Observational Study of a Wintertime Heavy Rain Event in Northern Taiwan

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Abstract

In this study, a wintertime abnormally heavy rain (AHR) event in northern Taiwan is investigated. During the heavy rain period, the prevailing flow underneath 800 hPa was easterly and with pronounced wind disturbances embedded in. The low-level easterly flow had a jet-like structure. The jet axis was located at latitude north of 25N and altitude 950-925 hPa. The amplitude of the jet reached 10 m s^{-1} with significant vertical and lateral shears. The wind disturbance was about 100 km south of the jet axis and had its maximum amplitude at 925 hPa. The heavy rain event occurred when the maximum southerly component of wind disturbance encountered the east coast of Taiwan. Warm and moisture advections associated with the southerly flow produced an unstable atmospheric condition favorable for mesoscale precipitation system to develop. The precipitation characteristic of AHR is also analyzed by using WFS Doppler radar data. It is shown the larger scale precipitation was stratiform in nature and embedded with narrow and shallow convective rainbands. The orientation of these bands was approximately east to west. These convective rainbands had their maximum reflectivity below 3 km and propagated at a speed similar to the wind speed of southeasterly. The convective bands formed at the leading edge of wind disturbances embedded within the prevailing southeasterly.

1. Introduction

From climatological rainfall data, it was shown by Chen and Liu (1981) that the abnormally heavy rain (AHR) events, defined as the daily precipitation being two standard deviations greater than climatological mean, over northern Taiwan during the northeast monsoon in winter is not an uncommon phenomenon. They observed that the frequency distribution of the starting time of AHR in cases studied exhibits a pronounced diurnal pattern. By using surface wind and rainfall data, Chen et al. (1983) showed that the pronounced diurnal variation of rainfall was strongly modulated by the diurnal cycle of local circulation. The AHR cases appear to be closely related to the diurnal divergence pattern due to the interaction of the local circulation and the prevailing northeast monsoonal flow. In studying the meteorological conditions and possible triggering mechanisms for the AHR cases in northern Taiwan, Chen and Lee (1983) showed that the favorable conditions included (1) a local surface convergence generated by a land-sea differential friction effect as well as by the interaction between the local circulation and a large-scale northeast monsoonal flow; (2) potentially unstable air in the lower troposphere, and (3) warm advection in the lower troposphere. They also suggested that the differential vorticity advections in the vertical induced by the short wave trough and ridge in the lower troposphere was the triggering mechanism for the mesoscale precipitation systems.

Although plausible explanation for the occurrence of wintertime AHR in northern Taiwan has been proposed, more questions need to be answered. For example, the structure and the origin of these short waves in the lower troposphere east of Taiwan are not clear. The presence of the easterly wave disturbances not only produced the favorable environment for the mesoscale precipitation system to develop but also provide the dynamical mechanism for triggering these precipitation systems. In wintertime, due to the cold air outflows from the continent of Asia, the prevailing wind is northeasterly in northern Taiwan in the lower troposphere. The flow regime with zonal easterly could sometimes extend up to 700 hPa and above it zonal westerly prevails. What are the dynamical processes related to the formation of this wave disturbances in the lower troposphere deserve further investigation. On the other hand, no digital radar data were available in the previously mentioned studies. Detailed meso- and cloud scale structures of these mesoscale precipitation systems have not been discussed. It is a common experience for the local scientists and forecasters that the precipitation systems are either difficult to be identified through enhanced satellite imagery or simulated by operational NWP model. The relatively high cloud top temperature seldom showed signature of deep convective cloud systems usually seen in warm season heavy rain situation (e.g., Meiyu season).

Thus, a better understanding of mesoscale structure of the precipitation systems related to wintertime AHR should be helpful to quantitative precipitation forecast study in this region.

In this study, a wintertime heavy rain event in northern Taiwan is examined. On December 12, 2000, daily rainfall of 147 mm rain was recorded in I-Lan station (located at northeast coast of Taiwan), and in the following day (13th), the heavy rain occurred in Kea-Long and Tan-Shui stations (located at north and northwest coast of Taiwan, with daily rainfall of 151 and 90 mm/day, respectively). The rainy areas propagated from northeast coast of Taiwan into north and northwest coast. This northwestward propagation behavior is very similar to what has been observed previously by Chen and Lee (1983) in their case study.

