ATBD of
Multi-sensor merged aerosol properties (Ver 4.1)
(for data assimilation)

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1. Summary

JAXA EORC multi-sensor merged aerosol property product is a dataset aiming to provide quality controlled and bias corrected observations for data assimilation to aerosol transport models.

As the first public version, Ver. 4.1, it is produced every three hours and includes average of aerosol optical thickness at 500 nm (AOT) with optimal weighting, uncertainty estimate, and the variables of original individual sensors, Himawari-8/9 AHI (hurly 0.05-deg grid AOT_Merged data; https://www.eorc.jaxa.jp/ptree/userguide.html#401) and GCOM-C SGLI (1-km daily tile grid data; https://suzaku.eorc.jaxa.jp/GCOM_C/data/update/Algorithm_ARNP_en.html). Angstrom exponent (AE) and single scattering albedo (SSA) included in the file is unvalidated or invalid in the current version. The data area is the global from 0E to 360E, 90N to 90S with 0.05-degree equal rectangular grids.

Additional quality control (masking) is applied, and bias of each sensor products are corrected based on validation with AERONET measurements (https://aeronet.gsfc.nasa.gov/).

2. File name

The files are named as following rule:

Ex. JAXA_AEROSOL_20240201_00_02_D_G005_V041.nc
YYYYMMDD_HS_HE_O_TRES_VVVV.nc

YYYYMMDD: Year Month Day
HS: Start hour of observation
HE: End hour of observation (23 means 23:59.999)
O: always "D" for the aerosol properties
T: G:Global or R:Resional
RES: grid resolution (degrees)
VVVV: product version

3. File contents (netcdf4)

The merged aerosol product files include following contents:

Global Attributes:
- title = 'Equal latitude-longitude map of GCOM-C Aerosol data'
- id = 'JAXA_AEROSOL_20240201_00_02_D_G005_V041.nc'
- date_created = '2024-02-25T04:19:13Z'
- pixel_number = 7200
- line_number = 3601
- upper_left_latitude = 90
- upper_left_longitude = 0
- grid_interval = 0.05
- _NCProperties = 'version=2,netcdf=4.7.0,hdf5=1.8.21,'

Dimensions:
- latitude = 3601
- longitude = 7200

Variables:
- latitude : 'latitude'
- longitude : 'longitude'
- AOT : 'Aerosol Optical Thickness at 500 nm'
- UNC_AOT : 'Uncertainty of Aerosol Optical Thickness'
- AAE : 'Angstrom Exponent of 500 nm and 380 nm'
- UNC_AAE : 'Uncertainty of Angstrom Exponent'
- SSA : 'Single Scattering Albedo at 380 nm'
- UNC_SSA : 'Uncertainty of Single Scattering Albedo'

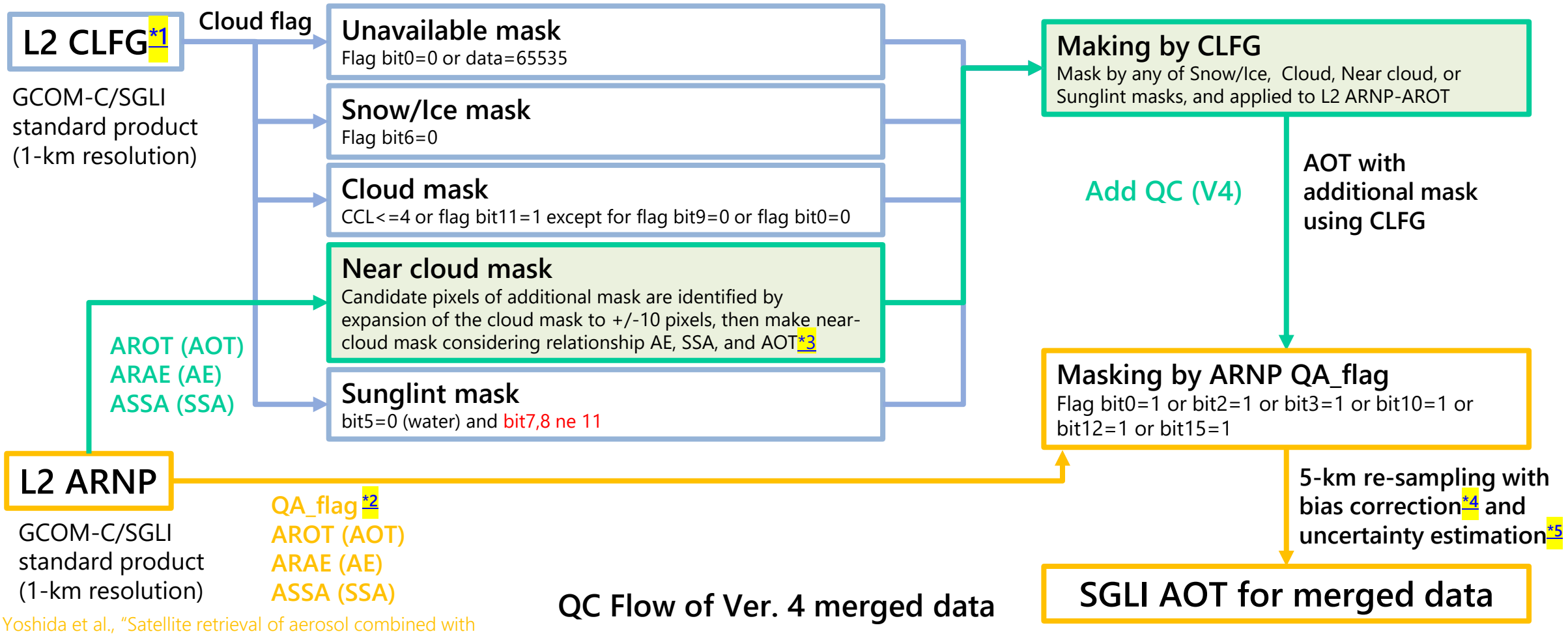
- Obs_time_SGLI : 'Observation time (SGLI)'
- QA_flag_SGLI : 'Quality Assurance flag (SGLI)'
- AOT_SGLI : 'Aerosol Optical Thickness at 500 nm (SGLI)'
- UNC_AOT_SGLI : 'Uncertainty of Aerosol Optical Thickness (SGLI)'
- AAE_SGLI : 'Angstrom Exponent of 500 nm and 380 nm (SGLI)'
- UNC_AAE_SGLI : 'Uncertainty of Aerosol Angstrom Exponent (SGLI)'
- SSA_SGLI : 'Single Scattering Albedo at 380 nm (SGLI)'
- UNC_SSA_SGLI : 'Uncertainty of Single Scattering Albedo (SGLI)'
- CLFG_SGLI : 'Cloud flag for the binning (SGLI)'

- Obs_time_AHI : 'Observation time (AHI)'
- QA_flag_AHI : 'Quality Assurance flag (AHI)'
- AOT_AHI : 'Aerosol Optical Thickness at 500 nm (AHI)'
- UNC_AOT_AHI : 'Uncertainty of Aerosol Optical Thickness (AHI)'
- AAE_AHI : 'Angstrom Exponent at 640 nm and 470 nm (AHI)'
- UNC_AAE_AHI : 'Uncertainty of Aerosol Angstrom Exponent (AHI)'

✓ Uncertainty and averaged Angstrom exponent (AE) and single scattering albedo (SSA) included in the file is unvalidated or invalid in the current version.

4. Algorithm overview

SGLI standard aerosol products (Level-2 ARNP) includes error pixels sometimes (mainly due to cloud contamination), on the other hand, enough number of available data should be remained for enough observation frequency and area coverage. We applied additional Quality Control (QC) using SGLI cloud flag product (Level-2 CLFG) to meet the both requirements as follows.



