GCOM-C Data Validation Plan for Land, Atmosphere, Ocean, and Cryosphere

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Japan Aerospace Exploration Agency (JAXA) will launch an Earth observing satellite for climate studies named “Global Change Observation Mission – Climate (GCOM-C)” in 2017 which carries a multi-spectral optical sensor named Second-Generation Global Imager (SGLI). The GCOM-C satellite will observe various geophysical variables such as vegetation, land surface temperature, aerosol, clouds, ocean color, sea surface temperature, snow cover extent, snow grain size and so on. The objectives of the SGLI observations are to elucidate the roles of the geophysical variables in the recent changing Earth’s climate system and to establish long-term satellite data record of the variables. Three kinds of target accuracies to be achieved for the SGLI observations are defined for evaluating the success of the GCOM-C satellite mission. First one is the minimum thresholds to be achieved for the first SGLI data release at one year after the launch of GCOM-C. Second and third thresholds are the standard and goal accuracies to be achieved at five years after the launch for evaluating the full and extra success of the mission. The target accuracies for individual SGLI products are available at the GCOM-C web site (http://suzaku.eorc.jaxa.jp/GCOM_C/index.html). The quality and accuracies of SGLI products are planned to be evaluated and maintained through validation activities organized by the SGLI validation team consisting of JAXA and SGLI principal investigators (PIs). Uncertainties of the SGLI data products will be characterized through the comparison with *in-situ* observations, similar products derived from other satellites, climatological data, and/or numerical model simulations. This paper summarizes the overall validation plan for the SGLI geophysical variable products.

Key Words: GCOM-C, SGLI, Satellite Remote Sensing, Validation, *In-situ* Measurement

1. Introduction

JAXA will launch an Earth observing satellite for climate study named “GCOM-C” in Japanese fiscal year JFY2017 which carries a multi-spectral optical imager SGLI.¹⁾ SGLI is a successor of Global Imager (GLI) onboard the Advanced Earth Observing Satellite-II (ADEOS-II) which was launched in December 2002 and unfortunately stopped operation in October 2003. The GCOM-C will observe various geophysical variables (GVs) related to land, atmosphere, ocean, and cryosphere such as vegetation, land surface temperature, aerosol, clouds, ocean color, sea surface temperature, snow cover extent, and snow grain size and so on in order to elucidate their climatic roles and to establish long-term satellite data record of those GV s.

2. Second Generation Global Imager (SGLI)

SGLI has 19 spectral channels spanning from near ultra-violet at the wavelength of 380 nm to thermal infrared at 12 μ m as shown in Table 1. Signal to noise ratio (SNR) of individual channels are defined at the standard radiance (L_{std}). Both the SNR and the maximum radiance (L_{max}) detectable by

SGLI are determined based on the usage of the channels. Among the SGLI channels VN4, VN6, VN7, and VN10 are high-gain channels with low L_{max} designed for the retrieval of ocean color variables such as chlorophyll-a concentration, total suspended matter, and colored dissolved organic matter etc. Spatial resolution (instantaneous field of view (IFOV)) for nadir looking channels of visible to near infrared regions (VN1-VN11) and a shortwave infrared channels SW3 (1.63 μ m) is 250 m, whereas other shortwave infrared (SW1, 2, 4) and slant-viewing polarization channels (P1-P2) have 1 km ground resolution. Thermal infrared (TIR) channels (T1-T2) have fine IFOV of 500 m as standard resolution but optionally SGLI has a capability to acquire 250 m resolution data for T1-T2 channels. Currently the finer 250 m resolution data for T1-T2 are planned to be acquired over terrestrial and coastal regions on a global scale, which will be a great advantage of SGLI as global observation sensor for monitoring temperature of spatially heterogeneous surfaces such as terrestrial patchy vegetation, snow, sea ice with low concentration, and coastal water and so on.

