Detection of Rapidly Developing Cumulus Areas through

MTSAT Rapid Scan Operation

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Abstract

The Meteorological Satellite Center (MSC) of the Japan Meteorological Agency (JMA) is currently developing a new product showing the information of rapidly developing cumulus areas (RDCAs) in which cumulus clouds are expected to evolve potentially into thunderstorms within one hour. The method used with this product requires Rapid Scan Operation (RSO) observations by MTSAT-1R at intervals of five minutes. The product detects RDCAs through four processes: Detection 1, Motion cancellation, Detection 2 and Consistency. The Detection 1 detects cumulus areas at the developing stage as candidates for RDCAs. The algorithm for this process is based on that of the Cloud Grid Information operationally generated at MSC and developed for the RDCA product. The Motion cancellation process is included to calculate the time trends of parameters for the Detection 2 process. In order to accurately identify time trends as the growth of target clouds, the related motions have to be cancelled. The Detection 2 detects vigorously developing cumulus areas among the candidates evaluating temporal variation of the clouds. The algorithm for this process employs the time trend parameters of IR TB 10.8 μm used in the Convective Initiation product of EUMETSAT and those of VIS Albedo originally introduced. The Consistency process is introduced to detect cumulus at the developed stage. The preliminary results examined for MTSAT RSO images on 18 August 2010 show that all four thunderstorms are detected with lead times ranging from 10 to 35 minutes and one RDCA area ends in decline without thunder-related activity.

1. Introduction

On 1 July 2010, the Japan Meteorological Agency (JMA) switched satellite operations over from MTSAT-1R to MTSAT-2. Using the backup satellite MTSAT-1R, JMA plans to begin to perform Rapid Scan Operation (RSO) in summer 2011 and provide images to aviation users.

RSO observation provides information at frequent intervals on rapidly changing phenomena such as cumulonimbus development. Using these data, The Meteorological Satellite Center (MSC) has been developing a new product for the future detection of rapidly developing cumulus areas (RDCAs) in which cumulus clouds are potentially expected to evolve into thunder storms within one hour. Convective Initiation (CI) product provided by EUMETSAT is referred for the development of this product. CI identifies rapidly growing cumulus as candidates to evolve into potentially strong convective storms up to one hour in the future. Since RDCA product will be provided to the aviation users, thunderstorms which can be especially lethal to aviation safety are selected for the targets to be detected through the product.

This paper outlines the RDCA algorithm at the current point and gives some results examined.

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2. MTSAT-1R Rapid Scan Operation

MTSAT-1R RSO provides frequent observation images at intervals of five minutes over the limited area including almost all Japan. The observation area is scheduled to cover the region from 25 to 45°N and from 120 to 150°E as shown in Fig. 1. Channels of RSO data are the same with those of global observation operated until 1 July consisting of one visible (VIS) and four infrared (IR) channels, whose wavelengths are shown in Table 1. The horizontal resolutions of RSO images are also same with those of the global observation: 1 km for the visible (VIS) channel and 4 km for the infrared (IR) channels at the sub-satellite point (SSP).

All five channels are used for the RDCS product. For the calculation, the imagery data are arrayed on 0.01° × 0.01° grids from 20 to 50°N and from 120 to 150°E.

![Fig. 1. Sample Rapid Scan Operation observation image from MTSAT-1R](image)

Table 1. Wavelength and spatial resolution of MTSAT-1R

<table>
<thead>
<tr>
<th>Channel</th>
<th>VIS</th>
<th>IR 10.8 μm</th>
<th>IR 12.0 μm</th>
<th>WV 6.8 μm</th>
<th>Near-IR 3.8 μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength(μm)</td>
<td>0.55-0.90</td>
<td>10.3-11.3</td>
<td>11.5-12.5</td>
<td>6.3-7.0</td>
<td>3.5-4.0</td>
</tr>
<tr>
<td>Resolution at SSP (km)</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

3. Algorithm

Fig. 2 shows the flow to generate the RDCA product. It consists of four processes: Detection 1, Motion cancellation, Detection 2 and Consistency. Fig. 3 shows a life cycle of cumulonimbus. Cumulus clouds at the developing stage shown in left four clouds in Fig. 3 are selected through the processes of Detection 1, Motion cancellation and Detection 2. The clouds at the developed stage shown as the fifth cloud from the left in Fig. 3 are detected in the Consistency process.

