NUMERICAL STUDY OF THE SHAPES AND MAINTENANCE MECHANISMS OF MESO-β SCALE LINE-SHAPED PRECIPITATION SYSTEM IN THE MIDDLE-LATITUDES

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1. Introduction

Precipitation systems that cause severe disasters often have the line-shaped precipitation regions. These precipitation system has a scale of 100km (meso-β scale), and the convective cells generate one after another in the systems. The repeating generation of the cells leads to the long life of the systems.

Line-shaped precipitation systems reported so far are divided into mainly two types; squall line (SL) type and back building (BB) type. The structure of the SL type is similar to the squall lines observed in the Midwest of U.S. In the BB system, the convective cells generate in the tip of the system repeatedly, and move backward. Besides these types, the systems with the carrot-shaped cloud region often inflict heavy rainfalls.

The structure and long-lasting mechanism of the SL type are relatively well-known. However, other types are not fully investigated yet. Therefore, the precipitation systems of each type were analyzed by special observation data and the outputs of the numerical simulation. The results of the analyses are summarized in the section 2.

Because the results of the analyses indicate that the environment of the systems (e.g. vertical profiles of horizontal wind and humidity) depends on their types, the numerical experiments were performed by changing the environment conditions to investigate the factors that determine the type of the precipitation systems.

2. Case studies

In this section, the observed features of the observed line-shaped precipitation systems are summarized.

2.1 Squall line (SL) type

A line-shaped precipitation system developed over the Kanto area on 16 August 1995 (Seko et al,1998). The intense convections developed along the front side of the system, and the wide weak precipitation region existed on its rear side. The airflow structure consisted of the two airflows: One is the low-level inflow of warm and humid air from the south. It was lifted up by the outflow of the system along its front-side edge. And another flow is the middle-level rear inflow that invaded into the system. When this system passed, the temperature descended more than 10°C and the gust of 24m/s was observed. This indicates that the rear inflow generated the cold pool by the evaporation of the water substances.

2.2 Back Building (BB) type

The cloud cluster that consisted of the several meso-βscale precipitation systems stayed over the southern Kyushu on 7 July 1996 (Seko et al. 2000). The meso-β scale system was further composed of several short convective bands. The short band in the meso-β scale system indicates that a scale exists between the meso-β scale and meso-γ scale. Hereinafter, this scale of the short bands is referred to as the meso-βs scale. In these meso-βs bands, the new convective cells generate at the tip of the band repeatedly, and moved backward. Because the generation point of the cells was only near the tip of the band, the length of the bands was shorter than that of the meso-β scale system. The direction of the middle-level inflow was almost same to that of the low-level inflow, and the bands extended to the leeward side of the middle-level wind. The low-level inflows entered the meso-β system from the south and ascended at the tip of the meso-βs scale bands. The middle-level airflows passed between the meso-βs scale bands.

2.3 Back and Side Building (BSB) type

The precipitation system with the carrot shaped cloud region was observed over the Kanto area when the typhoon 9426 was approaching to Japan (Seko et al.1999). The precipitation system extended to the same direction of the middle-level wind and the width of the cloud became wider at the leeward side, producing the carrot-shaped cloud region. The relation of the low-level inflow and middle-level wind was different from those of the SL type and the BB type: the direction of the middle-wind was perpendicular to that of the low-level inflow. The convective cells were generated on the upwind side of the middle-level wind (back building) and moved to the leeward side, and merged into the long intense convective band. After merging with the band, the convective cell was enhanced by the low-level inflow from its lateral side (side building). From these features, this carrot-shaped band had the new mechanism that should be called 'back and side building type'.

3. Numerical experiment under the simplified environmental condition

The comparison of the observed precipitation systems suggests the environmental factors that determine their type. The low-level convergence was common in aforementioned three cases. On the other hand, the middle-level wind direction to the low-level inflow and the middle-level humidity depended on the types. Thus, the numerical simulations were performed by changing these factors. In this study, non-hydrostatic model of Meteorological Research Institute was used. The horizontal grid interval of 2km was adapted to reproduce the convective cells.

When the direction of the middle-level wind was opposite to that of the low-level inflow, the intense convective band developed along the convergence line. The rear inflow at the middle-level descended and the cold pool was produced near the surface (Fig. 1a).

When the directions of the middle-level wind was same as that of the low-level inflow, the short convective bands generated side by side along the convergence line in the meso-β scale system (Fig. 1b). The short convective bands extended to the direction of the middle-level wind. In these bands, the new convective cells were generated at the upwind tip of the bands, and moved to leeward. When the direction of the middle-level wind was perpendicular to the low-level inflow, the intense band developed (Fig. 1c).

