

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor & UGC Approved Journal)

Website: www.ijirset.com

Vol. 6, Issue 9, September 2017

Characteristics of Low-level Jets on Meiyu Precipitation Clouds over Dongshan, China

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ABSTRACT: The Meiyu frontal systems play a major role not only in the energy and water cycle in the Asian monsoon regions, but also causes flood disasters in the East Asia region. Elucidating the behaviour of the systems is important for understanding and predicting regional climate changes. Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Japan and Chinese Academy of Meteorological Sciences (CAMS), China studies was conducted on heavy rainfall in the downstream of the Yangtze River during 2001 and 2002. High resolution data of horizontal winds profiles (zonal and meridional) in the lower troposphere, derived from a L-band wind profiler radar at Dongshan (31.1° N, 121.1° E) during a 2- Meiyu seasons of 2001 and 2002 has been utilized to study Meiyu seasonal and intra-seasonal variability of winds and to understand the characteristics of low-level jets (LLJs) over coastal areas of China Continent and its linkages with rainfall the warm seasons. Winds display a systematic seasonal evolution with behaviour opposite in phase in the two altitude regimes below and above a height of 4-5 km. The low-level jet (LLJ) is closely related to severe rainfall events, air pollution, wind energy utilization, aviation safety, sandstorms, forest fire, and other weather and climate phenomena. Two peaks in LLJ incidence were revealed at 500–800 m (BLJs) and 2100–2200m(SSJs) altitudes. BLJs and SLJs showed different behaviour in their temporal variation of the occurrence frequency, wind direction, and relation to rainfall. The BLJs displayed a more evident diurnal cycle than the SSJs, with maximum incidence occurring in night time and early morning. The relation between LLJs and precipitation was examined by comparing the frequency of LLJs occurrence on rainy days (cases), with daily (4-hourly) accumulated rainfall within 1 to 10 mm, and non-rainy days (cases) because the missing rate of WPR data is high during heavy rainfall events. Both BLJs and SSJs occur more often on rainy days than on non-rainy days. In shorter time scales (4 hours), both BLJs and SSJs tend to occur frequently during, before and after rainy cases, except SSJs before rainy cases.

KEYWORDS: Meiyu seasons, Dongshan, Low Level Jets, Boundary Layer Jets, Synoptic System Jets

I. INTRODUCTION

Wind plays a vital role in atmospheric energetics and it transports heat, mass, moisture and pollutants from one place to another. These transport processes, in turn, affect the local weather including cloud and precipitation processes. Hence, detailed observations of winds with high spatial and temporal resolutions are necessary to understand the processes and their interaction with the environment. The ability to understand atmospheric phenomena increases as the ability to observe them with finer resolution in time and space improves. Wind profilers are a powerful tool to obtain vertical profiles of three components of wind velocities at high spatial and temporal resolution, and are widely used not only for atmospheric research but also for operational weather prediction. In clear air, the technique involves backscattering of the UHF/VHF radar signal from turbulent variations in the refractive index and measuring the Doppler shift of the return. Three or more beam directions (non-coplanar) can be used to get a complete wind velocity vector. This technique has been described in a number of reviews including those by Gage and Balsley (1978), Balsley and Gage (1980), Larsen and Rottger (1982) and Kalapureddy et al. (2007).

Low-level jets (LLJs) are defined as horizontal wind speed maxima in the lowest few kilometres of the troposphere (e.g., Stensrud 1996). LLJs are observed in many parts of the world. Their occurrence is often associated

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with the development and evolution of deep convective precipitation. The characteristics of LLJs have been widely documented in observational studies (Chen et al. 1994; Frisch et al. 1992; Lothon et al. 2008; Parish et al. 1988), numerical simulations (Chou et al. 1990; Jiang et al. 2007; Kato 1998; Parish and Oolman 2010; Werth et al. 2011; Zhong et al. 1996), and theoretical analyses (Blackadar 1957; Holton 1967; Van de Wiel et al. 2010).

Among all the weather systems, LLJs show the closest relationship with rainfall, which therefore attracts the most attention from meteorological researchers. Due to the influence of the East Asian summer monsoon and the existence of complex topography, China consistently suffers from torrential rainfall events. Statistical results show that the correlation coefficient between LLJ and rainstorm can be up to 80% in China (Tao et al., 1979). In the 1950s, Tao (1965) used the position of the LLJ to make rain-fall forecast, and then a large number of studies appeared in the 1980s, focusing on the relationship between LLJ and torrential rainfall events (e.g., Sun and Zhai, 1980; Huang, 1981; Yu, 1986). At present, the LLJ is still a key indicator in rainfall prediction over East China. Because of the sharp vertical shear below the jet core, this region is always accompanied by potential instability. Therefore, the LLJ not only transports heat and moisture during precipitation, but also frequently stimulates the mesoscale fluctuation propagating along the jet core due to its strong instability. This kind of sharp increase of wind speed can trigger mesoscale convective systems and thus lead to torrential rainfall events (Sun and Zhai, 1980).

In this paper, high temporal and vertical resolution 1289-MHz WPR data at the Dongshan site (located in Dongshan, China, see Fig. 1) has been used to gather WPR data of high temporal and vertical resolution. On the basis of these high-resolution data, we documented and evaluated the statistical characteristics of LLJs influence on precipitating clouds over Dongshan during the 2001–2002 warm seasons (pre-Meiyu, Meiyu, and post-Meiyu periods). The Meiyu period (Baiu period in Japan) is an early-summer rainy season in subtropical China and Japan when extremely heavy rainfall is one of the most significant weather phenomena (Tao and Chen 1987). The main objective in this study is to clarify the difference in statistical characteristics between BLJs and SSJs in Dongshan and provide statistical evidence for their formation mechanisms. In Section III, we present the data and statistical methods used. The vertical distribution of LLJ occurrence frequency for classification of LLJs and the observed characteristics, including their temporal variation of the occurrence frequency, horizontal wind direction, and relationship with warm-season precipitation and also the relationship between BLJs (simultaneous occurrence of BLJs and SSJs) are discussed in Section IV. From statistical results combined with previous theories, possible formation mechanisms for the BLJs and SSJs are also discussed in shown in Section IV. The final section summarizes our results.