![Fig. 2. RDCA product flow](image)
3.1 Detection 1

The Detection 1 tries to find cumulus cloud areas in the developing stage as the candidates for RDCAs. There are four types of check terms using eight types of parameters as shown in Table 2. Parameter 1 and 6 are used for the computation of the Cloud Grid Information product at MSC to detect cumulus clouds. The other parameters are originally introduced for RDCA product.

Check 1 is installed to select cumulus cloud out from the whole grid data taking advantage of the cumulus feature of that the optical thickness is higher than over low stratus and thin cirrus (MSC 2002). The texture of cloud top surface is checked whether it is rough as cumulus through Check 2. Whether the clouds have potentials to grow in height more and more in the future is tested through Check 3. Such cumuli have the large depth enough between the tops and the tropopause. The updraft strength related to convection intensity in clouds is checked using Slope Index described in Section 4. The condition thresholds in Table 2 (as TH_min and TH_max) are decided subjectively based on analysis of sample cases from 2008 and 2009 at the current point. During this term, RSO data are derived by MTSAT-2. MSC will redetermine these thresholds statistically using RSO data derived by MTSAT-1R in 2010.

Fig. 3. A concept model of the thunderstorm lifecycle (E. Brotak, 2009).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Conditions</th>
<th>Check terms</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P1</strong> Vis. Albedo / cos(sunZenithAngle)</td>
<td>1-1 (TH_min&lt; P1 only)</td>
<td>Check 1: optical thickness</td>
</tr>
<tr>
<td><strong>P2</strong> Vis. Albedo_MAX - Vis. Albedo_AVERAGE</td>
<td>1-2 (TH_min&lt; P2&lt; TH_max only)</td>
<td>Check 2: cloud texture</td>
</tr>
<tr>
<td><strong>P3</strong> Standard deviation of Vis. Albedo</td>
<td>1-3 (TH_min&lt; P3&lt; TH_max only)</td>
<td>Check 2: cloud texture</td>
</tr>
<tr>
<td><strong>P4</strong> TB_10.8_MIN - TB_10.8_AVERAGE</td>
<td>1-4 (TH_min&lt; P4&lt; TH_max only)</td>
<td>Check 2: cloud texture</td>
</tr>
<tr>
<td><strong>P5</strong> Standard deviation of TB 10.8</td>
<td>1-5 (TH_min&lt; P5&lt; TH_max only)</td>
<td>Check 2: cloud texture</td>
</tr>
<tr>
<td><strong>P6</strong> TB difference IR 10.8 - IR 12.0</td>
<td>1-6 (TH_min&lt; P6&lt; TH_max only)</td>
<td>Check 1: optical thickness</td>
</tr>
<tr>
<td><strong>P7</strong> TB difference WV 6.8 - IR 10.8</td>
<td>1-7 (TH_min&lt; P7&lt; TH_max only)</td>
<td>Check 3: Depth between cloud tops and the tropopause</td>
</tr>
<tr>
<td><strong>P8</strong> Slope Index</td>
<td>1-8 (TH_min&lt; P8 only)</td>
<td>Check 4: Updraft in clouds</td>
</tr>
</tbody>
</table>

(MAX and MIN are calculated with the grids in the 7 × 7 area. AVERAGE and the standard deviation are calculated from the values within the 21 × 21 area.)
3.2. Motion cancellation

The Motion cancellation process is included to calculate the time trends of parameters for the Detection 2 process. In order to accurately identify time trends as the growth of target clouds, the related motions have to be cancelled. For the Motion cancellation process in the RDCA product, the cross-correlation coefficient method is used. This technique is generally adopted for Atmospheric Motion Vectors (AMV) products not only at MSC/JMA but also at most other satellite centers (Oyama R. 2010). It is used to identify a certain size of segment called a template in a base image using the segment that has the most closely corresponding pattern in a compared image. The similarity is calculated as correlation coefficient values.

