CHAPTER IV

LOW LEVEL JET
4.1 Introduction

Low Level Jet (LLJ) is the region of relatively strong winds in the lower part of the atmosphere. According to a definition suggested by Reiter (1961) should have marked gradients of wind speed in the horizontal and vertical. There are several places where strong low-level currents are observed. The LLJs are generally located in the lowest 1 to 2 km of the troposphere. These are strongly influenced by orography, friction, diurnal cycle of heating and corresponding variations of pressure gradient and static stability (Asnani, 1993).

The UHF wind profiler measurements have the advantage of better height and temporal resolution over conventional radiosonde method for wind measurements. Three-year UHF radar high-resolution wind observations have been utilized to characterize diurnal and seasonal features of LLJ over Gadanki and Bangkok, there are used to understand strength of the LLJ propagation towards north pole with a focus on diurnal variability of low level winds. Boreal-summer monsoon seasonal winds show conspicuously strong westerly LLJ with average wind speeds. Strong westerly LLJ lasting for a few days has been observed during active monsoon periods and weak wind speeds with wind reversal during break monsoon periods. Low-level wind speeds show diurnal variation with maximum and minimum intensity during early morning and evening hours respectively.
Monsoon dynamics play an important role in determining the amount of precipitation/rainfall across the country during the southwestern monsoon. Among many dynamical parameters, the strong cross-equatorial flow in the lower troposphere widely known as the monsoon low-level jet (MLLJ) plays an important role on the Indian summer monsoon (ISM) rainfall, which occurs during June–September. The strong cross-equatorial flow, which is the manifestation of large thermal gradients between the Asian landmass and surrounding oceans, turns to westerlies because of the Coriolis force over the Arabian Sea forming the MLLJ (Hoskins and Rodwell 1995), and its dynamics have been studied in detail by Rodwell and Hoskins (1995). The strength of MLLJ is modulated between the active and break phases of the ISM. The position and strength of MLLJ decides the barotropic instability required for the genesis of low pressure systems including monsoon depressions over the Bay of Bengal. Further, the variations in the strength of MLLJ determine moisture transport over the Indian landmass. Better understanding of the variations of the MLLJ may lead to better forecasts of the genesis of monsoon synoptic systems.

Using Lower Atmospheric Wind Profiler (LAWP) data over Gadanki, Kalapureddy et al. (2007) showed that the MLLJ core lies at a height of 1.8±0.6 km and found the mean jet intensity to be 20 m/s. Using a similar instrument over Pune (18.38N, 73.58E), Joshi et al. (2006) found that the jet core height varies between 1.6 and 3 km. But it is to be noted
that the height coverage of LAWP during clear-air conditions is mostly limited to 2–2.5 km. Using National Centers for Environmental Prediction (NCEP) National Center for Atmospheric Research (NCAR) reanalysis data, Joseph and Sijikumar (2004) studied the vertical structure of the MLLJ and showed that the MLLJ core lies at 850 hPa uniformly at all locations. However, very recently Roja Raman et al. (2009) observed that these model-derived winds available at standard pressure levels significantly underestimate values when compared to the ground-based observations over the Indian region. It is worth mentioning that most of the above cited studies used over Gadanki station data for studying the MLLJ. However, for the present study, Gadanki and Bangkok wind profiler high-resolution datasets are utilized to understand MLLJ characteristics and also propagation speeds towards north pole.

4.2 Data base

The wind measured using LAWP located at Gadanki, Bangkok during 1998-2000 has been used to study the LLJ characteristics and its effects. The observations that are presented correspond to the height range of 0-6 km. The data corresponding to the months June-September are more concerned for this study. During these months, convection and SW monsoon dominate this region. In this study only clear-air days are considered. Average of 4 hours data of first 10 days of very month for morning evening separately are used during 1998, 1999 and 2000 respectively. The observations have been taken from Bangalore, Madras.

