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THE MEIYU PRECIPITATING CLOUD SYSTEM STUDIES USING WIND PROFILER IN CHINA

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1. INTRODUCTION

The season of the plum rains (Meiyu in Chinese or Baiu in Japan) or, intermittent drizzle, is a special meteorological phenomenon of the middle and low reach areas of the Yangtze River. Usually, the plum rain season starts in the middle of June and ends in early July, lasting for about 20 days. Due to the rains, the humidity runs between 80 and 90 per cent. At the same time, the air temperature is very high, ranging from 16 to 36 degrees centigrade. During Meiyu rainy season, the quasi-stationary Meiyu front can extend from western China to western Japan and is characterized by a weak temperature gradient, strong vertical wind shear, and large moisture gradient across the front at low levels [Ding, 1994; Ninomiya, 2000]. Precipitation systems imbedded in the Meiyu front are essentially convective in nature. Several field experiments have been carried out over Kyushu Islands and over the East China Sea [Yoshizaki et al., 2000]. Chen et al., (1998) investigated heavy precipitation caused by low-level jet along the western side of the central mountain range of Taiwan under the Taiwan Area Mesoscale Experiment (TAMEX). Lau et al. (2000) carried out an international field experiment during the South China Sea Monsoon Experiment (SCSMEX) with the objective for better understanding the key physical processes for the onset and evolution of the summer monsoon over Southeast Asia and southern China aiming to improve monsoon predictions. The experimental field study, Huaihe River Basin Experiment [HUBEX], was performed around Huaihe River basin in China to investigate energy and hydrological processes of multi-scale cloud systems in the Meiyu front and their interaction with land surface hydrology by utilizing data from the Doppler radars, radiosonde and surface meteorological stations [Shinoda and Uyeda, 2002]. The chance to observe the frequent

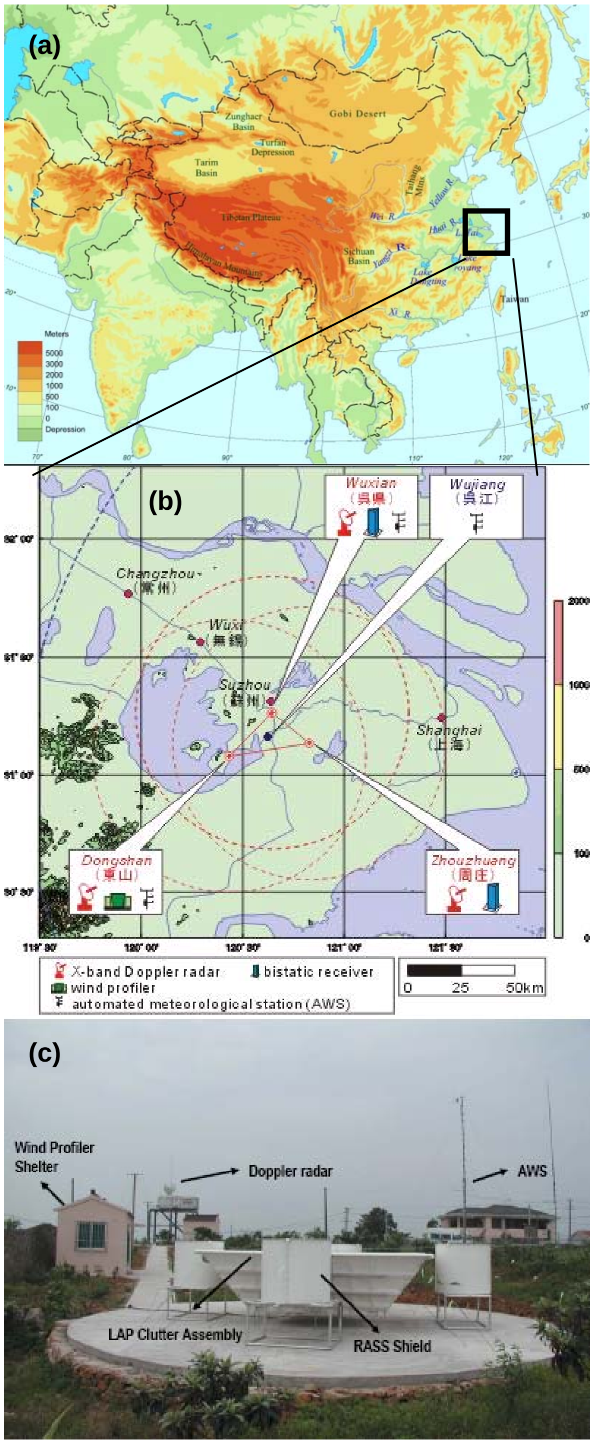

Fig. 1 (a) Map showing the location of the around the experimental site. (b) The map for the observational network. (c) Photograph showing the Dongshan Site instruments.

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occurrence of the Meiyu frontal heavy rainfall is limited. Consequently a few studies were carried out in the vicinity of the Yangtze River to understand the Meiyu frontal systems. These 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 behavior of the systems is important for understanding and predicting regional climate changes, as well as Institute of observational Research for Global Change (IORGC), Japan and Chinese Academy of Meteorological Sciences (CAMS), China on heavy rainfall in the downstream of the Yangtze River was conducted during 2001 and 2002. During the intensive observational period (IOP) Doppler weather radars, wind profiler radar, automated weather stations and a network of soundings are utilized to reveal the features of precipitating cloud systems. However, for the first time lower atmospheric wind profiler (hereafter LAWP or wind profiler) with radio acoustic sounding system (RASS) was used to understand the atmospheric boundary layer (ABL) evolution and the vertical structure of the precipitating cloud systems passing over head of the wind profiler during Meiyu season.

