GCOM Science Plan

March, 2010

Ver. 1.1

Contents

1. Introduction (Haruhisa Shimoda: Tokai University)

The Global Change Observation Mission (GCOM) is a mission designed to observe changes of the global environment in a comprehensive and continual manner following the path established by the ADEOS and ADEOS-II. The ADEOS was launched in August, 1996 and ceased operation in June, 1997 when the solar cell paddle was damaged. Its successor, the ADEOS-II, was launched in December, 2002 but its operation ended shortly afterwards in October, 2003 as in the case of the ADEOS. The GCOM inherits the missions of these two earlier satellites and is designed to conduct continual observation over a long period of time.

The accidents of the ADEOS and ADEOS-II have made the Japan Aerospace Exploration Agency (JAXA) concentrate its satellite development efforts on small and medium satellites rather than large satellites. The GCOM will, therefore, be supported by two series of medium size satellites, i.e. GCOM-W and GCOM-C. The GCOM-W satellite principally carries the successor to the AMSR and will primarily observe water and energy cycles. The GCOM-C principally carries the successor to the GLI and will primarily observe climate change. Each satellite has a design life of five years and each series consists of three satellites. Follow-on satellites will be launched four years after the launch of each preceding satellite to guarantee mutual calibration and verification between satellites. In this way, each series will guarantee continual observation for at least 13 years.

The GCOM satellites will not be sufficient to observe the complete range of global environmental changes. For this reason, the GCOM should not only cooperate with other earth observation satellites of the JAXA, including Aqua/AMSR-E (launched in 2002), ALOS (launched in 2006), GOSAT (Greenhouse Gas(GHG) observation: launched in 2009), GPM (precipitation observation: scheduled to be launched in 2013) and EarthCare (cloud and aerosol observation: scheduled to be launched in 2013), but also have its sights set on possible joint research with such foreign satellites as NPP (scheduled to be launched in 2010), NPOESS and METOP, etc. of which the mission periods will overlap with those of the GCOM satellites.

Earth observation work is only considered effective when it produces scientific and practical outcomes. However, such outcomes do not naturally result from the work. While the JAXA has established the Earth Observation Research Center (EORC) for the active use of satellite data, its limited human resources cannot be expected to produce all possible outcomes from the available satellite data. Collaboration with universities, independent research corporations and other suitable organizations is essential.

Following the enactment of the Basic Space Law which mentions the review of the JAXA's organizational set-up, it is uncertain at present how the JAXA will be transformed in the coming years. The present GCOM Science Plan is formulated to ensure that the JAXA will be able to produce scientific and practical outcomes through the GCOM regardless of change which may greet the JAXA in the near future.

2. Outline of GCOM Phase 1 Satellites (Haruhisa Shimoda: Tokai University)

Here, the planned satellites for GCOM Phase 1 are outlined.

2.1 GCOM-W1

2.1.1 Orbit

Synchronous sub-recurrent orbit
Altitude: approx. 700 km
Local sun time at descending node: 13:30
Launch year: FY 2011

2.1.2 Main Specifications

Mass: approx. 1.9 tons
Power: approx. 4 kW
Data transmission: X band, 10 Mbps

2.1.3 Main Specifications of the Sensor (AMSR2)

Type	Conical scanning microwave radiometer
Antenna	Offset parabolic antenna diameter of 2.0 m
Swath width	≧ 1,450 km
Quantisation Bit Rate	12 bit (all channels)
Incidence Angle	55° (detection accuracy: 0.0833° or less)
Polarisation	Vertical and horizontal
Cross Polarisation Characteristics	-20 dB or less (excluding 7.3GHz channel)
Main Beam Efficiency	≧ 90%
Dynamic Range	2.7 – 340 K
Brightness Temperature Error	System error: ≦ ± 1.0 K (maximum amplitude: 150 K equivalent)(target) Fluctuation error: ≦ 0.3 K (3σ, equivalent to 150 K)(target)
Geometric Error	≦ 2.5 km (some 50% of the smallest IFOV)
Sampling Interval	Approximately 5 – 10 km (no underwraps with the 3 dB beam width excluding 89GHz)

Central Frequency (GHz)	Ground IFOV (km, cross-track)	Band Width (MHz)	Temperature Resolution (K, 1σ , 150 K)
6.925	35	350	0.34
7.3	35	350	0.43
10.65	24	100	0.70
18.7	13	200	0.70
23.8	15	400	0.60
36.5	7	1000	0.70
89.0	3	3000	1.2

2.2 GCOM-C1

2.2.1 Orbit

Synchronous sub-recurrent orbit
Altitude: approx. 800 km
Local sun time at descending node: 10:30
Launch year: FY 2013

2.2.2 Main Specifications

Mass: approx. 2.0 tons
Power: approx. 4 kW
Data transmission: X band, 138 Mbps

2.2.3 Main Specifications of the Sensor (SGLI)

The SGLI (Second Generation Global Imager) sensor consists of two types of radiometers: visible and near infrared radiometer (VNR) and infrared scanner (IRS). The VNR is a push-broom type radiometer while the IRS is a whisk-broom type radiometer. The VNR is actually made up of two types of cameras: camera measuring non-polarisation and camera measuring polarisation. The non-polarisation measuring camera is composed of three optical systems and has a spatial resolution of 250 m. The polarisation measuring camera is composed of two optical systems for each target wavelength band and measures polarisation in three directions in each wavelength band. The swath width is 1,150 km and the spatial resolution is 1 km. Each optical system has the function of forward or backward tilting in the travelling direction of the satellite to measure forward-scattered light.

The IRS is a radiometer with four short wavelength infrared channels and two thermal infrared channels. The swath width is approximately 1,400 km on the ground. The spatial resolution varies depending on the channel. One short wavelength infrared channel has a spatial resolution of 250 and offer 1 km. The thermal infrared channels have a spatial resolution of 500 m. The observation wavelength and technical specifications of SGLI are shown next.

Table 2.2.1 VNR Non-Polarisation Observation Unit

Ch.	Central Wavelength [nm]	IFOV [m]	⊿λ [nm]	Lstd [W/m2/str/μm]	Lmax. [W/m2/str/μm]	S/N	Main Targets
VN1	380	250	10	60	210	250	Aerosol; CDOM
VN2	412	250	10	75	250	400	Aerosol; CDOM; PAR; EVI
VN3	443	250	10	64	400	300	Absorbent aerosol over the sea; CHL; CDOM; PAR; EVI; snow/sea ice covered area; snow impurities
VN4	490	250	10	53	120	400	CHL (middle)
VN5	530	250	20	41	350	250	Cloud detection; CHL (high); PAR; NPP; snow/sea ice covered area
VN6	565	250	20	33	90	400	CHL (baseline); SS
VN7	673.5	250	20	23	62	400	Atmospheric correction; SS
VN8	673.5	250	20	25	210	250	NDVI; EVI; BSI; SI; snow/sea ice covered area; NDSI
VN9	763	250/ 1000	12	40	350	1200	Geometric thickness of clouds
VN10	868.5	250	20	8	30	400	Atmospheric correction
VN11	868.5	250	20	30	300	200	NDVI; EVI; BSI; SI; snow/sea ice covered area; snow grain size; NDSI

Table 2.2.2 VNR Polarisation Observation Unit

Ch.	Central Wavelength [nm]	IFOV [m]	⊿λ [nm]	Lstd [W/m2/str/μm]	Lmax. [W/m2/str/μm]	S/N	Main Targets
P1	673.5	1000	20	25	250	250	Aerosols; BSI; SI; snow/ice BRDF; snow/ ice categories
P2	868.5	1000	20	30	300	250	Aerosols; BSI; SI; snow/ice BRDF; snow/ ice categories

Table 2.2.3 IRS Short Wavelength Infrared Unit

Ch.	Central Wavelength [nm]	IFOV [m]	⊿λ [nm]	Lstd [W/m²/str/μm]	Lmax [W/m²/str/μm]	S/N	Main Targets
SW1	1050	1000	20	57	248	500	Cloud optical thickness; NDII; types of sea ice
SW2	1380	1000	20	8	103	150	Cloud detection
SW3	1630	250	200	3	50	57	Cloud detection; snow grain size; cloud phase; vegetation moisture content; soil moisture content
SW4	2210	1000	50	1.9	20	211	Effective cloud grain size

Table 2.2.4 IRS Thermal Infrared Unit

Ch.	Central Wavelength [μm]	IFOV [m]	⊿λ [μm]	Tstd[K]	Tmin[K] /Tmax[K]	NEdT@Tstd	Main Targets
T1	10.8	250/500	0.7	300	340	0.2	Cloud detection; cloud top temperature; cirrus characteristics; LST; SST; snow surface temperature
T2	12.0	250/500	0.7	300	340	0.2	Cloud detection; cirrus characteristics; atmospheric correction; LST; snow surface temperature

*IFOV 250m is the option

3. Objectives and Expected Outcomes of GCOM (Haruhisa Shimoda: Tokai University)

The fundamental roles of the GCOM are to improve national life and to positively contribute to mankind. To be more precise, the GCOM will continue the work of the ADEOS and ADEOS-II and will advance observations to build up the knowledge base required to clarify global environmental issues. The main target is climate change and the GCOM will deal with the requirements under the Kyoto Protocol and contribute to the Global Earth Observation System of Systems (GEOSS). At the same time, the practical use of observation data will be promoted to ensure the positive contribution of the GCOM to improving national life.

The long-term, continuous observation of physical quantities greatly affecting changes of the global environment, particularly climate change, will achieve the following outcomes to contribute to the understanding of these changes.

- Development and demonstration of a system capable of observing physical quantities (sea surface temperature, soil moisture and others), which are effective to clarify climate change and the water circulation mechanism on a global scale, continually over a long period of time

- Improved accuracy of the existing climate prediction models by providing accurate numerical values for parameters with a high level of uncertainty at present

- Clarification of GHG sinks and sources

- Verification of climate prediction models and improvement of the accuracy of these model with data on long-term change of physical quantities

- Establishment of the trends of global environmental changes (global warming, vegetation changes, desertification, changes of substances in the atmosphere, spread of wide area air pollution, ozone layer depletion and others) based on long-term change of physical quantities minus short-term (approximately 3 – 6 years) natural changes

- Clarification of the unit processes of global environmental change using observed data

- Estimation of radiative forcing, energy/carbon flux, albedo and others by combining the physical quantities observed by satellite, ground observation data and suitable models through collaboration with user organizations to achieve the above goals

- Advancement of the understanding of the earth system through the series of work listed above

- Contribution by Japan to international environmental strategies using the outcomes of the GCOM activities

Further contribution will be made using the observed data to improve the following aspects of national life as a direct contribution.

- Improved accuracy of weather forecasting (especially in relation to the prediction of the likely course of typhoons and the locations of downpours)
- Improved prediction accuracy of abnormal weather and climate
- Improved accuracy of ocean route information
- Supply of fishing ground information
- Improved efficiency of coastal management
- Higher accuracy of predicted crop yields
- Observation of volcanic fumes and prediction of the extent of impacts
- Monitoring and prediction of air pollution caused by yellow sand and other causes
- Detection of forest fires

The GEOSS 10 Year Implementation Plan announced by the GEO (Group on Earth Observation) which functions as a working group for the Earth Observation Summit has set the following nine key topics for the Earth Observation Plan for the next 10 years.

① disasters; ② health; ③ energy; ④ climate; ⑤ water; ⑥ weather; ⑦ ecosystem; ⑧ agriculture; ⑨ biodiversity

The GCOM can contribute to the GEOSS especially in terms of climate, water, weather and ecosystem although its contribution to the other five topic will be far from insignificant.

Any improvement of the accuracy of climate change prediction requires improved observation accuracy for uncertain factors listed in the IPCC report. Those uncertain factors which can be observed under the GCOM are listed next.

(1) Uncertainty of radiative forcing
  - Aerosols
  - Clouds

(2) Uncertainty of flux
  - Energy cycle
    - Energy flux between atmosphere and ocean
    - Ocean surface circulation
    - Energy flux between snow/ice and atmosphere
    - Earth radiation budget
  - Carbon cycle
    - GHG sinks and sources
    - Carbon flux
  - Water cycle
    - Rainfall
    - Transportation of latent heat from ocean
    - Evapotranspiration
    - Water transportation on land
    - Snow cover

(3) Uncertainty of process and feedback
  - Production and dissipating processes of clouds and aerosols

- Impacts of climate change on rainfall and snowfall
- Ecological process of land vegetation and impacts of climate change on land vegetation
- Impacts of global warming on short-term climate change

(4) Signs of global warming
- Changing snow and ice conditions in high latitude regions
- Stratospheric temperature in high latitude regions

To solve the above uncertainties, the following concrete goals are set under the GCOM.

- Development of an algorithm to highly accurately calculate physical quantities
- Preparation of weather values for input to models
- Separation of trends from natural changes using long-term data sets and verification of models
- Understanding of regional characteristics
- Clarification of the process and improved accuracy of models

4. GCOM Science Research Programme

4.1 Atmospheric Science

4.1.1 Atmospheric Science by GCOM (Teruyuki Nakajima: University of Tokyo)

The atmospheric observation function of the GCOM satellite series is designed to be optimal for studying the state and changes of the earth's climate. To be more precise, global imaging observation at medium spatial and spectral resolutions is provided by a set of the AMSR2, a microwave scanning radiometer, and and the SGLI, an imager of the near ultraviolet, visible and infrared regions, possessing important wavelength channels for the measurement of aerosols, water vapor, clouds and rainfall. Sensor combination of NOAA/AVHRR and SSM/I, ADEOS-II/GLI and AMRS, AQUA/MODIS and AMRS-E, and TRMM/VIRS and TMI are some examples of sensors falling in this category. Using data provided by these sensors, global maps of aerosols, water vapor, clouds and rainfall have so far been prepared and used for climate studies, environmental monitoring and other purposes.

Remote sensing of the atmosphere using the AVHRR and SSM/I began around 1981 (1987 for the SSM/I) despite problems with the sensor sensitivity and others. Taking this history into consideration, data on the atmosphere has been collected for nearly 30 years, providing an important data set for studies on climate change. As it is now becoming possible to separate phenomena of a decadal oscillation, which is one of the critical scales for atmosphere-ocean interaction, separation between natural climate changes caused by internal forcing and anthropogenic changes, such as global warming, is now thought to be possible for studies on climate change. In the age of GCOM, climate changes of human origin, such as global warming, are expected to become prominent and precious data sets on long-term changes of the monsoon cycle, regional rainfall and other matters will be acquired. Observation of changes of the continental scale aerosol distribution in line with changes of human activities will also be made. In the case of clouds, while it is difficult to clarify long-term changes because of the huge extent of spatiotemporal changes, there is a strong likelihood that the field characteristics will become clearer through the combined analysis of multiple sensor data and ground observation data. As a result, knowledge on the role of clouds in climate change will be acquired. Existing general circulation models cannot determine whether clouds accelerate or inhibit global warming. There are other phenomena of which clarification should be sought through combined analysis. These include changes of the Hadley circulation due to global warming, changes of tropical cyclones and El Nino, changes of monsoon circulation and subsequent changes of extreme phenomena, such as heavy rain events, etc., changes of rainfall on the Asian continent, etc., changes of the distribution of atmospheric cooling and heating due to water vapor and clouds and changes of radiative forcing by aerosols and clouds. These phenomena have not yet been clarified with sufficient accuracy by the existing means of satellite observation and modelling.

As briefly described above, the GCOM promises major scientific achievements provided that two preconditions are met. The first is the development of long time-series data sets which are essential for climate study. The second is the supply of multi-sensors data from space as data from a single sensor is not sufficient to meet the need for the study of the relationship between various parameters for the recent analysis of the atmospheric field. Particularly important is combined analysis involving active lider sensor, cloud radar and precipitation radar data sets. To satisfy these two conditions, maximisation of the coordination potential with other sensors must be attempted. In this case, it must be kept in mind that data from different local times are required for the long-term analysis of atmospheric phenomena with considerable diurnal changes. For example, analysis of the radiation balance at the top of the atmosphere requires the effective radiation temperature of water vapor. Meanwhile, a study on the impact of global warming must eliminate apparent changes caused by shifts of satellite orbit as much as possible. Such impact of a shifting orbit also occurs with long-term time series data on the effective cloud particle radius which is often used as an indicator for cloud field changes caused by man-made aerosols. From this viewpoint, coordination with satellites launched by other countries is extremely important. An initiative of achieving AM and PM trains through the extension of the NASA's A-Train is worthy of consideration. To be more precise, the strategic combination of satellites on the 10:30 orbit and 13:30 orbit could revolutionise the quality of the information obtained from satellite systems. Including such potential, the combined analysis of knowledge from the GCOM series with knowledge obtained from other satellites should significantly contribute to weather and climate studies as well as the science of the earth's surface system. Satellite observation much progresses hand in hand with the study of a model to interpret satellite data, necessitating the development of assimilation and other technologies. Moreover, as the calibration of onboard satellite sensors is essential to produce data over a long period of time, the maintenance of the ground observation network will prove to be a major contribution to the GCOM and the international satellite community.

4.1.2 Clouds and Aerosols (Teruyuki Nakajima: University of Tokyo)

Imaging of the microwave spectral region by the AMSR2 can produce global-scale data on water vapor, cloud water content and rainfall intensity. Meanwhile, imaging of the near ultraviolet, visible and infrared regions by the SGLI can produce data on clouds and aerosols at a spatial resolution up to the best resolution of 250 m. The knowledge acquired through such observation greatly contributes to clarification of the roles played by clouds and aerosols in global warming and other climate change issues which we face today. For example, both the 3rd and 4th IPCC reports state that modelling of the impacts of clouds and aerosols on the climate constitutes a major uncertain factor in the prediction of global warming. This uncertainty surrounding cloud modelling originates from the facts that it is difficult to simulate clouds with a general atmospheric circulation model of which the grid size is some 100 km and that it is difficult to evaluate changes of the cloud field caused by air pollution due to man-made aerosols. In dealing with the question of cloud formation, it is crucial to improve the accuracy of modelling of the stratification conditions of the troposphere, transportation of water vapor, formation of water clouds and ice-crystal clouds and mechanism of precipitation. For this purpose, the use of a regional model based on a system of several km grids and a global non-hydrostatic model, such as NICAM, is necessary along with research based on the conventional general circulation model. These high resolution models can realistically express convection cells and their organization. Their ability to express the transportation of aerosols to a cloud system with the cells means that the process of cloud droplet formation by cloud nuclei can be more realistically represented. Because the model enables the formation of clouds without strong reliance on the cumulus parameterization of cirrus used in a general circulation model, it becomes possible to accurately estimate the roles of clouds in the climate system and the climate sensitivity strongly affected by clouds. This means the extreme importance of acquiring accurate atmospheric data to verify various simulation models. AMSR2 and SGLI, both of which can cover the entire earth with high resolution, should be able to provide effective data. The range of important information on clouds includes water vapor content, cloud optical thickness, total cloud water path, amount of ice and crystal particles and rainfall intensity.

Meanwhile, the range of important information on aerosols and aerosol-cloud interaction includes the aerosol optical thickness, aerosol Ångström exponent, aerosol type, cloud particle radius and drizzle content. These can be estimated based on SGLI data as well as combined data of SGLI and other microwave radiometers. In the case of the global distribution of the aerosol optical thickness, there is a systematic difference between satellite observation and the model, making improvement necessary. This difference is believed to occur because of the difficulty of observing optically thin aerosols and the difficulty of modelling due to the complexity of the aerosol generation and removal processes. For the improvement of remote sensing data, substantial improvement of the observation accuracy is expected with the SGLI which is equipped with near ultraviolet, multidirectional and polarization observation functions. The accuracy of land aerosol analysis will especially improve. The availability of a 250 m channel should prove effective to eliminate clouds of less than the pixel size. With such improvement, the observation accuracy at the top of the global atmosphere should improve by approximately 0.5 W/m^2 in terms of radioactive forcing.

Regarding the impacts of aerosols on the cloud field, correlation between the cloud optical thickness (and effective particle radius) and density of aerosols is being studied using satellite data and a model but the study results are still too scattered to determine a meaningful correlation. Especially vague is the impact of aerosols on clouds above land and deep convective clouds. A high resolution model should be fully functional in the age of the GCOM as mentioned earlier and the high spatial resolution data on clouds and aerosols supplied by the AMSR2 and SGLI will constitute extremely timely data to deal with these problems. Recent studies have established that radiative forcing at the surface created by man-made aerosols cause changes of the cloud fraction and rainfall on a global scale. It is, therefore, important to determine the global distribution of the aerosol optical thickness and light absorptive capacity from this viewpoint. For this purpose, an algorithm to determine the single scattering albedo of aerosols through the simultaneous analysis of data provided by the ground observation network is required. The highly accurate estimation of the radiation budget at the surface using such data is now possible.

