# CRYOSPHERE PRODUCTS IN THE FIRST GENERATION OF THE GLOBAL CHANGE OBSERVATION MISSION-CLIMATE (GCOM-C1)

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**Commission VIII**

**KEY WORDS:** Snow Cover, Snow Grain Size, Snow Impurity, Surface Temperature, Remote Sensing, Climate

**ABSTRACT:**

The "Global Change Observation Mission-Climate" (GCOM-C) is a project of Japan Aerospace Exploration Agency (JAXA) for the global and long-term observation of the Earth environment. The GCOM-C is expected to play an important role in monitoring and understanding global climate change. It will be a kind of health checkup of the Earth from space. The GCOM-C also aims to construct, use, and verify systems that enable continuous global-scale observations of various geophysical parameters. The GCOM-C is a part of the JAXA's GCOM mission which consists of two satellite series, GCOM-C and GCOM-W (Water), spanning three generations in order to perform uniform and stable global observations for 13 years. Whereas GCOM-W carries a multi-frequency, dual-polarized, passive microwave radiometer named Advanced Microwave Scanning Radiometer 2 (AMSR2) to observe water-related targets such as precipitation, water vapor, sea surface wind speed, sea surface temperature, soil moisture, and snow depth, GCOM-C carries a multi-spectral optical radiometer named Second Generation Global Imager (SGLI), which will have special features of wide spectral coverage from 380nm to 12µm, a high spatial resolution of 250m, a field of view exceeding 1000km, two-direction simultaneous observation, and polarization observation. The GCOM-C mission aims to contribute to improving our knowledge and prediction of the global carbon cycle and radiation budget through high-accuracy observation of global vegetation, ocean color, temperature, cloud, aerosol, and snow and ice through the SGLI observations. The GCOM will take over the Advanced Earth Observing Satellite-II (ADEOS-II) mission and transition into long-term monitoring of the Earth. One of the important targets to be observed by GCOM-C is snow and sea ice in the cryosphere. SGLI on GCOM-C1 will retrieve not only snow cover extent but also snow physical parameters such as snow grain size, temperature, and mass fraction of impurity mixed in snow layer. The snow physical parameters are important factors that determine spectral albedo of the snow surface. Thus it is essential to monitor those parameters from space in order to better understand snow metamorphosis and melting process and also to study the response of snow and sea-ice cover extent in the Polar Regions to a climate forcing such as global warming. A final goal of these observations is to improve land-surface processes in numerical climate models by accumulating knowledge on the evolution of snow and sea ice in the cryosphere.

## 1. INTRODUCTION

Snow physical parameters such as snow grain size and mass fraction of impurities mixed in the snow layer are important factors that determine spectral albedo of the snow surface (Warren, 1982). Thus it is essential to monitor those parameters from space in order to study the response of snow and sea-ice cover extent in the Polar Regions to a climate forcing such as global warming (Aoki et al., 2003).

The optical sensor "Global imager (GLI)" onboard the Japanese earth observing satellite "ADEOS-II", which was launched in December 2002 and unfortunately stopped operation in October 2003, observed sunlight reflection and infrared emission from the Earth's surface globally for about seven months. Temporal and spatial variations of snow impurities, grain size, and surface temperature as well as snow and sea-ice cover extent have been retrieved from the GLI data on a global scale (Stamnes et al., 2007, Hori et al., 2007). For validating the GLI snow products, field experiments were also conducted to obtain the vertical profiles of snow physical parameters at ground observation sites in Hokkaido, Japan and Barrow, Alaska during the operation periods of GLI and Moderate Resolution Imaging Spectroradiometer (MODIS) onboard NASA's earth observation satellite TERRA (Aoki et al., 2007). Among the snow parameters, snow grain size of shallow layer derived from near-infrared reflectance and snow surface temperature are found to be consistent well with ground truth observation, whereas snow grain size of top layer derived from shortwave infrared reflectance and snow impurity were overestimated compared with the ground truth data (Aoki et al., 2007).

