Algorithm Theoretical Basis Document for Cloud Type/Phase Product

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Abstract

The cloud type/phase product is an element of the fundamental cloud product, which incorporates cloud mask, cloud type/phase and cloud top height. The Meteorological Satellite Center (MSC) of Japan Meteorological Agency (JMA) separated cloud mask, cloud type/phase and cloud top height, which were contained in miscellaneous level 2 products in the Himawari-7 era, and put them together as a fundamental cloud product. The cloud type/phase product provides information on cloud type (opaque/semi-transparent/fractional) and the phase of cloud drop (water/ice/unknown or mix) at the cloud top. The analysis method is mainly based on the NWCSAF (NoWCasting Satellite Application Facility) cloud type algorithm because the method is well established and relatively easy to understand. Cloud phase comparison between the MSC product and the Level 2 product of MODIS (MYD06L2) and Calipso (CAL_LID_L2_01kmCLay-ValStage1-V3-30) was carried out from 20 July to 2 August 2015. The ice phase capture ratio was greater than 80% for both MODIS and Calipso.

1. Introduction

Himawari-8 carries the Advanced Himawari Imager (AHI), which has 16 observational bands for the provision of a wealth of information on cloud microphysics. Meteorological satellite operating organizations around the world have made out cloud type and cloud phase in recognition of their importance, and the Meteorological Satellite Center (MSC) of Japan Meteorological Agency (JMA) also began to provide the fundamental cloud product when Himawari-8 entered its operative period. MSC simultaneously separates cloud mask, cloud type/phase and cloud top height from other level 2 satellite products and puts them together into a single output called the fundamental cloud product. It can be used for other level 2 products such as those for aerosols, sea surface temperature and volcanic ash, and users no longer need to compute their own cloud information.

Cloud type studies produce comparatively qualitative information, enabling determination of clouds as opaque, semi-transparent or fractional in the MSC cloud type product. Brightness temperature difference is the main metric utilized to determine cloud type. The algorithm theoretical basis document for the cloud product of NWCSAF (Meteo France 2012) describes the cloud type determination that MSC uses for reference. The GOES-R cloud type algorithm theoretical basis document (Pavolonis 2010) also deals with cloud types, but these are cloud phases such as ice or water. In cloud phase studies, the difference in the imaginary part of the complex refractive index between two bands is used to determine the ice or water particle phase for IR bands. Strabala et al. (1994) proposed cloud particle phase discrimination using 8-, 11- and 12-micron brightness temperatures and their difference from data collected by the high-resolution infrared sounder (HIRS) on board NOAA's polar orbiters. For near-infrared bands, Baum et

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al. (2012) investigated cirrus clouds using MODIS data. This document outlines the cloud type/phase product and the related algorithm, which is based on the NWCSAF algorithm (Meteo France 2012). The product includes information on cloud type and cloud phase. The document also describes the required input data, output data and evaluation.

1.1. Content

This is the Algorithm Theoretical Basis Document for the cloud type/phase product. It describes the algorithms used and covers related practical considerations.

1.2. Definitions, acronyms and abbreviations

AHI: Advanced Himawari Imager (mounted on Himawari-8 and -9 for observation with 16 bands; central wavelengths: 0.47, 0.51, 0.64, 0.86, 1.6, 2.3, 3.9, 6.2, 6.9, 7.3, 8.6, 9.6, 10.4, 11.2, 12.4, 13.3 microns) .

Aqua: NASA's low-earth-orbit earth science satellite.

A_{srf}: Surface albedo depending on surface type, sun zenith angle, atmospheric conditions and other variables.

BRDF: Bi-directional reflectance distribution function.

Calipso: NASA's satellite for analyzing clouds and aerosols in relation to weather and climate. The unit is equipped with cloud-aerosol lidar for observation of aerosols and cloud microphysics.

Cloud mask: A cloud mask product providing information on pixel clear/cloudy status and aerosol detection. Cloud mask data are created from Himawari-8's output, and are also an element of the fundamental cloud product. Cloud mask data contain only high- and low-quality flags, while the cloud type product provides a much wider range of data on quality.

Daytime: The period during which the sun zenith angle is smaller than 80 degrees.

Effective emissivity at 11.2 microns (ε(11.2)): The effective emissivity of 11.2 microns at the center wavelength is the product of cloud amount and cloud emissivity as estimated in consideration of cloud at the tropopause level. Although effective emissivity differs from the product of actual cloud emissivity and actual cloud amount, it has similar characteristics in that observed radiance is related to the ratio of contribution from cloud top radiation and surface radiation. This means that thick cloud has high effective emissivity and thin cloud has low effective emissivity.

EUMETSAT: An intergovernmental European organization founded in 1986 that operates the Meteosat geostationary satellite and the low-earth-orbiting Metop and Jason satellites. The organization runs a satellite application facility (SAF) to support research, development and operational activities not carried out at EUMETSAT headquarters.

$\varphi_{\{sun-sat\}}$: Angle between sun and satellite.

JMA: Japan Meteorological Agency.

LRC: Local radiative center as incorporated in GOES-R Cloud Type and Cloud Height Algorithm Theoretical Basis (Pavolonis 2010).

LUT: Look-up table containing radiance values to support discrimination between ice phase cloud and water phase cloud. The radiances were calculated using RSTAR (see "RSTAR" in this section) under various conditions for ice phase and water phase.

