Polar Multi-Sensor Aerosol Product: Factsheet

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Document Change Record

Issue / Revision	*Date*	*DCN. No*	*Summary of Changes*
v1	14 October 2014		First version-released for operational dissemination.
v1B	08 January 2015		Update to PMAp release 1.0.10, small corrections
v2	14 January 2016		Update to PMAp release 2
V2B	28 February 2017		Update to PMAp release 2.1

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1 THE POLAR MULTI-SENSOR AEROSOL PROPERTIES PRODUCT

Aerosols are suspended particulate matter in the atmosphere carried by air masses. Aerosol particles can be solid or liquid and can cover a wide range of particle sizes, from 0.005 µm to 100 µm, depending on aerosol type. This wide range leads to a large variation in scattering and absorption characteristics.

This algorithm is dedicated to retrieving aerosol optical depth (AOD) at 550 nm under daylight conditions, for clear-sky and partially cloudy scenes. The provided cloud optical depth (COD) and related parameters are available over all surface types and under daylight condition. Future versions of the algorithm will extend the availability of aerosol related parameters over all surface types.

The retrieval algorithm relies primarily on data from the GOME instrument with the support of AVHRR and IASI instruments. A detailed description of the algorithm is provided in [AD 1]. A complete list of user requirements applicable to PMAp is provided in [AD 2]. For a more detailed summary of the algorithm, the usage of the data and the data formats, please see the PMAp product user guide [AD 7].

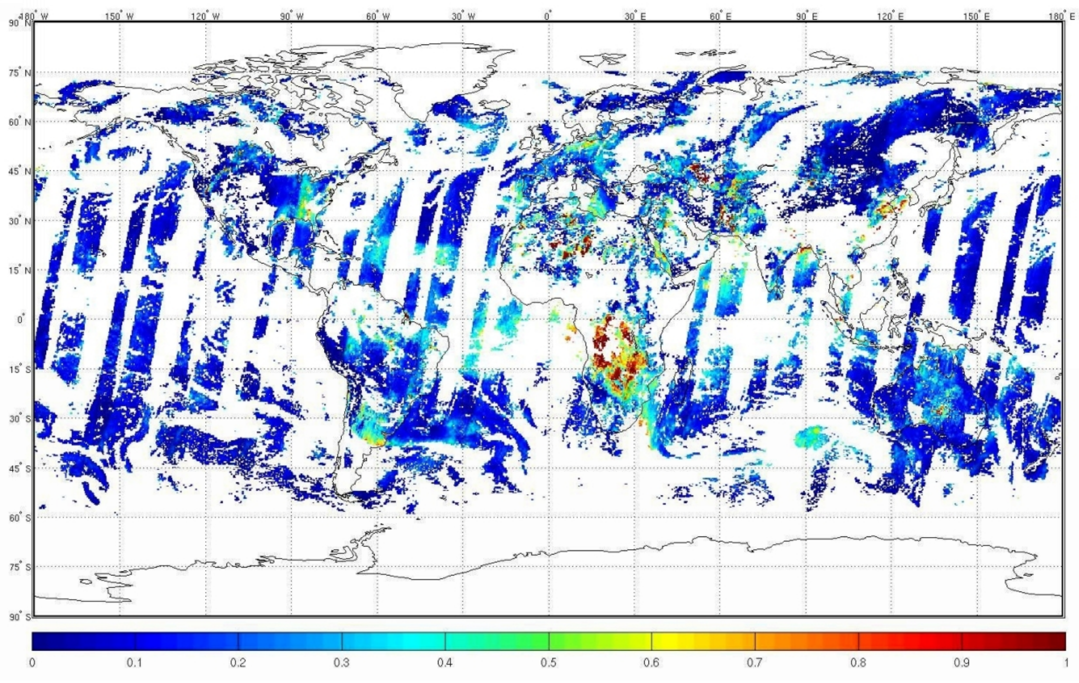


Figure 1: PMAp-derived AOD values from both Metop-A and B platform using level-1b data from GOME-2 PMD and AVHRR measurements.

1.1 PMAp processor and format version history

Version	Start sensing	End sensing	PFS native[1]	Nectdf4[2]
1.0	26 March 2014	17 March 2016	1	1
2.0	17 March 2016	23 February 2017	2	2
2.1	23 February 2017		2	2

[1]PFS document major version number
[2]Product user manual document major version number

1.2 The GOME instrument

GOME-2 is a medium-resolution double UV-VIS spectrometer, fed by a scan mirror which enables across-track scanning in nadir, as well as sideways viewing for polar coverage and instrument characterisation measurements using the moon. The scan mirror directs light into a telescope that is designed to match the field of view of the instrument to the dimensions of the entrance slit. This scan mirror can also be directed towards internal calibration sources or towards a diffuser plate for calibration measurements using the sun.

GOME-2 comprises four main optical channels which focus the spectrum onto linear silicon photodiode detector arrays of 1024 pixels each, and two Polarisation Measurement Devices (PMDs) containing the same type of arrays for measurement of linearly polarised intensity in two perpendicular directions.

