Structures of Explosively Developing Extratropical Cyclones in Northwestern Pacific by Satellite Data

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Abstract
Horizontal distributions of explosively developing extratropical cyclone formed and developed in Northwestern Pacific Ocean in precipitation, water vapor, cloud liquid water, and surface wind fields are analyzed using the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) on Aqua Satellite dataset in recent 7 winter seasons. Cyclone center-relative compositing mean fields are constructed for four life stages: 1) developing, 2) maximum deepening, 3) minimum center sea level pressure (SLP), and 4) decaying. These stages are distinguished by a value and a kind of differentiation in center SLP using a database of cyclone tracking derived from a reanalysis dataset. The developing processes of the composited cyclone are documented.

In developing stage, the water vapor pass (WVP) has south-north (high-low) contrast corresponding to the temperature distribution. Corresponding to the cold-dry air mass advections, WVP concentration starts from western part of the cyclone center in the maximum deepening stage. The concentration is distinct along the cold front in the minimum SLP stage. The horizontal distributions at the maximum deepening stage agree with the previous study using global objectively analyzed dataset (GANAL). As the deepening rate is larger, the value and concentration is higher and stronger. Precipitation appears around the root of front corresponding to large cloud liquid water, while there is no precipitation near the cyclone center in minimum center SLP and decaying stages regardless of the strength.

Keywords: Extratropical cyclone, winter precipitation, satellite observation

1. Introduction
Extratropical cyclone is one of sources to supply heat and moisture from mid-latitude to high-latitude regions, so that it plays an important role for energy and material transportations. Explosively developing extratropical cyclones particularly form and develop frequently in northwestern Pacific and Atlantic in winter.

Development mechanisms of extratropical cyclones have been studied using numerical models and re-analysis data mainly in the Atlantic Ocean. On the other hand, Yoshida and Asuma² mention the characteristics of explosive cyclones in northwestern Pacific. They classified the cyclones into three types depending on cyclogenesis and rapid development, and suggested that the each type of cyclone has favorable terms of frequent appearance and atmospheric conditions such as jet stream and baroclinicity.

Satellite data enables us to investigate global vertical and horizontal structure in moisture, wind, and precipitation/clouds of the systems regardless of land and ocean. The heights of the cyclones and frontal precipitation over northwestern Pacific are concentrated around 3 km of echo top height and 6 km of cloud top height observed by the Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR) and infrared imager. Field and Wood showed that surface speed and/or water vapor path cause response a variability of cyclone-mean rain rate, cloud fraction, etc. derived from categorized cyclone relative composited using

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Fig. 1. Cyclone tracks investigated in this study. They correspond to PO-O cyclones defined by Yoshida and Asuma (2004). Triangles show positions of formation, circles show positions of maximum deepening rate, and crosses show positions of minimum center SLP.
the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Advanced Microwave Scanning Radiometer-EOS (AMSR-E) onboard the Aqua satellite. They concluded that the systemwide mean rainfall rates and composite structure are broadly agree with satellite estimates. However, the spatial distributions largely depend on the life stages the cyclones). Except for some case studies, there are few studies using composite analysis to focus on developing process of extratropical cyclones.

This study presents the developing processes of vertical and horizontal structure in the extratropical cyclones using satellite observation data.

2. Data and Method

This study investigates explosively extratropical cyclones which form and had rapidly developed in 20°N–65°N and 100°E–180° in 7 winter seasons (2002/2003–2008/2009 from October to March). The cyclone identification and tracking algorithms are based on Serreze6). We applies to SLP data installed in the Japanese 25-year Reanalysis (JRA-25) and the Japanese Meteorological Agency (JMA) Climate Data Assimilation System (JCDAS) products provided by the JMA7). At first, the JRA25/JCDAS longitude-latitude grids in northern hemisphere were converted to the Equal-Area Scalable Earth (EASE) grid about 125 km square area. For the SLP in EASE grids, a cyclone center was detected at the grid point less than 0.5 hPa next to 8 grid points. When the cyclone center existed less than 4 grid points (~500 km) from the previous 6 hours, the cyclone identified as the same. The definition of explosively developing cyclones and their classification method were applied to Yoshida and Asuma15). For this study we just use PO-O type cyclones (Fig. 1) because the AMSR-E products do not retrieve any hydrospheric products on the most of track over land for the rest of two-types. In order to identify for life stages for the every explosive cyclones selected in this study, we defined four life stages; 1) developing stage at the intermediate time between formation and maximum developing, 2) maximum developing stage at maximum deepening rate, 3) minimum center SLP stage, and 4) decaying stage at the intermediate time between minimum center SLP and cyclolysis.

We used some satellite observation data which form the constellation satellites named A-Train. The AMSR-E Ocean Products version 58) provides 0.25° × 0.25° grid data. The CPR is a spaceborne cloud profiling radar. The 2B-GEOPROF product provides cloud geometric profile expressed in terms of occurrence and reflectivity. The minimum detectable signal has −28 dBZ that enable to detect cloud top height.