MODIS: Moderate resolution imaging spectroradiometer on board the Aqua and Terra satellites.

MSC: Meteorological Satellite Center.

Nighttime: Period during which the sun zenith angle is larger than 93 degrees.

NWCSAF: Nowcasting satellite application facility.

λ: Center wavelength of the AHI bands in microns.

r_{eff}: Effective radius of cloud particles.

R_{bde}: Bi-directional reflectance.

R (λ): Observed reflectivity at the central wavelength of λ microns, where λ is 0.64 or 1.6.

RSTAR: A radiative transfer code developed by the Center for Climate System Research at the University of Tokyo (Nakajima and Tanaka 1986).

RTTOV: A radiative transfer code developed by EUMETSAT (Eyre 1991).

Surface category: MSC uses the Global Land Cover Characteristics Data Base Ver 2.01 of USGS to identify earth surface attributes. The cloud type product features four main categories: 1. water area; 2. lowland, urban or crop area; 3. mountain, desert or rock area; and 4. forest area.

τ: Optical thickness.

θ_{sunZ}: Sun zenith angle (the angle from the sun to the zenith at an arbitrary point on the earth's surface).

θ_{satZ}: Satellite zenith angle (the angle from the satellite to the zenith at an arbitrary point on the earth's surface).

$T(\lambda)$: Observed brightness temperature at the center wavelength of microns, where is 3.9, 6.2, 7.3, 8.6, 11.2, 12.4 or 13.3.

$T_{plev}(\lambda)$: Estimated brightness temperature at the center wavelength of λ microns as calculated under the assumption of cloud presence with a height corresponding to the surface. λ corresponds to the AHI observation wavelength. By way of example, it may be 6.2, 7.3, 8.6 and so on. Plev is a constant value for pressure between the surface and the tropopause. By way of example, it may be surface, 850 hPa, 500 hPa and so on. A surface value indicates that there is no cloud. RTTOV is used for estimation as outlined later.

$T_{cloud}(\lambda)$: Estimated brightness temperature at the center wavelength of λ microns as calculated under the assumption of opaque cloud. In regard to radiative transfer, the cloud top is at height $T_{plev}(\lambda)$, which accords with $T(\lambda)$. λ corresponds to the observation wavelength. By way of example, it may be 6.2, 7.3, 8.6 and so on.

Terra: NASA's low-earth-orbit earth science satellite.

* http://edc2.usgs.gov/glcc/globdoc2_0.php

Twilight time: Period during which the sun zenith angle is smaller than 93 degrees and larger than 80 degrees.

2. Outline of cloud type and phase product

The cloud type/phase product provides information on cloud type (opaque, semi-transparent or fractional) and the phase of cloud drop (water, ice or unknown/mixed). The method of analysis is based on a threshold technique largely modeled on the NWCSAF cloud type algorithm. Cloudy pixels in Cloud Mask (Imai and Yoshida 2016) are processed in the cloud type product.

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2.1. Input data

i. AHI observation data

Reflectances at 0.64 and 1.6 microns and brightness temperatures at 3.9, 7.3, 8.6, 11.2 and 12.4 microns are used in the product.

ii. Radiative transfer calculation data based on JMA's global spectral model

Wavelengths correspond to those of the AHI observation data described above.

iii. Cloud mask data

iv. Satellite navigation data

Values represent latitude, longitude, satellite zenith angle, satellite azimuth angle, sun zenith angle, sun azimuth angle and scanning time for each pixel.

v. Ancillary data

Values represent elevation on land, surface category and white sky albedo. The surface category is described in Subsection 1.2. The white sky albedo of the MODIS albedo product (Moody at al. 2005) is used for the type/phase product.

2.2. Process flow of the cloud type/phase product

As the cloud phase product is associated with the cloud type product, the cloud type procedure is run first (Fig. 1).

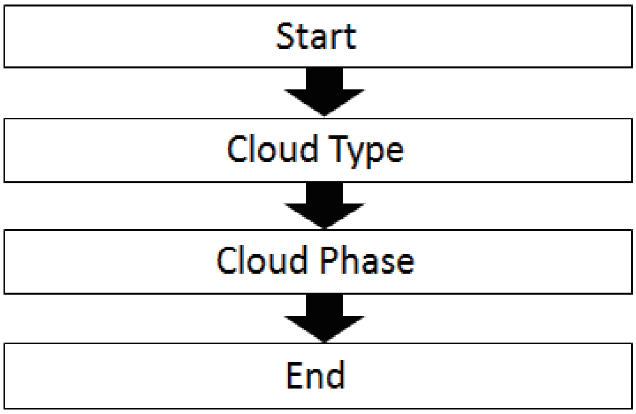

Fig. 1. Process flow of the cloud type/phase product

2.3. Output data

i. Cloud type information

Clouds are identified as opaque, semi-transparent or fractional. The opaque and semi-transparent categories have seven levels based on brightness temperature as observed at 11.2 microns, and the fractional category has only one level. A total of 15 types of information are provided. The seven levels are classified based on comparison between T(11.2) and Tplev(11.2).