The helitage and ground verification system developed through the ADEOS-II mission are very useful for the analysis of cloud and aerosol data although further development is necessary. Given the fact that a simultaneous analysis method for satellite and ground data and analysis based on an assimilation method using a model are now available, these methods should be used to produce highly accurate products in the age of the GCOM. In response to the arrival of a new age, new systems must be developed to compare models and to conduct assimilation analysis along with analysis using the inverse problems of conventional satellite remote sensing.

4.1.3 Water Cycle (Taikan Oki: University of Tokyo)

The total volume of water on the earth's surface is estimated to be approximately 1.4×10^{21} kg which accounts for a mere 0.02% of the total mass of the earth. When the earth is looked at from space, however, nearly half of the surface is covered by clouds. Even if there are no clouds, two-thirds of the earth's surface is covered by oceans. Vegetation is generally rife on land, creating the impression that the surface of the earth is full of water. Despite the very small absolute share of the planet's mass, it is no exaggeration to say that the earth is perceived as a planet of water from space. (Oki, 2005)

Radiation energy from the sun is unevenly absorbed by the latitude belts on the earth's surface. Consequently, the atmosphere and oceans transport energy to eliminate this unevenness from the warm tropical zone to the cold high latitude regions. Water not only circulates along the earth's surface in line with the general circulation but also undergoes phasal changes among the solid state (ice), liquid state (water) and gaseous state (vapour). Through these phasal changes, energy is released or absorbed, affecting the atmospheric as well as ocean circulations. The vapour content in the atmosphere has a dominant effect on the radiation balance on the earth's surface. As such, the existence of water and its circulation is one of the principal factors determining the environment of the earth's surface.

Fig. 4.1.1 shows the location, amount and speed of movement of water on the earth's surface using data provided by Korzu (1978), Shiklomanov (1997), Oki (1999) and Dirmeyer et al. (2006). The figures in parenthesis show the stored water volumes ($10^3 km^3$) and each figure at the side of an arrow is the water displacement volume ($10^3 km^3$/year) which is called the flux. The precipitation and evapotranspiration amounts are also shown for the main categories of land use. The figures in parenthesis for these land use categories are their respective areas ($10^6 km^2$) on the earth's surface. Macroscopic observation shows that the evapotranspiration amount is higher than the precipitation amount on the ocean surface. This means a net surplus transportation of vapour from the oceans to land where water falling in the form of rain or snow may return to the atmosphere through evapotranspiration or to the oceans via rivers. While this figure indicates the intake amounts for agriculture, industry and domestic use, it is uncertain how much water is evaporated or returned to rivers or joins the groundwater. However, one thing is certain. The impacts of human activities on the global scale water cycle can no longer be ignored, making it essential for the scientific study on the global environment to include the "real" water cycle where the impacts of human activities are added to the "natural" water cycle in the study scope. (Oki, et al., 2006)

Fig. 4.1.1 Schematic Chart of Global Water Cycle: Based on Data Provided by Korzun (1978), Shiklomanov (1997), Oki (1999) and Dirmeyer, et al. (2006)
(Errors relating to farmland and other areas in Oki and Kanae, 2006 are corrected.)

Vapour amount above oceans < 10 >	Total amount of evapotranspiration from oceans < 436.5 >			Total amount of precipitation on land < 111 >	Vapour amount above land < 3 >
		Net amount of vapour transportation < 45.5 >	Snowfall < 12.5 >	Rainfall < 98.5 >	
	Glaciers and snow cover < 24,064 >	Amount of evapotranspiration from land < 65.5 >	Forests < 40.1 >	Water in organisms < 1 >	Permafrost <300 >
	Grassland < 48.9 >	Farmland < 12.6 >	Marshes < 0.2 > Wetland < 11 >	Surface outflow < 15.3 >	Base outflow (groundwater) < 30.2 >
Total amount of precipitation on oceans < 391 >	Others < 29.3 >	Non-irrigated farmland (rainwater-fed farmland)	Irrigated farmland	Lakes < 2.7 >	Lakes < 176 >
Oceans < 1,338,000 >	Domestic water use	Rivers < 2 >	Industrial water use	Soil moisture < 17 >	Groundwater < 23,400 >
Only glaciers are considered for Antarctica. - Circulation amount: $10^3 km^3$/year - Stored amount: $10^3 km^3$ - Area: $10^6 km^2$					

The water cycle is not only related to such disasters as floods and drought but is also essential to preserve life. A healthy water cycle is essential for the sound functioning of the ecosystem. The quality of drinking water has short-term as well as long-term health implications while water is the main determining factor for the productivity improvement of food production in some regions. Water is also essential for industrial production as a medium for washing or cooling. Hydroelectric power generation which only accounts for 4% of the total electric energy generated in Japan is responsible for half or most of the power generation in Canada, Brazil and Laos. Inland water surfaces, such as large rivers and lakes, play the important role of providing transportation routes for raw materials and products. In short, adequate management of the water cycle is essential for the preservation of human health and socioeconomic development.

The types of water used by human society are called water resources. When discussing the use of water resources, the figures showing the water flow, i.e. figures accompanying arrows, in Fig. 4.1.1 are more important than those shown in boxes. Unlike fossil resources, water resources are used in terms of flow but not stock. To be more precise, when the use of river water is contemplated, the relevant amount of resources is an annual runoff of 45,500 km^3/year not 2,000 km^3 which is believed to exist in river channels throughout the world at any given time. Any discussion about the availability of water for agricultural purposes, for example, should be based on this runoff compared to the total water demand for agricultural, industrial and domestic use of some 3,800 km^3/year. When the scarcity of the earth's water resources is discussed, it is sometimes explained that 97.5% of the earth's water is seawater and that a large proportion of the remaining freshwater is represented by deep groundwater and ice beds, making the use of water by human really difficult. From the viewpoint of understanding water resources as flows, it can be seen that this explanation is somewhat misleading.

As a general rule for the remote sensing as well as observation of the global scale water cycle, the observation of flow or flux is more difficult than the observation of stock or stated quantity. The accurate measurement of precipitation over a wide area is especially difficult because of its huge spatiotemporal fluctuations. Nevertheless, it is the main driving force of the water cycle on land along with solar radiation and, therefore, precipitation must be observed/estimated with a high level of spatiotemporal resolution to produce the necessary accuracy for specific application purposes. From the viewpoint of the global water cycle, it is desirable for such water flow figures as the river flow rate and amount of evapotranspiration to be monitored by earth observation satellites along with precipitation. In regard to the river flow rate, the observation of water level fluctuations of major rivers using an altitude meter has at last recently commenced. In the case of the amount of evapotranspiration, the only available option at the moment is either indirect estimation or numerical model simulation.

The estimated global scale water cycle and water balance figures include estimates based on numerical model simulation. It is known that even if calculation is conducted using the same weather data, discrepancies between different numerical models (here, numerical simulation models called land surface models which calculate the water and energy balances on the land surface) are larger than discrepancies of the estimated mean values of different models. Fig. 4.1.2 shows the global terrestrial water budget based on the findings of the Global Soil Moisture Project Phase II (Dirmeyer, et al., 2006). Every model has its own inference of whether precipitation takes place in the form of rain or snow. Observation of the amount of precipitation includes melted solid precipitation, such as snow, and there are no reliable estimates on the proportions of rain and snow in the overall amount of precipitation. It is hoped that observation efforts to acquire such basic data will be made for a better understanding of the water cycle.

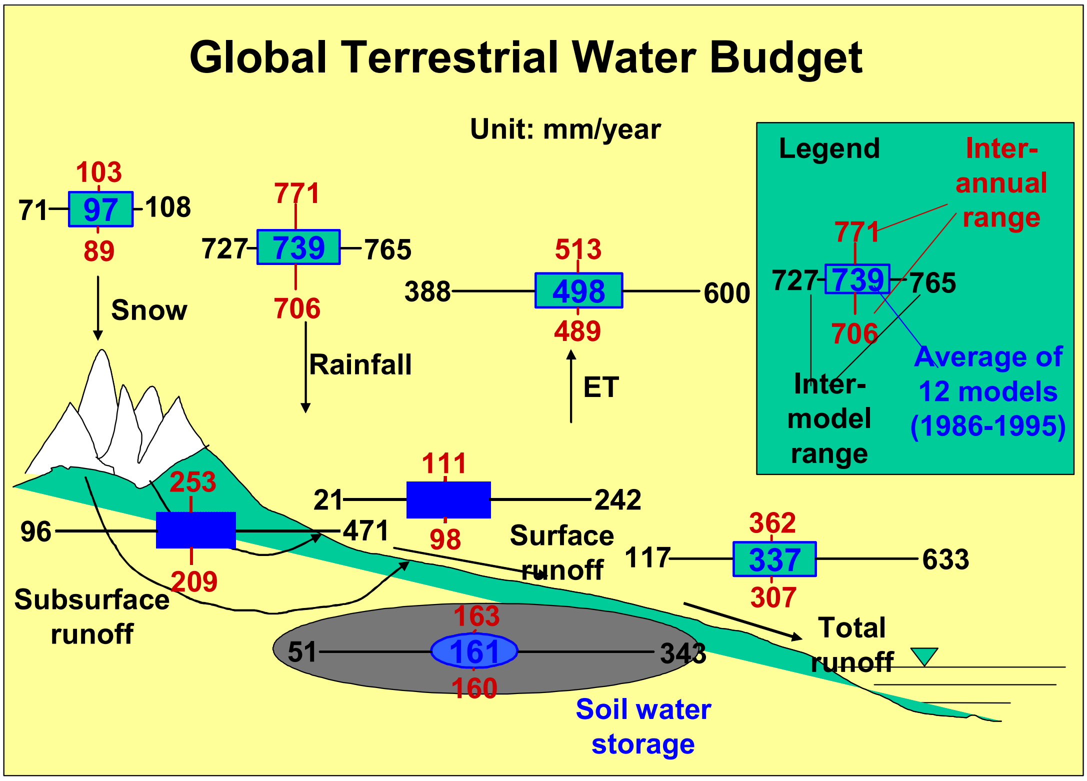

Fig. 4.1.2 Annual Changes in 10 Year Average Global Water Balance Estimation Using Land Surface Models and Discrepancies Between Models (Dirmeyer, et al., 2006)

Fig. 4.1.3 schematically shows the long-term changes of the global scale water cycle and its impacts on society. Not only the impacts of climate change but also increased food production and the increased use of water due to demographic and economic growth and changes of the land cover lead to changes of the hydrological cycles, affecting society in the form of increased/decreased water stress which represents vulnerability to drought or an increased/decreased flood risk. When the global scale water cycle is viewed in terms of such a framework, it is clear that observation of GHGs causing climate change and observation of the land cover, land use and vegetation distribution affecting food production are as important as observation of the "water stock" directly related to the water cycle, such as ice bed, glacier and snow cover areas, distribution of lakes, soil moisture and groundwater fluctuations, for observation of the earth's environment from space in relation to the water cycle system on the earth's surface. It is thought that a collaborative research programme contributing to clarification of the entire water cycle system on the earth's surface and fully utilising the observation and estimation results provided by other satellites and sensors in connection with the water cycle should be developed under the GCOM.

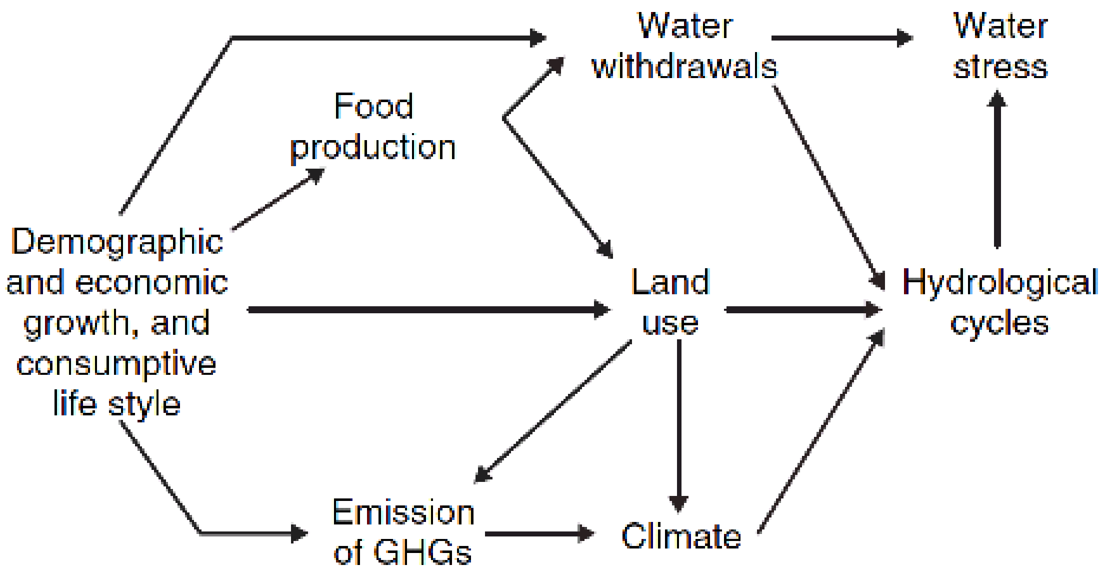

Fig. 4.1.3 Impacts of Increased Human Activities Due to Population Growth and Economic Development on the Global Scale Water Cycle Through Climate Change and Food Production (Oki, 2005)

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4.2 Marine Science

4.2.1 Marine Meteorology and Physical Oceanography (Naoto Ebuchi: Hokkaido University)

4.2.1.1 Composition of Sea Surface Temperature Data Set

The sea surface temperature provides very important basic data for researches on the interactions between the atmosphere and ocean. This data is also used to determine the boundary conditions for the various kinds of atmospheric general circulation models. In addition to continual observations of the sea surface temperature using spaceborne infrared radiometers since the late 1970's, the use of microwave radiometers, such as the TRMM/TMI, ADEOS-II/AMSR and Aqua/AMSR-E, for sea surface temperature observation has been becoming popular in recent years. Although microwave radiometers are inferior to infrared radiometers in terms of the spatial resolution and observation accuracy, they have the advantage of observation without cloud interferences. New efforts are in progress to compose sea surface temperature data sets with high temporal and spatial resolutions by means of blending the observation data of these two types of radiometers to utilise the advantages of each type.

The GCOM plans the global observation of the sea surface temperature using both infrared and microwave radiometers. It can be expected that sea surface temperature data sets with high temporal and spatial resolutions will be produced through the integration of the GCOM data with the data observed by other active satellites orbiting the earth during the lifetime of the GCOM satellites. The resulting global sea surface temperature data set based on observations by infrared and microwave radiometers starting with the AMSR and AMSR-E will cover a period of more than 20 years with the GCOM. The availability of very accurate sea surface temperature data with a long observation period will help the detection of the emerging trend of climate change regarding the sea surface temperature and will make great progress in studies on atmospheric and oceanic variations of decadal scales.

4.2.1.2 Development of Sea Surface Flux Data Set

Accurate estimation of the momentum and heat fluxes across the sea surface is extremely important to clarify the mechanism of atmosphere-ocean interactions and the role of the oceans in climate change. In the ADEOS-II mission, the composition of a sea surface flux data set was planned by combining the observation data of the GLI, AMSR and SeaWinds with data from other satellites. Techniques have been developed to estimate four flux components (shortwave and longwave radiations, and latent and sensible heats), freshwater (evaporation – precipitation) and momentum flux using data provided by existing microwave radiometers, microwave scatterometers and visible/infrared radiometers. At present, a technique to estimate the sea surface heat, freshwater and momentum fluxes using the bulk method is near completion. This technique uses satellite observation data including the sea surface temperature, microwave brightness temperatures, sea surface wind speed and direction and cloud cover.

Under the GCOM, this new technique will be used to prepare a sea surface flux data set. Its estimation accuracy will be examined through comparisons with in situ observations. The development of such a data set for a period of more than 10 years through this mission will help to disclose the ocean heat transports as well as the formation and advection processes of water masses, hopefully contributing to clarification of the atmosphere-ocean feedback mechanism of decadal scales. The fusion or assimilation of satellite observation data with numerical models, such as the atmospheric general circulation model, will make the development of a technology to establish more accurate sea surface flux data an important research and development theme. It must be mentioned that sea surface wind vectors observed by a microwave scatterometer is essential for the estimation of momentum flux. As no microwave scatterometer is aboard the GCOM-W1, the use of observation data by the QuikSCAT/SeaWinds and Metop-A/ASCAT operating in the GCOM period is planned for this purpose. From the GCOM-W2 onwards, however, it is desirable for the GCOM satellites to carry a microwave scatterometer. Moreover, the addition of the function to measure the sea surface salinity to the microwave radiometer in the future should prove to be highly effective for the estimation and verification of freshwater flux.

4.2.1.3 Continuation of Typhoon Database

Tropical cyclones, of which typhoons are a typical example, constitute a very important research subject for not only the purpose of disaster prevention but also for the transfer of water and energy from the tropics to the mid-latitude region. The JAXA/EORC has been developing a typhoon database on the basis of observation data provided by the TRMM, ADEOS-II and Aqua/AMSR-E. The structure as well as the development, maintenance and weakening of a typhoon are becoming much clearer with the combined use of sea surface wind, integrated water vapour, integrated cloud liquid water and sea surface temperature.

Under the GCOM, the develpoment of such typhoon database can be continued and it is hoped that understanding of such matters as the development process of a tropical cyclones and its contribution to water and energy transfer will be advanced. Sea surface wind vectors observed by a microwave scatterometer are essential for further clarification of the structure of a typhoon. As the GCOM-W1 satellite does not carry a microwave scatterometer, the use of the observation data of the QuikSCAT/SeaWinds and Metop-A/ASCAT, both of which are orbiting at the same time as the GCOM-W1 satellite, is planned. It is highly desirable that the GCOM-W2 satellite and subsequent satellites carry a microwave scatterometer. The use of the observation data under the GCOM for weather forecasting, disaster prevention and other practical purposes will be discussed later.

4.2.1.4 Researches on Water Cycle over the Ocean

A new method to investigate the atmospheric water cycle over the ocean has recently been developed using the sea surface wind vectors observed by microwave scatterometers, such as the ADEOS-II/SeaWinds and QuikSCAT/SeaWinds, and the integrated water vapour observed by microwave radiometers, such as the TRMM/TMI, ADEOS-II/AMSR and Aqua/AMSR-E. This method is now used to investigate basin-scale water cycle over the oceans. Estimation of the moisture transport through a vertical cross-section requires, in principle, the vertical integration of the product of the water vapour and the wind velocity along an orthogonal direction to the cross-section in each layer. Traditionaly data from meteorological analyses are used for this purpose. The newly developed method expresses the moisture transport as a product of the integrated water vapour and typical wind velocity. The typical wind velocity in this method is empirically determined using the sea surface wind vector observed by a microwave scatterometer. A similar method can be used under the GCOM to clarify the water cycle over the ocean and its variations. As the GCOM-W1 satellite does not carry a microwave scatterometer, the use of observation data of the QuikSCAT/SeaWinds and Metop-A/ASCAT is planned as in the case of the development of a sea surface flux data set. It is highly desirable for the GCOM-W2 satellite and subsequent satellites to carry a microwave scatterometer. Moreover, the addition of the function to measure the sea surface salinity to the microwave radiometer in the future will greatly contribute to the estimation of freshwater flux and clarification of the water cycle. The water vapour transport estimated by this method can be used along with the results of atmospheric general circulation and other numerical models in a mutually complementary manner. This will lead to new researche directions, such as validation of the new method and models through comparative studies and the development of data fusion or assimilation techniques.

4.2.1.5 Researches on Atmosphere-Ocean Interactions

The data products with a high accuracy and high temporal and spatial resolutions over a long period of time produced under the GCOM will make it possible to investigate the atmosphere-ocean interactions of various scales. Possible research themes in the equatorial and tropical regions include the El Nino/Southern Oscillation and variations of inter-tropical convergence zone, the Indian Ocean Dipole, intra-seasonal oscillations, and monsoon variations and their influences to the water cycle.