2. EXPERIMENTAL LOCATION AND DATA COLLECTION

A joint field experiment by the Institute of observational Research for Global Change, Japan and Chinese Academy of Meteorological Sciences, China on heavy rainfalls in the downstream of the Yangtze River was conducted during June-July 2001 and 2002. To examine the detailed three-dimensional structure of the MCS in the downstream of the Yangtze River [Fig.1 (b)] observational network of meteorological instruments were installed. Three X-band Doppler radars, two bistatic receivers, one lower atmospheric profiler with radio acoustic sounding system, and three automatic weather stations (AWS) were deployed for the intensive observational campaigns. Two bistatic receivers are used to constitute a bistatic multiple-Doppler network [*Wurman*, 1994]. The two-bistatic receivers are placed at Wuxian and Zhouzhuang whereas the transmitting radar is located at Dongshan. For the details of the instruments (Doppler radars and bistatic receivers) strategy refer to *Yamada et al*. (2003) and Geng et al. (2004). However, for the present study, the data collected from LAWP/RASS and AWS were used.

The LAWP/RASS was installed [as shown in Figure 1(c)] along with an automatic weather station (AWS), the Institute of Low Temperature Sciences of Hokkaido University Doppler radar and micro rain radar in the premises of the Dongshan Meteorological Observatory, in the Jiangsu province, about 80 km west to Shanghai, PR China. Dongshan (31°4′47″ N; 120°26′3″ E) experimental site is surrounded with vegetation and some rural houses. The site is on the peninsula of the Taihu Lake, which is the largest in China with 2425 sq km area. About 3 km to the west side of the site there are a few hills approximately 200 m high.

Two intensive observational campaigns were conducted during Meiyu period between June and July 2001 and 2002. The primary reason for this was to increase our chance of getting sufficient good data to diagnose the formation and three-dimensional structure of the Meiyu precipitating cloud systems in the lower ridge of the Yangtze River. LAWP had been operated in two modes: low mode and high mode up to 4 km and 11 km height during non-rainy and rain conditions, respectively. We made an attempt to understand the evolution of the turbulence structure of the convective boundary layer, with an emphasis on the nature of the decay of turbulence during morning and evening transition period during Meiyu period. The LAWP/RASS was operated continuously from 4 June 2001 to 16 July 2001 during first campaign [hereafter, Intensive Observational Period (IOP-2001)] and from 12 June 2002 – 31 July 2002 during second campaign (hereafter, IOP-2002). An Automatic Weather Station (AWS) is in continuous operation since its installation and provides valuable data of surface parameters viz., wind, temperature, air pressure, relative humidity, solar and net radiation, and rainfall accumulation. During IOP-2001 and IOP-2002, the LAWP/RASS captured several convective precipitating cloud systems in the vicinity of Meiyu front.

3. SYNOPTIC–SCALE CONDITIONS DURING EXPERI-MENTAL DAYS

Several researchers [Ding, 1994; Ninomiya, 2000] paid attention to the structure and formation processes of the Meiyu front and the influence of larger-scale circulation systems on the front mainly using satellite data. They showed that the Meiyu front is generally characterized by the low-level southwesterly jet stream, strong moisture gradient and the moist neutral stratification. The following discussion of the synoptic and climatological variability over Dongshan during Meiyu period is drawn from Geostationary Meteorological Satellite (GMS), 6-hourly synoptic weather chart [analyzed by the Japan Meteorological Agency every day at 00, 06, 12 and 18 UTC (UTC= LT – 8 hrs)], and from Dongshan-AWS data. Figure 2 shows the temperature, water vapor mixing ratio and barometric pressure traces at the LAWP site for the IOP-2001 and IOP-2002. During IOP-2001, very hot and humid, with water vapor mixing ratio was well over 20 g/kg at the surface during the day on days 178-187 (27 June – 06 July). The Majority of the was observed during (183 mm of the accumulated 271 mm) 19, and 22–24 June of IOP-2001 due to the mesoscale convective precipitation associated with frontal systems passage. Whereas, in IOP-2002, the precipitation activity (accumulated rainfall of 190.5 mm) around Dongshan area is significantly less compared to IOP-2001.