QC Flow of Ver. 4 merged data

Yoshida et al., "Satellite retrieval of aerosol combined with assimilated forecast", Atmos. Chem. Phys., 21, 1797–1813, 2021

Quality Control flags (specification of SGLI standard products)

*1 L2 CLFG

bit	Ver.1,2,3	Description
0	Algorithm Execution	0 = Not executed, 1 = Executed
1	Clear Confidence Level	000 = 0.00 (Cloudy) 001 = 0.00 - 0.17 010 = 0.17 - 0.33 011 = 0.33 - 0.50 100 = 0.50 - 0.67 101 = 0.67 - 0.83 110 = 0.83 - 1.00 111 = 1.00 (Clear)
2		
3		
4	Day/Night	0 = Night , 1 = Day
5	Land/Water	0 = Water , 1 = Land
6	Snow/Ice	0 = Yes , 1 = No
7	Sun Glint Cone Angle	00 = 0 - 15 [deg.] 01 = 15 - 25 10 = 25 - 35 11 = 35
8		
9	Heavy Aerosol	0 = Yes , 1 = No
10	Cirrus Probabilty	0 = Yes , 1 = No
11	Cloud Inhomogeneity	0 = Yes , 1 = No
12	Phase	00 = Uncertain 01 = Water 10 = Ice 11 = Mixed
13		
14	Cloud Shadow	0 = Yes , 1 = No
15	VN Data Availability	0 = Not available, 1 = Available

*2 L2 ARNP/QA_flag

Bit	ver.3	Description	ARAE_L3_mask*	AROT_L3_mask*	ASSA_L3_mask*
0	Data Availability	0=Available, 1=Not Available	0	0	0
1	Land / Water Flag	0=Water, 1=Land	0	0	0
2	Coastal Flag	0=No, 1=Yes	0	0	0
3	Cloud Flag	0=Clear, 1=Cloudy	0	0	0
4	Aerosol Optical Thickness Confidence Flag	00=Very Good; 01=Good, 10=Marginal, 11=No Confidence or Fill	0	0	0
5	Aerosol Optical Thickness Confidence Flag		0	1	0
6	Angstrom Exponent Confidence Flag	00=Very Good; 01=Good, 10=Marginal, 11=No Confidence or Fill	0	0	0
7	Angstrom Exponent Confidence Flag		1	0	0
8	Aerosol Single Scattering Albedo Confidence Flag	0=Very Good or Good, 1=Marginal or No Confidence or Fill	0	0	1
9	Heavy aerosol	0=No, 1=Yes	0	0	0
10	Sunglint Flag	0=No, 1=Yes	0	0	0
11	Stray-Light Flag	0=No, 1=Yes	0	0	0
12	Cloud Shadow Possibility Flag	0=No, 1=Yes	0	0	0
13	Uncertain Surface Reflectance Flag (Turbid Water, Snow/Ice Covered Surface or Rtoa_obs < Rtoa_Rayleigh)	0=No, 1=Yes	1	1	1
14	Use Polarization	0=No, 1=Yes	0	0	0
15	A prior of retrieval	0=MODEL, 1=CONSTANT	0	0	0

*3 Near cloud mask

Candidate pixels of additional mask are identified by expansion of the cloud mask to +/-10 pixels (in original 1-km grids), then make near-cloud mask considering relationship among AE, SSA, and AOT as follows.

Near cloud mask is on when $\chi^2 \geq 1.0$

$$\chi^2 = \frac{dx^T S_x dx}{3}$$

dx is matrix of AOT, AE and SSA subtracted by fixed average. Sx is a 3x3 covariance matrix.

Practically it can be processed as follows:

```
tssa=0.997
Sx= [14.6918 ,     2.388085,   29.720606;
       2.388085,  14.538207,  -20.236309;
      29.720606, -20.236309, 1006.3494];
Xav=[0.075376898; 1.1708500; 0.97185898];
dx=[aot; ae; ssa]-Xav(1:3);
If ssa<=tssa
  kai2= (dx(1:3) T * Sx(1:3,1:3) * dx(1:3) )/3.
else
  kai2= (dx(1:2)T * Sx(1:2,1:2) * dx(1:2) )/2.
endif
If kai2>=1.0
 set near cloud mask
end
```

*4 Bias correction, and *5 uncertainty estimation

Bias of AHI and SGLI and AOT uncertainty is estimated statistically by validation with AERONET measurements.
After the bias correction, the multiple sensor data are averaged with weighting of 1/error^2

AHI AOT bias and uncertainty

(1) AHI bias correction

$AOT_{\mathrm{corr}} = \mathrm{a} * AOT_{\mathrm{AHI}}$

Land area: a=1.173

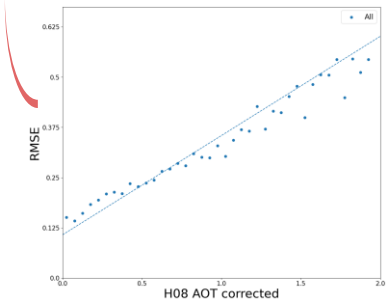
Water area: a=1.033

(2) Estimation of errors after the bias correction

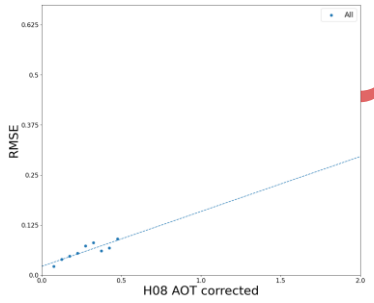
$Err_{\mathrm{AHI}} = slope * AOT_{\mathrm{AHI}} + offset$

$slope_{land} = 0.283, offset_{land} = 0.079$

$slope_{water} = 0.192, offset_{water} = 0.011$



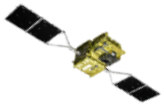
Relation between AHI AOT range and errors (land area)



Relation between AHI AOT range and errors (water area)

AHI AOT (Level-3 merged) is quality controlled by multiple image within 1 hour[*6].

SGLI AOT bias and uncertainty



(1) SGLI bias correction

$AOT_{\mathrm{corr}} = AOT_{\mathrm{SGLI}} * (1 - \mathrm{a} * \exp(\mathrm{b} * AOT_{\mathrm{SGLI}}))$

Land area: a=0.759, b=-2.953

Water area: a=0.546, b=-1.062

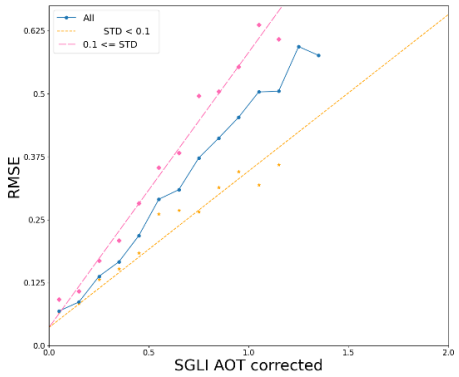
(2) Estimation of errors after the bias correction

$Err_{\mathrm{SGLI}} = slope * AOT_{\mathrm{SGLI}} + offset$

Land area: (0.1°× 0.1° area STD<0.1) : $slope_{land} = 0.311,\ offset_{land} = 0.036$

Land area: (0.1°× 0.1° area STD>=0.1) : $slope_{land} = 0.546, offset_{land} = 0.036$

Water area: $slope_{water} = 0.418,\ offset_{water} = 0.004$



Relation between SGLI AOT range and errors (RMSD from AERONET AOT) over the land area. Data for standard deviation in 0.1°× 0.1° area spatial deviation STD is <0.1 and >=0.1.

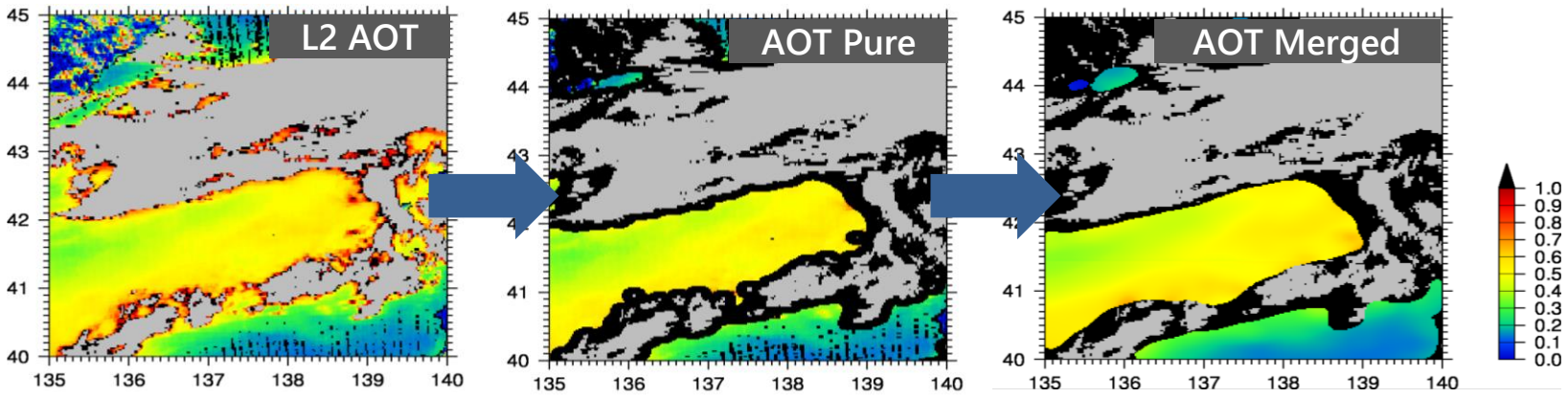
Investigated by JFY2023 service agreement with RESTEC

