Study of Low-Level Jet and Extremely Heavy Rainfall over Northern Taiwan in the Mei-Yu Season

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ABSTRACT

Extremely heavy rainfall (at least 100 mm d^{-1}) is one of the most disastrous weather phenomena in the early-summer rainy season of East Asia. This season is called the Mei-Yu season in Taiwan. Thirty-five cases of this rainfall event over northern Taiwan in May–June 1965–84 were selected for studying its relationship between the low-level jet (LLJ) and extremely heavy rainfall. As in Japan and China, extremely heavy rainfall is found to be closely associated with a LLJ. For example, there was an 84% likelihood that a LLJ of at least 12.5 m s^{-1} would be present at 700 mb 12 h before the start of the rainfall event. Conversely, when a LLJ was present over Taiwan in 1980–84, there was a 91% likelihood that such a rainfall event was in progress or would begin on the next day.

Results provide evidence that the LLJ plays an important role in the development of this rainfall event. It appears that cumulus convection in the area of rainfall homogenizes the vertical wind profile so as to dissipate the LLJ or displace it to the immediate south, where its frequency is found to increase during and after the event. This sequence of events provides observational support to the theoretical and numerical studies which show that the LLJ may form to the south of heavy rainfall as a part of the secondary circulation driven by convective latent heating.

1. Introduction

One of the most significant weather phenomena occurring during the early-summer rainy season in subtropical China and Japan is extremely heavy rainfall of at least 100 mm d^{-1} (Chen, 1983; Matsumoto et al., 1971; Ramage, 1971; Tao and Chen, 1987). This season is called the Mei-Yu season in China and the Baiu season in Japan. A close relationship between extremely heavy rainfall and a low-level jet (LLJ) in the 850–700 mb layer during the Mei-Yu season was found in observational studies (Akiyama, 1973a,b; Chen, 1977; 1983; Chen and Chi, 1978; Matsumoto, 1972; Ninomiya and Akiyama, 1974) and numerical simulations (Chou, 1986; Kuo and Anthes, 1982; Ninomiya, 1980; Ninomiya and Tatsumi, 1980). Synoptically, a southwesterly LLJ is often observed to the south of the lower-tropospheric front (called a Mei-Yu front in China and a Baiu front in Japan) which usually possesses a nearly continuous cloud band with convection. The Mei-Yu front usually forms between the tropical and polar air masses in the late spring and early summer. It moves slowly south-southeastward to establish a quasi-stationary position extending from southern Japan to southern China. The Mei-Yu front is characterized by a smaller horizontal temperature gradient than that in

a typical polar front but is accompanied by a strong moisture gradient and horizontal wind shear (e.g., Akiyama, 1973a; Chen and Chang, 1980).

Low-level jets in the Great Plains of the United States were found to be important for their rapid transport of heat and moisture from the Gulf region into areas of convective storms which produce heavy rainfall (Bonner, 1966; Maddox, 1983; Means, 1952; 1954). The formation of LLJ in that area has been studied extensively. For example, Newton's (1956) observational study showed that an LLJ can form as a result of pressure gradient response to leeside cyclogenesis to the east of the Rockies (Newton type). On the other hand, Wexler (1961) proposed that the formation of an LLJ is due to the combined effects of mountain friction and conservation of potential vorticity for the southerly flows over the western portion of the North Atlantic subtropical high (Wexler type). Blackadar (1957) explained the nocturnal formation characteristics of the LLJ as a result of inertial oscillation due to the boundary-layer mixing processes (Blackadar type). On the other hand, Lettau (1967) explained that these nocturnal formation characteristics are due to the boundary-layer thermal wind variations caused by the diurnal radiation cycle over sloped terrain (Lettau type). Recently, results of a numerical and observational study by Uccellini and Johnson (1979) showed that the LLJ can form due to the increase of lower-tropospheric isobaric winds through the forcing process of upper-tropospheric jet streaks (Uccellini–John-

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son type). Are those processes which contributed to the development of LLJs in the Great Plains of the United States also important for the formation of LLJs in subtropical China and Japan during the early summer rainy season? This is an intriguing but relatively unexplored question for the LLJ in the East Asian Mei-Yu season. Vertical momentum transport due to convection (e.g., Akiyama, 1973b; Matsumoto, 1972; Matsumoto et al., 1971; Ninomiya and Akiyama, 1974), Coriolis acceleration of the northward motion in the lower branch of the mesoscale secondary circulation induced by convective latent heat release (Chou, 1986; Chen, 1982) and synoptic-scale forcing of the strong migratory high over the East China Sea through pressure gradient increase (Chen and Pu, 1985) have been proposed as possible mechanisms for the formation of the LLJ in China and Japan. Determining the relative importance of these different mechanisms is one of the major objectives for the Taiwan Area Mesoscale Experiment (TAMEX) (NCAR, 1985; Chen, 1986). This will be studied more extensively by using the data collected during the TAMEX field phase of May–June 1987.