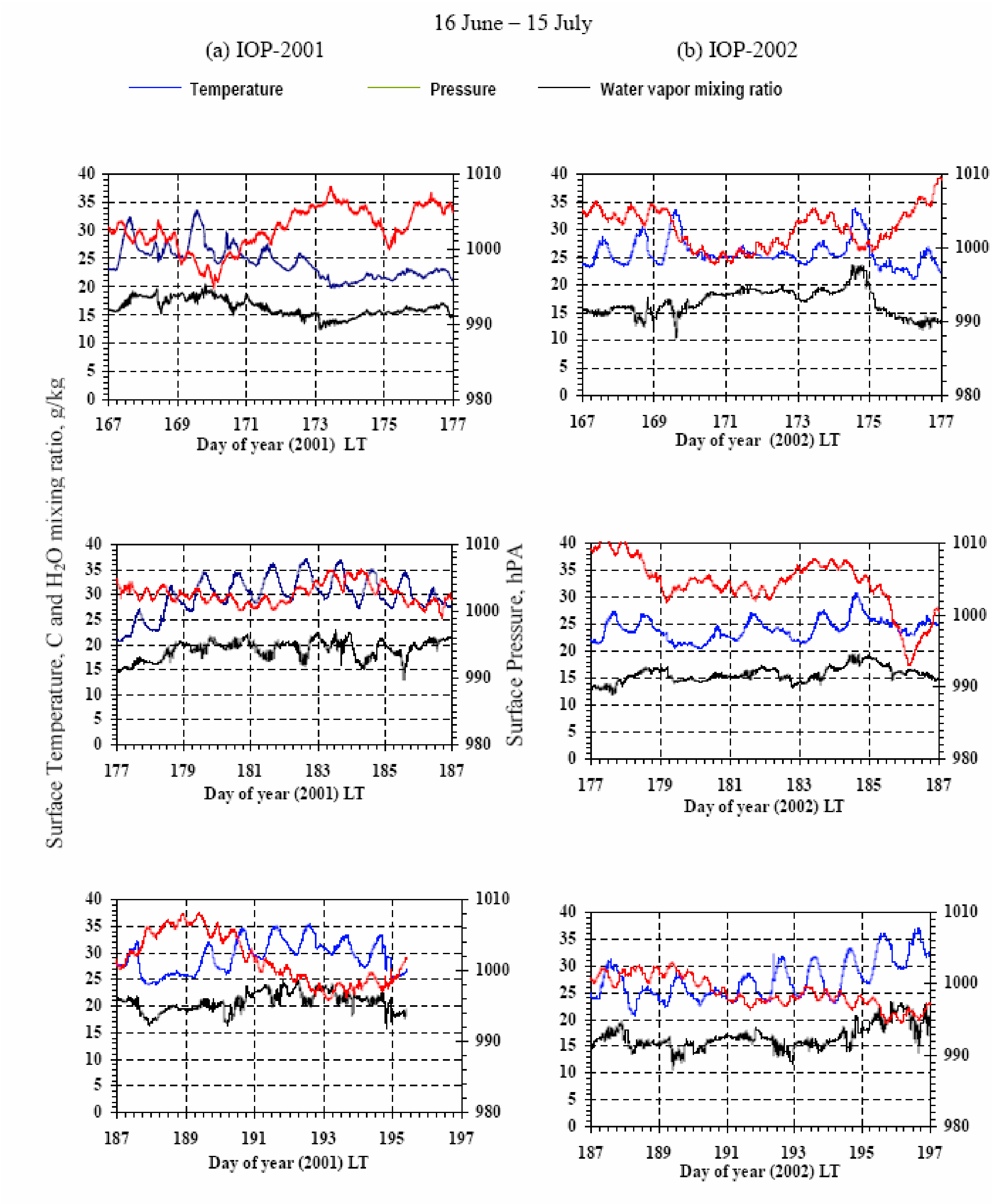

Fig.2. Surface barometric pressure, temperature, and water vapor mixing ratio measured by the Automatic weather station at the wind profiler site from 16 June to 15 July during (a) IOP-2001 and (b) IOP-2002.

4. PRELIMINARY RESULTS

In this section, we present some preliminary results of the experiments (intensive observation period of 2001 and 2002), both in statistical form and case studies. Data analysis is continuing, and we expect to report the detailed results related to the objectives described above in near future.

4.1 Convective Atmospheric boundary layer evolution during Meiyu period

The convective boundary layer (CBL) is critical to the studies of both climate and weather. The relatively warm, humid air in the CBL provides a majority of the thermodynamic energy responsible for convective storms in the Meiyu period. The evolution of the profilers with RASS have begun to revolutionize our ability to observe the CBL.

The vertical extent of CBL can be defined in different ways: the height where vertical gradient of the potential temperature or virtual potential temperature has a maximum; the crossover point of buoyancy flux profiles; the region of enhanced radar reflectivity due to strong humidity gradients and turbulence [Angevine et al., 1998]. The enhancement in radar reflectivity is in accordance with numerical experiments which show maximum refractive index structure constant in the inversion layer or in the regions where temperature and humidity gradients are large [Angevine et al., 1994; Haghiguchi et al., 1995]. In the present study radar reflectivity [Signal to noise ratio (SNR)] is used to identify