In the mid to high latitude regions, recent studies using the all-weather sea surface temperature data observed by microwave radiometers, such as the TRMM/TMI, ADEOS-II/AMSR and Aqua/AMSR-E, and the sea surface wind vector observed by microwave scatterometers, such as the QuikSCAT/SeaWinds and ADEOS-II/SeaWinds, have established that a new type of atmosphere-ocean interactions where sea surface temperature variations lead to atmospheric changes is functioning. The traditional thinking is that the mid to high latitude region has a mechanism whereby variations in the surface cooling by wind dominate variations in the sea surface temperature through the latent and sensible fluxes. In this case, there is a negative correlation between the anomalies of the sea surface temperature and the sea surface wind. In contrast, the existence of a mechanism whereby oceanic changes cause anomalies in the sea surface temperature and the stability of the marine atmospheric boundary layer, resulting in changes of the sea surface wind, has been discovered in areas of western boundary currents, such as the Kuroshio, Gulf Stream, Agulhas Current and Malvinas Current, the Antarctic Circumpolar Current region and the Eastern Equator Pacific region. In this case, there is a positive correlation between the anomalies in the sea surface temperature and the sea surface wind. Many studies have been conducted on the impacts of atmospheric and ocean fluctuations in the tropical region, such as El Nino/Southern Oscillation on the global climate through various teleconnection patterns. However, the impacts of oceans in the mid to high latitude region on the global climate have not yet been clarified. It is hoped that the possible mechanism whereby oceans in the mid to high latitude region drive atmospheric variations can be studied in detail using the various data sets to be obtained under the GCOM.

As final outcomes of the GCOM, data sets over a period of 10 years or nearly 20 years if the

ADEOS-II mission period is added will be made available. Understanding of the variations in the atmosphere-ocean system of decadal scales will be greatly improved with such data sets.

4.2.2 Marine Biology and Ocean Carbon Cycle (Toshiro Saino: JAMSTEC)

4.2.2.1 Carbon Cycle and Primary Production of the Ocean

The ocean is the largest pool of water and CO_2 on the Earth surface, hence it plays a determining role in the cycles of water, heat, energy and carbon on the Earth surface. Both in the terrestrial and oceanic environments, organisms are playing central roles not only in the water cycle but also in carbon cycle, and linking the two cycles. Phytoplantkton living in the shallow waters of the ocean form the starting point of the material cycle as the primary producer. Photoplankton by themselves as autotrophs, and heterotrophs such as zooplankton, bacteria and almost all of the organisms depending their energy on supply from the primary production by phytoplankton, form particles in the shallow layer of the ocean. The process whereby some of these particles are transported to deep water by gravity can be taken, from the view point of the carbon cycle, as the transformation processes in which the CO_2 dissolved in the ocean from the atmosphere is converted into organic form in shallow ocean and exported into deep ocean. This mechanism is called the "biological pump" in the material cycle in the ocean.

For the prediction of global warming and its effects, such as climate change and changes of the Earth's environment, and for the formulation of preventive or mitigation measures, understanding of the mechanisms of the water and energy cycles as well as the carbon cycle in the Earth surface layer is essential to refine the climate change prediction model. However, it is not an easy task to establish a proper understanding of these mechanisms because of the likelihood that the responses of communities of living organisms and the ecosystem to the changing climate and environment, particularly the "biological pump" in the carbon cycle, are not linear. Any research on the response of the ecosystem in the ocean carbon cycle must firstly involve rigorous temporal-spatial observation of how the primary production in the ocean responds to environmental changes in the ocean's shallow layer for the purpose of clearly understanding this phenomenon. The primary expectation of the GCOM/SGLI from the viewpoint of research on marine biology and the ocean carbon cycle is the inheritance of the series of observations made by practical ocean-colour satellite sensors up to the present for the purpose of conducting long-term monitoring activities on communities of organisms in the ocean's shallow layer and quantitatively describing the changes.

4.2.2.2 GCOM/SGLI Data Products for Marine Biology and Ocean Carbon Cycle

The best characteristic of the GCOM/SGLI is the sensor's ability to measure coastal sea areas with a spatial resolution of 250 m using the visible band. In coastal sea areas, there are significant temporal-spatial fluctuations of oceanic phenomena compared to the oceanic region because of complicated coastal topography and tidal effects. The time-dependent changes are also large in coastal sea areas which are prone to the effects of human activities. Monitoring of the biological process in coastal waters by the GCOM/SGLI is perfectly suited to the observation of these changes. While in this Science Plan the use of the GCOM/SGLI ocean colour data products for coastal sea areas for coastal management is described separately, there are great expectations of the GCOM/SGLI ocean colour data products from the viewpoint of studying marine biology and the carbon cycle in the ocean.

Various efforts have been made to quantitatively estimate the ocean carbon cycle, especially the CO_2 flux on the ocean surface. The biggest uncertainty in these efforts originates from unreliable estimates for coastal sea areas. Improvement of this unreliability is the most urgent task and the launch of the GCOM with the SGLI sensor is quite timely.

4.2.2.3 Process Study on Ocean's Shallow Layer Using Compound Satellite Data

The primary objective of the satellite observation of ocean colour is to monitor the activities of communities of organisms and the carbon cycle in the ocean's shallow layer and to quantify their changes. In addition to seven standard products, the GCOM/SGLI will also produce ocean colour-based applied products such as the depth of the euphotic zone, inherent optical properties of seawater, primary productivity, classification of functional photoplankton groups and detection of red tides as well as compound products utilizing data from other satellites on ocean colour and sea surface temperature. The applied products from GCOM/SGLI will provide optical data to characterize photoplankton, other particles and dissolved organic materials, and hence are promising the improved accuracy of satellite data products.

Refinement of the climate change prediction model requires clarification of the structure of photoplankton communities, changes of the primary production and the causal relationship between a change of the primary production and a change of the ocean carbon cycle. For this purpose, it is essential to conduct process study using a set of time-series data of standard products and applied products relevant to carbon cycle research. The process study is designed to identify the causal relationship between the above data and another set of time-series data for external forcing functions onto the ocean's shallow layer. The latter includes data on air-sea flux such as wind, solar radiation and precipitation, data on changes of the physical structure, such as the convergence, divergence and eddies in surface currents, and data on the chemical material supply process, such as the deposition of aeolian dust and advection of coastal seawater.

From the viewpoint of research on marine biology and the ocean carbon cycle, it is desirable to develop algorithms for new data products. These include parameters for materials flux such as primary production, new production and export production and parameters for materials' abundance such as the CO_2 partial pressure, pH and nitrate ion concentration in the ocean's shallow layer. The development of a new algorithm for the air-sea gas exchange coefficient is also needed. These time-series satellite data will be highly valuable for verification of the climate change prediction model.

4.2.2.4 Field Observation of the Ocean for Process Study Using Satellite Data

For the proper implementation of process study using satellite data, it is essential for satellite data to accurately represent ocean phenomena. As the time-scale of the biological process in the ocean's shallow layer is approximately one day, field observation of the ocean to verify the process must be compatible with this time-scale. In the coastal sea areas for which GCOM/SGLI data are expected to be available, a time resolution of a scale of several hours is required in consideration of the tidal effects. As field observation of the ocean with this kind of time-scale is only possible by automatic monitoring using various sensors, the development of such sensors and measuring technologies, including sensors' platform technology, is essential.

4.2.2.5 Development of a New Satellite Data Processing Method

What is the most problematic for the use of satellite ocean colour data is the observation bias due to the lack of data for cloud-covered areas. Primary production, which forms the basis of carbon cycle in the ocean, responds to the intensity of light in a non-linear manner. The use of only data acquired for cloudless areas leads to serious error. This kind of error may fall within the allowable range in the case of GAC data when the number of the data is sufficient for statistical processing, but is extremely serious for process study using individual LAC data.

The development of an objective cloud region interpolation method using ocean colour satellite images is required to overcome this problem. Significant progress is currently being made with the 4D data assimilation method. It is hoped that expansion of this method to an integrated physical circulation and ecosystem model will make it possible to estimate the concentration level of chlorophyll-a in the ocean's shallow layer for the cloud covered regions.

4.3 Land Area

4.3.1 Land Cover and Its Changes (Haruhisa Shimoda)

4.3.1.1 Land Cover Maps

Land use maps and land cover maps provide basic information on the land area in the sense that they indicate what is on the ground. For a country or an area smaller than a country, these thematic maps can function as basic map for various development plans. A study on changes of the land use and/or land cover can reveal historical changes of the land use of a country, progress of urbanisation and changing situation of vegetation among others. In contrast, a land cover map of an area bigger than a country or even a global land cover map can provide basic information to estimate the global radiation balance and carbon cycle based on the global ground reflectance and global vegetation coverage. By studying the changes of the said reflectance and vegetation coverage, it is possible to establish changes of radiative forcing on the ground surface and to estimate the impacts of climate change on the ground surface.

4.3.1.2 Land Use and Land Cover

Although land use and land cover sound the same, they are different concepts, requiring careful attention. Land use literally means for what purpose specific land is used. In other words, it indicates the function of the land. In contrast, land cover means what is on the land. Land cover is what can be directly observed by remote sensing while land use can be roughly inferred.

For example, commercial and industrial sites in land use categories can vividly illustrate the difference between the concept of land use and that of land cover. When there is a building which is used for commercial purposes, the land in question is classified as a commercial site. If the building is used by a manufacturer, the land is classified as an industrial site. As such difference cannot be clearly determined from above, the land is classified as something like the site of a concrete building in terms of land cover. While land use categories may be identical to land cover categories as in the case of paddy fields and cultivated land, they generally differ. As such, the following explanation primarily refers to land cover.

4.3.1.3 Flow of Land Cover Classification

The processing work for land cover classification is mostly identical to the general process for image classification. Firstly, corrections by means of geometric correction and radiation quantity correction are made to extract the characteristics. This may be followed by post-processing and evaluation classification accuracy. The most important parts of this process are the setting up of the classification categories and extraction of the land cover changes.

The setting up of the classification categories has critical importance for land cover classification as explained later. When the categories are incorrectly set up, the classification accuracy suffers and/or the validity of the classification results is lost. The extraction of changes poses a major challenge for land cover classification. The extraction of secular changes in particular is an important issue to ensure the practical applicability of the classification results. However, land cover changes on images can be caused by seasonal changes and weather changes in addition to secular change and the extraction of changes with a high level of accuracy is a daunting task.

4.3.1.4 Classification Categories

As mentioned earlier, the adoption of particular classification categories greatly affects the land cover classification. To determine the classification categories, it is essential to consider both the characteristics of the images and the purpose of land use. When approached from the image side, it is obvious that the characteristics of each classification category must differ from those of other categories. When categories with similar characteristics are selected, the number of incorrect classification results increases.

In general, the classification categories are set up based on the purposes of land use. If there are categories with similar characteristics, some arrangement is necessary to clearly distinguish them or to unify them into a single category. Meanwhile, there are cases where areas in the same classification category show different characteristics on images. For example, trees of the same species can show different characteristics depending on the specific features and type of soil of the tree sites. In such cases, it is necessary to differentiate the classification categories used for finalised land cover maps and the classification categories required for land classification on images. At the stage of classifying the land cover on images, subjects with different characteristics must be classified into different classes. When different classes are identified, those classification categories belonging to the same land cover category must be integrated at the end of the image classification process.

4.3.1.5 Mixels (Mixed Pixels)

Individual pixels of remote sensing data often contain several land cover categories. In fact, it can be argued that the entire coverage of a pixel by the same land cover category is quite rare. A pixel which contains more than one land cover category is called a mixel (mixed pixel). It is, therefore, necessary to infer the ratios of different land cover categories in a mixel. This process is called un-mixing. These ratios can be obtained by solving simple simultaneous equations if the spectral characteristics of individual land cover categories are different and known and also if the number of spectral channels exceeds the number of land cover categories contained in a mixel.

In reality, such an instance is rare and the conditions stated above are not commonly met, making the situation an ill-posed problem. To convert this ill-posed problem to a well-posed problem, the constraint conditions must be established. Many methods have been proposed to solve mixel-related problems. In the field of remote sensing, however, no methods capable of performing un-mixing in a stable manner have yet been discovered except in some very special situations because of the general uncertainty about what exists on the ground.

4.3.1.6 Changes of Land Cover

The methods to extract changes of the land cover can be largely classified into those to extract changes between images and those to extract changes in the classification results after the classification of individual images. The methods to extract changes are further classified into methods to determine differences, methods to calculate an inner product of two images and methods relying on analysis of the main constituents. In general, the accurate extraction of changes is difficult to achieve. This is because images can include such changes which are not related to land cover changes as seasonal changes and weather changes (for example, it rained on the previous day) in addition to actual land cover changes.

In the case of the latter, i.e. extraction of changes of the classification results, the problems described above for the extraction of changes between images are less prominent provided that different classification classes are set up between two images.

Which ever method to detect land cover changes is used, accurate geometric correction is required. Misalignment by even a single pixel between images taken at different times means a succession of changed pixels along the boundary of different land cover categories. This misalignment is normally minimised by mean of the relative geometric correction of images taken at different times.

4.3.1.7 Land Cover Classification by SGLI

Up to the present, the AVHRR on board the NOAA, the MODIS on board the Terra and the Aqua and MERIS on board the ENVISAT have been mainly used for the purpose of global and regional land cover classification. When the AVHRR was commonly used, the NDVI and seasonal changes of the NDVI were used as characteristic values for land cover classification because of the constraints posed by the wave bands of the AVHRR. Another reason for the use of the NDVI as a characteristic value was the insufficient atmospheric correction by the AVHRR. Use of the NDVI offers a simple atmospheric correction effect. Meanwhile, since the standard products of the MODIS have become available, the ground surface reflectance data provided by the MODIS has been increasingly used for land cover classification. The MODIS uses seven channels from the visible band to the short-wave band to scan the land area and the amount of information contained in these channels is far more than that of the NDVI. As NBAR (Nadir BRDF Adjusted Reflectance) products which have recently become available particularly offer far more accurate reflectance than conventional products, highly accurate land cover classification can be expected.

Meanwhile, the MERIS is characterised by its use of advanced spectrometers and high spatial resolution. 12 channels in the visible and near infrared regions can be used for land cover classification and the bandwidth of each channel of 10 nm is quite narrow. The spatial resolution of 300 m is higher than the 500 m of the land area observation channels of the MODIS (250 m for two channels). Accordingly, the land use classification results of the MERIS are, in theory, expected to provide a high level of classification accuracy based on these characteristics. Up to the present, several experiments have been conducted to compare the performance of the MODIS and MERIS and the MODIS offers a higher level of classification accuracy. The reasons for this probably lie with the facts that the MERIS lacks a short-wave infrared channel and that the standard products of the MERIS do not include ground surface reflectance.

Compared to these sensors, the SGLI is believed to be advantageous from several aspects.

Firstly, it has 10 usable channels from the visible to the short-wave infrared regions. The number is greater than that of the MODIS and a short-wave infrared channel, which the MERIS does not have, is included. The spatial resolution of these 10 channels is 250 m and is higher than that of the MODIS and MERIS. In regard to atmospheric correction, it is believed that better correction is achieved because of the superior aerosol amount extraction capacity of the SGLI than the MODIS and MERIS. The standard products of the SGLI include the vegetation roughness index and the shadow index. Polarisation products can also be used even though the spatial resolution is not as good as that of other products. The combined use of these products should be able to provide the best land cover classification results so far.

4.3.2 Vegetation (Yoshiaki Honda: Chiba University)

Land vegetation greatly affects the global environment as it influences climate change through involvement in the water and energy cycles. Mankind relies on land vegetation for the supply of most of its food as mankind has largely obtained its food from vegetation by means of the harvesting of plants, hunting of animals which live on plant food, cultivation of crops and/or a nomadic life relying on grassland. Moreover, vegetation has been used to provide fuel and the raw materials for various applications. The survival of mankind without land vegetation is inconceivable. Food, energy and the environment (atmosphere and water, etc.) supporting the life of mankind are closely related to vegetation. Ancient civilisations which emerged and prospered along great rivers were dependent on the rich vegetation supported by fertile soil. Their decline is said to have been caused by the decline of vegetation which was consumed to sustain human activities. It is, therefore, essential to consider the role played by land vegetation when the global environment or the survival of mankind on the earth is questioned.

There is concern regarding the severe effect of the changing climate on the state of vegetation. For example, global warming prompts those plants which favour a cold environment to move to areas of a high latitude or high altitude. Coniferous forests in permafrost areas of Siberia, etc. are expected to shrink in accordance with the shrinkage of the permafrost areas. Climate change caused by global warming may cause a decline of forests and grassland through changes of the water cycle and other changes, reducing the plant diversity in the affected areas. The richness of vegetation is generally said to be related to the types of local species. A decline of vegetation is highly likely to reduce the overall biological diversity in areas in addition to a reduction of the number of plant species.

The impacts of global warming vary from one area to another. In one area, an increase of the total annual precipitation may simply mean flooding during the rainy season due to the concentration of precipitation in the rainy season and drought during the dry season as a result of the changing pattern of precipitation. Or, global warming may simply mean progressive aridification in other areas. Any prediction of the impacts of climate change on vegetation has many uncertainties. It is essential to check the ongoing situation as frequently as possible, making global observation in quasi-real time necessary.

The survival of vegetation depends on the interactive relationship of various elements, particularly the carbon, nutrient, water and energy cycles. It is possible for human activities to cause changes to all of these cycles.

Vegetation is in constant interchange with the atmosphere through photosynthesis and breathing. Even after death, it releases carbon into the atmosphere through decomposition or burning. Human activities have been changing the state of carbon stock through farming and other types of land use and changes of land use after the felling of trees and other activities. The increased emission of GHGs because of the expansion of economic activities has greatly changed the quantity of carbon stock in the atmosphere. Forest clearance from the high latitude region to the tropical region has substantially reduced the carbon stock of vegetation. It cannot be denied that human activities have changed the state of carbon stock on the earth. An IPCC report in 2000 estimated the carbon stock by type of vegetation and soil for nine different vegetation zones (biomes) as shown in Table 4.3.1 but stated that the absolute values were not very reliable.

Table 4.3.1 Global Carbon Stock of Vegetation and Top One Metre of Soil

Biome	Area ($10^6 km^2$)	Carbon Stock (Gt C)		
		Vegetation	Soil	Total
Tropical Forests	17.6	212	216	428
Temperate Forests	10.4	59	100	159
Boreal Forests	13.7	88	471	559
Tropical Savanna	22.5	66	264	330
Temperature Grassland	12.5	9	295	304
Deserts and Semi-Deserts	45.5	8	191	199
Tundra	9.5	6	121	127
Wetland	3.5	16	225	240
Cropland	16.0	3	128	131
Total	151.2	466	2,011	2,477

Note: Because of the ambiguous definition of biome, the values in the table have a high level of uncertainty even though the table still roughly indicates the size of the carbon stock on the ground.

Original Source: Table 1 of the IPCC Special Report on Land Use, Land Use Changes and Forestry, 2000

The IPCC also reported the global annual budget of CO_2 for 1980 to 1989 and for 1989 to 1998 expressed in Gt C yr^{-1} as shown in Table 4.3.2. The IPCC also reported the global average annual budget of CO_2 in the 1980's and 1990's as shown in Table 4.3.2-2. Even though the amount of carbon uptake by terrestrial ecosystems is quite uncertain, the table still show that terrestrial ecosystems, including vegetation, may have served as a net sink for CO_2. For example, newly planted forests maintain the role of a CO_2 sink for several decades. However, their role as a CO_2 sink gradually declines to the extent that these forests may even become a source of CO_2 emission. There is much room for future research on how vegetation adapts to climate change and, therefore, the future of carbon absorption and release by vegetation as a result of climate change is riddled with uncertainties.

Table 4.3.2 Average Annual Budget of CO_2 for 1980 to 1989 and for 1989 to 1998 Expressed in Ct C yr-1

(The error limits correspond to an estimated 90% confidence interval.)

	1980 to 1989	1989 to 1998
1) Emission from fossil fuel combustion and cement production	5.5 ± 0.5	6.3 ± 0.6[a]
2) Storage in the atmosphere	3.3 ± 0.2	3.3 ± 0.2
3) Ocean uptake	2.0 ± 0.8	2.3 ± 0.8
4) Net terrestrial uptake = (1) – [(2) + (3)]	0.2 ± 1.0	0.7 ± 1.0
5) Emission from land use changes	1.7 ± 0.8	1.6 ± 0.8[b]
6) Residual terrestrial uptake = (4) + (5)	1.9 ± 1.3	2.3 ± 1.3

a Note that there is a one year overlap (1989) between the two decadal time periods.
b This figure is the average annual emission for 1989 – 1995 for which data is available.
Original Source: Table 2 of the IPCC Special Report on Land Cover, Land Cover Changes and Forestry, 2000

Much of the knowledge on vegetation changes due to global warming is, in fact, uncertain. The IPCC's 4th Evaluation Report reported that there is a high likelihood that terrestrial ecosystems, including forests, will function to increase the CO_2 stock in the atmosphere because of global warming, thereby possibly accelerating global warming, i.e. positive feedback. This situation demands a comprehensive prediction model incorporating various chemical and physical processes, including the carbon cycle process of ecosystems and others, in addition to the conventional climate model. R & D activities on a "global system model" based on such a concept have already begun. In terrestrial ecosystems, animals and plants migrate in an attempt to adapt to climate change. In the case of plants, there is a chance that the migration speed using seeds is insufficient and the development of a model which is capable of expressing the migration and distribution of plants, incorporating the possible consequences of such insufficient migration speed, is necessary. This type of model can be described as a dynamic ecosystem model. Such a model is extremely important for the accurate expression and prediction of the CO_2 cycle of ecosystems.

