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The Utilization of Rapid Scan Observation Data through Rapid Development Cumulus Area Index to Estimate Updraft

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Synopsis

Rapid Scan Observation (RSO) of Himawari-8 data is used to generate Rapid Development Cumulus Area (RDCA) index ranging from 0.1 to 0.9 by adapting logistic regression model. RDCA indicates the developing process of cumulus clouds that are potentially expected to evolve into thunderstorm within one hour in around 10 km^2 area. As the RDCA index represents cloud development without updraft information, we try to prove the RDCA index can reflect updraft information by comparing the time series of RDCA index with differential reflectivity parameter (Z_{DR}) and vertical wind velocity estimation obtained by multi Doppler analysis. Based on two cases, we found a good temporal correlation between RDCA index time series and Z_{DR} for two cases, and only one case has a good temporal correlation between RDCA index and vertical wind velocity estimation.

Keywords: Himawari-8, RSO, XRAIN, Updraft, Z_{DR}

1. Introduction

The Guerilla-heavy rainfall (GHR) is a special term for the heavy rainfall in Japan, which occurs in very short time and extreme amount of rainfall. Currently, the number of the occurrence of GHR has increased. In 2008, about 50 people washed away and five people died due to the occurrence of GHR in Toga River, Japan. It is very important to study the process of the occurrence of GHR to predict its occurrence, and to secure more evacuation time for a warning alert before flash flood occurrence.

The study of the early detection of GHR by using radar proposed that a first radar echo aloft called "baby-rain cell" inside a single cumulonimbus cloud is an important signal of GHR occurrence (Nakakita et al. 2010). Then, the study was continued by analyzing the vertical vorticity in the baby-rain cell (Nakakita et al. 2017). For earlier detection of GHR, the rapid scan observation (RSO) data of weather satellite Himawari-8 which has fine temporal and spatial resolutions is employed (Wendi et al. 2018a).

The Rapid Development Cumulus Area (RDCA) concept was introduced by utilizing several bands of RSO data. RDCA reflects the development process of cumulus clouds which can be identified by the irregular shape of the cloud surface in its development. The potentially expected of cloud to evolve into thunderstorm within one hour in around 10 km^2 area which is informed by RSO data is used to generate RDCA index by adapting the logistic regression model (Sumida et al. 2016). The usage of the RDCA index which previously has 0.1° × 0.1° of spatial resolution and five minutes of temporal resolution is changed from lightning prediction to the baby-rain cell of GHR prediction, since the occurrence of lightning coincides with the GHR occurrence. The threshold to determine the RDCA

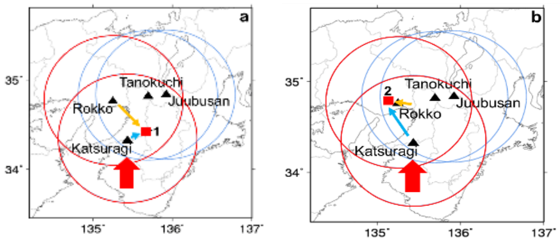

Fig. 1 Two cases for dual Doppler analysis a) case on 3rd August 2015; case 1, b) case on 6th August 2016; case 2. The analyzed rain cells are marked by red square boxes. The yellow arrow indicates the direction from Rokko radar to the target rain cell. The blue arrow indicates the direction from Katsuragi radar to the target rain cell. Red arrow indicates view direction for 3D image.

index "1" or "0" is eliminated to get a detailed RDCA index which will be used to detect the early stage (baby-rain cell) of GHR.

In the previous research we used the detailed RDCA index which ranges from 0.1 to 0.9 to predict the occurrence of baby-rain cell of GHR, and we have confirmed that the RDCA index can detect the baby-rain cell 5-20 minutes before the detection of baby-rain cell by radar (Wendi et al. 2018a). Moreover, the value of RDCA index which ranges from 0.1 to 0.9 can represent of cloud development process before the occurrence of GHR, where lower values of RDCA index represent for the cloud in developing stage, and higher values represent for the cloud in the mature stage. To verify that RDCA index can represent cloud development process, the RDCA index is compared with radar-estimated cumulus cloud stage (Wendi et al. 2018b). We have found a good temporal correlation between RDCA index time series and radar-estimated cumulus cloud. However, the RDCA index-estimated cumulus cloud development does not has updraft information. Since the occurrence of lightning coincides with the occurrence of updraft, we try to prove that the RDCA index can be used to express updraft by comparing the RDCA index time series with updraft estimation using Z_{DR} column and radar-estimated vertical velocity of rain cell obtained by multi Doppler analysis.

