Aerosol Optical Depth product derived from Himawari-8 data for Asian dust monitoring

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Abstract

The Meteorological Satellite Center (MSC) of the Japan Meteorological Agency (JMA) has developed an aerosol optical depth (AOD) product using visible and near-infrared Himawari-8 data collected during the daytime. The product is used in JMA's Asian dust monitoring.

1. Introduction

Aerosol optical depth (AOD) products based on satellite data are used by the Japan Meteorological Agency (JMA) to monitor dust events in East Asia. JMA's Meteorological Satellite Center (MSC) has derived AOD products from GMS-5 (Okawara et al. 2003) and from MTSAT-1R/-2 satellites (Hashimoto 2005).

A new AOD algorithm for Himawari-8 developed by JMA's Meteorological Research Institute (MRI) has also been incorporated into the MSC product server system.

This paper describes the Himawari-8 AOD product. The algorithm is outlined in Section 3.

2. Himawari-8

Himawari-8 is the world's first next-generation geostationary meteorological satellite (Bessho et al. 2016). It was launched on 7 October 2014 and has been operational since 7 July 2015. The unit took over East Asia and Western Pacific observation previously conducted for more than three decades by five GMS (geostationary meteorological satellite) units and two satellites from the MTSAT (multifunctional transport satellite) series.

Himawari-8 carries the Advanced Himawari Imager (AHI), which has 16 bands (See Table 1 for AHI specifications). Himawari-8/AHI performs full-disk observations at 10-minute intervals, and observes the Japan area and specific target areas at 2.5-minute intervals. The Himawari-8 AOD product is derived from full-disk observations conducted during the daytime.

Table 1. Himawari-8 AHI specifications

	Band #	Central wavelength (μm)	Spatial resolution (km)
Visible	#1	0.47	1
	#2	0.51	
	#3	0.64	0.5
Near-infrared	#4	0.86	1
	#5	1.6	2
	#6	2.3	
Infrared	#7	3.9	
	#8	6.2	
	#9	6.9	
	#10	7.3	
	#11	8.6	
	#12	9.6	
	#13	10.4	
	#14	11.2	
	#15	12.4	
	#16	13.3	

3. Algorithm

3.1. Overview

AOD (at 0.5 μm) and the Ångström exponent (a proxy for particle size) are simultaneously estimated for areas over the ocean using two bands with signals different to those of particle size. AOD (at 0.5 μm) is estimated for areas over land using the near-infrared band (2.3 μm) adopted for estimation of land surface (background) reflectance. Lookup tables (LUTs) representing

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theoretical relationships between AHI visible and near-infrared reflectances and aerosol properties are compiled from radiative transfer simulation (see Section 3.2). AOD and the Ångström exponent are retrieved from the LUTs using Himawari-8 observation. As the aerosol type is assumed to be Asian dust for the LUTs, the algorithm is not optimized for other aerosol types (e.g., haze).

The processing of the algorithm is as outlined below. A flowchart of the processing is shown in Figure 1.

- Step 1 (input data collection): AOD product processing involves use of the data listed below. All data files are stored in a 5,500 x 5,500 infrared pixel array.
  - Radiances (bands 3, 4, 6)
  - Satellite/Solar zenith/Azimuth angles
  - Cloud mask from fundamental cloud product (Imai and Yoshida 2016)

  Spatial coregistration is completed in such a way that a 4 x 4 pixel array for AHI band 3 (0.64 μm) and a 2 x 2 pixel array for band 4 (0.86 μm) nominally correspond to an infrared pixel (see Table 1 for the spatial resolution of each band). The radiances of bands 3 and 4 are spatially averaged.

  Reflectance is defined as

  $$R = \pi I / S_0 \cos(\theta_0),$$

  where I is radiance, S_0 is solar irradiance and θ_0 is the solar zenith angle. The reflectances of bands 3, 4 and 6 ($R_{0.64}$, $R_{0.86}$ and $R_{2.3}$) are used in the subsequent steps.
- Step 2 (scene selection): AOD is retrieved for clear pixels during the daytime. Cloud mask comes from a fundamental cloud product (Imai and Yoshida 2016). Scenes with either of following are excluded from processing:
  - Sun glint angle (i.e., the angle between the satellite viewing direction and the direction of specular reflection) < 30°
  - Satellite/Solar zenith angles > 70°

  Land and sea areas are differentiated using land mask data.

  As aerosols cannot be detected over bright surfaces such as those of desert areas, only dark scenes ($R_{2.3} < 0.25$) are targeted for retrieval over land.

