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Low level jet variations during summer monsoon onset and rainfall variations

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An attempt has been made to identify low level jet (LLJ) stream influence on Monsoon onset over Kerala (MOK) by considering the wind intensities at 850 hPa over AS (5-20°N and 55-75°E) during the period 1997-2012. The intensity of LLJ confirms an apparent increase after onset; however, rainfall over Kerala is not well correlated with LLJ intensities. During El Nino years, there is a significant positive relation between LLJ and consecutive rainfall after onset.

[**Keywords***:* Low level Jet (LLJ), Monsoon onset over Kerala (MOK), rainfall, summer monsoon, El Nino]

Introduction

The summer monsoon has been studying since the ancient times but the methodology, approach and scope of the studies have undergone tremendous changes with time. Over the southwest of Kerala strong convection and westerly wind are well established[1], with stagnating rainfall belt covering entire equatorial Indian Ocean progresses northward across India and bring widespread rainfall over India. The onset of monsoon is associated with changes in the atmospheric circulation features in the lower and upper troposphere, a sustained increase in the rainfall over Kerala and the island stations over the southeast Arabian Sea (AS) is an essential feature of the monsoon onset. The long-term mean date of MOK varies between 30 May and 2 June according to different estimates; having a standard deviation of 8-9 days[2].

The MOK is associated with a large area of organized rainfall caused by deep convection extending eastward a few thousand kilometres from the low latitude regions of the Arabian Sea (AS) in the north Indian Ocean[3]. The moisture required for this large area is mainly generated in the south Indian Ocean and carried to the convective heat source associated with MOK by a strong cross-equatorial LLJ stream[4,5,6]. A strong cross-equatorial LLJ with a core around 850 hPa exists over AS during the boreal summer monsoon season (June through September).

A number of interesting changes occur in the circulation of the atmosphere when the summer monsoon sets in over India. Intense southwesterly surface winds in the AS and heavy rainfall along the west coast of India are annual occurrences of the summer monsoon. Objectives of this paper are to validate the variations of LLJ during the monsoon season and rainfall over India, the variations between LLJ intensities and rainfall over Kerala with the advent of MOK and their relation. The mean LLJ intensity and cumulative rainfall variations over Kerala are calculated and compared five days prior and five days after onset to confirm the relation between LLJ and MOK

Materials and Methods

Onset dates have obtained from India Meteorological Department (IMD) and presented in table 1 during the study period. Since the onset of southwest monsoon (SWM) takes place at Kerala, daily precipitation data has been obtain over Kerala region from Global precipitation climatology project (GPCP) merged precipitation. GPCP products include satellite and gauge precipitation information made available with spatial resolution of 1 degree to study weather and climate variations[7]. Monthly mean time series of precipitation has been obtained from daily values for 1997-2012. The study area covers a major portion of AS i.e. over 10ºS - 30ºN and 50ºE - 75ºE, which has different wind pattern during the SWM.

It is important to study the wind pattern especially over 850 hPa, where strong LLJ observed and which brings moisture to Indian sub-continent.

To study LLJ intensities at pressure level of 850 hPa daily wind data is acquired from National Centre for Environmental Prediction (NCEP) II reanalysis. Description about NCEP reanalysis data and the project is given by Kalnay et al.[8]. Higher intensity of LLJ found in central AS over the area 5-20°N and 55-75°E. This study mainly focused on LLJ variations over AS prior and after MOK and the relationship between LLJ intensities and Indian rainfall to attain a concurrent relationship between them.