An accurate understanding of terrestrial vegetation is essential for an accurate understanding of the CO_2 cycle in the natural world and also for an objective understanding of the present state of the global environment. Very precise observation on the ground as well as time-series data at a global level is essential to accurately determine various parameters for terrestrial vegetation. Data on precipitation and soil moisture is required to accurately establish a picture of the water environment for vegetation. Meanwhile, the depth of laid snow in a water basin constitutes important information to predict vegetation activities from spring onwards. Such data can be provided by the AMSR-2. In arid areas, research on the historical changes of water stress on vegetation activities can establish the state of desertisation or devastation of land.

The SGLI is characterised by such functions as multi-angle observation and polarisation observation which are beyond the capability of previous sensors and can provide atmospherically-corrected land reflectance data in addition to geometrically corrected radiance. Atmospheric correction on the ground is expected to improve the accuracy of various products and can generate products utilising the existing vegetation categories and research outcomes, products relating to the physical quantities of vegetation, such as biomass, and products which are useful for research on ecological models of vegetation. The types of data to be made available by the SGLI include a vegetation index for use by various analyses and studies on vegetation, vegetation roughness index indicating the roughness of the vegetation surface which is related to the 3D structure of vegetation, shadow index indicating the quantity of shadows created by crowns, ground biomass related to vegetation biomass, ground surface temperature related to vegetation activities, effective radiative absorption rate of photosynthesis and leaf area index. Moreover, it is hoped that research work will progress on such themes as the water stress trend related to the water stress on vegetation, land cover classification which is useful for the monitoring of land use changes and fire detection which is useful for the monitoring of forest fires.

4.3.3 Terrestrial Carbon Cycle (Yoshio Awaya: Gifu University)

There is a common consensus that global warming is attributable to the rising concentrations of CO_2 and other GHGs. Clarification of the global carbon cycle based on detailed analysis is essential to realise effective global warming prevention measures. The land area covers some 30% of the earth's total surface. Plants absorb and fix carbon through photosynthesis and are thought to constitute the largest carbon sink. As such, the terrestrial carbon cycle must be clarified to establish a fair picture of the carbon budget.

The carbon budget of the ecosystem is shown by the following expression as the net ecosystem production (NEP).

NEP = NPP・Rs = GPP・R・Rs

Where,

NPP	:	net primary production
Rs	:	breathing quantity of heterotrophic organisms
GPP	:	gross primary production
R	:	breathing quantity of plants

The carbon cycle in a land area can be clarified by means of quantitatively assessing each element of the above expression and mapping time-series changes.

The growth increment of plants is generally determined by the characteristics of the species and site conditions. When the subject is a large community with large coverage, the site conditions are likely to be the main determinant. The environmental factors affecting the growth increment are the quantity of solar radiation, temperature, quantity of precipitation and water conditions and the nutrients of the soil. Accordingly, it is possible to estimate the growth increment using a model in which all of the above environmental factors act as variables. The breathing amount can mostly be expressed as a function to temperature. In the case of trees, the surface area of the tree trunk and branches must be taken into consideration in addition to the amount of the leaves. The amount of the CO_2 discharge by soil is, in fact, the breathing amount of plant roots and heterotrophic organisms. At present, it is difficult to measure these separately on the ground.

There can be two approaches to estimating the NEP by remote sensing. One approach is the use of remote sensing to estimate various parameters, which are components of a process model developed based on physiological and ecological measurements, and to use these parameters as input data (process-based model). In this model, the leaf area index (LAI) and surface temperature of plants are the principal input parameters. Another approach is to firstly estimate the fraction of the absorbed photosynthetically active radiation (PAR) for a plant community using the normalised difference vegetation index (NDVI), etc. and to then estimate the NEP using the quantity of solar radiation, light use efficiency and stress functions relating to the temperature and water content (community-based model). In this model, the NDVI and surface temperature are the principal input data. Data on the quantity of solar radiation estimated using meteorological satellite data is believed to offer a higher accuracy than objective analysis data for areas with scarce observation points and constitute important input data.

Meanwhile, estimation of the NEP poses the following problems.

(1) Difficulty of estimating the soil moisture under dense vegetation by means of remote sensing
(2) Difficulty of estimating the CO_2 release by soil over a wide area
(3) Difficulty of accurately estimating the LAI as satellite data is saturated with high LAI vegetation
(4) Less realistic tuning for estimation of the NEP at the community level as the process model is based on parameters measured under limited conditions and for individual leaves of specific species

Although the process-based model is the present-day mainstream NEP estimation method, it is not exactly an appropriate method in view of problems (3) and (4) above. Today, many flux observation sites are available in regard to various types of vegetation in the world and the CO_2 flux is being measured by the eddy correlation method, clarifying the temporal-spatial fluctuations of the NEP at the community level. There is a problem of a flux imbalance in that the observed flux value by the eddy correlation method does not match the value observed by the bulk method, etc. However, as the eddy correlation method measures representative values at the community level and the scale of the measurement results is similar to that of remote sensing data, the results can be easily compared and their combination is expected to offer an effective tool for NEP estimation.

Based on the current situation described above, research on the terrestrial carbon cycle under the GCOM must take the following points into special consideration.

(1) The accuracy of the surface temperature product should be improved as a common parameter for both the process-based model and the community-based model. As it is desirable to measure the surface temperature between 13:00 and 14:00, the surface temperature data from the GCOM on the morning path will require tuning.

(2) The advantages and disadvantages of the process-based model and the community-based model should be compared to develop or transplant a model which is suitable for the GCOM.
(3) In regard to the LAI, the estimation method using the reflectance factor which has undergone atmospheric correction and topographical correction should be verified in addition to those estimation methods using such vegetation indices as the NDVI and EVI.

(4) In regard to breathing by woody portions, the available research on this process should be reviewed with a view to establishing a method to estimate the breathing quantity by woody portions based on the woody biomass.

(5) Flux observation data should be actively used for parameterisation methods.

(6) A simple community-based model using the fAPAR and light use efficiency should be established as part of the efforts to develop a detailed model.

4.3.4 Hydrology (Toshio Koike: University of Tokyo)

The terrestrial water cycle has shown considerable temporal-spatial fluctuations, causing significant damage to human society through floods and droughts which account for two-thirds of both human casualties and material damage by all natural disasters. A proper understanding of the fluctuation mechanism, improvement of the prediction accuracy and the establishment of an international system to share information are essential to avoid water-related crises. Quantitative and temporally as well as spatially continual comprehension of the individual components of the water cycle from the viewpoint of the water volume and heat flow is required to understand the relationship which is accompanied by a time lag due to the water storage effects of deposited snow and soil moisture (weather memory) and the water cycle system with a teleconnection system between separate places due to advective flow so that the prediction accuracy can be improved.

In addition to the understanding and prediction of water cycle fluctuations under the current climate, changes of the water cycle caused by climate change, typically global warming, have been indicated by the 4th Assessment Report of the IPCC. It is now imperative to develop the capacity to monitor ongoing changes through clarification of the process of change in the past. As a climate change model is essentially a question of boundary values, it is necessary to develop a model which is capable of accurately describing changes in land areas as well as changes in ocean areas.

The recent advancement of remote sensing by earth observation satellites has greatly contributed to improvement of the monitoring situation. In particular, microwave radiometers capable of conducting wide area and all weather observation day and night offer the prospect of the quantitative observation of water surfaces, soil moisture, water in vegetation, raindrops, cloud water, deposited snow and ice particles through different combinations of wavelength bands and polarised waves. The technique of quantitative earth observation using a microwave radiometer on board a satellite was established by the mechanical scanning type special sensor microwave imager (SSM/1) of the Defense Meteorological Satellite Program (DMSP) of the US in 1987. The TRMM Microwave Imager (TMI) on board the Tropical Rainfall Measuring Mission (TRMM) satellite in 1997 made it possible to observe the non-synchronous 10 GHz band which is advantageous for land surface observation even though observation was limited from the equator to the mid-latitude region. In 2002, the AMSR and AMSR-E, both of which were high performance microwave radiometers developed by Japan, were launched in succession. They had a 6.925 GHz observation frequency with a relatively high spatial resolution useful for soil moisture observation. While observation by the AMSR came to an end after a year because of the break down of the satellite proper, the AMSR-E is still active today beyond its design life of five years.

Meanwhile, the Coordinated Enhanced Observation Period (CEOP) Project implemented as a WCRP (World Climate Research Programme) project had made a huge contribution. The CEOP is an international programme to conduct wide-ranging studies, including studies designed to facilitate the understanding and prediction of the water and energy cycle processes, studies on the monsoon system and studies to downscale global wide area prediction data to regional data. For these purposes, terrestrial observation study groups, satellite operating organizations and meteorological organizations joined together to prepare data sets of the local, regional and global water cycles. Under this programme, observation data from 35 reference sites and satellites and outputs from 11 numerical meteorological forecast centres under various weather conditions was gathered in a period of two years and three months from 1st October, 2002 to 31st December, 2004.

What is required is the continuous observation of global water cycle fluctuations by means of combining quantitatively observed land area hydrological values with water cycle elements in the atmosphere and oceans so that the combined information can be effectively used for measures which are designed to alleviate damage by floods and droughts and also to adapt to climate change. To successfully achieve this requirement, it is necessary to integrate the global water cycle data observed or predicted by various methods and of various scales as in the case of the CEOP in addition to obtaining data from individual satellites. The following activities should then be conducted to advance the terrestrial observation around the GCOM using the database developed by the said integration of data.

(1) Advancement of the microwave radiation transfer model targeting soil (including frozen soil), vegetation and deposited snow
(2) Development of an algorithm for single sensor or multiple sensor operation
(3) Advancement of the water cycle model using satellite data
(4) Development of the optimum estimation method for water cycle model parameters through data assimilation
(5) Development of a land area hydrological data assimilation method

4.4 Snow and Ice (Fumihiko Nishio: Chiba University)

4.4.1 Development of the Science of Snow and Ice by GCOM

The impacts of global warming thought to be attributable to the trend of a temperature rise since the Little Ice Age in the 18th century and the more recent increase of GHGs are expected to show up most strongly in changes of the earth's cryosphere, primarily the polar regions. Long-term, continuous monitoring of the sea ice distribution and the ice sheet distribution in the earth's cryosphere is necessary as changes take place over a long period of time. Global warming is thought to have direct impacts on the reduced distribution of sea ice, increased snow deposit on ice sheets, increased area of melting around ice sheets and increased discharge of icebergs. Clarification of the elementary steps of various phenomena in the cryosphere and long-term, continual observation, particular in the polar regions, are extremely important to ascertain such impacts.

Satellite observation constitutes the most important method for continual observation and monitoring in the polar cryosphere. While the combined use of multiple sensors for the visible region to the microwave region is essential, the use of microwaves is particularly effective because of the frequent cloud cover and long nights.

The GCOM, SGLI and AMSR2 will be used to observe in a much higher resolution than those sensors in use today. For example, continual monitoring of the cryosphere can be conducted for the mapping of sea ice, glacier and ice sheets and also to record changes of the margins due to global warming.

It is known that there has been a general trend of receding glaciers on the earth because of the gradual temperature rise since the Little Ice Age. Even though research on the recession speed and mechanism is progressing through an increased number of actual observations and various models, not many details have been established because of the severe environment in the polar regions. One of the satellite observation results which have been available since the 1970's is that the sea ice area in the Arctic Ocean has reached its smallest size in recorded history of less than 4,300,000 km^2 in September, 2007.

As the SGLI with many channels can conduct observation with high resolution and stereo vision, it may be able to detect topographical changes as well as changes of the ice thickness. Changes of the albedo on glacier, ice sheet and sea ice surfaces are closely related to the trend of a temperature rise and the SGLI can detect the optical characteristics of snow and ice surfaces in a small area. Moreover, the spectral data provided by the SGLI is useful to detect impurities caused by minerals, bacterial activities and others on snow and ice surfaces as changes of the albedo or spectral changes.

Meanwhile, the multiple waveband and multiple polarised wave data provided by the AMSR2 is useful for the understanding of huge snow and ice areas on ice sheets and the interaction between the atmosphere and snow and ice surfaces. Such data is vital for understanding of the interaction for material transfer between ice sheets and the atmosphere and the mass balance process of ice sheets.

Research on sea ice is facing the tough challenge of clarifying the interactions involving sea ice, ocean and the biosphere in the polar regions. Monitoring of the sea level of sea ice and the distribution of thin and thick sea ice is required and the relation between sea ice and primary biological products must be examined. The types of information required for this research include the mass balance of sea ice based on the thickness and moving speed of sea ice, heat exchange between the atmosphere and ocean, gas and water vapour flux, impacts of deposited snow on the sea ice growth process, sea ice growth speed, discharge speed of brine, ocean structure (ocean density and circulation), radiance balance and changes of the albedo on the sea ice surface, physical temperature on the sea ice surface and seasonal/spatial fluctuations of primary biological products and production processes.

4.4.2 Changes of Sea Ice, Glacier and Ice Sheet Distributions: Science Using Microwaves

The AMSR2 can extract various physical quantities, mainly those related to water such as vapour and cloud water contents and amount of precipitation in the atmosphere, deposited snow volume and soil moisture content on land, ocean surface wind velocity, sea surface water temperature, sea ice volume and deposited snow volume on the Antarctic ice sheet surface, by means of measuring weak microwaves radiated by the earth. As the radiation characteristics of microwaves considerably differ for water (H_2O) depending on its gaseous, liquid or solid phase, such characteristics can be used to accurately extract physical quantities through multi-frequency observation.

The AMSR2 can achieve a high level of spatial resolution with its large antenna which is some 2 m in diameter and can also use data in such low frequency bands of 7 and 10 GHz. The analysis and monitoring of phenomena in the cryosphere will be conducted with emphasis on the analysis of high spatial resolution data and low frequency data. For this analysis, data from the SGLI will also be used. Because of the availability of quasi-real time global data, efforts will be made to demonstrate the possible use of microwave radiometer data for weather forecasting, etc.

An AMSR algorithm will be developed and improved using AMSR-E data and airborne microwave radiometer (AMR) data to achieve the research objectives. The calibration and product preparation methods will have been finalised in advance to guarantee the data quality.

4.4.2.1 Deposited Snow Distribution, Deposited Snow Area and Frozen Ground

Analysis of the changing distribution and area of deposited snow is important from the viewpoint of monitoring global warming. There are many research themes on land because of the uncertainty regarding reflectance. Firstly, AMSR-E data will be used to check seasonal changes of vertically and horizontally-polarised microwave radiation from various types of ground surfaces. Next, the feasibility of establishing the deposited snow volume and soil moisture content based solely on brightness temperature data will be examined using AMR data. As microwave radiation rapidly changes with the phase change from water to ice or vice-versa, it is hoped that detection of the state of the surface will be relatively easy.

4.4.2.2 Sea Ice Distribution and Concentration

The sea ice area around Antarctica shows much seasonal change as a huge area of some 3.5 million km^2 in summer and some 20 million km^2 in winter is covered by sea ice. In the case of the Arctic Ocean which is surrounded by the Eurasian Continent and the North American Continent, most of the ocean is covered by sea ice throughout the year. As such, the size of sea ice plays a dominant role in the heat balance and ocean circulation. Time-series changes of the sea ice distribution, therefore, are an important indicator for global warming. It is possible for the AMSR2 to determine the general distribution of sea ice in both semispheres. While sea ice observation by microwave radiometers has been in progress since the early 1970's as basic research, the relationship between the emissivity and physical characteristics of sea ice is not yet clearly understood. The reasons for this lie with the rough spatial resolution of several tens of km of the radiometers on board satellites and the fact that the types of sea ice within this range are not uniform. Moreover, any snow deposit on sea ice changes the emissivity and the physical temperature of the sea ice or deposited snow may change by as much as some 10°C due to the atmospheric temperature. It is, therefore, necessary to compare the observation data of the airborne AMR and truth data to establish more reliable basic data.

4.4.2.3 Changes of Ice Sheet Distribution

Continual observation of the changing distribution of the Greenland and Antarctic ice sheets using microwaves is important to understand the process of how the impacts of global warming emerge. The crucial observation targets in this context are the deposited snow volume on ice sheets, melting zone around ice sheets, outflow of glaciers and seasonal as well as yearly change of the brightness temperature in all areas of the ice sheets.

Calculation of the mass balance of the Antarctic ice sheet requires information on the mass balance of the ice sheet in the form of snow and ice and the contribution of ice deposition to changes of the sea level, in turn affected by the ice deposition on the ice sheet located inland from the grounding line. For this reason, it is important to proceed with basic research on the mass balance of the Antarctic ice sheet and the development of an algorithm for the elementary steps using AMSR2/SGLI data. The development of an algorithm to estimate the deposited snow volume data on the surface provided by the AMSR2 is urgently necessary to understand the actual state of global warming and the mass balance of the Antarctic ice sheet. What is important here is the comparison of data related to the mass balance with other geoscience data as part of the research on the elementary steps to determine the mass balance of glaciers and ice sheets and its changes.

4.4.3 Science of Optical Observation

4.4.3.1 Snow Cover Distribution

What is normally problematic for observation of the snow cover distribution is how to distinguish areas covered by snow from clouds. While research on the AVHRR has established the effectiveness of combining intermediate-infrared and thermal-infrared observations, it is anticipated that the 1.6 μm channel of the SGLI will further improve the accuracy. Moreover, the development of an algorithm to estimate the snow cover distribution in continental forest areas should improve the accuracy even further.

4.4.3.2 Sea Ice Distribution and Concentration

While the general global distribution of sea ice can be observed by the AMSR2, use of the SGLI which has a higher spatial resolution than the AMSR2 is essential for assessment of the state of local polynyas and differences in the sea ice concentration. A highly accurate picture of the sea ice distribution can be achieved with the use of both sensors. Information on the state of the sea ice surface (snow distribution on sea ice and reflectance) and surface temperature is essential to calculate the heat balance of sea ice areas. Data from these sensors can also be used to classify the thickness of sea ice and the type of ice plate.

4.4.3.3 Changes of Polar Ice Sheets

Observation of the changes of the Antarctic and Greenland ice sheets, especially changes of glacier movement, is very important from the viewpoint of monitoring global warming. The large-scale collapse of the ice shelf at the Antarctic Peninsula has been reported in recent years. The scale of this collapse is as large as more than several tens of kilometres and it is large enough for observation by the SGLI. Although changes of glaciers require a high resolution sensor for detailed analysis, observation by the SGLI is important from the viewpoint of observing changes over a wide area.

4.4.3.4 Monitoring of Giant Icebergs

The outflow of giant icebergs has frequently been reported in recent years, raising questions in connection with global warming. As giant icebergs pose a serious danger to ships, their careful monitoring is necessary. As the SGLI can observe the polar regions with a resolution of 250 m on almost a daily basis, it should prove useful for the monitoring of giant icebergs.

4.4.3.5 Albedo of Snow and Ice Surfaces

The albedo in the cryosphere is an important parameter for analysis of the global heat budget and global warming. Ice-albedo feedback is the biggest factor affecting the climate in the global cryosphere. The albedo of snow and ice is liable to change by the wavelength, diameter and shape of the snow particles, impurities in the deposited snow, snow cover density, moisture content and surface conditions. The research to develop a model on the relationship between the albedo and wavelength, size and shape of the snow particles and snow cover depth has made much progress. Spectral observation of the albedo can be expected to allow estimation of the snow cover distribution and depth. As the SGLI observes the cryosphere in 19 wavelength bands, it is expected to produce valuable data to clarify the relationship between precise snow and ice surface conditions and the albedo.

4.4.3.6 Surface Temperature of Snow and Ice

The surface temperature of snow and ice is important information for the accurate inference of the conditions of snow and ice surfaces. This information is also essential for assessment of the heat balance in the cryosphere and the interaction between the atmosphere and snow/ice.

However, the GCOM cannot produce better surface temperature data than that provided by the NOAA/AVHRR. Therefore, this data is considered to be additional data for analysis with its combination with other wavelength bands.

4.4.3.7 Physical Properties of Snow Cover

Although the albedo of snow cover changes depending on the wavelength, size and shape of the snow particles, impurities in the deposited snow, snow cover density, moisture content and surface conditions, the exact relationship is not clearly understood. Meanwhile, the physical properties of snow cover also change depending on the meteorological conditions of the snow cover area, presence of any atmospheric fall-outs and time duration after snowfall. Accordingly, the properties of snow cover contain information on the history of the said snow cover. For example, the particle size of the deposited snow can be estimated using the 1.1 – 1.2 μm wavelength band. As the particle size of fresh snow tends to be small, it may be possible to determine whether or not there has been fresh snowfall in a snow covered area. It is known that the albedo in the near-infrared region increases when drifting snow takes place. Using this knowledge, it may be possible to estimate the wind velocity on the ground surface. As mentioned earlier, the SGLI uses 19 wavelength bands to observe the cryosphere and it is hoped that it will be able to obtain valuable data to clarify the relationship between the albedo and the precise conditions of snow and ice surfaces.