One of new features of SGLI is the polarization observation function which enables us to observe the Earth’s surface forward or backward at an off-nadir angle of 45-degree at

three polarization angles (0 and ± 60 deg.). The degree of polarization is useful for retrieving aerosol over land. It is expected that a combination use of the slant-viewing (P1 and P2) and nadir looking (VN8 and VN11) channels, that is, multi-angle observations will also make a roughness estimations of vegetation over land and ice sheet over Greenland and the Antarctica, which will contribute to enhancing the accuracy of the retrieval of biomass and snow physical variables over those regions.

Table 1. SGLI channel specification.

	λ	$\Delta\lambda$	L_{std}	L_{max}	SNR at L_{std}	IFOV
CH	VN, P, SW: nm T: μm	VN, P: $\text{W}/\text{m}^2/\text{sr}/\mu\text{m}$ T: Kelvin	VN, P, SW: -, T: NEAT			m
VN1	380	10	60	210	250	250
VN2	412	10	75	250	400	250
VN3	443	10	64	400	300	250
VN4	490	10	53	120 ^{*1}	400	250
VN5	530	20	41	350	250	250
VN6	565	20	33	90 ^{*1}	400	250
VN7	673.5	20	23	62 ^{*1}	400	250
VN8	673.5	20	25	210	250	250
VN9	763	12	40	350	1200	250/1000
VN10	868.5	20	8	30 ^{*1}	400	250
VN11	868.5	20	30	300	200	250
P1	673.5	20	25	250	250	1000
P2	868.5	20	30	300	250	1000
SW1	1050	20	57	248	500	1000
SW2	1380	20	8	103	150	1000
SW3	1630	200	3	50	57	250
SW4	2210	50	1.9	20	211	1000
T1	10.8	0.74	300	340	0.2	250/500
T2	12.0	0.74	300	340	0.2	250/500

*1: VN4, VN6, VN7, and VN10 are high gain channels with lower dynamic range for ocean color.

3. SGLI Products and Validation

There are 29 GVs to be retrieved from SGLI-observed radiances (i.e., Level-1) as Level-2 standard products (See Table 2 shown at the end of this paper and also refer to the GCOM-C web ²⁾ for the details of the product definitions both for the standard and research products and the algorithm theoretical basis documents (ATBD)). In this section the SGLI Level-2 products and the validation strategy for land, atmosphere, ocean, and cryosphere are briefly introduced.

3.1. Land

Various land GVs are defined as standard product as shown in Table 2. First two are products for geometric and atmospheric corrections over land (Product ID: LTOA and RSRF). Remaining land GVs except for the last land surface temperature (LST) are vegetation-related products such as vegetation index (VGI), above-ground biomass (AGB), vegetation roughness (VRI), shadow index (SDI), fraction of absorbed photosynthetically active radiation (FPAR), and leaf

area index (LAI). The target accuracies for those vegetation-related products are defined for grass and forest regions separately.

The accuracy of the geometric correction is evaluated using ground control points (GCPs) prepared with AVNIR-2 high resolution images. Accuracies of other land products are evaluated primarily based on the comparison with *in-situ* observed GV data and secondarily on the comparison with similar GV products (if available) derived from other satellite observations by optical images (e.g., MODIS and VIIRS), space-borne lidars (e.g., MOLI and GEDI are under planning), and synthetic aperture radar (SAR) (e.g., PALSAR2). For the *in-situ* observations of AGB, SDI, LAI, FPAR, and LST we are establishing several super sites in Japan which has at least a 500 m by 500 m square uniform field in forest area and thus can provide *in-situ* derived GVs comparable to SGLI observations with 250 m spatial resolution.³⁾

3.2. Atmosphere

Most of the atmosphere GVs have been handed down from ADEOS-II/GLI mission to GCOM-C/SGLI except for the product of aerosol by polarization (ARPL). The ARPL is a new product to be derived from the SGLI polarization observations. Other cloud and aerosol GVs such as cloud flag/classification (CLFG), classified cloud fraction (CFR), cloud top temperature/height (CLTT, CLTH), water cloud optical thickness/effective radius (COTW, CERW), ice cloud optical thickness (COTI), aerosol over the ocean (AOTO, AAEO), and land aerosol by near ultra violet (AOTL, AAEL) are derived from SGLI observations by non-polarization channels.