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(Chennai), Port Blair, Ho Chi Minh, DaNang, and Chiang Mai radiosonde station to study wind speed at 850 hPa during monsoon (June to September) 1998, 1999 and 2000.

4.3 General characteristic of boundary layer winds over Gadanki and Bangkok

To understand the general lower troposphere seasonal variation of wind speed and wind direction characteristics over Gadanki observations during 1998-2000 are presented in figure 4.1. LAWP observed vertical profiles of wind parameters, such as 3-D wind vectors (U, V and W), horizontal wind speed ($V_h$) and wind direction. In this vector diagrammatic representation of winds, the arrowhead indicates the wind direction and length of the arrow represents magnitude of the wind speed. In this figure, the vertical profiles of horizontal wind speeds are averaged for every 5 days and are presented for all the months for the years 1998, 1999 and 2000. It is evident from the figure that the wind structure has a seasonal characteristic feature in relation to the two different Indian monsoon seasons. From figure 4.1, it can also be noticed that the strong westerly (blue colored vectors) winds prevail during middle of May to middle of September, which is the SW/summer monsoon period over peninsular India. Frequent easterlies (red colored vectors) can be seen during rest of the year. The change in wind direction from easterly to westerly happened during the month of May and the reverse (westerly to easterly) in the month of September. The wind reversal (red arrows) observed
during monsoon period is an indication of break monsoon period. Mostly, the LLJ characteristic features during summer are easterly in direction and magnitudes are of the order of 14-16 m/s with varying jet core heights around ~1.6±0.3 km, whereas LLJ features during June to September are westerly in direction and magnitudes are of the order of 15-25 ms\(^{-1}\) with jet core heights varying around 1.8±0.6 km. The vertical thickness (spread) of LLJ is observed to be high around 3.2 km during June-August. It has been further observed that these LLJ features appear to be conspicuously stronger in their magnitudes during the SW monsoon season. It may be indicated that local winds are greatly modulated and modified by the synoptic monsoon flow over the Indian subcontinent during June-August.

To understand the general lower troposphere seasonal variation of wind speed and wind direction characteristics over Bangkok observations during 1998 and 1999 are presented in figure 4.2 LAWP observed vertical profiles of wind parameters, such as 3-D wind vectors (U, V and W), horizontal wind speed (V\(_h\)) and wind direction. In this vector diagrammatic representation of winds, the arrowhead indicates the wind direction and length of the arrow represents magnitude of the wind speed. In this figure, the vertical profiles of horizontal wind speeds are averaged for every 10 days and are presented for all the months for the years 1998 and 1999. It is evident from the figure that the wind structure has a seasonal characteristic feature in relation to the different Bangkok monsoon
seasons. From figure 4.2, it can also be noticed that the strong westerly (red colored vectors) winds prevail during middle of April to end of September, which is the SW/summer monsoon period over peninsular Bangkok. Frequent easterlies (blue colored vectors) can be seen during rest of the year. The change in wind direction from easterly to westerly happened during the month of May and the reverse (westerly to easterly) in the month of September. The wind reversal (blue arrows) observed during monsoon period is an indication of break monsoon period. In Bankok the LLJ characteristic features do not appear.

Figure 4.1. Five-days mean wind vector diagram of horizontal wind speed trends observed during the years 1998(top), 1999(middle), and 2000(bottom).
Fig 4.2 Five-day mean wind vector diagram of horizontal wind speed trends observed during the years 1998 and 1999.
(http://salmon.nict.go.jp/1.3GWPR/index.html)