Table 1 — Indian summer monsoon onset dates as declared by IMD

Year	Onset date	Year	Onset date
1997	09-Jun	2005	07-Jun
1998	02-Jun	2006	26-May
1999	25-May	2007	28-May
2000	31-May	2008	31-May
2001	26-May	2009	23-May
2002	09-Jun	2010	31-May
2003	13-Jun	2011	31-May
2004	04-Jun	2012	05-Jun

Results and Discussion

Variation of LLJ during monsoon months

LLJ contributes lot of moisture and momentum flux to the monsoon system. The changes in the monsoon LLJ can substantially affect the moisture transport and associated precipitation characteristics over the monsoon region[9]. Composite variations of LLJ intensity during the monsoon months over study period depicted in figure 1. Monsoon onsets with rapid intensification of the Arabian Sea winds and moisture build up phase over the Arabian Sea during which synoptic and mesoscale transient disturbances

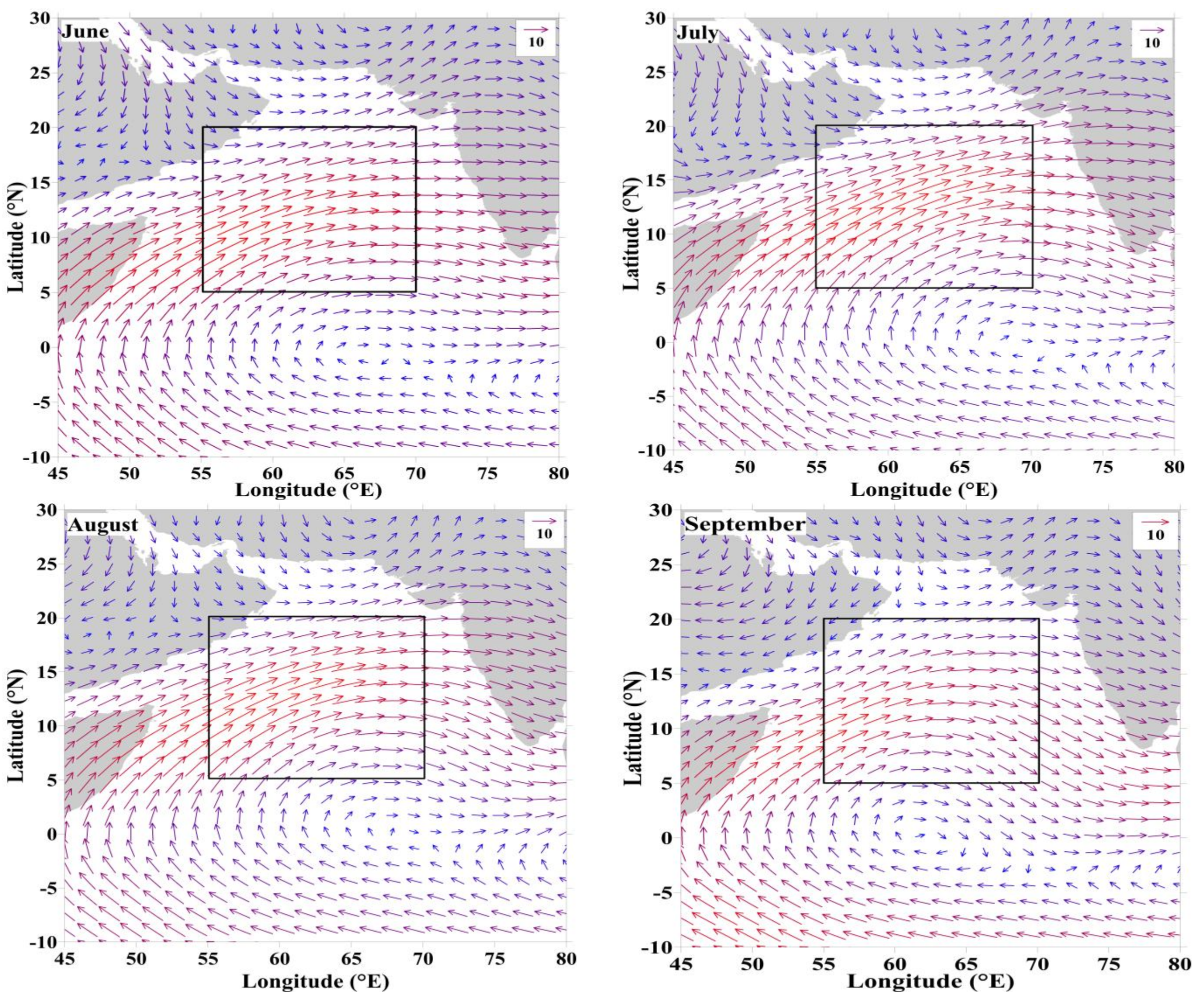

Fig. 1 — Composite of wind from 1997-2012 during monsoon months

develop[10]. Figure 1 indicating the LLJ striking the Kerala on onset during June. It is evident from the figure 1 that LLJ transports moisture from southern Indian Ocean to Arabian Sea[6]**.** The LLJ stream over peninsular India plays a vital role in Indian summer monsoon[6]. A linkage between southwest monsoon winds over the AS and Indian rainfall has indicated more than a quarter –century ago[4]. Major part of the LLJ penetrates into east Africa during May and subsequently, traverses the northern parts of the AS before reaching India in June. When LLJ reaching Kerala, there develops a synoptic disturbance, produces rainfall over Kerala, and continues further to produce rainfall throughout the monsoon months[11]. LLJ is playing an important role during southwest monsoon by transporting Moisture from southern Indian Ocean to Indian subcontinent to produce rainfall passing through AS[12].

Interannual variation of LLJ during monsoon months and relation with all India rainfall:

LLJ intensities from 1997-2012 have been given in figure 2 from June through September. Summer monsoon has significant seasonal and inter-annual variabilities, which can affect Indian rainfall[13]. Maximum intensities of LLJ can observe in the months of July and August (table 2). During the monsoon onset period over India, from the first week of June onwards[3,14] westerlies are well organized. During 1997, an El Nino year, the LLJ intensity is minimum (6 m/s) in June. In the other El Nino years during the period of study viz., 2002, 2006 and 2009 the minimum intensity in June are observed as 11m/s, 8m/s and 8m/s respectively. In these years, such minimum intensity is not been observed in the months of July and August. Large fluctuations in LLJ intensities observed in June. This has been pointed out by the authors that the rainfall in the month of June is erratic and having much variation in El Nino years[15]. In June, all El Nino years are depicting lower intensities, however there is an exceptional case of lower LLJ intensity in 1999 (La Nina year). LLJ intensities during July are indicating different scenario when compared with June. Year 2002 July LLJ intensity observed to be the lowest than other study period. In general, the wind, moisture transport and rainfall over India will be higher in July than June[6]. Year 2002 is a drought year with lowest rainfall associated with lower LLJ intensity; however, in June LLJ intensities are normal. In August, lower LLJ intensities are observed in 2009 (El Nino) and in 1999 (La Nina), which reveals LLJ and rainfall are having direct relation with each other.1997 is a strong El Nino year, in August due to LLJ intensities are higher than normal leading to normal rainfall. LLJ intensities over AS and consecutive rainfall over India are reduce during the withdrawal of summer monsoon month i.e., in September. LLJ intensities are higher in September 2007, which leading to extension of rainfall to October over India. Subrahmanyam et al[16] explained that lag in rainfall and extends to October during El Nino+1 year.

The same phenomena can be observed in 2007 and 2010; both the years are normal years after El Nino

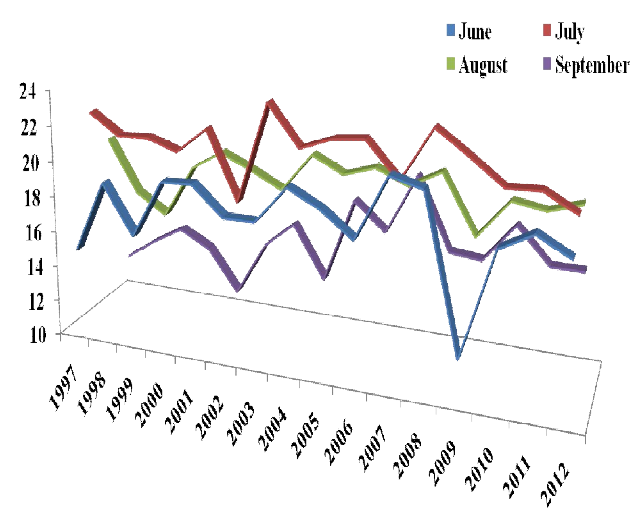

Fig. 2 — mean LLJC variations in monsoon months (June through September) over study period

Table 2 — Correlation coefficients (CC) between five days cumulative rainfall and mean LLJC intensities before and after onset over Kerala.