Validation of aerosol products are basically conducted through the comparison with *in-situ* observations of aerosol optical thickness (AOT) obtained from ground observation networks such as the SKYNET ⁴⁾ and AERONET.⁵⁾ As for the validation of the cloud flag (CLFG) product, the achievement of release threshold (RT) is evaluated comparing with cloud amount estimated from ground based sky-camera images, whereas those of standard accuracy (SA) and target accuracy (TA) are evaluated as those of the CFR product by evaluating solar irradiances derived both from *in-situ* observations (direct measurements of solar irradiance obtained from the Baseline Surface Radiation Network (BSRN) and other *in-situ* networks) and satellite observations (derived using cloud flag and cloud fraction products). Climatology of cloud fraction obtained from ISCCP ⁶⁾ and those from ground based sky-camera images are also used for supplemental evaluations. RT of CLTT and CLTH is indirectly evaluated through the calibration of SGLI TIR channels and also by comparing with objective analysis meteorological data of atmospheric temperature profile provided by Japan Meteorological Agency (JMA). On the other hand, SA and TA of CLTT and CLTH are evaluated using remotely sensed GVs obtained through *in-situ* observations and other airborne- and satellite observations. RT of COTW and CERW is evaluated with other satellite products, while SA is indirectly evaluated as cloud liquid water (CLW) derived both from *in-situ* observation (microwave radiometer etc.) and satellite observations (taking into account the SGLI-derived COTW

and CERW). TA of COTW and CERW is evaluated by the same approach with the SA and also by comparing directly with *in-situ* observed cloud optical thickness (COT) by sky-radiometer. Finally, RT of COTI is evaluated with other satellite products, while SA and TA are evaluated using *in-situ* measured COT by sky-radiometer.

3.3. Ocean

There are seven standard ocean GVs consisting of three radiometric products (normalized water leaving radiance (NWLR), atmospheric correction parameter (AOT at VN7 and VN10), and photosynthetically available radiation (PAR)), three biogeochemical/bio-optical products (chlorophyll-*a* concentration (CHLA), total suspended matter concentration (TSM), and colored dissolved organic matter (CDOM)), and a thermal product (sea surface temperature (SST)). All of these ocean GVs, which have been handed down from ADEOS-II/GLI mission to GCOM-C/SGLI, are indispensable products for studying carbon cycle in the ocean.

Validations of these ocean GVs are planned to be conducted primarily through the comparison with *in-situ* data. Supplementary similar GVs derived from other satellite data are also used for assessing relative quality of SGLI products. While *in-situ* data for SST validation obtained using buoys and ships in various ocean all over the world are available through the online near-real time *in-situ* Quality Monitor (iQuam; <http://www.star.nesdis.noaa.gov/sod/sst/iquam/>) developed at NESDIS,⁷⁾ validation data for other ocean GVs have to be acquired by ship cruises. In addition, when evaluating the achievement of RTs, accuracies of in-water GVs are defined for offshore ocean. Within the one year after the launch of GCOM-C, the availability of *in-situ* data particularly acquired at the offshore ocean sites could be very limited. Therefore, not only the validation with *in-situ* in-water data but also the comparison with the products of other satellites will be important for assessing the quality of SGLI products for the RT evaluations.

3.4. Cryosphere

There are four cryosphere GVs defined as SGLI standard products, essentially all of which have been handed down from the ADEOS-II/GLI mission. Snow and ice covered area (SICE) and Okhotsk sea-ice distribution (OKID) are the products for showing the areal distributions of snow and ice, while snow and ice surface temperature (SIST) and snow grain size of shallow layer (SGSL) are physical properties of snow and ice surface characterizing the longwave and shortwave radiative properties of the surface.

