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WIND VARIATIONS AROUND OROGRAPHIC RAINBAND OBSERVED BY WIND PROFILER NETWORK IN JAPAN

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1. Introduction

The summer monsoon rainfall are identified as Meiyu in China and Baiu in Japan. Most of heavy rainfall are caused by developed mesoscale convective systems (MCSs) with a band-shaped structure from the Baiu season (June and July) through summer. Some of them have so small scale (× 100 km) that they are not simulated well. But they bring heavy rainfall when they are maintained for a long time and it is important to understand the mechanisms of them.

In April 2001 the Japan Meteorological Agency (JMA) started the operation of the Wind Profiler Network and Data acquition System (WINDAS; Ishihara and Goda, 2002; Ishihara et al.,2003). The network consists of 31 1.3 GHz wind profilers installed across Japan. Wind profiler observations are well suited to examine detailed wind behavior including the vertical wind component associated with MSCs.

On 1 August 2004, after the typhoon Namtheun (T0410) run through the west part of Shikoku region (see Figure 1), some line-shaped MCSs were generated over the region. The rainband were maintained for about 20 hours and brought heavy rainfall in specific area. As a result, a lot of damage was caused in that region. In this study, we find out wind behavior and background field using various observation data to investigate generating and maintenance mechanisms of the rainband.

2. Observation Data

The four 1.3 GHz (L-band) wind profilers parts of WINDAS are able to show the wind field continuously over Shikoku region as shown in Figure 1. The specification of the radars is shown in Table 1. Wind profilers can observe clear-air motion which cannot be observed by weather radars. Therefore they provide a vertical profile of three components of wind velocity vector below about 7–4 km height with high time and range resolutions just before and/or after a precipitation. Characteristic features of the rainband were observed operational C-band (5.6 GHz) meteorological radar provided by JMA. Upper-air sounding data observed at Shionomisaki twice a day (00 UTC and 12 UTC) are used to show atmospheric condition around the rainband.

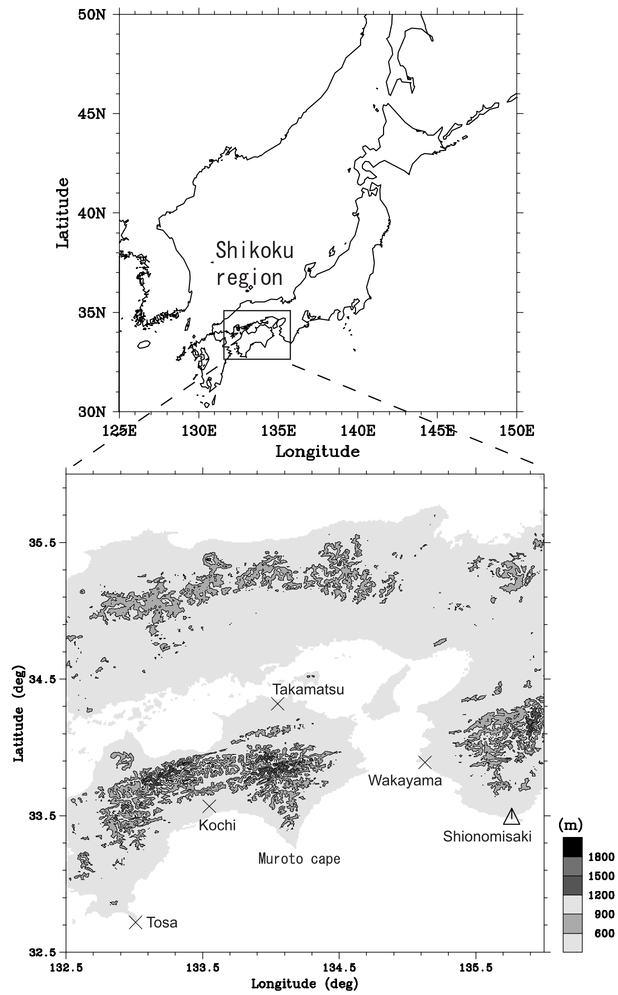

Figure 1: Topographic map around Shikoku region and observation sites of wind profiler (Tosa, Kochi, Takamatsu and Wakayama) and upper-air soundings (Shionomisaki).

