# Variability in Summer Monsoon Rainfall over Pune, a Leeward Side Station of Western Ghats in India

**J.V. Revadekar, Hamza Varikoden and V.V. Sapre**
Indian Institute of Tropical Meteorology, Pune
Email: jvrch@tropmet.res.in

**ABSTRACT**

*The summer monsoon (June through September) accounts for 80% of the annual rainfall over India. It exhibits large variability in different space and time scales. Present study attempts analysis on variability in summer monsoon rainfall over Pune a lee side station of Western Ghats of India using data for the period 1901-2012. Rainfall anomalies over Pune examined during El Nino and La Nina years and their intensities show below (above) normal rainfall during El Nino (La Nina) years. Further magnitude of the rainfall anomalies decreases from strong to weak intensities of Nino events. Strong positive relation is found between rainfall and zonal and meridional components of wind at 850hPa over southern part of India and the Arabian Sea, whereas negative relationship is found over northwest India (correlation coefficient is significant at 5% level). It indicates that cyclonic circulation over the north Arabian Sea favours rainfall activities over Pune. During flood years, similar features are observed with strong cyclonic circulation at 850 hPa over the north Arabian Sea. Droughts are associated with weakening of westerlies over Pune.*

***Key Words**: Summer Monsoon, El Nino, La Nina.*

## 1. Introduction

Indian summer monsoon (JJAS), which dominates over most parts of the country is of paramount importance as it contributes about 70 to 90% of the annual rainfall (Rao, 1976). The summer monsoon, though well-known for its regularity and dependability on the seasonal scale, the rainfall associated with it does show significant variation on different spatial and temporal scales (Mooley and Parthasarathy, 1984; Rupa Kumar et al., 1992; Singh and Sontakke, 2002; Guhathakurta and Rajeevan, 2006). Chhabra et al., (1997) shown an increase in the precipitation in urban and industrial cities and decreasing trend over hilly stations. Several studies (Balling and Idso, 1989; Karl et al., 1988) have attempted analysis of local and regional climates. The monsoon winds passing over the Arabian Sea are obstructed by the Western Ghats and thus orographically uplifted and become more unstable by cooling as a result of the adiabatic process. After crossing the Western Ghats, these winds become moisture barren due to the local heating from leeward side (Joseph et al 2004). Therefore, Pune on the leeward side region receives very little amount of rainfall while comparing with windward side stations. Thus, from the west coast, rainfall increases along the slopes of the Western Ghats and rapidly decreases on the eastern leeward side. Where orography is irregular, rainfall features are also irregular and complex with respect to time and space (Venkatesh and Jose, 2007). Amount of rainfall is determined by many factors like availability of moisture, wind velocity, wind direction and orography of the region. The maximum rainfall appears to occur in the high altitudinal zones (Sarkar 1967; Patwardhan and Asnani 2000). The monsoon rain system seems to be perturbed with regional factors (Manjunatha et al., 2015).

Indian subcontinent is one of the prime locations which is greatly affected by ENSO. Several studies in the past have established the relationship between SSTs over the ENSO region and the climate over India, indicating that the ENSO-monsoon teleconnections account for the largest proportion of the interannual variability of the monsoons (Pant and Rupa Kumar, 1997). Most of these studies have focused on the relationship between the SSTs over Nino3.4 region and the mean seasonal temperatures/precipitation over the Indian land mass. The impact of ENSO on the climate over the Indian Ocean as well as the Indian region is characterized by a suppression of convection in the

El Niño phase and enhancement of convection in the La Niña phase (Gadgil et al., 2004).

The relationships between El Niño and Indian summer monsoon is well known and has been studied rigorously by many scientists (Sikka, 1980; Pant and Parthasarathy, 1981, Bhalme et al., 1983. Bhalme, 1984; Rasmusson and Carpenter 1983; Shukla and Paolino, 1983; Parthasarathy and Pant, 1985; Gregory 1989a, b; Webster and Yang, 1992; Mooley, 1997; Webster et al., 1998; etc.). The ENSO-monsoon teleconnections involve significant concurrent relationships between monsoon rainfall and various ENSO indices (Krishna Kumar et al., 1995). Negative Southern Oscillation Index (SOI) (Pant and Parthasarathy, 1981; Bhalme and Jadhav, 1984; Parthasarathy and Pant, 1985) and warmer sea surface temperature in the central and eastern equatorial Pacific are associated with lower monsoon rainfall and drought conditions (Angell, 1981; Khandekar and Neralla, 1984; Parthasarathy et al., 1988a, b).

