NUMERICAL STUDY ON STRUCTURE AND MAINTENANCE MECHANISM OF TYPHOON SPIRAL BANDS USING THE CLOUD RESOLVING STORM SIMULATOR

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1. INTRODUCTION

Spiral bands are one of the characteristic meso-beta-scale structures of a typhoon in mature stage. Observational studies showed that spiral bands cause strong rainfall. It is, however, still unknown what dynamics and physical processes work to produce the strong rainfall within spiral bands, because it is difficult to perform an in-situ observation of a typhoon in its mature stage. Previous numerical studies have simulated the typhoon-scale distributions of spiral cloud bands. Detailed three-dimensional mesoscale structure, physical processes within the typhoon spiral band, and interactions of two neighboring spiral bands located near the typhoon center, however, are little unknown, because huge memories and high speed CPU are necessary for the numerical experiment of three-dimensional typhoon with resolving individual clouds. In order to simulate the detailed structure of spiral bands within a typhoon and to reveal dynamics and cloud physical process of the spiral band, we performed the typhoon simulation with fine mesh grid spacing using the Cloud Resolving Storm Simulator (CReSS)(Tsuboki and Sakakibara, 2002) and Earth Simulator.

In this study, we show detailed three-dimensional mesoscale structure of the typhoon spiral band, cloud microphysics processes of strong rainfall within the spiral band, and the effect from the inner spiral band to the outer neighboring spiral band when two spiral bands are located within a distance of a few tens kilometers near typhoon center.

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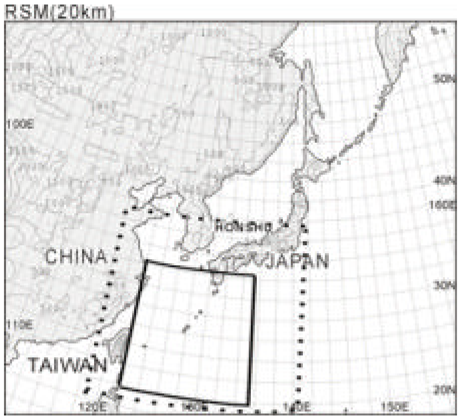

Fig. 1. Map of domains for JMA-RSM, CReSS-5km, and CReSS-2km. CReSS-5km is the area surrounding dotted lines and CReSS-2km is surrounding solid lines.

2. MODEL AND DATA

We used the Cloud Resolving Storm Simulator (CReSS) in this study. CReSS is a three-dimensional cloud resolving numerical model which formulated in the non-hydrostatic and compressible equation system with the cold rain bulk parameterization of the microphysics. In order to understand detail structure and physical process within the spiral band, two numerical experiments were conducted; one is an experiment with a horizontal resolution of 5km (CReSS-5km) and the other is of 2km (CReSS-2km). Vertical resolution in both experiments is stretched from 100m at the lowest level to 400m with height. The initial data for CReSS-5km is the Regional Spectrum Model by the Japan Meteorological Agency (JMA-RSM) at 00UTC September 4, 2002. In this data, T0216 (SINLAKU) in mature stage located near Okinawa, Japan. CReSS-5km ran for 24 hours. In CReSS-2km, this typhoon was simulated for 10hours from 06UTC using CReSS-5km outputs.

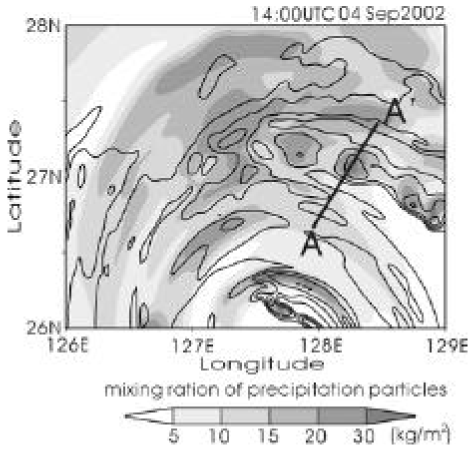

Fig. 2. Vertically integrated mixing ratios at 14UTC. Shadings are mixing ratio of precipitation particles. Contours are mixing ratio pf cloud particles every 1.5 kg m^{-2} from 1.0 kg m^{-2}.

