Detection of Polar Mesospheric Clouds Utilizing Himawari-8/AHI Full-Disk Images

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Abstract With the objective of advancing the polar mesospheric cloud (PMC) detection capability by the Advanced Himawari Imager (AHI) onboard the Japanese geostationary-Earth-orbit (GEO) meteorological satellite Himawari-8, a novel two-step PMC detection technique applied to the Himawari-8/AHI full-disk images has been developed. The two-step approach is dividing the PMC detection into stronger (the first step) and weaker (the second step) signals and enhances the detection capability while significantly decreasing the false PMC detections. The improved PMC sensitivity by Himawari-8/AHI is comparable with the Cloud Imaging and Particle Size (CIPS) onboard the Aeronomy of Ice in the Mesosphere (AIM) satellite. With this encouraging result, PMC observations from Himawari-8/AHI provide an additional extensive data set to the aeronomy and space science community.

1. Introduction

Polar mesospheric clouds (PMCs) or noctilucent clouds (NLCs) consist of water-ice particles that can be produced in the predominantly high latitude summer mesopause region. The first report on PMCs was made by Leslie (1885). At the same time, two famous astronomers (the German astronomer Otto Jesse and the Russian astronomer Vitold Tseraskii) not only observed the NLCs in 1885 but also made their triangulation measurements. Vitold Tseraskii took the first photographs of NLCs in 1885 and 1886 (cf. Dalin et al., 2012). Since then, various methods have been used to perform PMC observations. Optical imaging and lidar systems can provide exceptional spatial and temporal resolution of PMC, while limited by tropospheric weather and limited spatial coverage. Conversely, PMC observations from space are valuable for continuous and large spatial coverage observations (with lower spatial and temporal resolution, compared with the ground-based optical observations), and thus enable significant systematic data coverage. This approach is favorable for long-term monitoring of PMCs and their variability, which may be linked to global change (cf. Thomas, 1996; von Zahn, 2003) because water-ice particle production can be enhanced by CO2 cooling and H2O increase, which may be induced by CO2 and CH4 increases (cf. Lübken et al., 2018; Roble & Dickinson, 1989).

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of GEO satellite can produce full-disk images including the Earth’s limb, which would provide valuable opportunities for PMC observations by continuous limb-viewing from its almost fixed location relative to the Earth. As a continuation of the initial report on Himawari-8 PMC observation (Tsuda et al., 2018), an improved PMC detection method for application to the Himawari-8 data has been developed. In the present paper, we introduce the PMC detection method, and evaluate the detected PMC data against PMC data extracted from Cloud Imaging and Particle Size (CIPS) onboard AIM (cf. Lumpe et al., 2013; Russell III et al., 2009).

2. Data

Himawari-8 is the Japanese GEO meteorological satellite (Bessho et al., 2016), that has been in regular operation since 7 July 2015. Himawari-8/AHI has 16 observation bands, including three visible bands: blue (0.47 μm), green (0.51 μm), and red (0.64 μm). In the initial survey, Tsuda et al. (2018) used the full-disk images in the Portable Network Graphics (PNG) format, which has an 8-bit resolution (i.e., values ranging from 0 to 255), generated from data in the three visible bands. In the present work, we used the full-disk images of the band-1, blue (0.47 μm), in the level-1a data, Himawari Standard Data (HSD), which has an 11-bit resolution (i.e., values ranging from 0 to 2047). The color value has a linear relation with the intensity (or radiance). The full-disk HSD band-1 images are 11,000 × 11,000 pix² with a time resolution of 10 min. The Himawari-8/AHI band-1 has the spatial resolution in the perpendicular direction to the line-of-sight (LOS) is ∼1 km, and the spatial resolution along the LOS can be ∼400 km in the case of this kind of limb-viewing observation (cf. Benze et al., 2018). In the analysis, we use the top 20% of the full-disk image for observation in the Northern Hemisphere (i.e., 2,200 × 11,000 pix²), and the bottom 20% of that for observation in the Southern Hemisphere (i.e., 2,200 × 11,000 pix²). The geometric accuracy of the images is typically less than 0.6 km. More detailed information for the full-disk HSD can be found in Bessho et al. (2016).

3. Method

This section describes the data processing to detect PMCs from the full-disk HSD together with examples of PMC detections. After preprocessing in the data, we perform PMC detections with a two-step detection process resulting in an enhanced PMC detection capability and reduced false PMC detection rate. Stronger PMC signals are detected in the first step, and weaker PMC signals are detected in the second step.