II. RELATED WORK

The formation mechanisms of LLJs varied in previous studies, depending on the location of LLJs. The formation mechanisms could be classified into two types. The first is more related to local diurnal oscillations, such as inertial oscillations (Blackadar 1957; Van de Wiel et al. 2010), shallow baroclinicity produced by sloping terrain (Holton 1967) or by land-sea thermal contrast over the coastal regions and orographic blocking (Li and Chen 1998; Lin et al. 2011). The second type is more coupled with synoptic or sub-synoptic-scale weather systems, such as isallobaric forcing (Uccellini and Johnson 1979), baroclinicity from the development of extra tropical cyclones (Djuric and Damiani 1980; Newton 1967), and diabatic effects (Uccellini et al. 1987). Given the different LLJ formation mechanisms, more detailed terminology should be coined to distinguish LLJs.

In this paper, LLJs are classified into two types following Chen et al. (1994): (1) boundary layer jets (BLJs), which occur in the planetary boundary layer with significant vertical shear of horizontal wind and significant diurnal variation; and (2) synoptic-system-related LLJs (SSJs, as LLJs defined by Chen et al. 1994), which occur in the 600 to 900 hPa layer and are usually related to synoptic-scale weather systems. Previous studies of LLJs over East Asia tended to focus on the relationship of LLJs to heavy precipitation during Meiyu periods (Chen and Yu 1988; Matsumoto et al. 1971; Ninomiya and Murakami 1987; Tao and Chen 1987). A few also discussed climatological characteristics (Chen et al. 2005; Pham et al. 2008) compared to those in the United States (Bonner 1968; Karipot et al. 2009; Mitchell et al. 1995; Song et al. 2005; Whiteman et al. 1997). In these studies (Chen and Yu 1988; Matsumoto et al. 1971; Ninomiya and Murakami 1987; Tao and Chen 1987), LLJs over East Asia were defined as narrow horizontal zones of high speed flow along the south side of the Meiyu fronts. The role LLJs play in transporting warm and moist air northward has received much interest. These LLJs are coupled to the East Asia monsoon and closely related to the Meiyu fronts. They hence fall into the SSJs category. Compared to SSJs, BLJs over East Asia are less documented.

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Rife et al. (2010) reported the diurnal variation in LLJs over China at a 450-m height level from their 1985–2005 global downscaled reanalysis.

Pham et al. (2008) identified the diurnal variation in LLJs over Okinawa, southern part of Japan from hourly wind profiler radar (WPR) data. These studies provided evidence of the incidence of BLJs (LLJs with obvious diurnal variations in boundary layer) over East Asia. So far, our understanding of East Asia LLJs is insufficient due to a lack of detailed SSJs and BLJs characteristics. Moreover, the LLJs at different locations over East Asia may not have the same characteristics. Chen et al. (2005) statistically classified LLJs over Taiwan into different types by their height, appearance (single jet or double jet), and movement (migratory and non-migratory) through the use of 12-hour sounding data. Unfortunately, the low-temporal-resolution observations they used might miss detailed LLJs behavior, such as the diurnal cycle. Compared with conventional observation, WPR data have much higher temporal resolution. Thus, we believe that long-term WPR data are suitable for identifying the statistical characteristics of LLJs (Pham et al. 2008). Pham et al. (2008) reported an interesting aspect of the LLJ over Okinawa, but did not study BLJs and SSJs separately over Okinawa. Differences between BLJs and SSJs in various locations over East Asia need to be further evaluated.

III. DATA AND METHODOLOGY

The 1290-MHz WPR installed at the Dongshan site (31.1°N, 121.1°E) in Dongshan (Fig. 1) can operate in low-power and high-power modes, which have vertical scanning ranges of 187–1109 m and 854–3005m respectively, with intervals of 100 m. The temporal resolution for both modes is 30 min. Vertical scanning data in each mode are combined to produce vertical wind profiles from 187 m to 3005 m every 30 minutes. The scanning overlap part of the two modes, the low-power mode data are removed because they have a higher missing rate (6.36%) than the high-power mode data (0.73%). The high vertical resolution and coverage allow us to capture the peaks at different heights related to the LLJs. The WPR data were checked for availability and quality before statistics were compiled. We checked the data duration and missing rate. The 2-year record was continuously stored during warm seasons (Meiyu, pre-Meiyu, and post-Meiyu periods) from 2001 to 2002. The Meiyu periods in Dongshan were from 7 June to 3 July in 2001 and from 20 June to 8 July in 2002 according to the Dongshan Water Authority.



Fig.1: Wind Profiler Radar (WPR) installed at Dongshan (31°4'47" N; 120°26'3" E), China

In this study, the pre-Meiyu (post-Meiyu) period was treated as one month before (after) the corresponding Meiyu period. The missing rate (ratio of missing profiles to the total number of profiles) was 9.37% during the study

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periods, which is similar to the rate reported by Phamet al. (2008). The missing rate below 500 m is lower than that found by Pham et al.(2008). A relatively higher data missing rate was found in the early morning and late afternoon. In addition to the WPR data, we also used National Centres for Environmental Prediction (NCEP) Final(FNL) Operational Global Analysis data on a 1.0 x1.0 degree grid every 6 hours over the same period to provide the corresponding environmental conditions associated with the LLJs. The zonal temperature anomaly is defined as the difference between the zonal mean temperature (average from 111°E to 133°E) and the mean temperatures during the warm seasons. Additionally, hourly accumulated precipitation data were collected from an automatic weather station at the same location (station 58461 in Dongshan) during the study period to analyze the relationship between the LLJs and precipitation.