  If $(R_{0.86} - R_{2.3}) / (R_{0.86} + R_{2.3}) < 0.1$, the land surface type is judged to be soil; otherwise, it is marked as vegetation. Different LUTs are used for each.
- Step 3 (LUT interpolation): As LUT data are functions of satellite-earth-sun geometry (i.e., satellite/solar zenith angles and relative azimuth angles), LUTs are interpolated to fit the geometry for each pixel.
- Step 4 (retrieval): AOD and the Ångström exponent are retrieved from the interpolated LUT using band 3 and 4 reflectances for areas over the ocean. AOD and the surface reflectance of band 6 are retrieved from the interpolated LUT using band 3 and 6 reflectances. The surface reflectance of band 3 is determined as a function of that of band 6 in the LUT.
- Step 5 (output): AOD and the Ångström exponent (over ocean areas only) are provided as GPV data (0.02° x 0.02°).

3.2. LUT calculation

LUTs are provided by Yuzo Mano of MRI. The settings of LUT calculation basically follow Mano et al. 2009.

- Aerosol model
  Bimodal log-normal size distribution is assumed. Aerosol particles are assumed to be spheroidal and randomly oriented. The minor/major-axis ratio is based on the study of Okada et al. 2001, in which mineral aerosols were sampled in arid regions of China and their particle shapes were examined using an electron microscope. The complex refractive index is essentially the same as that of Mano et al. 2009.
- Surface reflectance
  The ocean surface is simulated using multiple facets whose slopes vary with wind speed over the ocean (Cox and Munk 1954). A constant wind speed of 5 m/s is assumed.
- Radiative transfer model

The atmosphere is divided into two layers (1,013 – 500 hPa and 500 – 100 hPa). Each layer is assumed to be plane-parallel and vertically homogeneous. Aerosols are located in the lower layer. Radiative transfer is calculated using the discrete ordinate method with 150 streams.

Figure 2 shows examples of LUTs for AOD retrieval.

4. Results

Figure 3 shows the Himawari-8 AOD product for 00 UTC on 1 August 2015. The AOD values and distribution seem reasonable with reference to MSC's MTSAT-2 AOD product and JMA's sun-photometer AOD product. However, the distribution of the Ångström exponent (not shown) is questionable, and remains under investigation.

Another issue involves detection of thick aerosols, which are sometimes missing from the product. Figure 4 shows an example. With reference to other sources (e.g., MSC's MTSAT-2 AOD product), the blank area surrounded by aerosols around 41°N appears to be thick aerosols. From this, it can be inferred that cloud mask tends to classify thick aerosol as cloud.

5. Conclusion

MSC has routinely derived the AOD product from Himawari-8 full-disk observation data since 7 July 2015. The spatial coverage is 114°E – 160°E, 52°N – 17°N. Processing is performed hourly during the daytime (full disk observations from (hh-1):50 to hh:00; hh = 00 – 06). The Himawari-8 AOD product is used for Asian dust monitoring by JMA.