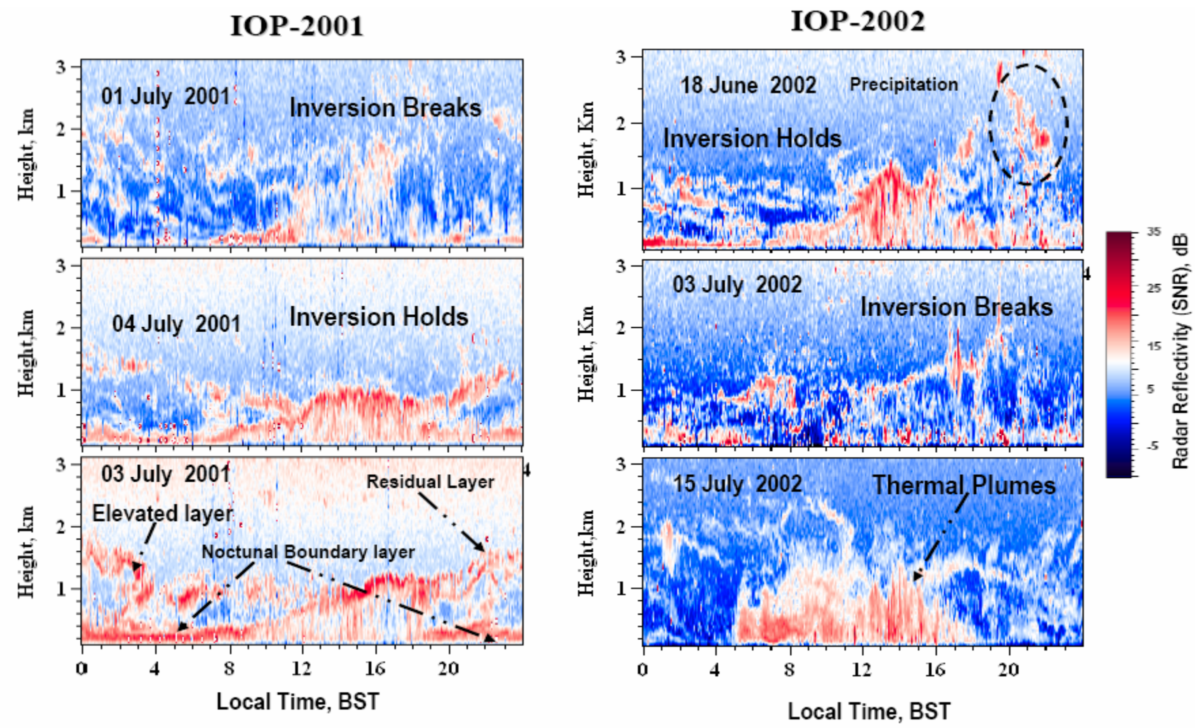

Fig. 3. Atmospheric Boundary layer evolution during IOP-2001 and IOP-2002. Time-height cross section of Radar reflectivity (SNR) observed during different days showing different CBL structures.

thermodynamic state of CBL is therefore of great importance in forecasting the convective storm initiation. The CBL is also the mediator of land-atmosphere interactions that can influence weather and climate. For example, CBL conditions alter surface-atmosphere exchange processes such as evaporation and transpiration and are in turn altered by these fluxes. Thus the patterns of interaction between the land and the atmosphere drive the local and thus climatological patterns of weather development. High-resolution wind profilers and/or wind the top of the boundary layer.

To examine the diurnal variation of ABL, time-height cross-section of range-corrected reflectivity (dB) is given in Figure 3. In the low-mode, the vertical beam has vertical resolution of 60 m and temporal resolution for every 3 minutes. The strong reflectivity observed during the morning hours corresponds to the morning transition or the morning rise of inversion. This strong reflectivity region appears in the lowest observational heights and ascends gradually, reaching a maximum height in the afternoon hours. Several days observations show that strong reflectivity region marks the height of the daytime boundary layer or convective boundary layer (CBL). So this can be considered as the top of the boundary layer. The observations of this echo associated with morning transition in this study are similar to those observed by other wind profiler radars in clear air days [White et al., 1991; Angevine et al., 1994; Hashiguchi et al., 1995]. The LAWP cannot clearly measure the height of the nocturnal boundary layer because it is at or below the minimum height of the LAWP. The case studies considered here show that the vertical extent of the boundary layer differs from day to day. The ABL height reaches an average value of ~ 1.2 km during the Meiyu period with a range of 0.9 to 1.4 km. This value is low compared to tropical latitudes, where the boundary layer height maximum is mostly around 2 km with a range of 1.5 to 3.2 [Angevine et al., 1998; Reddy et al., 2002]. But the general features of the CBL over Dongshan are comparable to those from the sub-tropical region [Hashiguchi et al., 1995].

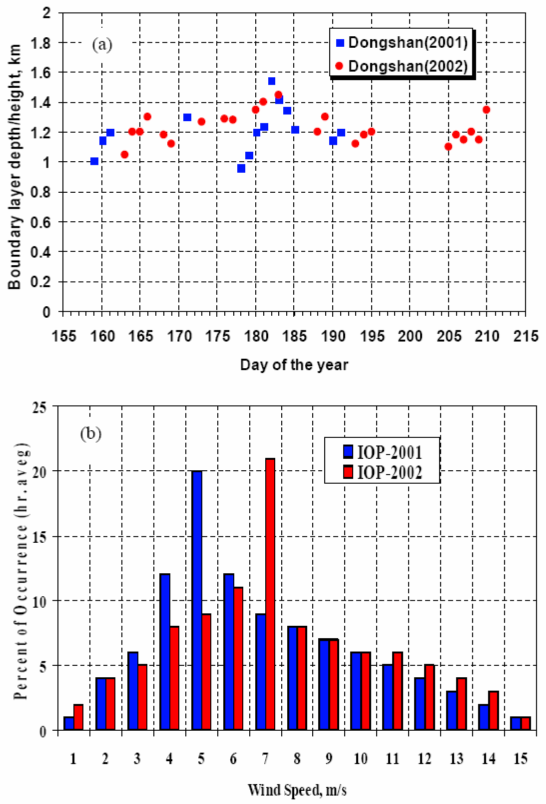

Fig.4 (a) Boundary layer heights (average over 1200-1500 BST) from LAWP measurements during IOP-2001 and IOP-2002. (b) Boundary-layer wind speed statistics during IOP-2001 and IOP-2002 (excluding Precipitation days).

