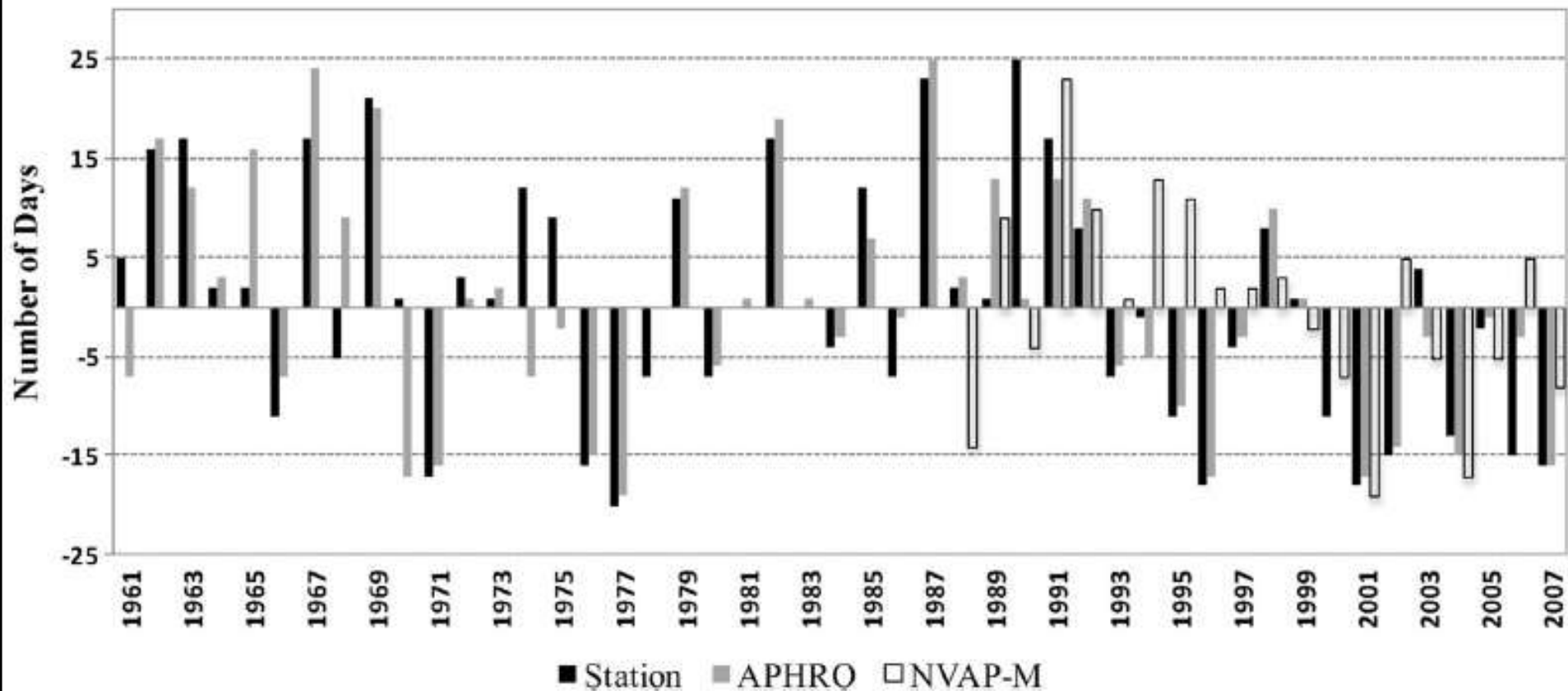
$$NPWI = \frac{(PW - PW_{\min})}{(PW_{\max} - PW_{\min})}$$

Where  $PW_{\max}$  and  $PW_{\min}$  are the 20-year average (1988–2007) of the annual maximum and minimum daily PW, respectively