We investigated two cases of GHR caused by isolated cumulus clouds in Kinki region which is shown in Fig. 1a and 1b. Based on analysis, we found a good temporal correlation of RDCA index with Z_{DR} column and vertical wind velocity estimation for those cases, but we found a poor correlation between RDCA index and vertical wind velocity estimation for one case. The good correlation from those

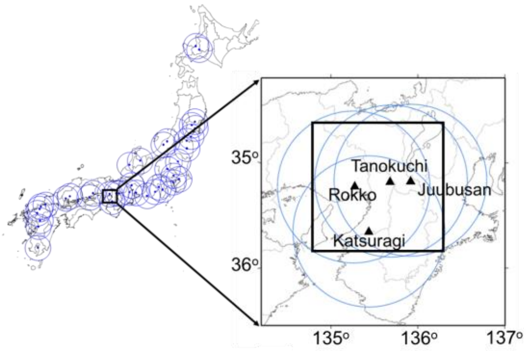

Fig. 2 39 XRAIN in Japan and four radars in Kinki region as a part of XRAIN

comparisons give us an opportunity of the potential of RDCA index in estimating the occurrence of updraft in the area without radar coverage such as Indonesia.

2. Data and Methodology

The RSO data of Himawari-8 satellite and XRAIN data are used in this study. Himawari-8, a Geostationary Meteorological Satellite was launched by the Japan Meteorological Agency (JMA) locating at about 36,000 km above the equator and 140° east in the space. It not only has fine spatial and temporal resolutions, 0.5-2.0 km and 2.5 minutes, respectively (Bessho et al. 2015) but also equipped by 16 observation bands, including three visible bands, three near-infrared bands, and ten infrared bands.

X-band polarimetric RAdar Information (XRAIN) was installed by Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan in 2010. It is especially designed for quantitative rainfall estimation and flash flood prediction for small river basins. Fig. 2 shows 39 of XRAIN in Japan and four of them are located in our research target area, Kinki region. XRAIN is polarimetric Doppler radar which is equipped with polarimetric parameters (Z_{HH}, Z_{DR} K_{DP}, Φ_{DP}, ρ_{HV}). The Z_{DR} parameter can be used for indirect updraft estimation by detecting water droplet above the freezing level. Not only equipped with polarimetric parameters, the XRAIN is also can be used to obtain the Doppler information which will be used for an estimation of the vertical wind velocity.

2.1 Updraft estimation by RDCA index

RDCA index ranges from 0.1 to 0.9 representing the cloud development process can be used to estimate the GHR occurrence (Wendi et al. 2018a).

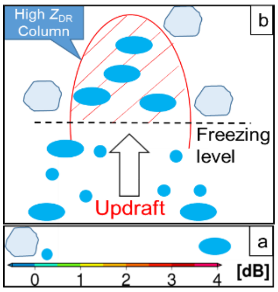

Fig. 3 a) Difference shape of hydrometeor based on Z_{DR} value, b) Z_{DR} column implying strong updraft

Low values of RDCA index represent for cloud development stage and high values mean the cloud in the mature stage (Wendi et al. 2018b). RDCA index was originally developed for lightning prediction, because of that, there is a possibility for RDCA index to estimate the updraft, since the occurrence of lightning coincides with the occurrence of updraft.

2.2 Updraft estimation by Differential reflectivity parameter (Z_{DR})

The indirect index of updraft can be obtained from the value of Z_{DR} parameter, because, the Z_{DR} value can be used to interpret the shape and size of hydrometeor. The low (high) values of Z_{DR} denote vertically (horizontally) which can represent for snow (raindrops) as it is shown in Fig. 3a. The detection of raindrops above the freezing level by the detection of Z_{DR} column can imply strong updraft as it is shown in Fig. 3b, since in the normal condition the hydrometeor type above the freezing level is mostly in the ice type. In this study, the value of Z_{DR} greater than or equal to 2 dB above the freezing level is used to identify the updraft area (Adachi et al. 2007; Nakakita et al. 2017).