– Level 1 (Extremely high cloud)

$T(11.2) < 0.5 \times T_{400hPa}(11.2) + 0.5 \times T_{200hPa}(11.2)$

– Level 2 (High cloud)

$0.5 \times T_{400hPa}(11.2) + 0.5 \times T_{200hPa}(11.2) \leq T(11.2) < T_{400hPa}(11.2)$

– Level 3 (Relatively high cloud in the middle cloud)

$T_{400hPa} \leq T(11.2) < 0.5 \times T_{400hPa}(11.2) + 0.5 \times T_{600hPa}(11.2)$

– Level 4 (Relatively low cloud in the middle cloud)

$0.5 \times T_{400hPa}(11.2) + 0.5 \times T_{600hPa}(11.2) \leq T(11.2) < T_{600hPa}(11.2)$

– Level 5 (Low cloud)

$T_{600hPa}(11.2) \leq T(11.2) < 0.5 \times T_{600hPa}(11.2) + 0.5 \times T_{surface}(11.2)$

– Level 6 (Very low cloud)

$0.5 \times T_{600hPa}(11.2) + 0.5 \times T_{surface}(11.2) \leq T(11.2) < T_{surface}(11.2)$

– Level 7 (Extremely low cloud)

$T_{surface}(11.2) \leq T(11.2)$

ii. Cloud phase information

Cloud phase is identified as ice, water or unknown/mixed.

3. Cloud type/phase product algorithm

3.1. Cloud type product

Cloud type determination for the product is based on the threshold technique. Each pixel is identified as opaque cloud, semi-transparent cloud or fractional cloud as described in the previous section depending on observed brightness temperature, reflectance, and brightness temperature difference between two wavelengths. The tests performed for each level are described in this section, and the algorithm is described in the subsequent subsections.

The cloud types identified in this product do not correspond to the ten basic types commonly referenced in surface weather observation; essentially, only the categories of opaque cloud and semi-transparent cloud are used. MSC of JMA also provides High-resolution Cloud Analysis Information (HCAI) (Suzue et al. 2016) containing cloud type information similar to that indicating ten basic cloud types.

3.1.1. Opaque or semi-transparent cloud at Levels 1, 2, 3 and 4

A $T(11.2) - T(12.4)$ test is utilized to discriminate opaque cloud and semi-transparent cloud in these levels. The semi-transparent cloud test is carried out first. If the result is positive (i.e., the pixel is semi-transparent), the opaque cloud test is not carried out. If the result is negative, the pixel is given an opaque cloud status.

– Semi-transparent cloud

$T(11.2) - T(12.4) > T112T124opaque$

– Opaque cloud

$T(11.2) - T(12.4) \leq T112T124opaque$

The threshold for $T112T124opaque$ is derived from

$$T112T124opaque = T_{surface}(11.2) - T_{surface}(12.4) + Offset\_112\_opaque$$

Here, $Offset\_112\_opaque$ is a constant value considered to exhibit the highest skill score in opaque cloud separation. The offset is taken from an LUT (see the Appendix for information on the offset).

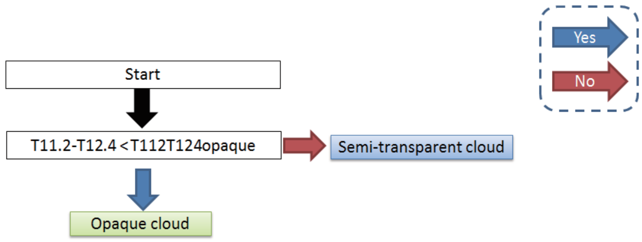

Fig. 2. Flow of cloud type determination for Levels 1, 2, 3 and 4

3.1.2. Opaque or semi-transparent cloud at Levels 5, 6, and 7 and fractional cloud

In these categories, $T(11.2) - T(12.4)$, $R(0.64)$, $T(3.9) - T(11.2)$ and $T(8.6) - T(11.2)$ tests are utilized to discriminate semi-transparent, opaque and fractional cloud. The $R(0.64)$ test for semi-transparent cloud covering lower-layer cloud is carried out in the daytime only, and the $T(3.9) - T(11.2)$ test is for lower opaque cloud at nighttime. The $T(8.6) - T(11.2)$ test is for separation of lower fractional cloud and semi-transparent cloud.

i. Daytime

The opaque cloud test is carried out first. This is followed by the fractional cloud test, and remaining cloud is classified as semi-transparent.

- Opaque cloud

$T(11.2) - T(12.4) < T112T124opaque$

And

$R(0.64) > maxCiR064$

- Fractional cloud

$T(8.6) - T(11.2) \leq T86T112fractional$

- Semi-transparent cloud

All pixels other than those in the above categories

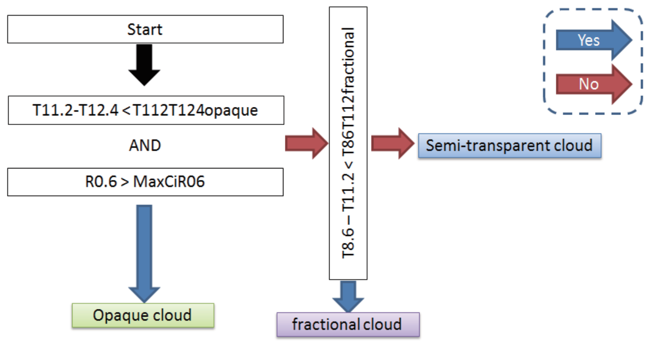

Fig. 3. Flow of cloud type determination for Levels 5, 6 and 7 in the daytime

The $maxCiR064$ threshold is used to allow semi-transparent cloud to be distinguished from opaque cloud in the NWCSAF algorithm (Meteo France 2012). This is based on the concept that semi-transparent cloud and opaque cloud are separated by the maxCiR064 threshold reflectance derived from $T(11.2)$. The maxCiR064 threshold and $T(11.2)$ have a linear relationship.