# Monsoon Onset Dates - Results

Year	ST	AP	Year	ST	AP	NV	Year	ST	AP	NV
1961	06 July	23 June	1977	11 June	11 June	–	1993	24 June	24 June	01 July
1962	17 July	17 July	1978	24 June	30 June	–	1994	30 June	25 June	13 July
1963	18 July	12 July	1979	12 July	12 July	–	1995	20 June	20 June	11 July
1964	03 July	03 July	1980	24 June	24 June	–	1996	13 June	13 June	02 July
1965	03 July	16 July	1981	01 July	01 July	–	1997	27 June	27 June	02 July
1966	20 June	23 June	1982	18 July	19 July	–	1998	09 July	10 July	03 July
1967	18 July	24 July	1983	01 July	01 July	–	1999	02 July	01 July	28 June
1968	26 June	09 July	1984	27 June	27 June	–	2000	20 June	30 June	23 June
1969	22 July	20 July	1985	13 July	07 July	–	2001	13 June	13 June	11 June
1970	02 July	13 June	1986	24 June	29 June	–	2002	16 June	16 June	05 July
1971	14 June	14 June	1987	24 July	25 July	–	2003	05 July	27 June	25 June
1972	04 July	01 July	1988	03 July	03 July	16 June	2004	18 June	15 June	13 June
1973	02 July	02 July	1989	02 July	13 July	09 July	2005	29 June	29 June	25 June
1974	13 July	23 June	1990	26 July	01 July	26 June	2006	16 June	27 June	05 July
1975	10 July	28 June	1991	18 July	13 July	23 July	2007	15 June	14 June	22 June
1976	15 June	15 June	1992	09 July	11 July	10 July	–	–	–	–

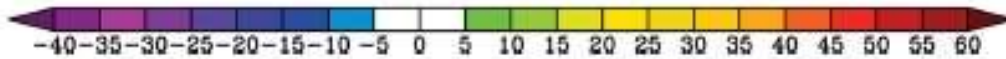
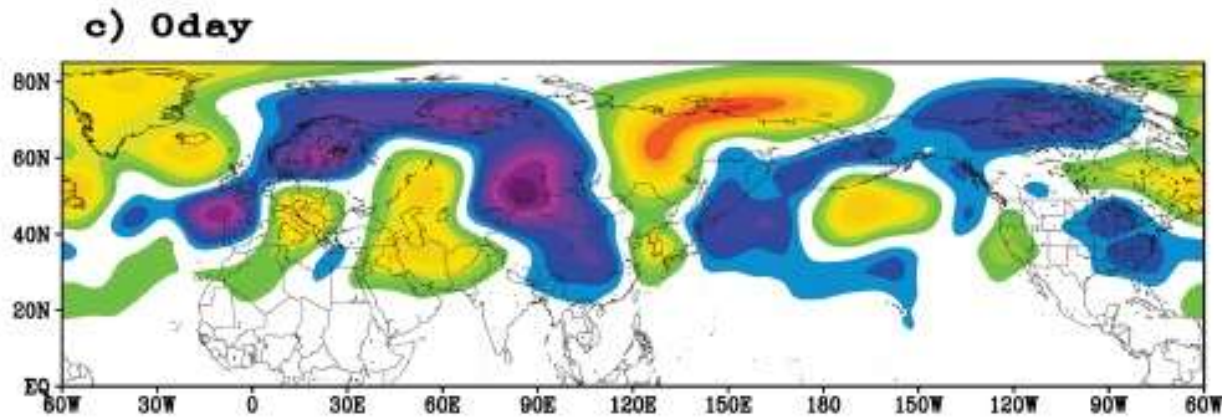
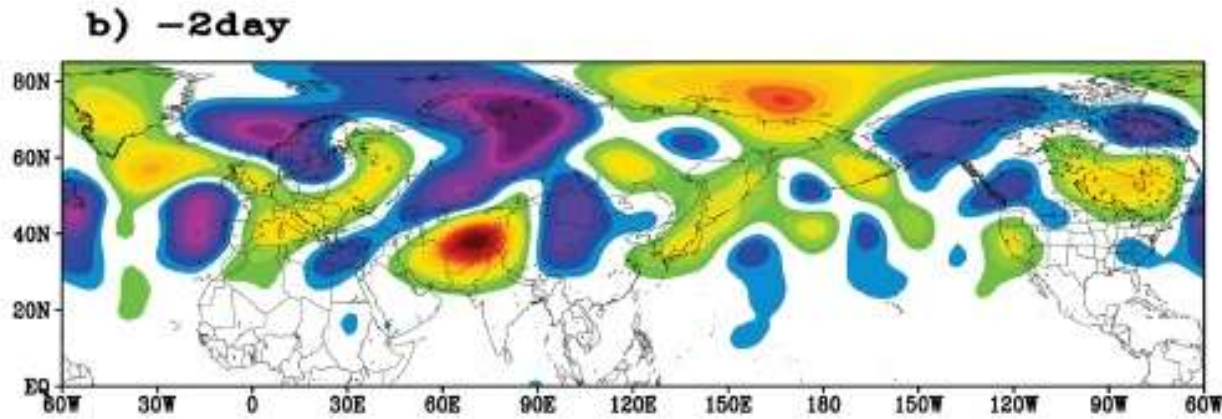
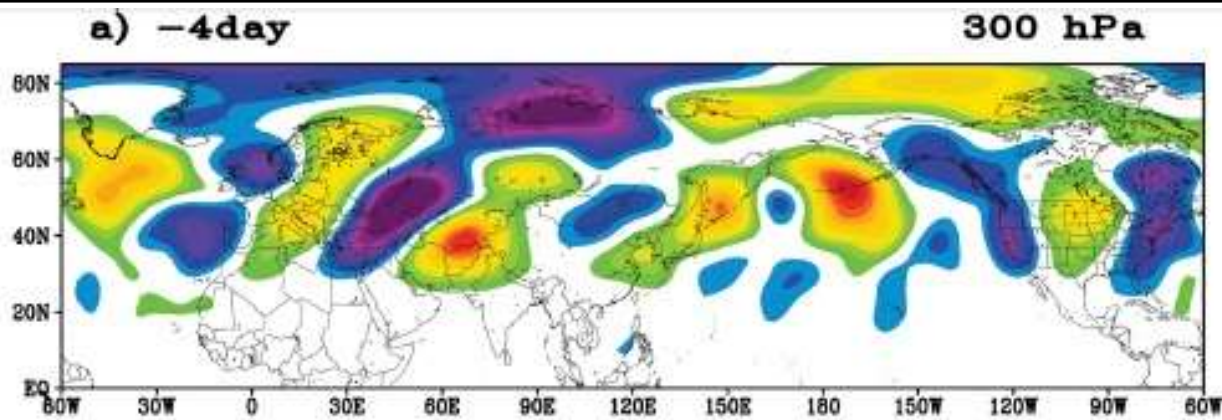
*ST* onset dates computed through PMD station data, *AP* onset dates computed through APHRODITE gridded data, *NV* onset dates computed through NVAP-M data set