Previous statistical studies have adopted various criteria for identifying LLJs. For the Great Plains of the United States, Bonner (1968) introduced a LLJ classification method by defining threshold values for the maximum wind speed, the maximum height of maximum wind, and the required vertical shear magnitude above the jet. These criteria have been widely used (with small changes in the threshold values) in literature (Mitchell et al. 1995; Whiteman et al. 1997). In East Asia, a set of criteria suitable for LLJs over Taiwan, in addition to some specific criteria (wind direction, horizontal shear), also included the height of maximum wind, the threshold values for maximum wind, and the vertical shear below wind maximum (Chen and Yu 1988; Chen et al. 1994). The vertical shear above the wind maximum was also adopted as a criterion (Chen et al. 2005). In addition, Pham et al.(2008) applied criteria that were similar to Bonner's(1968) for LLJ detection over Okinawa. Over mainland China, however, most researchers have identified LLJs simply by horizontal wind speed at specific levels, mainly due to the limitations of data resolution. Their criteria, that horizontal wind speeds at 925, 850, or 700 hPa levels are equal to or greater than 12 m s⁻¹, do not include the requirements of vertical shear of horizontal wind. In this paper, the WPR data allowed us to consider the vertical shear of horizontal wind for identifying LLJs in Dongshan. We adopted the Whiteman criteria (Whiteman et al. 1997), that (1) the maximum wind speed is more than 10 m s⁻¹ in the lowest 3 km and (2) the wind speed must decrease by at least 5 m s⁻¹ from the height of the wind maximum to the wind minimum below a height of 3 km or to a height of 3 km when no minimum is found. The criteria require LLJs to have a significant vertical shear of horizontal wind, which ensures they have jet-like profiles. The criteria are relatively weak for maximum wind speed, in order to provide a larger number of LLJ samples and higher statistical significance. We defined the height of LLJs as the height of the maximum horizontal wind speed maxima when LLJs occur. The LLJ direction is defined as the wind direction at the height of the LLJ.

In the subtropical eastern Pacific coast in the vicinity of Yangtze river region, significant weather is almost associated with heavy rain, tropical cyclones or both. Unlike weather systems in the low-latitude, these weather systems often show their presence better in the upper air wind field than in the geo potential height field due to the relatively slack height gradient in this region. Therefore, the ability of the wind profiler radar (WPR) to provide wind profiles at high frequency, say once every 10-min, could offer great help to local forecaster in monitoring, and sometimes extrapolating in real time the precipitating cloud systems. From the time of installation of the WPR in June 2001, a number of significant weather events have been successfully captured by the Dongshan-WPR.

IV. RESULTS

Figure 2 shows the time-height pattern of Low level jet in the form of wind vectors on 04th July 2001. The length of each arrow is proportional to the wind velocity, and the arrow direction corresponds to the wind direction. Vectors are not plotted at times and ranges for which a consensus was not obtained among the observations in the 1-hr averaging period. Vectors are directed upward for a northward (southerly) component, and towards the right for a eastward (westerly) component. Vectors are plotted at times and heights for which a consensus was obtained among the observations in the 1-h averaging period. This is the most familiar way of presenting WPR data. Each column of wind vectors corresponds to one-hour averaged data. The WPR excels in capturing moisture-laden mid-tropospheric wave. Whenever, there is significant weather system developing in the vicinity, the moisture influx in the mid-troposphere increases. This enhances the data capture rate especially for the layer between 2 and 6 km, allowing mid-tropospheric weather events to be seen in great details (as shown in Fig.3). Also, for meteorological events where changes in upper air pattern may precede changes in surface pattern, the WPR data appears to be able to provide clues to the future development of surface events.

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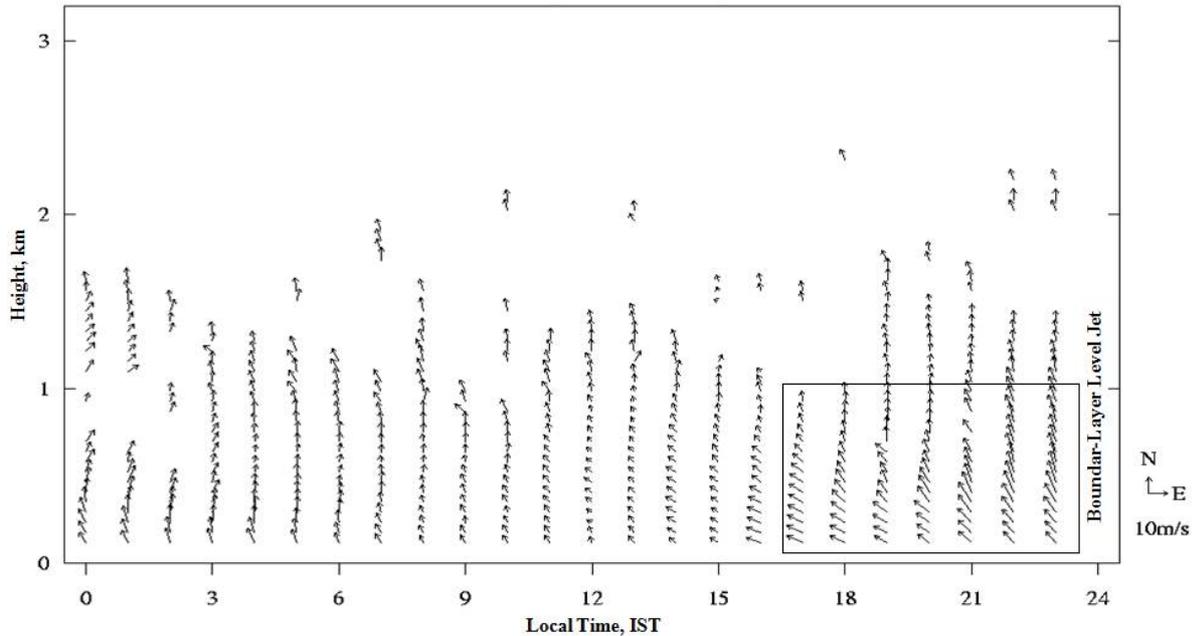


Fig.2: Time-series of wind profile measured at Dongshan during the passage of Low Level Jet (LLJ) on 04th July 2001. The Boundary Layer (BJT) Jet is denoted with a rectangle