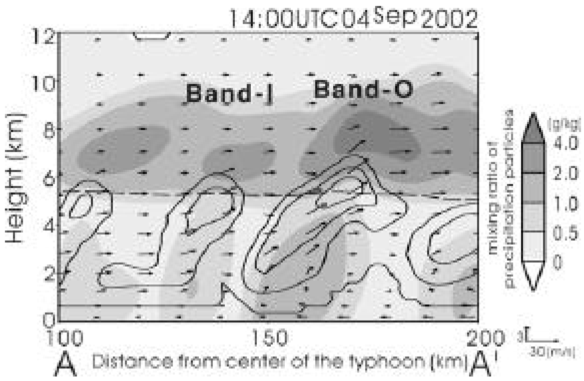

Fig. 3. Vertical cross-section of mixing ratios along A-A' in Fig.2. Shadings are mixing ratio of precipitation particles. Contours are mixing ratio of cloud particles every 0.3 g kg^{-1} from 0 g kg^{-1}. Dotted line is 0 degree line.

We used CReSS-2km outputs for analysis of the structure of spiral band and cloud microphysics within the spiral band. For the back trajectory analysis, CReSS-5km outputs were used. JMA-RSM and calculation domains are shown in Fig.1.

3. RESULTS

3.1 Structure of the typhoon spiral band

Large amounts of cloud particles are mainly present in the central part of the spiral band (Figs. 2, 3). They are transported along the axis of the spiral band from lower level to upper level, and generated from water vapor transported from lower level by condensation. Large amounts of precipitation particles are present in the outermost part of the spiral band. In particular, the maximum mixing ratio of precipitation particles is present on the outer side of the maximum mixing ratio of cloud particles, because wind over about 2km height is outward flow.

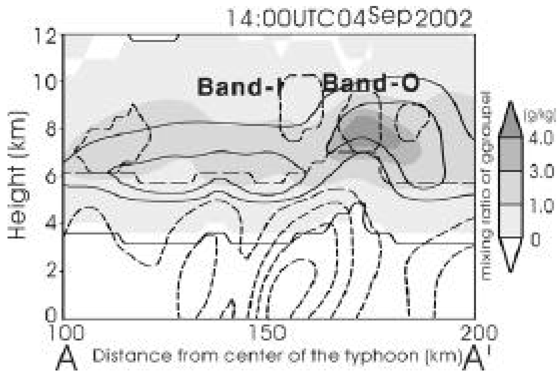

Fig. 4. Vertical cross-section of mixing ratio of precipitation particles along A-A' in Fig.2. Shadings are mixing ratio of graupel. Solid lines are mixing ratio of snow every 0.3 g kg^{-2} from 0 g kg^{-1}. Dotted lines are mixing ratio of rain water every 0.4 g kg^{-1} from 0 g kg^{-1}.

Examining more detailed distribution of precipitation particles in the spiral band, we show the vertical cross-section of spiral bands in Fig. 4. There are large amounts of graupel above strong rainfall areas in band-O. Snow is present mostly in the area between band-I and band-O, while a small amount of graupel exists there. This result shows that strong rainfall in the spiral band is caused by collecting cloud water by graupel.

3.2 Cloud microphysics within the spiral band

The strong rainfall process within the spiral band is clarified by investigating cloud microphysics. In particular, we investigate generation and growth of precipitation particles by collecting cloud particles. In the spiral band, large amounts of snow collect cloud water and grow to graupel by riming (Fig. 5a). Little snow grows to graupel between band-I and band-O, because there is small amount of cloud particles there. Therefore, there are larger amounts of snow between bands than in a spiral band. Large amounts of snow grow to graupel within spiral bands. Graupel grows larger by riming within Band-O (Fig.5b). Comparing riming by snow within Band-O with that of Band-I, riming by snow occurred to the same extend (Fig. 5a).