4.4 Monsoon Low-Level Jet characteristics over Gadanki

Figures 4.3(a) and (b) present the vector representation of winds for each day during monsoon period (May-September) for the years 1999 and 2000 respectively. Similar figure of 1998 is dropped due the several data gap. The figure is constructed by forming the six mean vertical profiles for each day and each profile is an average over four-hour period. The aim of this figure is to show that the day-to-day changes in wind structure and the common features over the month. Such wind profiles corresponding to each month depict the gradual easterly wind changes to westerly wind during middle of May, nearby the monsoon onset and also westerly to easterly during middle of September i.e. the monsoon withdrawal period. Setting of well-organized westerlies can be seen from
June first week onwards, which is the monsoon onset period over southern part of India (Krishnamurti, 1985; Joseph et al., 1994). In the month of July and August, strong westerlies are well established and are concentrated at an altitude of ~1.8 km, which form monsoon LLJ. Further it has been observed that a few daylong continuous strong westerly LLJ features have been seen frequently during June to August (e.g. see figure 4.6 which will be described later). The strong westerly LLJ, around 850 hPa, passing in between 10ºN - 20ºN latitude is one of the necessary criteria in defining active monsoon spell besides active convection (rainfall) in that latitude belt (Webster et al., 1998; Goswami and Ajaya Mohan, 2001). Hence, the observed strong westerlies are presumed to be indicative of active monsoon phase around Gadanki. Figures 4.3(a) and (b) further show the typical active monsoon LLJ feature observed during 12 – 17 July and 24 - 30 July and 02 - 09 August during 1999 and 09 - 15 July, 08 – 12 and 21 - 29 August during 2000 respectively. It is also evident from the figures 4.3(a) and (b), the reduction in wind magnitude whenever there was a change of phase from westerly to easterly (wind reversal) almost for the few continuous days during July and August. This could be the indication of break monsoon High resolution Monsoon Low Level Jet characteristics over Tropical India “Radar Studies on Atmospheric Boundary Layer and Precipitation over a Tropical station Gadanki”. Our results show the break of monsoon periods over Gadanki during 14 - 28 July 1998; 16 - 24 August 1998; 04 - 09 July 1999; 16 - 19 August 1999 and 29 July - 06 August 2000. The above periods are more
or less analogous to the Indian Meteorological Department (IMD) reports (Thapliyal et al., 1999, 2000, 2001).

Figure 4.5a. Four-hour average horizontal wind vector diagram observed during May-September for the years 1999. (http://salmon.nict.go.jp/1.3GWPR/index.html)
Figure 4.5b. Four-hour average horizontal wind vector diagram observed during May-September for the years 2000. (http://salmon.nict.go.jp/1.3GWPR/index.html)
4.5 LLJ Characteristics during active monsoon Period (June-September) over Gadanki

This section concentrates mainly on horizontal and vertical structures of LLJ during monsoon period using contemporaneous National Centers for Environment Prediction (NCEP)/National Center for Atmospheric Research (NCAR) reanalysis wind data and southern India IMD radiosonde/radio-wind stations along with LAWP observed winds over Gadanki. The period June to September of 1998, 1999, 2000 is chosen for exploring active monsoon time LLJ characteristics. Further, during this period, LAWP wind data are found to be fairly continuous. Moreover, radiosonde measured vertical profiles of meteorological parameters at the radar site are available during this period. The zonal wind during this 4 month monsoon time period is presented as wind speed graphs Figure 4.4. The vertical structures of LLJ over radar site can be understood from this figure. This figure also clearly demonstrates the month-to-month changes along with diurnal variation of monsoon LLJ. Strong westerly zonal winds with varying intensities of LLJ and a clear oscillation of level of maximum wind can be observed during the course of the months. Fig 4.4(a) shows averaged hourly wind profiler with wind speed and height resolution of 4 m/s and 1 km. Long-term (10 Day average) wind speed averages during Indian summer monsoon period show existence of LLJ, confirming strongly influence on monsoon activity over Gadanki Semi-arid region compare to Bangkok where LLJ influence is minimal.