*6 AHI L3 Hourly QC/Average Algorithm

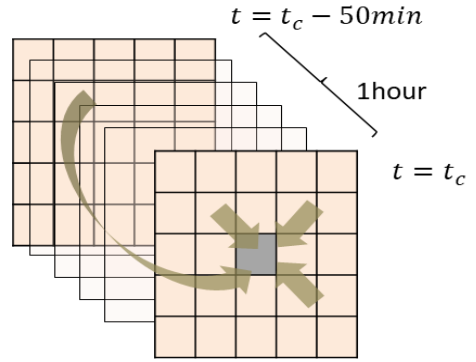
Hourly optimal estimation (AOT_{pure} and AOT_{merged}) are made by AOTs with strict cloud-screening using differences in spatiotemporal variability characteristic of aerosols and clouds (from analysis of the AHI 10-min observations)

AOT_Pure : a subset of L2 AOT with strict quality control of cloud contamination

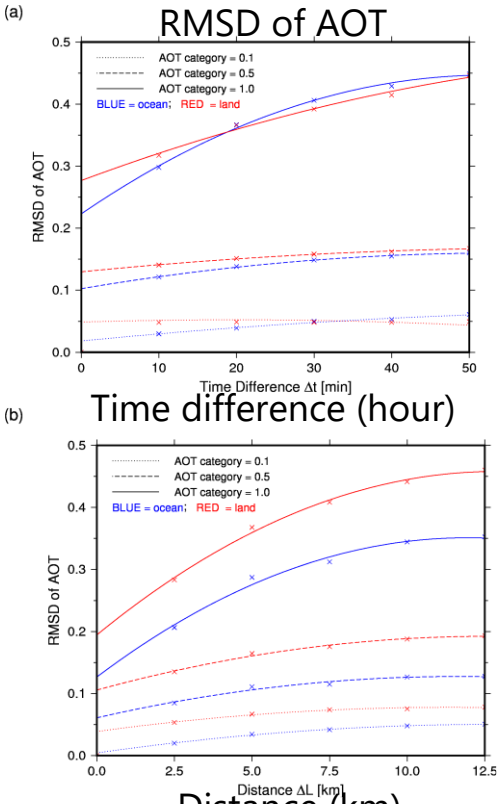
AOT_Merged : the spatial and temporal optimum interpolation of AOT_pure within an hour (i.e. AOT_Merged is derived by 6 slots of 10-min AOT_pure).



Note : L2 AOT in this figure is Version Beta



RMSD in AOT from center pixel (a) observed at the same place as the center and (b) observed at the same time as the center pixel. AOT(x0, y0) categories of 0.1, 0.5, and 1 are indicated in dotted, dashed, and solid lines, respectively. Blue is for over ocean and red is for over land. The "distance" axis indicates the distance from the center pixel. The "time difference" axis indicates the difference in time from the center pixel. Quadratic curve fitting is also shown to each of the plot.

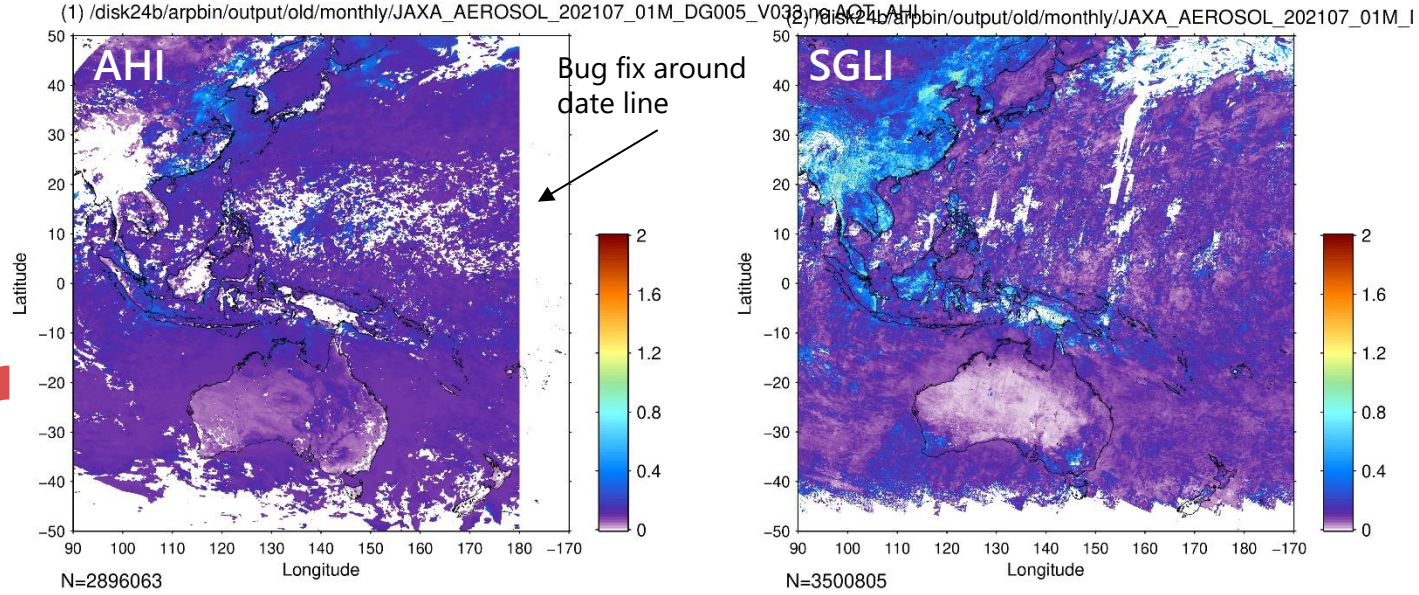


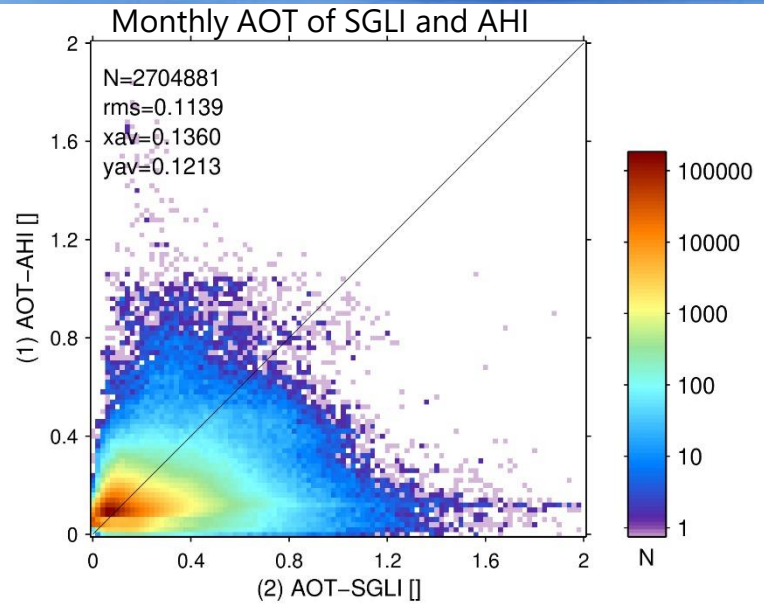
Kikuchi et al., "Improved Hourly Estimates of Aerosol Optical Thickness using Spatiotemporal Variability Derived from Himawari-8 Geostationary Satellite", *IEEE Trans. Geosci. Remote Sensing*, 2018, doi: 10.1109/TGRS.2018.2800060.

5. Evaluation and image examples

5.1 Consistency between AHI and SGLI AOT

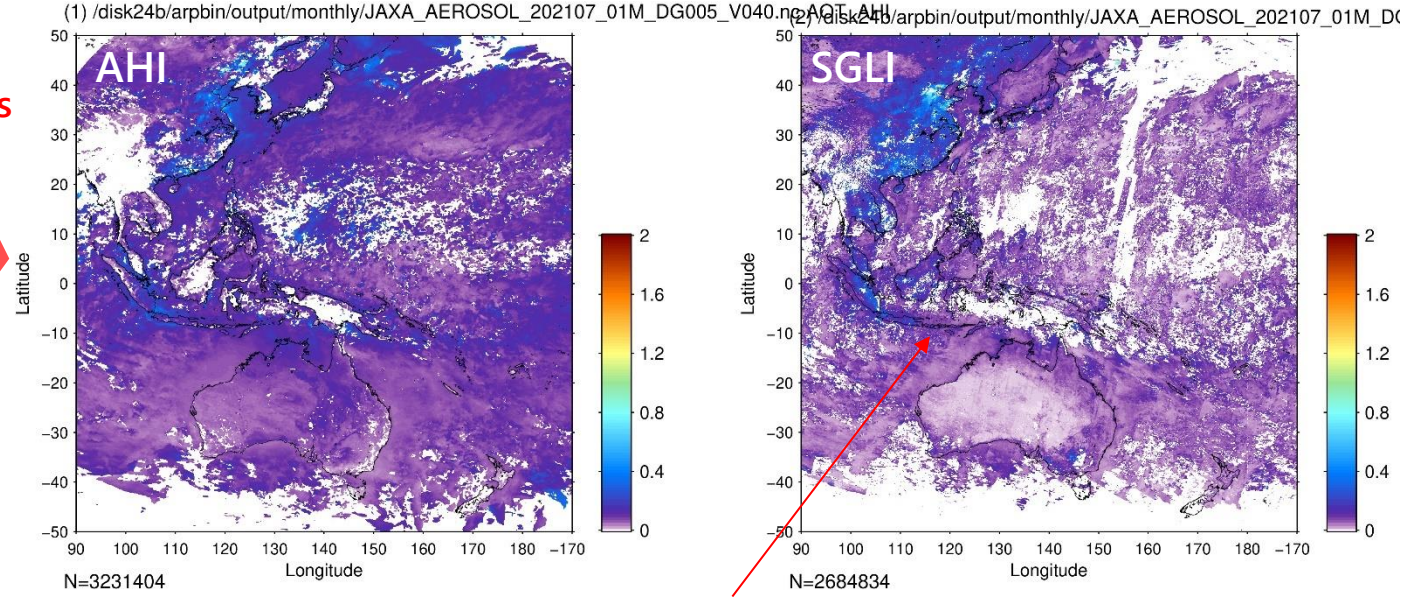
Example of Monthly AOT In July 2021 (Old ver.3.3)

