STRUCTURE AND DEVELOPMENT OF TWO MERGED RAINBANDS ALONG THE BAIU FRONT AND THE "WATER VAPOR FRONT" OVER THE EAST CHINA SEA DURING X-BAIU-99

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1. INTRODUCTION

Over the East China Sea during the Baiu season, convective rainbands are often generated to the south of the synoptic-scale convergence of the Baiu front. During a field experiment of X-BAIU-99 (Fig. 1), development of two merged rainbands observed over the East China Sea. A northern rainband was located along the Baiu front, and a southern rainband was observed in southerly wind field. The formation mechanism of a rainband other than the convergence of the Baiu front still has not been understood over ocean where there are no land effects. In this study, structure and development of two merged rainbands are investigated to understand the formation mechanism of rainbands in the south of the Baiu front.

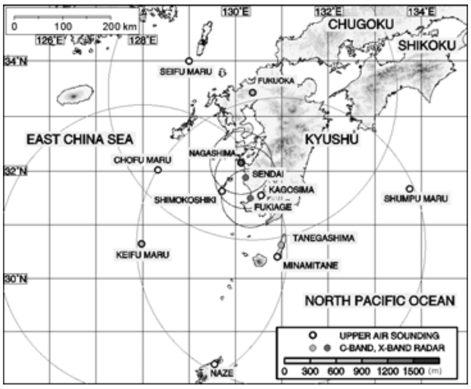

Fig. 1. Map of the experimental region of the X-BAIU-99. Three large circles show the maximum observation ranges of C-band radars. Three small circles show the maximum observation ranges of X-band Doppler radars.

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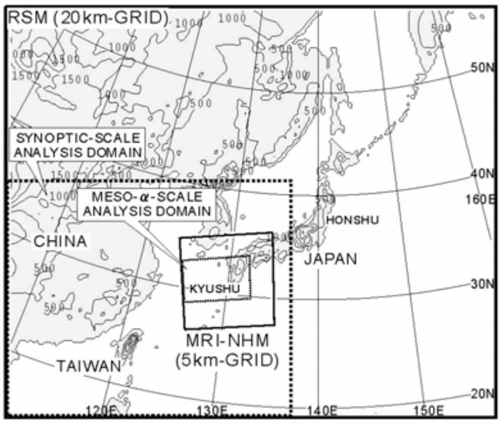

Fig. 2. Map of domains of a 20-km resolution hydrostatic model: 20 km-RSM (the thick-lined box) and a 5-km resolution non-hydrostatic model: 5 km-NHM (the thin-lined box). Analysis domains of synoptic-scale and meso-α-scale are represented by the thick and thin dotted boxes, respectively.

2. DATA

In this study, the following data with the X-BAIU-99 are used. Data from three C-band radars at Fukuoka, Tanegashima, and Keifu Maru are used for detecting meso-α-scale behaviors of precipitation systems. Dual Doppler analysis with X-band Doppler radars at Sendai and Fukiage are used for investigating meso-β-scale air-flow structure. Upper-air sounding data at seven additional sites (Nagashima, Shimokoshiki, and Minamitane, and observation vessels Seifu Maru, Chofu Maru, Keifu Maru, Shumpu Maru) were used for the initial field of numerical simulations. The numerical simulations (Fig. 2) are conducted with a 20 km-resolution Regional Spectral Model (20 km-RSM, a hydrostatic model used operationally in Japan)

