Article ID: 1006-8775(2003) 02-0158-06

THE ANALYSIS OF THE RELATIONSHIP BETWEEN PULSE OF LLJ AND HEAVY RAIN USING WIND PROFILER DATA

LIU Shu-yuan (刘淑媛)[1,2], ZHENG Yong-guang (郑永光)[2], TAO Zu-yu (陶祖钰)[2]

(1. *Air Force Meteorology Center, Beijing* 100843 *China*; 2. *National Laboratory for Severe Storm Research*, *Department of Atmosphere Science*, *Peking University*, Beijing 100871 China)

ABSTRACT: Detailed analysis and comparisons are made on the data of Hong Kong wind-profiler and the weather/precipitation every hour during the HUAMEX and the experiment for the monsoon of the South China Sea (SCSMEX) in 1998. It is found that the wind-profiler data could reveal the meso-scale phenomena in the PBL of Southwest Monsoon, which was closely related to rainstorms. The center of the low-level jet under the altitude of 2 km, which corresponded to the appearance of heavy rain, appeared 1 to 2 hours after the center of low-level jet (LLJ) did above the 2-km altitude. An index *I* is designed to represent the intensity and height of the LLJ. This index can express clearly the close relationship between the precipitation and the LLJ. The results show that the wind-profiler is somewhat predictive to a rainstorm.

Key words: wind profiler; heavy rain; low-level jet

CLC number: P413 **Document code:** A

1 INTRODUCTION

With the principle of Doppler effect, the wind-profiler acquires high-resolution vertical wind profiles every few minutes and every few dozens of meters[1, 2]. In contrast, data obtained with conventional soundings do not reflect the true conditions right over the sounding site, for the balloons are going with the wind in upper levels. The National Oceanic and Atmospheric Administration, U.S.A., made a final assessment of the wind-profiler networks deployed in central America between 1987 and 1994[3]. It claimed that the wind-profiler was better than any other upper-level wind measuring systems in both temporal and spatial resolution and its 6-min.interval profiles displayed continuous and detailed variations of synoptic systems like shortwave perturbations.

As shown in studies on heavy rains[4, 5], heavy rains in southern China are accompanied with the strengthening of low-level jet in the lower part of the troposphere while meso- and fine- scale perturbations on the jet axis are closely related with processes of severe precipitation. Tao[5] points out that precipitation of high intensity could happen downstream of areas where there are large perturbations of velocity in the LLJ. Then how large LLJ perturbations relate to precipitation in the local region? In his mesoscale research on the “608” heavy rain for 1998, Shi[6] used wind velocity soundings for 700 hPa and 850 hPa to study the perturbations in LLJ. He reports that LLJ and super low-level jet appear a few hours ahead of the precipitation. As it is difficult to obtain detailed spatial and temporal data via the conventional means, meso- and fine-scale LLJ perturbations are understood little. High in temporal and spatial resolution, the data from wind-profilers offer valuable mesoscale information, which is the basis for the study on

Received date: 2002-07-28; **revised date:** 2003-11-03
Foundation item: A key project in Natural Science Foundation of China (980456032); Project 973 (G1998040907); Foundation Project for Visiting Scholar in Key Laboratory of Higher Education College
Biography: LIU Shu-yuan (1972 –), female, native from Tianjin, undertaking the study of mesoscale meteorology and radar detection.

© 1994-2009 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

the relationship the perturbation and precipitation.

During the HUAMEX from May to July 1998, the Hong Kong Observatory provides complete sets of wind-profiler data. The profiles are 10 minutes in temporal resolution, 30 layers in vertical stratification and 202 m in spatial resolution. The maximum for the latter can be 6240 m. The wind profiles for Sham Shui Po, Hong Kong, is used here to study the relationship between heavy rain processes in Hong Kong and LLJ perturbations.

2 RELATIONSHIP BETWEEN RAIN RATE AND LLJ

Tab.1 gives the statistics of precipitation in Hong Kong closely related with the Southwest jet stream in the planetary boundary layer (PBL) for May, June and July in 1998 (when the southwesterly was the governing airflow with the maximum wind speed greater than 12 m/s at the jet axis). Hourly comparisons are made between weather phenomena and wind profiles during the processes and the analysis shows a corresponding relationship between the intensification of perturbation in the southwest jet stream, expansion towards low levels and the severe weather and heavy precipitation. Next is a detailed analysis of the precipitation process on June 7th – 9th, which is the largest of all during the period of interest.