In view of the above mentioned papers, present study attempts to analyse variability in summer monsoon rainfall over Pune in relation to El Nino/ La Nina events and also to examine its relationship with circulation parameters. This attempt to explore the characteristics of regional rainfall is very important. The regional scale studies are more helpfull for planners and farmers. Dynamical downscaling of General Circulation Model (GCM) output using Regional Circulation Models (RCMs) to explore local/regional informations is important in this context.

## 2. Data

Summer Monsoon Rainfall values over Pune for the period 1901-2012 are used in the present analysis to examine linear trend and variability. The detrended seasonal rainfall are correlated with seasonal zonal and meridional winds available from NCEP/NCAR Reanalysis from 1958 to present (Kalnay et al. 1996; Kistler et al. 2001) at each grid. Correlation coefficients are tested for significance at 10 and 5% level. Composite anomalies in rainfall over Pune are calculated during El Nino and La Nina years for their different intensities such as weak, moderate and strong as specified in http://ggweather.com/enso/oni.htm. Performance of summer monsoon rainfall over Pune is compared

**Location of Pune**

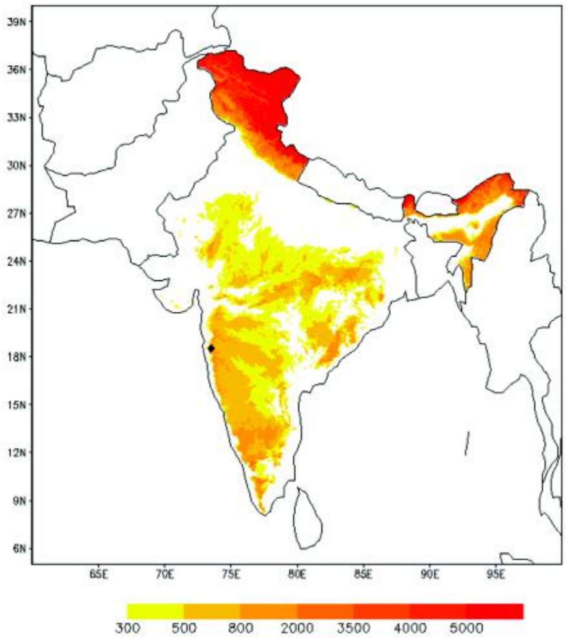


Fig.1: Location of Pune (Dot) in India (background shades present elevation)

with nearby stations Pashan and Lohgaon using daily rainfall data collected from All-India weather summary prepared by India Meteorological Department for the period 1st June to 30th September 2010.

## 3. Results and Discussion

### 3.1 General Characteristics

The seasons in a year over Pune can be classified in to four: Pre-monsoon, MAM; Summer monsoon,JJAS; Post-monsoon, OND and Winter,DJF (Kaushar Ali et al., 2012). Fig 2 shows annual cycle of rainfall over Pune based on monthly means using data for the period 1901-2012. Minimum rainfall observed over Pune is during the month of January and maximum is in the month of July. In July, highest rainfall is observed and secondary maximum is seen during September with a slight trough in August. The main rain giving months are summer monsoon months with an average rainfall of about 138 mm/month. Pune receives considerable rainfall during northeast monsoon (OND) also, with the average rainfall of 37.6 per month.

The Indian summer monsoon is driven by seasonal variations in land-sea temperature