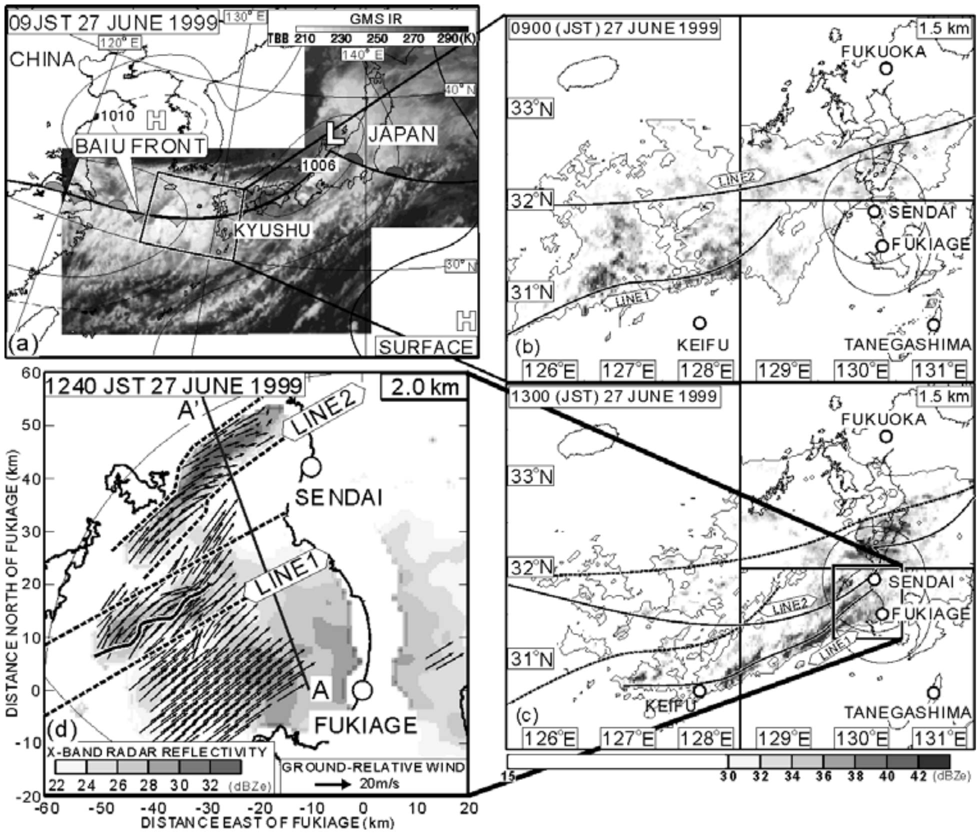

Fig. 3. (a) GMS infrared image superimposed on surface weather map at 09JST on 27 June 1999, composite reflectivity images with C-band radars at (b)09JST, (c)13JST, and (d)reflectivity image and ground-relative winds with X-band Doppler radars at 1240JST. The dashed lines shown in (c) represent the positions of LINE1 and LINE2 at 09 JST. The thick solid line along LINE1 in (d) denotes the weak convergence line. The line of A-A' indicates the position of vertical cross section shown in Fig. 4.

and a 5 km-resolution Non-Hydrostatic Model (5 km-NHM, a non-hydrostatic model developed by Meteorological Research Institute). The 5 km-NHM is one-way nested within the RSM from 06 JST to 15 JST on 27 June 1999.

3. RESULTS

3.1 Overview of two merged rainbands

Figure 3 shows overview of two merged rainbands. Over the East China Sea, convective clouds are seen to develop in the south of the Baiu front at 09 JST on 27 June 1999 (Fig. 3a). According to composite reflectivity image with C-band radars (Fig. 3b), a northern rainband is located along 32 degree N, and a southern rainband is located in about 100 km south of the northern rainband at 09 JST. The southern and northern rainbands are called LINE1 and LINE2, respectively. LINE2 moves southeastward, and merges into the quasi-stationary LINE1 at 13 JST (Fig. 3c). LINE1 develops rapidly in this merging. Before the merging at 1240 JST, LINE1 formed in a southwesterly wind field associated with a low-level convergence line (Fig. 3d). LINE2 formed along a synoptic-scale convergence line of the Baiu front ahead of low-level northerly winds (Fig. 4). As the merging of LINE1 and LINE2 occurred, the low-level convergence along LINE1 was intensified, and LINE1 developed rapidly (not shown, see Moteki et al. 2004a).