The PMDs are required because GOME-2 is a polarisation-sensitive instrument; therefore the intensity calibration must take account of the polarisation state of the incoming light. This is achieved using information from the PMDs. For this algorithm, the radiances and stokes fractions measured by the PMD are used to retrieve aerosol optical properties. PMDs are available for the following wavelength ranges:

Band-S					**Band-P**				
No.	***pix1***	***pixw.***	***wav1***	***wav2***	***No.***	***pix1***	***pixw.***	***wav1***	***wav2***
0	22	5	311.709	314.207	0	20	5	311.537	313.960
1	30	4	316.762	318.720	1	29	4	317.068	318.983
2	37	12	321.389	329.139	2	36	12	321.603	329.267
3	50	6	330.622	334.443	3	49	6	330.744	334.560
4	57	6	336.037	340.161	4	56	6	336.157	340.302
5	84	17	360.703	377.873	5	83	17	361.054	378.204
6	102	4	380.186	383.753	6	101	4	380.502	384.049
7	117	19	399.581	428.585	7	116	19	399.921	429.239
8	138	27	434.083	492.066	8	137	27	434.779	492.569
9	165	18	494.780	548.756	9	164	18	495.272	549.237
10	183	2	552.474	556.262	10	182	2	552.967	556.769
11	187	11	568.070	612.869	11	186	11	568.628	613.680
12	198	9	617.867	661.893	12	197	9	618.711	662.990
13	218	4	744.112	768.269	13	217	4	745.379	769.553
14	224	2	794.080	803.072	14	223	2	795.364	804.351

Table 1: GOME-2 PMD band definitions (v3.1) as adapted by EUMETSAT based on level 1B spectral calibration of PMD data from PPF version 3.8 from orbit 3372 (14 June 2007). This set of definitions has been uploaded for orbit on 11 March 2008.

1.3 The GOME instrument operations and monitoring

The GOME-2 flight model 3 (FM3) instrument has been operated on the Metop-A platform number 2 (M02) since 2006. Level 1 data has been available since 2007. GOME-2 flight model number 2 (FM2) has been operated on Metop-B platform number 1 since 2012.

Note: The operational processing of PMAp data started in February 2014.

This PMAp product is based on the PMD footprint and the swath width settings of the two GOME-2 instruments on the Metop-A and Metop-B platforms and follows the operational 29-day cycle used for both. The instrument operations for both are in Figure 2 and Figure 3. Since 15 July 2013, both GOME-2 instrument on board Metop-A and Metop-B have been operated in tandem with changed swath settings of GOME-2 / Metop-A to a full width of 960 km, while GOME-2 on Metop-B remains on the full swath width of 1920 km. Accordingly, the ground pixel footprint of GOME-2 PMD devices and the corresponding PMAp scientific products is 5 × 40 km for Metop-A and 10 × 40 km for Metop-B. The multi-sensor PMAp product is produced as a GOME-2 product with the spatial resolution of the GOME-2 PMD footprint:

Satellite Platform	***Spatial resolution (GOME-2 PMD spatial resolution)***	***Swath***
Metop-A	5 km × 40 km (since 15th July 2013)	960 km
Metop-B	10 km × 40 km	1920 km
Metop-C	TBD	TBD

Daily performance reports for both instruments are on the dedicated GOME website: http://gome.eumetsat.int

The 29-day instrument operations plans for Metop-A and Metop-B are in Figure 2 and Figure 3. The 29 days repeat cycle of routine operations and viewing configuration has also changed recently for both instruments. The monthly calibration sequence is issued for both instrument on the same day with two nadir static orbits (no scanning) followed by one orbit during which the PMD data is down-linked at full spectral resolution (256 channels for both PMDs) but at reduced spatial read-out resolution (12 read-outs in forward and 4 read-outs in backward scanning direction at the same ground spatial resolution for PMDs, i.e. with gaps in between the read-outs). This latter configuration is called the monthly PMD RAW read-out configuration.

Note: PMAp data is not available for both nadir static orbits nor is it available for the PMDRAW orbit issued every 29 days in one sequence. PMAp data is available for all other calibration modes as indicated in Figure 2 and Figure 3**.**

GOME-2 / Metop-A is configured to operate once per month at a reduced swath width of 320 km. Both 29-day operational schedules are summarized in Figure 2 and Figure 3.

See also the web page: http://gome.eumetsat.int > Timelines.

GOME-2/Metop-A timeline planning per 412/29 repeat cycle. Version 5.0, July 2013 - Start of Tandem Operations

day	orbit offset	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	X	X	X	M1	M2	D1	D2	X	X	S	S	R	X	X	X
2	15	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
3	29	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
4	43	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
5	57	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	X
6	72	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
7	86	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
8	100	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
9	114	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
10	128	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	X
11	143	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
12	157	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
13	171	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
14	185	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
15	199	N3	N3	N3	N3	N3	D1	D2	N3	N3	N3	N3	N3	N3	N3	N3
16	214	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
17	228	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
18	242	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
19	256	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
20	270	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	X
21	285	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
22	299	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
23	313	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
24	327	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
25	341	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	X
26	356	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
27	370	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
28	384	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
29	398	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	

D1	CALNS6	Daily calibration, part 1 (SLS/WLS) with 960 km swath
D2	CALNS0	Daily calibration, part 2 (Sun) with 960 km swath
M1	CALNS4	Monthly calibration, part 1 (LED, WLS, SLS modes) with 960 km swath
M2	CALNS5	Monthly calibration, part 2 (SLS over diffuser mode) with 960 km swath
N3	NOT320	Narrow swath (320 km)
S	NADIR	Nadir static
R	PMDRAWNS	PMD monitoring (nominal readout/raw transfer mode) with 960 km swath
X	NOT960	Nominal swath (960 km)

Figure 2: The 29-day instrument operation cycle for GOME-2 on Metop-A. Different colours and ID tags indicate different instrument operations settings as explained in the document key.

GOME-2/Metop-B timeline planning per 412/29 repeat cycle. Version 1.0, July 2013 - Start of Tandem Operations

day	orbit offset	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	X	X	X	M1	M2	D1	D2	X	X	S	S	R	X	X	X
2	15	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
3	29	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
4	43	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
5	57	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	X
6	72	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
7	86	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
8	100	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
9	114	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
10	128	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	X
11	143	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
12	157	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
13	171	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
14	185	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
15	199	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	X
16	214	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
17	228	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
18	242	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
19	256	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
20	270	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	X
21	285	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
22	299	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
23	313	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
24	327	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
25	341	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	X
26	356	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
27	370	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
28	384	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	
29	398	X	X	X	X	X	D1	D2	X	X	X	X	X	X	X	

D1	CAL6	Daily calibration, part 1 (SLS/WLS) with 1920 km swath
D2	CAL0	Daily calibration, part 2 (Sun) with 1920 km swath
M1	CAL4	Monthly calibration, part 1 (LED, WLS, SLS modes) with 1920 km swath
M2	CAL5	Monthly calibration, part 2 (SLS over diffuser mode) with 1920 km swath
S	NADIR	Nadir static
R	PMDRAW	PMD monitoring (nominal readout/raw transfer mode) with 1920 km swath
X	NOT1920	Nominal swath (1920 km)

Figure 3: The 29-day instrument operation cycle of GOME-2 on Metop-B. Different colours and ID tags indicate different instrument operations settings as explained in the document key.