RT evaluations of the cryosphere GVs except for the areal products of SICE and OKID are basically conducted through the comparison with similar GV products derived from other satellites or climatological data, because the chance of the acquisitions of *in-situ* data particularly of snow grain size over remote snow and ice fields in the cryosphere is quite limited during the one year after the launch of GCOM-C satellite. For the SA and TA evaluations five years after the launch, we will use *in-situ* acquired data for the validation. For the validation of SICE, *in-situ* snow depth data available on-line through global meteorological station networks such as Global Historical Climatology Network-Daily (GHCND) provided by

NOAA/NCDC⁸⁾ will be used together with other satellite images including high resolution sensors such as Landsat-8/OLI and Sentinel-2/MSI. Accuracy of OKID will be evaluated through the comparison with high resolution satellite images from e.g., MODIS, VIIRS and other high resolution sensors. In addition, aerial photographs provided by the Japan Coast Guard will be used to assess the reliability of the product for practical uses. As for the SIST validation, *in-situ* snow surface temperature which is derived from the radiometer data of automatic weather stations (AWS) installed on the Greenland ice sheet⁹⁾ and other available BSRN AWS stations will be used together with *in-situ* data acquired by campaign observations. Finally, the evaluations of SGSL will use *in-situ* acquired snow grain size and the optical measurement data. The former is the grain size determined with microscopic observations at the ground sites, while the latter is the optically-equivalent grain size converted from the snow reflectance measured with spectrometers or the specific surface area (SSA) measured with an integrating sphere device at the sites in Hokkaido, Greenland, Svalbard and Antarctica. The relation between the physical ice particle size and the optically-equivalent grain size derived from the spectrometer data has been verified in the past study.¹⁰⁾

4. GCOM-C Validation Monitor Web

To monitor the temporal variation of the accuracies of the retrieved GVs, we have been developing an automated system for the validation of several GCOM-C products (the GCOM-C Validation web).¹¹⁾ Currently, the systems for monitoring temporal variations of LTOA, SST, NWLR, LST, SICE, and SIST and for estimating the accuracies of LST, AOT, CLFG, COTW/CERW, COTI, and SIST have been developed and being tested on the web using MODIS-derived GVs available at JASMES.¹²⁾ The validation web is still a prototype and will be opened to the public after the launch of GCOM-C satellite. Figs. 1(a) and 1(b) show an analysis result of the temporal stability of satellite-derived SST and a scatter plot showing the accuracies of satellite-derived SST determined with *in-situ* data obtained from the iQuam. Figures 2 and 3 show another example of scatter plots for evaluating accuracies of AOT and SIST. These are still preliminary results before quality assurance. After the GCOM-C launch, actual SGLI data will be used as the satellite data source and the accuracies of the SGLI-derived GVs will be monitored on the Validation web.

5. Summary and Conclusions

Multiple geophysical variables ranging from land vegetation, atmospheric aerosol and clouds, marine ecosystem to remote polar snow and ice are planned to be retrieved from SGLI-observed multi-spectral radiances after the launch of GCOM-C satellite in 2017. We have been establishing validation strategy and field campaign sites for evaluating the accuracies of the wide variety of the SGLI geophysical variables. The quality of SGLI products are evaluated primarily through the comparison with *in-situ* acquired geophysical variables and secondarily using climatological data and/or similar geophysical variables derived from other

satellites. During the one-year after the launch, the number of *in-situ* data can be quite limited. Therefore, the data from other satellites and climatology will be useful. On the other hand, acquisitions of *in-situ* data are key toward the final evaluations of the standard and goal accuracies five years after the launch of GCOM-C. Therefore, we will continue to make efforts to explore available *in-situ* data for the validation.