Taiwan has started its meteorological modernization in mid-80s. More than 300 automatic rainfall stations were installed around the island including the mountainous areas and more than 100 rainfall stations are located in the region interested. Besides this, 4 S-band Doppler radars were also installed around the island. The Wu-Fen-San radar is located in the northern tip of Taiwan and provides a much better coverage of precipitation data over the ocean northeast of Taiwan. In the study, these data are used to reveal the synoptic and mesoscale conditions related to the AHR in northern Taiwan and Doppler radar data are analyzed to show the precipitation characteristics associated with the mesoscale precipitation systems.

2. Synoptic conditions for wintertime AHR in northern Taiwan

During the period of heavy rain (12-13 December 2000), northern Taiwan was under the influence of northeast monsoonal flows. From synoptic maps (not shown), at and below 850 hPa, northeasterly flows associated with pronounced cold air from Asia continent prevailed in this period of time. A baroclinic zone with horizontal temperature gradient 1.6℃ /100km existed in northern Taiwan. The horizontal temperature gradient increased to 2.6 ℃/100km in next 24 hours (0000UTC, Dec. 13). Above 700 hPa, southwesterly flows dominated. A short wave trough passed this region on 0000UTC, Dec. 13 and moved eastward. Consequently, a surface low formed in northeast of Taiwan 12 hours later. In order to have a better idea of the synoptic condition upstream, QUIKSCAT data were collected. QUIKSCAT data showed the ocean surface winds east of Taiwan on 1100 UTC Dec. 12, were northeasterly and changed to southeasterly 12 hours later. By analyzing the sounding data upstream (data taken from sounding station of Ishigaki island, Japan, 47918), it shows that during AHR in northern Taiwan, the low level prevailing wind changed from northeasterly to southeasterly between 1200 UTC Dec. 12 and 0000UTC, Dec. 13 (Fig.1). This flow pattern would attribute to low-level warm and moisture advections and produce an unstable environment.

It is interesting to know what the structure and how this easterly wind disturbance originates. Sounding data from Japan, Taiwan, and China were used for the analysis (Ishigaki island 47918, Taipei 46692, Hwalien 46699, Fuzhou 58847). The analysis period was from 0000UTC Dec. 8 to 1200 UTC Dec. 15, 2000. Time mean values of each variable analyzed (geopotential, potential temperature, mixing ratio, and zonal and meridional wind components) at various levels and different stations were calculated. The deviations were

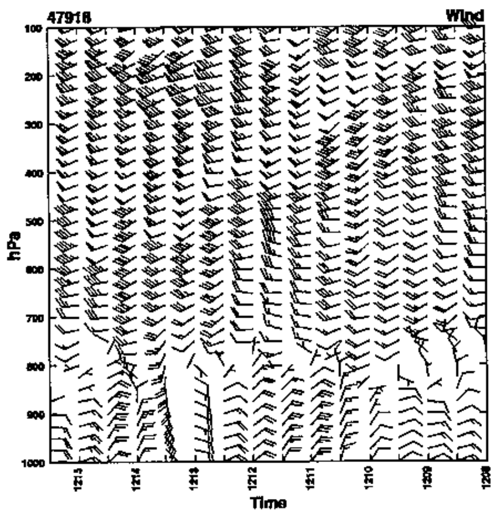

Fig.1. Time-height section of horizontal winds from sounding station Ishigaki island (47918).