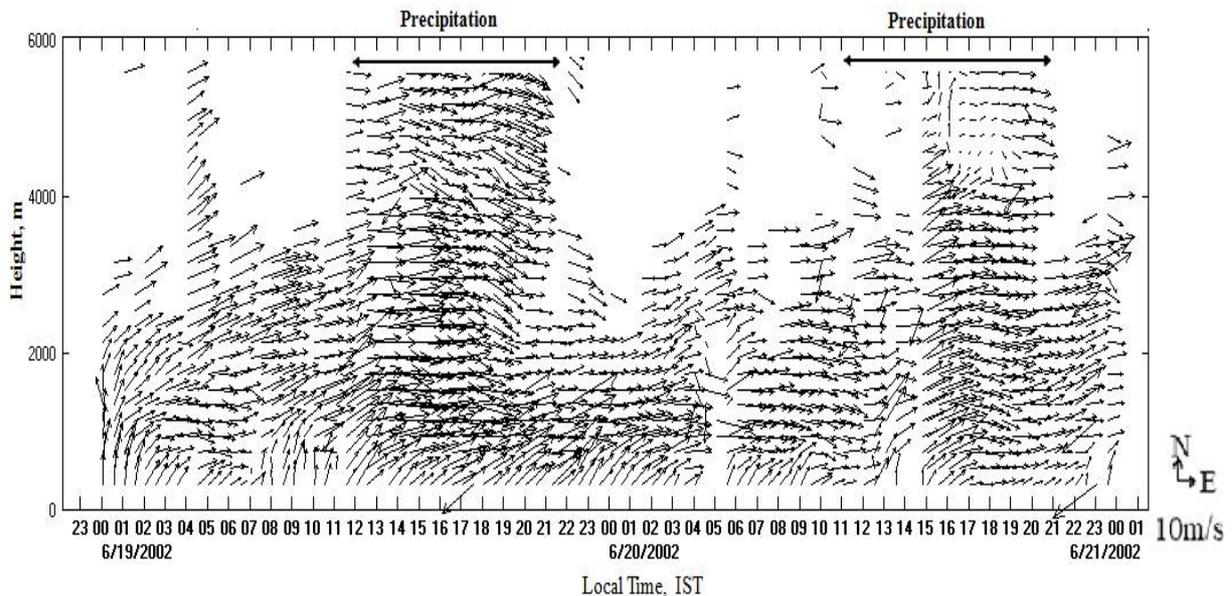


Fig.3: Time-series of wind profile measured at Dongshan during the passage of Synoptic-system related Jet (SSJ) on 19th and 20th June 2002.

Figure 3 shows the evolution of wind profiles over Dongshan for a 49-hrs period beginning at 0000 hrs LT on 19th June 2002 and ending at 0000 hrs LT on 20th June 2001. It is found that SSJ are formed during southerly and south-westerly with a maximum magnitude up to 20 m/s. This figure demonstrates impressively the appearance of the SSJ through 2-dimension wind field of the mesoscale convective system. The system was developed due to the low-

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level processes in modulating development of tropical convection (self-perpetuating), as well as due to convective feedbacks from the monsoonal flow. From Fig.3 one could find strong low-level wind shear to favour shear perpendicular convective organization, whereas weak low-level shear (< 5 m/s between 950 and 700 mbar) frequently fostered convective bands oriented parallel to the mean upper-tropospheric shear.

The vertical distribution of the occurrence frequency of LLJs is shown in Fig. 4. LLJs occur throughout the 0–3 km levels, but they occur most frequently at preferred levels. Two peaks are evident in the occurrence frequency profile: one at 500–900 m and another at 1900–2300 m. Previous reports of LLJs over the Great Plains of the United States did not quite agree on LLJ altitude, likely because of different vertical resolutions of the data used. Bonner (1968), using 22 sounding observations, proposed that the mean altitude of LLJs was about 580–1020 m above ground level (AGL), whereas Whiteman et al. (1997) suggested that southerly LLJs are most frequently found at 300–600 m AGL with higher vertical resolution radio sonde data. These LLJs over the US Great Plains showed obvious diurnal variations and occurred within the planetary boundary layer (below 1000 m AGL). Our observations indicate that LLJs in Dongshan are not limited to the planetary boundary layer. Further evidence from observations of LLJs over East Asia also supports such vertically stratified LLJ distributions.

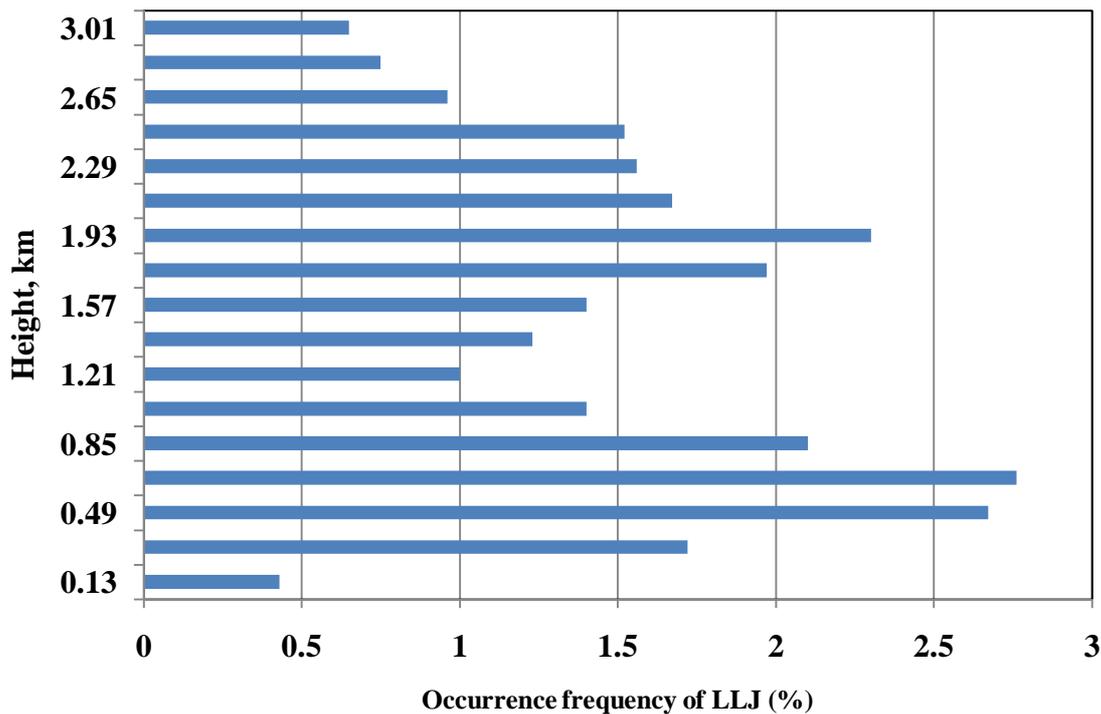


Fig.4: Vertical profiles of the occurrence frequency of LLJs for the 2-years warm season.