2.3 Updraft estimation by dual Doppler analysis

The single Doppler radar observation cannot give the information of vertical wind velocity, since it can only provide the component of radial wind velocity which is directed toward or away from the radar. To estimate the vertical wind velocity, we adopt the variational method which can estimate the vertical wind velocity by combining some of Doppler radar information. Two Doppler radars observation are used to estimate the vertical wind velocity which can inform the occurrence of updraft. Fig. 4 illustrates how the Doppler information from two radars can estimate the vertical wind velocity.

The main idea for this method is to minimize a cost function, which defines the sum of squared errors of the difference between observational and analysis data (Shimizu and Maesaka 2007). Since we used the Cartesian coordinate system for reflectivity and Doppler velocity data which has a rectangular dimension of about 1 km × 1 km × 500 m, then the vertical wind estimation is also has the same spatial dimension.

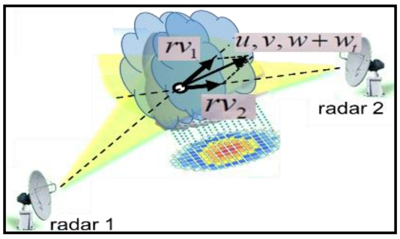

Fig. 4 The observation of two radars for the same rain cell.

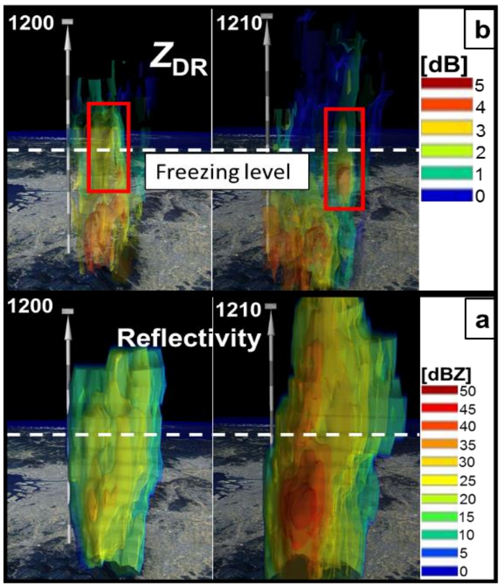

Fig. 5 3D of a) reflectivity, b) Z_{DR} parameter. White black pole is height indicator from zero until 10000 m with the range of each bar is 1000 m.

3. Results and Discussion

3.1 The usefulness detection of Z_{DR} parameter in estimating updraft

The three-dimensional (3D) image of the difference detection of reflectivity and Z_{DR} value for the same rain cell for case 1 is shown in Fig. 5a and 5b, respectively. At 12:00 Japan Standard Time (JST for short, and all time uses this time zone in the following) the reflectivity value is nearly detected similar about 30 dB from the ground until 9 km. At 12:10, the reflectivity values increase to about 50 dB below the freezing level, but reflectivity values are

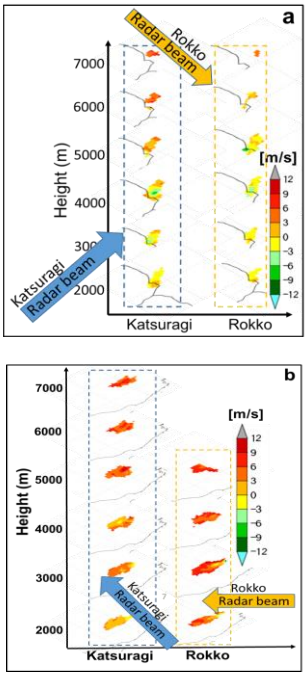

Fig. 6 Doppler velocity from Katsuragi and Rokko radar observation for a) case 1 at 12:00, b) case 2 at 13:55. Radar beams reflect to Fig. 1a and 1b.

weaker at above the freezing level than at below the freezing level. The reflectivity is detected until about 10 km of altitude. The difference detection values by using Z_{DR} is shown in Fig. 5b. At 12:00 the Z_{DR} value is detected about 4 dB below the freezing level, and the values decrease to about 3 dB above the freezing level. At 12:10 in Fig. 5b, the values of Z_{DR} above the freezing level is still detected about 2 dB although the area of high Z_{DR} decrease.