The depth of the atmosphere's convective boundary layer is of cardinal importance for air quality monitoring and prediction, and it could also be important for initializing and evaluating numerical weather prediction models. Convective boundary layer observations using wind profiler over China are rare compared to tropics [Reddy et al. 2002] and other mid-latitude regions [Hashiguchi et al., 1995]. The wind profiler can measure the height of the CBL which is also described as the mixing depth or boundary layer depth. Figure 4(a) shows the midday boundary layer height for all the days with well-formed CBL during IOP-2001 and IOP-2002. The height shown for each day is the average of four hours in early afternoon (11:00 – 15:00 BST) of the boundary layer heights determined for each hour by subjective examination of the results of a peak-finding algorithm run on the reflectivity. We found that the average CBL height varies between 0.9 and 1.4 km in IOP-2001. Whereas in IOP-2002, the average CBL height variations are between 1 and 1.4 km. The depth of the Atmospheric boundary layer and the intensity of the turbulence within it have a strong impact on the development of precipitating cloud system in the Meiyu period. The boundary layer height variation mostly depends on temperature and humidity. The low boundary layer heights during IOP 2002 could be due to low relative humidity. Figure 4(b) shows statistics of the daytime boundary layer winds during IOP-2001 and IOP-2002 days. These are averages of winds over all heights within the CBL. The boundary layer wind speed distribution was sharply peaked at approximately 5 m/s, a speed over 10 m/s occurs very rarely. These results suggest that the low (calm) wind speeds are favorable for the CBL development. During these days, horizontal winds are generally weak and most of the time blow from southeasterly or southerly direction [not shown here]. However, further detailed investigations are needed and in progress.

4.2 Vertical structure of the precipitating cloud systems observed near Meiyu fontal Cyclone

In this section, typical observations recorded by the LAWP illustrate the vertical structure and temporal evolution of precipitating cloud systems during IOP-2001 and IOP-2002. The shape of the Doppler spectra is characterized by the first three spectral moment information of the hydrometeors in the precipitating cloud systems. The moments yield the reflectivity of the hydrometeors, the reflectivity-weighted fall speed of the hydrometeors and the variance of the hydrometeor fall speeds within the observing volume [Gage et al. 2002]. The primary importance of this section is to obtain vertical air motion and inferences on microphysical structure during Meiyu period. During IOP-2001 and IOP-2002, many interesting characteristics of the mesoscale convection in this region were found.

are evident in this figure during periods of rainfall recorded at the surface by the influence of Typhoon and Meiyu frontal system. Variations in precipitation concentration are apparent as vertical streaks in Reflectivity above 2 km. This suggests that rain mass concentration was mixed horizontally by increasing wind shear and

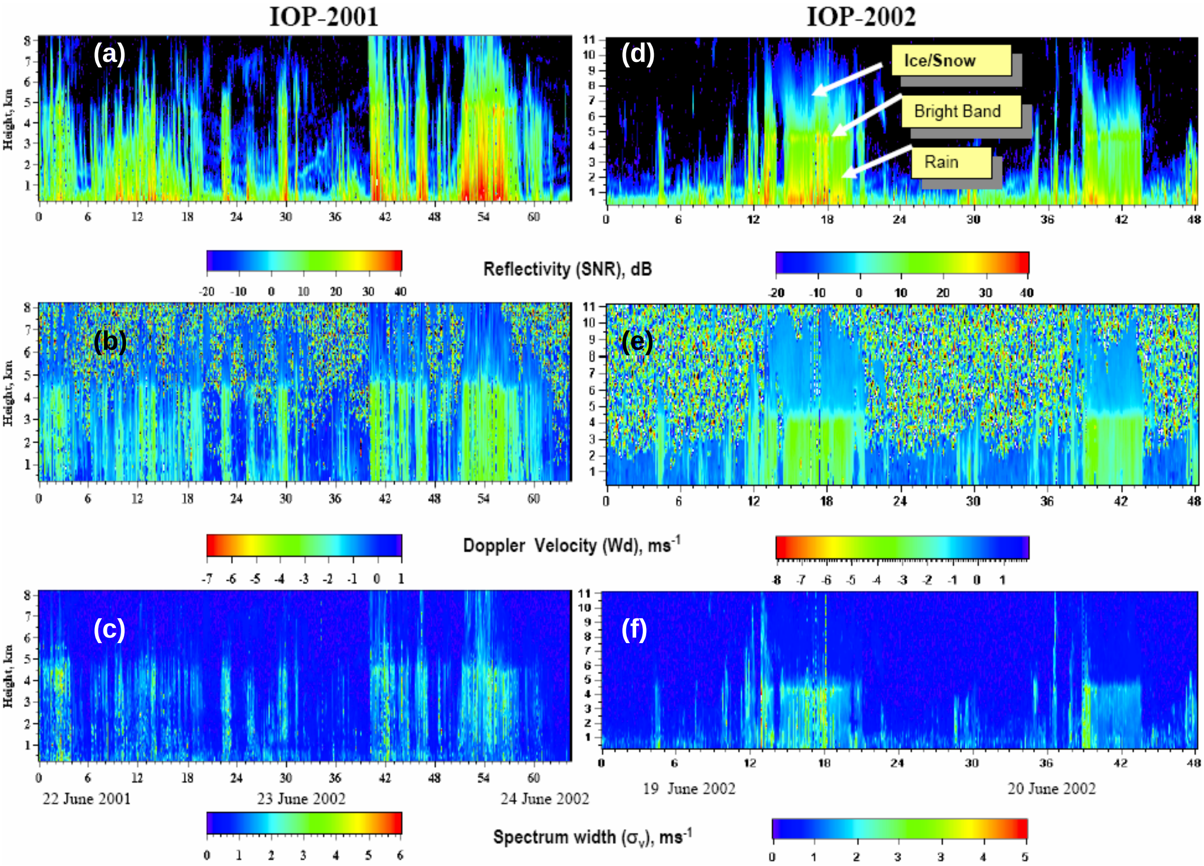

Fig.5. Vertical structure of the precipitating cloud systems observed during IOP-2001 (left three panels) and IOP-2002 (Right three panels). Time-height cross section of [top two panels (a) & (d)] Reflectivity (SNR), dB; [middle two panels (b) & (e)] Doppler velocity, m/s; and [bottom two panels (c) & (d)] Doppler spectrum width, m/s.