The present paper deals with the relationship between the LLJ and extremely heavy rainfall over northern Taiwan in the Mei-Yu season. The variation of LLJ frequency with respect to the heavy rainfall occurrence was analyzed. The variation of vertical wind profiles was studied during the period of heavy rainfall. The possible role of LLJs in the occurrence of extremely heavy rainfall and the role of convection in the formation of LLJs implied in this synoptic-climatological analysis are discussed.

2. Case selection and data analysis

The extremely heavy rainfall events (at least 100 mm d^{-1}) for six surface stations in northern Taiwan during the Mei-Yu seasons (May–June) of 1965–84 were analyzed. It was observed that a total of 35 events (1.8 events per season) of extremely heavy rainfall were apparently caused by the mesoscale convective systems (MCSs) associated with the Mei-Yu frontal cloud band. In this period, two cases of equally heavy rains due to localized thunderstorms and typhoons occurred. These cases were not included in this study. Altogether, 35 cases of extremely heavy rainfall events were chosen in the present study.

The 850 and 700 mb charts were used to analyze the LLJs over subtropical China and the western North Pacific. Upper-level winds at four rawinsonde stations in Taiwan were used to help the analysis. The one located in Taipei (46692; 25°02'N, 121°31'E) is operated by the Central Weather Bureau and the ones in Taoyuan (46697; 25°03'N, 121°13'E), Makung (46734; 23°35'N, 119°33'E), and Tungkong (46747; 22°27'N, 120°26'E) are operated by the Chinese Air Force Weather Wing (Fig. 1). For the period of 1965–74, both 0000 and 1200 UTC data at the Taoyuan station were

FIG. 1. Four rawinsonde stations in Taiwan used to help the analysis.

used. For the period of 1975–84, 0000 UTC data at Taoyuan and 1200 UTC data at Taipei were used. Due to the fact that Taipei is very close to Taoyuan (about 15 km in distance), upper air observations in northern Taiwan at these two stations are essentially the same.

Wind analyses were carried out at both 850 and 700 mb and axes of 12.5 and 15 $m s^{-1}$ isotachs were then obtained for the period from 36 hours before (–36 h) to 24 hours after (+24 h) the starting time of each heavy rainfall event (0 h). These wind speed criteria were chosen based on synoptic experience for better describing the behavior of the LLJs. The starting time here is defined as the time with greater than 10 mm h^{-1} rainfall at one or another of the six stations for that event. Due to the fact that the wind analyses were available only at 12 h interval synoptic times of 0000 and 1200 UTC, the synoptic time closer to the time for starting an event was actually taken as the starting time. The ending time of an event is defined as the time when no station reports greater than 1 mm h^{-1} rainfall. These events lasted for 15 h on the average. The axis of maximum wind speed at 850 or 700 mb with length greater than 600 km and with reasonably

strong horizontal cyclonic shear ($\geq 7 \times 10^{-5} \text{ s}^{-1}$)/vertical shear ($\geq 7 \times 10^{-3} \text{ s}^{-1}$) was considered as the axis of an LLJ in this study. A 2° latitude by 2° longitude grid square was used to analyze the geographical distribution of the LLJ frequencies with respect to the time of heavy rainfall occurrence in the region of 20° – 30° N , 100° – 130° E . Cases of LLJs over northern Taiwan, i.e., those with jet axis within 1° latitude from Taipei, were used to study the variation of vertical wind profiles during the period of heavy rainfall events.

Figure 2 gives an example of the typical Mei-Yu front at 850 mb and the formation of a southwesterly jet which presumably was due to the enhanced secondary circulation by the MCSs over the southern China coast. At 0000 UTC 3 June 1986, a Mei-Yu front was over the East China Sea and southern China with a weak low located over the East China coast.