As a successor of ADEOS-II, Japan Aerospace Exploration Agency (JAXA) launched a satellite project named the "Global Change Observation Mission" (GCOM) for the global and long-term observation of the Earth environment (Imaoka et al., 2010). The GCOM consists of two satellite series, i.e., GCOM-W (Water) and GCOM-C (Climate), spanning three generations in

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order to perform uniform and stable global observations for 13 years. Whereas the GCOM-W carries a multi-frequency, dual-polarized, passive microwave radiometer named Advanced Microwave Scanning Radiometer 2 (AMSR2) to observe water-related targets such as precipitation, water vapor, sea surface wind speed, sea surface temperature, soil moisture, and snow depth, the GCOM-C carries a multi-spectral optical radiometer named Second Generation Global Imager (SGLI), which is not only a successor of GLI having features of wide spectral coverage from 380nm to 12μm, a high spatial resolution of 250m, a field of view exceeding 1000km, but also have a special feature of two-direction simultaneous observation, and polarization observation. The GCOM-C mission aims to contribute to improving our knowledge and prediction of the global carbon cycle and radiation budget through high-accuracy observation of global vegetation, ocean color, temperature, cloud, aerosol, and snow and ice through the SGLI observations. SGLI is expected to play an important role in monitoring and understanding global climate change.

Currently the first satellite of GCOM-W (GCOM-W1) is scheduled to be launched in 2011. Also, the first GCOM-C (GCOM-C1) is planning to be launched around 2014. Achieving such a global comprehensive long-term observation, the GCOM will eventually contribute to improving future climate projection through a collaborative framework with climate model institutions. Demonstrating capabilities of operational applications through providing continuous data to operational agencies is another important purpose.

SGLI will take over the GLI snow related products and further explore new possibility of snow retrieval such as vertical profile of snow grain size in the shallow layer and surface roughness on the polar ice sheets. In this paper, we will summarize characteristic of SGLI sensor for Cryosphere use, snow related products, and their expected applications.

## 2. SGLI CHARACTERISTIC

SGLI has 19 channels spanning from near ultra-violet at the wavelength of 380nm to thermal infrared at 12μm. 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. All the channels except for the four high-gain ocean channels (VN4, VN6, VN7, and VN10) are planned to be used for analyzing snow and ice parameters as shown in Table 1. Spatial resolution (instantaneous field of view (IFOV)) for nadir looking visible to near infrared channels (VN1-VN11) and SW3 (1.63μm) is mainly 250m, whereas other shortwave infrared (SW1, 2, 4) and slant-viewing polarization channels (P1-P2) have 1km ground resolution. Thermal infrared channels (T1-T2) have fine resolution (standard: 500m (optional: 250m)) which can be a great advantage of SGLI for monitoring temperature of spatially heterogeneous surfaces such as snow cover in forest, polynya (open water surrounded by sea ice), sea ice area 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. The degree of polarization is possibly useful for classifying snow and sea ice. It is expected that a combination use of the slant-viewing (P1 and P2) and nadir looking (VN8 and VN11) channels will also make a roughness estimation of ice sheet surface possible.