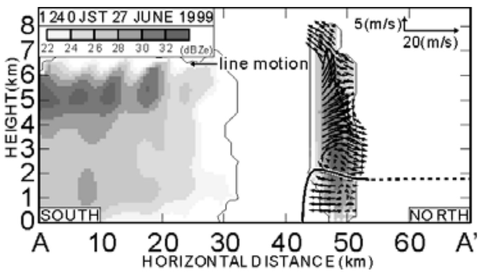

Fig. 4. Vertical cross section of reflectivity and ground-relative winds along A-A' shown in Fig. 3(d). The thick line indicates the boundary of a layer of northerly winds.

3.2 <u>The “water vapor front” in the south of the Baiu front</u>

In order to investigate the thermodynamic and moisture structures of the two rainbands, a numerical simulation is conducted with the 5 km-NHM. In the 5 km-NHM simulated field (Fig. 5a), LINE2 forms along a convergence line ahead of northerly winds. The convergence line is accompanied by remarkable horizontal gradients of potential temperature θ (2-3 K per 50 km) and mixing ratio of water vapor q_v (2-3 g kg^{-1} per 50 km, not shown) at a height of 0.02 km. The features of the convergence line are consistent with those of the Baiu front shown in many previous studies (e. g., Matsumoto et al. 1971; Kato, 1985). LINE1 forms along a weak convergence line in the south of the Baiu front. It is found that the weak convergence line has almost no gradient of θ differing from the Baiu front. However, the weak convergence line was accompanied by only a gradient of q_v (2 g kg^{-1} per 10 km, not shown, see Moteki et al. 2004b) in the layer of 0.5-1.5 km. In this study, the weak convergence line in the south of the Baiu front is named a “water vapor front.” It is found that there are two distinct frontal convergence lines over the East China Sea: the Baiu front and the “water vapor front.”

Figure 5b shows a vertical cross section across the Baiu front and the “water vapor front.” At the position of the “water vapor front,” a depth of a warm-moist air mass becomes rapidly shallow. A high q_v and θ (warm-moist) air mass is over 1-km deep to the south of the “water vapor front,” but its depth becomes less than 0.5 km between the “water vapor front” and the Baiu front. The warm-moist air mass flows into the Baiu front only in the layer below 0.5 km. These two types of frontal structures raise as significant question. What is an air mass flowing from the west between the two fronts?

In order to investigate the synoptic-structures of the two fronts, a numerical simulation is conducted with the 20 km-RSM. Over the East China Sea, two significant convergence zones are seen (Fig. 6a). Comparing to the surface weater map in Fig. 3a, a northern convergence zone ahead of northerly winds is correspond with the Baiu front. A southern convergence zone can be recognized as the “water vapor front,” and it extends from the eastern coast of China to Kyushu with a length of about 1000 km.

In Fig. 6b, there are three air masses around the two fronts. A cold and dry air mass to the north of the Baiu front is associated with northerly winds. A oceanic moist air mass over the East China Sea is associated with southwesterly winds, and its q_v at the surface is over 19 g kg^{-1}. A continental moist air mass over the mainland of China is associated with weak southwesterly or westerly winds, and its q_v at the surface is 15-19 g kg^{-1}. Because roughness over lands is larger than that over oceans, winds of the continental moist air mass is much weaker than those of the oceanic moist air mass.

It is found that the continental moist air mass flows partially over the western part of the East China Sea between the Baiu front and the “water vapor front.” The boundary of continental and oceanic moist air masses is accompanied by a weak convergence due to the difference of speed and direction of winds. Therefore, the convergence line of the “water vapor front” was formed by two distinct moist airflows over the East China Sea.