FIG. 2. The 850 mb front and wind observations at (a) 0000 UTC and (b) 1200 UTC 3 June 1986. One full wind barb = 5 m s^{-1} ; one half barb = 2.5 m s^{-1} . Scalloped areas indicate the convective systems shown in GMS IR pictures. The 10 m s^{-1} isotach (dashed line) was analyzed with the help of geopotential height gradient.

Southwesterlies without the existence of an LLJ prevailed to the south of the front and only very limited convection occurred over southern China. During the next 12 h, the front moved slowly southward and elongated convective systems occurred along the southern China coast. An LLJ formed concurrently to the south of the convective area with an axis located over the northern South China Sea and the Taiwan Strait at 1200 UTC June 3. Four out of six surface stations over northern Taiwan reported greater than 100 mm d^{-1} rainfall when this LLJ moved over northern Taiwan on June 4.

3. Relationship between LLJs and extremely heavy rainfall

The frequencies of LLJs in the region of 20° – 30° N , 110° – 130° E , (northern Taiwan, roughly located near center of this region) are shown in Table 1 from 36 hours before (-36 h) to 24 hours after ($+24 \text{ h}$) the start of extremely heavy rainfall. They are presented for both 12.5 and 15 m s^{-1} LLJs at 850 and 700 mb levels. While all of the 850 mb weather charts for 35 cases of heavy rainfall events were available, some of the 700 mb charts were missing. The cases of heavy rainfall events varying with time for 700 mb LLJ analyses are due to this missing data problem. At 850 mb, frequency of LLJs gradually increased and reached a maximum at the time of extremely heavy rainfall occurrence (0 h). This reflects the fact that the LLJ in association with the Mei-Yu front generally moved slowly southeastward from southern China towards northern Taiwan. At the time of the start of extremely heavy rainfall over northern Taiwan, the chance of the existence of a 15 m s^{-1} LLJ at 850 mb in the near vicinity of northern Taiwan was high (63%). After the start of the extremely heavy rainfall occurrence, the frequency of 15 m s^{-1} LLJs decreased dramatically. Due to slowness of the LLJ movement, the axes of maximum wind speeds were generally observed over Taiwan from 0 h to $+24 \text{ h}$. Thus, the dramatic decrease in these LLJ frequencies indicated the weakening and/or dissipating of the LLJ after extremely heavy rainfall. A similar tendency with a greater frequency was found for the 12.5 m s^{-1} LLJ at 850 mb.

At 700 mb, frequency of LLJs gradually increased until 12 hours before (-12 h) the time of extremely heavy rainfall occurrence. It then decreased slightly after -12 h . Notice that the frequency of LLJs reached a maximum at 850 mb right at the time of and at 700 mb 12 hours before (-12 h) the start of extremely heavy rainfall. This tends to reflect the northwestward tilt of the southeastward moving LLJ, in consistency with the thermal structure in the lower troposphere. Also, the frequencies were higher at 700 than at 850 mb for all the time periods analyzed. This is in agreement with the observations over Japan where the LLJs in association with the heavy rainfall in the Baiu (Mei-Yu)

TABLE 1. Cases of LLJs in the area of 20° – 30° N, 110° – 130° E and cases of heavy rainfall with complete data for 35 cases of heavy rainfall events over northern Taiwan in the Mei-Yu seasons (May–June) of 1965–84 from 36 hours before (–36 h) to 24 hours after (+24 h) the time of heavy rainfall occurrence. Number in the parenthesis is the percentage of LLJ cases with respect to heavy rainfall cases (see text for details).

Level (mb)	LLJ speed (m s^{-1})	Cases	Time					
			–36 h	–24 h	–12 h	0 h	+12 h	+24 h
850	12.5	LLJ	17 (49)	20 (57)	21 (60)	23 (66)	12 (34)	15 (43)
		Heavy rainfall	35	35	35	35	35	35
	15	LLJ	16 (46)	19 (54)	20 (57)	22 (63)	11 (31)	10 (29)
		Heavy rainfall	35	35	35	35	35	35
700	12.5	LLJ	24 (75)	22 (73)	27 (84)	22 (73)	23 (72)	21 (68)
		Heavy rainfall	32	30	32	30	32	31
	15	LLJ	23 (72)	21 (70)	26 (81)	22 (73)	23 (72)	19 (61)
		Heavy rainfall	32	30	32	30	32	31

season was found near 700 mb on the average (Akiyama, 1973b; Matsumoto, 1972; Ninomiya and Akiyama, 1974). Apparently, the altitude of this Mei-Yu LLJ is higher than that of the classical planetary boundary layer LLJ in the Great Plains of the United States (e.g., Bonner, 1968). For extremely heavy rainfall events over northern Taiwan, there was an 84% chance that it was accompanied by a 12.5 m s^{-1} LLJ and an 81% chance that it was accompanied by a 15 m s^{-1} LLJ at 700 mb 12 hours before the rainfall occurrence in the near vicinity. In other words, the occurrence of both extremely heavy rainfall and 700 mb LLJs were very closely related.