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Table 1: Specifications of the Wind Profiler of WINDAS.

Antenna	Phased-array antenna
Operating frequency	1357.5 MHz
Aperture	16 m^2
Transmitter peak power	3 kW
Height resolution	100 m
Height range	0.1–10 km

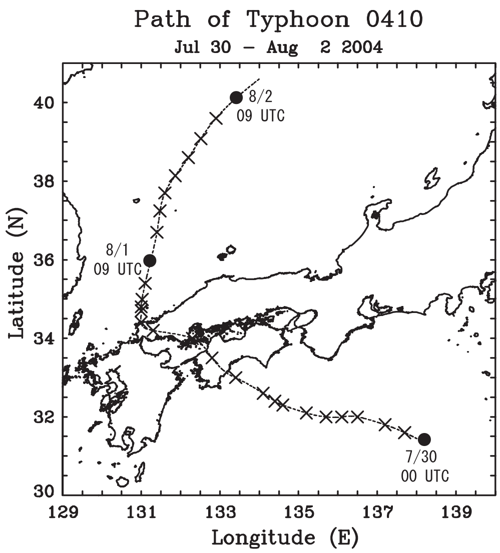

Figure 2: The path of typhoon Namtheun from 00 UTC 30 July to 09 UTC 2 August. Cross ($\times$) are put on the curve in 3 hours intervals.

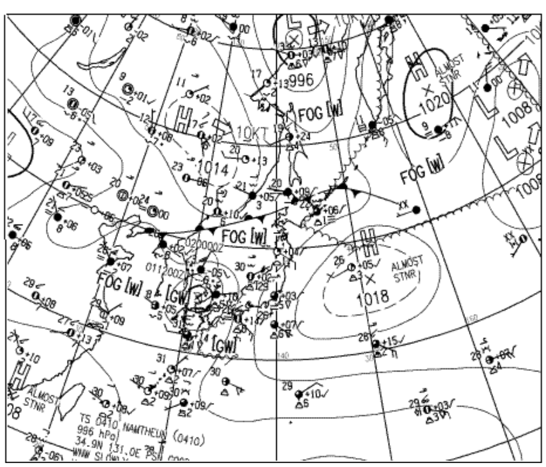

Figure 3: Surface weather chart at 00 UTC on 1 August 2004.

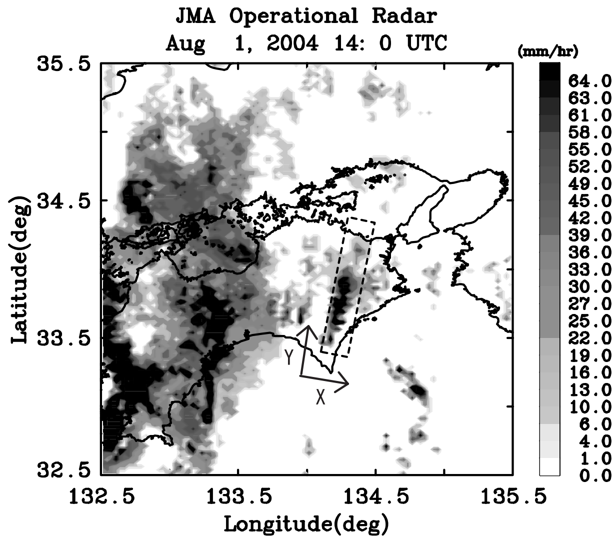

Figure 4: Horizontal distribution of precipitating intensity observed by JMA operational radar at 14 UTC on 1 August 2004. In this study we notice the rainband enclosed by rectangle.

3. Results

3.1 Background field and characteristic features of the rainband

As shown in Figure 2, Typhoon Namtheun struck the west side of Kochi around 7 UTC 31 August, 2004. It run through the west part of Shikoku region and moved to the north over the Japan sea. The surface weather chart at 00 UTC 1 August is shown in Figure 3. The center of typhoon was analyzed at the northwest of the Shikoku region and it also on the edge of Pacific high pressure. In this situation, southerly wind became dominant easily in the lower layer around Shikoku region.