3.1. Preprocessing

We calculate positions (i.e., latitude, longitude, and height) of each pixel of Himawari-8/AHI full-disk image, as tangential points in the limb viewing, as outlined in Tsuda et al. (2018). The geographical footprints of the obtained position data are shown in Figure 1. It should be noted that the footprints are fixed because of the GEO orbit. Then, based on the position data, we produce spatial averaged intensity data for each bin with 1° latitude and 1-km altitude, and thus height profiles in the averaged intensity are obtained at each latitude. This averaging process corresponds to resampling as a function of latitude and height, and it can increase the signal-to-noise ratio (SNR) and data reduction in the Himawari-8/AHI full-disk image. In addition, we calculate standard deviation data for each bin.

Figure 2 shows an example of latitude-height distribution in the resampled data for the band-1. Clear signals due to PMC scattering can be seen at 80–85 km heights around of 55°–81°N in the east side in the Northern Hemisphere, which means the PMCs extended over Alaska (see Figure 1). At lower heights (<60 km height), stronger signals can be found, which would be mainly due to Rayleigh scattering by the atmospheric molecules (such as N₂ and O₂). At higher heights (>90 km), significant signals cannot be found, in which the signal levels can be considered as the background levels (or dark levels).

3.2. PMC Detection at the First Step

The detection method is applied for a height profile at each latitude from the resampled data. In the first step, we use a simple threshold to extract significant PMC signals. To determine the threshold, we utilize the resampled data at 91–100 km heights, which can be considered as a dark level. From the resampled data at 91–100 km
heights, we calculate an average, $I_{\text{dark}}$, with its uncertainty estimate, $\sigma_{\text{dark}}$, which can be obtained through the error propagation of each standard deviation at each height in the resampled data. Then, assuming that the height range of expected PMCs is 75–90 km heights, the signal level, $I_{\text{data}}$, and its standard deviation, $\sigma_{\text{data}}$, at each height (from 75 to 90 km) in the resampled data are compared with $I_{\text{dark}}$ and $\sigma_{\text{dark}}$, as shown in Equation 1.

$$I_{\text{data}} - A \times \sigma_{\text{data}} > I_{\text{dark}} + B \times \sigma_{\text{dark}}$$

Thus, uncertainties from both the background level, $\sigma_{\text{dark}}$, and the signal level, $\sigma_{\text{data}}$, are considered in Equation 1. If Equation 1 is true at a height, it is judged that PMC is detected at that height. If not, it is judged that PMC is not detected at that height.

The factors, $A$ and $B$, for multiplying $\sigma_{\text{data}}$ and $\sigma_{\text{dark}}$ are important to control the threshold of PMC detection (or PMC detection sensitivity) in the first step. The PMC detection sensitivity may increase when the factors are smaller. On the other hand, such smaller factors may induce false detections more frequently. Here, we tested several combinations in $A$ and $B$ (not shown here), and determined those factors manually to eliminate false detections as much as possible. As the results, $A$ is determined as 1.0 and $B$ is determined as 5.0. As one of the tests, for example, we confirmed that there is no PMC detection (i.e., no false detection) during fall, winter, and spring (i.e., no PMC season) using the determined factors. Thus, we set the factors to be high enough to eliminate false detections.

![Figure 1](image1.png)

**Figure 1.** (a) A map showing footprints (red) of the tangential points at tangential heights of 80–85 km in the Northern Hemisphere, considering the Himawari-8/AHI limb viewing. (b) Same as (a), but in the Southern Hemisphere. It should be noted that the center longitude is 140.7°E, which is the sub-satellite longitude of Himawari-8.

![Figure 2](image2.png)

**Figure 2.** Intensity averaged for 1° latitude and 1-km altitude in the Himawari-8/AHI band-1 at 00:00 UT on 19 June 2020 in the Northern Hemisphere (NH).
Figure 3 shows some examples in the PMC detection results. In the cases at 75°N and 58°N, we successfully detected PMCs (as marked by red) in the first step. As for 55°N, we can see a slight enhancement at 80–85 km heights which would be due to PMC scattering signals, but this is judged that there was no PMC because the signals were weak, compared with the defined threshold in the first step (i.e., Equation 1 was not satisfied). To detect such weak PMC signals, we need a smaller threshold. However, such smaller threshold (in the first step) can be a source of false detections. In particular, Rayleigh scattering signals around 75 km can be a major cause of false detections (see Figure 3). The Rayleigh scattering signals are exponentially larger at lower heights, because of higher atmospheric density at lower heights. Thus, in the first step, we set the threshold to be high enough, compared with such Rayleigh scattering signals around the lower edge of the expected PMC height range (i.e., 75–90 km heights).