Fig. 1. (a) Temporal variations of bias (red line) and root mean square error (RMSE, blue line) of satellite-derived SST together with the number of *in-situ* data (black line) used for the bias estimations, (b) the scatter plot between *in-situ* acquired and satellite-derived SST. All the *in-situ* data were obtained from the iQuam⁷⁾ while the satellite data were from JASMES.¹¹⁾

Fig. 2. A tentative comparison of AOTs at the wavelength of 554 nm obtained from *in-situ* acquired AOT at SKYNET⁴⁾ Chiba site and satellite-derived AOT from JASMES.¹¹⁾

Fig. 3. A tentative comparison between *in-situ* acquired SIST and satellite-derived SIST. The *in-situ* data were obtained from the AWS of SIGMA-B⁹⁾ while the satellite-derived SIST were from JASMES.¹¹⁾

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Table 2. Accuracy targets of SGLI Leve-2 products and validation data sources.

Area	Product name [ID* ¹]	Release threshold* ² (RT)	Standard accuracy* ² (SA)	Target accuracy* ² (TA)	Validation data sources
Land	Precise geometric corrected radiance [LTOA]	<1 pixel	<0.5 pixel	<0.25 pixel	- GCP database derived from AVNIR-2 etc.
	Atmospheric corrected reflectance [RSRF]	0.3 (<=443 nm),	0.1 (<=443 nm),	0.05 (<=443 nm),	- <i>In-situ</i> observation
		0.2 (>443 nm) (scene) * ^{L1}	0.05 (>443 nm) (scene) * ^{L1}	0.025 (>443 nm) (scene) * ^{L1}	- Model simulation (BiRS)
	Vegetation index [VGI_ (NDVI/EVI_)]	Grass:25 % (scene), forest:20 % (scene)	Grass:20 % (scene), forest:15 % (scene)	Grass:10 % (scene), forest:10 % (scene)	- <i>In-situ</i> observation - Other Sat. (MODIS, VIIRS etc.)
	Above-ground biomass [AGB_]	Grass:50 %, forest: 100 %	Grass:30 %, forest:50 %	Grass:10 %, forest:20 %	- <i>In-situ</i> obs.@0.25 km ² sites - Other Sat. (MOLI, GEDI, PALSAR2, other SARs etc.)
	Vegetation roughness index [AGB_ (VGI_)]	Grass: 40 % (scene) forest: 40 % (scene)	Grass & forest:20 % (scene)	Grass & forest:10 % (scene)	- <i>In-situ</i> observation
	Shadow index [VGI_ (SDI_)]	Grass: 30 % (scene) forest: 30 % (scene)	Grass & forest:20 % (scene)	Grass & forest:10 % (scene)	- <i>In-situ</i> obs.@0.25 km ² sites - Other Sat. (MODIS, VIIRS etc.)
	Fraction of absorbed PAR [LAI_ (FPAR)]	Grass:50 %, forest: 50 %	Grass:30 %, forest:20 %	Grass:20 %, forest:10 %	- <i>In-situ</i> obs.@0.25 km ² sites - Other Sat. (MODIS, VIIRS etc.)
	Leaf area index [LAI_]	Grass:50 %, forest: 50 %	Grass:30 %, forest:30 %	Grass:20 %, forest:20 %	- <i>In-situ</i> obs.@0.25 km ² sites - Other Sat. (MODIS, VIIRS etc.)
Atmosphere	Land surface temperature [LST_]	<3.0 K (scene)	<2.5 K (scene)	<1.5 K (scene)	- <i>In-situ</i> obs.@0.25 km ² sites - Other Sat. (MODIS, VIIRS etc.)
	Cloud flag/ Classification [CLFG]	10 % (with whole-sky camera)	(Evaluated as the classified cloud fraction product)		- Cloud amount from sky-camera based on BI-SI method,
	Classified cloud fraction [CLPR (CFR*)] * is the No. of the ISCCP classes	20 % (on solar irradiance) ^{*A1}	15 % (on solar irradiance) ^{*A1}	10 % (on solar irradiance) ^{*A1}	- Irradiance obs. from BSRN and Skynet etc. (SGLI irradiance is derived from Cloud flag/ fraction) - Climatology from ISCCP etc. - Classified CFR from sky-camera
	Cloud top temp/height [CLPR (CLTT/CLTH)]	1 K ^{*A2}	3 K/2 km (top temp/height) ^{*A3}	1.5 K/1 km (temp/height) ^{*A3}	- Cal. of TIR bands & JMA Objective analysis data (for RT) - RS data from ground, airborne, and other satellites (lidar, radar, radiometer (for SA & TA)
	Water cloud OT/ effective radius [CLPR (COTW/CERW)]	10 %/30 % (Cloud OT/radius) ^{*A4}	100 % (as cloud liquid water ^{*A5})	50 % ^{*A5} / 20 % ^{*A6}	- Other Sat. (MODIS, VIIRS etc. for RT) - <i>In-situ</i> obs. of COT by Skynet sky-radiometer (for TA)
	Ice cloud optical thickness [CLPR (COTI)]	30 % ^{*A4}	70 % ^{*A6}	20 % ^{*A6}	- <i>In-situ</i> obs. of COT by Skynet sky-radiometer - Other Sat. (MODIS, VIIRS etc.)
	Aerosol over the ocean [ARNP (AOTO/AAEO)]	0.1 (Monthly $\tau_{670, 865}$) ^{*A7}	0.1 (scene $\tau_{670, 865}$) ^{*A7}	0.05 (scene $\tau_{670, 865}$)	- <i>In-situ</i> obs. of AOT by Skynet & AERONET sky-radiometer - Other Sat. (MODIS, VIIRS etc.)
	Land aerosol by near ultra violet [ARNP (AOTL/AAEL)]	0.15 (Monthly τ_{380}) ^{*A7}	0.15 (scene τ_{380}) ^{*A7}	0.1 (scene τ_{380})	- <i>In-situ</i> obs. of AOT by Skynet & AERONET sky-radiometer - Other Sat. (MODIS, VIIRS etc.)
	Aerosol by Polarization [ARPL (AOTP/AAEP/ASSA)]	0.15 (Monthly $\tau_{670, 865}$) ^{*A7}	0.15 (scene $\tau_{670, 865}$) ^{*A7}	0.1 (scene $\tau_{670, 865}$)	- <i>In-situ</i> obs. of AOT by Skynet & AERONET sky-radiometer - Other Sat. (MODIS, VIIRS etc.)
Ocean	Normalized water leaving radiance [NWLR (L***)] *** is wavelength.	60 % (443~565 nm)	50 % (<600 nm) 0.5 W/m ² /str/ μ m (>600 nm)	30 % (<600 nm) 0.25 W/m ² /str/ μ m (>600 nm)	- <i>In-situ</i> observation - Temporal variation of SGLI nLw - Other Sat. (MODIS, VIIRS etc.)

