Development and validation of the cirrus cloud mask method by using near infrared band observed from geostationary satellite

Takuma Yamaguchi(1) and Nawo Eguchi(2)

(1) Interdisciplinary Graduate School of Engineering Sciences, Kyushu University
(2) Research Institute for Applied Mechanics, Kyushu University

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Introduction 1  Cirrus cloud detection and satellite observation

• To clarify the processes of climate system, it is necessary to quantitatively understand the contribution of cirrus clouds (Ci) to the radiation balance and the amount of water vapor entering to the stratosphere.

• Ideally, the observation of cirrus cloud is required highly temporal and spatial resolutions due to its spatio-temporal variations (e.g., a few hours, a few meters for geometric thickness).

**Satellite that can observe a wide area with the same accuracy is effective for observing cirrus clouds.**

<table>
<thead>
<tr>
<th>Passive sensor (e.g., MODIS)</th>
<th>Active sensor (e.g., CALIOP)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Merit</strong></td>
<td></td>
</tr>
<tr>
<td>• Wide field of view</td>
<td>• Optically thin clouds can detect</td>
</tr>
<tr>
<td>• high temporal resolution (especially geostationary satellites)</td>
<td></td>
</tr>
</tbody>
</table>
Introduction 2  Trends in upper level cloud detection with satellite

Increased number of on-board bands + effective Ci detection using near-infrared water vapor absorption bands

⇒ Recently, geostationary satellites mount 1.38μm (water vapor strong absorption) band

FY-4A (China) 2016～

GOES-16 (US) 2016～

GK-2A (Korea) 2018～

Not mounted on Himawari-8/9
Detection method of clouds including cirrus cloud

- Single-channel threshold method
  - 1.38 μm WV band (cf., Gao et al., 1993)
- Dual-channel threshold method
  - Split Window (cf. Inoue, T., 1987)
  - CO₂ slicing (cf. Menzel et al., 2008)
- Recently, machine learning (cf. Samuel et al., 2020)

Table 1: Cloud detection using GK–2A threshold method

<table>
<thead>
<tr>
<th>μm</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>Cloud presence (compared to clear sky)</td>
</tr>
<tr>
<td>10.4</td>
<td>Cloud presence</td>
</tr>
<tr>
<td>1.38</td>
<td>Cirrus clouds</td>
</tr>
</tbody>
</table>

Purpose of this research

Development of upper level cloud detection method using L1b products of geostationary satellites including 1.38 wavelength band
<table>
<thead>
<tr>
<th>Product</th>
<th>Observation area</th>
<th>Temporal Resolution</th>
<th>Horizontal Resolution</th>
<th>Spectrum ((\mu m))</th>
</tr>
</thead>
<tbody>
<tr>
<td>GK–2A L1B data</td>
<td>Full disk</td>
<td>10 min</td>
<td>2 km</td>
<td>1.38 (Reflectance) 11, 6.9, 3.9 (Brightness Temperature)</td>
</tr>
<tr>
<td>GK–2A L2 product Total precipitable water</td>
<td>Full disk</td>
<td>10 min</td>
<td>6 km</td>
<td></td>
</tr>
</tbody>
</table>

**Comparison product**

<table>
<thead>
<tr>
<th>Product</th>
<th>Observation area</th>
<th>Temporal Resolution</th>
<th>Horizontal Resolution</th>
<th>Spectrum ((\mu m))</th>
</tr>
</thead>
<tbody>
<tr>
<td>GK–2A product Cloud Detection (Cloud Mask)</td>
<td>Full disk</td>
<td>10 min</td>
<td>2 km</td>
<td></td>
</tr>
<tr>
<td>Himawari–8 L2 product Cloud properties</td>
<td>Full disk (60S–60N, 80E–160W)</td>
<td>10 min</td>
<td>5 km</td>
<td></td>
</tr>
<tr>
<td>CALIPSO Clay 5km ver4.2</td>
<td>Analysis period: 2019–08–01 4:35:00 to 4:45:00 UTC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CALIPSO Vertical Feature Mask – Ver4.1</td>
<td>Analysis period: 2019–08–01 4:30:16.2 to 4:57:44.9 UTC</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Cirrus cloud detection by using the threshold method

A) Scatter light from upper clouds ⇒ Observed by satellite

B) No scattered light from ground surface ⇐ Absorbed by water vapor, under the case of sufficient water vapor (WV)

Condition

Observed Reflectance > Clear sky Reflectance + Offset
⇒ Presence of cirrus clouds

Gao and Goetz 1993
Method 2  Flow of cirrus cloud detection

Quality flag

Yes

SZA < 85°

No

Missing

Twilight or Nighttime

PWV > 1cm

Not enough Water vapor

Ref1.38 < 0.01

Ice cloud

Threshold Test

T6.9 < 240 K
T11 – T3.9 < -20 K

Clear sky

Liquid water cloud

SZA : Solar Zenith Angle
PWV : Precipitable Water Vapor
Ref : Reflectance
T : Brightness Temperature

cf. MOD35 ATBD 2010

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Comparison of the GK–2A cirrus mask developed in this study with the standard product

- The area with cirrus clouds generally coincides with the area identified as having clouds by the standard product.
- Discriminates upper clouds in cloud regions that cannot be identified by standard products alone.
Comparison of GK–2A cirrus mask with Himawari–8 Cloud type mask

• Roughly coincides with the location of the upper clouds in Himawari–8
• Overall, the number of GK–2A products detecting cirrus clouds is high ⇒ verification required

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Comparison of GK-2A cirrus mask with CALIOP Vertical Feature Mask

- Possibility of detecting not only thick cloud but also thinner upper cloud
- Few detections in high latitude ⇒ verification required

CALIPSO Vertical Feature Mask
2019-08-01 04:30:16.2 to 04:57:44.9 UTC

CALIPSO orbit at 0–40N, 110E–150 (red line) and August 1 2019 (4:40UTC) cirrus cloud
Comparison of GK-2A cirrus mask with CALIOP Clay product

- Ci Detection rate

$$\frac{\text{The number of Ci CALIOP}}{\text{The number of Ci GK2A}} \approx 66\%$$

- The possibility to detect multilayer and thick clouds well

⇔ Single layer and COD less than 0.1 clouds are few detections

⇒ Need to review the threshold considering the surface type and higher latitude

Ci detected by GK2A (Green), CALIOP Cloud Optical Depth (COD) (Red dots), Matched with GK2A (Blue dots)
CALIOP Cloud Top Height (CTH) (Red dots), Matched with GK2A (Cyan dots)
2019-08-01 04:35:00 to 04:45:00 UTC at 0-15N, 15-30N
Summary and near future works

Summary

• Develop the cirrus cloud detecting method by using water vapor absorption band’s 1.38μm
• Compared among GK-2A, Himawari-8, and CALIPSO cloud mask products, qualitatively, the detection of upper clouds was confirmed

Future works

• Quantitative validation of the threshold method developed in this study by comparing it with cloud information obtained from the CloudSat–CALIPSO combined analysis KU product (Hagihara et al., 2010)
• Set thresholds based on observation location (impacted PWV)
  • Surface type Land/ocean/desert
  • Viewing / Solar zenith angle
• Discussed the usefulness of cloud mask products for other geostationary satellites e.g., Himawari-8