For more details on GOME-2 operations and the instrument settings, see the GOME-2 factsheet available here:

http://www.eumetsat.int > Data > Technical Documents > GDS Metop > GOME-2 > GOME-2 factsheet

1.4 The AVHRR Instrument

The AVHRR/3 is a six-channel scanning radiometer providing three solar channels in the visible/near-infrared region and three thermal infrared channels. The AVHRR/3 has two one-micrometre wide channels between 10.3 and 12.5 micrometres. The instrument utilises a 20.32 cm (8-inch) diameter collecting telescope of the reflective Cassegrain type. Cross-track scanning is accomplished by a continuously rotating mirror directly driven by a motor. The three thermal infrared detectors are cooled to 105 K by a two-stage passive radiant cooler. A line synchronisation signal from the scanner is sent to the spacecraft MIRP processor which in turn sends data sample pulses back to the AVHRR.

Although AVHRR/3 is a six-channel radiometer, only five channels are transmitted to the ground at any given time. Channels 3a and 3b cannot operate simultaneously. The transition from channel 3a to 3b (and vice-versa) is done by telecommand and reflected in the science data. For Metop-A, channel 3a is operated during the daytime portion of the orbit and channel 3b during the night-time portion.

The following table summarises the spectral characteristics of AVHRR/3:

Channel	*Central wavelength (µm)*	*Half power points (µm)*	*Channel noise specifications*	
S/N @ 0.5 % reflectance			NEdT @ 300 K	
1	0.630	0.580 - 0.680	9:1	-
2	0.865	0.725 - 1.000	9:1	-
3a	1.610	1.580 - 1.640	20:1	-
3b	3.740	3.550 - 3.930	-	< 0.12K,0.0031 mW/(m^2 sr cm^{-1})
4	10.800	10.300 - 11.300	-	< 0.12 K, 0.20 mW/(m^2 sr cm^{-1})
5	12.000	11.500 - 12.500	-	< 0.12 K, 0.21 mW/(m^2 sr cm^{-1})

Table 2: Spectral Characteristics of AVHRR/3

Note: Information in this section is taken from [AD 6AD 6].

1.5 The IASI Instrument

The Infrared Atmospheric Sounding Interferometer is composed of a Fourier transform spectrometer (IASI) and an associated Integrated Imaging Subsystem (IIS). The Fourier transform spectrometer provides infrared spectra with high resolution between 645 and 2760 cm^{-1} (3.6 µm to 15.5 µm). The IIS consists of a broad band radiometer with a high spatial resolution. However, the IIS information is only used for co-registration with the Advanced Very High Resolution Radiometer (AVHRR).
The main goal of the IASI mission is to provide atmospheric emission spectra to derive temperature and humidity profiles with high vertical resolution and accuracy. Additionally it is used for the determination of trace gases such as ozone, nitrous oxide, carbon dioxide and methane, as well as land- and sea surface temperature and emissivity and cloud properties.

IASI has 8461 spectral samples, aligned in three bands between 645.0 cm^{-1} and 2760 cm^{-1} (15.5µm and 3.63 µm), with a spectral resolution of 0.5 cm^{-1} (FWMH) after apodisation (L1c spectra). The spectral sampling interval is 0.25 cm^{-1}. The IASI sounder is coupled with the IIS, which consists of a broad band radiometer measuring between 833 cm^{-1} and 1000 cm^{-1} (12µm and 10µm) with a high spectral resolution.

The following table summarises the spectral characteristics of IASI:

Band	*wavelength (µm)*	*wave number (cm^{-1})*
1	8.26 – 15.50	645.0 – 1210.0
2	5.00 – 8.26	1210.0 – 2000.0
3	3.62 – 5.00	2000.0 – 2760.0

Table 3: Special Characteristics of IASI.

The usage of IASI is planned as a part of the project, but IASI data is not currently being evaluated by the algorithm.

Note: Information in this section is taken from [AD 5].

2 AERSOSOL AND CLOUD RETRIEVAL ALGORITHM OVER LAND AND OCEAN

The PMAp aerosol algorithm has three steps:

- **Step 1**: At the beginning, a pre-classification is applied based on AVHRR, IASI and the UV absorbing index of GOME-2. This includes the detection of clouds, calculation of cloud correction factors, detection of strong aerosol events (in particular volcanic ash and dust) and a pre-classification of possible aerosol types.
- **Step 2:** A set of AODs at 550 nm are retrieved using one GOME-2 PMD band. The selected band depends on the condition (dark ocean, ocean with slight glint effects, dense vegetation, bright surfaces/deserts or continents with moderate albedo). Each of these AODs is retrieved with respect to different aerosol types and microphysical properties. At this point, it is not known which selection of aerosol type and microphysical properties is the best representation of the given scene. For clear sky pixels over ocean, the chlorophyll pigment concentration is fitted in addition to the processing.
- **Step 3:** One of the AODs from Step 2 is selected which fits best to the GOME-2 PMD measurements (reflectances and stokes fractions) which are usable for the given scene. The included bands may depend on different elements, e.g. on the surface albedo, the predicted clear-sky top of atmosphere stokes fraction, and the cloud coverage.