4. Geographical frequency of the LLJ

For the sample of rainfall events under consideration, Fig. 3 shows the frequency of occurrence of a segment of a 12.5 m s^{-1} LLJ at 850 mb. The occurrence is for the period from –12 h to +12 h and is tabulated for grid areas with dimensions of 2° of latitude and longitude. The frequency of a 15 m s^{-1} LLJ is similarly shown in Fig. 4. Although the former are also contained in the latter set of data, of course, the results are presented separately because of the different character of the stronger cases over Taiwan and immediately downstream.

The NE–SW orientation of the pattern reflects the orientation of the wind in the LLJ. The location of the axis of maximum frequency over northern Taiwan throughout the rainfall occurrence is consistent with the results shown in Table 1. This concentrated pattern of frequency was not observed in a sample of data for all dates during this season, irrespective of rainfall.

Further, to estimate the likelihood of a rainfall event, given the existence of an LLJ, all jets during the period May–June 1980–84 were examined. At 700 mb, 21 cases of LLJs of at least 15 m s^{-1} were found south of 28° N at 120° E (cf. Figs. 3–6). In 19 of these (91%) a heavy rainfall event occurred over northern or southern Taiwan, or both, on the same day or the next.

The grid point with maximum frequency in Figs. 3 and 4 lay immediately downstream from northern Taiwan. It is interesting to note that the total frequency over northern Taiwan and this grid decreased dramatically after the occurrence of the extremely heavy rainfall event for both weaker and stronger jets. For the 12.5 m s^{-1} LLJs, the frequencies were 23, 20 and 14 at –12 h, 0 h and +12 h, respectively. For the 15 m s^{-1} LLJs, they were 20, 14 and 8, respectively. This shows a much higher percentage decrease (60%) for the stronger jets as compared to the weaker ones (40%) from –12 h to +12 h. On the other hand, the total frequency over two grid squares (southern Taiwan and the downstream grid) to the immediate south of the heavy rainfall area increased remarkably after the occurrence of extremely heavy rainfall. They were 5, 5 and 10 for 12.5 m s^{-1} LLJs and 2, 3 and 6 for 15 m s^{-1} LLJs at –12 h, 0 h and +12 h, respectively. This shows a much higher percentage increase (200%) for the stronger jets as compared to the weaker ones (100%) from –12 h to +12 h.

Figure 5 shows the frequency of occurrence of a segment of a 12.5 m s^{-1} LLJ at 700 mb. The occurrence is for the period from –12 h to +12 h and is tabulated for grid areas with dimensions of 2° of latitude and longitude. The frequency of a 15 m s^{-1} LLJ is similarly shown in Fig. 6. The maximum frequency over north-

FIG. 3 Frequency distribution of the 12.5 m s^{-1} LLJ at 850 mb for (a) 12 hours before heavy rainfall (-12 h), (b) at time of heavy rainfall (0 h), and (c) 12 hours after heavy rainfall ($+12 \text{ h}$) over northern Taiwan for 35 events in the 1965–84 Mei-Yu seasons (May–June). Key grid squares used in the discussion are indicated by heavy solid lines.

ern Taiwan or its immediately downstream grid to the east again shows a close relationship between the occurrence of both extremely heavy rainfall and the LLJ. Frequency over this area reached a peak value at the time of heavy rainfall occurrence. Similar to that at 850 mb, total frequency for these two grid squares over northern Taiwan and its immediate east showed a dramatic decrease after the heavy rainfall occurrence. For the 12.5 m s^{-1} LLJs, the frequencies were 29, 32 and 22 at -12 h , 0 h and $+12 \text{ h}$, respectively. For the 15 m s^{-1} LLJs, they were 24, 27 and 19, respectively. This shows a 30% decrease for both jets from 0 h to $+12 \text{ h}$. On the other hand, the total frequency over two grid squares to the immediate south of heavy rainfall area increased greatly after the heavy rainfall occurrence.