A line can be drawn through two points:

・(223.15, 0.35): Coldest point at 11.2 microns

・($T_{surface}(11.2)$,R_{bde}): Warmest (surface) point at 11.2 microns

The bi-directional effect of the overcast model proposed by Manalo-Smith et al. (1998) is used for calculation of R_{bde}.

Figure 4 shows an example of the relationship between $T(11.2)$ and $maxCiR064$. The straight line is used to distinguish semi-transparent cloud from opaque cloud.

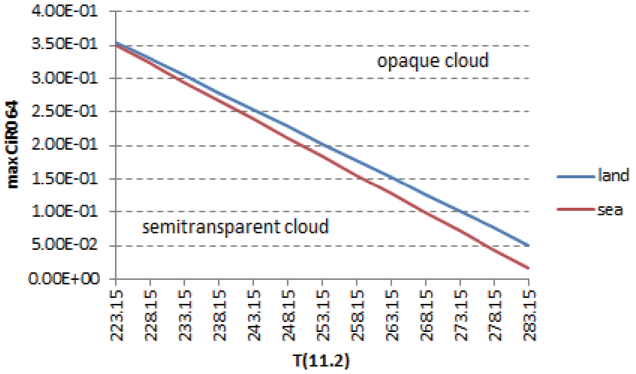

Fig. 4. Relationship between $T(11.2)$ and $maxCiR064$

ii Twilight

The procedure for twilight tests is the same as that for the daytime except for the $R(0.64)$ test.

- Opaque cloud

$T(11.2) - T(12.4) < T112T124opaque$

- Fractional cloud

$T(8.6) - T(11.2) \leq T86T112fractional$

- Semi-transparent cloud

All pixels other than those in the above categories

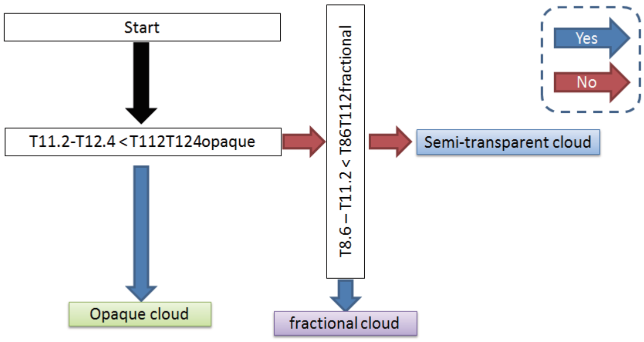

Fig. 5. Flow of cloud type determination for Levels 5, 6 and 7 at twilight

iii Nighttime

The procedure for nighttime testing involves application of the $T(3.9) - T(11.2)$ test to detect lower-layer opaque cloud.

- Opaque cloud

$T(11.2) - T(12.4) < T112T124opaque$

And

$T(3.9) - T(11.2) < T39T112opaque$

- Fractional cloud

$T(8.6) - T(11.2) \leq T86T112fractional$

- Semi-transparent cloud

All pixels other than those in the above categories

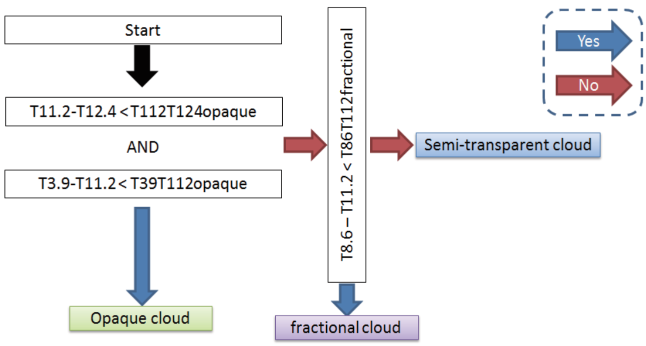

Fig. 6. Flow of cloud type determination for Levels 5, 6 and 7 at nighttime

The $T39T112opaque$ and $T86T112fractional$ thresholds are used to detect opaque cloud and fractional cloud, respectively, at nighttime.

$$T39T112opaque = T_{surface}(3.9) - T_{surface}(11.2) + Offset\_39\_opaque$$

$$T86T112fractional = T_{surface}(8.6) - T_{surface}(11.2) + Offset\_86\_fractional$$

$Offset\_39\_opaque$ and $Offset\_86\_fractional$ are constant values considered to have the highest skill score in separation of opaque cloud. These biases are contained in an LUT (see the Appendix for further information on biases).

3.2. Cloud phase product

This section describes cloud particle phase classification, which is also based on the threshold technique. The flow is shown in Fig. 7.