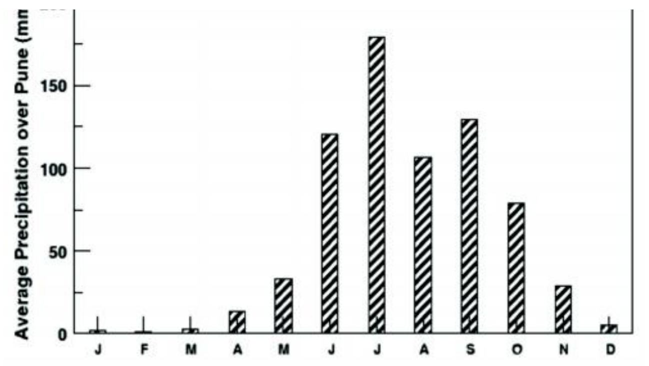


Fig. 2: Monthly mean precipitation over Pune

contrast between Asian landmass and adjacent ocean to the south. During summer, a zone of strong southwesterly surface winds rich in moisture from the Indian Ocean and the Arabian Sea extends from the northern part of the east coast of Somalia towards India Peninsula (Joseph and Raman, 1966; Findlater, 1977). Fig 3 shows the southwest monsoon low-level cross-equatorial winds over the Indian Ocean and the westerly flow over the subcontinent and the adjoining Arabian Sea and the Bay of Bengal. Winds at 200 hPa in Fig 3 show upper level anticyclonic circulation. Numerous studies have shown that the Tibetan Plateau acts as an elevated heat source that maintains the upper-tropospheric anticyclone during the boreal summer (e.g.,Koteswaram 1958; Flohn 1968; Krishnamurti 1971; Hahn and Manabe 1975; Luo and Yanai 1984; Yanai and Wu 2006; Liu et al. 2007). The wind reverses as the monsoon withdraws from the region and easterly flow sets in during post-monsoon season, which again brings some rain over the region. Amount of rain decreases with the progress of the season and magnitude of rainfall amount is much less compared to the summer monsoon season.

### 3.2. Trend and variability in summer monsoon rainfall

The summer monsoon is the most important characteristic of the Indian climate. While it has been a dependable source of water for the region since the time immemorial, the significant year-to-year variations have caused many vagaries leading to droughts and floods. From the west coast, rainfall decreases eastward sharply after the Western Ghats, reaches a minimum over the central parts of Deccan plateau and thereafter increases gradually upto east coast (Rao, 1976). Understanding the nature of its variability has been one of the most challenging tasks before the Indian meteorological community.