The detection of rain drop above the freezing level by the high value of Z_{DR} can be a representative of the strong updraft. We compare the RDCA index with Z_{DR} column to see the correlation between them to confirm that RDCA index can be used to estimate updraft.

3.2 Doppler velocity of two radar observations

The Doppler information of two different radars for case 1 at 12:00 is shown in Fig. 6a. It defines the direction and speed of movement of the rain cell. Positive (negative) number indicates that rain cell moves toward (away) the radar. The Doppler information from Katsuragi and Rokko radars is different due to the direction of radar observation to the targeted-rain cell, where the blue arrow is the observation direction from Katsuragi radar and the yellow arrow is the observation direction from Rokko radar. The Doppler echo from Katsuragi radar shows that the radar can capture rain cell better than Rokko radar. It might be due to the distance of Katsuragi to the target of rain cell is more near than the location of Rokko radar to the targeted-rain cell (the radar direction and targeted-rain cell location can be seen in Fig. 1a).

The different detection of Doppler observation from Katsuragi and Rokko radars is shown in Fig. 6b, where Katsuragi radar can detect the rain echo until 7000, but Rokko radar can only detect the rain until 5000 m.

The Doppler information given by Katsuragi radar at 2000 m shows that the rain cell moves toward radar with about less than 3 m/s. The rain cell movement increases to more than 3 m/s at the height of 3000 m. The rain cell moves with the difference direction (away from radar) at the height of 4000 m with the speed about -3 m/s. Then the rain cell moves toward radar at the height of 5000 m to 7000 m with the speed about 6 m/s.

The different of Doppler information is shown by Rokko radar observation. At the height of 2000 m to 5000 m, the rain cell moves toward radar with the speed of about 6 m/s. The rain cell speed observed by Rokko radar is faster that the Katsuragi observation. It may be due to the location of Rokko radar is closer from Katsuragi radar. The rain cell movement observed by Katsuragi and Rokko radars is different at the height of 4000 m, where the movement of the rain cell detected by Katsuragi radar moves away while the observation from Rokko radar shows that the rain cell moves toward radar. Again, we assume that the location of radar may give this wrong information. (The radar direction and targeted-rain cell location can be seen in Fig. 1b).

3.3 The comparison between RDCA index time series with Z_{DR} parameter and vertical wind velocity estimation

The comparison between RDCA index time series with Z_{DR} and vertical wind velocity for case 1 is shown in Fig. 7a, 7b and 7c, respectively. As it is shown in Fig. 7a, the RDCA index is firstly detected at 11:40. The value of RDCA index fluctuates until 11:55. The RDCA index starts increasing at 11:55 until 12:10. In the increasing of RDCA index, the Z_{DR} parameter value is detected above the freezing level with value more than 2 dB. The detection of higher Z_{DR} value above the freezing level is detected until 12:10. Here we found that in the increasing of RDCA index, as the indication of the occurrence updraft, the Z_{DR} value bigger than 2 dB is detected above the freezing level, which is also an updraft indirect indication occurrence. At 12:15, the Z_{DR}

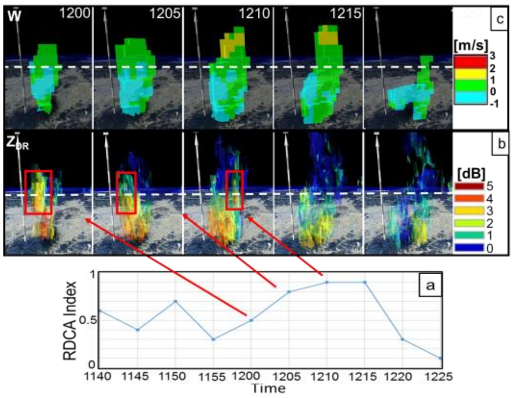

Fig. 7 The comparison of a) RDCA index time series, b) Z_{DR} parameter, c) Vertical wind velocity estimation for case 1.