Figure 4 shows horizontal distribution of precipitating intensity. After the typhoon passed, some line-shaped MCSs were observed over Shikoku region around 00 UTC 1 August. In this study we notice a rainband enclosed rectangle in Figure 4 because it hardly changed its position and direction till 20 UTC 1 August, for about 20 hours while other precipitating echoes were changing its directions and positions. The rainband was narrow ($\sim$30 km), long ($\sim$100 km) and was along the mountain ridge over the Shikoku region. Figure 5 in-

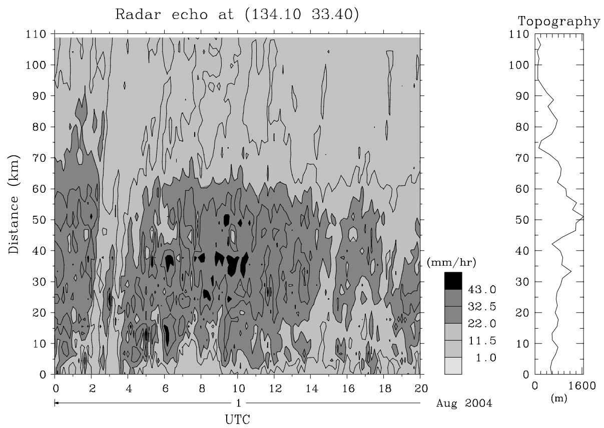

Figure 5: Time series of the maximum rainfall intensity of an X-axis in a rectangle as shown in Figure 4 on from 00 to 20 UTC 1 August 2004 and land height averaged in the rectangle along the X-axis. A vertical axis corresponds to Y-axis in Figure 4.

dicates time series of the maximum rainfall intensity along the X-axis of the rectangle shown in Figure 4. Strong (more than 50 mm/hour) and stationary rainfall was observed from 00 to 20 UTC. Cellar radar echoes generated on the north side of the Muroto cape (corresponding to the rectangular north in Figure 5) were thrown northward one after another and formed rainband. The length of the rainband was about 100 km from 00 to 02 UTC, and 60 km from 12 to 20 UTC. It became shorter as time passed. Horizontal velocity of the cellar radar echo averaged from 00 to 02 UTC was about 20.5 m/s. It became 15.8 m/s from 12 to 20 UTC. Horizontal speed of precipitating echo also became slower as time passed. Moreover, it is thought that the rainfall was strengthened by geographical features because especially strong rainfall echoes were observed in the high mountain area.

Upper-air soundings launched at Shionomisaki on 00 and 12 UTC 1 August are used to examine the atmosphere condition around the rainband. The atmosphere was convectively unstable and very moist (relative humidity in the layer was more than 85 %) below 3 km height. We calculated the Froude number Fr = U / Nh, where h is the height of the mountains assumed to be 1 km height, N is the Brunt-Väisälä frequency, and U is horizontal wind speed averaged below the mountain height. During the rainband observed, the Froude number was about 1. Following Smolarkiewicz and Rotunno (1989, 1990), it is easy for the airflow with large Fr ($\sim$ 1) among the present cases to rise over the mountains than detour them. Lifting Condensa-