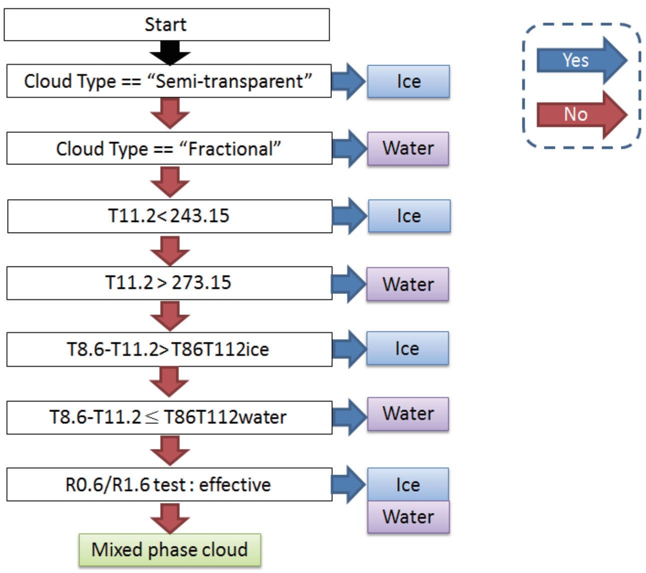

Fig. 7. Flow of cloud phase processing

Cloud particle phase discrimination involves the use of cloud type and satellite data on variables such as brightness temperature. For opaque cloud, the relationships linking $T(11.2)$, $T(8.6) - T(11.2)$, $R(0.64)$ and $R(1.6)$ are used to determine the particle phase. For other types, the phase is the same as that of the local radiative center (LRC) if the LRC is opaque; otherwise, the ice phase is attributed to semi-transparent cloud and the water phase is attributed to fractional cloud.

3.2.1. Cloud type discrimination results

For opaque cloud pixels, phase discrimination involves the use of the satellite data described in this section. The phase is ice for semi-transparent cloud pixels and water for fractional cloud pixels.

3.2.2. $T(11.2)$ test

For opaque cloud, the phase is ice when $T(11.2)$ is below freezing temperature without an ice nucleus and water when $T(11.2)$ is above freezing temperature.

・Ice particle cloud

$T(11.2) < 243.15$

・Water droplet cloud

$T(11.2) > 273.15$

3.2.3 $T(8.6) - T(11.2)$ test

As described in 2.3, the ice or water droplet phase is attributed on the basis of the $T(8.6) - T(11.2)$ temperature difference, which is generally larger for ice cloud than for water cloud.

・Ice particle cloud

$$T(8.6) - T(11.2) > T_{cloud}(8.6) - T_{cloud}(11.2) + Offset\_86\_ice$$

The value of $Offset\_86\_ice$ is set in reference to an

LUT, and is a constant considered to have the highest skill score in ice particle cloud detection. The score is calculated from the Calipso cloud phase product (Hu el al. 2009) and NWP data (see the Appendix for information on the constant).

・**Water droplet cloud**

$$T(8.6) - T(11.2) \leq T_{cloud}(8.6) - T_{cloud}(11.2) + Offset\_86\_water$$

The value of $Offset\_86\_water$ is set in reference to an LUT, and is a constant considered to have the highest skill score in ice particle cloud detection. The score is calculated from the Calipso cloud phase product (Hu et al. 2009) and NWP data (see the Appendix for information on the constant).

3.2.4. $R(0.64)$ and $R(1.6)$ tests

If the values of $R(0.64)$ for water droplet cloud and ice particle cloud are the same, the value of $R(1.6)$ for ice cloud will be smaller than that for water droplet cloud. This characteristic allows discrimination of the two cloud types. Based on this, consistent cloud phase determination is achieved through comparison of $R(0.64)$ / $R(1.6)$ observation values and radiative transfer calculation.

In this method, an LUT is created using the RSTAR radiative transfer model with various conditions of $R(0.64)$ and $R(1.6)$. In the radiative transfer calculation, the reflectances of ice and water phase cloud at 0.64 and 1.6 microns are acquired. The reflectance is varied with the conditions of cloud altitude, cloud thickness, cloud particle shape/radius, positional relationship between the sun and the satellite, atmospheric profile and surface reflectance. The calculation conditions are summarized below.

i. Geometric conditions

・Sun zenith angle (θ_{sunZ}): every 10 degrees from 0 to 90

・Satellite zenith angle (θ_{satZ}): every 10 degrees from 0 to 90

・Azimuth difference between sun and satellite ($\varphi_{\{sun-sat\}}$) (degrees) : 0, 2.5, 5, 10, 15, 25, 35, 45, 55, 65, 75, 85, 95, 105, 115, 125, 135, 145, 155, 165, 170, 175, 177.5, 180

ii. Cloud

・Optical thickness (τ): 0.25, 0.50, 1, 2, 4, 8, 16, 32, 64, 96, 128

・Cloud height: 3 km

iii. Effective radius (r_{eff}) and shape for ice cloud

・Effective radius (μm): 10, 20, 30, 40

・Shape: spherical

iv. Effective radius and shape for water droplet cloud

・Effective radius (μm): 4, 8, 16, 32

・Shape: spherical

v. Other conditions

・Surface albedo (A_{srf}) ($R(0.64)$): 0.02, 0.05, 0.1, 0.2, 0.3, 0.5

・Surface albedo (A_{srf}) ($R(1.6)$): 0.02, 0.05, 0.1, 0.2, 0.3, 0.5, 0.7, 1.0

・Atmospheric profile: standard for mid-latitude summer

The value shown below is then set to the LUT.

$$R_{\{ice/water\}}(\lambda, \tau, r_{eff}, \theta_{sunZ}, \theta_{satZ}, \varphi_{\{sun-sat\}}, A_{srf})$$