Remarks:

- The aerosol cases included to the retrieval within step 2 can be defined by external parameters which are usually a subset of the 28 cases over ocean and 6 cases over land. The radiative transfer data for these cases is provided by a look-up table (LUT).
- It should be stated that most of the information available in the GOME-2 data is already used by retrieving one AOD-related parameter. Most information is obtained for clear sky pixels over ocean far from sun glint conditions because both clouds and bright surfaces are avoided for all bands. However, a lot of this additional information is needed to fit the chlorophyll pigment concentration. It is impossible to distinguish all cases provided by the LUT, because the remaining independent information is usually equal or lower than the noise of the measured signal. Nevertheless, some information remains dependent on the observation geometry. The algorithms use this information to improve the retrieved AOD. The information on the aerosol type and additional microphysical parameters available in addition to the AVHRR pre-classification should be considered as quite limited.

2.1 Radiative transfer Look Up table

This LUT is taken from the document by Hasekamp, Tuinder, and Stammes. See [RD 1]:

2.1.1 Look up table for the AOD retrieval over sea

The LUT contains reflectances and stokes fractions for ten PMD bands (PMD5 to PMD14, see Section. 2.1) and 28 aerosol models. The reflectances are modelled on observation geometry: solar zenith angle (SZA), relative azimuth angle (RAZI), viewing zenith angle (VZA), wind speed and the amount of chlorophyll. The models are characterized by Hasekamp et. al. [RD 1] and dependent on microphysical properties of the aerosols: effective radius and the variance of the effective radius for small and coarse mode respectively, the real and the imaginary part of the refractive index (m_r and m_i) and the fraction of the aerosol coarse mode f_l. This Look-up table is shown in Table 4.

Aerosol model	*Eff. Radius liquid*	*Eff. Radius solid*	*Eff. Variance small*	*Eff. Variance large*	f_l	m_r	m_i	*Aerosol type*
1	0.11	0.84	0.65	0.65	1.53e^{-2}	1.40	–4.0e^{-3}	oceanic
2	0.12	2.19	0.18	0.81	4.36e^{-4}	1.40	–4.0e^{-3}	industrial
3	0.13	2.24	0.50	0.81	4.04e^{-4}	1.40	–4.0e^{-3}	industrial
4	0.21	2.50	0.18	0.81	8.10e^{-4}	1.45	–4.0e^{-3}	industrial
5	0.14	2.15	0.22	0.62	7.00e^{-4}	1.45	–1.2e^{-2}	industrial
6	0.15	2.26	0.22	0.62	6.84e^{-4}	1.45	–1.2e^{-2}	industrial
7	0.18	2.69	0.22	0.62	6.84e^{-4}	1.45	–1.2e^{-2}	industrial
8	0.12	2.43	0.20	0.87	1.70e^{-4}	1.50	–1.0e^{-2}	biomass
9	0.15	2.70	0.20	0.87	2.06e^{-4}	1.50	–1.0e^{-2}	biomass
10	0.20	3.42	0.20	0.87	2.94e^{-4}	1.50	–1.0e^{-2}	biomass
11	0.11	2.52	0.17	0.70	2.07e^{-4}	1.50	–2.0e^{-2}	biomass
12	0.12	2.67	0.17	0.70	2.05e^{-4}	1.50	–2.0e^{-2}	biomass
13	0.14	3.28	0.17	0.70	1.99e^{-4}	1.50	–2.0e^{-2}	biomass
14-18	0.10	1.60	0.32	0.42	4.35e^{-3}	1.53		dust
19-28	Same as model 7-16 with altitude 3-4 km (model 0-18: altitude 1-2 km)							

*Table 4: Radiative transfer LUT classification used in PMAp. [***Error! Reference source not found.***] and [***Error! Reference source not found.***].*

2.1.2 Look up table for the AOD retrieval over land

The LUT for the AOD retrieval over land contains a subset of the cases available over ocean. The aerosol LUT over land contains 5 models (aerosol nos. 1-5). The microphysical properties of these cases are identical to the aerosol models 2, 5, 8, 12, 16 over ocean. The reflectances and stokes fractions are stored dependent on their solar zenith angle, viewing zenith angle, relative azimuth angle, surface albedo, and surface pressure.

2.2 Clouds, volcanic ash and aerosol classes

Cloud fraction and the volcanic ash flag are also retrieved by PMAp. The result is used as an input for the AOD algorithm. Then, in addition, the cloud optical depth (COD) is retrieved after the AOD retrieval. The AOD is required as input for the COD retrieval.

2.2.1 Cloud fraction and cloud filter

The first-guess cloud fraction is based on the cloud product distributed by the AVHRR Level-1 product [L1AVH]. The AVHRR instrument provides a total of eight cloud tests: Four tests for clear-sky, and four tests for cloudy pixels. This product defines an AVHRR pixel as *cloudy* if one of the four tests gives a *true* flag for the "if not cloudy then fail" tests and a *false* flag for the "if not clear then fail" test. In fact, an AVHRR pixel is considered as cloudy if one test indicates a cloud. Pixels with failures for all the AVHRR cloud tests are treated as cloudy. The geometric cloud fraction is then given by collocation of the AVHRR pixels to GOME-PMD.

These cloud tests are available from AVHRR:

No.	***tests...***	***used to...***
T11	brightness temperature of AVHRR channel 4	reveal low temperature to medium or high clouds
T11–T12	difference in brightness temperature of channel 4 and 5	detect cirrus clouds
Albedo test	reflectances in the two VIS channels	detect bright clouds
T4	spatial coherence test over sea	detect cloud edges, thin cirrus and small cumulus over sea

The thresholds for the different tests depend on season, geographical location, satellite viewing angle and availability of distinct data sets (forecast data and/or climatological data).

The cloud fraction is used as a first guess of the cloud situation. PMAp retrieves a cloud-free reflectance dependent on the aerosol class. This calculation is based on a combination of the AVHRR cloud flags, additional thresholds, and the analysis of spatial homogeneity in the VIS, NIR and TIR. A pixel is classified as cloud free if the average radiance of the AVHRR pixels within the GOME footprint is close to the cloud free reflectance. See [**Error! Reference source not found.**] for details.