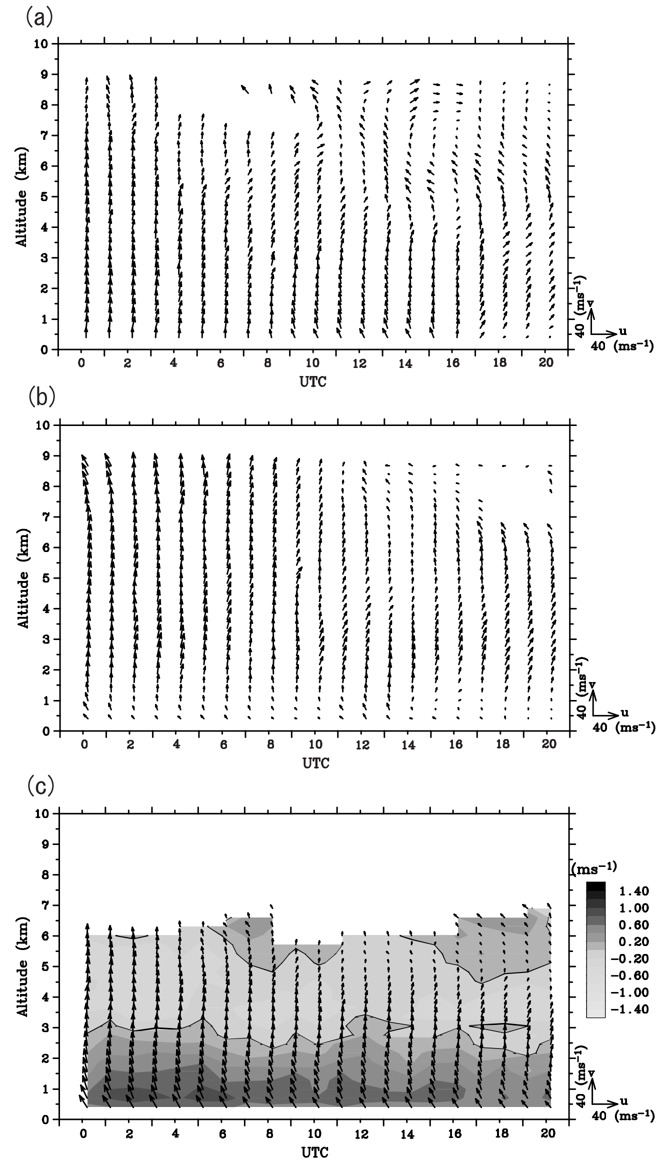

Figure 6: Time-height cross sections of horizontal wind (arrows) observed by wind profiler at (a) Kochi, (b) Takamatsu and (c) Wakayama on 1 August 2004. Vertical wind expressed by contours in (c).

tion Level (LCL) and Level of Free Convection (LFC) calculated from the surface were so low ($\times$ 400 m and $\times$ 900 m, respectively) that if there was airflow ascending to the peaks of the mountains, a necessary condition for the generation of clouds was satisfied, namely the upslope triggering for the convection.

3.2 Wind behavior along the rainband

Horizontal wind observed by wind profiler at Kochi, Takamatsu, Wakayama were shown in Figure 6. Kochi corresponds to windward side of the rainband. Southerly wind was dominant from the surface up to about 7 km during the rainband was observed, from 00 to 08 UTC. Though wind direction was changed with height after 8 UTC, it is not represent the wind around the rainband because the disturbance which goes west reached Kochi at this time. Takamatsu corresponds to leeward side of the rainband. Southerly wind was also dominant from 1.5 km to 7 km height there. Wind speed around 2 km height was almost consisted with moving speed of precipitating clouds calculated in previous section. Therefore it seems that the precipitating clouds generated on the north side of the Muroto cape were thrown northward by the southerly wind around 2 km height and formed rainband.

Wakayama located in the east side of the rainband. Updraft more than 0.4 m/s was observed in lower layer below 3 km height. This updraft was observed for a long time and similar updraft was observed at Tosa located in the west side of the rainband (not shown). Therefore the updraft in the lower layer was thought to be existed to the wide range which include Muroto cape and it enabled the continuation of the rainband. Moreover, southeasterly wind blew into the rainband below 2 km altitude and it had strengthened the precipitating clouds further.

4. Concluding Remarks

In this paper, the localized heavy rainfall that happened in Shikoku region on 1 August 2004 was examined. The line-shaped MCS was extended from the north of Muroto cape and was $\sim$ 100 km and 20 km in length and width. It maintained for about 20 hours almost without changing its direction and position. Precipitating clouds were generated the north of Muroto cape and advected to leeward (northward) by the lower wind (about 2 km altitude) one after another and then formed the rainband. Convectively unstable stratification was found below 3 km height and there was much water vapor in that layer. The Froude number averaged in a layer from the sea surface 1 km altitude was $\sim$ 1 Therefore airflow should be risen over mountains than detour them. The LCL and LFC was low enough to develop precipitating clouds by updraft caused by geographical features. Updraft more than 0.4 m/s had been observed in lower layer below 3 km height while the rainband was observed. Moreover, there southeasterly wind blew into the rainband below 2 km altitude and it had strengthened the precipitating clouds further.

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