The cloud particle phase is set from the LUT. The procedure is as outlined below.

i. The values of θ_{sunZ} , θ_{satZ}, $\varphi_{\{sun-sat\}}$ and A_{srf} for every pixel are determined based on navigation and ancillary data. Here, A_{srf} is from MODIS white sky albedo data (Moody et al. 2005). $R_{\{ice/water\}}(\lambda, \tau, r_{eff})$ is also obtained from the LUT.

ii. Values of τ corresponding to each value of r_{eff} are determined based on comparison of $R(0.64)$ and $R_{\{ice/water\}}(0.64, \tau, r_{eff})$.
A value of $R_{\{ice/water\}}(1.6, r_{eff})$ corresponding to τ is then determined.

iii. $R(1.6)$ and $R_{\{ice/water\}}(1.6, r_{eff})$ are compared for all values of r_{eff}. If the results all indicate water, the phase is marked as water; if they all indicate ice, the phase is marked as ice; otherwise, the phase is marked as unknown or mixed.

4. Data format

Data are provided in flat binary format, with those of cloud type and cloud phase expressed as 1-byte integers. Data are written in files following the order from northwest to southeast with 5,500 pixels and 5,500 lines. The pixel sequence is the same as that of the Himawari Standard Data format.

4.1. Cloud type values

Cloud type is expressed as 1-byte integers as indicated below.

-128: Error pixel associated with satellite data errors and similar
0: Clear pixel in cloud mask
1: Extremely high opaque cloud
2: High opaque cloud
3: Relatively high opaque cloud in the middle layer
4: Relatively low opaque cloud in the middle layer
5: Low opaque cloud
6: Very low opaque cloud
7: Extremely low opaque cloud
8: Extremely high semi-transparent cloud
9: High semi-transparent cloud
10: Relatively high semi-transparent cloud in the middle layer
11: Relatively low semi-transparent cloud in the middle layer
12: Low semi-transparent cloud
13: Very low semi-transparent cloud
14: Extremely low semi-transparent cloud
15: Fractional cloud

4.2. Cloud phase values

Cloud phase is expressed as 1-byte integers as indicated below.

-128: Error pixel associated with satellite data errors and similar
0: Clear pixels in cloud mask
1: Ice phase
2: Water phase
3: Unknown or mixed phase

5. Validation

The Meteorological Satellite Center of Japan Meteorological Agency carried out cloud phase validation using the MODIS level 2 product over a period of two weeks from 20 July to 2 August 2015. The comparison indices used were the capture ratio (Eq. 5-1), the false alarm ratio (Eq. 5-2) and the undetected error ratio (Eq. 5-3) as calculated from a contingency table. Table 1 shows an example of an ice phase contingency table.

$$\text{Capture ratio} = \frac{OO}{OO + XO}\ (eq\ 5-1)$$

$$\text{False alarm ratio} = \frac{OX}{OO + OX}(eq5-2)$$

$$\text{Undetected error ratio} = \frac{XO}{OO + XO}(eq5-3)$$

Table 1. Contingency table in case of ice phase
OO represents the number of cases in which both Calipso or MODIS and cloud phase results indicate ice phase. OX represents the number of cases in which cloud type indicates ice phase but Calipso or MODIS does not. XO and XX represent the inverse situations.

		Modis/Calipso Cloud Phase	
		Ice cloud	No Ice cloud
Cloud Phase(JMA)	Ice cloud	OO	OX
	No Ice cloud	XO	XX

Figures 8 (a) and (b) show the results of cloud phase validation. Although the capture ratio for the ice phase is comparatively favorable, the undetected error ratio and false alarm ratio are large for the unknown/mixed phase. The capture ratio for the latter phase is also low.

MSC has not carried out validation for the cloud type product because data in the Calipso and MODIS level 2 products are not appropriate for comparison.

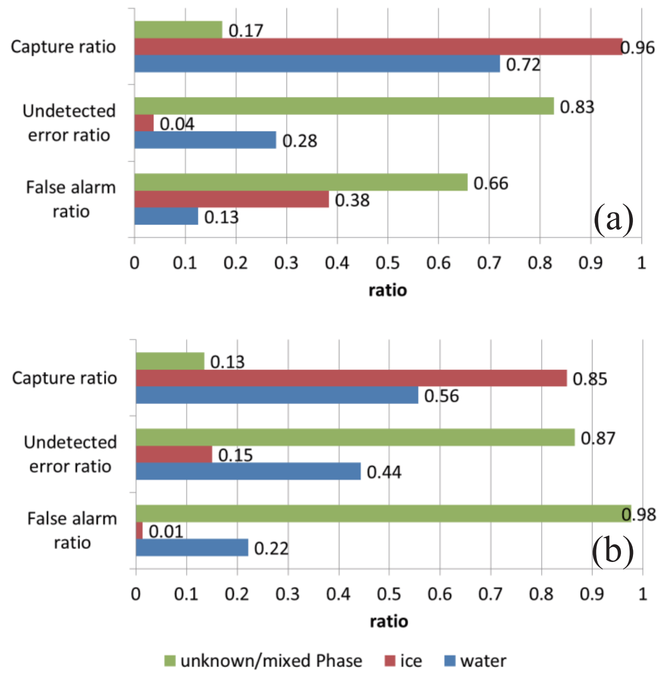

Fig. 8 (a) Comparison of JMA cloud phase to MODIS L2 product

Fig. 8 (b) Comparison of JMA cloud phase to Calipso L2 product

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References:

Baum, B. A., W. P. Menzel, R. A. Frey, D. Tobin, R. E. Holz, S.A. Ackerman, A. K. Heidinger, and P. Yang, 2012: MODIS cloud top property refinements for Collection 6. J. Appl. Meteor. Clim., 51, 1145-1163.