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4.6 Diurnal evolution of Monsoon LLJ and its effects on the boundary layer over Gadanki and Bangkok

The LLJ during June to September of 1999 are chosen to explore the representative monsoon LLJ diurnal features and probable effects associated with strong and weak LLJ periods are presented in this section. The horizontal wind speed in figure 4.4 shows strong northwesterly oriented LLJ features with diurnally varying jet core heights and intensities. It can also be observed that the LLJ intensities are relatively strong and its core existing at 1.2 km during around 0600-0800 LT. It can be noticed that the LLJ is stronger and elevating at its lowest height during early morning hours. The reduced LLJ intensities are observed with its core heights elevating as high as 3.0 km during around Convective Boundary Layer (CBL) period. LLJ structure during CBL period is rugged and not much coherent whereas during around nocturnal period, it is very much organized and concentrated. The CBL forces might have responsible for this. It can be observed from figure 4.4 that significant change in wind speed as well as LLJ core height can be noticed morning hours. It is interesting to notice that there exists a consistent secondary wind maximum just below the LLJ at ~ 1 km during before noontime, i.e. 0800 LT. The LLJ diurnal features during July 2000,. It is clear that the horizontal wind speeds show strong northwesterly oriented LLJ feature with diurnally varying jet core heights and intensities on almost all the presented days with changing LLJ structure. It can also
be observed that the LLJ intensities are reducing and jet core heights are elevating high during CBL period. It can be noticed that the LLJ strengths are strong and elevating at its lowest height (~1.8 km) during early morning hours. It can observed from fig 4.5 significance change LLJ diurnally during summer monsoon 1998. It is observed to be prominent only during early morning hours. The jet is stronger by the morning and has become weak during noon hours and further weakens gradually from afternoon to the end of the day. The strong and weak LLJ features are observed on August 1998. During this year the LLJ has appear at ~1.2 km. Figure 4.6 shows LLJ change during summer monsoon 1999. The strong LLJ features have been observed on September 1999. This month jet core Sharpe and note the maximum wind speed 17 m/s at the height 1.2 km. Figure 4.7 gives LLJ change during summer monsoon 2000. The strong LLJ features have been observed on July 2000. During this month recorded maximum wind speed 19 m/s at the height 1.2 km. At end of the day, the jet core observed to be less coherent and weak compared to morning time, the jet is stronger by the morning and has become weak during noon hours and further weakens gradually from afternoon to the end of the day Maximum wind speeds (19 m/s) are observed during morning hours.

Bangkok has no features of LLJ and Figures 4.5, 4.6 and 4.7 also shows that LLJ features over Bangkok. These figures are comparing between LLJ features over Gadanki and Bangkok
Fig 4.5 Average wind speed graphs Year 1998 (Morning (06LT to 08LT), Evening (17LT to 19LT)) (no data available in the month of September 1998 for both Gadanki and Bangkok)
Fig 4.6 Average wind speed graphs Year 1999 (Morning (06LT to 08LT), Evening (17LT to 19LT))

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Fig 4.7 Average wind speed graphs Year 2000 for Gadanki (Morning (06LT to 08LT), Evening (17LT to 19LT)) (no data available for Bangkok in this period)

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Fig 4.8 Average wind speed [3 years (1998, 1999 and 2000) average, each profile 5 days average] at 850 hpa pressure during monsoon period (June to September).

Year to year variability

Fig 4.8 Average wind speed [3 years (1998, 1999 and 2000) average, each profile 5 days average] at 850 hpa pressure during monsoon period (June to September).
Three years (1998, 1999 and 2000 June, July, August and September months) Radiosonde data from Bangalore, Madras (Chennai), Port Blair, Ho Chi Minh, DaNang, and Chiang Mai radiosonde station are utilized to understand the Low Level Jet propagation towards mid-latitude. The results suggest that the LLJ intensity is started to weaken from Ho Chi Minh, DaNang, and Chiang Mai radiosonde station. The possible reasons could be due to the coriolis forces and also the effect of Pacific ocean air currents. Further study is necessary to substantiate this phenomenon in detail.