Tab.1 Precipitation in Hong Kong that is closely related with the Southwest jet stream in the PBL for May, June and July in 1998

time	May 14th	June 7th – 9th	June 22nd –23rd	July 12th – 13th	July 3rd – 4th
Rainfall / mm	15	457	86	97	100

2.1 *Analysis of synoptic process for June 7th – 9th, 1998*

There was a severe precipitation in Hong Kong on June 7th – 9th June, 1998, which gave the city rainfall of 411.3 mm on June 9th. A weak surface cold front was north of Guangzhou during the period of strong precipitation in Hong Kong on June 8th – 9th. The precipitation took place in the warm and humid air within the southerly airflow east of the low vortex, which was in the northwest of Guangzhou. Hong Kong was then controlled by a southwesterly. It was a severe mesoscale convective precipitation in the warm sector of the weak cold front. At 00:00 (UTC, same below) June 9th, the southwest wind reached the maximum (16 m/s) at 925 hPa, according to the observation at stations on the southern coast, indicating the presence of a strong southwesterly jet stream in the PBL. As shown in the moisture flux obtained with objective analysis of conventional observations, strong jet SW streams in PBL provides moisture conditions needed for the precipitation (Fig.1).

There were low-level clouds above the shallow, transformed cold air mass returning from the sea. They brought about weak precipitation as recorded at 13:00 on June 7th – 8th. Later it intensified to mesoscale convective precipitation. The precipitation for the two days is then the focus of our analysis.

2.2 *Analysis of wind profiles*

From the principle with which the wind profiler works, we know that highly accurate results can be obtained only if the measured wind field is isotropic, which is not the case in real atmosphere. With invalid and guessed parts removed from the observed data, we applied the technique of hourly smoothing to the data available at intervals of 10 minutes. Fig.2 gives the mean wind profiles for June 8th and 9th, 1998. To make wind shear (such as that with the passage of a cold front) display in a form similar to that in weather maps, the time axis in the altitude-time cross-section of the wind field was changed to scales increasing by the hour from

© 1994-2009 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

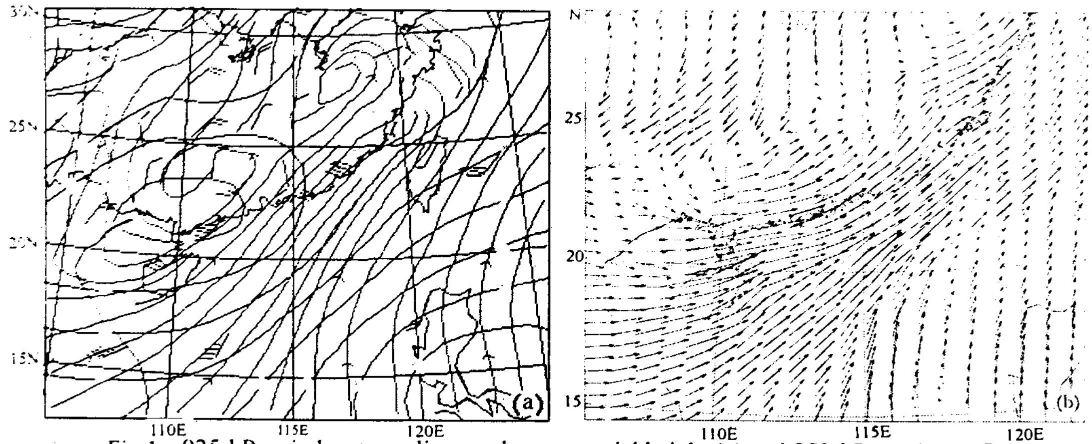

Fig.1 925-hPa winds, streamlines and geopotential height (a) and 850-hPa moisture flux vectors (b) at 00:00 June 9th.

right to left.

A strong easterly airflow was found below 1.0 km from 00:00 to 03:00 on June 7th. It began weakening from 03:00 while the South China Sea monsoon was increasing above the layer and expanding downwards.