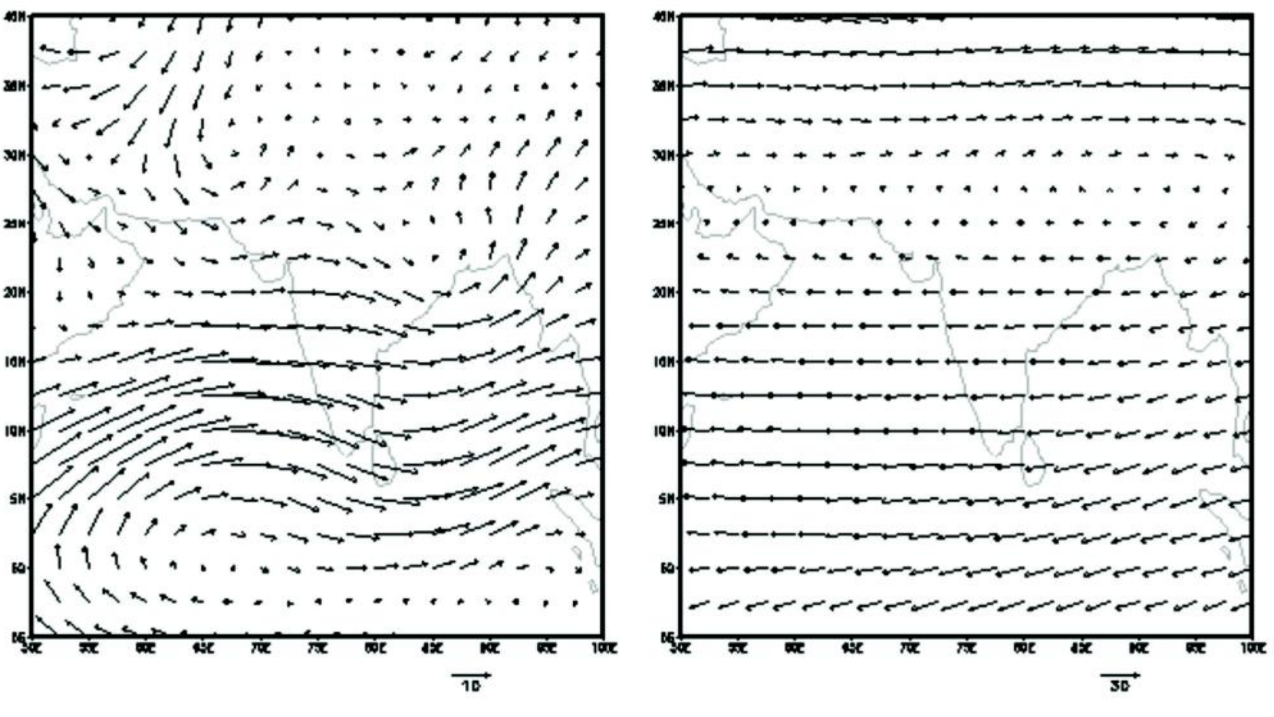


Fig. 3: Summer monsoon wind pattern at 850hPa (left) and 200 hPa (right).

On an average Pune receives ~550 mm rainfall during summer monsoon season, which constitutes about 80% of the annual rainfall. However there exists considerable year-to-year variability in seasonal rainfall over for the period 1901 to 2012 with standard deviation of 160 mm (Fig 4). Five-year moving average show there exists periodic epochs of above and below normal rainfall. Recent epoch of above normal rainfall has high magnitude and long duration. In addition statistically significant (t-test) increasing trend in summer monsoon rainfall of ~ 2 mm per year is observed.

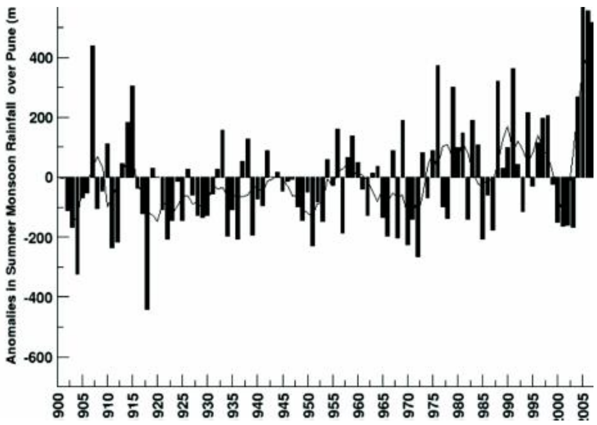


Fig. 4: Year to year variability of Summer monsoon precipitation over Pune during 1901-2012.

### 3.3 Composite of anomalies during El Nino & La Nina

Several studies in the past have established the relationship between SSTs over the ENSO region and the climate over India. Therefore rainfall over Pune is examined in relation to ENSO events. Fig 5 shows composite anomalies in summer monsoon rainfall over Pune during weak to strong La Nina and El Nino years based on the classification given in http://ggweather.com/enso/oni.htm. The impact of ENSO on the climate over the Indian Ocean as well as the Indian region is characterized by a suppression of convection in the El Niño phase and enhancement of convection in the La Niña phase (Gadgil et al., 2004). Consequent upon this, rainfall over Pune also shows positive anomalies during all categories of La Nina and negative anomalies during El Nino. Magnitudes of positive rainfall anomalies are higher during La Nina conditions. Weak El Nino does not affect the seasonal rainfall considerably. The rainfall during weak El Nino is near to normal condition. In the case of moderate El Nino years, even though the rainfall is below normal condition, it is not influencing much when it is compared with its La Nino counterpart.

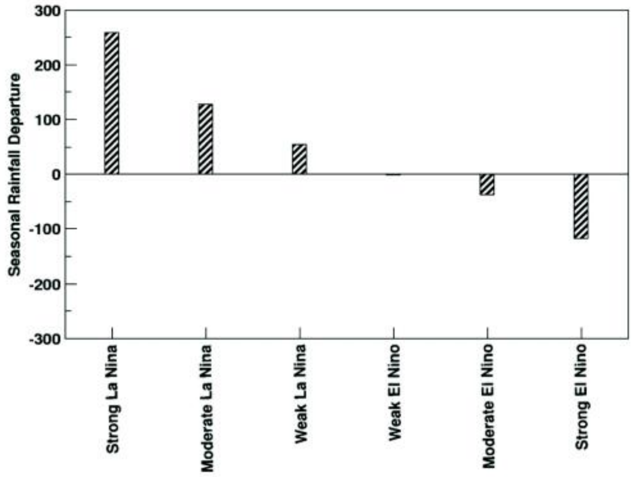


Fig. 5: Composite of anomalies in summer monsoon rainfall over Pune during weak to strong La Nina and El Nino years.