5. Practical Use of GCOM

5.1 Improvement of Accuracy of Weather Forecasting (Kozo Okamoto: Japan Meteorological Agency)

Accurate forecasting of the weather can improve the daily lives of people and contribute to the development of agriculture, forestry, fisheries and other industries. Accurate as well as timely weather forecasting is extremely important to protect people's lives and assets from natural disasters caused by heavy rain and stormy winds. The core data for weather forecasting is generated by numerical weather prediction (NWP) and its quality is largely determined by the accuracy of the initial values. One of the most important tasks for the world's major NWP centres, including the Japan Meteorological Agency (JMA), is the preparation of highly accurate initial values by means of assimilating highly accurate observation data over a wide area using an advanced data assimilation system.

JMA has a nationwide observation network using weather radars, the Automated Meteorological Data Acquisition System (AMeDAS), wind profilers and radiosone balloons and assimilates the data obtained by this network in an appropriate manner to forecast heavy rain and other meteorological phenomena. However, this observation network extends only just outside the Japanese archipelago and is insufficient to observe the inflow of wet air from the ocean which occasionally triggers localised downpours. Moreover, only limited data from ships, buoys, aircraft and island observation posts is available for ocean areas in the tropical Pacific region despite the importance of such data for the prediction of the emergence and subsequent path of a typhoon. For this reason, satellite observation is extremely important to frequently obtain vital data covering a wide area of ocean and upper atmosphere. Typical data obtained by geostationary satellites and polar orbit satellites and used in operational assimilation systems are upper layer wind data from the continual images provided by high resolution visible and infrared imagers, vertical profile data for temperature and vapour and cumulative vapour and precipitation volumes observed by infrared and microwave radiometers (sounders/imagers) and ocean wind data observed by microwave scatterometers.

Vapour data observed by a microwave imager in particular is known to improve the mesoscale forecast of heavy rain, global distribution of precipitation and prediction of typhoon track. As an example, Fig. 5.1.1 shows the 3, 6 and 9 hour forecasts at the time of a heavy downpour in Fukui Prefecture in 2004. Analysis at the 18 UTC on 17^{th} July, 2004 could not accurately determine the moisture field because of the absence of vapour observation data for the Sea of Japan and the South China Sea. The 6 and 9 hour forecasts using the observed values at this particular time as the initial values incorrectly predicted that the precipitation in Fukui Prefecture would not persist and that precipitation would occur in Yamaguchi Prefecture. In contrast, the assimilation of the potential precipitation calculated from Aqua/AMSR-E data with the actual precipitation using the four-dimensional variational method produced a moisture field which actually reflected the actual situation. The 9 hour forecast based on this information predicted weak precipitation in Fukui Prefecture and no precipitation in Yamaguchi Prefecture. Meanwhile, Fig. 5.1.2 shows that the mean error of a typhoon track forecast is reduced when brightness temperature data for the sea surface under a clear sky provided by the SSM/I, TMI and AMSR-E is assimilated in the global data assimilation system.

As the observation accuracy and spatial resolution of the GCOM-W/AMSR2 are better than those of the current AMSR-E, further improvement of the accuracy of weather forecasting is expected. Moreover, Very few of other microwave imagers is expected during the operation period of the GCOM-W1. Therefore, the GCOM-W1 is quite significant for the preservation of the global observation system as real-time coverage is crucial for operational data assimilation systems.

Sea surface temperature (SST), snow cover depth and sea ice concentration products derived by microwave imagers are now used for analysis of the SST, land surface and sea ice. The analysis results are used as boundary or initial values for NWP. For example, analysis of SST is extremely important for prediction of the emergence and track of a typhoon by NWP models.

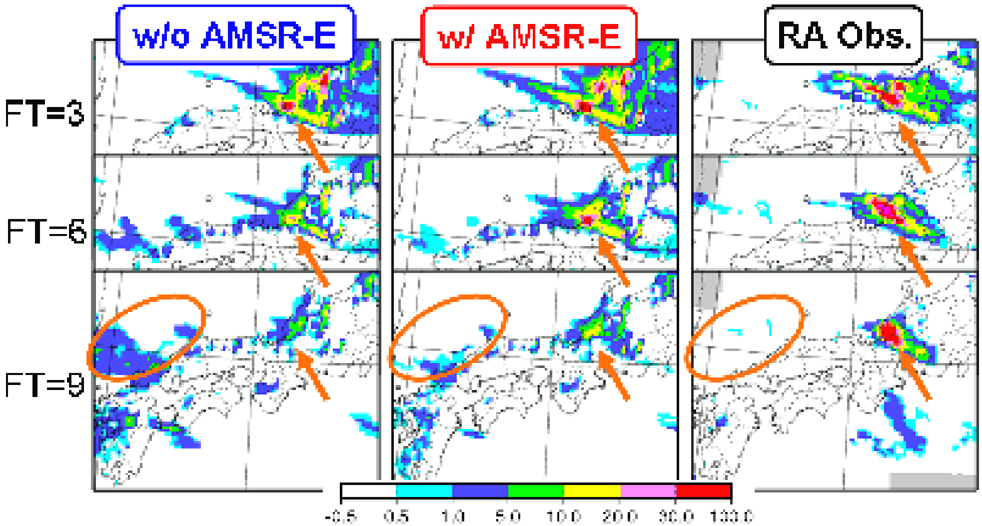
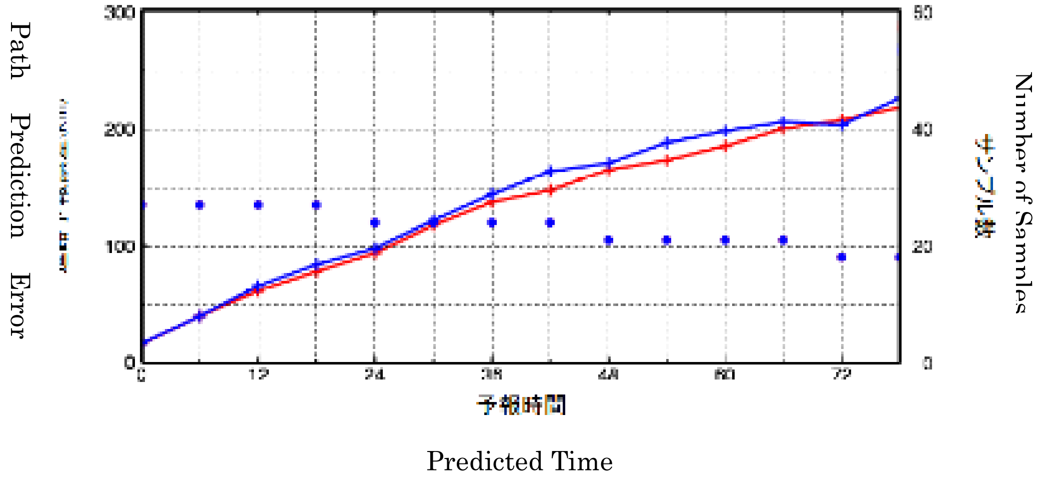


Fig. 5.1.1 3-hour precipitation computed by the JMA's mesoscale numerical prediction model using the analysis results at 18 UTC on 17th July, 2008 as the initial values. Those on the left are 3.6 and 9 hour forecasts without the assimilation of AMSR-E data, those in the middle are with assimilated AMSR-E data and those on the right are the actual precipitation analysed by the ground radar and AMeDAS corresponding to each of the forecast times.

It is hoped that the GCOM-W/AMSR2 will further improve the accuracy of analysis. However, the existing operational global data assimilation system can only use data above the ocean in clear regions. In addition, the observation data is not fully utilised as data in the 7 and 10 GHz bands is not used by either the global data assimilation system or the mesoscale data assimilation system. To rectify the situation, efforts are being made to assimilate the brightness temperature in precipitation areas and to utilise the surface information using low frequency channels. As part of these efforts, an experiment is in progress to assimilate all weather ocean wind data developed with the JAXA with a view to improving the accuracy of the typhoon intensity. At present, the data assimilation system of the JMA only assimilates statistically prepared pseudo-atmospheric pressure and wind data called typhoon bogus near the centre of a typhoon. With the use of real observation data, it is hoped that pressure and wind similar to the actual values can be analyzed and predicted.

Fig. 5.1.2



The mean prediction error of the central position of the typhoon by the global NWP model is shown by the predicted time for Typhoon No. 11 through Typhoon No. 18 in 2004. The blue line shows the prediction without the assimilation of SSM/I, TMI and AMSR-E data while the red line shows the prediction with assimilation. The round dots indicate the number of samples used to compile the statistics (right scale).

The data and products to be provided by the GCOM/SGLI are expected to be used for NWP and other work by the JMA. The high resolution and high precision visible and infrared data can be used to verify the cloud and radiative processes of the NWP model as albedo and radiance data as well as cloud and aerosol products. At present, the physical quantities corresponding to the albedo and brightness temperature observed by geostationary satellites are computed using the NWP results. These quantities are then compared with the actual observation values to verify and improve the cloud process of the model in question. In regard to aerosols, products of the MTSAT, AVHRR and MODIS are used to monitor the ongoing situation of aerosols, including aeolian dust, and to prepare climatic values. The SGLI may be able to improve this work. There will be a growing need for the assimilation of cloud and aerosol data to prepare their initial values against the background of the increasing resolution of the model, refinement of the cloud and precipitation processes and upgrading of disaster prevention and air pollution information. Many unsolved issues from the viewpoint of technology and computational resources must be dealt with for the direct assimilation of albedo and brightness temperature data in the visible and near infrared bands. In the case of ozone, a highly accurate product, if such a product is made available, should be effective for the preparation of ultraviolet information, application to climate analysis and verification of chemical transport models. The idea of using the SST product of the SGLI for SST analysis, as in the case of the AMSR2 product, is currently being examined.

5.2 Monitoring and Prediction of Air Pollution by Yellow Sand and Other Pollutants (Takashi Nakajima: Tokai University)

5.2.1 Necessity for Monitoring of Air Pollution Particles

Fine particles suspended in the atmosphere include those from natural sources, such as sea salt particles generated from splashed seawater, dust blown up from the ground surface, soot from forest fires and volcanic fumes, and those primarily originating from human activities, such as dust discharged through the use of fossil fuels in factories and by automobiles and secondary particles converted from gaseous air pollutants. In this section, air pollution particles refer to those with a high potential to cause damage to health and other damage in daily life among the various pollutants mentioned above. Air pollution particles released into the atmosphere may travel several thousand of kilometres from their original source, riding on the airstream. There is concern in recent years in regard to the increasing trend of forest fires which produce a huge quantity of soot and the yellow sand phenomenon in East Asia, making the monitoring of air pollution particles ever more important. The SGLI on board the GCOM-C satellite has many observation channels, from the near ultraviolet band to the infrared band, and can be used to observe air pollution particles.

5.2.2 Examples of Air Pollution Particles Observed by the GLI and MODIS

Figs. 5.2.1(a) and (b) show the state of a forest fire originating at the shore of Lake Baikal captured by the Global Imager (GLI) on board the ADEOS-II satellite. The GLI is the predecessor of the SGLI to be mounted on the GCOM-C satellite. It was possible to extract soot in an effective manner using the near ultraviolet channel (380 nm) of the GLI. Fig. 5.2.2 shows the extracted air pollution particles, including soot from the forest fire, over a wide area using the near ultraviolet and visible light channels of the GLI. From this image, it can be detected that soot which was originally generated at the shore of Lake Baikal has travelled a long distance to almost reach Alaska. The 380 nm near ultraviolet channel is a unique channel only used for imagers developed by Japan among moderate spatial resolution wide swath imagers. Because of its usefulness, its inclusion in the SGLI has been decided. In addition to the 380 nm near ultraviolet channel, the SGLI also has two polarisation observation channels at 670 nm and 865 nm in the visible to near-infrared band and are expected to be a powerful tool for the monitoring of air pollution particles. Fig. 5.2.3 shows an example of the observation of the yellow sand phenomenon captured by the MODIS sensor on board the Terra satellite. It is clearly shown here that the continent's yellow and has spread widely from the east coast of the continent to the Sea of Japan. As these examples suggest, the observation of air pollution particles from space has been gradually entering the realms of practical use.

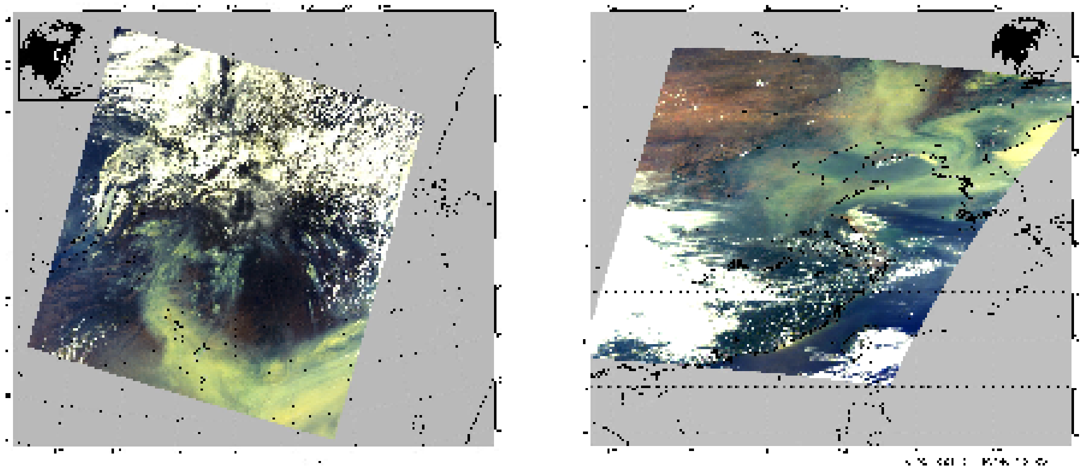


Fig. 5.2.1 State of soot generated by a forest fire near Lake Baikal (a) (19th May, 2003) and the spread of the soot to East Asia (b) (20th May, 2003). These images were processed at the Tokai University Research and Information Center (TRIC) using ADEOS-II/GLI data provided by the JAXA/EORC

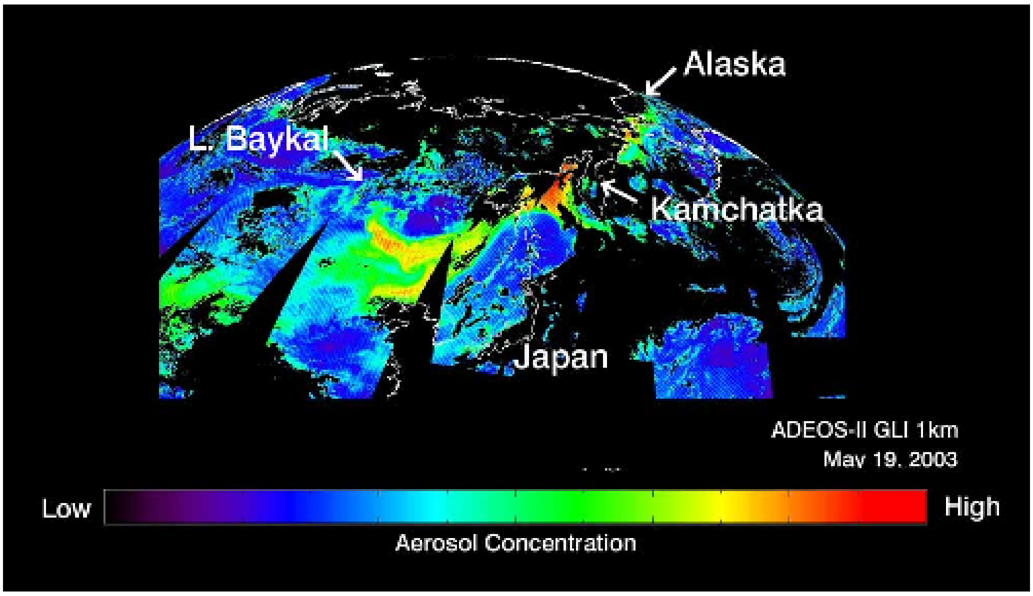


Fig. 5.2.2 Distribution of air pollution particles on 19th May, 2003 as extracted through a combination of the 380 nm and 400 nm channels of the GLI. It is clearly shown that the soot generated near Lake Baikal has travelled a long distance to reach Alaska. The image is provided by the JAXA/EORC.

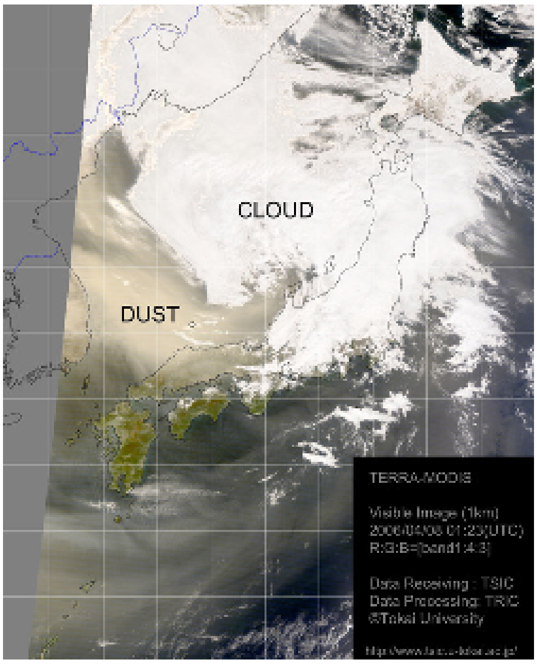


Fig. 5.2.3 Captured image of the yellow sand phenomenon spreading to the Sea of Japan as well as part of the Japan islands (10:23 Japan local time on 8th April, 2006). This image was processed at the TRIC using data from the Terra/MODIS sensor (developed by the NASA) which was received by the TRIC.

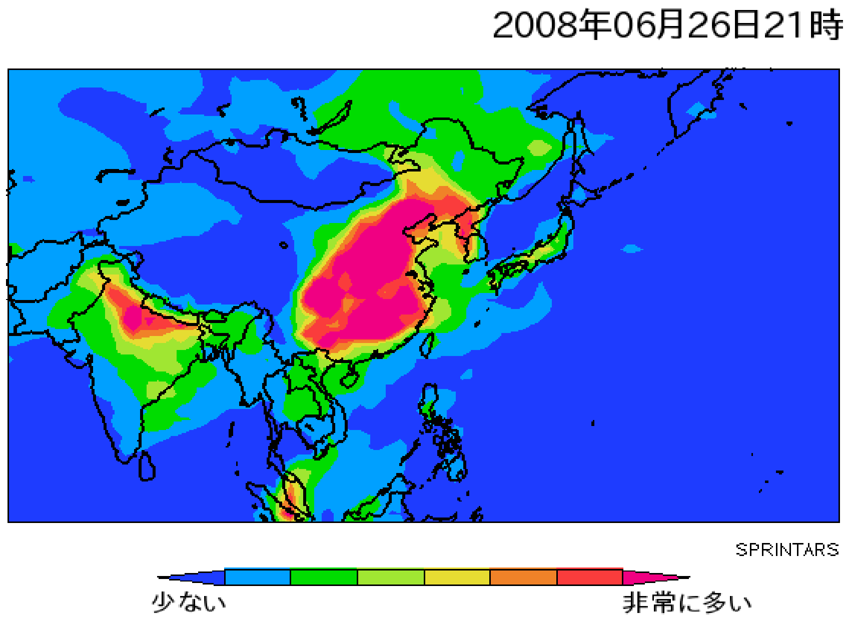
5.2.3 Satellite Observation Used for Prediction of the Distribution of Air Pollution Particles

The observation of air pollution particles from space is not only used to observe the state of such particles at the time of observation but also for verification of the development process of an aerosol transport model to be used for prediction in the future. To be more precise, the practical applicability of an aerosol transport model can be checked by comparing the computation results of the aerosol transport model developed in accordance with various rules of physics with the actual values observed by a satellite in both the short-term real field and in the long-term average field. Fig. 5.2.4 shows the density distribution of air pollution particles (soot, organic carbon and sulphate aerosols) in East Asia as predicted by the SPRINTARS, an aerosol transport model (developed by Takemura et al, 2000). Areas with a high density of aerosols are predicted for a wide area in Southeast Asia near the source and the northern part of the Indian Sub-Continent. As the spatial resolution of aerosol transport models has been steadily improving, it will be necessary for the SGLI to observe with a lateral spatial resolution of several kilometers.