It is shown in Fig.2 that the easterly in the PBL had largely withdrawn from the PBL by June 8th so that thick southwesterly took control in the middle and lower layers of the troposphere. Of the wind speed centers that exceeded 14 m/s, five appeared successively in levels above 2 km (23:00 on June 7th – 02:00 June 7th, 04:00 – 07:00, 09:00 – 15:00, 19:00, 21:00 – 23:00, June 8th) and four appeared in levels below 2 km (00:00 – 02:00 June 8th, 06:00, 13:00 – 14:00, 19:00 - – 22:00, June 8th). They were at the intervals between 1 and 6 hours, typical of the mesoscale. The commencement of two showers respectively at 00:00 and 07:00 all correspond to the centers of 14 m/s below the altitude of 2 km. The appearance of two thunderstorms at 14:00 and 20:00 are also in agreement with the centers of 16 m/s below the height of 2 km. At 22:00, the 14-m/s wind speed centers dropped to the level of 300 m when severe thunderstorms appeared at 22:00 and 23:00, with hourly rainfall being as high as 44.9 mm and 48.0 mm, respectively. Studying the time from which the 14 m/s wind speed was surpassed in both high and low levels, we find that the maximum appeared earlier above 2 km than below it. The centers of LLJ had earlier appearance than the super-low-level jet stream centers by 1 – 2 hours. Strong precipitation over a previous period coincided with the centers of super-low-level jet streams. It shows that the arrival of a LLJ or strong perturbations do not necessarily trigger immediate heavy precipitation. Heavy precipitation is more closely related with LLJ perturbations and how far they expand to the near-surface layers. It suggests possible increased low-level perturbations due to downward propagation of momentum at a time when the southwesterly was expanding downwards.

During the period from 00:00 to 12:00 June 9th, two successive processes of heavy rain appeared that exceeded 100 mm in 6 hours each. Wind speeds higher than 14 m/s from 00:00 to 05:00 stay below the altitude of 1.5 km when thunderstorms persist over Hong Kong. At 03:00 and 08:00 June 9th, there were strong southwest winds of 16 m/s – 18 m/s in the lower layer of the PBL, with the hourly rainfall being as high as 33.5 mm, 37.8 mm and 71.7 mm, respectively for 03:00, 04:00 and 09:00. At 06:00 and 11:00, winds greater than 14 m/s lifted to heights above 2 km and precipitation weakened. At 20:00, the low-level southwesterly jet stream strengthened again and centers of 12 m/s reappeared below 1.5 km, rainfall dropping to 10.6 mm for the hour 21:00. Temporally, the expansions of LLJ towards the near-surface layer and general perturbations matched well with the appearance of heavy precipitation. It is a further sign that they are closely related to each other.