A unique point of the RDCA product is its use of three successive VIS images for this method (Shimoji K. 2010, personal communications) while only two successive images are generally used for the AMV product (Fig. 4). Three successive temporary images – A (first), B (second, as a base image) and C (third) – give two series of correlation coefficient values: 

$$CC_{BA}(pixA, linB, \Delta pix_{BA}, \Delta lin_{BA})$$ and $$CC_{BC}(pixB, linB, \Delta pix_{BC}, \Delta lin_{BC})$$.

\((pix, lin)\) is the center grid of each template. They are selected so that \((pix_A, lin_A)\), \((pix_B, lin_B)\) and \((pix_C, lin_C)\) have the same coordinate origins geographically. These values are combined to make a new series of values named \(CC_O\) as shown in (1).

$$CC_O = CC_{BC}(pix_B, lin_B, \Delta pix_{BC}, \Delta lin_{BC}) + CC_{BA}(pix_A, lin_A, \Delta pix_{BA}, \Delta lin_{BA})$$  \hspace{1cm} (1)

Here, pixel movement is considered uniform during the observations of the three images. \((pix_B, lin_B)\) and \((pix_C, lin_C)\) are identified where \(CC_O\) is the maximum value, and the time trend is calculated with the value at the two grids.

3.3. Detection 2

The Detection 2 process has the purpose to detect the vigorously developing cumulus areas from the candidate areas selected in the Detection 1 process. Table 3 shows two check terms and five parameters used for the process. Parameter 11 and 12 are introduced based on CI product of EUMETSAT. The other parameters are original of MSC.

Check 5 is operated to detect vigorously developing cumulus clouds in terms of albedo of cloud top surface. When a convective cloud is rapidly developing, albedo of the top surface is rapidly getting higher. Check 6 also try to detect the same targets by using the time trend of brightness temperature (TB) of IR 10.8 μm. The areas where the cloud tops are rapidly growing in height are considered as the regions over which TB IR 10.8 μm is quickly decreasing.

In order to accurately estimate the growth of a target cell’s height, in addition to implementing the Motion cancellation process, it is also necessary to consider cell transformation on a scale smaller than that allowed by the template size. The time trend of the maximum VIS albedo as Parameter 9 and the time trend of the minimum TB IR 10.8 μm as Parameter 11 can indicate the time trend of a cell’s height even if the cell transforms on such a small scale.
3.4. Consistency

The forth process is that for Consistency. Fig. 3 shows that the height of a cumulus cloud vigorously increases while it is in the lifecycle stage of developing. The target cumuli in the stage will be detected by the processes of Detection 1, Motion cancellation and Detection 2. However, thunderstorms continue to influence on aviation safety in the following stage of developed. The Consistency process is included in order to keep the critical cumulus (cumulonimbus) marked during the developed stage. The process is implemented to check whether a cloud area is really declining or not when previously seen cloud grids are no longer detected.

Table 4 shows the conditions used in this process. The purposes for the check terms are as explained as below. Check terms on which effect are not found in the investigations using RSO data in 2008 to 2009 are rejected from Table 1 and Table 2. Grids that meet the conditions of the Consistency process are considered to be RDCAs.

After the four processes, the VIS albedo within the 21 × 21 area surrounding the grids detected as being RDCAs are checked. Those with values brighter than 0.54 × cos(sunZenithAngle) are also considered to be RDCAs.
4. Slope Index

The Slope Index (Parameter 8 in Table 2) is used as an indicator of updraft strength. It is an index originally introduced in the RDCA product based on the Rosenfeld Lensky Technique (RLT), which is used to gain insights into precipitation formation processes through satellite observation (Rosenfeld and Lensky 1998). Particles at cloud tops with strong updrafts are smaller than those at cloud tops with weak updrafts at the same level, as shown in Fig. 5. It is assumed that the bottoms of the clouds have the same altitude in this theory (Lindsey et al. 2006). Particles in strong updrafts are brought upward in so short a time that they can reach the top without growing in radius.

![Fig. 5. A concept illustration of cloud particles in weak and strong updrafts (Source: EUMETSAT)](image)

Fig. 5 shows slopes of temperature versus particle radius corresponding to strong and weak updrafts. The slope of strong updraft is steeper than weak updraft.