5.2.4 Various Research Themes to Achieve Practical Application

The observation of air pollution particles by the GCOM-C/SGLI faces several problems. Firstly, there is a problem of distinguishing these particles from clouds. Particularly in the case of an optically thick particle layer made up of soot from forest fires or yellow sand, the conventional classification methods can mistakenly record a layer of air pollution particles as cloud cover, making the development and verification of an algorithm to distinguish them essential. Next, it is necessary to improve the detection accuracy of air pollution particles above land. The detection of particles in the atmosphere in a land area with generally a high level of surface reflectance is more difficult that detection in a sea area with a lower reflectance. Therefore, the development of a highly accurate algorithm for this purpose is required. Identification of the types of air pollution particles is another important research theme. A positive outcome of the GLI project is the proposal of a particle classification algorithm using four wavelengths in the visible light through near infrared band (Higurashi and Nakajima, 2002) which can be used with SGLI data. The practical application of observation data demands satellite and on board sensor operation over a long period of time and brightness calibration.

21:00 on 26th June, 2008



Low ←   → Extremely High

Fig. 5.2.4 Density of air pollution particles (soot, organic carbon and sulphate aerosols) in East Asia as predicted by an aerosol transport model (SPRINTARS) at 21:00 on 26th June, 2008. The image is provided by the Research Institute for Applied Mechanics (RIAM) of Kyushu University. (http://sprintars.riam.kyushu-u.ac.jp/indexe.html)

Active use of the ground observation network is important for the verification of satellite observation results. As part of the Global Earth Observation System of Systems (GEOSS), the SKYNET ground observation network (Takamura et al., 2004) has been developed, primarily in East Asia, and is used for the verification of data for practical application. Satellite observation data can be verified through the combined use of the estimated cloud cover by the skycamera installed at key SKYNET observation sites, observation of particle characteristics by skyradiometers, etc. and observation of the vertical distribution by lidars. At present, atmospheric observation is being conducted at more than 10 sites in East Asia, including super sites located at Cape Hedo in Okinawa Prefecture, Tsukuba City in Ibaraki Prefecture and Cheju Island in Korea. The further development and operation of observation sites is required with support under the GCOM project.

< References >

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Takamura, T., Nakajima, T. and SKYNET Community Group, 2004: Overview of SKYNET and its Activities, OPTICA PURAY APLICADA, 37(3), 3303-3308

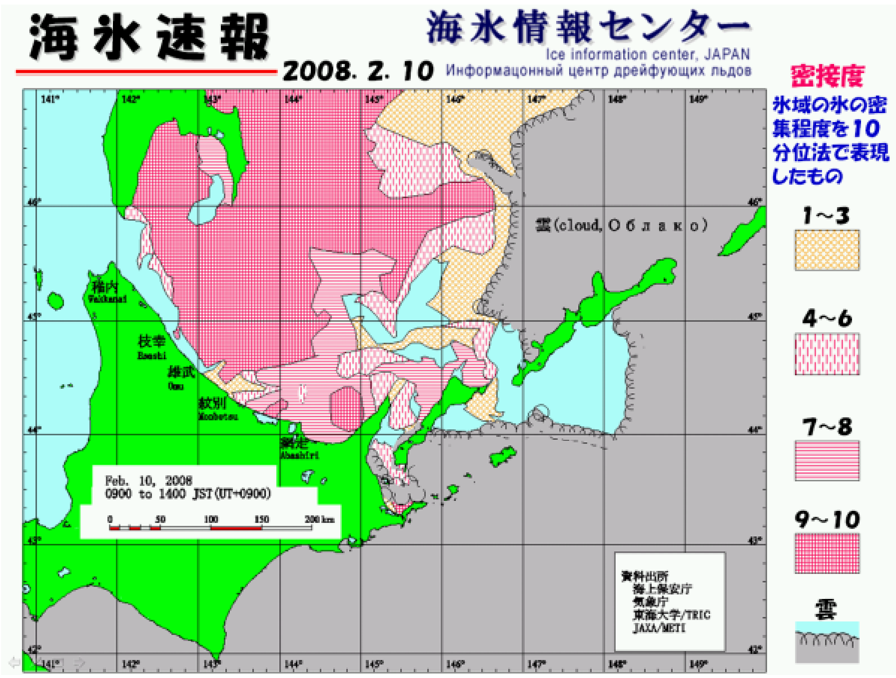
Takemura, T., Okamoto, H., Maruyama, Y., Numaguti, A., Higurashi A. and Nakajima, T., 2000: Global Three-Dimensional Simulation of Aerosol Optical Thickness Distribution of Various Origins, Journal of Geophysical Research, 105, 17853-17873 (http://sprintars.riam.kyushu.u.ac.jp/indexe.html)

5.3 Improved Accuracy of Sea Route Data (Kenji Matsumoto: Japan Coast Guard)

Part of the Sea of Ohkotsk near Hokkaido is covered by ice every winter and this ice hampers normal navigation and coastal fishery. In March, 1970, a large-scale sea disaster took place in Hitokappu Bay of Etorofu Island due to drifting ice. This disaster led to the establishment of the Ice Information Center at the Regional Coast Guard Headquarters in the First Region.

Every year from late December to early May, the Ice Information Center daily gathers information on ice from Coast Guard stations, meteorological observation stations, patrol boats, vessels in the area, aircraft belonging to the Japan Coast Guard and the Ministry of Defence and satellites and provides the rearranged information at 17:00 hours via the Internet and fax transmission.

Sea Ice Quick Report



Ice Concentration

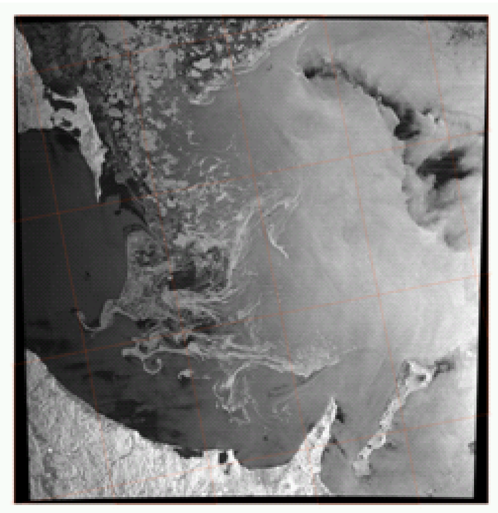
10 grade classification of ice concentration in ice covered areas

Sources: Japan Coast Guard
Japan Meteorological Agency
Tokai University/TRIC
JAXA/METI

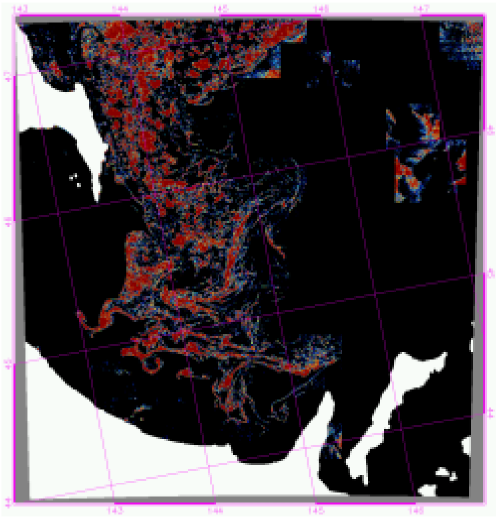
The use of satellites is extremely useful for observation of the sea ice distribution cover over a wide area. The satellite data recently used for this purpose is provided by such optical sensors as the MODIS on board the NASA's Terra satellite and the NOAA's AVHRR, a microwave radiometer. However, as the Sea of Ohkotsk in winter experiences rough weather almost every day with extensive cloud cover, it is not easy to constantly know the distribution of ice.

In order to facilitate the use of image data obtained by a synthetic aperture radar and microwave sensors capable of establishing the sea ice distribution through cloud cover, the Hydrographic and Oceanographic Department of the Japan Coast Guard is conducting joint research with the JAXA on the development of a sea ice observation method using ALOS data and the use of such data. This joint research aims at the development of a method to produce ice concentration images by the automated processing of ALOS observation data with a view to preparing ice quick report maps. The research also aims at improving the accuracy of ice interpretation for the ice concentration images produced. The types of images currently used to prepare sea ice quick reports for practical use are wide area ScanSAR images (including images for which the antenna pattern is corrected), ice concentration images obtained by a synthetic aperture radar (PALSAR) and optical sensor and microwave radiometer images. For the preparation of a sea ice quick report, wide area ScanSAR images provide a detailed distribution of ice and allow estimation of the degree of unevenness of the ice surface. Ice concentration images are very convenient for the preparation of a quick report as they show the general distribution of ice and the degree of ice concentration for quick recognition.

Sea of Ohkotsk: ScanSAR image



Sea of Ohkotsk: Ice distribution image



When routine ScanSAR images are compared with aerial observation results of MODIS images, the following problems can be recognised.

- A similar level of backscattering brightness can be produced by either a sea ice surface or open water surface. A brightness difference which deters a definitive interpretation can occur on an ice area.
- High and low brightness sites which can be easily misunderstood as ice can occur on the open sea.
- Information on the backscattering brightness alone cannot confirm a newly generated ice area.

Various steps are adopted to solve these problems when a sea ice quick report is prepared. For this, various types of information are required in addition to the knowledge and experience of the staff members responsible. The verification of such thin ice as glease ice and nilas is very important as far as ice information is concerned because these types of ice are formed at the early stage of the sea ice generation process and can hamper the navigation of vessels by blocking the intake port for engine cooling water.

Two types of radiometers, i.e. GCOM-C/SGLI and GCOM-W/AMSR2, will be launched under the GCOM. It is hoped that these radiometers will make a vital contribution to the solving of the above problems by means of verifying ① the separation between a sea ice area and open water area and ② the adequacy of the separation of a sea ice area into a sea ice area for which the ice concentration is displayed and a thin ice area.

The sea ice quick reports currently use multiple satellite data and the suspension of any such data could hamper the provision of ice information. The launch of two sensors under the GCOM should considerably improve the reliability of the continually provided ice information.

< Reference >

Examples of Graded Ice Concentration in a Sea Ice Quick Report
Concentration: Indicates the degree of ice concentration on average in a certain ice area in the 10 grade classification method.

5.4 Provision of Fishing Ground Data (Katsuya Saito: JAFIC)

5.4.1 Current Conditions for Fisheries

Japanese fisheries are moving from the conventional growth-oriented fisheries to resources management-type fisheries aimed at efficiently and permanently utilising marine resources following the ratification of the UN Convention on the Law of the Sea in 1996. While this transition is taking place, the actual conditions surrounding fisheries are quite severe because of rising fuel prices and sluggish fish prices. The recent hike of fuel prices in particular has inflicted massive damage to the entire fisheries industry of which the first priority now is to minimise the fuel oil consumption, including the efficient use of fish lamps, rather than the management of marine resources.

5.4.2 Urgent Necessities

Under such severe business conditions, the fishing operation efficiency must be further improved. Advancement of the information required for fishing operation is necessary for efficient operation along with improvement of the performance and efficiency of fishing gear and fishing boats. The availability of real-time information directly related to operation on the likely locations of dense schools of fish, efficient routes to reduce fuel consumption and sea areas for safe operation plays an important role in efficient and safe operation.

In addition to the real-time sea data required for daily operation, information and time-series data on the sea conditions over a wide area is also crucial for resources management-type fisheries. Understanding of the entire food chain in the sea with phytoplankton at the bottom provides a clue to the changing resources situation of fish which are higher predators. It is known that the meandering of the Black Stream (Kuroshio) significantly affects the changing size of true sardine and other fish resources. Therefore, information on the marine conditions is essential to establish the cause(s) of fluctuating marine resources.

Moreover, real-time data on damage to fisheries by red tide, etc. and marine pollution over a wide area should contribute to reducing the said damage when such data is made available.

5.4.3 Present Problems and Tasks

The water temperature, salt content and quantity of phytoplankton and zooplankton constitute basic information on the marine conditions to assist fisheries. In regard to the sea surface water temperature and colour in particular, efforts have been made to apply remote sensing images to fisheries since the 1980's. However, remote sensing using the visible light to infrared bands to observe the water temperature and sea colour is strongly affected by clouds and the sea area around Japan tends to have many areas for which data is missing because of the presence of cloud cover.

The NOAA/AVHRR of which the data is most frequently used for fisheries has a spatial resolution of approximately 1 km which is the standard resolution for satellite-based fisheries data. However, a better resolution is required to accurately establish the marine conditions of fishing grounds. A higher resolution is particularly required for coastal areas in which many fishing boats operate.

As the marine conditions are constantly changing like the atmospheric conditions, frequent observation is important. The availability of data at very short intervals is crucial for such data to be useful for fisheries. There is much expectation regarding the further use of new remote sensing data other than water temperature data such as sea level and night-time visible band images, the application of which to fisheries has been increasing since 2000.

5.4.4 Provision of Fisheries Data by GCOM

The effectiveness of sea surface water temperature observation by generations of microwave radiometers (TMI, AMSR-E and AMSR) is widely recognised by those involved in fisheries. Among the various sensors of the GCOM, the highest expectations are for microwave radiometers as a new generation of sensors is expected to provide images of a higher resolution. The sea surface water temperature observation by the microwave radiometer on board the GCOM-W will enable the provision of surface water temperature images with few areas of absent data due to cloud cover as a microwave sensor is capable of conducting all-weather observation. From the viewpoint of providing information to assist safe operation, the provision of reliable water temperature images for fishery operators in operation will be possible although the resolution will not be as high as that of images provided by other types of sensors. From the viewpoint of applied research, the assured availability of sea surface water temperature images even in the early summer rainy season or winter for which sufficient data has not been available so far by the existing sensors covering the visible light through infrared bands will make it possible to increase the number of matching-ups between fishing ground data and satellite images to improve the accuracy of the prediction of sea conditions and promising fishing grounds. Uniform observation data over a wide area will form an important data set for clarification of the relationship between changes of the marine resources and ocean conditions for which a relatively macroscopic approach is required. Such data will, therefore, greatly contribute to research on marine resources.

The data obtained by multiple wavelength visible light to infrared sensors, such as the OCTS and GLI, has been indispensable for fisheries. The high resolution, multiple wavelength observation by the visible light to infrared sensor on board the GCOM-C will provide various information on the marine conditions, including the sea colour and sea surface water temperature. From the viewpoint of providing vital information, frequent observation with a high resolution of 250 m will provide detailed data for fishing boats operating along the coast as well as those operating in adjacent waters, likely contributing to improvement of the operational efficiency. From the viewpoint of applied research, the new sensor will enable the observation of minor whirls and fronts, clarification of the conditions of fishing grounds through the simultaneous observation of the water temperature and sea colour and detailed analysis of differences between a water temperature front and sea colour front, all of which have been beyond the capability of satellite sensors with a resolution of some 1 km commonly in use at present. The findings of such research will greatly contribute to improvement of the prediction accuracy for fishing grounds and sea conditions. Conventional analysis primarily relies on chlorophyll density images but the various products to be provided by the GCOM will enable analysis of the optical characteristics of fishing ground conditions and the relationship of such conditions to CDOM and SS. From the viewpoint of research on marine resources, the effective use of products relating to basic production and other matters is hoped for. High resolution sea colour images may well be used for the early detection and prediction of red tide.

The ocean wind vector obtained by a microwave scatterometer should assist the safe and efficient operation of fishing and other vessels. Wave data is among the most appreciated type of weather data by fishery operators. If almost real-time ocean wind vector and time-series data on ocean wind are made available, they will constitute highly effective data for fisheries. There has been hardly any research comparing actual fishing ground data with microwave radiometer data and the availability of new sets of data is likely to provide an insight into the impacts of ocean wind on the formation of fishing grounds and movement of fishing grounds. Such knowledge will assist the accurate prediction of promising fishing grounds.

Multi-sensor remote sensing combining a microwave radiometer, microwave scatterometer and visible light to infrared sensor is likely to provide a new approach for research as well as a new data supply route in the age of the GCOM.

5.5 Improvement of Coastal Water Management Efficiency (Joji Ishizaka: Naggoya University)

While coastal waters account for only less than 10% of the total sea area of the world, more than half of the total fihs catch comes from these waters. Meanwhile, as more than half of the global population live in coastal land areas, the impacts of human activities on coastal waters are quite large. For example, various substances of artificial origin flow into coastal waters from factories located near the coast. Such substances are also discharged into coastal waters from rivers, the atmosphere and navigating ships, polluting these waters. The construction of dams on rivers affects the quality of river water and the sediment transport mechanism while reclamation and other work affecting the coastline are frequently conducted. In recent years, global warming is believed to be causing a rise of the sea temperature and sea level.

Regular observation is essential for the management of coastal waters which are believed to be subject to significant impacts of artificial activities. However, the scale of coastal waters is much smaller than that of the open ocean and it is known that considerable short-term change occur in coastal waters due to tides, etc. In the case of red tides (harmful algal blooms) which often cause considerable damage to the coastal fish culture industry for example, most of them occur on a small scale of less than 1 km in length/width and are likely to last for several days even though there are some exceptionally large cases. For the monitoring of such a phenomenon, a high resolution sensor with a lower observation frequency cannot follow the actual changes and the application scope of a global sensor with a low resolution is limited. The SGLI capable of providing daily data with a resolution of 250 m is the most suitable sensor for the monitoring of coastal waters.

The SGLI can be used to observe a number of phenomena for the purpose of coastal water management. Firstly, there are the red tides mentioned earlier. Not all red tides are harmful to human activities and it is not easy for current remote sensing technologies to accurately identify the types of red tides. However, it is possible to determine the chlorophyll-a concentration, i.e. total amount of phytoplankton, and colour which is believed to represent a red tide. When such information becomes available for a specific sea area or time, it will be possible to judge whether or not the observed red tide is indeed a harmful algal bloom through collaboration with field observers so that the information can be quickly transfered to fishery operators. Such efforts have already been made by the Fisheries Agency and fisheries experiment stations using MODIS data, etc. processed by the JAXA. It is hoped that the availability of the high resolution data obtained by the SGLI will make it possible to deal with red tides, etc. of a much smaller scale in inner bays and other relatively small water areas. When the classification of phytoplankton, which is currently difficult, becomes a reality, the data will be much useful. Discussions on these topics are in progress by the Intergovernmental Panel on Harmful Algal Blooms of the UNESCO's Intergovernmental Oceanographic Commission (IOC) and the GOOS (Global Ocean Observation System) Scientific Steering Committee (GSSC).

Meanwhile, it is important to mitigate influence of red tides after they occurred. A red tide is often caused by eutrophication in coastal waters. Regular monitoring of the amount of chlorophyll-a, transparency and primary production in coastal waters will become possible with the launch of the SGLI and the accumulated data over a long period of time will enable a proper judgement of the state of eutrophication in a specific area, providing valuable information for long-term coastal water management. This type of effort is currently in progress under the Marine Environmental Protection of Northwest Pacific Region which is jointly being implemented by the Ministry of the Environment and the Northwest Pacific Region Environmental Cooperation Center to assist the UNEP's North-West Pacific Action Plan (NOWPAP) using MODIS data processed by the JAXA. The high resolution data to be provided under the GCOM is expected to be a great asset for this work.

In addition to chlorophyll-a and primary production, suspended solids (SS) can be used as an indicator for the resuspension of sediment and deposits from land. This indicator is useful for the monitoring of sediment input to coastal waters, the volume of which declines with the construction of dams or due to other reasons, or increased input as a result of mining exploitation or coastal development. Coloured dissolved organic matters (CDOM) can be used as an indicator for freshwater inflow (salinity) on a very small scale, the measurement of which by other existing remote sensing technologies is difficult. Oil spills can also be detected based on changes of the sea colour.

As explained so far, it is believed that the high resolution ocean colour data to be provided frequently by the SGLI can be used for coastal water management. The problems emerging in coastal waters today are not restricted to Japan but world-wide and are especially noticeable and critical in coastal waters in Asia where development is currently taking place at a great speed. In this context, high resolution data which is obtained globally at a high frequency will play a very significant role in global level coastal water management.

5.6 Improved Prediction Accuracy of Crop Yields (Katsuo Okamoto: National Institute for Agro-Environmental Sciences)

5.6.1 Importance of Prediction of Agricultural Production with GCOM-C1

"Agricultural policies will become important issues for all governments. Agricultural research has two aspects. One is to increase the unit yield. The other is to swiftly and accurately assess crop production on a global scale to determine the best balanced food supply and demand." wrote Idso et al. in the journal *Science* in 1977. In the subsequent 30 years, there has been a succession of reports predicting an increase of the food demand due to the population growth of the world and the great impact of abnormal weather due to climate change on crop production in various parts of the world as if reinforcing the arguments put forward by Idso et al. In the process of climate change, extreme events of weather occur frequently. Because of its heavy dependence on imported food, the second aspect of agricultural research pointed out by Idso et al. carries significant weight for Japan. For Japan to ensure a stable food supply, it is essential to know the domestic and overseas production (short-term production) each year as soon as possible. As the short-term production can be calculated using the planted area for the year and the yield per unit area (unit yield), it is hoped that accurate prediction can be swiftly and objectively made using satellite remote sensing data. As the data provided by the SGLI to be mounted on the GCOM-C1 satellite will cover the entire globe for four days, it will be possible to monitor the situation of crop growth using this data.