Year-wise departure (in days) of monsoon onset dates from the mean (1 July is the mean value for station and 30 June is for both APHRODITE and NVAP-M data sets) over Pakistan.

Latif and Syed (Theoretical & Applied Climatology, 2016)

# Geopotential Height

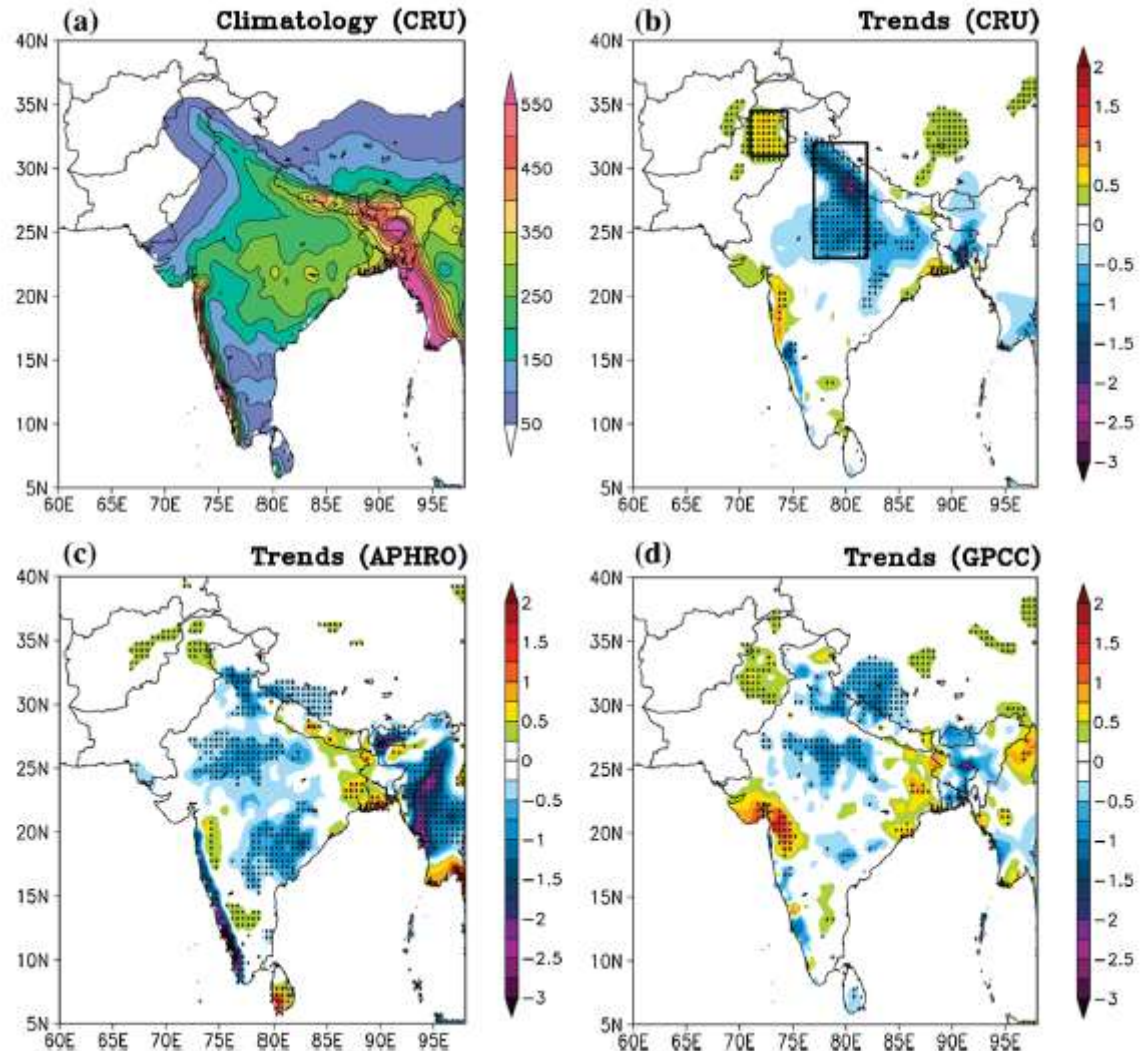


Geopotential height (m) composite anomalies at 300 hPa a 4 days before onset; b 2 days before onset; and c day of onset

Latif and Syed  
(Theor. Appl.  
Climatol., 2016)

# Dipole-type structure in Rainfall trends over north of Indo-Pak subcontinent

- Significant increasing trends over the core monsoon region of Pakistan and significant decreasing trends over the central-north India and adjacent areas.



# Link with Trends of BC over Pakistan

- the analysis of EDGAR-HTAP data for anthropogenic black carbon over Pakistan reveals the increasing trends along the foothills of Himalayas, the provinces of Punjab and Sindh. (Noor Ul Ain's manuscript in preparation)
- The summer monsoon rainfall trends using historical and future climate change (under RCP4.5 and RCP8.5 scenarios) simulations of different climate models from Coupled Model Intercomparison Project (CMIP5) show large variability across models. (Latif et al manuscript is being reviewed)