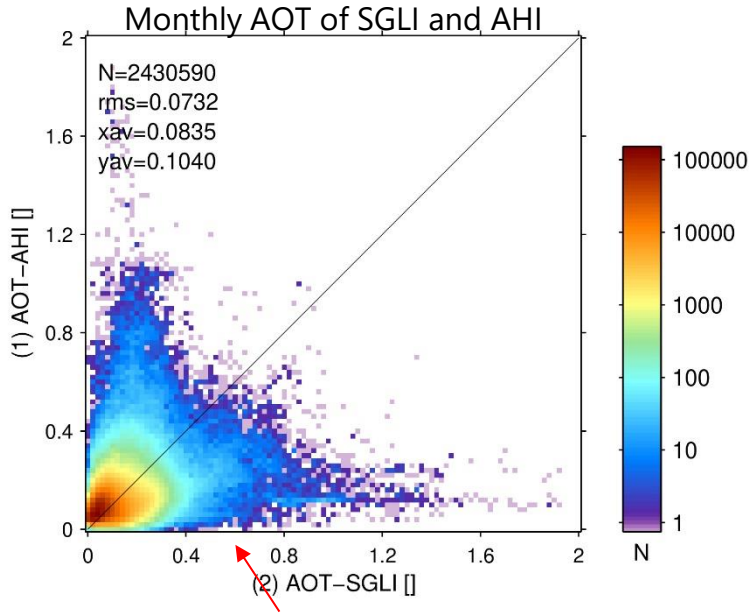




Bias correction (both AHI and SGLI), and improvement of QC around clouds (SGLI)

Example of Monthly AOT In July 2021 (Ver.4)



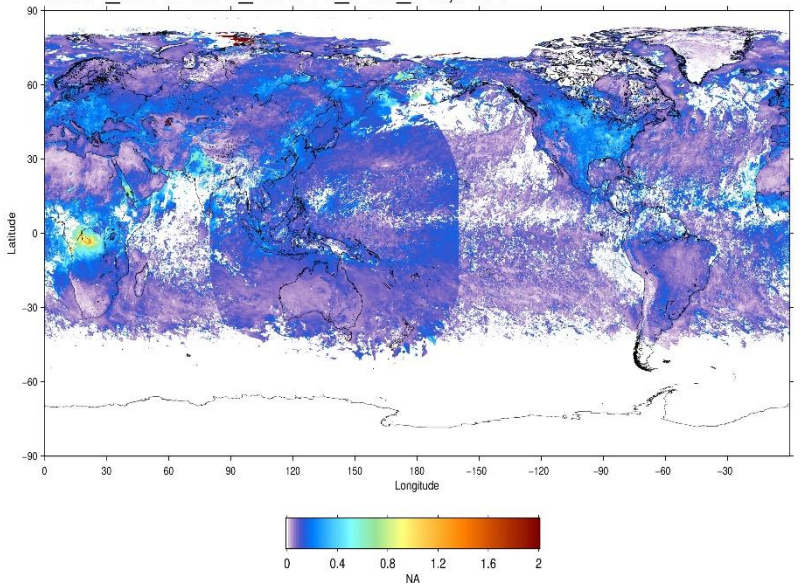


✓ Overestimate around clouds and sunglint were improved

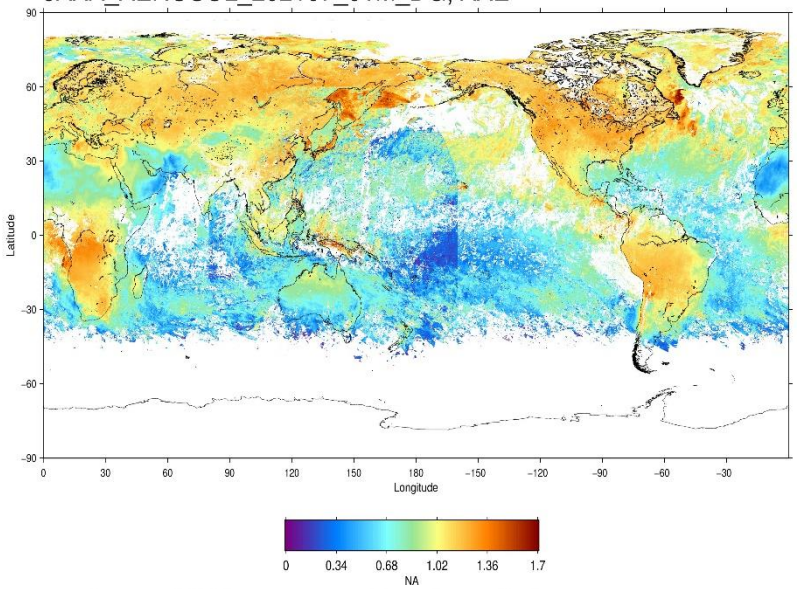
✓ Agreement between AHI and SGLI is improved