On 23 June 2001, a medium scale disturbance (Meiyu front) was generated near East China Sea and propagated to south of the wind profiler site. Typhoon Chebi (0102), located at South China Sea was traveling towards northward. From GMS satellite (not shown here) images it can be noticed that the Meiyu front was stationary around the experimental site. The Tropical Cyclone (0102) Chebi was downgraded from Typhoon and become extra-tropical low at 24.8^{o}N 119.4^o E at Taiwan Strait, moved northward. The stationary Meiyu front moved to north of the experimental site on 25 June 2001.

A time-height cross-section of reflectivity (SNR) obtained from 22-24 June 2001 during Meiyu frontal system and influence of the Typhoon Chebi (0102) is shown in Figure 5(a). Several different types of the vertical structure

associated turbulent eddies in the lowest 2 km. Likewise, the bright-band (layer of enhanced reflectivity) near 4.5 km reveals a time-varying intensity and small fluctuation in height. During the passage of typhoon Chebi, the heavier rain episodes occurred between 15:30 hrs and 22:30 hrs on the 23rd June illustrated a mixture of convection with stratiform rain. The Doppler vertical velocity field W_d [W_d= w + W_T, where w is vertical air motion and W_T is the particle terminal fall speed] in Fig. 5(b) reveals a largely stratiform structure, with primarily – 1 to –2 m/s (downward) velocities characteristic of snowfall speeds above the melting region. Positive W_d within the upper levels (6-8 km) implied weak updrafts of 1-2 m/s between 0300 and 1100 LT on 24 June 2001 during the passage of Meiyu frontal precipitating cloud system. Significant updraft was not prevalent in this portion of the

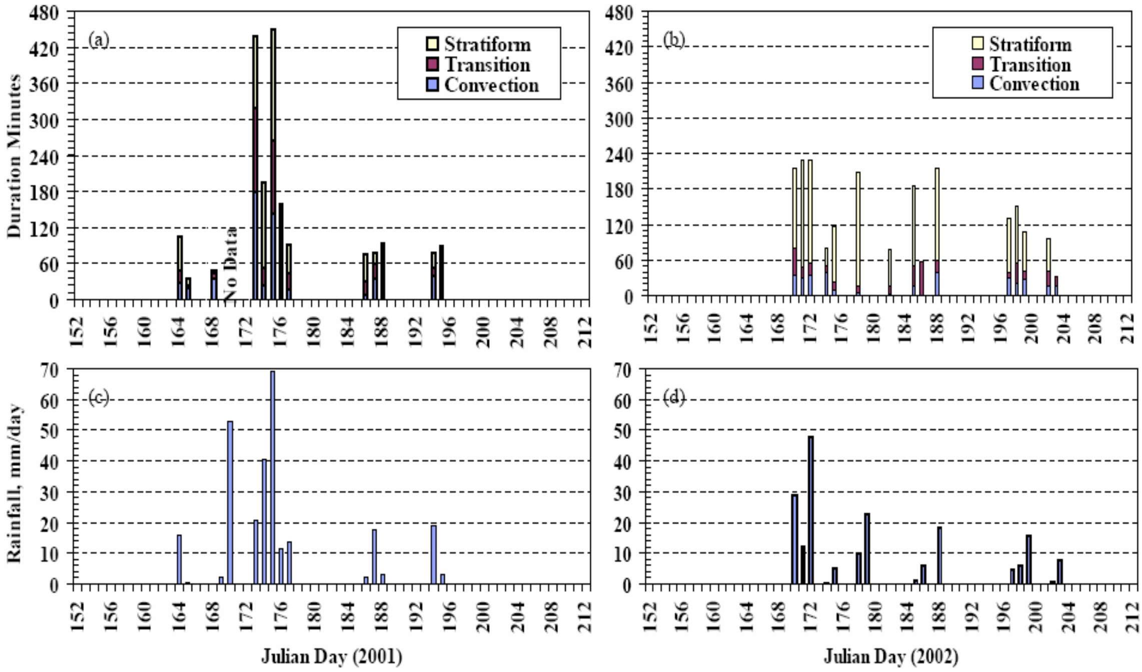

Fig.6 Time variation of precipitating cloud types classified by the Wind profiler during (a) IOP-2001 and (b) IOP-2002. Automatic Weather Station observed Daily rainfall over Dongshan during (c) IOP-2001 and (d) IOP-2002.

mesoscale precipitating cloud system. From inspection of time vs. height sections of vertical beam measurements of mean velocity and Doppler spectrum variance, it appears that the boundary layer depth was ~2 km through the period of high winds. The turbulent layer (< 2 km) is characterized by high values of spectrum width, σ_v [Fig. 5(c)] and fluctuations of W_d. During the strongest wind conditions, σ_v suggests a turbulent layer depth of about 1.5 km. The rain mass concentration becomes increasingly uniform between the melting level and the surface.

On 19 and 20 June 2002 [Fig. 5(d)], convection begins with a series of intermittent erect convective cells. Above 5 km there is evidence of updrafts and downdrafts extending up to about 12 km. Following the most active convection on 20 June 2002, there is a transition to mature stratiform rainfall. The mature stratiform rainfall commences around 1425 hrs BST on 19 June 2002 and 1405 hrs BST on 20 June 200. It can be recognized by the bright band in reflectivities at the melting level below 5.0 km [Fig. 5(d) & (e)]. Above the melting level, Doppler velocities [Fig.5 (e)] of 1-2 ms^{-1} associated with falling ice and snow, and small spectral width [Fig. 5(f)] indicative of, at most, weak vertical motions and turbulence characterize the period of stratiform precipitation.