| CH | λ | Δλ | $L_{std}$ | $L_{max}$ | SNR at $L_{std}$ | IFOV | Possible Targets |
|---|---|---|---|---|---|---|---|
| | VN, P, SW: nm T: μm | | VN,P: W/m$^2$/sr/μm T: Kelvin | | VN,P,SW: -, T: NEΔT | m | (See Table 2 for Product ID) |
| VN1 | 380 | 10 | 60 | 210 | 250 | 250 | SNP[*1] |
| VN2 | 412 | 10 | 75 | 250 | 400 | 250 | SNIP, SIALB |
| VN3 | 443 | 10 | 64 | 400 | 300 | 250 | SNP[*1] |
| VN4 | 490 | 10 | 53 | 120 | 400 | 250 | *Ocean channel* |
| VN5 | 530 | 20 | 41 | 350 | 250 | 250 | SICA[*2], SIC, SNP[*1] |
| VN6 | 565 | 20 | 33 | 90 | 400 | 250 | *Ocean channel* |
| VN7 | 673.5 | 20 | 23 | 62 | 400 | 250 | *Ocean channel* |
| VN8 | 673.5 | 20 | 25 | 210 | 250 | 250 | SICA[*2], SIC, SNP[*1] SCAFM, ISRGH |
| VN9 | 763 | 12 | 40 | 350 | 1200 | 250/ 1000 | SICA[*2] |
| VN10 | 868.5 | 20 | 8 | 30 | 400 | 250 | *Ocean channel* |
| VN11 | 868.5 | 20 | 30 | 300 | 200 | 250 | SNP[*1], SCAFM, ISRGH |
| P1 | 673.5 | 20 | 25 | 250 | 250 | 1000 | SIC, ISRGH |
| P2 | 868.5 | 20 | 30 | 300 | 250 | 1000 | SIC, ISRGH |
| SW1 | 1050 | 20 | 57 | 248 | 500 | 1000 | SIC, SCAFM, SNP[*1] |
| SW2 | 1380 | 20 | 8 | 103 | 150 | 1000 | SICA[*2], SCAFM |
| SW3 | 1630 | 200 | 3 | 50 | 57 | 250 | SICA[*2], SCAFM, SNP[*1] |
| SW4 | 2210 | 50 | 1.9 | 20 | 211 | 1000 | SCAFM |
| T1 | 10.8 | 0.74 | 300 | 340 | 0.2 | 250/ 500 | SICA[*2], SIC, SIST |
| T2 | 12.0 | 0.74 | 300 | 340 | 0.2 | 250/ 500 | SICA[*2], SIC, SIST |

SNP[*1] includes SNGSL, SNGSS, SNGST, SNIP, and SIALB. SICA[*2] includes OKID and ISBM.

Table 1. SGLI channel specification and cryosphere targets

## 3. CRYOSPHERE PRODUCTS OF SGLI

Table 2 summarizes SGLI cryosphere products. There are twelve products consisting of four standard products (which will be operationally processed and released to the public soon after the launch) and eight research products (which are still in research phase and may be released after thorough validation).

### 3.1 Area/Distribution

One of traditional satellite remote sensing products is snow and ice cover. SGLI's snow and ice cover products have a global 1km spatial resolution product named "Snow and Ice covered area (SICA)" and a regional 250m resolution product "Okhotsk sea-ice distribution (OKID)". "Snow covered area in forest and mountain (SCAFM)" is also one of snow cover products but the snow cover at both forest and mountain is more difficult to detect from space compared with snow cover at open area such as tundra, ice sheet, and sea ice. "Snow and ice classification

(SIC)" is to classify several snow and ice types using reflectances at visible to shortwave infrared channels.

| Type | Product name | Product ID | Category | GLI heritage*1 |
|---|---|---|---|---|
| Area/ distribution | Snow and Ice covered area (incl. cloud detection) | SICA | Standard | A |
| | Okhotsk sea-ice distribution | OKID | Standard | A |
| | Snow and ice classification | SIC | Research | B |
| | Snow covered area in forest and mountain | SCAFM | Research | B |
| Surface properties | Snow and ice surface temperature | SIST | Standard | A |
| | Snow grain size of shallow layer | SNGSL | Standard | B |
| | Snow grain size of subsurface layer | SNGSS | Research | C |
| | Snow grain size of top layer | SNGST | Research | C |
| | Snow and ice albedo | SIALB | Research | B |
| | Snow impurity | SNIP | Research | B |
| | Ice sheet surface roughness | ISRGH | Research | C |
| Boundary | Ice sheet boundary monitoring | ISBM | Research | B |

*1. Heritage levels from ADEOS-II/GLI study are shown by A-C; A: high heritage, B: Some issues remaining, C: new or many issues remaining to be resolved