	Correlation Coefficients (CC)	
Year	before Onset	after Onset
1997	0.02	0.92
1998	-0.22	-0.61
1999	0.57	0.51
2000	-0.68	-0.09
2001	-0.42	0.42
2002	0.56	-0.44
2003	-0.43	-0.09
2004	0.60	-0.14
2005	0.83	-0.18
2006	0.76	-0.59
2007	-0.15	-0.47
2008	0.53	-0.41
2009	-0.98	0.47
2010	-0.02	0.41
2011	0.68	0.17
2012	-0.04	0.33

years. However, 1998 is a La Nina year after a strong El Nino year in which the extension of rainfall to October has not occurred.

The relation between LLJ and rainfall over India illustrated in the figure 3 and correlation coefficients (CC) are given. LLJ is having good positive relation with rainfall during monsoon months, expect in August (CC=0.34). However, the seasonal LLJ and rainfall over India are indicating a significant positive relation (CC= 0.63). From the figure one can clearly understood that in July LLJ intensities and rainfall are higher than June has. Moisture transportation is higher in July leads to higher rainfall over India than in the month of June[6].

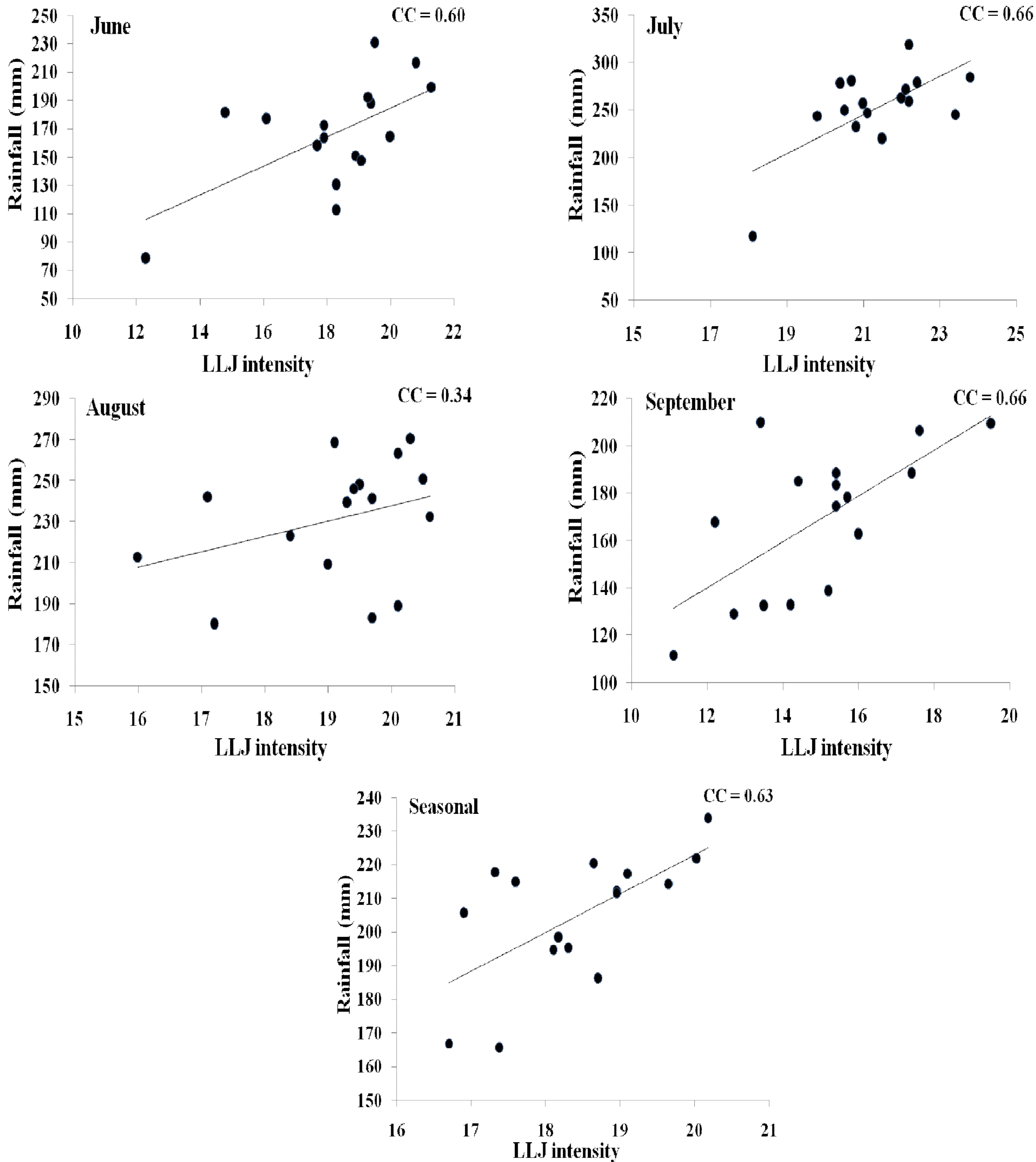

Fig. 3 — Relation between LLJC and all India rainfall during June through September and Seasonal. The correlation coefficients (CC) are given in the right side

Relation between LLJ and Rainfall five days prior and post onset of monsoon:

Onset dates (Table 1) have taken from IMD and the rainfall over Kerala 5days before and 5 days after the onset are used to compare with LLJ intensities. Many scientific workers pointed that LLJ plays a very important role not only in summer monsoon onset but also in progress during the months June through September[6]. During the onset phase of monsoon, we have taken LLJ intensities and rainfall over Kerala to compare the variations five days prior and after onset. Table 2 illustrates the correlation coefficients (CC) between cumulative rainfall and LLJ intensities before and after onset. We perform the student's t-test and the correlation coefficients calculated with 95% confidence level and presented in the table 2. It is clear from table 2 that there is an increase in the correlation after onset. However, this also shows a complex relation in 1997.