The occurrence frequency of LLJs over the Qingpu, coastal areas of China and also Okinawa Island during the Meiyu periods displayed a double-peak in the vertical: one peak around 1 km and another above 1 km and below 3 km (Du et al., 2012; Pham et al. 2008). The double-peak vertical structure of LLJ occurrence frequency over Dongshan in Fig. 4 is consistent with the finding of aforesaid research studies. With the aforementioned classification of LLJs according to their altitude, we believe that the two peaks could be associated with BLJs and SSJs, respectively. Therefore, we classified LLJs in Dongshan by their occurrence height: BLJs (below 1000 m) and SSJs (above 1000 m and below 3000 m). These two types of LLJs in Dongshan show different characteristics in diurnal variations in occurrence frequency, direction distribution, and relationship with precipitation. These characteristics are described in detail in the next section.

Figure 5 shows the occurrence frequency of BLJs and SSJs during the Meiyu periods. SLLJs occur more frequently in the Meiyu periods than BLJs variations. One possible explanation for the higher incidence of SLLJs

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during the Meiyu periods is the increased activity of synoptic- and sub-synoptic scale weather systems during these periods. Previous studies suggested that LLJs over East Asia are closely related to the development of the mesoscale convective systems (MCSs) embedded along Meiyu fronts (Akiyama 1973; Chen and Yu 1988). The increase in SSJs occurrence is a notable feature during the Meiyu period (Matsumoto et al. 1971; Tao and Chen 1987). Pham et al. (2008) showed that stronger LLJs (those with higher maximum wind speed and stronger windshear) occur more frequently during the Meiyu periods than the post-Meiyu periods over Okinawa. Therefore, the observation-derived occurrence of SLLJ during the Meiyu periods in our statistics generally agrees with those previous studies, particularly that the SSJ is closely related to the weather system. This possibility will be investigated further in next section.

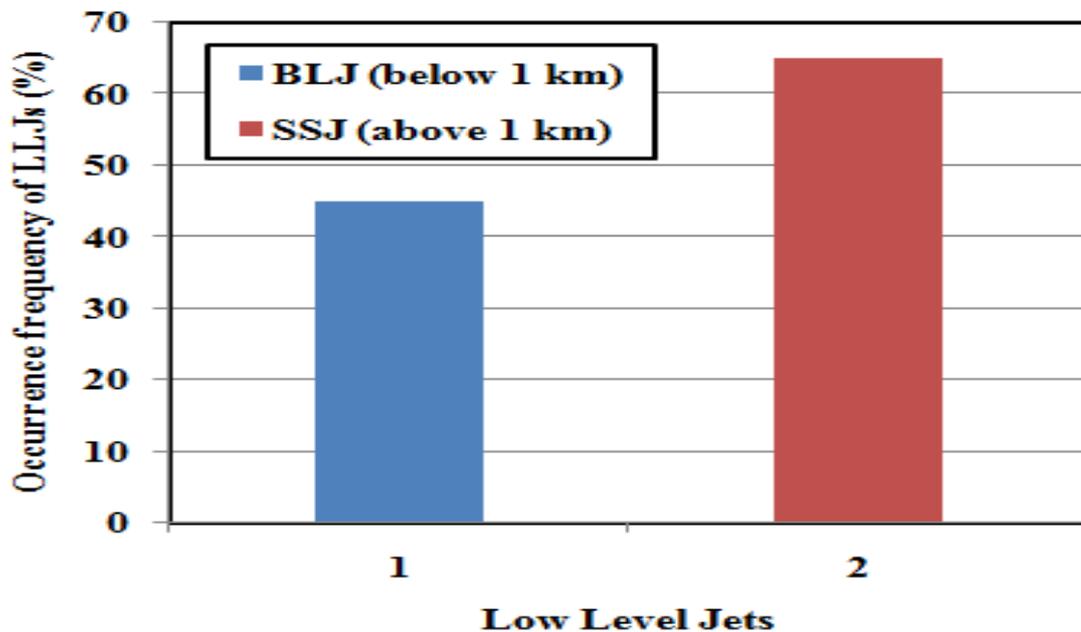


Fig.5: Occurrence frequency of BLJs and SSJs during Meiyu periods

Figure 6 shows the diurnal variations in occurrence frequency of LLJs (including BLJs and SSJs) in Dongshan. BLJs seem to display more pronounced diurnal variations than SSJs, with maximum occurrence frequency in night time and early morning. The statistical significance of the diurnal cycle of each type of LLJs was tested after Bell and Reid (1993). Using a multiple linear superposition method, the diurnal cycle of occurrence frequency can be approximated as

$$F(t) \approx f_0 + c \cos(\omega t) + s \sin(\omega t) \text{ ----- (1)}$$

Where f_0 represents the daily mean occurrence frequency, $\omega = 2\pi(24\text{h})^{-1}$, and $t = 0, 1, 2, \dots, 23$ h. We performed linear regression on the observed occurrence frequency to derive coefficients (c and s) for the BLJs and SLLJs, respectively. The goodness of fit of linear regression (R^2) is defined as

$$R^2 = 1 - \frac{SS_{reg}}{SS_{tot}} \text{ ----- (2)}$$

Where SS_{reg} and SS_{tot} are the regression and total variance, respectively. The results from linear regression showed that both BLJs and SLLJs displayed diurnal cycles (significant at the 95% confidence level). However, the diurnal cycle of the BLJs ($R^2 = 0.8717$) was clearer than that of the SLLJs ($R^2 = 0.6600$) from a statistical perspective.