### 3.3. PMC Detection at the Second Step

In the second step, to detect weaker PMC signals which cannot be detected in the first step, we remove Rayleigh scattering signals before judging PMC signals. So, we reproduce Rayleigh scattering signals, $I_{\text{ray}}$, using a polynomial approximation in Equation 2 with the least squares method, based on data below 75 km and above 90 km (i.e., not using data at 75–90 km heights where PMCs can occur).

$$\ln I_{\text{ray}} = \sum_{n=0}^{N} C_n z^n$$

Here, $z$ is height. For a better approximation, we have to determine some parameters, which are the order of the polynomial fitting (i.e., $N$ in Equation 2) and the upper and lower height ranges of data used for the polynomial fitting. For simplicity, the upper height range is fixed as 91–100 km heights. Then, we tested several combinations in the other parameters, and evaluated results from the fitting (not shown here). In the evaluations, we utilized data during no PMC seasons (except for summertime). Such data would consist of only Rayleigh scattering signals (without PMC signals) at 75–90 km heights, so it can be used as true data in the Rayleigh signals. Based on comparisons between such true data and the fitted data, we found a best combinations to minimize root mean square (RMS) and bias between them at 75–90 km heights. As the results, $N$ is determined as 5, and the lower height range of data used for the polynomial fitting is determined as 50–74 km.

Using the obtained $I_{\text{ray}}$, we perform PMC detection in the second step, which is expressed as Equation 3.

$$I_{\text{data}} - D \times \sigma_{\text{data}} > I_{\text{ray}} + E \times \sigma_{\text{dark}}$$

Figure 3 shows some examples in the PMC detection results. In the cases at 75°N and 58°N, we successfully detected PMCs (as marked by red) in the first step. As for 55°N, we can see a slight enhancement at 80–85 km heights which would be due to PMC scattering signals, but this is judged that there was no PMC because the signals were weak, compared with the defined threshold in the first step (i.e., Equation 1 was not satisfied). To detect such weak PMC signals, we need a smaller threshold. However, such smaller threshold (in the first step) can be a source of false detections. In particular, Rayleigh scattering signals around 75 km can be a major cause of false detections (see Figure 3). The Rayleigh scattering signals are exponentially larger at lower heights, because of higher atmospheric density at lower heights. Thus, in the first step, we set the threshold to be high enough, compared with such Rayleigh scattering signals around the lower edge of the expected PMC height range (i.e., 75–90 km heights).
In a similar manner of the first step, if Equation 3 is true at a height, it is judged that PMC is detected at that height. If not, it is judged that PMC is not detected at that height. Then, the factors, $D$ and $E$, for multiplying $\sigma_{\text{data}}$ and $\sigma_{\text{dark}}$ are determined to eliminate false detections as much as possible. In this manual inspection, we confirmed that there is no PMC detection (i.e., no false detection) during fall, winter, and spring (i.e., no PMC season) using the determined factors, same as the first step. As the results, $D$ is determined as 0.5 and $E$ is determined as 1.0. Thus, we successfully determine smaller factors (i.e., smaller threshold or higher detection sensitivity) in the second step, compared with those in the first step.

As shown in Figure 3c, in the second step, it is judged that the weaker PMC signals at 55°N were detected as PMC signals (as marked by blue). Here, we briefly mention the sensitivity limitation in this two-step PMC detection method, which can be characterized by a minimum value of detectable PMC signals, $I_{\text{data}} - I_{\text{ray}} (=D \times \sigma_{\text{data}} + E \times \sigma_{\text{dark}})$ in the second step (see Equation 3). The typical values of $D \times \sigma_{\text{data}} + E \times \sigma_{\text{dark}}$ is roughly ~0.6 counts, and then the conversion coefficient from counts to radiance is roughly ~0.4 W m$^{-2}$ sr$^{-1}$ μm$^{-2}$ counts$^{-1}$, which is the calibrated value provided with the HSD. Hence, the estimated sensitivity limitation in the PMC detection is roughly 0.24 W m$^{-2}$ sr$^{-1}$ μm$^{-2}$ for the Himawari-8/AHI band-1. On the other hand, it should be noted that one can see the unrealistic reproduced Rayleigh scattering profile in the case of stronger PMC, as shown by a blue curve in Figure 3a. In such stronger PMC cases, signals at lower heights (below 75 km) can include contamination due to PMC signals from fore- and far-sides along the LOS in the Himawari-8/AHI (not from the tangential points), and thus it can be difficult to reproduce Rayleigh scattering signals. For this reason, the PMC detection at the first step is also needed.