Table 2 SGLI Cryosphere products

### 3.2 Surface Properties

Among the SGLI products related to surface properties, "snow and ice surface temperature (SIST)" is expected to be the most reliable parameter with high retrieval accuracy (RMSE<1-2K) and has many applications e.g., for assessing snow melting area/duration and also estimating radiation budget. "Snow grain size of shallow layer (SNGSL)" has been retrieved from GLI data and the results exhibited good correlation with in-situ data (Aoki et al., 2007). Thus SNGSL is also promising one. Typical spatial distributions of both parameters are shown in Figure 1. In SGLI mission, vertical homogeneity of snow grain size will be assessed by retrieving grain sizes at different depths using multi-channels reflectance (VN11 for SNGSL, SW1 for SNGSS, and SW3 for SNGST). Also, "snow impurity (SNIP)" is retrieved based on the dependence of visible snow reflectance on impurity content in snow. From these snow parameters to be retrieved, finally, "snow and ice albedo (SIALB)" will be estimated. "Ice sheet surface roughness (ISRGH)" is a challenge to retrieve the ratio of height to width of a roughness pattern on the ice sheet surface. The roughness information is useful for correcting anisotropy of the bi-directional reflectance factor of snow surface and thus possibly contribute to an enhancement of retrieval accuracy of snow physical parameters such as snow grain sizes and impurity.

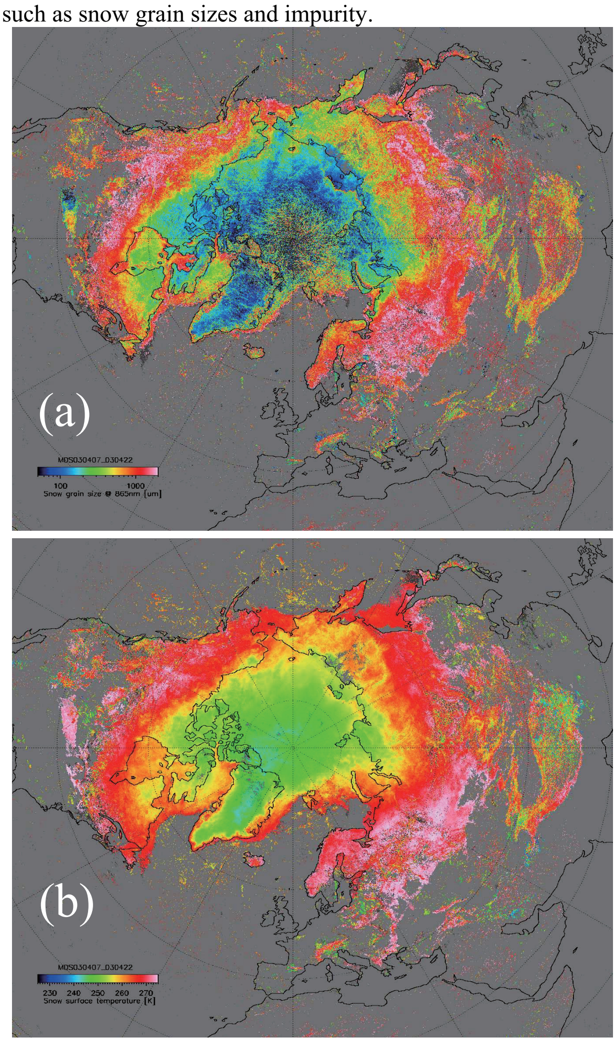


Figure 1. Typical hemispherical distribution of (a) snow grain size of shallow layer and (b) snow and ice surface temperature in spring (Apr. 2003) derived from MODIS data

### 3.3 Boundary of ice sheet

"Ice sheet boundary monitoring (ISBM)" is to monitor the boundary of ice sheet and ice shelf in the both polar regions at 250m resolution for detecting a sign of long-term change of the Cryosphere.