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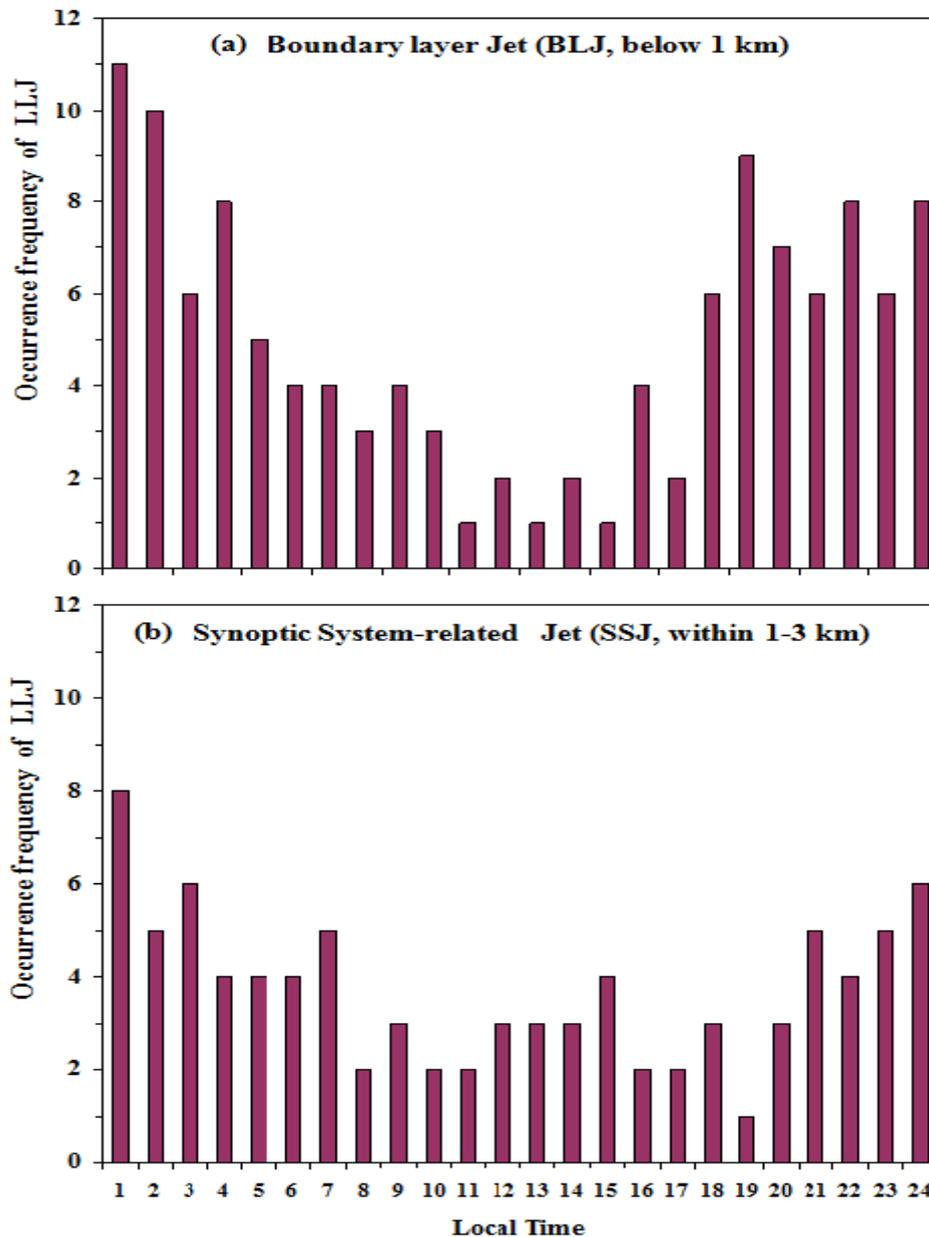


Fig 6: Diurnal variations in the occurrence frequency of (a) BLJs and (b) SSJs

The diurnal variation in the LLJ occurrence frequency over the US Great Plains has been studied extensively (Bonner 1968; Mitchell et al. 1995), and the LLJs over Okinawa showed the same diurnal variation (Pham et al. 2008). The diurnal cycle of LLJs (BLJs) is associated with boundary layer processes (Blackadar 1957). Douglas et al. (1998) proposed from observations of low-level wind at Puerto Peñasco that the diurnal cycle of low-level wind is limited below 1800m AGL, and its amplitude decreases with increasing height. In the previous section, we showed that the BLJ occurrence frequency increases throughout the warm seasons probably because of the increasing amplitude of inertial oscillations in the boundary layer. This idea is also supported by the fact that BLJs occur near the ground with larger thermal contrast in coastal regions. They hence exhibit more pronounced diurnal variation than SSJs.

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To study the relationship between LLJs and precipitation, we stratified the observation into rainy and non-rainy periods and performed a composite analysis. Since the missing rate of WPR data is high during heavy rainfall events, causing under estimation of the number of LLJs when heavy rainfall events occur, we defined a rainy day (rainy case) as a day (case) with daily (4-hourly) accumulated rainfall at Dongshan equal to or greater than 1 mm and less than 10 mm. A pre-rainy (post-rainy) case was defined as a 4-hourcase before (after) the corresponding rainy case. In our study, there were 26 rainy days and 57 rainy cases, respectively.

In Fig. 7, we compared the occurrence frequency of BLJs and SLLJs for rainy days and non-rainy days during the warm seasons. Both BLJs and SLLJs occur more frequently on rainy days than on non-rainy days. Compared to BLJs at 500-1000 m height and SLLJs, however, BLJs below a 500 m height do not have such difference in occurrence on rainy and non-rainy days. More precisely, we also compared the vertical distribution of LLJ occurrence for pre-rainy, rainy, and post rainy cases with total cases during the warm seasons. BLJs, especially located within a 500~1000m height, occur more frequently in pre-rainy, rainy, and post-rainy cases compared to the total cases. The occurrence frequency of SLLJs near a 1500 m height increases in the rainy and post-rainy cases compared with pre-rainy cases, whereas in post-rainy cases, SLLJs near a 2100 m height are obviously higher compared to the total cases. According to the statistical results, SLLJs tend to occur more often during and after rainy cases, whereas BLJs within a 500~1000 m height occur more often throughout rainfall events, including pre-rainy, rainy, and post-rainy cases. However, there seem to be no links between BLJs below a 500 m height and precipitation.

