Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

AHW29-P02 Room:Convention Hall Time:May 21 13:45-15:15

The development of disturbance on the atmospheric density stratification

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There are many unknown issues about line-shaped rainbands (LRBs) which is one of the meso-scale meteorological phenomena making torrential rainfall events in Japan. The LRBs caused severe floods and landslide disasters such as the Fukui heavy rainfall 2004, the Hokkaido heavy rainfall 2010 and the Niigata-Fukushima heavy rainfall 2011. For disaster prevention, it is very important to reveal the formation mechanism of LRBs. To know the mechanism, the authors try to examine the stability of the density stratification using the small amplitude wave theory. In this study, the rainfall and thermodynamic effects are not considered. To simplify the discussion, this theory notes only the up/down motion of disturbance in the stratified atmosphere.

It is considered that LRBs are generated by disturbance of the unstable stratified atmosphere. Here, the authors apply the ship wave theory to explain the LRBs. Ship wave is the water surface wave generated by moving ships or waterfowls, and we can regard this ship as the origin of disturbance in the stratified water and air. Thus, this phenomenon is similar to the LRBs formation mechanism in the disturbance of stratified fluid.

However, the disturbance form of ship wave is different from the LRBs. On the one hand ship wave is formed by diverging waves and transverse waves, on the other hand LRBs is the long linear cloud. Therefore, we have to explain that these two phenomena are not completely different, so the authors have decided to observe ship waves in detail. As the observation objects, the authors use the satellite images of lee waves which are known to make the cloud shapes like ship waves. Observing more than 500 lee waves images, the authors found some lee waves which are like LRBs. So we can say that ship wave may become the line-shaped disturbance if it satisfies some conditions.

Based on the above, the authors attempt to give an origin of disturbance to the piecewise linear boundary layer which have a density interface using ship wave theory. This theory is based on the fundamental equation such as Navier-Stokes equation, continuity equation and invariant density equation, using small amplitude wave theory and method of stationary phase. These equations finally result in the dispersion relation and vertical direction velocity by disturbance. Calculating the disturbance amplitudes for all the wave numbers, the authors find three disturbance development forms. These forms are determined by the density difference and the internal Froude number as follow: 1) The stratification is stable. 2) The stratification is unstable and the internal Froude number is more than 1. 3) The stratification is unstable and the internal Froude number is less than 1. Among those three cases, the first case makes the form of ship wave. It is not important for the formation mechanism of LRBs which occur in the unstable atmosphere. The unstable stratification cases are the time development disturbance and change the horizontal existence region of disturbance by the base flow parameters. Especially, the second case changes its disturbance region significantly with the Froude number. The authors consider that this disturbance region is important for the form of LRBs.

Keywords: line-shaped rainbands, stability, ship wave, lee wave