### 3.4 Correlation with horizontal winds

In view of anomalous rainfall over Pune during El Nino and La Nina, correlation analysis is done between rainfall and horizontal winds at 850 hPa and upper level (200 hPa) using data for recent four decade. Statistically significant positive correlation is seen over the Arabian Sea with zonal winds (Fig 6), indicating strengthening of westerlies favours rainfall activity over Pune. Similarly strengthening of southerlies favours rainfall activity over Pune due to enhanced moisture content over the Peninsular regions. In addition, Northwest India shows negative relationship with both zonal and meridional wind. Analysis indicates strong cyclonic circulation over the north Arabian Sea at surface level and Tibetan anticyclone over upper level brings heavy rainfall over Pune. Similar features are also seen in wind patterns during flood years and opposite or weak patterns in drought years (Fig 7). Thus it can be concluded that the horizontal winds at both low level and upper level play dominant role in modulating rainfall over Pune. As El Nino (La Nina) weakens (strengthens) winds over the region, it affects rainfall anomalies.

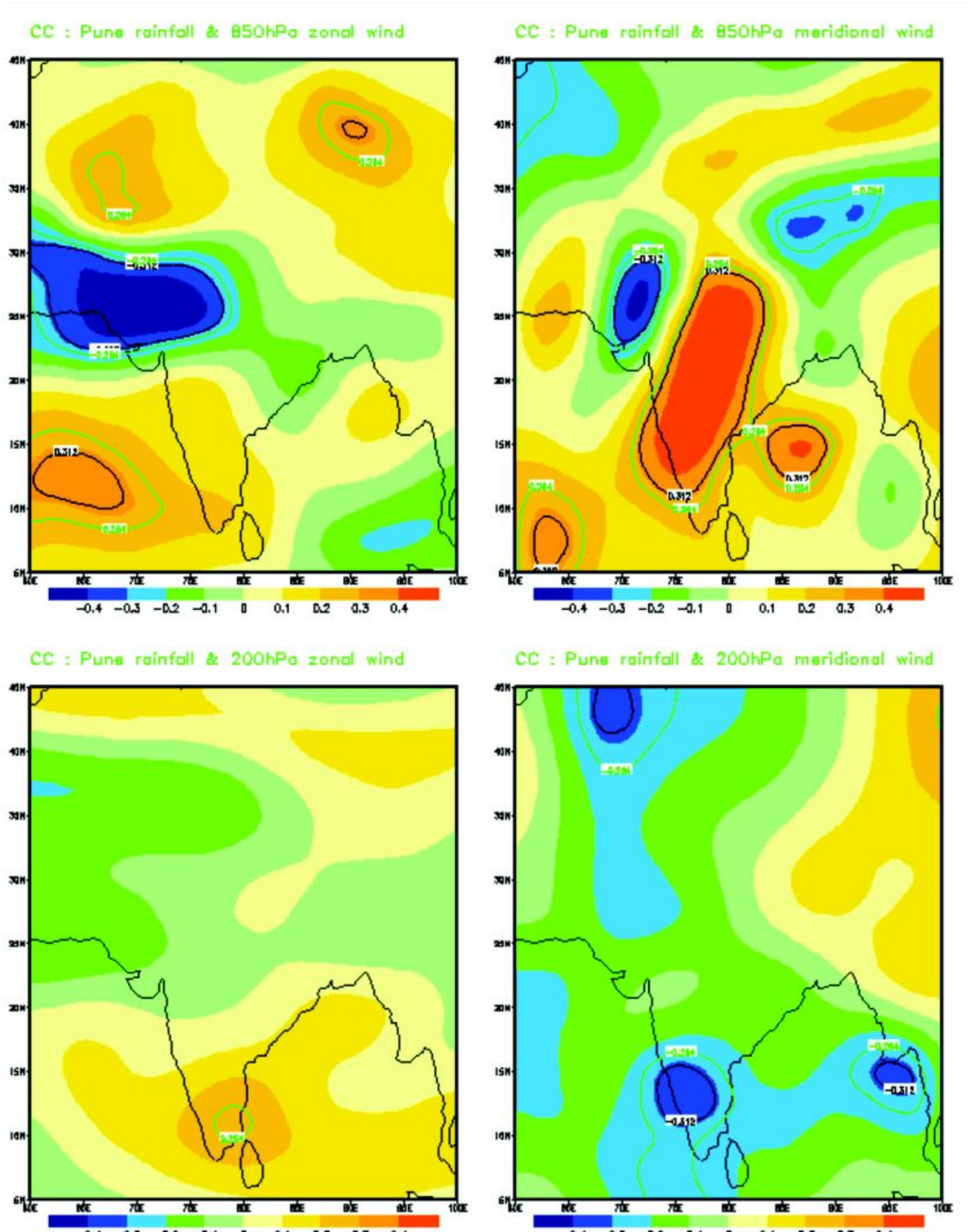


Fig. 6: Correlation coefficients between summer monsoon rainfall over Pune and (1) zonal wind at 850hPa (top-left), (2) meridional wind at 850hPa (top-right), (3) zonal wind at 200 hPa (bottom-left), and (4) meridional wind at 200hPa (bottm-right).