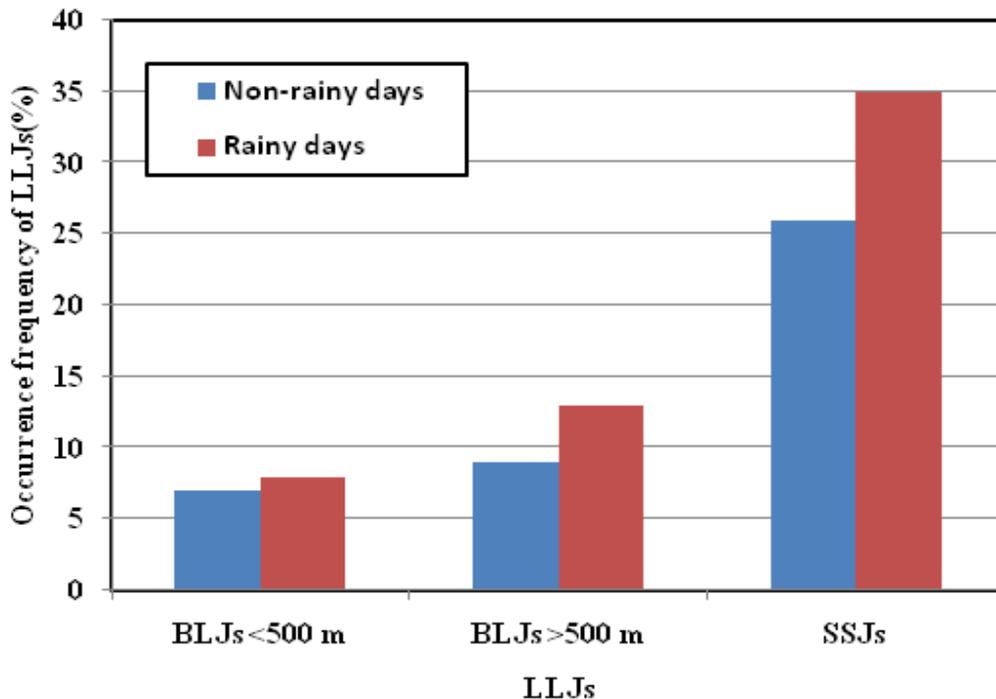


Fig.7: Occurrence frequency of Low Level Jets during Rainy and non-Rain days for BLJs below 500-m and within 500 ~1000-m and SSJs.

The Mei-Yu is a climatological phenomenon affecting a large area in eastern Asia and producing a large amount of rainfall in the region [Ding, 1994]. The Mei-Yu season is characterized by a quasi-stationary front (as shown in Fig. 8, the Meiyu front, or Baiu front) on surface weather maps which separates the Pacific subtropical high to the south from the migratory high over central China. At any given time, the Meiyu front is associated with the presence of an elongated cloud band, which is usually a mixture of deep convective clouds and stratiform clouds, extending from the interior of southern China to southern Japan on satellite images. As shown in Fig. 8, a east-west zone of disturbed weather along meiyu front stretches from the east China coast, initially across Taiwan and Okinawa, later, when it has shifted to the north, eastward into the southern peninsula of South Korea and Japan. The rainy season usually lasts from

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May to June in Taiwan and Okinawa, from June to July (approximately 50 days) in Russian Primorsky Krai, Japan and Korea and from July to August in Eastern China (especially in the Yangtze and Huai River regions).

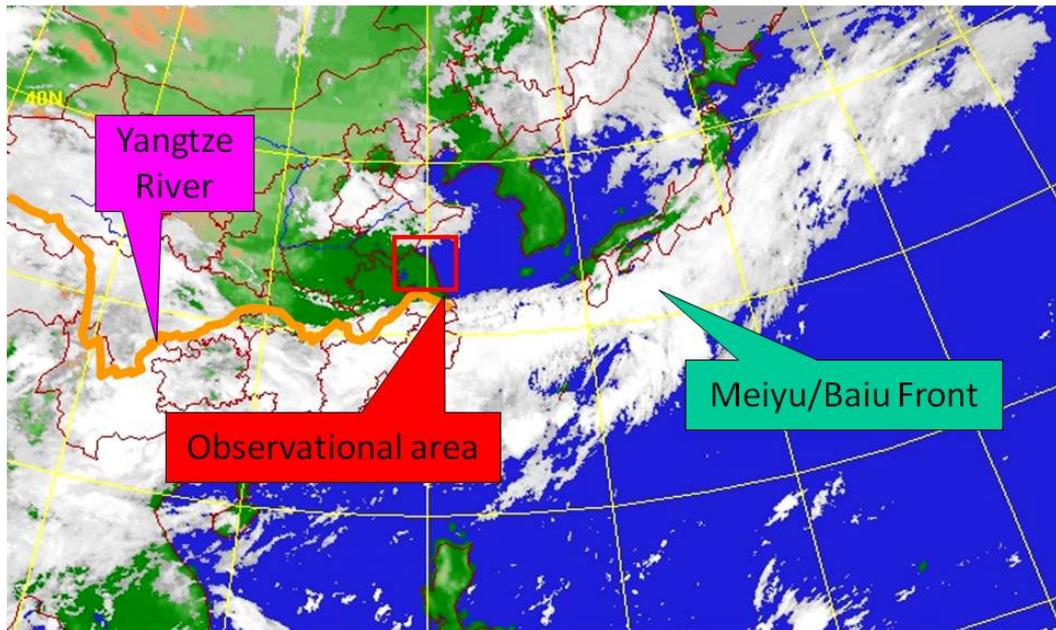


Fig 8: Satellite picture showing, Meiyu frontal system on 19 June 2001.

Figure 9 shows that 30-min average Radar reflectivity (SNR, dB), zonal (m/s), meridional(m/s), virtual temperature(T_v , °C), accumulated rainfall amount (mm) between 15 June to 15 July during IOP-2001 and IOP-2002. From Figure 9 (a) and (b) one can easily pickup rainy hours during meiyu period in the downstream of Yangtze river. From Figure 9 (c) and (d) zonal (east-west circulations) winds one can notice that during IOP-2001 easterly winds are prevailing during rainy days. Whereas during IOP-2002 westerly winds are predominant. To examine in more detail the intra-seasonal variability of the Signal-to-noise ratio (SNR, dB), zonal and meridional wind component and virtual temperature on a daily scale, and also to analyze its relationship with Meiyu precipitation, daily average zonal wind profiles during the months of 15th June- 15th July two years (2001 and 2002) are shown plotted as time-height cross-sections in Figure 9 [(a&b), (c. & d), (e) & (f), (g) & (h)], respectively. Daily total rainfall (mm) for Donghsan station (obtained from AWS Rain gauge) is also shown in Fig. 9 (i) and (j) for a qualitative comparison. Significant intra-seasonal variability can be seen in lower tropospheric zonal winds. During the monsoon season of 2001 there are several episodes of stronger westerlies [Fig. 9 (c)] spread throughout the season. On almost all days during the Meiyu season, LLJ is present having a jet core in the 2-4 km height range. The zonal wind speed in the jet core even reaches up to 18 ms⁻¹. This LLJ seems to have a role in the modulation of meiyu intra-seasonal oscillation. During 2002 two heavy rain spells occurred over Dongshan which were accompanied by strong westerlies (around 18 ms⁻¹) [Fig.9(d)]. A simple quantitative analysis carried out showed that during the days in which precipitation values were larger than 10 mm, the low-level westerly maxima (LLJ core speed) had mean speeds of 14.5 and 15.3 ms⁻¹, respectively during the years 2001 and 2002, larger than their mean seasonal values. Thus, precipitation spells/episodes during active meiyu during the year 2001 conditions are due to the large-scale zonal flow, closely related to a strong LLJ.