To investigate the rainfall type over the observation site, classifications of precipitating clouds are performed by using LAWP data. Reflectivity, Doppler velocity and spectral width derived from the vertically-pointing beam are used to determine the precipitating cloud type. For the classification of precipitating clouds, we used the same algorithm used by Reddy et al. 2002. Precipitating clouds are classified into three types [stratiform, mixed convective-stratiform (transition) and convective]. In the algorithm for classification, both the existence of melting layer and the existence of enhanced turbulence above the melting level are examined (see Figure 4 of Williams et al., 1995). If a melting layer exists and enhanced turbulence exists (does not exist) above the melting level, a precipitating cloud is classified as mixed stratiform/convective or transition (stratiform) type. If a melting layer does not exist and a enhanced turbulence exists (does not exist) above the melting level, a precipitating cloud is classified into deep/shallow convective type. Figure 6 shows the time variation of precipitating cloud types during IOP-2001 and IOP-2002. During IOP-2001 precipitating clouds are dominated by mixed and stratiform type. During IOP-2002, bothconvective-type and stratiform –type precipitating clouds are observed over the observation site.

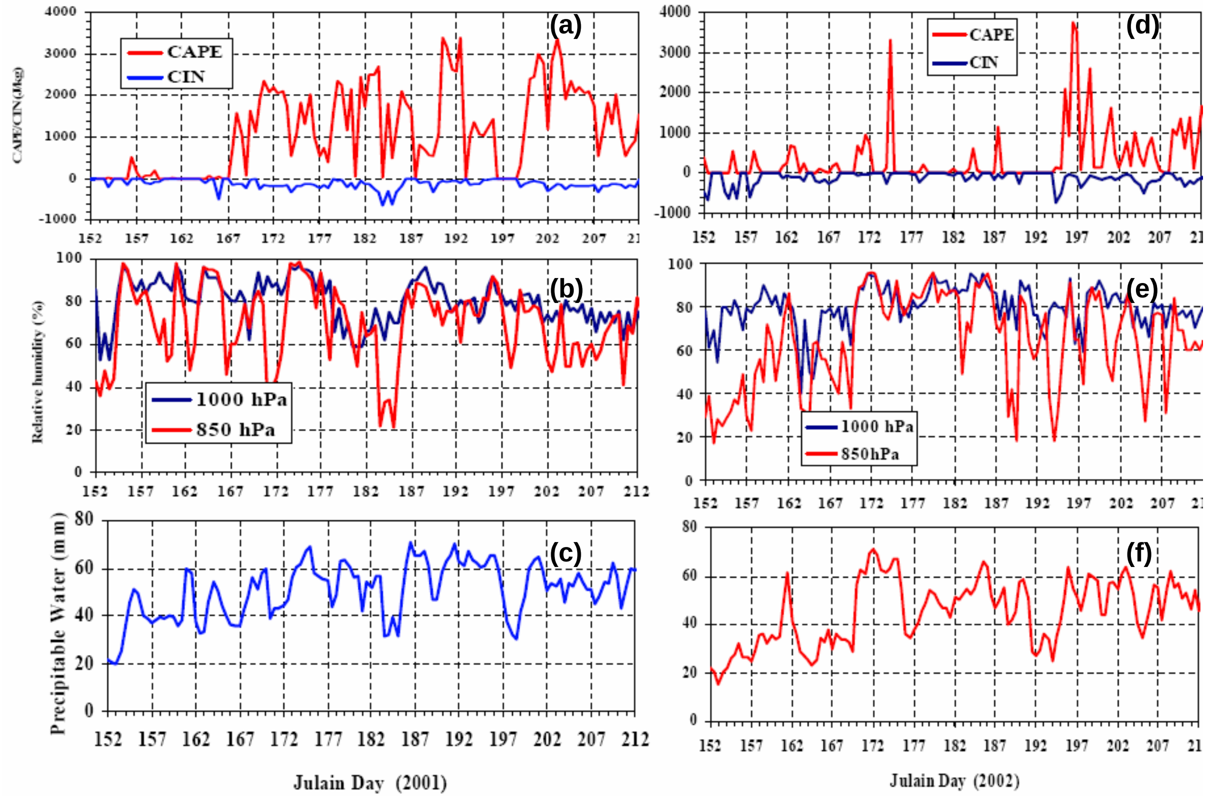

Fig.7 Characteristics of Meiyu season environmental conditions during IOP-2001 and IOP-2002. Time series of [(a) & (d)] CAPE and CIN, Relative humidity [(b) & (e)] and Precipitable water (mm) [(c) & (f)] during IOP-2001 (left panels) and IOP-2002 (right panels).

Convective Available Potential Energy (CAPE), Convection Inhibition (CIN), relative humidity and precipitable varied considerably around Shanghai region as shown in Figure 7 during IOP-2001 and IOP-2002. There was weak association between CAPE and environmental flow. From these figures it is evident that in the IOP-2001 and in IOP-2002 are mainly due to the difference in the distribution of water vapor and local environmental conditions. These observational results suggest that large difference in relative humidity and precipitable water.

5. CONCLUSIONS

Preliminary results indicate that the LAWP/RASS could help to improve the understanding of the atmospheric processes involved in severe weather conditions of the subtropical region. An attempt has been made to study the evolution of the CBL in non-precipitating and Meiyu convective days. A well-distinguishable feature is observed in the pre-convective environments, which can be used as precursor for the convection triggering. The LAWP observations demonstrate that during Meiyu period the average CBL is below < 1 km and where as, pre- and post-Meiyu period the average CBL height above 1 km. The results show that distinguishable CBL evolution was noticed during pre-Meiyu and Meiyu period.