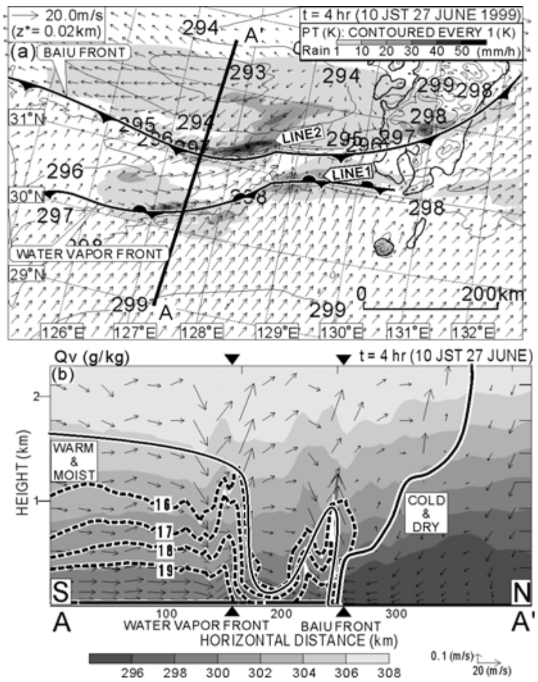

Fig. 5. (a)The rainfall area (shaded), potential temperature (contours), and horizontal winds reproduced by the 5 km-NHM at a height of 0.02 km at 10 JST on 27 June 1999. (b)Vertical cross section of potential temperature (shaded), mixing ratio of water vapor over 16 g kg^{-1} (dashed contours) along A-A’ shown in (a). The thick and thin solid line indicate the upper-boundaries of cold-dry and warm-moist air masses, respectively.

4. CONCLUSIONS

The present study found a existence of the "water vapor front" over the East China Sea. Two distinct frontal convergence lines of the Baiu front and the "water vapor front" developed the two rainbands without any land effects. In association with the frontal merging, the two rainbands merged and developed rapidly.

The "water vapor front" is the boundary of two distinct moist air masses over the East China Sea. One is an oceanic moist air mass from the southwest, and the other is a continental moist air mass from the west. The "water vapor front" has a remarkable gradient of q_v (2 g kg^{-1} per 10 km), but no gradient of θ differing from the Baiu front. The reason that convective rainbands are often generated in the south of the Baiu front can be clearly explained by the existence of the "water vapor front."

Finally, it should be pointed out that the definition of the "water vapor front" is almost the same as that of "dryline" over the Great Plains. That is, a weak convergence line with a remarkable moisture gradient between oceanic and continental air masses. Discussions about the "water vapor front" should be required in comparison with the "dryline" in the future.

Acknowledgements

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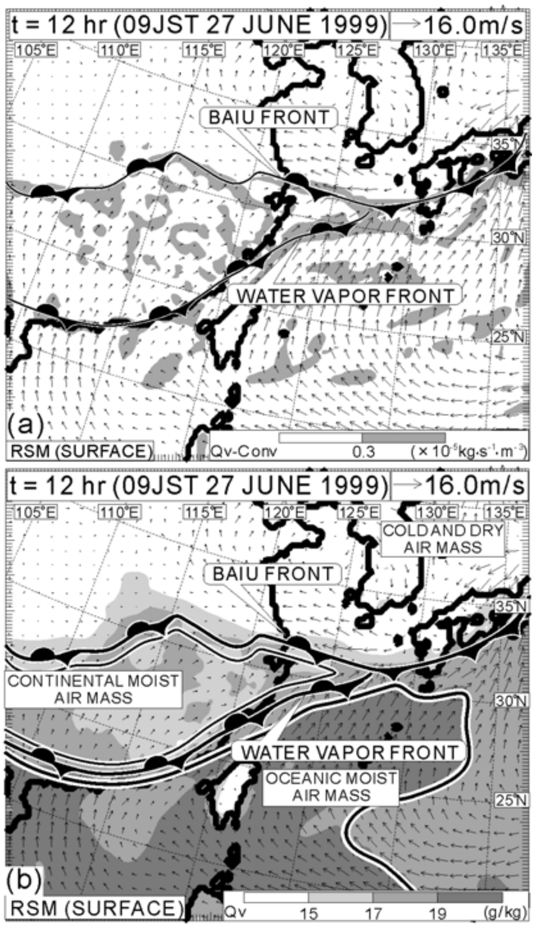

Fig. 6. (a)RSM-simulated fields of horizontal water vapor flux convergence at the surface at 09 JST on 27 June 1999, and (b)mixing ratio of water vapor at the surface.