***Note*:** The AVHHR cloud fraction distributed within the EUMETSAT GOME Level-1 product is different from the cloud fraction retrieved within the aerosol product PMAp.

2.2.2 Volcanic ash detection

PMAp uses two retrieval algorithms to detect volcanic ash:

The first algorithm selects one AVHRR pixel within the PMD footprint that has the lowest (highest negative) brightness temperature difference T4-T5 using channel 4 and channel 5 of AVHRR. For this AVHRR pixel, the radiances of all AVHRR channels are read. The algorithms apply a set of ten test settings to detect volcanic ash. If one of the test settings is passed, the presence of volcanic ash is assumed by the algorithm, totally independent of the cloud flags for the AVHRR pixel. Each test setting contains a combination of six thresholds which make use of the split-window technique (T4-T5), the wavelength dependency of the signal (600 nm to 1600 nm), and homogeneity tests. All threshold tests must be passed to return a positive ash result. The details of the test settings and sequence are provided in [**Error! Reference source not found.**]. The wavelength dependency between 600 nm and 1600 nm cannot be used for pixels over land, because the surface albedo show a strong wavelength dependency as well. The UV absorbing index calaculated from the GOME UV channels is used in combination with brightness temperature difference instead.

The second volcanic ash algorithm is based on IASI measurements and combines the brightness temperature difference technique between 10 and 12 microns with other brightness temperature differences including channels sensitive to SO_2 absorption.

2.2.3 Classification of aerosol class

The PMAp algorithm uses a pre-classification of the aerosol class based on AVHRR, the GOME UV index and IASI based tests. The classification is used as an input for the aerosol optical depth retrieval on GOME (step 2 and step 3 of the retrieval, see above) and as a useful output for the users of the PMAp product. Within the least square fit over several aerosol models, only a subset of the data available in the LUT is used. This depends on limitations defined by external parameters (useModel) and subsets predefined for each pre-classification. These aerosol classes are listed in Table 5.

Nr	*Class*	*Characterization*
0	No dust/fine mode (ocean only)	BTD ash tests negative and strong wavelength dependency of the measured signal between 0.6µm and 1.6 µm.
1	coarse mode (ocean only)	Desert dust, ash or coarse mode sea-salt without significant BTD signal but weak wavelength dependency in VIS/NIR
2	Thick biomass burning	Over ocean: UV index indicate UV absorbing aerosol, coarse mode tests negative, TIR dust/ash tests negative. Over land: Stokes fraction and UV index tests positive.
3	Thick dust/volcanic ash	Volcanic ash or thick dust, BTD in TIR indicate dust/ash, weak wavelength dependency in VIS/NIR (ocean) or UV index indicate absorbing aerosol
4	Volcanic ash with SO_2	Volcanic ash, IASI ash test positive (including tests with SO2 TIR channels), confirmation by AVHRR VIS/NIR or GOME-2 UV tests
15	No classification	

Table 5: Aerosol classes, PMAp algorithm

For details on the derivation of the aerosol classes and the selection of the fitted aerosol models, please refer to **Error! Reference source not found.**.

2.3 Cloud optical depth

Cloud optical depth is retrieved using single-band retrieval. In a first step, the “effective albedo” is inverted from TOA reflectance using a RTM-based LUT that depends on satellite observation geometry. The effective albedo is the albedo of a lambertian reflector at the surface, which gives the same TOA reflectance as the surface combined with the aerosol.

Note: The COD product is not yet validated official product. EUMETSAT plans to replace the database, as want to use one RTM for all multiple applications within the PMAp product family in the future. The following parameters are delivered:

- Cloud top temperature
- Ash plume brightness temperature

2.4 Quality flags and error calculation

2.4.1 Quality flags

PMAp removes bad pixels from the datasets. If the algorithm or the input dataset indicates that the AOD from PMAp is not meaningful, the value is removed from the dataset. There is usually no need to apply a specific filter. If you have a specific requirement in accuracy stricter than settings of PMAp, you may apply a limit in the AOD error and remove values where no error value is available.

The PMAp quality flags indicate MDRs where problems in the input data are found. Flags for GOME, AVHRR and IASI are provided separately. If there are problems in the GOME or the AVHRR input data, no AOD is retrieved. If there are problems in the IASI input data, AOD is retrieved without using the IASI part of the retrieval. This limits in particular the detection of volcanic ash and may be used as a filter if PMAp data is used to detect volcanic ash or thick dust.

2.4.2 PMAp Retrieval Flags

The PMAp aerosol product delivers a set of up to 16retrieval flags. Currently, there are seven. A positive retrieval flag does not mean a general bad quality of the retrieval because bad retrievals are filtered out automatically and bad inputs are accessible by the quality flags. The quality flags are delivered as an integer and need to be converted to the binary system by the user.

Example: quality flag 50 = 0110010.

integer	*binary system*
50	0110010

Bit 0	***Large cloud contribution to the signal (correction factor low) over sea***
The cloudy part is much brighter than the clear-sky part which enhances the error caused by the different shape of the footprints. Usually all unusable pixels are filtered out so that the value is not needed to filter bad AODs. However, for bright clouds, we currently assume that the AOD error value could be less accurate due to enhanced collocation issues. This flag could be useful to investigate the AOD error value within the product validation. ***Note***: This flag is not raised over land. Values fulfilling the filter criterion are skipped over land because over-land cloud correction and AOD are retrieved at different wavelengths.	

Bit 1:	***Observation geometry with typically enhanced errors in the retrieval over sea and land***
A set of pixels close to the limits set for observation angles (SZA, VZA, scattering angle). For applications specifically analysing dependencies on observation geometry this flag should be applied together with bit 3 and bit 4. As all these effects are taken into account in the AOD error appropriately and unusable values are thrown away, this flag needs not be applied for standard-users of AOD or for assimilation.	

