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The non-linear evolution of vortex disturbances along the Convergent Cloud Band

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Since existence of Convergent Cloud Band in winter over Japan Sea was pointed out (Okabayashi 1969), many studies on Convergent Cloud Band and meso-scale vortices along it have been conducted. In previous studies, it is concluded that meso-alpha-scale vortex disturbances by baroclinic instability (Ookubo 1995) and meso-beta-scale vortex disturbances are generated by barotropic instability (Nagata 1993). However, the situations of the analysis in these studies permit only one of these instabilities which were expected from observations. Since neither of these analyses treats the basic field which includes both instabilities, it has not been discussed disturbances with which scale are dominant.

The Convergent Cloud Band is characterized by a frontal structure with horizontal and vertical shear. By calculating the linear stability of a basic field which models such a frontal structure, we have been investigated the generation mechanism of the unstable modes and dominant unstable modes depending upon the characteristics of the basic field: the thickness of frontal transition layer, the potential temperature difference on ground and the stability of atmosphere. If the transition layer is thick, the growth rates of both meso-alpha-scale and meso-beta-scale unstable modes are almost same. As the transition layer becomes thin, meso-beta-scale unstable modes become dominant, meanwhile, other unstable modes having wave length of about 250km are newly generated which have features of both baroclinic and barotropic instabilities. As stability of atmosphere becomes small, meso-alpha-scale unstable modes become dominant.

In this study, in order to investigate the contribution of instabilities to generation and evolution of meso-scale vortex disturbances, we calculate time evolution of the basic field by using non-hydrostatic numerical prediction model CReSS (Tsuboki and Sakakibara 2006), and compare the vortex disturbances in the numerical model with the unstable modes in the linear theory.

First, we examine the case where the thickness of the frontal transition layer is 1000m and stability of the atmosphere is 1.6×10^4 as a reference case. In this case, although obvious vortices are not formed, meso-alpha-scale disturbance having wave length of 400km is found from anomaly of the pressure. The zonal-vertical cross-section shows that the constant-phase lines tilt westward with increasing height. The warm advection exists in front of trough, and the cold advection in rear of trough. These results show that the disturbance has the feature of baroclinic instability.

Second, we calculate time evolution of the basic field having the transition layer of 300m. The stability of the atmosphere is same as the reference case. In this case, meso-beta-scale vortex disturbances having wave length of 120km are generated in strong horizontal shear zone of the basic field. On the zonal-meridional cross-section at the height of maximum amplitude, the constant-phase lines tilt the direction of south-west to north-east. It indicates that eddy momentum flux tends to convert the mean kinetic energy through the horizontal shear, and these vortex disturbances develop through barotropic instability.

Third, we calculate time evolution of the basic filed having the stability of the atmosphere is 6.0×10^3 and the transition layer is 1000m. As the meso-alpha-scale disturbance generated in this case has the features of baroclinic instability as well as that of reference case. This disturbance develops faster compared to that of the reference case. This tendency agrees with the result by linear theory.

In this study, the features and generation mechanism of the disturbances have reasonable agreement with the results by linear stability analysis. In further study, we will investigate the contribution of heat flux to the development of the vortex disturbances.