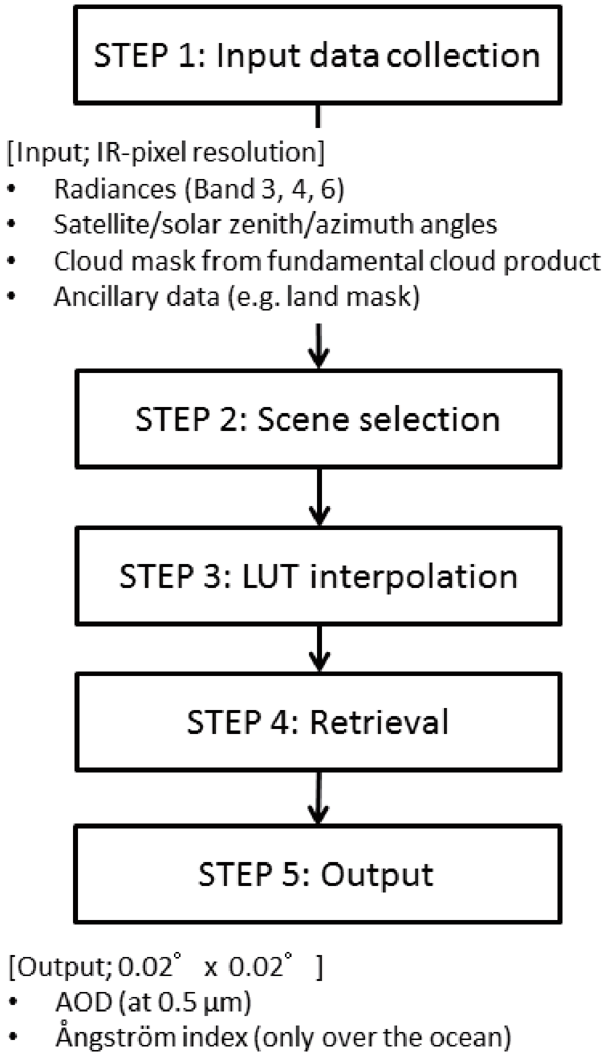

Figure 1. Himawari-8 AOD product processing

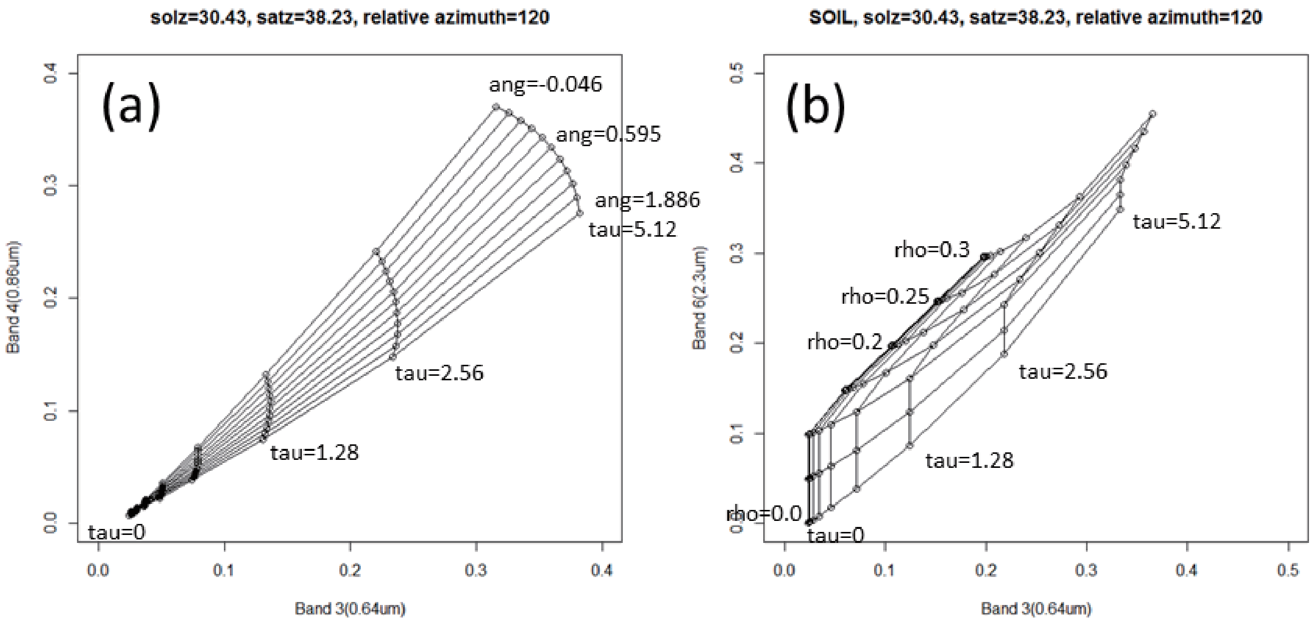

Figure 2. (a) Theoretical relationship between the reflectances of Himawari-8 AHI bands 3 and 4 over ocean areas for various aerosol loading conditions. AOD (denoted as tau) = 0.000, 0.020, 0.040, 0.080, 0.160, 0.320, 0.640, 1.280, 2.560 and 5.120; Angstrom index (denoted as ang) = 1.886, 1.529, 1.235, 0.988, 0.777, 0.595, 0.435, 0.294, 0.169, 0.056 and -0.046; solar zenith angle = 30.43°, satellite zenith angle = 38.23°, and relative azimuth angle = 120°. (b) Theoretical relationship between the reflectances of Himawari-8 AHI bands 3 and 6 over land areas (soil type) for various aerosol loading conditions. AOD (denoted as tau) = 0.000, 0.020, 0.040, 0.080, 0.160, 0.320, 0.640, 1.280, 2.560 and 5.120; surface reflectance of band 6 (denoted as rho) = 0.30, 0.25, 0.20, 0.15, 0.10, 0.05 and 0.00; solar zenith angle = 30.43°, satellite zenith angle = 38.23° and relative azimuth angle = 120°.