© 1994-2009 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

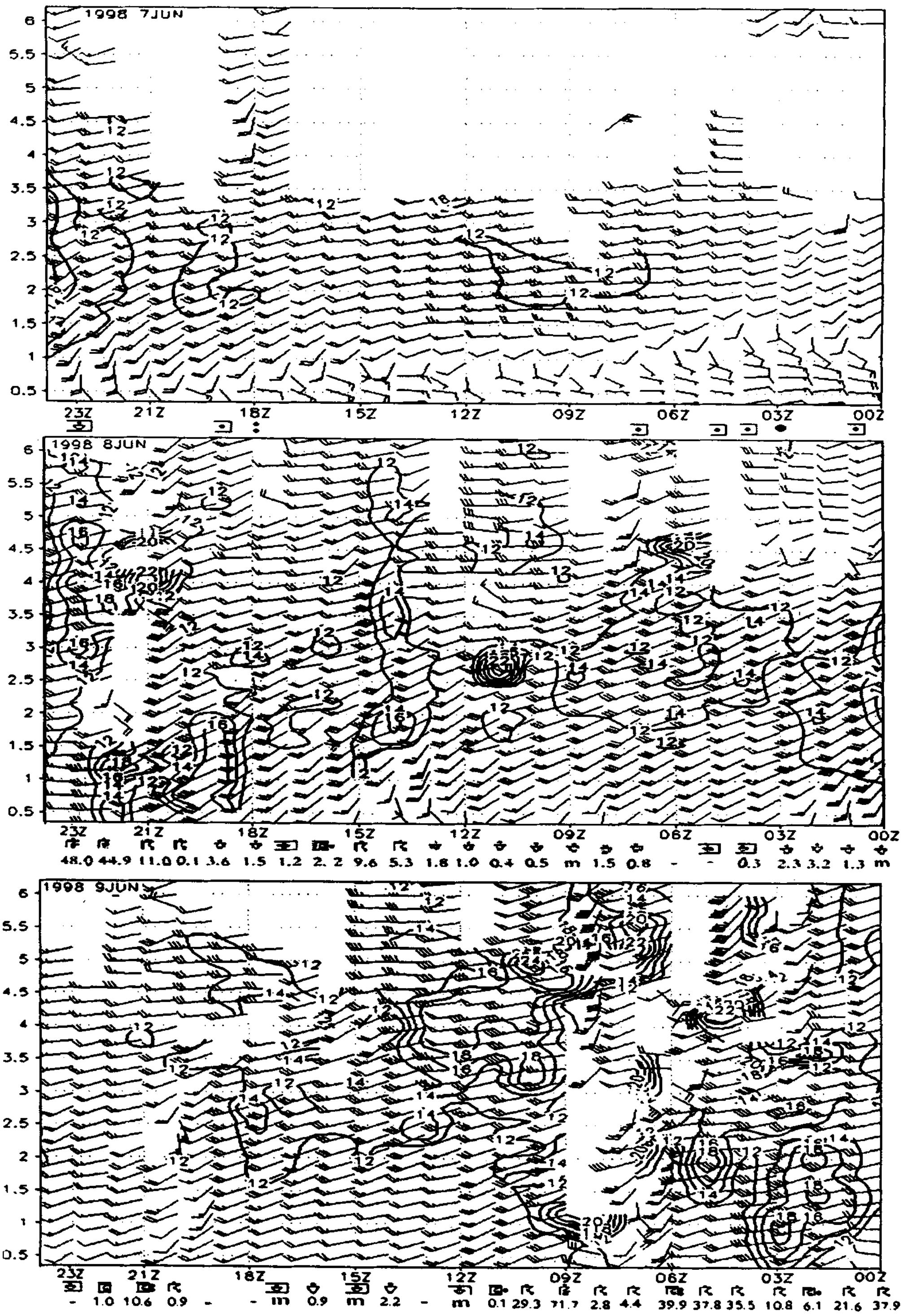

Fig.2 Time-altitude cross-sections for the wind profiles at Sham Shui Po, Hong Kong, June 7th – 9th, 1998 (a), weather phenomena during the time (b) and hourly rain (c). The wind speed isolines are marked from 12 m/s at intervals of 2 m/s. The abscissa is the time and the ordinate is the distance in km. "-" indicates no precipitation and "m" means trace precipitation.

© 1994-2009 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

It is known from the analysis above that the wind profile maps clearly show how the South China Sea monsoon advance in perturbation in the PBL and get stronger. It is more important to note that the arrival of LLJ over the observation station does not always trigger immediate onset of heavy precipitation, as far as the particular process is concerned. When the area of 12 m/s winds stayed above 2 km, there were no severe weather; when LLJ increased the speed to 14 m/s and expanded to layers below 2 km, showers or thunderstorms occurred. It is then obvious that the perturbation of LLJ and its expansion towards the surface are closely linked to heavy precipitation.

2.3 *Design of Index I and analysis*

To clearly illustrate the relationship between heavy rain intensity and LLJ, a LLJ index, $I = V / D$, is defined using the ratio of the maximum wind speed V (m/s) in the LLJ center in the PBL below 2 km to the lowest location of the 12-m/s wind speed center during the hour D (km). It is used to indicate quantitatively the extent to which LLJ extends and the intensity with which wind speed perturbs, and to examine its relation with rain rate. From the histogram showing variations of the LLJ index and corresponding hourly rainfall for June 8^{th} and 9^{th} (Fig.3), we see that the three periods of heavy precipitation from 20:00 June 8^{th} to 11:00 June 9^{th} (21:00 of 8^{th} – 02:00 of 9^{th}, 04:00 – 06:00 of 9^{th} and 09:00 – 10:00 of 9^{th}). The value of I was very large for the periods and rain rate rapidly increased 1 – 2 hours after the rapid increase of I values. Mean hourly amount of precipitation was above 35 mm in each of the three periods while the index I was about five times as large in just 1 to 2 hours. The perturbation of I is 6.2 over two the hours between 07:00 and 09:00 on 8^{th}, which had corresponding precipitation of 5.3 mm and 9.6 mm at 14:00 and 15:00, respectively. It is seen that the intensity of index I is positively proportional to that of precipitation. The study above shows that the index I is not only indicative of the close relationship between the perturbation of LLJ / extent to which expansion towards the surface and the heavy precipitation on the mesoscale, but also predictive of the appearance and heavy precipitation and magnitude of rain rate.