4. Results and Discussion

The full-disk HSD since 7 July 2015 have been continuously processed by using the developed PMC detection method, which is described in the previous section. In this section, we describe some results from the PMC detection by Himawari-8/AHI, and compare those with the PMC data, v5.20 level 2 data products, obtained by AIM/CIPS (cf. Lumpe et al., 2013; Russell III et al., 2009).

4.1. Day-to-Day Variation

Figure 4 shows the detected PMCs during 10 days on 16–25 June 2020 in the Northern Hemisphere. PMCs with stronger signals (detected in the first step) are shown as deep blue, and PMCs with weaker signals (detected in the second step) are shown as light blue. No PMC detections are shown as white. Missing data are shown as gray. It is noted that the extended gray areas at 38°–60°N in the east side around 06:00–13:00 UT on each day were treated as missing data with a shadow height of >50 km height as missing data.

Figure 4. Day-to-day variation in the detected PMCs in the Himawari-8/AHI band-1 at 38°–81°N in the east and west sides on 16–25 June 2020 in the Northern Hemisphere (NH). Deep blue indicates PMCs detected in the first step, and light blue indicates PMCs detected in the second step. Missing data are masked by gray. It is noted that we also regard data with a shadow height of >50 km height as missing data.
UT on each day were also treated as missing data due to the same reason. These are because we cannot observe Mie scattering due to PMC particles or Rayleigh scattering by the atmospheric particles when there is no sunlight. At higher latitudes (>60°N), there was no missing data related with the shadow height, because of the midnight sun at >50 km height.

It is found that there was a large scale motion in the detected PMCs from east to west during 18–21 June 2020. More specifically, the PMC occurrence region was mainly extending in the east side (down to the latitude of ∼50°N) at 12:00–24:00 UT on 18 June 2020, and it moved gradually to the west side. Then, it reached ∼50°N in the west side at 00:00–12:00 UT on 21 June 2020. The corresponding longitudes for ∼50°N are ∼64°E in the west side and ∼217°E in the east side (see Figure 1). Thus, the westward movement was roughly ∼150° in longitude during ∼2.5 days, which corresponded to ∼360° during ∼6 days. Then, it seems that a next large scale westward motion began in the east side on 23–24 June 2020 (i.e., 5–6 days later from the previous beginning on 18 June 2020). This kind of large scale motion would correspond to a part of the westward traveling quasi 5-day wave (Q5DW) structures reported in the previous publications (e.g., Dalin et al., 2008; Merkel et al., 2003; Nielsen et al., 2011; von Savigny et al., 2007).

Moreover, this result indicates that the observed mid-latitude PMC extensions (i.e., extensions to <60°N) can be related with the phase of such Q5DW-like structures, and it would be consistent with the suggestion by Nielsen et al. (2011). Here, it should be noted that the second step detected faint PMC extensions to lower latitudes (<60°N) in the east side on 18–19 June 2020 (shown as light blue). Thus, the second step is important for detection.

Figure 5. (a) Daily PMC occurrence rates obtained from the Himawari-8/AHI band-1 data at 38°–81°N from 7 July 2015 to 9 March 2021 in the Northern Hemisphere (NH). (b) Same as (a), but in the Southern Hemisphere (SH). Gray indicates missing data, which are due to the polar night.
of relatively faint PMCs, such as mid-latitude PMCs/NLCs (e.g., Nielsen et al., 2011; Suzuki et al., 2016). This kind of Himawari-8/AHI-observed mid-latitude PMCs would be more suitable for comparison with mid-latitude NLCs obtained from imaging observations from the ground, because the Himawari-8/AHI provides PMC observations by continuous limb-viewing from its almost fixed location relative to the Earth. In addition to such day-to-day scale variation, there seem to be many shorter time scale structures, which may be partly due to smaller scale waves, such as atmospheric tidal and/or gravity waves. This point would be an important advantage of the Himawari-8/AHI PMC observation, which is the 10-min interval observation from the almost fixed location relative to the Earth. However, more careful consideration is needed for investigations on such daily variations (or variations with time scales of less than 24 hr). This is because the PMC signals are due to the Mie scattering, so that the forward scattering would be the strongest. More specifically, the scattering can be stronger around ∼15:00 UT (i.e., 24:00 JST), when the field-of-views (FOVs) of Himawari-8/AHI points to the sunward direction. Thus, the observed shorter time scale variation may include also the scattering angle effect. More detailed data analysis, taking into account for the scattering angle effect, is one of our ongoing works.