	Atmospheric correction parameters [NWLR (T***)] *** is wavelength.	80 % (AOT@865 nm)	50 % (AOT@865 nm)	30% (AOT@865 nm)	- <i>In-situ</i> observation - Other Sat. (MODIS, VIIRS etc.)
	Photosynthetically available radiation [NWLR (PAR_)]	20 % (10 km/month)	15 % (10 km/month)	10 % (10 km/month)	- <i>In-situ</i> observation - Other Sat. (MODIS, VIIRS etc.)
	Chlorophyll-a concentration [IWPR (CHLA)]	-60~+150 % (offshore)	-60~+150 %	-35~+50 % (offshore), -50~+100 % (coast)	- <i>In-situ</i> observation - Other Sat. (MODIS, VIIRS etc.)
	Suspended solid concentration [IWPR (TSM_)]	-60~+150 % (offshore)	-60~+150 %	-50~+100 %	- <i>In-situ</i> observation - Other Sat. (MODIS, VIIRS etc.)
	Colored dissolved organic matter [IWPR (CDOM)]	-60~+150 % (offshore)	-60~+150 %	-50~+100 %	- <i>In-situ</i> observation - Other Sat. (MODIS, VIIRS etc.)
	Sea surface temperature [SSTD/SSTN (SST_)]	0.8 K (daytime)	0.8 K (day & night time)	0.6 K (day & night time)	- <i>In-situ</i> SST from iQuam - <i>In-situ</i> observation - Other Sat. (MODIS, VIIRS etc.)
Cryosphere	Snow and Ice covered area [SICE]	10 % (vicarious val. with other sat. data)	7 %	5 %	- DCDF snow depth only over land - Other Sat. (MODIS, VIIRS, OLI etc.)
	Okhotsk sea-ice distribution [OKID]		5 %	3 %	- Other Sat. (MODIS, VIIRS, OLI etc.) - Photos etc. (Aerial photos, hand-drawn ice map)
	Snow and ice surface Temperature [SIPR (SIST)]	5 K (vicarious val. with other satellite data and climatology)	2 K	1 K	- Ts from SIGMA, BSRN AWS@ Greenland, Dome-C etc. - <i>In-situ</i> obs.@Greenland, Hokkaido, Svalbard etc. (Campaign) - Other Sat. (MODIS, VIIRS, OLI etc.)
	Snow grain size of shallow layer [SIPR (SGSL)]	100 % (vicarious val. with climatology between Temperature and snow grain size)	50 %	30 %	- Vicarious Val. with Climatology of Temp-Grain size relation (for RT) - Auto-Optical Measurements @ Hokkaido, Svalbard etc. - <i>In-situ</i> obs. @Greenland, Hokkaido, Svalbard etc. (Campaign) - Other Sat. (MODIS, VIIRS, OLI etc.)