Example of monthly average of the merged product in July 2021

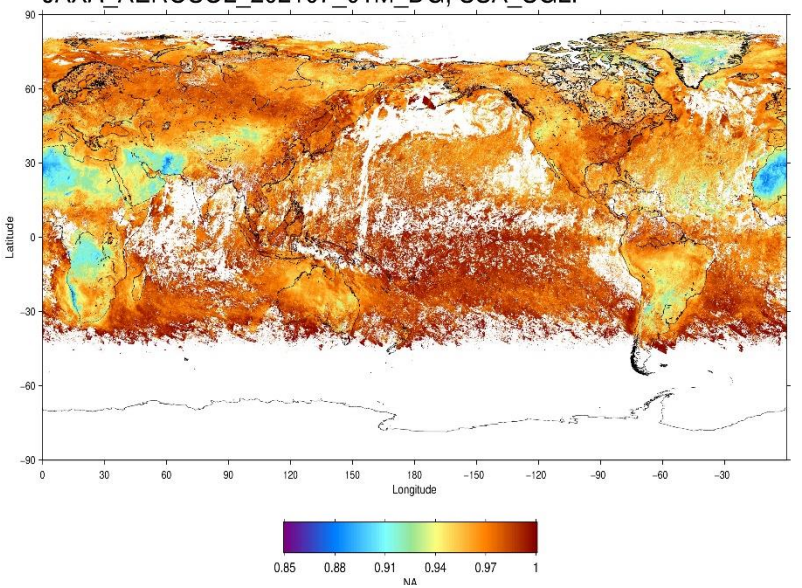
JAXA_AEROSOL_202107_01M_DG, AOT



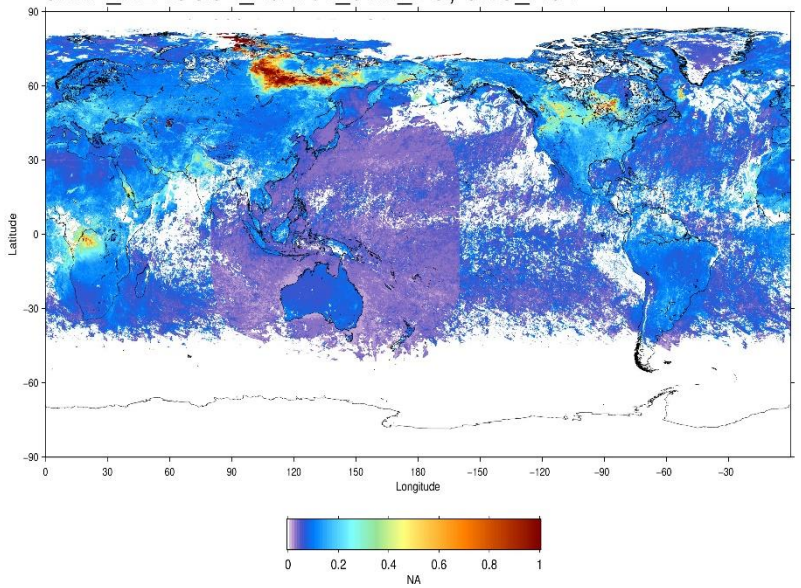
JAXA_AEROSOL_202107_01M_DG, AAE



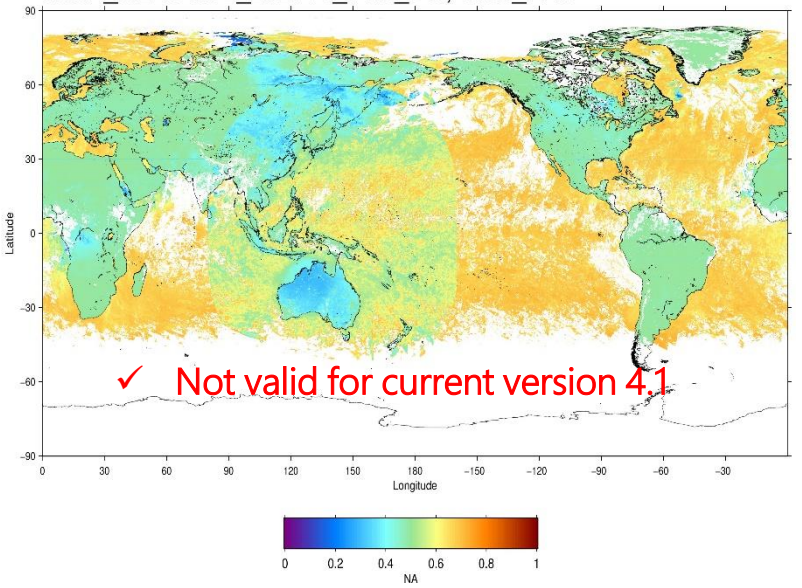
JAXA_AEROSOL_202107_01M_DG, SSA_SGLI



JAXA_AEROSOL_202107_01M_DG, UNC_AOT