3. Results

3.1 Case study for a typical explosive cyclone developed in 3-5 February 2008

Fig. 2. AMSR-E estimated cloud liquid water (upper color image) and vertical distributions of radar reflectivity factor observed by Cloudsat CPR (under color image) with orbit (red line on the upper image) for (a) developing and (b) maximum deepening stages. Sea level pressure (contour) and cyclone track (solid line) are illustrated on the upper image.
3.1.1 Synoptic Conditions

Figures 2 and 3 show a track of the explosive cyclone developed in 3–5 February 2008 and SLP fields at the four-life stages. The incipient cyclone was formed at 27°N and 127°E at 2 February 0600 UTC. The cyclone moved to ENE with 18 m s⁻¹ speed in average along the southern Japan Island. After the developing stage the cyclone increased its speed more than 23 m s⁻¹ with rapid depression, the cyclone has maximum deepening stages with 1.1 Bergeron at 3 February 1800 UTC. The cyclone continued both fast moving and depression until 961 hPa of the minimum center SLP stage at which 5 February 0000 UTC. At last, the cyclone disappeared at 6 February 1200 UTC with slow down (8 m s⁻¹) and system intensity.

3.1.2 Cloud liquid water (CLW)

At the developing stage CLW distributes widely from the west to east part of the cyclone, the CLW concentrated around the root of the front until the maximum deepening stage. A line of CLW formed and strengthened along to the cold front at the minimum center SLP and decaying stages, which seems to be a distinct frontal T-borne shape. At these stages, there is relatively weak CLW near the cyclone center with warm-core seclusion.

3.1.3 Vertical distributions of cloud

At the developing stage, the cloud top height near the cyclone center (35°N) reaches almost 10 km. A strong echo from precipitation (> 20 dBZ) also can be found at 7.5 km. While the southern edge of the cyclone cloud appears to be vertical, there are slope as going to top of the cloud. At the maximum deepening stage, the eastern side at the cyclone center also passed. The height of echo top does not have large difference. The CPR captured the cyclone center and cold front at the minimum center SLP stage. After the maximum deepening stage, the cloud top height keeps around 10 km although the cloud echoes were relatively weak over the cyclone center. In contrast, a narrow cloud radar pattern appears around the cold front compared to the horizontal distributions of CLW (30° and 35° N at the rest of two stages). This difference implies that cloud/precipitation is not well formed in spite of concentration of water vapor due to cold-dry advection from the backward of the cyclone.

3.2 Composite analysis

In order to check the possible factors to cause the strength of the explosive cyclones, we carried out a composite analysis for above mentioned parameters. The explosive cyclones for CO-O types (52 cyclones) are classified into strong (ST, ≥ 1.3 Bergeron) and weak (WE, < 1.3 Bergeron) patterns. The sample numbers of ST and WE are 17 and 35 cyclones, respectively. Atmospheric water vapor increases toward southward for both ST and WE patterns at the developing stage (Fig. 4). The slope for ST is steeper than that for WE, particularly the north part of the cyclone for ST is drier. Surface wind pattern (Fig. 5) also do not have remarkable difference of the distributions relative to the cyclone center, the northwestern dry advection are stronger for ST.

Compared to the results in Field and Wood⁴, the most different parameter of composite map is surface rain rate (not
Precipitation about 4 mm h⁻¹ appears from the center of the cyclone to the south-eastward at the maximum deepening stage. Although some precipitation bands derived from cold fronts are also observed for ST patterns at the minimum center SLP and the decaying stages, there is little precipitation around the center and eastward from a warm front. This difference may be because the precipitation could be the solid phase. Yamamoto et al.³ pointed out almost all precipitation did not estimated by TMI for the cold outbreak type from the comparison between TRMM PR and TMI. Precipitation retrieval algorithm for microwave radiometer are generally tuned to the tropical regions and are less suitable for the weak rain in mid-latitude regions⁹.

4. Concluding remarks

In order to better understand the vertical and horizontal structure of explosively developing extratropical cyclones depending on their life stage. Cloud liquid water, precipitation, and surface wind are concentrated around the center of the cyclone at the developing stage. Atmospheric water vapor increase latitudinally. At the maximum deepening stage, dry-cold air advection occurs from north-west of the cyclone center, which corresponds to the surface wind and atmospheric water vapor. The cold-dry advection, the concentrated area of the gale wind and atmospheric water vapor, moves south to south-east part of the cyclone center at the minimum center SLP and decaying stage. However, these changes depending on the life stages in precipitation do not appears maybe due to retrieval problem of microwave radiometer. There are not significant spatial differences from separately composited by deepening rate, but those contrast are distinct for all parameters except for precipitation. According to the case study, cloud echo-top height reaches around 10 km in the developing stages of an explosive cyclone, while significant echo pattern does not appear at the cold front for mature and decaying stage.

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References