5.6.2 Food Production and Biomass Energy Production

Increasing attention is being paid to biomass energy as a substitute to fossil fuels in order to reduce the emission volume of CO_2, one of the main GHGs believed to significantly affect climate change. Maize and sugarcane can be used raw materials for ethyl alcohol but are also types of food. While maize is consumed by human, a far greater quantity is consumed as animal feed. As such, maize is closely linked to the production of dairy as well as livestock products. Whether or not maize and sugarcane are used as food or raw materials for ethyl alcohol depends on socioeconomic factors. However, the modes of consumption greatly affect the food supply and demand situation and monitoring of the scale of the planting area and growth situation by the GCOM-C1/SGLI will be extremely important to predict the eventual production of these crops.

Meanwhile, palm oil has emerged as a strong candidate raw material for bio-diesel although palm oil is used as a raw material for detergent and edible oil. In the case of oil palm, the problem mainly lies with the cultivation locations rather than the right mix between its use as a food and its use as a biomass energy. As oil palm grows in the tropics, the cultivation sites must be created by cutting down tropical rain forests. Newly planted areas of oil palm are said to be entirely cut for replanting after some 25 years. This results in the contradiction that sites which can function as carbon sinks in the form of tropical rain forests are cleared to create farmland to restrain the use of fossil fuels. Observation of the tropics by an optical sensor is not very easy because of the high level of cloud cover. However, the use of the GCOM-C1/SGLI with a high observation frequency will make it possible to establish logging sites in tropical rain forests and to monitor the growth situation of maize and sugarcane.

5.6.3 Estimation of Crop Cultivation Area

At present, the planting area is estimated with an error margin of 10 – 20% using satellite remote sensing data. However, when the unit area for estimation is as small as an administrative area (for example, the area of a municipality in Japan), the error margin tends to be larger. Among the different types of cultivation sites, paddy fields for growing rice, the main staple food of the Japanese people, have the characteristic of being submerged during the planting season. Because of this characteristic, paddy fields can be easily distinguished from dry farmland growing other crops using data in the short wavelength infrared region provided by the GCOM-C1/SGLI. In general, the use of optical sensor data can more accurately estimate the rice-planted area than microwave sensor data. The problem is that rice cultivation areas in the tropical and temperate zones tend to have a high level of cloud cover during the cultivation period because of the monsoon climate. It has, therefore, been difficult to obtain reliable optical sensor data during the planting season which is suitable to detect planted paddy rice sites. The frequent observation by the GCOM-C1 will solve this fundamental shortcoming of the use of optical sensors. Moreover, this characteristic frequent observation capability will mean the provision of observation data throughout the cultivation period. Accordingly, it should be possible to prepare a classification map of various planted crops by combining observation data of suitable times, capitalising on the different cultivation period for each crop.

5.6.4 Estimation of Crop Growth Situation and Prediction of Crop Yield

An approach from the crop growth model is very effective to estimate the unit yield of crops. However, the use of such a model is restricted to a small area or site of which the parameters are known because of the large number of parameters to be input to the model and the lack of a global scale data set. Accordingly, the use of the satellite remote sensing technology is essential for the estimation or prediction of the unit yield for a wide area. Meanwhile, remote sensing data has a risk that different crop sizes due to different stages of growth may be mistaken for different sizes caused by different growth speeds as such data only shows an aspect of crop life at the time of observation. The high frequency observation by the GCOM-C1 can obtain observation data throughout the cultivation period, making it possible to distinguish different crop sizes due to different stages of growth and different crop sizes caused by different growth speeds. Such distinction can enhance the estimation accuracy of the growth situation of crops, leading to improved prediction of the eventual yield.

5.6.5 Research on Prediction of Agricultural Production and Contribution to Practical Application

The data provided by a high frequency, multiple wavelength observation satellite such as the GCOM-C1 is essential for the quick estimation or prediction of a cultivation area and yield of food, particularly main crops. The quasi-real-time prediction of the production for a year requires advance knowledge of (1) the location of farmland and grassland (land use and land cover classification), (2) which crop can be cultivated where (estimation of cultivation areas) and (3) which crop can produce how much (estimation of productivity). The GCOM-C1/SGLI will make a major contribution in these areas. When such information becomes available, it will be possible to achieve a stable food supply by means of studying (4) which crops are cultivated where in the current year (real-time planting classification) and (5) the expected/achieved crop yields (real-time estimation of production) every year.

5.7 Observation of Volcanic Fumes and Prediction of Geographical Scope of Influence (Minoru Urai: National Institute of Advanced Industrial Science and Technology)

Satellite images are a powerful weapon for the observation of volcanic fumes which spread over a wide area. These fumes contain volcanic ash which poses a serious threat to aircraft. Suspended volcanic ash in the air is a real problem in the North Pacific Region where important air routes pass over many active volcanoes. In a period of 12 years, at least 60 aircraft were damaged by suspended volcanic ash, seven of which experienced a fall of the engine output while in flight (Casadevall, 1993). Volcanic Ash Advisory Centers (VAACs) provide information, including the actual conditions and predictions, on volcanic ash along air routes to ensure the safe flight of aircraft from suspended volcanic ash blown into the air by volcanic eruptions. There are nine VAACs around the world which constantly monitor suspended volcanic ash using data provided by meteorological satellite and aircraft. For the satellite monitoring of volcanic ash, it is crucial to distinguish between volcanic ash and clouds. Prata (1989) proposed a method for this using the difference in temperature data provided by Channel 4 (10.3 – 11.3 μm) and Channel 5 (11.5 – 12.5 μm) of the AVHRR sensor on board the NOAA satellite. This method has subsequently been used for data provided by geosynchronous satellites and the MODIS (Tokuno, 1997 and Novak et al., 2007). Wen and Rose (1994) estimated the amount of suspended volcanic ash using the temperature difference data mentioned above provided by the AVHRR sensor. The height of the fumes following a large-scale eruption can be estimated using the minimum temperature obtained from infrared images of the fumes (Sawada, 1998). As the T1 channel (10.8 μm) and T2 channel (12 μm) of the SGLI sensor correspond to Channel 4 and Channel 5 of the AVHRR respectively, the techniques employed for the AVHRR data can be used for SGLI data. As the spatial resolution of 500 m of the T1 and T2 channels is higher than that of the AVHRR or MODIS, SGLI data should make it possible to detect volcanic ash with a higher spatial resolution.

Volcanic ash is said to damage crops even if only a few millimetres are deposited. When the thickness of the volcanic ash deposit is several centimetres, transport is paralysed and there is a risk to health. A volcanic ash deposit thickness of several tens of centimetres can cause houses to collapse. There have been many examples of establishing the distribution of fallen ash using visible light to near infrared satellite images. For example, the area of fallen ash due to the eruption of Mt. Usu in 2000 was observed using data provided by the ASTER, etc. At this time, satellite images identified the area of fallen ash which could not be trace by a ground survey (Urai et al., 2001). The amount of spewed volcanic ash is a useful value to assess the scale of an eruption. Satellite images are important to interpolate an iso-weight line diagramme for volcanic ash established by a ground survey. Meanwhile, aerial MSS observation provides data on an increase/decrease of the fallen ash distribution (Jitsubuchi, T. et al., 2002). Using the visible light to near infrared channels of the SGLI, it should be possible to detect areas of fallen ash.

To protect aircraft from volcanic ash, prediction of the movement of detected volcanic ash is important in addition to the detection of volcanic ash. Such prediction is also important to predict the overall amount of volcanic ash to fall. Searcy et al.. (1998) developed a model called "PUFF" to predict the movement of volcanic ash which is spewed into and suspended in the air following a volcanic eruption. This "PUFF" model predicts the vector of movement of particles in mini-scale time caused by wind, the gravity of particles and disturbance. The accuracy of 3D wind velocity and wind direction data and the accuracy of the particle size distribution of volcanic ash affect the prediction accuracy of volcanic ash movement.

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5.8 Forest Fire Detection (Haruo Sawada: University of Tokyo)

In 2000, some 360 million ha of the world's forest land and grassland were lost or damaged by forest fires. According to a report by the FAO, the number of forest fires is increasing worldwide. The annual loss of vegetation due to fire is estimated to be 5.1 billion tons and such a huge loss of vegetation is believed to be affecting the increase of CO_2 in the atmosphere. This is the reason why there is a strong argument in favour of firstly reducing the number of forest fires before planning an increase of the planting sites.

Forest fires are predominantly caused by human activities in all regions, for example, 95% in the Mediterranean area and 90% in South Asia. While the dry conditions of forest areas due to El Nino was a major cause of the large-scale forest fires which frequently occurred in Southeast Asia and other regions from 1997 to 1998, the lack of control of human activities in the fact of the dry conditions facilitated the occurrence of fire. Moreover, the failure to convey accurate information on the fires to the fire-fighting teams despite the importance of initial fire-fighting to effectively deal with a fire apparently exacerbated the scale of the damage.

The types of information which can be used as forest fire-related information are early warning information which can be used to issue a dry weather warning, early fire detection information enabling initial fire-fighting and a damage assessment map which is required for the rehabilitation of fire-damaged areas. Meanwhile, the risk of forest fires consists of the ignition risk, fire spread risk and fire-fighting difficulty. The ignition risk is directly attributable to human activities and the distance from residential areas and road network data are important factors to assess this risk. The fire spread risk means the risk of an ignited fire spreading and the degree of dryness of the vegetation and the weather are important factors to assess this risk. The fire-fighting difficulty is assessed in terms of the distance from the nearest road to the scene of a fire and the gradient of the land at the scene of a fire.

5.8.1 Early Warning of Forest Fires

The role of remote sensing in the early warning of forest fires is to improve the accuracy of information on the fire risk. The ignition risk and fire-fighting difficulty can be established based on GIS data. In the case of the fire spread risk which varies depending on the actual weather, mapping of the moisture content of the vegetation is effective as the moisture content can act as an indicator for the degree of dryness. Under the GCOM, the shortwave infrared SW3 channel of the IRS can be used for this purpose. As the ground resolution of this sensor is 250 m, it will be possible to prepare a detailed fire spread risk map which can be effectively used for the restriction of fire use and the prioritisation of patrol areas. However, a particular technique which is capable of generating prediction data through processing by a time-series model (use of the LMF-KF, etc.) will be required as it will be necessary to generate prediction data on the dryness of the vegetation. In regard to the fire spread risk, it is important to improve the fire spread risk assessment through the accumulation and feeding back of data. In this way, it is hoped that assessment of the fire spread risk will be improved at all levels, ranging from the global level to the national and regional levels.

5.8.2 Early Detection of Forest Fires

Early detection is extremely important to deal with forest fires which require swift initial fire-fighting. As early detection primarily depends on frequent observation, the GCOM alone will be unable to provide sufficient information. The forest fire early detection system in Japan ensures a high level of observation frequency through the use of all usable NOAA, TERRA and AQUA satellites and provides early detection data through the high speed processing of the original observation data. For the early detection of forest fires, the data provided by all of the relevant satellites should be used along with the GCOM satellite data to increase the observation frequency to make practical application of the early detection system possible. The thermal infrared IRS sensor has an advantage over other sensors in that its spatial resolution of 250 m is far higher than the spatial resolution of the NOAA/AVHRR (1 km) and others. Meanwhile, the thermal sensitivity of a maximum of 340 K is similar to that of the TERRA/MODIS.

5.8.3 Disaster Area Assessment

Areas which are subject to forest fires release CO_2 into the atmosphere in addition to the depletion of forest resources. Clarification of the degree of damage is important for the selection of the method to restore the forest environment. It is already known that the degree of damage can be established to a certain extent using the near infrared channel and far infrared channel. Estimation of the CO_2 volume corresponding to the degree of damage is an urgent task and it is hoped that the GCOM will act as an information source for the REDD (Reduction of Emission from Deforestation and Forest Degradation) which is to be implemented in the second commitment period in accordance with the Kyoto Protocol.

The GOFC-GOLD (Global Observation of Forest and Land Cover Dynamics) acts as a global information network for forest fires and is at the advanced stage of information accumulation and supply. The GCOM should consider intensive collaboration with the GOFC-GOLD.

5.9 Extreme Water Cycle Phenomena (Toshio Koike: University of Tokyo)

Serious water-related problems, such as disasters caused by heavy rain and water shortages, have been spreading throughout the world in recent years and the 21st Century is said to be a century of a water crisis. At the same time, there is much strong evidence that climate change is taking place due to GHGs which are being continuously emitted into the atmosphere through human activities. Observation data in the late 20th Century confirmed the trends of an increasing frequency of heavy rain, expanding geographical areas affected by drought and growing intensity of tropical depressions. Moreover, a prospect of the continuation of these trends in the coming years is suggested by integrated analysis of the outputs of many climate change prediction models. Changes of the water cycle at present and in the future, particularly such extreme phenomena as heavy rain and drought, can cause serious damage if they occur in areas which are vulnerable to disaster, including urban areas with a high population concentration and intermediate and mountainous areas with weak disaster resistance. As stated in the report entitled “Desirable Measures in the Water Disaster Field to Respond to Climate Change Caused by Global Warming” of the Panel on Infrastructure Development (June, 2008), strengthening of the monitoring and changes of the disaster-resistant social structure are required in addition to the conventional disaster prevention and disaster mitigation measures. One of these new measures should be the development of a scientific base to properly understand the mechanism of changes of the water cycle and to improve the accuracy of the prediction of likely changes to provide society with useful information to avoid water damage and crises.

The water cycle is an important sub-system of the global climate system along with the energy flow and the global and regional water cycles are closely related to hydrological phenomena at the basin level. In other words, precipitation and discharge to rivers at the basin level are strongly affected by fluctuations of the global water cycle. Accordingly, the development of a method which is capable of effectively downscaling water cycle fluctuation data at the global and regional levels to prediction data at the basin level will be extremely useful to deal with the problems of basin-level flooding and water shortages.

Meanwhile, the development of not only a prediction system but also an observation system has been very slow in developing countries. The 10 Year Implementation Plan for the Global Earth Observation System of Systems (GEOSS) agreed at the Third Earth Observation Summit (February, 2005) encourages the access of developing countries to data and models, calling for the strengthening of capacity development for disaster damage mitigation and environmental improvement through the provision of useful information and methods using earth observation data and global scale prediction models. Furthermore, the G8 Hokkaido Toyako Summit Leaders Declaration clearly states that “we will continue to enhance the cooperation with developing countries, particularly the most vulnerable countries, for their efforts to adapt to climate change, including disaster risk reduction”. One way to achieve these objectives is to develop a method which is capable of providing data for country and basin level predictions using earth observation data and for water cycle fluctuation predictions at the global and regional levels.

For sound decision-making regarding the reduction of flood or drought damage, it is necessary to downscale global and regional level data for prediction to data for local level prediction. To achieve this, the conventional numerical weather prediction models use a method which combines the statistical characters of the rough grid level model outputs for nesting or wide area prediction with the statistical characters of local observation data for the target area. However, this method cannot obtain important initial values for short-term numerical prediction, such as vapour content and cloud water content in the atmosphere and the soil moisture content and other hydrological data for land areas, with physical consistency corresponding to a small target area. As a result, the effective use of wide area prediction data for small area prediction with high accuracy has been difficult. The principal reasons for this are the difficulty of estimating the soil moisture content on a global scale and the absence of a reliable method to express the estimated soil moisture in a numerical model. Other reasons include the absence of a quantitative observation method for the vapour and cloud water contents above land areas even though such a method has been developed for its inclusion in numerical models for ocean areas.

In the case of long-term numerical prediction, modelling of the boundary conditions with physical relevance and stability is essential. The boundary conditions for a global model are the ocean surface and ground surface. In regard to the ocean surface, efforts have been made to establish physically consistent boundary conditions by means of integrating ocean and atmospheric models. In regard to the ground surface, many models have been proposed to describe the vertical one-dimensional energy and water flow. The systems developed, however, are a kind of one-way street in that a ground surface model is developed with a limited data set selected for its application to numerical prediction because of its global applicability and that the prediction results are verified by actual observation data despite the fact that sufficient accuracy is not guaranteed regarding the diversity of the land surface, particularly the physical characteristics of the soil and seasonal changes of the vegetation. Hardly any efforts have been made to improve the prediction accuracy through two-way examination, i.e. identification of model parameters under the condition where the observation data is consistent with the model outputs.

Under these circumstances, it is essential to develop earth observation and downscaling methods capable of effectively incorporating global and regional data on changes of the water cycle observed by satellites and then to provide quantitative local water cycle data which can be used for concrete measures. For improvement of the prediction accuracy of extreme phenomena on a basin scale and the provision of adequate data for river and water resources management based on the prediction data, it is also necessary to develop a data integration and analysis system which is capable of providing the necessary data by means of integrating global and regional data to data which can be used for decision-making on the concrete local measures mentioned above.

5.10 Environment (Yoshifumi Yasuoka: National Institute for Environmental Studies)

The concept of "the environment" is quite broad and satellite observation of the environment includes many fields and phenomena. Here, the focus is placed on the gathering of useful information to solve continental-scale environmental problems, especially those relating to the land, ocean and atmosphere in Asia, in view of the wide area, high frequency and multiple wavelength observation functions of the GCOM sensors. The acquisition of scientific and basic information is essential to solve environmental problems in individual fields. As GCOM satellite observation relating to individual subjects is described in 3., this section only deals with observation contributing to solutions to environmental problems of a regional to continental scale which are expected to be present at the time of the launch of the GCOM satellite. The GCOM sensors are considered to be the successors to such wide area, high frequency sensors as the AVHRR and MODIS, and the inheritance and further progress of the observation conducted by these sensors are emphasised. There are many parameters, including those listed below, relating to "the practical use of the environment" of which observation is expected to be conducted under the GCOM Project.

Land	:	detailed land cover; vegetation classification; plant seasons (phenology; crop classification and growth stages; forest fires; net primary production; snow cover; water stress trend; ground surface temperature
Ocean	:	chlorophyll-a concentration; amount of planktons; clarity; suspended solids concentration; basic production; red tide and blue tide; freshwater HAB; aquatic plants; sea surface temperature; water surface temperature
Atmosphere	:	aerosols; clouds (including cloud types); rainfall; precipitable water

Below are parameters selected from the viewpoint of their possible practice use in the near future.

5.10.1 Land

5.10.1.1 Evaluation of Wide Area Vegetation

Many continental-scale vegetation maps are already available based on data provided by various satellites. However, they are not necessarily suitable for practical use because of the small number of plant species listed or insufficient classification accuracy. Given the superior specifications of the GCOM/SGLI compared to the sensors in use so far, it is possible to aim at preparing a vegetation map for practical use. To be more precise, work will be conducted to expand the Green Census Map (Vegetation Distribution Map of the Basic Study on Natural Environmental Conservation) of the Ministry of the Environment, which is said to be the most detailed vegetation map in the world, to cover Asia (Asia vegetation map). A level of vegetation which can be properly identified based on phonological data created from time-dependent satellite data will be set by selecting 20 – 50 plant species.

5.10.1.2 Evaluation of Urban Heat Environment

There is very strong concern that the adverse impacts of global warming on urban areas will manifest in megacities in Asia along with the phenomenon of urban heat island (UHI). The

SGLI is capable of measuring the ground surface temperature distribution in consideration of the emissivity using thermal infrared multi-wavelength band data. The preparation of an urban heat environment map for the world's megacities will allow the clear identification of UHIs and evaluation of remedial measures.

5.10.2 Ocean

5.10.2.1 Red Tide Monitoring

Recent years have seen the increased occurrence of red tide due to eutrophication in coastal sea areas in developing countries in Asia. Red tide not only damages fisheries but also causes the considerable deterioration of the coastal environment. The development of the practical capability to monitor, evaluate and predict red tide is essential. As the SGLI has wavelengths to observe chlorophyll-a and planktons, the preparation of a water temperature, chlorophyll-a and plankton distribution map will greatly assist the semi-real-time monitoring of red tide.

5.10.3 Atmosphere

5.10.3.1 Atmospheric Pollution Map

The quantity of substances released into the atmosphere has been constantly increasing due to the growing intensity of economic activities in developing countries. The increase of aerosols into the atmosphere is said to be closely linked to global warming and there is concern in regard to the adverse impacts of photochemical smog on human health at the level of daily life.