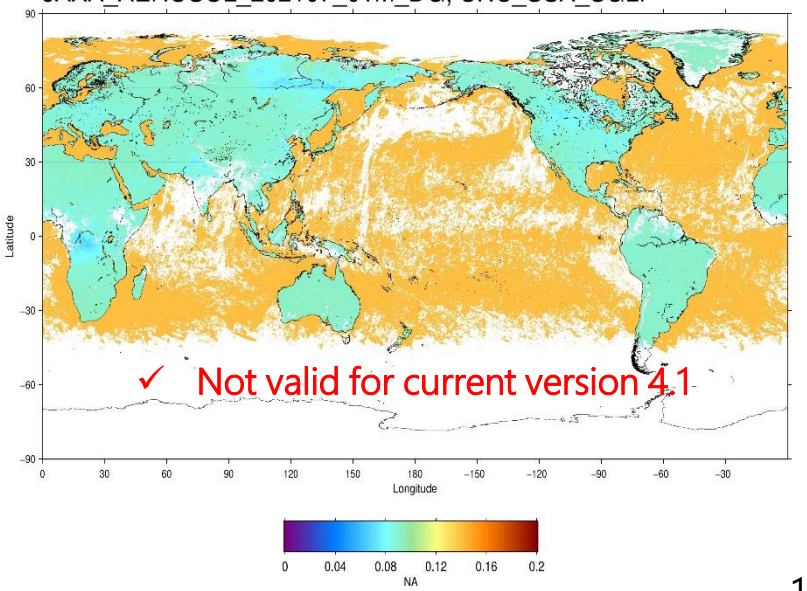


JAXA_AEROSOL_202107_01M_DG, UNC_AAE



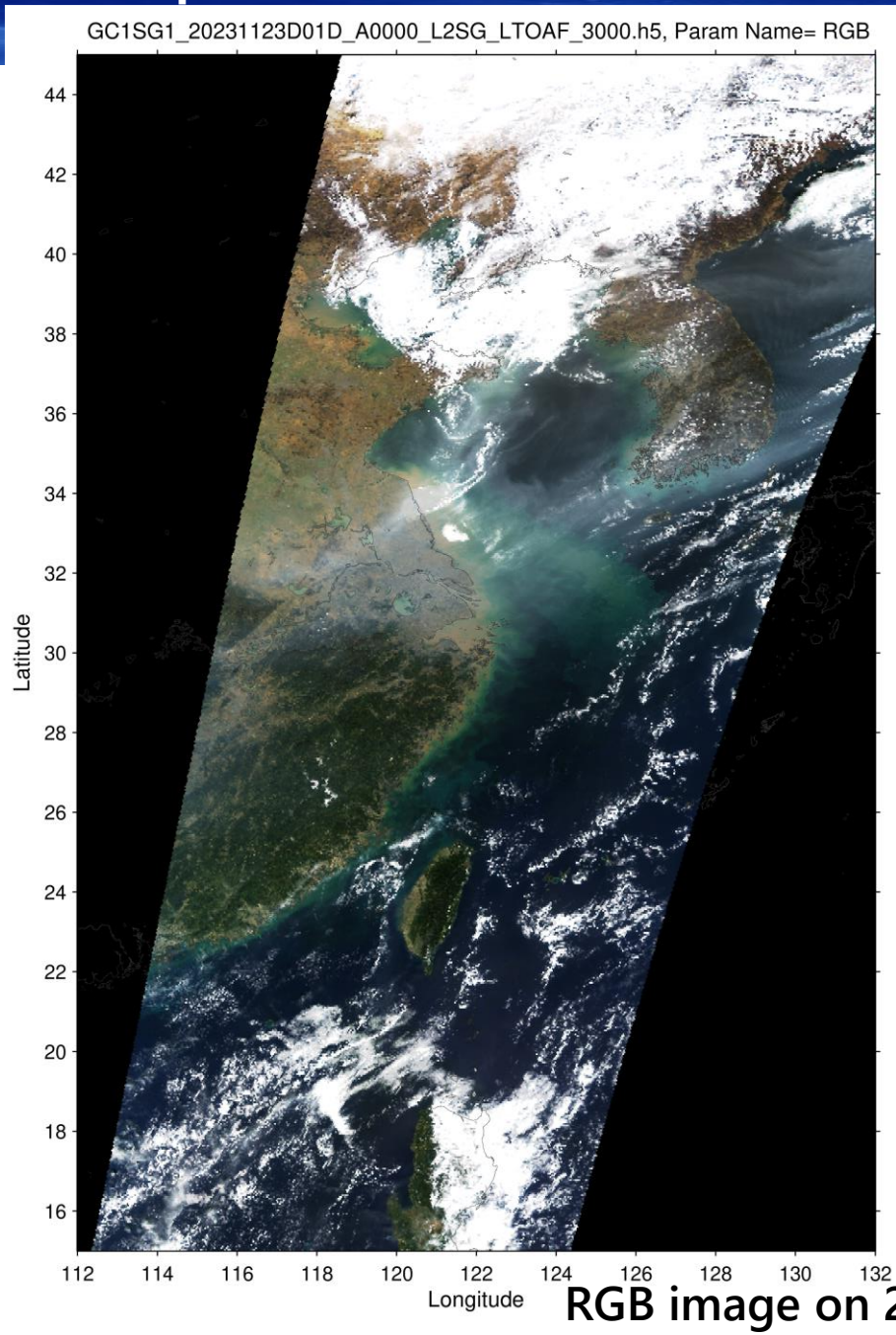
✓ Not valid for current version 4.1

JAXA_AEROSOL_202107_01M_DG, UNC_SSA_SGLI

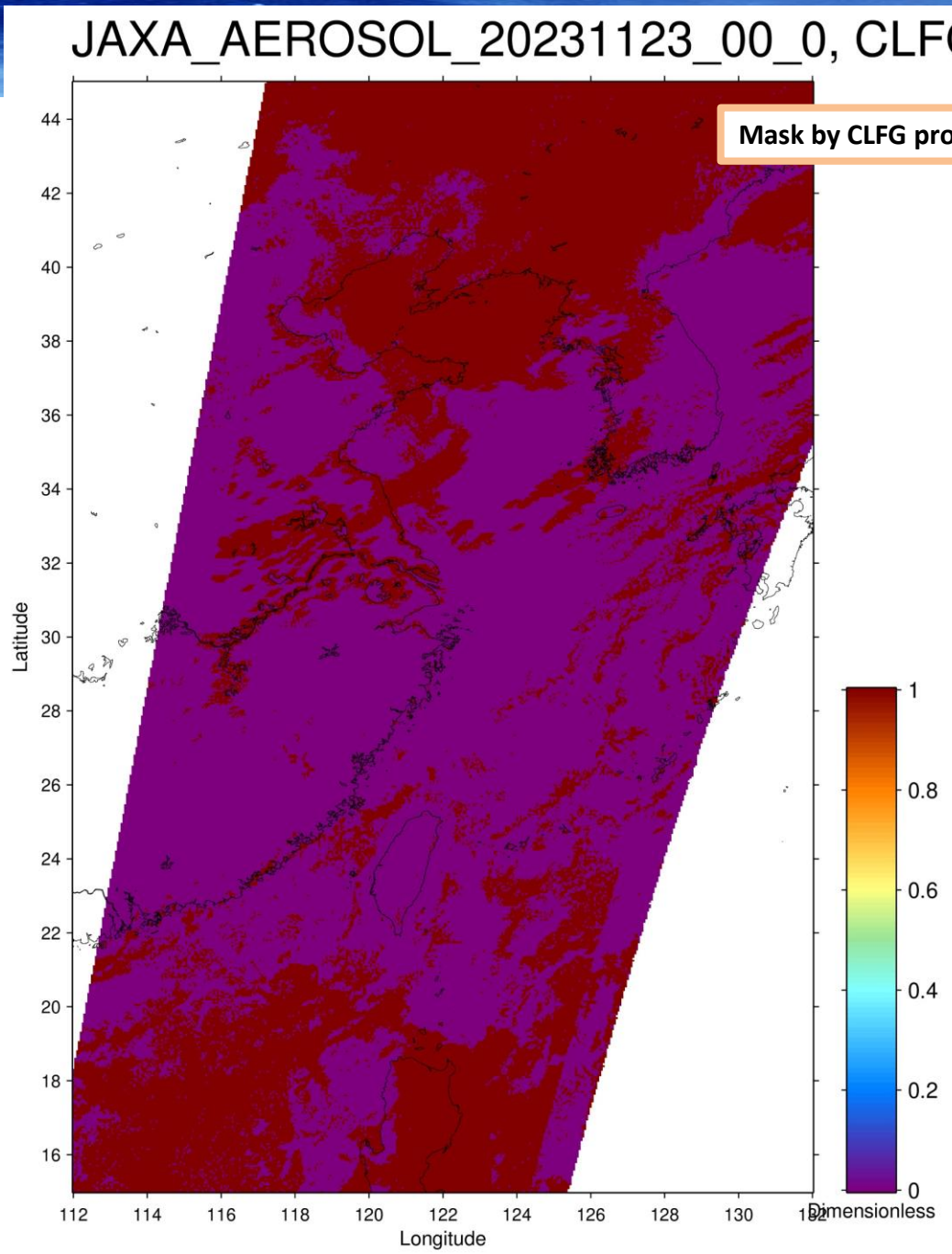


✓ Not valid for current version 4.1

5.2 Improvement of cloud mask



RGB image on 23 Oct. 2023

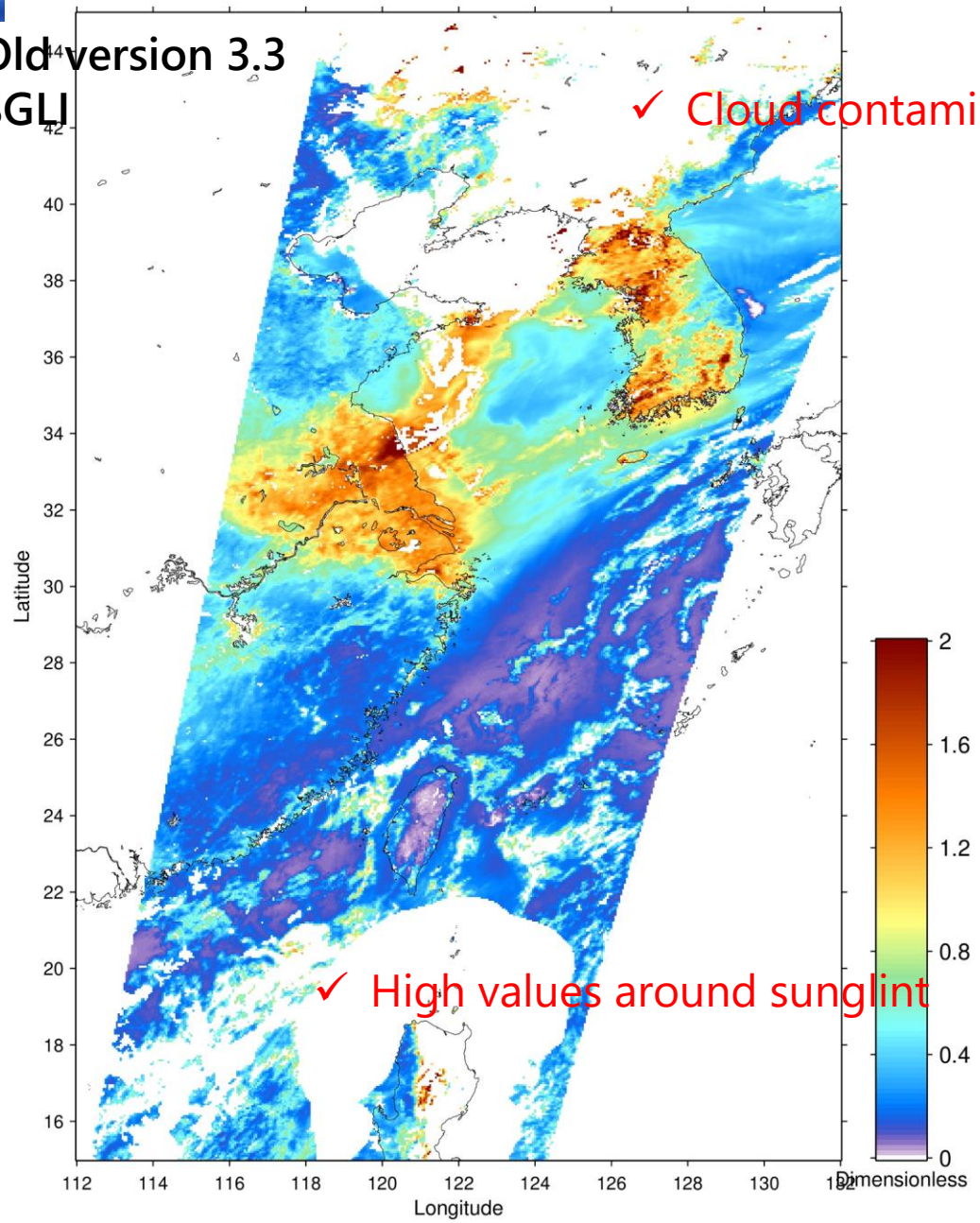