4.2. Year-to-Year Variation

To avoid such shorter time scale variation problem in the scattering angle, here we derived daily occurrence rates (or occurrence rates on each day) at each latitude from the detected PMC data at all (possible) local times.
Time variations in the daily occurrence rates during the whole period of Himawari-8/AHI observation (from 7 July 2015 to 9 March 2021) are shown in Figure 5. As for year-to-year variation in the Northern Hemisphere, it seems that the PMC occurrence rates tended to gradually increase during 2015–2020, and the occurrence rate was highest in summer 2020. On the other hand, the PMC occurrence rates in the Southern Hemisphere showed more complex features. For example, the PMC occurrence rate was not high in summer 2020–2021, compared with those in the other years. More detailed investigations on such year-to-year variations would be needed.

Moreover, we derived daily averaged PMC heights at each latitude from the PMC data, including height information, detected by the Himawari-8/AHI limb-viewing. Here, it should be noted that there would be an uncertainty in the PMC height determined by the limb-viewing observation, in which the observation points are assumed to be the tangential points. For example, PMC signals can be come from fore- and far-sides along the LOS in the Himawari-8/AHI (not from tangential points). In those cases, the PMC heights (i.e., tangential heights) can be underestimated, but those cannot be overestimated in any cases. Thus, it would be difficult to determine PMC peak...
heights or PMC center heights accurately. For this reason, we focus the highest PMC height among the detected PMC data points in each height profile, and it is defined as the upper edge of the PMC height.

Figure 6 shows the PMC heights (i.e., its upper edge) in the whole period. In the Northern Hemisphere, the PMC heights were generally less than 85 km. On the other hand, those can reach over 85 km more frequently in the Southern Hemisphere. Thus, it seems there was a significant hemispheric difference in the PMC height, and the PMC heights were higher in the Southern Hemisphere compared with those in the Northern Hemisphere. This tendency is consistent with the previous reports (e.g., Chu et al., 2001, 2003, 2004; Gardner et al., 2001; Russell III et al., 2010). Then, it seems that there were latitudinal (or spatial) variations in the PMC heights. For example, in summer 2020 in the Northern Hemisphere, the PMC heights tended to be lower at lower latitude (see Figure 6a), which would be basically consistent with results from the ground-based lidar observations at multiple locations (Chu et al., 2004). In addition, the PMC heights at 55–65°N in the east side seemed to be slightly lower than those at the same latitudes in the west side. Thus, the Himawari-8/AHI PMC observation can provide a new aspect with the denser latitudinal data coverage (with 1° interval in the present analysis), and it would enable us to investigate such more complex features in the PMC height in the future.

Figure 8. (a) Day-to-day variation in the detected PMCs in the Himawari-8/AHI band-1 at 38°–81°N in the east and west sides on 16–25 June 2020 in the Northern Hemisphere (NH). Deep blue indicates PMCs detected in the first step, and light blue indicates PMCs detected in the second step. (b) Same as (a), but for PMCs detected by AIM/CIPS. Deep blue indicates PMCs with albedo of $>6 \times 10^{-6}$, and light blue indicates PMCs with albedo of $>3 \times 10^{-6}$. We regard data which are not simultaneous AIM/CIPS and Himawari-8/AHI data as missing data, and thus those are masked by gray.
4.3. Validation