Zenith pointing WP provides high vertical resolution observations of the precipitating cloud systems that advect overhead. The precipitation systems observed during Meiyu period (IOP- 2001 and IOP- 2002) were dived into three rain types based on the reflectivity above the melting layer and the difference of the falling speed of the precipitation particles between 3 and 6 km height. The precipitation system had the bright band structure at around 5 km in height, and high echo region extended up to 9-11 km in height. In the passage of the cloud systems, during IOP-2001, convective and mixed types of rain systems are pre-dominant whereas during IOP-2001 convective systems embedded within a wide stratiform precipitation were observed. Differences between the cases in IOP-2001 and in IOP-2002 are mainly due to the difference in the distribution of water vapor and local environmental conditions. Our observational results suggest that large difference in relative humidity and horizontal wind speed apart from the large scale systems disturbances.

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REFERENCES

Angevine, W. M., A.W. Grimsdell, L.M.Hartten, and A.C.Delany, 1998: The Flatland boundary layer experiments, *Bull. Am. Meteorol. Soc.*, *79*, 419-431.

Chen, C., W.K.Tao, P.L.Lin, G.S.Lai, S.F.Tseng and T.C.C.Wang, 1998: The intensification of the low-level jet during the development of mesoscale convective systems on a Mei-Yu front, *Mon. Wea. Rev*., **126**, 349-371.

Ding, Y., *Monsoons over China*, 419 pp., Kluwer Academic, Norwell, Mass., 1994.

Gage, K.S., C.R.Williams, W.L.Clark, P.E. Johnston, and D.A.Carter, 2002: Profiler contributions to tropical rainfall measuring mission (TRMM) ground validation field campaigns, *J. Atmos.Ocean. Tech*., **19**, 843-863.

Geng, B., H.Yamada, K.Krishna Reddy, H.Uyeda and Y.Fujiyoshi, 2004: An Observational study of the development of a rainban on a Meiyu front causing heavy rainfall in the downstream region of the Yangtze River, *J. Meteorol. Soc. Japan*, **82**, 1095-1115.

Hashiguchi, H., M.D.Yamanaka, T.Tsuda, M.Yamamoto, T.Nakamura, T.Adachi, S.Fukao, T.Sato and D.L.Tobing, 1995: Diurnal variations of the Planetary boundary layer observed with and L-band clear-air Doppler radar, *Boundary Layer Meteorol*., **74**, 419-424.

Krishna Reddy, K., T. Kozu, Y.Ohno, K. Nakamura, A.Higuchi, K.Madhu Chandra Reddy, P.Srinivasulu, V.K.Anandan, A.R.Jain, P.B.Rao, R.Ranga Rao, G.Viswanthan, and D.N.Rao, 2002: Planetary boundary layer and precipitation studies using Lower atmospheric wind profiler over Tropical India, *Radio Sci.*, **37**, doi:10.1029/2000RS002538.

Lau, K.M., Y.Ding, J.T. Wang, R. Johnson, T. Keenan, R. Cifelli, J. Gerlach, T. Rickenbach, S.C. Tsay, and P.H. Lin, 2000: A report of the field operations and early results of the South China Sea Monsoon Experiment (SCSMEX), *Bull. Amer. Meteorol. Soc*., **81**, 1261-1270.

Ninomiya, K., 2000: Large- and meso-α-scale characteristics of Meiyu/Baiu front associated with intense rainfalls in 1-10 July 1991, *J. Meteorol. Soc. Japan*, **78**, 141-157.

Rogers, R.R., W.L.Ecklund, D.A.Carter, K.S.Gage and S.A. Ethier,1993: Research Applications of a boundary-layer wind profiler, *Bull. Amer. Meteorol. Soc*., **74**, 567-580.

Shinoda, T., and H.Uyeda, 2002: Effective factors in the development of deep convective clouds over the west region of Eastern China during the summer monsoon season, *J. Meteorol. Soc. Japan*, **80**, 1395-1414.

Stull, R.B., *An Introduction to Boundary Layer Meteorology*, 666 pp., Kluwer Academic, Norwell, Mass., 1988.

White, A.B., C.W.Fairall, and D.W.Thompson, 1991: Radar observations of humidity variability in and above the marine atmospheric boundary layer, *J. Atmos.Ocean. Tech*., **8**, 639-658.

Williams, C.R., W.L.Ecklund, and K.S.Gage, 1995: Classification of precipitating clouds in the tropics using 915 MHz wind profilers, *J. Atmos.Ocean. Tech*., **12**, 996-1012.

Wurman, J., 1994: Vector winds from a single transmitter bistatic dual-Doppler radar network, *Bull. Am. Meteorol. Soc.*, ***75***, 983–994.

Yamada, H., B.Geng, K.K.Reddy, H.Ueyda, and Y.Fujiyoshi, 2003: Three-dimensional structure of a meosocale convective system in a Baiu-Frontal depression generated in the downstream region of the Yangtze River, *J. Meteorol. Soc. Japan*, **81**, 1243-1271.

Yoshizaki, M., T.Kato, Y.Tanaka, H.Takayama, Y.Shoji, H.Seko, K.Aro, K.Manbe and members of the X-BAIU-98 Observation, 2000: Analytical and numerical study of the 26 June 1998 orographic rainband observed in Western Kyushu, Japan, *J. Meteorol. Soc. Japan*, **78**, 835-856.