JAXA_AEROSOL_20231123_00_0, AOT_SGLI

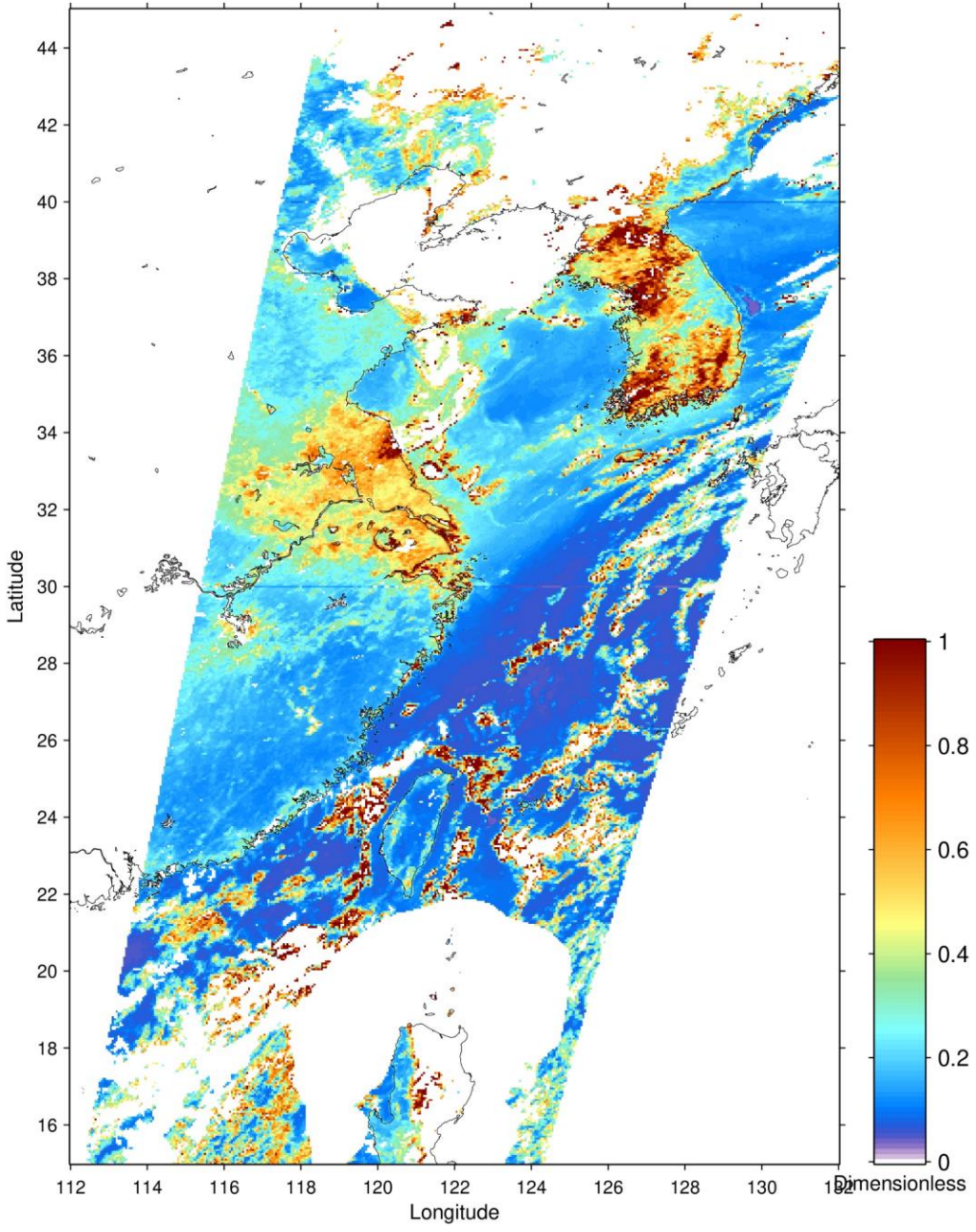
Old version 3.3 SGLI

✓ Cloud contamination

✓ High values around sunglint



JAXA_AEROSOL_20231123_00_0, UNC_AOT_

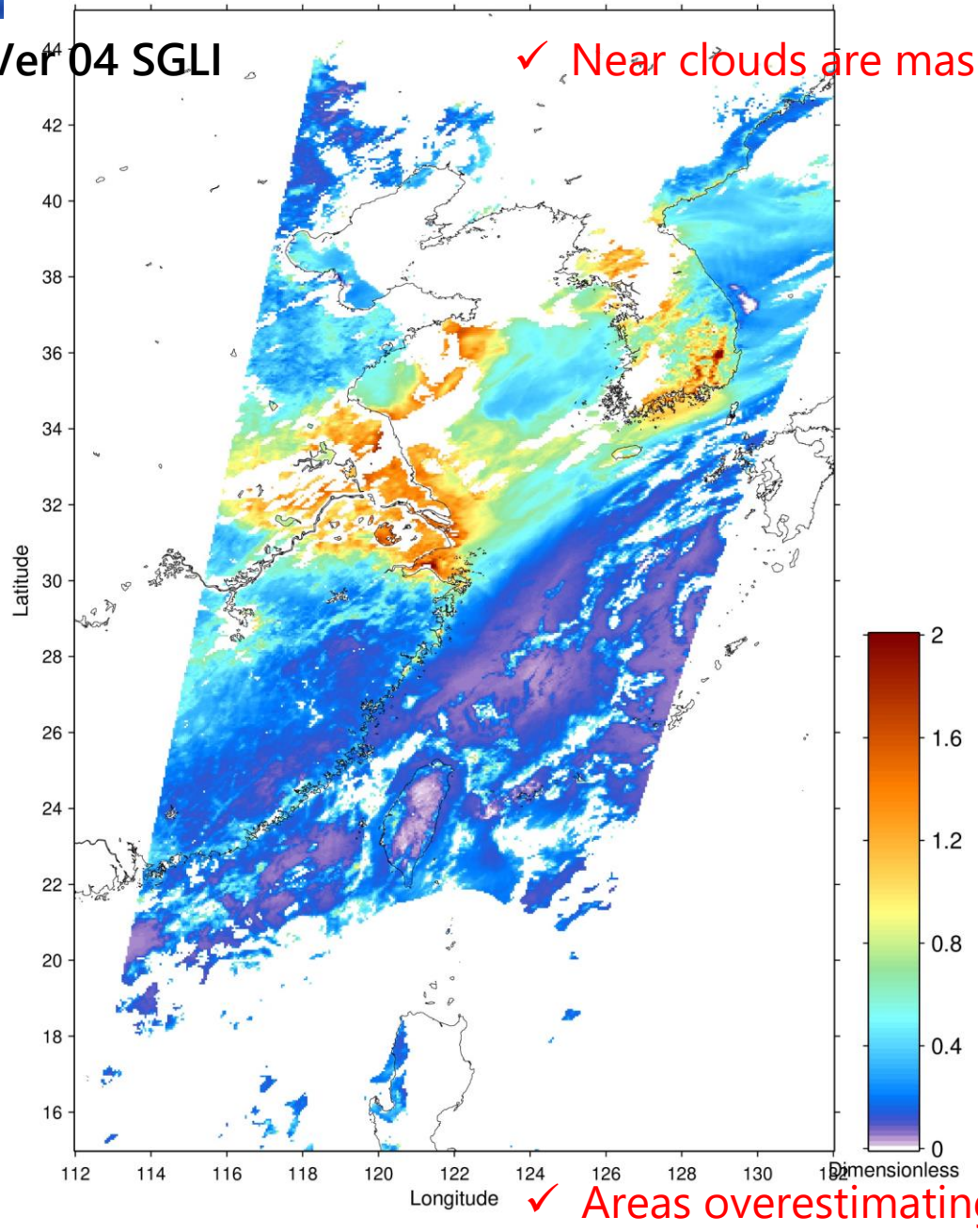


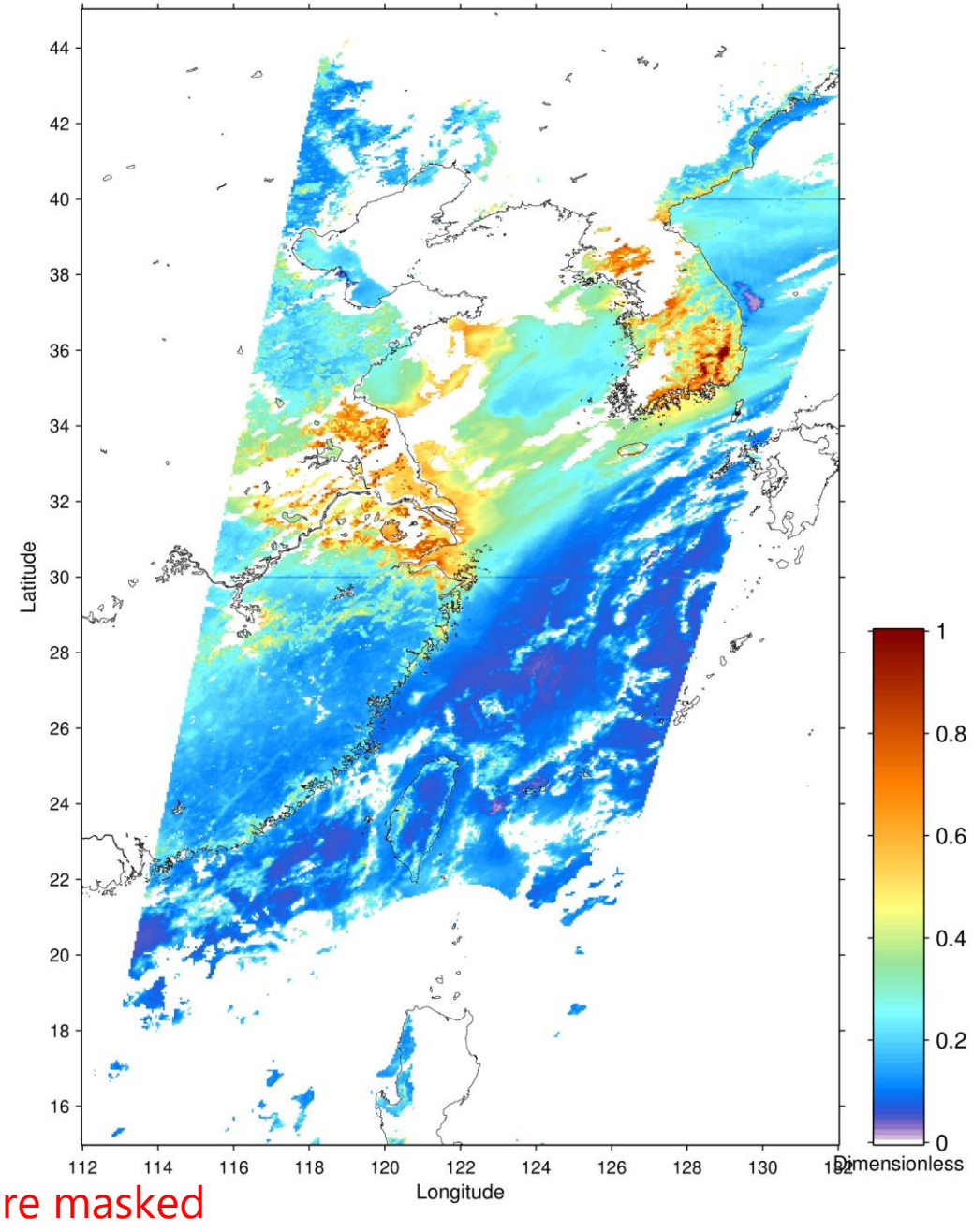
JAXA_AEROSOL_20231123_00_0, AOT_SGLI_I