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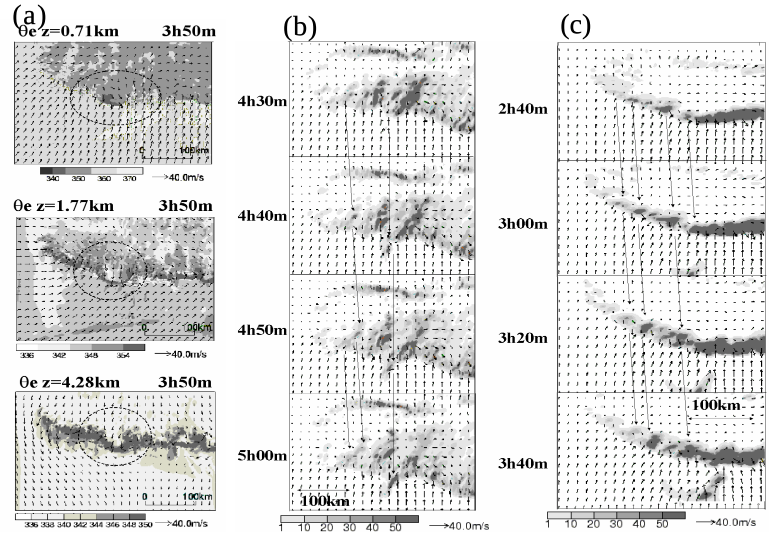

Fig.1 Precipitation system simulated with the simplified environment condition. (a) Horizontal distribution of equivalent potential temperature when the middle-level wind direction is opposite to the low-level inflow. (b)Precipitation distribution when the directions of the middle-level wind and low-level inflow are same. (c) Same as (b) except for the middle-level direction perpendicular to the low-level inflow.

Although the shape of the band was similar to the band in which the direction of the middle-level wind was opposite to that of the low-level inflow, the middle-level airflow did not descend and the intense cold pool was not produced. The convective cells generated on the upwind side of the middle-level flow, and moved to leeward.

These simulated features in three experiments were the same as the observed ones. This result indicates that the direction of the middle-level wind is one of factors that determine the type of the precipitation system.

When the relative humidity between the heights of 1.5km and 4.5km was reduced, the relation between the type of the precipitation systems and the directions of the middle-level wind and low-level inflow was not changed, although the weak precipitation generated more widely. This result indicates that the middle-level humidity is not the primary factor that determines the type of the system.

4. SUMMARY

Besides the precipitation systems of the SL type and the BB type that have been investigated so far, it was found that the precipitation system of the BSB type that often caused the heavy rainfall exists.

When three types of the precipitation bands were compared, there are the differences in their environments and structures. As for the environment of the systems, when the direction of the middle-level wind is opposite, same and perpendicular to that of the low-level inflow, the precipitation system of the SL type, the BB type and the BSB type developed.

The shapes and structures of these systems were explained from the viewpoint of the middle-level wind (Fig.2). In the SL, the middle-level rear wind descends in the precipitation system and enhances the outflow of cold air. The outflow intensifies the convergence with the low-level inflow, and the narrow intense convective band developed along the convergence line. In the BB type, the middle-level wind moves the convective cells to leeward, producing the meso-βs scale convective bands. Since the directions of the low-level and middle-level winds are same, the structure, with which the meso-βs scale bands develop side by side, is favorable for the low-level inflow to ascend without disturbing the middle-level wind. In BSB type, the new cell generates on the upwind side of the band, and moves to leeward with being intensified by the low-level inflow from the lateral side. This evolution of the cells produces the carrot-shaped precipitation region.

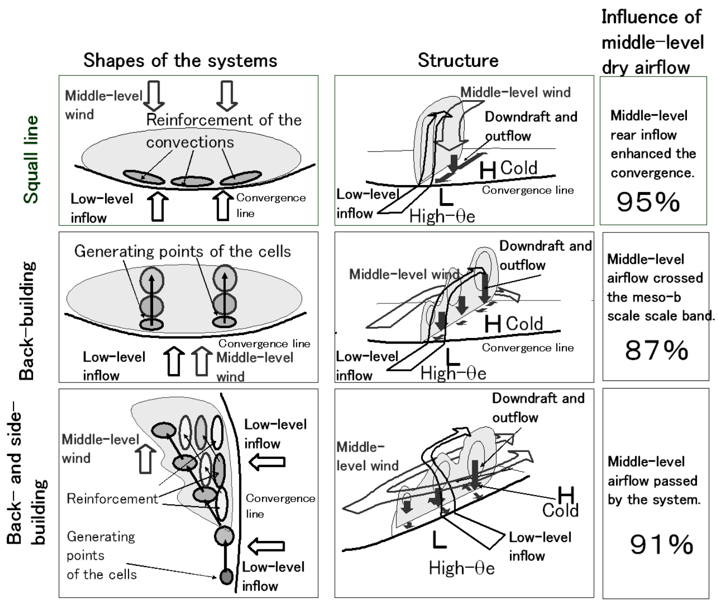

Fig.2 Schematic illustration of the shapes and structures of the precipitation systems. Right column indicates the decrease rate of precipitation amount

The numerical experiments were also performed with changing the middle-level humidity. The types of the systems were not changed when the middle-level humidity was reduced. However, the decrease of precipitation amount depends on the types. Precipitation amount was decreased slightly in the SL type, while it was decreased significantly in the BB type. This difference can be explained by the middle-revel flow. In the BB type, the middle-level flows entered the meso-β scale precipitation system and evaporated water substances while they crossed the precipitation regions. In the BSB type, the middle-level flow made a detour to avoid the system and the middle-level airflow did not evaporate water substances of the system. In the SL type, the cool pool that was intensified by the middle-level rear inflow strengthened the low-level convergence, enhancing the convections, although the rear inflow evaporated water substances.