Bit 2	***Measured signal exceeds upper or lower limits over sea and land***
AOD is set to 0 or 4, but the mathematically retrieved AOD is lower than 0 or higher than 4. Can be important for comparisons to other retrievals, if there is a systematic bias and slope, as the artificial setting to 0/4 has an impact on the correlation. AOD values lower than 0 can appear caused by overestimation of the surface reflectance.	

Bit 3	***Limitation in aerosol type pre-classification over sea, in particular fine/coarse mode classification***
The expected clear-sky and aerosol free reflectance is large compared to the total signal for a sea salt aerosol with an optical depth of 0.3. The AVHRR pre-classification fine/coarse mode is not available and dust detection is limited for small optical depth as well. This is reflected in the AOD error, the flag should not be used for most application of the AOD. The quality flag may be used under these conditions: 1.) The aerosol class/type is used. 2.) If one is looking specifically for volcanic ash because there is a higher risk that ash is undetected (misclassified as cloud).	

Bit 4	***Signal has an enhanced dependence on the actual wind speed***
Uncertainty in wind speed impacts results, to be used together with OBSGEO. The error of this effect is appropriately reflected within the AOD error column, the interesting point of this flag is a known systematic effect dependent on the viewing geometry.	

Bit 5	***Bad fit***
The fit over all PMD bands, both stokes fraction and reflectances, are bad. However, as some of the fitted bands - in particular all stokes fraction - are available for clear-sky pixels only, this flag is useful only if one limits the application to completely clear-sky pixels because the fit over partly cloudy pixels is usually good because of the large overestimation of the system. As two third of the pixels are partly cloudy and the AERONET comparisons also don't show a big decrease of the quality for partly cloudy pixels, it is usually not recommended to use this as a filter. One should also be aware, that the limitation to completely clear sky pixels could maybe systematically remove thick aerosols (e.g. dust aerosols).	

Bit 6	***Thick aerosols***
Pixels are detected as aerosols, but AVHRR sees cloud fraction above limits. Flag regularly raised for thick dust and volcanic ash. Higher risk for AOD overestimation due to undetected cloud. If one is interested in the AOD of an individual measurement, flag should not be used. Could be useful for time series or creation of climatologies to exclude single events with large AOD.	

2.5 Error calculation

The error is calculated as a standard deviation of a set of AODs obtained using the manipulation of inputs or intermediate results. We retrieve a randomized error, which does not include errors which introduce a constant offset or slope to the result. This statistical approach is selected to provide an error suitable for assimilation purposes. The inputs and intermediate results manipulated to retrieve a set of AODs for the error calculation are different for the retrieval over ocean and land. In both cases the following parameters are varied:

Parameter	*Description*
the cloud correction factor	The maximum and minimum values are obtained from the scatter between averaged AVHRR reflectances and the GOME-2 reflectance (standard deviation of the linear fit).
the solar zenith angle	the relative azimuth angle, the viewing zenith angle (the two nearest neighbours are used instead of the values of the actual measurements)
the aerosol model	All models included for the fit are used. See details in Section **Error! Reference source not found.**

Over ocean, additional variations are included for the following:

- the wind speed
- the chlorophyll pigment concentration

Over land, additional variations are included for the following:

- Errors in the surface albedo (the surface albedo is manipulated by a pre-defined offset and/or a pre-defined factor which should be chosen with respect to the expected error in the database.

At least 30 different AODs (under all different conditions) need to be calculated to retrieve an error of the AOD. If this is not possible (e.g. because of retrieval failures), no AOD error is calculated, but the retrieved AOD may not be accurate for these cases.

3 THE PMAP PRODUCT

3.1 Product accuracy requirements

The product user requirements in table form for each element of the PMAp product are given in the Product User Requirements document [AD 1]. For reference, we have provided two User Requirement tables for the main parameter Aerosol Optical Depth (AOD).

PMAp-01	*Aerosol Optical Depth*	
Type	Product	
Applications and users	Air quality, traffic, climate	
Characteristics and Methods	Multi-wavelength measurements of reflectances and stokes fractions, Radiative transfer modelling	
Comments	Aerosol and cloud products refer to different footprints. This product is retrieved for the aerosol footprint.	
Generation Frequency	MetOp GOME-2 PDU dissemination frequency: every 3 minutes on daylight side of orbit	
Input satellite data	GOME-2, AVHRR, IASI	
Dissemination		
Format	Means	Type
EPS native	EUMETCast, Internet	NRT, offline
Accuracy		
Threshold	Target	Optimal
0.2 (abs. threshold) or 30% (rel. Threshold) over sea 0.3 (abs threshold) or 40% (rel. Threshold) over land	10% or 0.05 (cloud free, ocean) 20% or 0.1 (cloudy, ocean and cloud free, land) 30% or 0.15 (cloudy, land)	0.05 or 5% (cloud free ocean) 10% (cloudy ocean and cloud free land) 20% (cloudy, land)
Verification method	comparison to MODIS, GOME-2 UV index, AERONET	
Coverage, Resolution and Timeliness		
Spatial coverage	Spatial resolution	Timeliness
Global	GOME-2 PMD resolution 10 km x 40km	≤ 3 hours

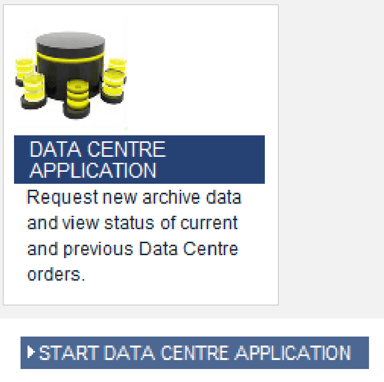
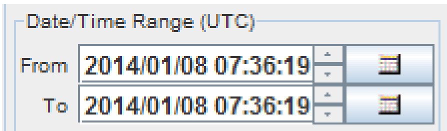
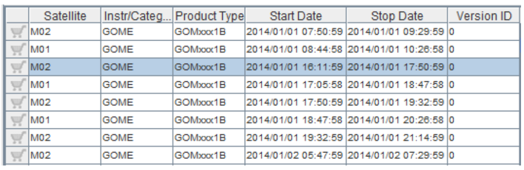
Table 6: PMAp-01 Aerosol Optical Depth product user requirements.