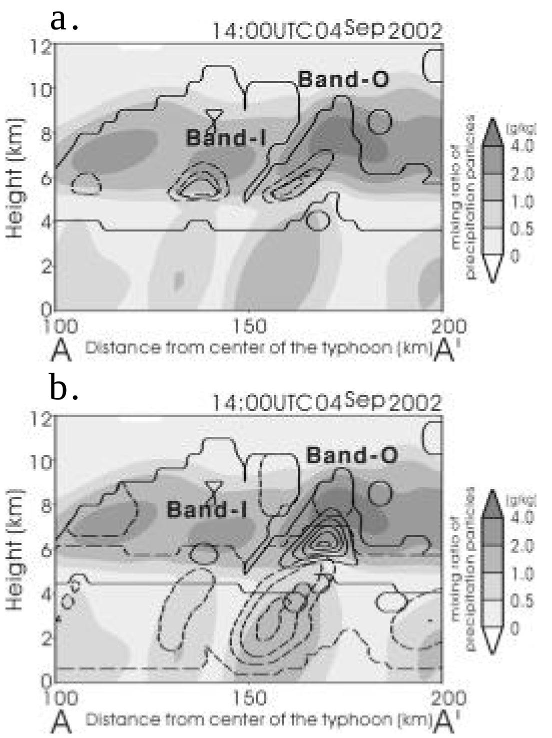

Fig. 5. Vertical cross-section of cloud microphysics processes along A-A' in Fig.2. a.: Dotted lines are riming by snow every $2*10^{-3}$ g $kg^{-1} s^{-1}$. Solid lines are growth from snow to graupel every $5*10^{-3}$ g kg^{-1} s^{-1}. Shading are mixing ratio of precipitation particles. b.: Dotted lines are collection of cloud water by rain water every $10*10^{-3}$ g kg^{-1} s^{-1}. Solid lines are riming by graupel every $10*10^{-3}$ g $kg^{-1} s^{-1}$.

Above the melting layer, cloud water within Band-O is larger than that of Band-I (Fig.3). Riming by graupel occurs more strongly by providing large amounts of cloud particles above the melting layer within the spiral band. It is necessary to produce or provide large amounts of cloud particles over the melting layer for strong rainfall within the spiral band. Therefore, it is found that riming by graupel is the most effective process for strengthening of rainfall within a spiral band.

3.3 Effect from the inner spiral band of two neighboring bands to the outer band

When two spiral bands are located within a distance of a few tens kilometers near typhoon center, it is often observed that rainfall of the outer band becomes intense. In Fig. 4, there are large amounts of snow between Band-I and

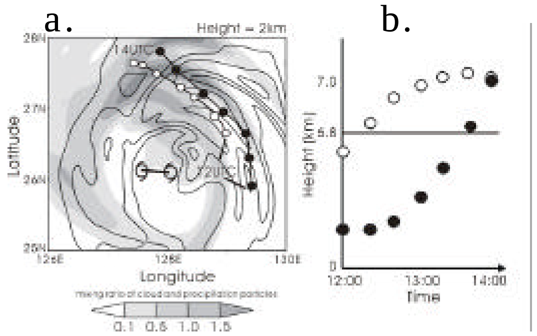

Fig. 6. Projection of trajectories set at 7km height from 12UTC to 14UTC. Horizontal track is a. Vertical track is b. The closed circle supposes cloud water, and the open circle is snow. Typhoon center moves from east to west. In a., shaded is mixing ratio of precipitation particles at height = 2km at 14UTC. Contours are mixing ratio of precipitation particles at 12UTC Contour levels are same as shaded levels. 0 degree line is at about 5.8km height.