JAXA_AEROSOL_20231123_00_0, UNC_AOT_

Ver 04 SGLI

✓ Near clouds are masked

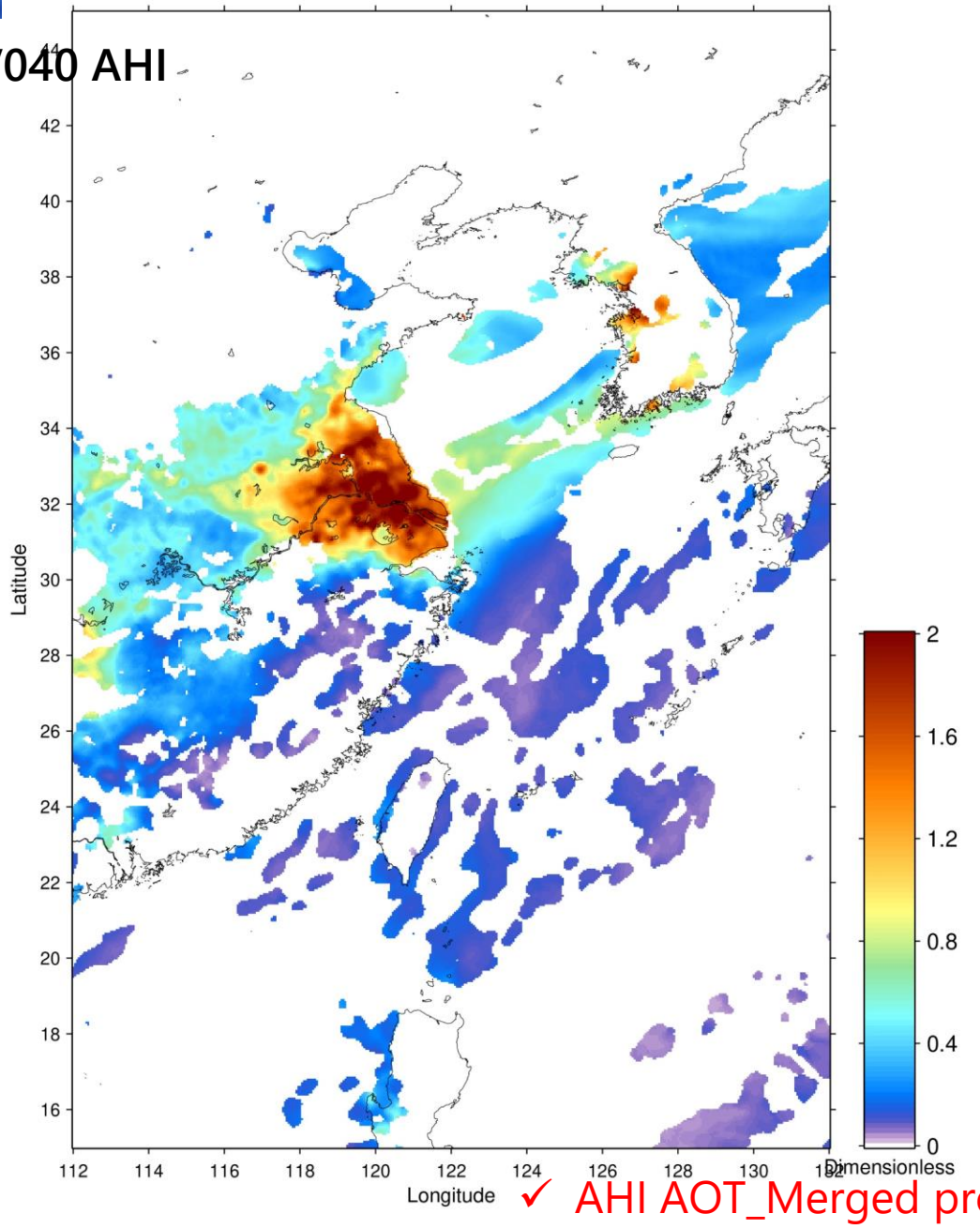




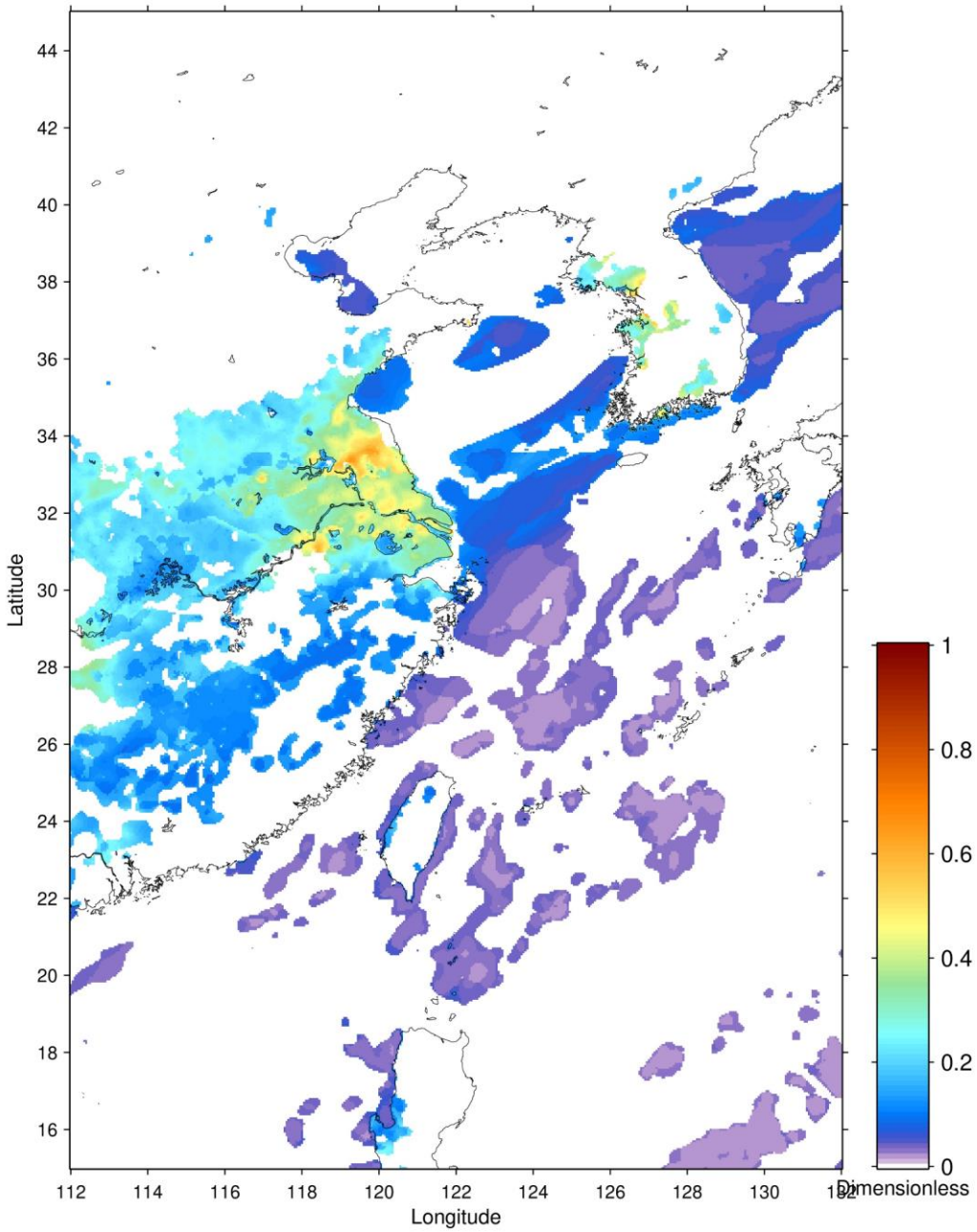
✓ Areas overestimating AOT are masked

JAXA_AEROSOL_20231123_00_0, AOT_AHI

V040 AHI



JAXA_AEROSOL_20231123_00_0, UNC_AOT_



✓ AHI AOT_Merged product

Example of AOT_SGLI monthly average in 2023/10