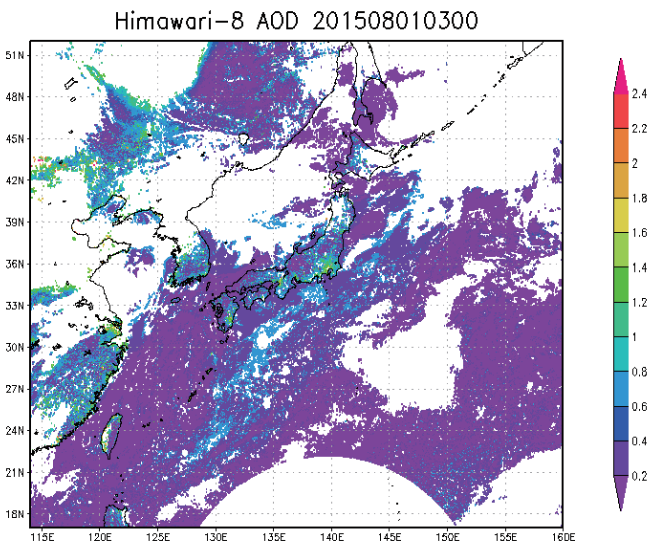

Figure 3. Himawari-8 AOD product for 00 UTC on 1 August 2015

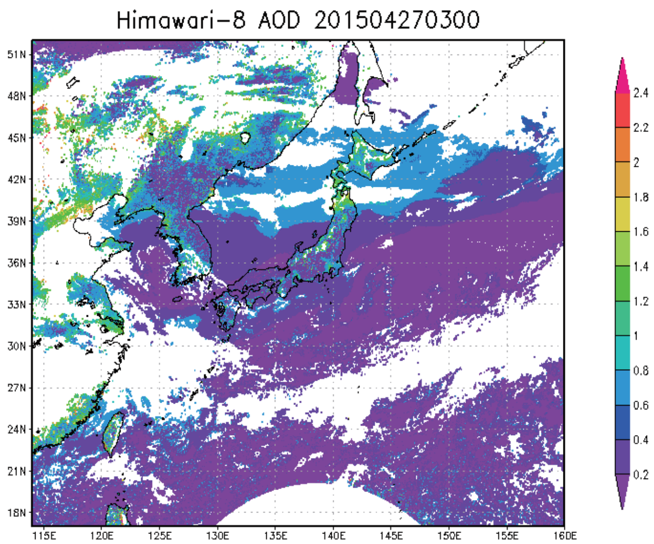

Figure 4. Himawari-8 AOD derived from in-orbit test data for 03 UTC on 27 April 2015

References

Bessho, K., K. Date, M. Hayashi, A. Ikeda, T. Imai, H. Inoue, Y. Kumagai, T. Miyakawa, H. Murata, T. Ohno, A. Okuyama, R. Oyama, Y. Sasaki, Y. Shimazu, K. Shimoji, Y. Sumida, M. Suzuki, H. Taniguchi, H. Tsuchiyama, D. Uesawa, H. Yokota, and R. Yoshida, 2016: An introduction to Himawari-8/9 - Japan's new-generation geostationary meteorological satellites. *J. Meteor. Soc. Japan*, 94, doi:10.2151/jmsj.2016-009.

Cox, C., and W. Munk, 1954: Measurement of the roughness of the sea surface from photographs of the sun's glitter. *J. Opt. Soc. Am.*, 44, 838-850.

Imai, T., and R. Yoshida, 2016: Algorithm theoretical basis for Himawari-8 Cloud Mask Product. *Meteorological Satellite Center Technical Note*, 61, 1-17.

Hashimoto, T., 2005: Aerosol Optical Thickness. *Meteorological Satellite Center Technical Note Special Issue*, 121-124. (in Japanese)

Mano, Y., T. Hashimoto, and A. Okuyama, 2009: Verification of satellite-derived aerosol optical thickness over land with AERONET data. *Papers in Meteorology and Geophysics*, 60, 7-16.

Okada, K., J. Heintzenberg, K. Kai, and Y. Qin, 2001: Shape of atmospheric mineral particles collected in three Chinese arid-regions, *Geophys. Res. Lett.*, 28, 3123-3126.

Okawara, N., Y. Yoshizaki, and M. Tokuno, 2003: Development of Aerosol Products from GMS/VISSR and NOAA/AVHRR Image Data. *Meteorological Satellite Center Technical Note*, 42, 43-52. (in Japanese)

黄砂監視のためのひまわり 8 号エーロゾル光学的厚さプロダクト

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要　旨

気象衛星センターはひまわり 8 号エーロゾル光学的厚さ（AOD）プロダクトを開発した。AOD は可視・近赤外データを利用して日中算出される。本プロダクトは気象庁の黄砂監視業務で利用される。

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