In 1997, the CC is indicating 0.02 before onset however, after onset; it is 0.92, which is higher. Onset area practically revealing no correlation before onset, however there is a significant relation after onset. If we observe the correlation for subsequent years after El Nino year, such a significant correlation is not been observed except in 2001 & 2009. In 2009 before onset there is an inverse relation (CC= -0.9), however after onset it tends to be a positive relation (CC= 0.47). In 2001 the negative CC (-0.42) turns to be positive (0.42) after onset. In 2000, CC is representing inverse relation between LLJ intensities and rainfall (-0.68 before onset and -0.09 after onset). However, the rainfall is not always indicating an increase immediately after the onset. In fact, in the years 1998, 1999, 2001, 2004, 2005, 2007, 2008, 2009, 2011 a decrease in rainfall is observed. This may be due to the fact that Kerala receives more rainfall by means of pre monsoon thunder showers. Kerala rainfall may not show a positive relation even though the intensity of LLJ confirms an apparent increase. It is interesting to note that the positive increase is well marked in El Nino years.

Overall study clearly points out that LLJ intensity is increasing after the onset of monsoon. Tropical deep convection is associated with MOK in spatial and temporal resolutions[6]. Thus, it has clearly established that LLJ transports moisture after the onset of monsoon, which clearly explains in rainfall increase. However, rainfall during the MOK is depends on several factors which are complex. During El Niño years, LLJ demonstrates a clear increase, June rainfall is erratic and indicating a definite increase before onset, however decreases subsequently. Rainfall over Kerala is not only an index for onset of monsoon but very much depends on increase in LLJ intensity.

Conclusions

Present study indicates that LLJ with a core around 850 hPa plays a very significant role in momentum and moisture flux transport during monsoon and revealing the significant relation with rainfall. During the period of study, in El Nino years lower LLJ intensities recorded indicates lower rainfall during onset of monsoon and also after onset. The rainfall is not always indicating an increase immediately after the onset; this may be due to pre monsoon thunder showers. It is interesting to note that during El Nino years of 1997 and 2002 a significant correlation found between LLJ intensities and rainfall.

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