They increased from 10 at 0 h to 15 at $+12 \text{ h}$ for the 12.5 m s^{-1} LLJ (50% increase) and from 9 at 0 h to 12 at $+12 \text{ h}$ for the 15 m s^{-1} LLJ (30% increase).

From the preceding discussion, the occurrence of extremely heavy rainfall over northern Taiwan was closely related to the LLJ occurrence at both the 850 and 700 mb levels. Also, the existence of an LLJ over or in the immediate vicinity of Taiwan implies a high chance (91%) of an extremely heavy rainfall event. After the occurrence of extremely heavy rainfall, the frequency of LLJs decreased dramatically over the region of extremely heavy rainfall and its immediate downstream and increased remarkably over the region to the immediate south. Since the area of the dramatic change in LLJ frequency was over Taiwan and its immediate vicinity, the random uncertainty of the analysis is presumably minimized. Does this change in LLJ frequency represent a motion to the south, or a redevelopment to the south, or wavelike oscillations of the

FIG. 4. As in Fig. 3, except for 15 m s^{-1} LLJ at 850 mb.

FIG. 5. As in Fig. 3, except for 12.5 m s^{-1} LLJ at 700 mb.

LLJ? This question can not be assessed at this moment only from these data and will be discussed later in conjunction with the changes in the vertical wind profiles.

5. Intensity variation of the LLJ

Among 35 cases of extremely heavy rainfall events chosen in this study, there were 10 cases accompanying an LLJ with axis located within 1° latitude of Taipei and with maximum wind in the 900–3000 m layer during the period from 12 hours before to 12 hours after the time of the start of extremely heavy rainfall. Vertical wind profiles for these 10 cases were composited with respect to the level of maximum wind at each of the three time periods (-12 h , 0 h , $+12 \text{ h}$) to study the intensity variation of the local LLJ during the period of extremely heavy rainfall occurrence. Although compositing at fixed elevations could easily smooth out important signals that exist at various levels from

case to case, the compositing with respect to the LLJ level in this study is believed to be able to show the possible overall change of LLJ intensity. Results are shown in Fig. 7. The average altitude of maximum wind level at -12 h , 0 h and $+12 \text{ h}$ was 2160 m, 1890 m and 2340 m, respectively. For seven out of ten cases, the altitude of maximum wind level decreased at 0 h and then increased at $+12 \text{ h}$. Although the magnitude of this altitude variation contains some uncertainty due to small sample size, the tendency of this variation is believed to be representative. Average maximum wind speed decreased during the period of the heavy rainfall event. It was 19.8 m s^{-1} , 17.7 m s^{-1} and 16.4 m s^{-1} at -12 h , 0 h and $+12 \text{ h}$, respectively. There were five cases with double maxima in wind speed in the lower troposphere at -12 h . The secondary maximum is reflected in the composite profile near 960 m. The changes in the vertical wind shears near the LLJ level

FIG. 6. As in Fig. 3, except for 15 m s^{-1} LLJ at 700 mb.

FIG. 7. Composite vertical wind profiles for ten cases of heavy rainfall over northern Taiwan accompanied by an LLJ with axis located within 1° latitude from Taipei at each of the three time periods: 12 hours before heavy rainfall (dotted), at time of heavy rainfall (solid), and 12 hours after heavy rainfall (dashed). Wind speeds were composited with respect to the level of each LLJ. X axis is wind speed in m s^{-1} and y axis is altitude at 300 m intervals above (+) and below (-) the LLJ level (0).

were mainly concentrated in the layer from 900 m below to 1500 m above the jet level. The shears above the jet level were 4.5 , 3.9 and $1.9 \text{ m s}^{-1} (1500 \text{ m})^{-1}$ at -12 h , 0 h and $+12 \text{ h}$, respectively. The shears below the jet level were 7.2 , 7.2 and $5.4 \text{ m s}^{-1} (900 \text{ m})^{-1}$ at -12 h , 0 h , and $+12 \text{ h}$, respectively. Therefore, it seems clear from the composite profile that vertical shear above and below LLJ level decreased at and after the time of the start of extremely heavy rainfall. Also, the decrease of the composite wind speed at 850 mb from -12 h ($\sim 15 \text{ m s}^{-1}$ at 600 m below jet level) to $+12 \text{ h}$ ($\sim 11 \text{ m s}^{-1}$ at 900 m below jet level) is consistent with the decrease in frequency of 12.5 m s^{-1} LLJs over northern Taiwan in Fig. 3.