# WRF output for July 1, 2014

## Kain-Fritsch

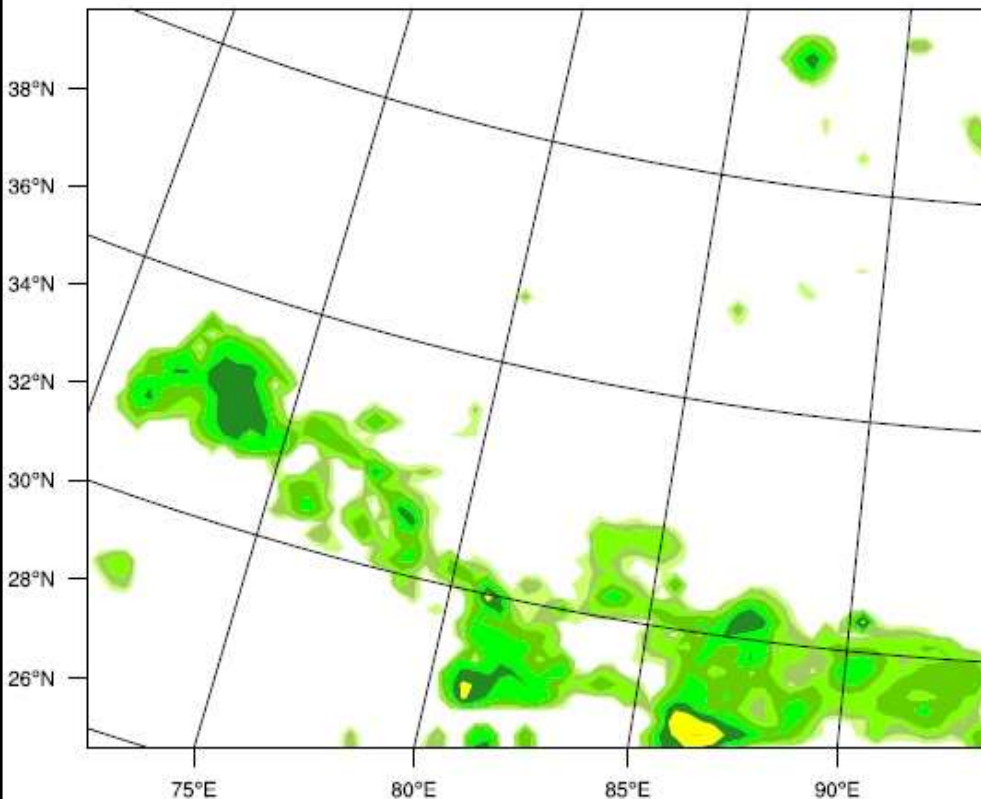
Valid: 2014-07-01\_06:00:00

REAL-TIME WRF

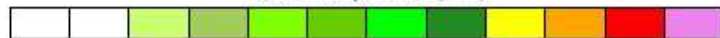
## GF

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Valid: 2014-07-01\_06:00:00

Total Precipitation (mm)

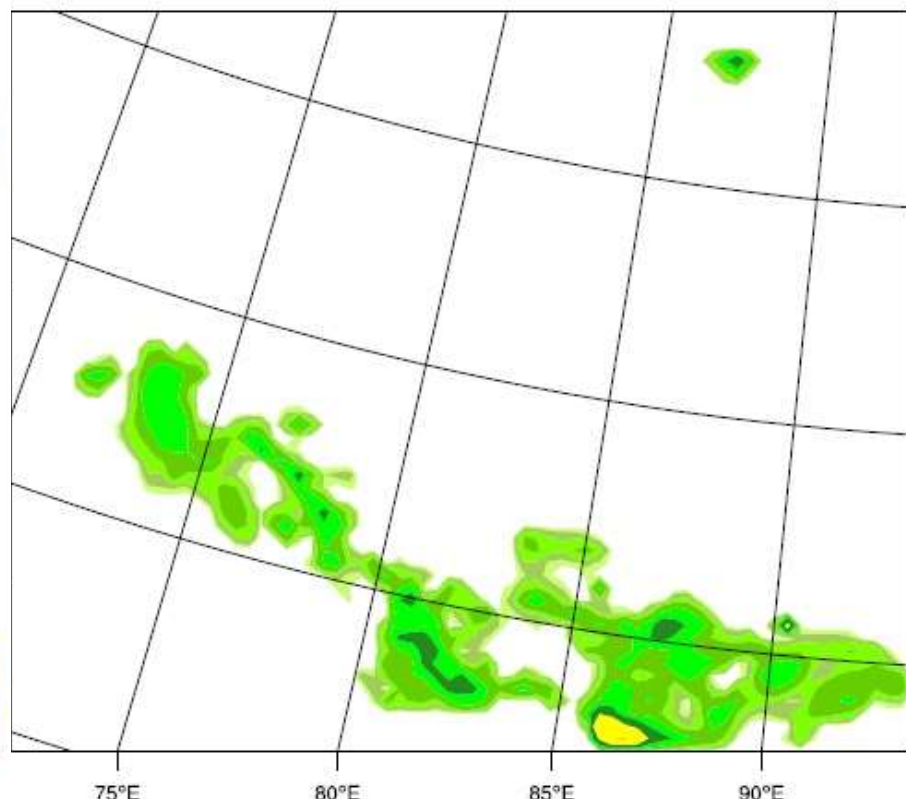


Total Precipitation (mm)



1 2 4 8 16 32 64 128 256 512 1024

Total Precipitation (mm)



Total Precipitation (mm)



