Studies on Orographic Rainbands Based on Combined Wind Profiler-Weather Radar Observations

Yasuko Umemoto
Laboratory of Radar Atmospheric Science, RISH, Kyoto University

The phenomena in the atmosphere are classified according to their horizontal scale. The scales of air motion encountered in cloud dynamics can be divided roughly into three ranges: the synoptic scale which exceeds about 2000 km in horizontal scale, the mesoscale which covers between about 20 and 2000 km in scale and the convective scale covering between 0.2 and 20 km (1). Convective clouds like thunderstorms as an isolated entity bring strong rainfall in 30 minutes ~1 hour and often occur in large groups and complexes. These complexes, referred to as Mesoscale Convective Systems (MCSs), are generally much larger than each cloud and of considerable scientific interest and practical importance. MCSs sometimes last for a long time through self-multiplication, which result in heavy rainfall in local area. It is important to understand MCSs very well, because they must be forecasted within several hours and it is difficult to forecast them in such a short time so far. MCSs also produce a large proportion of the earth's precipitation and thus are important from a climatological point of view. MCSs occur in a variety of forms such as multi-cell thunderstorms, supercell thunderstorms, squall lines and rainbands. When the generation mechanisms are considered, one important source of air motions in clouds is the flow of air over hills and mountains. While there are various types of orographic precipitation generated over and around the mountains (2), orographic precipitation of upslope or upstream triggering of convection often produce heavy rainfall and has been studied primarily over and around high mountains; e.g., the Rocky Mountains (3), Hawaii Islands (4), the Hokkaido Orofune mountain range (5), the southeast sides of the Kii Peninsula (6), Kyushu Yaku Island (7), and the Nagasaki Peninsula (8). However, the generating and developing mechanisms of these orographic precipitations have not been sufficiently clarified. It was difficult to obtain sufficient observational data over complex orographic and oceanic regions. Moreover time and space resolutions of operational observation by the Japan Meteorological Agency (JMA) have not been fine enough to investigate the MCSs.

A series of special observation campaigns, called "X-BAIU" were conducted over the East China Sea and Kyushu during the Baiu seasons from 1998 to 2002 (9). The purpose of this campaign was to investigate MCSs and disturbances in the Baiu front around Kyushu and the East China Sea. In these campaigns, X-band Doppler radars and wind profilers were installed. There had never been observations combining two or more the Doppler weather radars and two or more wind profilers done before. Wind profiler observations are well suited to examine detailed wind behavior including the vertical wind component associated with the MCSs (~100 km horizontal extent). Application of the wind profiler technique to the Baiu-frontal atmosphere was initiated by using a VHF-band profiler (the MU radar) (10, 11). In recent years, L-band wind profilers were developed in order to observe the lower troposphere (12). Wind profilers have the advantage that they can observe the wind behavior in no precipitation area, where typical weather radars cannot. However, the observation area is limited horizontally close to the radar. The JMA has operated the Wind profiler Network and Data Acquisition System (WINDAS) which consists of 31 wind profilers in Japan. In order to detect and predict severe storms, the interval of each site is 130 km on average.

To understand the structure of orographic rainbands and figure out mechanisms of their formation and development over coastal regions of Japan, detailed analyses of the orographic rainbands occurred in Kyushu in the Baiu season and in Shikoku in the summer season using various data sets are conducted. In order to understand the orographic rainband occurred over Kyushu, the rainbands extending northeastward from the Koshikijima Islands (Koshikijima line) observed on the south side of the Baiu frontal convergence zone on 28~29 June 1999 and 30 June~1 July 2002 during the field experiments "X-BAIU" are selected. The structures of the Koshikijima line are investigated based on observations by the C-band weather radars and the X-band Doppler radars. The Koshikijima line was consisted of some strong cellular precipitation clouds aligned in the southwest-northeast direction. The precipitation cells generated over the Koshikijima Islands propagated northeastward one after another in the rainband. The Koshikijima line with the length of 120~200 km and the width of 8~20 km had been maintained for about 11 hours. Vertical-temporal variations of wind around the Koshikijima line were indicated by the wind profilers and the X-band

Doppler radars. While the Koshikijima line appeared, strong southwesterly wind (~20 m/s) was predominant from the surface to 5 km altitude. The direction of the rainband agreed with the direction of the horizontal wind averaged below 3 km altitude. In addition, there was a strong shear normal to the rainband below 3 km altitude (13).

To understand the orographic rainband occurred over Shikoku, the rainband extending northward from the Muroto Cape on 1 August 2004 was selected. The rainband was generated on the north side of the Muroto Cape and stayed for about 20 hours after the typhoon Namtheun passed over Western Japan. The structure of the rainband was investigated by the C-band weather radars. The rainband had the length of ~100 km and the width of ~30 km, and consisted of some strong cellular precipitation clouds aligned in the south-north direction. The precipitation cells generated on the north side of the Muroto Cape propagated northward one after another in the rainband. Vertical-temporal variations of wind around the rainband were indicated by three wind profilers of the WINDAS. While the rainband occurred, strong southerly wind more than 15 m/s was predominant from the surface to 7 km altitude on the windward and leeward side of the rainband. The moving speed of cellular echoes in the rainband was almost consistent to the horizontal wind around 2 km altitude. In addition, there was a shear parallel to the rainband below 2 km altitude. Southeasterly wind was predominant below 2 km altitude on the east side of the rainband. Besides, updraft more than 0.4 m /s had been observed continuously in lower layer below 3 km altitude around the rainband.

Atmospheric conditions around the Koshikijima line and the rainband at Shikoku were examined by the upper-air sounding analyses. While these rainbands were observed, convectively unstable stratification, large Froude number (Fr) (>1), low Lifting condensation level (LCL) (below the top of the mountains around the rainband), large Convective available potential energy (CAPE) index and much water vapor were found in the lower layer. The generating process of these rainband is as follows: convective clouds were generated by effect of the geographical features and moved to the leeward side one after another by background wind. Then the precipitation cells formed the band-shaped rainfall. The direction of the rainband was result in the propagation of clouds, which was associated with the wind direction around 2~3 km altitude. In addition, generation and redevelopment of clouds by orographic effect and inflow on the leeward side of the rainband help the rainband to develop and form the long rainband. Even low mountains were capable of forming an organized precipitation band under the environmental fields in which there were a moist convectively unstable atmosphere, LCL was lower than the top of the mountains at the generating region, and there were both large Fr (>1) and strong wind in the lower troposphere. These results could be applied to not only the rainband in the present cases but also other region in other season.

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