6. Discussion and concluding remarks

The occurrence of extremely heavy rainfall over northern Taiwan is closely related to the existence of an LLJ in the near vicinity. In 84% of the cases studied here, heavy rainfall events were accompanied by an LLJ at 700 mb. A similar relationship was also observed for rainstorms in the Baiu season over the Japan Islands (e.g., Akiyama, 1973b; Matsumoto, 1972; Matsumoto et al., 1971; Ninomiya and Akiyama, 1974) and in the Mei-Yu season over subtropical China (Tao and Chen, 1987). The physical processes through which the existence of an LLJ leads to heavy rainfall have been proposed by various investigators. For example, Matsumoto (1972) suggested that the upward branch of the secondary circulation associated with the LLJ is responsible for the heavy rainfall. Chen's (1977) study,

on the other hand, suggested that the LLJ is the main mechanism for creating potential instability to the warm side of a Mei-Yu front and for generating the convective heavy rainfall by the associated convergence downstream. The relationship between the existence of an LLJ and the occurrence of extremely heavy rainfall increased before the time of the start of the rainfall and decreased afterwards. Also, the existence of a LLJ over or near Taiwan was accompanied by a high chance (91%) of extremely heavy rainfall event over northern and/or southern Taiwan. These together tend to suggest that the LLJ is the cause for the convection in Taiwan rather than the result of the convective momentum transport as proposed for the Japan Baiu case (Akiyama, 1973b; Matsumoto, 1972; Matsumoto et al., 1971; Ninomiya and Akiyama, 1974). Composite vertical wind profiles showed a significant decrease in the LLJ intensity and vertical wind shear during and after the extremely heavy rainfall events. This again strongly indicates that vertical mixing by the cumulus convective process tends to dissipate rather than to generate local LLJs. The fact that the frequency of LLJs decreased dramatically over northern Taiwan and its immediate downstream after the occurrence of extremely heavy rainfall further substantiates this argument.

The formation and maintenance of an LLJ to the south of the area of extremely heavy rainfall (mesoscale convective system) has been documented both in theoretical study (Chen, 1982) and numerical experiments (Chou, 1986; Ninomiya, 1980; Ninomiya and Tatsumi, 1980). Results of Chen's study (1982) suggested that the existence of an unstable inertia-gravity wave in the ascending motion region caused a thermally direct vertical circulation beneath the upper-level jet. A local temperature increase caused by condensation warming in the area of ascending motion accelerated the thermally direct circulation to the north and induced an indirect circulation to the south through the geostrophic adjustment process. It was concluded that the LLJ form through the Coriolis acceleration of northward flow in the lower branch of this indirect circulation. This mechanism was further substantiated in a numerical study by Chou (1986) who simulated the formation of an LLJ to the south of the area of strong convection in a two-dimensional frontogenesis model. In addition, Ninomiya (1980) and Ninomiya and Tatsumi (1980) simulated the formation of an LLJ to the south of a convective heavy rainfall area in their primitive equation model with a convective adjustment process. They attributed the formation of LLJs to the increase of pressure gradient caused by convective warming to the north. Results of these theoretical and numerical studies all suggested that an LLJ can form to the south of the convective heavy rainfall area presumably through the Coriolis acceleration of the induced secondary circulation. Although the observational study of an individual case using the current 12 h interval synoptic data to investigate this process is not suitable, a com-

posite study perhaps could shed some light on this process. In the present study, the frequency of the LLJ together with the intensity and vertical shear of the composite LLJ showed a remarkable decrease over the extremely heavy rainfall area after the heavy rainfall event. On the other hand, the LLJ frequency was observed to increase remarkably over the region to the immediate south of extremely heavy rainfall. Although the specific mechanism responsible for the formation of LLJs can not be addressed in the present data analysis, these results provide some observational evidence for the formation of some LLJs by convective warming process.

Although the LLJ and extremely heavy rainfall are closely related, their interactions are complicated and poorly understood. It is hoped that through the Taiwan Area Mesoscale Experiment, TAMEX (May–June 1987), some of the questions, such as the role of convective momentum transport and the formation mechanisms of the LLJ, will become clear.

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