The role of non-linear interaction among wave components in developing stage of meso-scale disturbances

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When winter pressure pattern grows stronger around Japan Islands, cold winter monsoon outbreaks from Eurasian Continent to Japan Sea. In such an environmental condition, strikingly broad cloud band, which is called “Convergent Cloud Band”, is often formed over the western Japan Sea. This region is called Japan Sea Polar-Airmass Convergence Zone (JPCZ), and it is well known that meso-alpha-scale or meso-beta-scale vortex disturbances often develop along this Convergent Cloud Band.

It has been suggested in previous studies that the meso-alpha-scale disturbances are caused by baroclinic instability (e.g. Ookubo,1995; Tsunboki and Wakahama, 1992) and meso-beta-scale disturbances by barotropic instability (Nagata, 1993). However, previous studies considered only one of these instabilities for analyzing generation mechanism of meso-scale disturbances. In such frameworks, it is impossible to discuss the kind of the dominant disturbances.

In order to address this problem, we considered a frontal structure, which can include both baroclinic and barotropic instabilities as the basic state. We discussed what kind of disturbances dominate by investigating linear stability. Under the typical parameters of the basic field which generate meso-scale disturbances on Convergent Cloud Band, both meso-alpha-scale and meso-beta-scale unstable modes have almost the same growth rates. Meso-alpha-scale unstable modes dominate in basic fields where frontal transition layer is thick and the stability of the atmosphere is small. For thin transition layer cases, intermediate type instability between barotropic and baroclinic instabilities is obtained as the fastest growing mode.

In this study, we calculate time evolution of the basic field by using non-hydrostatic model “CReSS”, and discuss the non-linear process of meso-scale disturbances. In the case with typical parameters, meso-beta-scale disturbances grow along strong horizontal shear zone initially according to the growth rate of meso-beta-scale disturbance calculated by linear stability analysis. After that, however, the growth of the meso-beta-scale disturbance slows down and meso-alpha-scale disturbances gradually become distinct.

The suppression of the growth of meso-beta-scale disturbances is caused by three wave non-linear interactions. When the disturbances grow sufficiently large the non-linear interactions subtract energy from the growing mode. In order for the three wave interaction to function, disturbances with other wave number are required. If there are only two unstable modes in the initial state, this process works only weakly and the growth of the meso-beta-scale disturbance continues for a long time, although meso-alpha-scale disturbance dominates after all.

Next, growth suppression of meso-beta-scale disturbances is explained from the viewpoint of interaction of waves using a simple two-dimensional model. In a simple two-dimensional model, the suppression of meso-beta-scale disturbances is also simulated, and this process is caused by interaction of waves. For meso-beta-scale disturbances, there are a plenty of waves with smaller wave number. The wave number means “total” wave number which also considers y-component. Since the scale of the meso-beta-scale disturbance is located between that of meso-alpha-scale disturbances and that of these large wave number disturbances, such an energy transport from a meso-beta-scale disturbance easily occurs. On the other hand, when meso-alpha-scale disturbances dominate initially, there are only little waves with smaller wave number and this energy transport process hardly occurs. Therefore energy transport from meso-alpha-scale disturbances to other waves is unlikely. These energy transport processes show that large meso-alpha-scale disturbances are more likely to keep the strength in later stage of the growth.