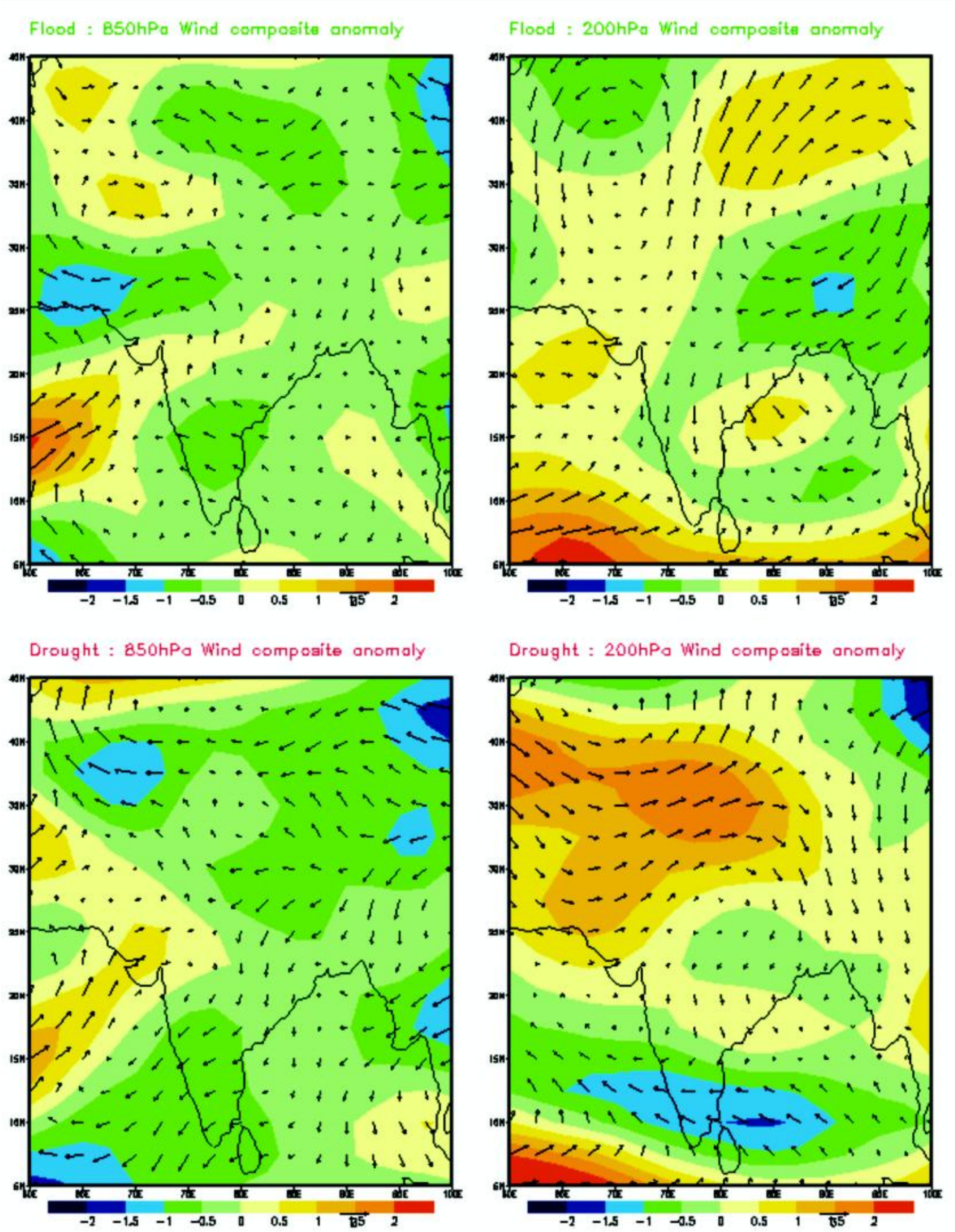


Fig. 7: Composite wind anomalies during (1) flood years (top) and (2) drought years (bottom) over Pune at 850hPa (right) and 200hPa levels (left).

### 3.5 Spatial rainfall: a case study

From the west coast, rainfall increases along the slopes of the Western Ghats and rapidly decreases on the eastern leeward side. Amount of rainfall is determined by many factors like availability of moisture, wind velocity, wind direction and complexity of the topography of the region. Therefore, rainfall analysis is also done in 2010 at three nearby stations, Pashan (west), Pune and Lohgaon (east) which are within few kilometers in radial distance (Fig 8). Seasonal rainfall for the summer monsoon 2010 (June-September) over Pune was 809 mm which was more than 40% above normal (~ 550 mm). Pashan received highest rainfall of 944 mm (normal not reported). However Lohgaon received lowest rainfall of 584 mm against its normal value of ~ 490 mm. Long-term averaged summer monsoon rainfall for Pune is 550 mm while for Lohgaon it is about 480 mm. All the three stations show rainfall during same spell. Further, rainfall over Pashan is higher and at Lohgaon it is lower in all the spells.

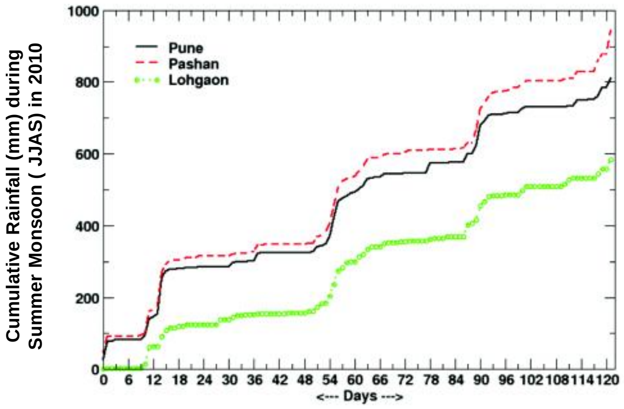


Fig.8: Daily cumulative rainfall (mm) over Pune, Pashan and Lohgaon for the period 1st June to 30th September 2010.

## 4. Summary and Conclusion

The most important characteristic of the climate of Indian region is the occurrence of monsoon, with the associated seasonal reversal of wind distribution. The summer monsoon (JJAS), which dominates most parts of the country is of paramount importance as it contributes about 70 to 90% of the annual rainfall. Pune which is situated at leeward side of the Western Ghat also shows dominance of the summer monsoon which gives 550 mm rainfall during the season, which constitutes about 80% of the annual rainfall.

Pune shows high impact of ENSO on rainfall distribution. Rainfall anomalies over Pune examined during El Nino and La Nina years and their intensities show below (above) normal rainfall during El Nino (La Nina) years. High rainfall anomalies are seen during strong Nino events. Magnitude of anomalies decreases with decrease in intensity of Nino events. Consequent upon this, strong positive link is seen between rainfall and zonal & meridional component of winds at 850 hPa over southern part of India and the Arabian Sea, whereas negative link is seen over northwest India. It indicates that strong cyclonic circulation over northern part of the Arabian Sea favours rainfall activities over Pune. Similar features are also seen in wind anomalies during flood years. Drought years show opposite features.

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