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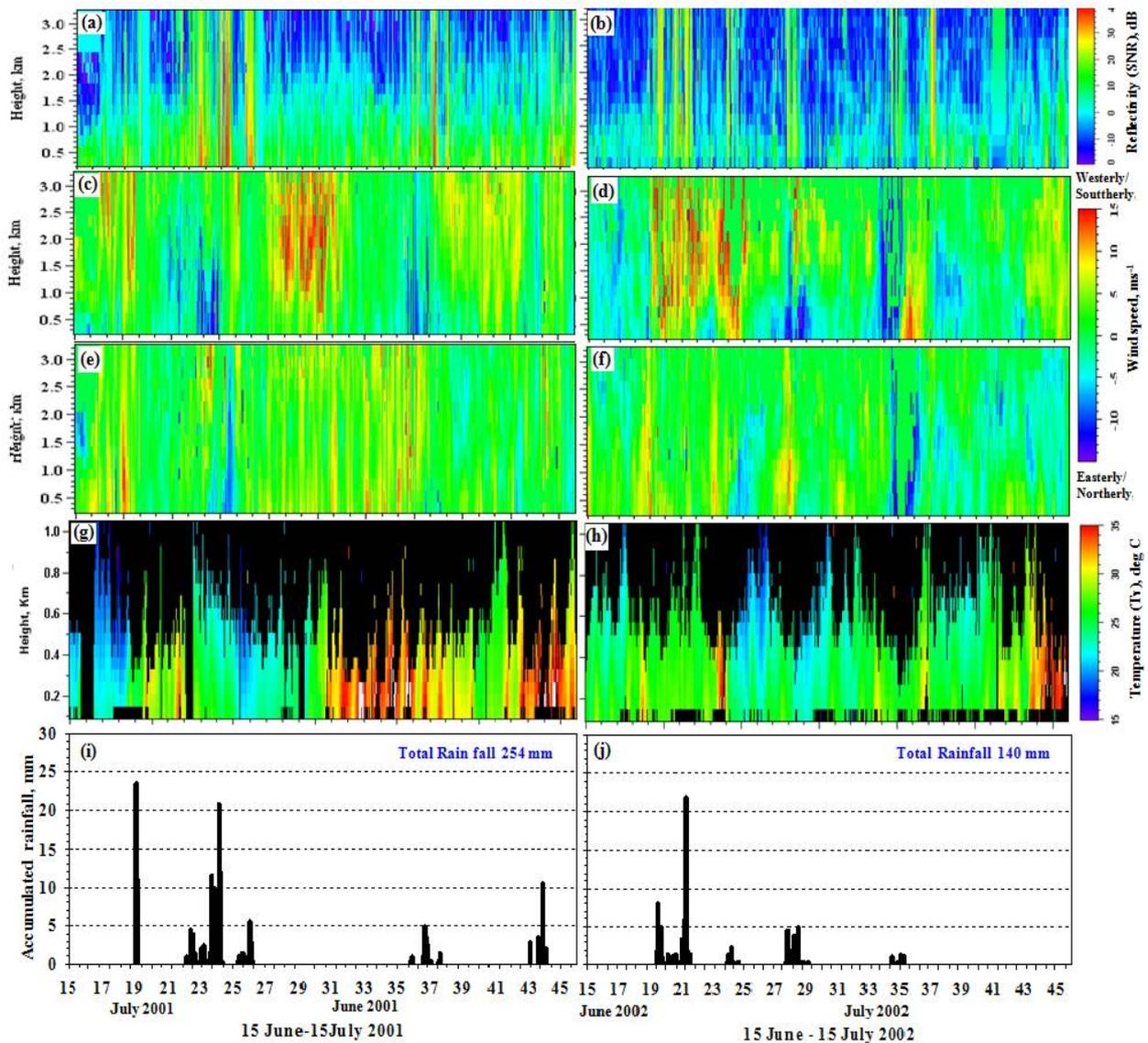


Fig.9: 30-min average Radar reflectivity (SNR,dB), zonal (m/s), meridional(m/s), virtual temperature(T_v , $^{\circ}$ C), accumulated rainfall amount (mm) between 15 June to 15 July during IOP-2001 and IOP-2002

V. CONCLUSION

Wind Profile Radar data at Dongshan, China has been utilized to study Meiyu seasonal and intra-seasonal variability of winds and to understand the characteristics of low-level jets (LLJs) over coastal areas of China Continent and its linkages with rainfall the warm seasons. From the study it was found that the low-level jet (LLJs) are closely related to severe rainfall events, air pollution, wind energy utilization, aviation safety, sandstorms, forest fire, and other weather and climate phenomena. The relation between LLJs and precipitation was examined by comparing the frequency of LLJs occurrence on rainy days (cases), with daily (4-hourly) accumulated rainfall within 1 to 10 mm, and non-rainy days. Thus, precipitation spells/episodes during active Meiyu during the year 2001 conditions are due to the large-scale zonal flow, closely related to strong LLJs.

International Journal of Innovative Research in Science, Engineering and Technology

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VI. ACKNOWLEDGEMENT

We are very much thankful to authorities of Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Japan and China Meteorological Administration (CMA), Beijing, China for their sincere efforts for collect cooperative research data and also permit us to use. We acknowledge the National Centres for Environmental Prediction (NCEP) Final (FNL) Operational Global Analysis data (on a 1.0 x1.0 degree grid every 6 hours) utilization from internet.

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