3.2 Data access

3.2.1 Offline data access

PMAp level-2 data, in both EPS native format as well as in netcdf4 format, can be accessed via the EUMETSAT EO portal (http://archive.eumetsat.int). This portal provides full Metop orbits of PMAp data offline. Follow the instructions below to access the data. Instructions for using netcdf4 format are in the following section.

Start from the EUMETSAT EO-Portal: https://eoportal.eumetsat.int/userMgmt

<table>
<tr><td>Login or register.</td><td></td></tr>
<tr><td>Start the Data Centre Application.</td><td>
</td></tr>
<tr><td>Select LEO as the Search Type.</td><td>
</td></tr>
<tr><td>Select Multi-Sensor Aerosol Optical properties and Platform (sub-level).</td><td></td></tr>
<tr><td>Specify a date and time range.</td><td>
</td></tr>
<tr><td>Choose Search.</td><td>
</td></tr>
<tr><td>Select an orbit from results returned.</td><td>
<table>
<tr><th></th><th>Satellite</th><th>Instr/Categ...</th><th>Product Type</th><th>Start Date</th><th>Stop Date</th><th>Version ID</th></tr>
<tr><td></td><td>M02</td><td>GOME</td><td>GOMxxx1B</td><td>2014/01/01 07:50:59</td><td>2014/01/01 09:29:59</td><td>0</td></tr>
<tr><td></td><td>M01</td><td>GOME</td><td>GOMxxx1B</td><td>2014/01/01 08:44:58</td><td>2014/01/01 10:26:58</td><td>0</td></tr>
<tr><td></td><td>M02</td><td>GOME</td><td>GOMxxx1B</td><td>2014/01/01 16:11:59</td><td>2014/01/01 17:50:59</td><td>0</td></tr>
<tr><td></td><td>M01</td><td>GOME</td><td>GOMxxx1B</td><td>2014/01/01 17:05:58</td><td>2014/01/01 18:47:58</td><td>0</td></tr>
<tr><td></td><td>M02</td><td>GOME</td><td>GOMxxx1B</td><td>2014/01/01 17:50:59</td><td>2014/01/01 19:32:59</td><td>0</td></tr>
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<tr><td></td><td>M02</td><td>GOME</td><td>GOMxxx1B</td><td>2014/01/01 19:32:59</td><td>2014/01/01 21:14:59</td><td>0</td></tr>
<tr><td></td><td>M02</td><td>GOME</td><td>GOMxxx1B</td><td>2014/01/02 05:47:59</td><td>2014/01/02 07:29:59</td><td>0</td></tr>
</table></td></tr>
<tr><td>Choose the Check-out icon below the listing when you have finished.</td><td></td></tr>
</table>

The data naming convention for offline archived full-orbit data is

GOME_PMA_02_[satellite_plattform]_[sensing_start]_[sensing_stop]_N_O_[processing_time]

Here is a sample product name:

GOME_PMA_02_M01_20140108114758Z_20140108115058Z_N_O_20140108123307Z

3.2.2 Online near-real time data access

PMAp level-2 data in netcdf4 can be received in near-real time via the EUMETSAT EUMETCast system. Data is bzip2 compressed and only available 3 hours after a specified sensing time, a three-hour lag in presentation.. EUMETCast data is in 3-minute increments called Product Dissemination Units (PDUs). Here is the netcdf4 address:

EUMETCast Channel 1
PID: 510,
Multicast Address: 224.223.222.230

The data naming convention for this data follows the WMO naming convention standard. This convention is specified here:
www.wmo.int > Programmes
> Space
> Data Access and Use
> Formats and Standards.

Sample product name:

```
W_XX-EUMETSAT- Darmstadt,
SOUNDING+SATELLITE,METOPA+GOME_O_EUMC_20130501233254_33902_eps_o_pmap_l2.nc.bz2
```

3.3 Data Availability

Data for PMAp level-2 in v. 1 **for water surfaces only** is available from date of inception 1 March 2014.
Date for PMAp level-2 in v. 2 **for water and land surfaces** is available from date of inception March 2016.

PMAp data is based on GOME-2 PMD level-1 data availability and GOME-2 instrument operations See Section 1.3.

Note: PMAp data is *not* available for the two nadir static orbits nor for the PMDRAW orbit issued every 29 days in one sequence. However, PMAp data is available for all other calibration modes as indicated in Figure 2 and Figure 3 in Section 1.3.

PMAp AOD data is available under day-light condition and over ocean surfaces only. PMAp COD data is available under day-light condition but over all surfaces.

PMAp also makes use of AVHRR and IASI level 1 data. If one or both of the latter level-1 data streams are not available, PMAp data will also not be available.

For details and current instrument and product-status monitoring for both GOME-2 and IASI, see the dedicated GOME web page:

http://gome.eumetsat.int

3.4 Main parameters and enumerated values

3.4.1 Aerosol section

Parameter	*Description*
aerosol_optical depth	Aerosol optical depth at 550 nm retrieved for the GOME-2 PMD ground pixel.
error_aerosol_optical_depth	Error of the AOD retrieved
aerosol_class	0: no dust / fine mode (ocean) 1: coarse mode (ocean) 2: Thick Biomass burning 3: volcanic ash/thick dust 4: volcanic ash with SO_2 15: no classification
flag_ash	0: no ash 1: ash 15: no classification
pmap_geometeric_cloud_fraction	Cloud fraction co-located with PMD pixel (corners corrected according to the time shift of the reference PMD band used for aerosol properties retrieval) as used for AOD PMAp for cloud-screening.
chlorophyll_pigment_concentration	Chlorophyll pigment concentration in mg/m^3 (ocean, clear sky)
quality_flags_aerosol	Quality flags of the aerosol product (1=problem found, 0=no problem detected). We provide the following flags: 1. Large cloud contribution to the signal (correction factor low) over sea 2. Observation geometry with typically enhanced errors in the retrieval over sea and land. 3. Measured signal exceeds upper or lower limits over sea and land 4. Limitation in aerosol type preclassification over sea, in particular fine/coarse mode classification. 5. Signal has an enhanced dependence on the actual wind speed 6. Bad fit 7. Thick aerosols
retrieval_algorithm	Retrieval algorithm used by the AOD retrieval 0: ocean, main retrieval for clear-sky pixels (Section. **Error! Reference source not found.**) 1: ocean, simplified retrieval for partly cloudy pixels (Section **Error! Reference source not found.**) 2: ocean, alternate retrieval, AOD from reflectance (Section. **Error! Reference source not found.**) 3: ocean, alternate retrieval, AOD from stokes fraction (Section. **Error! Reference source not found.**) >3: land, not implemented 4: land, dark surfaces, cloud free 5: land, normal mode, cloud free

Parameter	*Description*
	6: land, bright surfaces, cloud free 7: land, dark surfaces, partly cloudy 8: land, normal mode, partly cloudy 9: land, bright surfaces, partly cloudy 15: no retrieval
avhrr_geometric_cloud_fraction	Geometric cloud fraction retrieved from AVHRR pixels inside the GOME-2 pixel.
flag_cirrus_cloud	Flag indicating the presence of cirrus clouds based on AVHRR measurements
flag_snow_ice	Flag indicating if a pixel is partly or completely covered by snow or ice. The flag is derived from the AVHRR cloud product.
split_window_btd	Average brightness temperature of AVHRR channel 4 and AVHRR channel 5
wind_speed	10m wind speed from ECMWF forecast [m/s]
land_fraction	Fractional coverage of land surfaces within the PMD
reflectance_inhomogeneity	Variance of the reflectances in AVHRR channel 1 within the GOME-2 PMD pixel.

3.4.2 Cloud section

Parameter	*Description*
cloud_optical_depth	Cloud optical depth retrieved for the GOME-2 PMD ground pixel.
cloud_top_temperature	Cloud top temperature from AVHRR channel 4
quality_flag_cloud	Quality flags of the cloud product (1=problem found, 0=no problem detected). We provide the following flags: 0: low accuracy for the actual observation geometry 1: albedo retrieval failed, surface albedo taken from climatology 2: large error due to significant impact of the surface on the result 3: sun glint
avhrr_geometric_cloud_fraction	Geometric cloud fraction retrieved from AVHRR pixels inside the GOME-2 footprint.
land_fraction	Fractional coverage of land surfaces within the PMD
reflectance_inhomogeneity	Variance of the radiances in AVHRR channel 1 within the GOME-2 PMD pixel.

3.5 The Netcdf4 data model

NetCDF (Network Common Data Form) is a machine-independent, self-describing, binary data format standard for exchanging scientific data; it is supported by many high-level languages using dedicated APIs. The project homepage is hosted by the Unidata program at the University Corporation for Atmospheric Research (UCAR). All details on how to access netcdf version 4-type data are provided, including links to viewers and readers as well as API libraries.

The PMAp netcdf *long-name* parameter naming is following the Climate and Forecast (CF) governance standard applied by EUMETSAT to support product development in the frame of the GSICS Data Management Working Group.

A detailed description of the netCDF format can be found in the PMAp Product User Guide available online together with other technical documents (see sect. 3.6)

3.6 EPS native product format

The description of PMAp products provided as full orbits offline in EPS Native format provided is available from the technical documentation section on the EUMETSAT Technical Documents web page:

www.eumetsat.int > Data > Technical Documents > GDS Metop > PMAp

Note: The EPS Native product contains additional information on instrument status and instrument data mode flagging, which is not relevant for the scientific or operational use of PMAp level-2 data.

APPENDIX A

Applicable Documents

Ref	*Document on EUMETSAT Technical Documents Page*	*EUMETSAT Reference Number*
AD 1	Polar Multi-Sensor Aerosol Product: User Requirements	EUM/TSS/REQ/13/688040
AD 2	Polar Multi-Sensor Aerosol Product: Algorithm Theoretical Basis Document	EUM/TSS/SPE/14/739904
AD 3	Polar Multi-Sensor Aerosol Product: Product Format Specification	EUM/TSS/SPE/14/740198 EUM/OPS-EPS/DOC/12/0639
AD 4	EPS Generic Product Format Specification	EPS/GGS/SPE/96167
AD 5	IASI Level 1 Product Guide	EUM/OPS-EPS/MAN/04/0032
AD 6	AVHRR Level 1b Product Guide	EUM/OPS-EPS/MAN/04/0029
AD 7	PMAP product user guide	EUM/TSS/REP/14/745438

Reference Documents

Ref	*Document Name*	*Authors*
RD 1	*Final report of the O3M-SAF activity: Aerosol retrieval from GOME-2: Improving computational efficiency and first application,* 2008.	O. Hasekamp, O. Tuinder and P. Stammes,

Acronyms Used in this Document

Acronym	*Meaning*
AER	Aerosol Product
AOD	Aerosol Optical Depth
ARA	Aerosol Retrieval Algorithm
ATBD	Algorithm Theoretical Basis Document
BT	Brightness Temperature
BTD	Brightness Temperature Difference
CMa	Cloud Mask
CFR	Cloud fraction ratio
COD	Cloud optical depth
IR	Infrared
LUT	Look-Up Table
NIR	Near Infrared
PMAp	Polar Multi-sensor Aerosol Product
RAZI	Relative Azimuth Angle
RTM	Radiative Transfer Model
PMD	Polarization Monitoring Device
SZA	Solar Zenith Angle
TOA	Top Of Atmosphere
VIS	Visible (solar)
VZA	Viewing Zenith Angle