Eyre J. R., 1991: A fast radiative transfer model for satellite sounding systems., ECMWF Research Dept. Tech. Memo. 176.

Hu Y., D. Winker, M. Vaughan, B. Lin, A. Omar, C. Trepte, D. Flittner, P. Yang, S. L. Nasiri, B. Baum, R. Holz, W. Sun, Z. Liu, Z. Wang, S. Young, K. Stamnes, J. Huang, and R. Kuehn, 2009: CALIPSO/CALIOP Cloud Phase Discrimination Algorithm. J. Atmos. Oceanic Technol., 26, 2293-2309.

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

Meteo France, 2012: Algorithm Theoretical Basis Document for “Cloud Products” (CMa-PGE01 V3.2, CT-PGE02 v2.2, & CTTH-PGE03 v2.2).

Moody, E. G., M. D. King, S. Platnick, C. B. Schaaf, and F. Gao, 2005: Spatially complete global spectral surface albedos: Value-added datasets derived from Terra MODIS land products. IEEE Trans. Geosci. Remote Sens., 43, 144-158.

Nakajima, T., and M. Tanaka, 1986: Matrix formulations for the transferof solar radiation in a plane-parallel scattering atmosphere. J. Quant. Spectrosc. Radiat. Transfer, 35, 13-21.

Pavolonis, M., 2010: GOES-R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document For Cloud Type and Cloud Phase.

Smith, M. N., G. L. Smith, S. N. Tiwari, and W. F. Staylor, 1998: Analytical forms of bidirectional reflectance functions for application to Earth radiation budget studies, Journal of Geophysical Research, 103 (D16) 19733-19751.

Strabala, I. K, S. A. Ackerman, and W. P. Menzel, 1994: Cloud Properties inferred from 8-12-µm Data. J. Appl. Meteor., 33, 212-229.

Suzue, H., T. Imai, and K. Mouri, 2016: High-resolution

Cloud Analysis Information derived from Himawari-8 data. Meteorological Satellite Center Technical Note, 61, 43-51.

Appendix:

Values for $Offset\_112\_opaque$, $Offset\_39\_opaque$, $Offset\_86\_fractional$, $Offset\_86\_ice$ and $Offset\_86\_water$

Determination of offset values is based on comparison between the cloud classification of the Calipso cloud phase product (Hu et al. 2009) and cloud type identified using the method described in Subsections 3.1.1 and 3.1.2. The skill score is adopted as a comparison index. By way of example, the 2 x 2 contingency table shown below is used for the opaque cloud detection ($T39T112opaque$) described in Chapter 3.1.2. Skill score is defined using the following equation:

$$Skill\ Score = \frac{(OO + XX) - Sc}{N - Sc}$$

$$\mathrm{Sc} = \frac{(OO + XO)}{N} \times (OO + OX) + \frac{(OX + XX)}{N} \times (XO + XX)$$

$$N = OO + OX + XO + XX$$

Table A-1. Contingency table

OO represents the number of cases in which both Calipso and cloud type results indicate opaque cloud. OX represents the number of cases in which cloud type indicates opaque cloud but Calipso does not. XO and XX represent the inverse situations.

		Calipso Cloud Classification	
		Opaque cloud	No opaque cloud
Cloud Type(JMA)	Opaque cloud	OO	OX
	No opaque cloud	XO	XX

Skill score varies with the offset (Fig A-1). The offset value with which the highest skill score is achieved is adopted. In this example, the offset value is 2K.

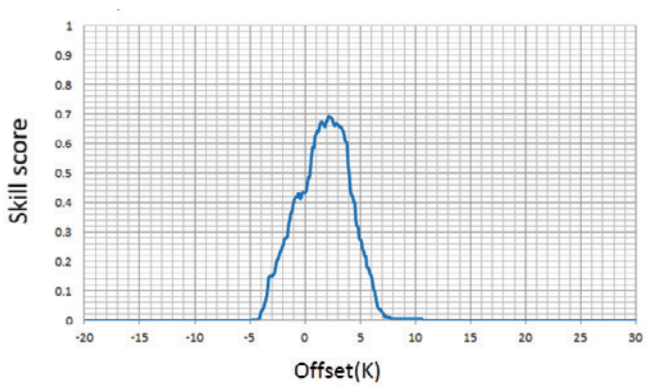

Fig. A-1. Bias values for T39T112opaque and skill scores. This test is for opaque cloud detection at nighttime using T(3.9) – T(11.2) as described in 3.1.2.

In practice, the offset value is acquired for each value of $T(11.2)$ and surface land type. This offset tables are shown in Figs A-2 (a), A-2 (b), A-2 (c), A-2 (d) and A-2 (e). In this study, data from Meteosat-9's SEVIRI imager were used because $T(8.6)$ was required. The study covered an overall period of eight weeks (two weeks during each of winter 2011 – 2012 (December and January), spring 2012 (March and April), summer 2012 (June and July) and autumn 2012 (September and October)). In the future, the offset value will be updated based on additional years of accumulated AHI data.