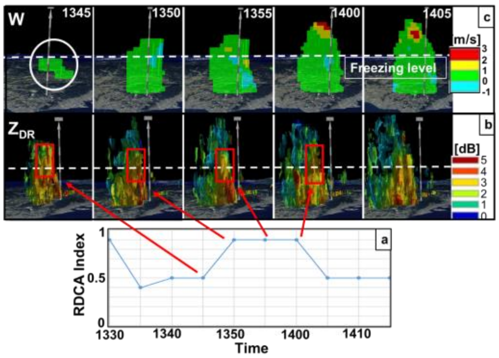

Fig. 8 The comparison of a) RDCA index time series (b) Z_{DR} parameter, c) Vertical wind velocity estimation for case 2.

value above the freezing level is less than 2 dB, even the RDCA index shows a high value. The different detection between RDCA index and Z_{DR} value in estimating updraft is found. There is still possibility of the occurrence of updraft even without the occurrence of rain drop above the freezing level which can be detected by the higher Z_{DR} value above freezing level.

The 3D image of the vertical wind velocity estimated by dual Doppler radar is shown by Fig. 7c. At 12:00, the estimation of vertical wind velocity is about 0-1 m/s, which indicates the occurrence of updraft. The vertical wind velocity estimation increases to about 1-2 m/s at 12:10 and 12:15.

Fig. 8a-c shows the comparison between RDCA index time series with 3D image of Z_{DR} parameter, and vertical wind velocity estimation, respectively. Fig. 8a presents, that the RDCA index is detected at 13:30 with value 0.9. The RDCA index fluctuates until 13:40. The RDCA index increases at 13:50 with the value 0.9. Then, the RDCA index keeps the high value until 14:00 before it decreases to 0.5 at 14:05. In the increasing of RDCA index, the Z_{DR} column is detected above the freezing level as it is shown in Fig. 8b. This is the indication of the occurrence of updraft. At 14:05, in the decreasing of RDCA index to 0.5, the Z_{DR} column is still detected above the freezing level. It is found that, even by value 0.5, the RDCA index can give the information of updraft.

The 3D image of vertical wind velocity estimation by dual-Doppler analysis is shown in Fig. 8c. The echo of vertical wind velocity which is captured by radar at 13:45 is only in the lower level, while the echo from Z_{DR} can be seen until 8 km (see Fig. 8b). It assumes that the computation of vertical wind velocity estimation might failed due to no Doppler information from rain cell observed by radar. At 13:50, the vertical wind velocity is detected as minus value, which is mean, at this time, the downdraft is occurred. This condition is different with the detection of Z_{DR} column, where the updraft is detected since the detection of Z_{DR} column above freezing level.

4. Conclusions

In the first trial by using two cases, we investigate the possibility of RDCA index to estimate an updraft during the development process of cumulus cloud. We compared the RDCA index time series with radar-informed updraft obtained by Z_{DR} value and vertical wind velocity estimation. Based on the comparisons, we found a good temporal correlation between RDCA index time series with Z_{DR} column for two cases, and we just found the good temporal correlation between RDCA index and vertical wind velocity for one case. The poor temporal correlation for another case may be due to the targeted rain cell location. The investigation of the capability of the RDCA in obtaining updraft information by comparing it with Z_{DR} column and vertical wind velocity estimation is more accurate to minimize the fallacious estimation of updraft.

With a series of our work, the investigation of the utilization of RSO data to predict the occurrence of GHR through RDCA index has verified that RDCA index can predict the occurrence GHR earlier than radar detection (Wendi et al. 2018a). The capability of RDCA index which ranges from 0.1 to 0.9 in obtaining cumulus life stages has verified through the comparison of RDCA index time series and radar-estimated cumulus life stage (Wendi et al. 2018b). The comparison showed a good temporal correlation, which can give the possibility of RDCA index to estimate the cumulus life stage. Finally, the updraft occurrence during the development cloud is verified in this paper, through the comparison of RDCA index time series and radar-estimated updraft. In summary, all the positive verifications of RDCA index for GHR prediction, cumulus life stage and updraft estimation give us the opportunity to utilize the RDCA index to be an operational parameter to predict the occurrence of GHR.

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