calculated by subtracting the time mean value from the total amount. The results showed that the low-level easterly flow extended to 800 hPa level and had a jet-like structure. The jet axis was located at latitude 25.3N and altitude 950-925 hPa. The amplitude of the jet reached 10 m s^{-1} with significant vertical and lateral shears. The anomaly pattern of meridional wind component showed pronounced wind disturbances below 800 hPa. The maximum amplitude of wind disturbance was found at Ishigaki island station (Fig.2a) and was about 100 km south of the jet axis identified with the four stations indicated above. The maximum amplitude of the disturbance was at 925 hPa. It can be seen that the southerly component of wind disturbance was build up since 1200UTC Dec. 11 in a rate of 1 m s^{-1}(3hours)$^{-1}$ and reached its maximum value at 1200 UTC Dec. 13. The meridional wind changed from southerly back to northerly right after this with a rate of 4 ms^{-1}(3hours)$^{-1}$. The abrupt change of the meridional wind after 1200 UTC Dec. 13 was attributed to the newly formed eastward-propagating surface low system. Fig.2b showed the time height section of equivalent potential temperature (θ_e) anomaly pattern. Significant increase of θ_e at levels below 500 hPa was observed during the period of AHR. The occurrence of positive anomaly θ_e is coincided with the occurrence of southeasterly in this region as expected. Warm and moisture advections associated with the southerly flow produced an unstable atmospheric condition favorable for mesoscale precipitation system to develop. The origin of this easterly wind disturbance and the possible role of the disturbance to the formation of surface low east of Taiwan are not discussed. In studying the tropical easterly waves in West Africa, Reed et al. (1977) attributed the formation of the easterly wind disturbances to barotropic instability of the deep easterly zonal mean wind. The transformation of mean kinetic energy to eddy kinetic energy is the major process in generating the wind disturbances. A preliminary examination of the wind data from adjacent stations indicates that the mean flow seems to satisfy the necessary condition for barotropic instability. More will be discussed in the presentation. On the other hand, the formation of surface low and accompanying cyclonic vortex is not addressed in this study. The interaction between the upper westerly wave, the air-sea interaction of the Kuroshio with the boundary layer flow, and the precipitation systems embedded within the easterly wind disturbances are all played some roles and need to be further studied.

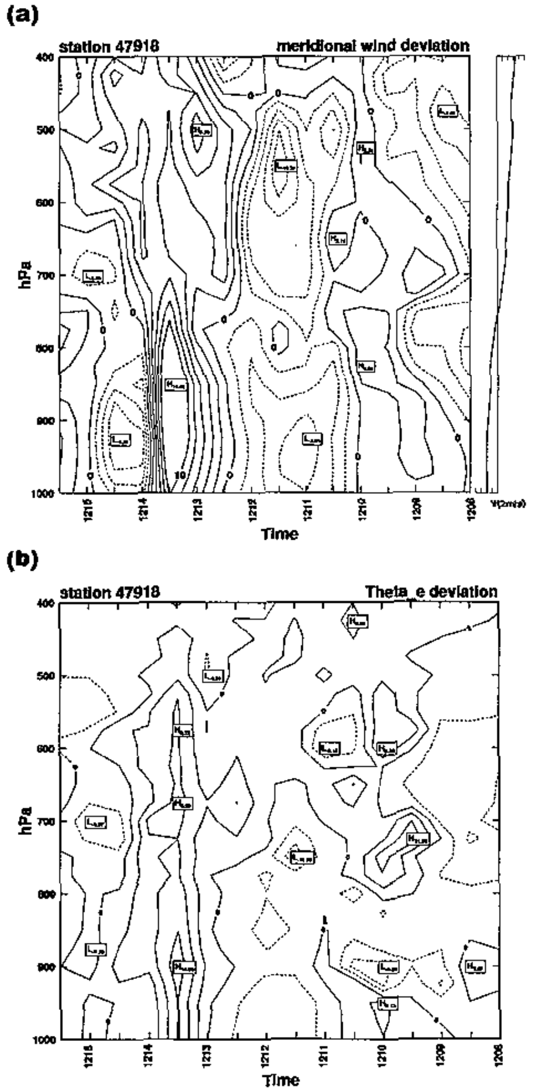

Fig.2. Time-height sections of (a) meridional wind component and (b) equivalent potential temperature anomaly from sounding station Ishigaki island (47918).