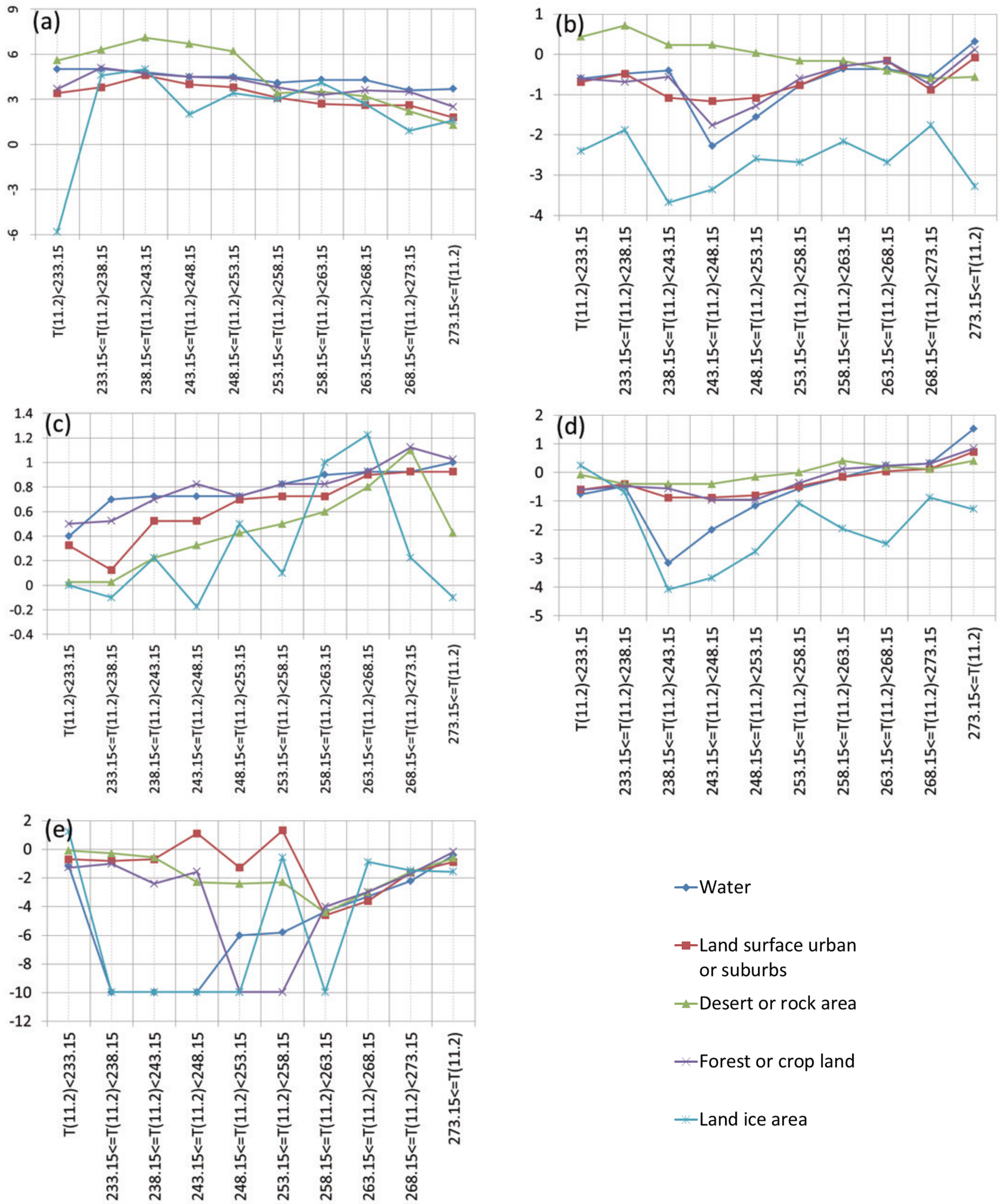

Fig. A-2

(a) Bias values for T3.9T11.2opaque (b) Bias values for T8.6T11.2fractional

(c) Bias values for T11.2T12.3opaque (d) Bias values for ice phase (e) Bias values for water phase

Determination of these values is based on land type and T(11.2)

雲タイプ・相アルゴリズム記述書

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要旨

雲タイプ、相プロダクトは基本雲プロダクトを構成する１つである。基本雲プロダクトは雲マスク、雲タイプ、雲の相、および雲頂高度からなる。気象庁ではひまわり８号を機に様々な２次プロダクトが含んでいる雲マスク、雲タイプ、相、雲頂高度プロダクトを独立させ、基本雲プロダクトとして一つにまとめ上げた。雲タイプ、相プロダクトは不f透明、半透明、断片雲といった雲タイプと、水、氷、未定・混合といった雲の相を出力する。解析手法は過去に実績があり、比較的理解しやすいNWCSAFの雲タイプアルゴリズムに主に基づいている。雲の相に関して、2015年7月20日から8月2日において気象庁気象衛星センタープロダクトとMODIS（MYD06L2）プロダクト及びCalipso（CAL_LID_L2_01kmCLay-ValStage1-V3-30）との比較を実施したところ、氷相では80%以上の捕捉率となった。

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