Common notes:

*1: Product ID of Leve-2 product is written in [] and Level-3 is written in ().

*2: The accuracy thresholds are defined for each mission success level. The “release threshold” is the minimum level for the first data release at one year from launch. The “standard” and “goal” accuracies correspond to full- and extra success criteria of the mission respectively. Accuracies are basically shown by root mean square error (RMSE: Eq. (1)) with the unit of geophysical variables (GVs). However, the target accuracies written with the unit of percent (%) except for flag-type products are defined as the ratio of RMSE and the average of *in-situ* observations (Eq. (2)). As for the flag-type products (e.g., CLFG), overall accuracies of the flag judgments are statistically evaluated using *in-situ* observation data.

$$RMSE_{GV} [\text{Unit of GV}] = (1/N * \sum (S(i) - T(i))^2)^{1/2} \quad (1)$$

$$RMSE_{GV} / Ave_{in-situ} [\%] = (1/N * \sum (S(i) - T(i))^2)^{1/2} / (1/N * \sum T(i)) \times 100 \quad (2)$$

where N is the number of observations, S(i) is SGLI data, T(i) is *in-situ* data.

Land notes:

*L1: Defined with land reflectance~0.2, solar zenith<30 deg., and flat surface. Release threshold is defined with AOT@500 nm<0.25.

Atmosphere notes:

*A1: Comparison with *in-situ* observation on monthly 0.1-degree grid.

*A2: Vicarious validation on sea surface and comparison with objective analysis data.

*A3: Inter comparison with airplane remote sensing on water clouds of middle optical thickness.

*A4: Release threshold is defined by vicarious validation with other satellite data (e.g., global monthly statistics in the mid-low latitudes).

*A5: Comparison with cloud liquid water by *in-situ* microwave radiometer.

*A6: Comparison with optical thickness by sky-radiometer (the difference can be large due to time-space inconsistency and large error of the ground measurements).

*A7: Estimated by experience of aerosol products by GLI and POLDER.