Band-O. For generating graupel within Band-O, Snow between two bands is generated in Band-I and transported from Band-I to Band-O. Because there is little source for generating snow between two bands (Fig. 3). For understanding the effect of intensifying precipitation from the inner band to outer band, we used back trajectory technique (Golding, 1984). The back trajectory analysis is performed using the following algorithm

$$\mathbf{x}^{n-1/2}=\mathbf{x}^{n}-\mathbf{u}^{n}(\mathbf{x}^{n})*\Delta t/2$$

$$\mathbf{x}^{n-1}=\mathbf{x}^{n}-\mathbf{u}^{n-1/2}(\mathbf{x}^{n-1/2})*\Delta t$$

where $\mathbf{x}$ is position, $\mathbf{u}(\mathbf{x})$ is the interpolated mode velocity at position $\mathbf{x}$ and n is the time level. For the back trajectory analysis, CReSS-5km output every 5 minutes from 14UTC to 12UTC was used.

Origins of the back trajectories of snow and cloud water are edge of Band-O where riming by snow occurred and the place of the most generating graupel, respectively. Horizontal projection of trajectories set at 7km height is shown in Fig. 6a, and vertical projection is shown in Fig. 6b. In Fig. 6a, trajectory of cloud water (closed circles) moves along Band-O. Trajectory of snow (open circles) which suited Band-O at 14UTC has reached band-I at 12UTC. In Fig. 6b, moreover, it is shown that cloud water is transported from a height of about 2km to 7km.

The open circle is above the melting layer until 14UTC which reach Band-O from 1220UTC which comes out to the outside of band-I. This indicates that snow generated within Band-I is transported to Band-O by the outward flow. For generation and growth of graupel to intensify precipitation within Band-O, snow transported from Band-I becomes seeder, cloud water produced from lower level within Band-O is feeder.

4. CONCLUSIONS

Detail three-dimensional structures of the typhoon spiral band and cloud microphysics process for strong rainfall within the spiral band were studied by the numerical simulation with fine mesh. Large amounts of cloud particles and precipitation particles are present within the spiral band. Cloud water and water vapor are transported along the axis of the spiral band from lower level to upper level. Above the melting layer, there are large amounts of graupel above strong rainfall areas in a spiral band. Snow exists mostly in the area between bands.

In the spiral band, large amounts of snow transported from inside of the band by outflow collect cloud particles and grow to graupel. Generated graupel grows larger by riming, when there are large amounts of cloud water above the melting layer. Within spiral bands, generation and growth of graupel are the most effective processes to produce intense rainfall. There results show that cloud rain processes with the spiral band are important to intensify the rainfall within the spiral band.

When two spiral bands near typhoon center are located within a distance of a few tens kilometers, the conceptual model of mechanism of intensifying rainfall within the outer spiral band is shown Fig. 7. Snow particles generated within the inner band are transported to the outer band by outflow. And they become seeds for graupel generating within the outer band. Providing large amounts of cloud water over the melting layer by updraft within the outer band, generated graupel grows larger and falls down.

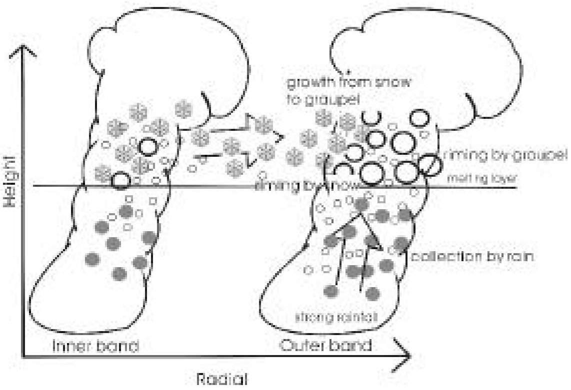

Fig. 7. Conceptual model of mechanism of intensifying rainfall within the outer spiral band. Small circles are cloud water White and gray big circles are graupel and rain.

Acknowledgements

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