3. Precipitation characteristics of AHR

It is a common experience that no apparent cold cloud top was observed by satellite IR imagery while AHR occurred in northern Taiwan. It is important to know whether the precipitation processes associated with AHR are convective or stratiform in nature? The precipitation characteristics of AHR are examined by using WFS Doppler radar data. Fig. 3 shows the plan position indicator displays of reflectivity and radial winds at elevation angel 1.4°. The time is chosen because it is close to the time heavy rain occurred at I-Lan station. To the east of radar, the reflectivity field revealed a wide spread weak echo region without apparent horizontal gradient. This distribution indicated the large area precipitation is stratiform in nature. Embedded within were narrow line-shaped rainbands with stronger echo intensity. The orientation of these rainbands was approximately east to west. These rainbands propagated northwestward at a speed similar to the wind speed of southeasterly. Fig.4 gives a vertical cross section of reflectivity and radial wind display perpendicular to the rainbands shown in Fig.3. These rainbands had their maximum reflectivity below 3 km. Examine the surface rainfall data, it is found the narrow rainbands corresponded well with stronger rainfall and suggested a convective nature of precipitation. It is also noted that pronounced wind disturbance signature associated with the narrow convective rainbands was observed. The rainbands formed at the leading edge of these wind disturbances. Speed convergence within the leading edge of wind disturbance appeared to produce vertical motions attributed to the triggering of these rainbands.

4. Concluding remarks

In this paper, the synoptic conditions and mesoscale precipitation characteristics of a wintertime AHR case in northern Taiwan is studied. During the heavy rain period, the prevailing flow underneath 800 hPa was easterly and had a jet-like structure. The amplitude of the jet reached 10 m s^{-1} with significant vertical and lateral shears. The wind disturbance was about 100 km south of the jet axis and had its maximum amplitude at 925 hPa. The AHR case occurred when the maximum southerly component of wind disturbance encountered the east coast of Taiwan. Warm and moisture advections associated with the southerly flow produced an unstable atmospheric condition favorable for mesoscale precipitation system to develop. The precipitation characteristic of AHR is also analyzed by using WFS Doppler radar

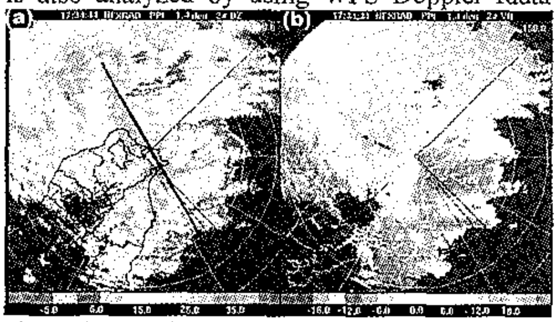

Fig.3. Plan position indicator display of (a) reflectivity and (b) radial wind at elevation angel 1.4 taken from WFS Doppler radar on 1734 UTC Dec. 12, 2000.

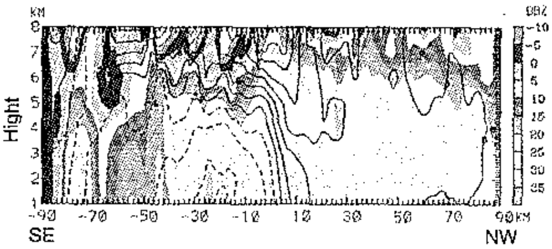

Fig.4. Vertical cross section of reflectivity and radial wind taken from WFS Doppler radar on 1734 UTC Dec. 12, 2000.

data. It is shown the larger scale precipitation was stratiform in nature and with narrow and shallow convective rainbands embedded. The orientation of these bands was approximately east to west. These convective rainbands had their maximum reflectivity below 3 km and propagated at a speed similar to the wind speed of southeasterly. The convective bands formed at the leading edge of wind disturbances embedded within the prevailing southeasterly.

In the study, the formation mechanism of the easterly jet at the marine boundary layer is not discussed. The easterly wind disturbance and its interaction with the upper westerly short wave are not discussed. The triggering mechanisms for the narrow convective rainbands are not clear. More works are still progressed.

Acknowledgements

This research was sponsored by National Science Council support to Taiwan Weather Research Program, under grants NSC89-2111-M002-026 & NSC90-2111-M002 -023.

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