In order to estimate these effective radii, (4) and (5) are used (Oku and Ishikawa 2008).

\[
\ln(A_{38}) = a_0 + a_1 \times R_e + a_2 \times R_e^2 + a_3 \times R_e^3, \quad (4)
\]

\[
a_0 = -0.68460, \quad a_1 = -0.08243, \quad a_2 = -0.00749, \quad a_3 = 0.00033,
\]

where \(A_{38}\) is the albedo at 3.8 \(\mu\)m, and \(R_e\) is the effective radius. \(a_0, a_1, a_2\) and \(a_3\) are constant parameters. Oku and Ishikawa noted that (4) and (5) are suitable only for the water particles of optically thick clouds. Clouds that satisfy Conditions 1-1 to 1-7 are considered as

![Fig. 6. Schematic illustration of the cloud microphysical concept (Rosenfeld, 2003)](image)
being optically thick. When a grid has a value of TB IR 10.8 μm under 250 K, Parameter 8 is not calculated because such cold clouds will consist of ice particles rather than water particles.

A38 can be derived in a way similar to the approach of Lindsey et al. (2006). The emission temperatures at 10.8 μm and 3.8 μm are regarded as identical for optically thick clouds. The Slope Index is composed of Re and TB IR 10.8 μm within a 21 × 21 grid segment surrounding the current grid, and is defined as shown in (7). In order to calculate inclinations, the reduced major axis approach is used (Sokal and Rohlf 1995). This method to quantitize updraft strength using RLT is JMA’s original.

\[
Slope \text{ Index} \equiv \arctan \left( \frac{\sum_{i=1}^{21} \sum_{j=1}^{21} (TB_{10.8(i,j)} - TB_{10.8})}{\sum_{i=1}^{21} \sum_{j=1}^{21} (R_e(i,j) - R_e)^2} \right), \quad (7)
\]

5. Example

The results from 18 August 2010 show that the RDCA product has a certain level of suitability. On this day, a number of high-pressure areas were located around Japan, and many heat thunderstorms were recorded. The central area of Japan is focused for testing of the RDCA product. The target domain is from 34 to 39°N and from 136 to 142°E (marked with a red rectangle on the weather chart in Fig. 7), and the target time is from 0210 to 0500 UTC. Four thunderstorms were observed by LIDEN (LIghtning DEtection Network) and radar in the target area during this period. LIDEN is a JMA network system that observes the time, position and type of lightning.

The results for 0255 UTC are shown on the right of Fig. 8. The detected cloud included thunder strokes from 0330 UTC. The lead time is 35 minutes. The other three target clouds are also successfully detected with lead times ranging from 10 to 20 minutes. However, the cloud area detected at 0435 UTC ends in decline without thunder-related activity (Fig. 9).
6. Conclusion

This paper outlines a new product developed by MSC/JMA to detect rapidly developing cumulus areas (RDCAs) using RSO data derived by MTSAT-1R at intervals of five minutes. RDCAs are cumulus cloud areas which are potentially expected to evolve into thunderstorms within one hour. The results from 18 August 2010 show that the RDCA product has a certain level of suitability. All four target thunderstorms are successfully detected with lead times ranging from 10 to 35 minutes. However, one area detected as RDCA ends in decline without thunder-related activity. MSC will continue to develop this product to make progress in terms of length of lead times and accuracy. Investigation and verification for each process will be continued. In addition, the condition thresholds are currently decided subjectively based on analysis of sample cases from 2008 and 2009, and RSO data are derived by MTSAT-2. MSC plans to statistically redetermine these thresholds using RSO data derived by MTSAT-1R. As part of a mid-to-long range plan, we are attempting to simulate satellite observations using radiative transfer models from NWP. Using data that simulate various meteorological conditions, it is expected that optimal thresholds and conditions will be found for each meteorological pattern. In addition, this will provide various vertical profiles showing the situation throughout the whole cumulonimbus lifecycle, and the results are expected to serve as a base for investigation aimed at understanding the mechanisms of such severe phenomena.

References