.1 .2 .4 .8 1.6 3.2 6.4 12.8 25.6 51.2 102.4

# WRF output for June 25, 2014

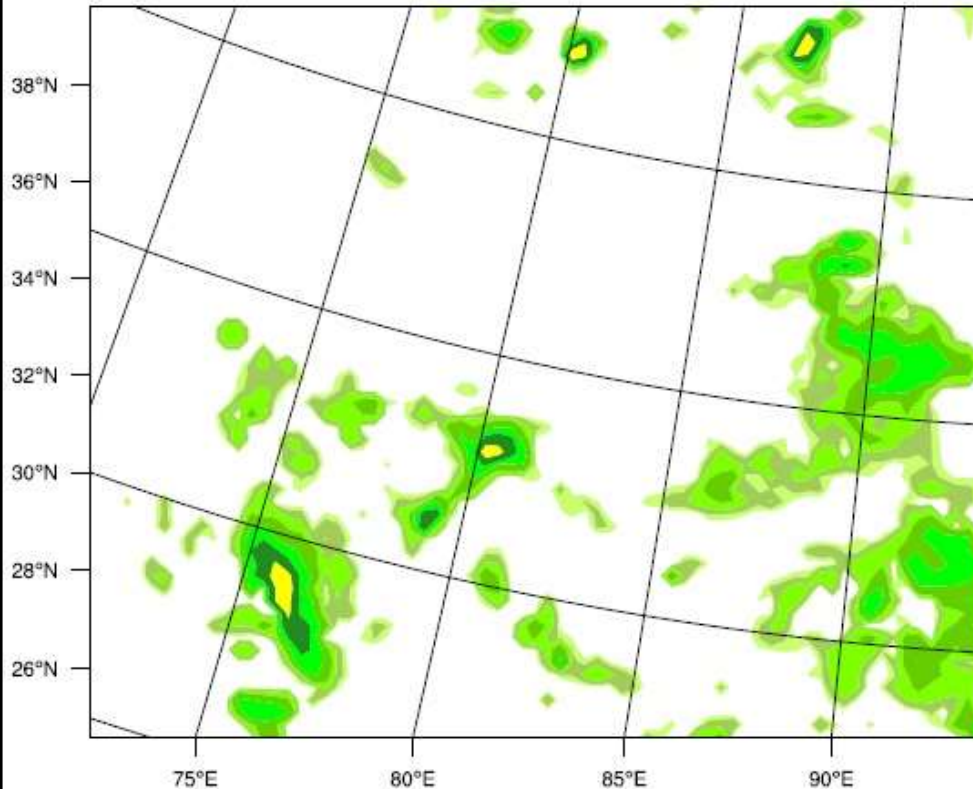
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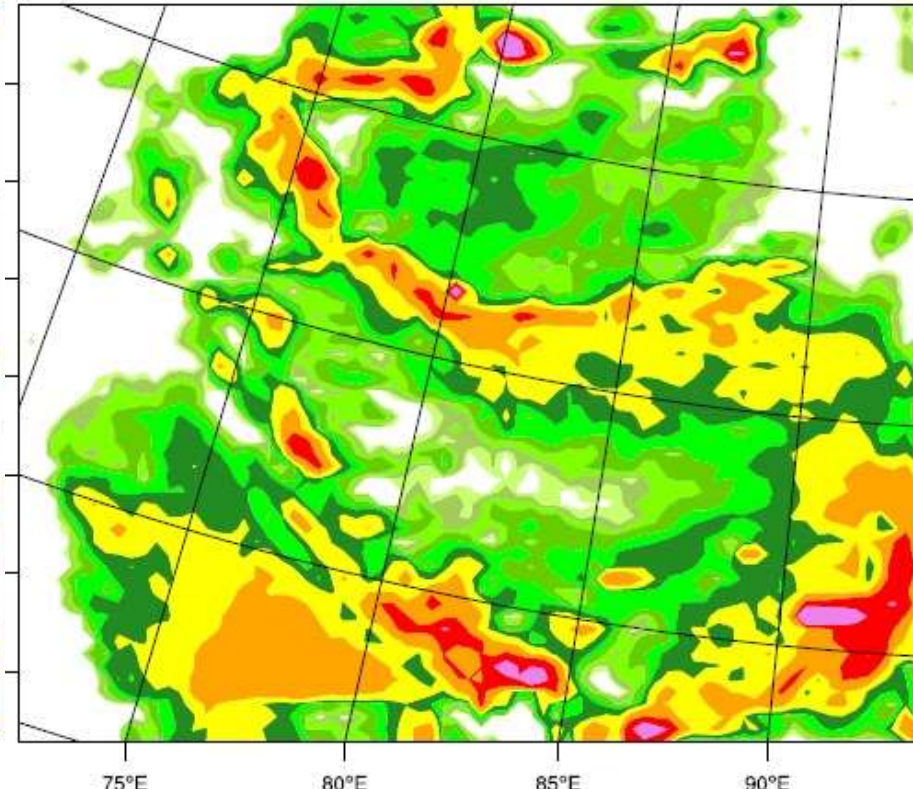
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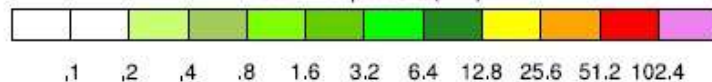
Total Precipitation (mm)



Total Precipitation (mm)



Total Precipitation (mm)



Total Precipitation (mm)