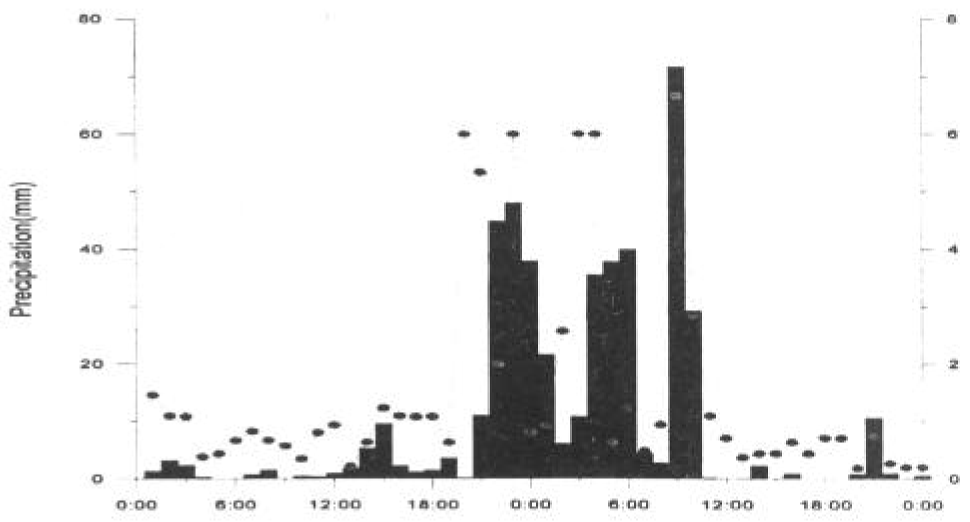

Fig.3 Histogram showing variations of the LLJ center index I (solid line) and corresponding hourly rainfall for June 8^{th} and 9^{th}. The abscissa is the time, which increases from left to right beginning from 00:00 on June 8^{th}.

© 1994-2009 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

3 CONCLUDING REMARKS

With hourly mean wind field data obtained by wind profilers, temporal combinations are clearly revealed in the troposphere between the mesoscale features and perturbations of LLJ and the processes of heavy precipitation. For the heavy rain in southern China in which the LLJ often plays an important role, meso- and fine- scale perturbations of LLJ for a single measuring station are indicative of severe weather and precipitation in the area around it. The LLJ perturbations and its expansion towards the surface are closely related with heavy rain. When LLJ arrives over the station, heavy precipitation is not necessarily triggered at once and the onset of every severe precipitation or weather will come with the rapid intensification of the Southwest LLJ perturbation and downward expansion. It shows that there may be downward propagation of momentum to increase perturbation at low levels when the southwesterly expands downwards.

As what the index *I* designed in the work indicates, rain rate is closely related with the extent to which the LLJ expands downwards in the PBL and the magnitude of wind speed at the center of the LLJ in the PBL. When the value of *I* increases rapidly, so does the local rainfall in 1 to 2 hours afterwards, suggesting increased index *I* in positive proportion to rainfall intensity. The wind profiles are not only helpful in analyzing the sequential corresponding relationship between the southwest LLJ and short-term heavy rain, but also useful in improving the short-term forecast of heavy rain.

Similar conclusions can be obtained for other processes of heavy rain taking place from May to July in 1998 in the Hong Kong area.

Acknowledgements: We appreciate the Hong Kong Observatory for providing the wind profilers measurements needed in our work. Mr. CAO Chao-xiong, who works at the Institute of Tropical and Marine Meteorology, CMA, Guangzhou, has translated the paper into English.

REFERENCES:

[1] ZHANG Ai-chen. Modern Meteorological Observation [M]. Beijing: Peking University Press, 2000. 289-298.
[2] YANG Jing-ji. Detailed Introduction to Instrumentation —Airflow Profilers [R]. Hong Kong: Hong Kong Observatory. 2000.
[3] The national weather service and the office of oceanic and atmospheric research and recommendations for future use[R]. Published by U.S. Department of Commerce and National Oceanic and Atmospheric Administration. 1994. 1-141.
[4] LU Han-cheng. Principles and Forecasts of Mesoscale Weather [M]. Beijing: Meteorological Press, 2000. 251-281.
[5] TAO Shi-yan. Heavy rains in China [M]. Beijing: Science Press, 1980. 29-33.
[6] SHI Ding-pu. Analysis of mesoscale characteristics of heavy rains during the yearly-first raining seasons in southern China [A]. Research on Heavy Rains across the Taiwan Straits and Neighboring areas [M]. Beijing: Meteorological Press, 2000. 175-185.

© 1994-2009 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net