As a final part of this work, we perform a validation in the detected PMC data by Himawari-8/AHI, based on a comparison with the AIM/CIPS PMC data (cf. Lumpe et al., 2013; Russell III et al., 2009). Figure 7 shows some examples in the simultaneous observations between Himawari-8/AHI and AIM/CIPS. The FOVs of Himawari-8/AHI are fixed because of its GEO. Then, the FOVs of AIM/CIPS can be overlapping with those of Himawari-8/AHI at each orbit because of its LEO. The overlapping region can be variable depending on the AIM/CIPS orbits. Here, we pick up only such overlapping AIM/CIPS data, and calculate the averaged AIM/CIPS albedo data at each grid in the resampled Himawari-8/AHI data. It should be noted that the distance along the LOS in the Himawari-8/AHI grid is defined as 400 km (or ±200 km of the tangential points from the limb-viewing) to determine the grid box size, based on the work by Benze et al. (2018). Then, we tested several thresholds (>2 × 10⁻⁶ sr⁻¹, >3 × 10⁻⁶ sr⁻¹, >4 × 10⁻⁶ sr⁻¹, >5 × 10⁻⁶ sr⁻¹, >6 × 10⁻⁶ sr⁻¹, >7 × 10⁻⁶ sr⁻¹, etc.) for PMC detections from the AIM/CIPS data. As an example, Figure 8 shows a comparison between the detected PMCs from Himawari-8/AHI and AIM/CIPS on 16–25 June 2020. The data period is same as that in Figure 4, but showing only data when simultaneous observations were achieved. For the thresholds in AIM/CIPS PMC detection, deep blue indicates PMCs with albedo of >2 × 10⁻⁶ sr⁻¹, and light blue indicates PMCs with albedo of >3 × 10⁻⁶ sr⁻¹. It seems that the both detected PMC data showed similar features each other. For example, an extension of PMCs to lower latitudes on 18 June 2020 was well captured by the both Himawari-8/AHI and AIM/CIPS.

Then, comparisons in the daily occurrence rates from the simultaneous PMC data at 38°–81° are shown in Figure 9. Here, the threshold in the PMC detection by the AIM/CIPS data is set to the albedo of >3 × 10⁻⁶ sr⁻¹, to obtain the best consistency with the Himawari-8/AHI PMC data. The results show an excellent consistency between the two different PMC datasets. For example, both data showed a repetition of increases and decreases in the beginning of PMC seasons, which are probably due to the Q5DW structures, and the timings and amounts of the increases and decreases were in good agreement with each other. It is widely known that the AIM/CIPS have been providing a great performance, from which the PMC data would be highly reliable. Thus, it is considered
that the new PMC data obtained from this work on Himawari-8/AHI would be also highly reliable. As for the sensitivity in the PMC detection, the two-step detection method in the Himawari-8/AHI showed the same level of performance (or the same level in the occurrence rate) as the detection threshold of albedo of $>3 \times 10^{-6}$ sr$^{-1}$ in the AIM/CIPS (see Figure 9). Thus, the performance in the Himawari-8/AHI PMC data would be well enough for scientific PMC research, while it is the limb-viewing observation from the GEO.

5. Future Outlook

The developed PMC detection method is currently applied to real-time Himawari-8/AHI data, and a website presenting real-time PMC activity is opened to the public (http://ttt01.cei.uec.ac.jp/himawari/). Although the obtained PMC data may include the scattering angle effect which is the systematic effect mainly related with the daily variation, the current data product would be of benefit to various PMC science in the longer time scales, from day-to-day scale to year-to-year scale. The Himawari-8/AHI PMC data can be also useful for collaborations with the relevant observations, for example, the ground-based NLC observations by the camera network at mid-latitudes (Dalín et al., 2008). In addition, we expect further data analysis, taking into account for the scattering angle effect, will allow us to produce newer PMC science in the shorter time scale (with the 10-min resolution), hopefully in the near future.

Data Availability Statement

The Himawari-8/AHI data, obtained by the Meteorological Satellite Center of the Japan Meteorological Agency (JMA), are available from the National Institute of Information and Communications Technology (NICT) Science Cloud (https://sc-web.nict.go.jp/himawari/). The PMC data derived from the Himawari-8/AHI data are available on request to T. T. Tsuda (takuo.tsuda@uec.ac.jp) or are directly accessed at the website by University of Electro-Communications (http://ttt01.cei.uec.ac.jp/himawari/). The AIM/CIPS PMC albedo data (v5.20 level 2 data products) are available at the website by Laboratory for Atmospheric and Space Physics (LASP), University of Colorado Boulder (https://lasp.colorado.edu/aim/download-data-L2.php).

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