### 3.4 Possible blended products with GCOM-W1/AMSR2

There are no products officially defined as a blended product which is processed using GCOM-C1/SGLI (optical radiometer) and GCOM-W1/AMSR2 (passive microwave radiometer) data. Snow cover, however, is the most probable candidate for the blended product by combining snow cover extent of SGLI with finer spatial resolution with snow water equivalent (snow depth) from AMSR2. Also, grain size information of snow cover from SGLI data could be an input when retrieving snow depth from AMSR2 data. Inversely, snow depth is useful for assessing the quality of snow grain size and impurity products because the retrieval of these parameters can be erroneous when snow depth is shallow (Hori et al., 2007). Snow and ice type (or albedo) classified with SGLI data may also be useful to determine emissivity of snow and ice in the microwave region for the better AMSR2 snow/sea ice retrieval. These possibilities should be explored toward the launch of GCOM series satellite.

## 4. EXPECTED APPLICATIONS OF SGLI PRODUCTS

### 4.1 Improvement of numerical climate models

From the analysis of GLI data, snow grain size (of shallow layer) was found to depend significantly on snow surface temperature on a global scale (Hori et al., 2007). When the surface temperature is lower, snow grain size is kept smaller corresponding to new snow. As the surface temperature increases to 270 K near the melting point of ice, however, the grain size gradually increases to around 500–1000 µm. Then, when the temperature reaches the melting point around 273 K snow grains rapidly grow into large granular particles. The close relationship between snow surface temperature and grain size further suggests the possibility to assess the potential of snow grain to metamorphose. This information will be useful to validate a snow metamorphism model such as CROCUS (Brun et al., 1992) and thus could contribute to the improvement of land processes controlling snow albedo in numerical climate models (Aoki et al., 2003).

### 4.2 Toward construction of a half-century long datasets

One of important objectives of the GCOM mission is to monitor long-term trend of geophysical parameters for understanding the mechanism of earth's climate system. For this purpose, the data from GCOM series satellites are not enough. Thus, JAXA launched a website named "JAXA Satellite Monitoring for Environmental Studies (JASMES)" (JAXA, 2009) for semi-near real-time monitoring of earth's environmental variables. Through this website JASMES provides users with not only satellite datasets (flat binary) but also information on the current status of the climate variables such as solar radiation reaching the earth's surface (photosynthetically available radiation: PAR), snow and cloud cover, dryness of vegetation (water stress trend), and wild fire. MODIS data since February 2000 are currently processed for this analysis but SGLI data will be used after the launch of GCOM-C1. Furthermore, the data from Advanced Very High Resolution Radiometer (AVHRR) onboard polar orbiting satellites operated by the National Oceanic and Atmospheric Administration (NOAA) since 1978 are also under preparation toward establishing a half-century long datasets of remote sensing after the success of the GCOM mission.


Figure 2. JASMES website (JAXA, 2009). The RGB image on the top page shows icons indicating that some of the archived parameters are beyond normal climate condition at the regions.

## 5. CONCLUSIONS

JAXA is establishing the GCOM series satellites which are a successor of ADEOS series launched by the National Space Development Agency of Japan (NASDA, one of the former organizations of JAXA). First generation of GCOM-Water (GCOM-W1) satellite will carry a passive microwave radiometer "AMSR2" and observe geophysical parameters related to water cycle, while GCOM-Climate (GCOM-C1) satellite will carry multi-channel optical radiometer "SGLI" and observe climate variables related to carbon cycle and radiation budget. First generation of GCOM satellites are planned to be launched in JFY2011 (GCOM-W1) and around JFY2014 (GCOM-C1). In cryosphere science field, also, SGLI will observe various snow and ice parameters such as snow cover, various snow physical parameters related to radiation budget and hydrological cycle. For obtaining better retrieval accuracy, blended products between SGLI and AMSR2 data are desired to be processed. Concept of long-term observation over 13 years is also a key feature of the GCOM mission for a better understanding of the mechanisms of global climate changes.

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