Meanwhile, another problem of atmospheric pollution is attracting attention. This involves the long-range transportation of dust lifted into the air as a result of the progress of desertification and other causes. The arrival of yellow dust in Japan from China is one such example. As this kind of cross-national boundary pollution via the atmosphere covers a wide area, monitoring and evaluation by means of satellite observation are essential. The SGLI has a waveband which is capable of observing air constituents and it is hoped that such observation will lead to the preparation of an air pollution map (meteorological chart).

5.10.3.2 Vapour Distribution

Global warming in recent years has increased the precipitable water in the atmosphere. Although precipitable water does not proportionally determine the level of rainfall, the availability of a precipitable water map can play an important role in meteorological forecasting. While precipitable water has so far been observed by radiosonde balloons and GPS satellites, the observation network does not fully cover developing countries. The thermal infrared data of the SGLI will enable the estimation of precipitable water and it is hoped that the relevant wide area observation will materialise. More accurate weather observation will also be possible through combination with the rainfall observation data provided by the AMSR-E satellite sensor and the GPM satellite system.

6. Observation Objectives and Products of Onboard Sensors

6.1 AMSR2 (Keiji Imaoka: Japan Aerospace Exploration Agency)

6.1.1 Objectives

6.1.1.1 Observation of the Earth Environment

The GCOM-W satellite will be responsible for the long-term continual observation of the global water and energy cycles, including those in the polar regions, as part of the overall objectives of the GCOM to monitor and to develop a further understanding of climate change. To be more precise, it will observe (i) the cryosphere where sea ice, ice sheets and snow cover are said to manifest the signs of global warming most significantly before anything else, (ii) changes of the sea surface temperature, precipitation and vapour content, typically associated with El Nino, as a result of the interaction between the atmosphere and oceans and (iii) sea wind and soil moisture to quantitatively establish the water and energy exchanges involving the atmosphere, oceans and wind because of the need for data on such exchanges to properly understand various aspects of climate change.

Such wide-ranging observations will require a system which is capable of quantitatively measuring the entire globe accurately and frequently. Observation using a microwave radiometer which receives microwave radiation from the earth's surface and the atmosphere is suited to quantitative observation as the data contains volumetric and surface information on the atmosphere, clouds, snow cover and soil because of the high level of transmission of microwaves. Because the measurement is not that of reflected sunlight, it has the advantages of night-time and polar region observation. A microwave radiometer can, therefore, achieve frequent observation of the targets under cloud cover, capitalising on the high level of transmission of microwaves. The AMSR2 onboard the GCOM-W will inherit the missions of the AMSR and AMSR-E and will continue observation of the sea surface temperature, sea surface wind velocity, vapour content, cloud liquid water, precipitation, sea ice concentration, snow water equivalent and soil moisture. The emphasis of the AMSR2 will be the continuation of the observation currently conducted by the AMSR-E so that uninterrupted data sets can be produced based on long-term observation for some 20 years by three generations of microwave radiometers, i.e. ADEOS-II/AMSR, Aqua/AMSR-E and GCOM-W/AMSR2.

6.1.1.2 Contribution to Society

High sensor accuracy and stability are imperative to achieve the effective monitoring of climate change while the steady provision of data to and collaboration involving scientists, climate model development organizations and other stakeholders are essential for a proper understanding and prediction of climate change. To achieve these, a system which is capable of swiftly processing the observation data and distributing the processed data to all organizations concerned is required. The processing of satellite data should be conducted along with the processing of ground station data in an integral manner.

There is a growing demand for continually observed, reliable satellite data for such practical applications as numerical weather forecasting and fisheries. The AMSR-E data is already being used for the long-term observation of the sea surface temperature not affected by cloud and also for weather forecasting, especially the prediction of the precipitation level in association with typhoons and heavy rain. For these purposes, the supply of uninterrupted time-series data as well as quasi-real-time data is required.

6.1.1.3 Relationship with Other Missions

It is impossible for a single polar orbit satellite to gather a sufficient quantity of data on such fast changing phenomena as precipitation and clouds for practical application. Even for a long-term observation mission, such as the monitoring of climate change, there is a limit to the achievable accuracy by a single polar orbit satellite because of sampling errors and differences in climate change signals caused by biased local times for observation. Because of this, the GCOM will be mutually complementary to such satellite system as the JPSS (Joint Polar Satellite System).

6.1.2 Products and Development of Algorithms

6.1.2.1 Products

The products based on AMSR2 data are explained next.

(1) Brightness Temperature

The brightness temperature is a basic quantity to be used as an input to estimate physical quantities and can be directly used for the time-series analysis of a land area or ice sheet. In the recent assimilation process of numerical models, there is a tendency for the direct assimilation of the brightness temperature to prepare better initial values. For this reason, it is essential that the brightness temperature is strictly calibrated so that it can be prepared and supplied as a stable product.

(2) Atmosphere

The standard products relating to the atmosphere will be the vertically integrated water vapour content and cloud liquid water and the precipitation amount covering the ground surface. In addition, the vertical profile of the precipitation amount using multi-frequency data will be estimated for research purposes. Water vapour is a major element in the large-scale water cycle and is also the gaseous body with the highest greenhouse effect on the earth. As suggested by satellite data provided by the Microwave Sounding Unit (MSU) and SSM/I, the water vapour content is understood to increase in accordance with a temperature increase. Meanwhile, the phenomenon of precipitation plays the role of returning water to the earth's surface and precipitation data is indispensable for computation of the fresh water flux. Precipitation is also important as a source of energy supply to the atmosphere through the release of latent heat. Changes in the phenomenon of precipitation due to climate change directly affect human activities in terms of water resources and water disasters and, therefore, precipitation data is very important from the viewpoint of daily life. Data on the precipitation amount and data on the water vapour content are already used by numerical weather forecasting models.

(3) Ocean

The ocean-related standard products will be the sea surface temperature and sea surface wind speed. The former is a physical quantity which can indicate natural fluctuations, such as El Nino, and is considered to constitute an index for global warming. The AMSR2 will enable frequent observation of the sea surface under non-precipitating clouds utilising the characteristic of microwave observation. Its operation is not affected by clouds or volcanic aerosols and is mutually complementary to infrared observation in terms of the observation error. The AMSR2 can, therefore, improve the monitoring accuracy of climate change through combined observation with infrared sensors. Sea surface wind data is essential for estimation of the energy flux and CO_2 flux between the atmosphere and ocean. Both sea surface temperature data and sea surface wind speed data are useful for the monitoring and prediction of the generation, central position and intensity of typhoons and, therefore, are vital for actual meteorological observation and forecasting.

(4) Cryosphere

The standard products related to the cryosphere will be the sea ice concentration and snow accumulation on the land area. The AMSR2 is also capable of estimating the sea ice thickness for research purposes through combination with other satellite observation data (polarisation ratio by the SAR and observation by a laser altimeter). The receding sea ice area, snow cover and ice sheets are believed to be early signs of global warming. Detection of their changes by satellite monitoring is relatively easy. Accurate understanding of the distribution of sea ice, snow cover and ice sheets is essential as they not only greatly change the amount of heat transport by providing thermal insulation between the atmosphere and the earth's surface but also affect the radiation balance through the albedo effect. In addition to the distribution, data on the state of freezing and melting is required along with thickness data. For example, the amount of heat transport from the sea ice surface to the atmosphere considerably depends on the ice thickness, making estimation of the ice thickness, especially in thin ice areas, very important. For observation of the Antarctic ice sheet and the ice shelves at its edges, the brightness temperature is directly used. For an ice sheet made of pure water, the penetration depth greatly varies depending on the observation frequency. The depth is believed to be approximately 10 m in the case of the 7 GHz channel while it reflects the temperature near the surface in the case of the 89 GHz channel. The use of a high frequency can track the short-term phenomenon of a rising temperature while the use of a low frequency can retrieve signals roughly indicating the mean annual temperature reflecting the state of the temperature over a longer period.

(5) Land

The standard products relating to land will be the soil moisture content and snow water equivalent already mentioned in 2) Cryosphere. The water content of vegetation and the ground surface temperature will also be measured for research purposes. The behaviour of soil moisture determines the level of evapotranspiration and recharging level of groundwater, affecting the water cycle on land. However, the wide area, quantitative measurement of these phenomena is impossible without the use of a satellite. For this reason, the observation data of the AMSR2 will play an important role in the improvement of medium to long-term weather forecasting and the prediction of climate change. Similarly, the ground surface temperature determines the water and heat balance on land and is considered to be an indicator for global warming. As the soil moisture and ground surface temperature are factors affecting the vegetation, this data should prove useful for the observation of vegetation by the GCOM-C/SGLI.

Standard products are the results of the routine processing of entire data for general distribution. In contrast, research products are experimental products for research purposes and include prototype versions of standard products. The decision on which types of research products are to be produced is made based on the latest observation outcomes. The classification of standard and research products is based on the stage of progress of algorithm development and the validation results after satellite launch. Table 6.1.1 lists the standard products of the AMSR2. R & D on research products will be conducted based on a new concept or necessity or through the combination with other satellite/sensor data and the likely research products at present including the following.

- Integrated cloud liquid water over sea ice areas and land areas
- Precipitation over cold latitudes
- Sea ice thickness
- All-weather sea surface wind speed
- Hydrological assimilation data over land area

Table 6.1.1 Standard Products of the AMSR2

Product[*1]		Areas	Resolution	Accuracy[*2]				Remarks
				Data Release[*3]	Standard[*4]	Goal[*5]	Range	
Geophysical Quantities	Brightness Temperature (6 Frequency Channels and 2 Polarised)	Global	5-50 km	± 1.5 K	± 1.5 K	± 1.0 K ± 0.3 K	2.7~340 K	System error (maximum amplitude; 150 K equivalent) Fluctuation error (3σ; 150 K equivalent)
	Integrated Water Vapour	Global, over ocean	15 km	± 3.5 kg/m²	± 3.5 kg/m²	± 2.0 kg/m²	± 0~70 kg/m²	Vertically integrated amount; excluding sea ice and precipitation areas
	Integrated Cloud Liquid Water	Global, over ocean	15 km	± 0.10 kg/m²	± 0.05 kg/m²	± 0.02 kg/m²	0~1.0 kg/m²	Vertically integrated amount; excluding sea ice and precipitation areas
	Precipitation	Global, except cold latitude	15 km	Ocean: ± 50% Land: ± 120%	Ocean: ± 50% Land: ± 120%	Ocean: ± 20% Land: ± 80%	0~20 mm/hr	Precipitation amount on ground surface; relative error for an average of 50 km (ratio of RMSE to mean

		s						precipitation intensity)
	Sea Surface Temperature	Global, over ocean	50 km	± 0.5°C	± 0.5°C	± 0.2°C	-2~35°C	Excluding sea ice and precipitation areas; target accuracy is mean monthly bias value per 10° latitude
	Sea Surface Wind Speed	Global, over ocean	15 km	± 1.5 m/s	± 1.0 m/s	± 1.0 m/s	0~30 m/s	Excluding sea ice and precipitation areas
	Sea Ice Concentration	Polar regions, over ocean	15 km	±10%	±10%	±5%	0~100%	Accuracy is indicated by sea ice concentration (%)
	Snow Depth	Land	30 km	± 20 cm	± 20 cm	± 10 cm	0~100 cm	Excluding ice sheet and dense forest areas; accuracy is shown in terms of snow thickness which is expressed as the absolute mean error of instantaneous values
	Soil Moisture	Land	50 km	± 10%	± 10%	± 5%	0~40%	Volumetric moisture content in global land areas (including arid and cold areas) where vegetation cover is equivalent to a moisture content of 2 kg/m^2 or less; excluding ice sheet and dense forest areas; accuracy is shown as the absolute mean error of instantaneous values

*1 The brightness temperature is the conversion of the sensor's engineering output to the most basic observation value while geophysical quantities are the results of the conversion of the brightness temperature via the respective conversion algorithm.

*2 Unless otherwise stated, the accuracy is shown as the root mean square error (RMSE) of the instantaneous values. The accuracy of the brightness temperature depends on the onboard and ground calibration accuracy. The accuracy of geophysical quantities depends on the accuracy of the brightness temperature, performance of the relevant conversion algorithm and the validation method.

*3 The minimum level of accuracy for the release of data which can contribute to the analysis of climate change

*4 Useful and standard level of accuracy, taking the past performance of the AMSR and AMSR-E into consideration

*5 Level of accuracy containing many issues for further research in relation to the performance of the algorithm and calibration accuracy, etc.

6.1.2.2 Algorithms

(1) Target Algorithms

1) Products

Algorithms will be developed for each of the standard products listed in Table 6.1.2.1-1 and research products to be described later.

2) Processing Levels

The assumed processing levels are shown in Table 6.1.2

Table 6.1.2 Processing Levels of AMSR2 Data

Processing Level	Definition
1A	Storage of sensor output engineering values; satellite altitude and position data, sensor status data, brightness temperature conversion factor, latitude/longitude information for each observation point and other; no map projection
1R	Level 1A data converted to the brightness temperature for storage; no map projection
1R	Spatial resolution matching for Level 1B1 data
2	Computed geophysical quantities from Level 1B/1C data; no map projection
3	Temporal-spatial statistical processing of Level 1B/1C data and map projection

(2) Level 1 Algorithms

Various codes and algorithms are required to produce Level 1 products, and the main algorithms related to data directly accessed by users are explained below.

1) Brightness Temperature Computation Algorithm

This algorithm computes the brightness temperature from the engineering values observed by the AMSR2 and the inputs are the observed and calibrated count values, monitored physical temperature values and others. The radiometric model and related factors are decided prior to satellite launch based on the ground sensor test and analysis results. Further adjustments are made during the on-orbit calibration prior to the supply of data for processing.

2) Geometric Data Computation Algorithm

This algorithm computes the observation position, angle of incidence and others of the AMSR2 using the observation geometry of the sensor and satellite altitude as well as position data. The geometric model for the sensor and related factors are determined prior to launch based on the satellite and sensor design data and ground test and analysis results. Further adjustments are made during the on-orbit calibration to supply data for processing.

3) Quality Information Adding Algorithm

This algorithm computes the data quality for each observation point, scan and file of the AMSR2 so that the computation results can be attached to products in the form of a quality flag, etc. The AMSR2 will newly add a quality flag to radio wave interference using 6.925 GHz and 7.2 GHz.

4) Spatial Resolution Matching Algorithm

The spatial resolution of a microwave radiometer considerably varies depending on the frequency channel because of its principles of observation. When a geophysical quantity is computed through a combination of several frequencies, the difference in the spatial resolution between the different frequencies must be taken into consideration. This algorithm ensures that the Level 1R products have a matched spatial resolution for various frequencies for their convenient use.

(3) Level 2 Algorithms

The priority issues for future research are described below for algorithms to compute Level 2 geophysical quantities for products which are considered to be standard products at present.

1) Integrated Water Vapour

The development of an improved version of the algorithm used by the AMSR-E is necessary in view of the likely collaboration for quality evaluation and a data assimilation technique utilising the outputs of the current numerical weather forecasting systems. The reliable algorithms to be developed will be used for (i) estimation of the integrated water vapour based on accurate temperature, vapour and sea surface wind data using the analytical or forecast values produced by a high resolution numerical weather forecasting model assimilating GPS occulation observation and a microwave scatterometer, (ii) improvement of the estimation accuracy in areas with thick cloud cover or precipitation and (iii) analysis of long-term changes.

2) Integrated Cloud Liquid Water

As recently launched satellites carry a cloud radar and/or lider, it is becoming possible to obtain global data on the vertical distribution of clouds. A new algorithm to compute vertical integrated cloud liquid water using such data will be developed as an upgraded version of the algorithm used by the AMSR-E.

3) Precipitation

Further improvement of the algorithm for scattered precipitation, which restricts the accuracy of estimation in the torrid zone through temperate land and frigid zone, is essential. To be more precise, improvement is required in regard to the radiative transfer models which consider non-spherical ice crystals, land-precipitation retrieval over various types of surfaces, such as snow areas, retrieval of solid precipitation in high latitude areas and effective use of ancillary data, including objective analysis data. It is hoped that the precipitation algorithm of the AMSR2 is a general algorithm which can be used for similar sensors in consideration of its use in the GPM Plan.

4) Sea Surface Temperature

Estimation of the sea surface temperature by the AMSR2 will be an effective method of all-weather observation. The development of a more accurate algorithm is essential through precise surface emissivity modelling which will consider such environmental conditions as the temperature difference between the sea surface and atmosphere, sea surface wind direction and others based on the algorithm used by the AMSR-E. The possibility of improved accuracy will be examined using the 7.3 GHz channel to be newly added to the AMSR2 for reduction of the impact of radio wave interference and other purposes.

5) Sea Surface Wind Speed

As in the case of the sea surface temperature, the development of a model to estimate the precise sea surface-emissivity which is capable of considering various sea environment conditions, including the precise correction of the sea surface wind direction, is required. The progress of research to estimate the sea surface wind speed using such low frequencies as 7 GHz and 10 GHz in any weather conditions may lead to the development of a research product.

6) Sea Ice Concentration

Improvement will be sought primarily for reduction of the land effects, reduction of the atmospheric effects and a better estimation accuracy of the sea ice concentration in thin ice areas using the Bootstrap algorithm and NASA Team algorithm, both of which are typical sea ice concentration computation methods at present, as the base. The processing of data over thin ice areas is linked to not only the improved estimation of the sea ice concentration but also the accuracy of the ice thickness estimation affecting the amount of heat transport between sea ice and the atmosphere. Therefore, much care is required in regard to these areas.

7) Snow Depth

There is much room for improvement of the quantitative estimation of the snow depth. To be more precise, such estimation must take into consideration the state of the soil under snow cover, distinction between snow cover and dry cold areas without snow cover and continual estimation from the dry snow season to the snow melting season, particular the impacts on vegetation due to snow on the crowns.

There is sufficient ground observation data to achieve the required improvement and it will be necessary to continue intensive observation as well as long-term fixed point observation.

8) Soil Moisture

Estimation of the soil moisture has much progressed with the introduction of the AMSR-E. However, the computation of highly reliable global soil moisture data will require the development of (i) a flexible algorithm which is capable of dealing with different soil textures, surface roughness and vegetation types, (ii) a method which is capable of continually computing changes of the soil moisture, starting from the snow melting process, and (iii) a method to estimate the soil ice content in cold regions (monitoring of the permafrost zone).

6.1.3 Calibration and Validation

6.1.3.1 Calibration

(1) Pre-Launch Calibration

The sensor characteristics relating to calibration will be identified to make the ground test and test items reflect such characteristics. If necessary, correction methods will be examined for their application to the sensor models for brightness temperature correction and geometric correction which determine the inputs to the Level 1 (brightness temperature) processing algorithm.

(2) Validation of Initial Calibration

1) Calibration of Brightness Temperature

As there is a de facto lack of a method to evaluate the absolute brightness temperature, the final calibration will be conducted based on the general assessment of the compatibility of the results of the following calibration evaluation methods.

① On-Orbit Calibration

On-orbit calibration will be conducted as two-point calibration using low and high temperature calibration source data. Firstly, the characteristics of each calibration source data will be established through comparison with various types of telemetric data. Optimisation will be conducted through the adjustment of the sensor model factors or the introduction of a new model. In the case of low temperature calibration sources, the contribution by the earth, moon and satellite body, excepting the contribution by deep space, will be removed. In the case of high altitude calibration sources, adjustments will be made with a model computing the effective radiant temperature from the telemetric data on the calibration source temperature.

② Deep-Space Calibration

Using the observation result for the deep-space temperature retrieved by deep-space calibration manoeuvring, low temperature absolute calibration (checking of the compatibility between the main mirror and CSM), evaluation and correction of the scan bias and evaluation of the spill-over amount (TBD) will be conducted.

③ Multiple/Mutual Calibration

Because of the absence of an ideal target for absolute calibration on the earth, mutual calibration with a group of similar microwave radiometers in operation during the lifetime of the AMSR2 will be conducted along with comparative validation using both ground observation data and the observation data of other sensor and radiative transfer calculation results.

④ Sensor Characteristics and Data Quality Evaluation

The scan bias and inter-scan bias, such sensor characteristics as the differences between individual receivers (89 GHz A + B systems, 6.9 – 7.3 GHz, etc.), temperature resolution and stability of gains will be evaluated through the statistical processing of the observation, calibration and telemetric data. In addition, the global distribution and frequency of abnormal values caused by artificial radio waves will be evaluated and an appropriate abnormal values removal method will be decided.

1) Geometric Calibration

Evaluation of the geometric accuracy will be conducted by means of comparing the observation data for each channel and pre-set mapping information on coastal lines, islands and others. The evaluation results will then be used to adjust the alignment data of the sensor model and registration parameters between different frequencies.

(3) Constant Calibration and Validation

In addition to the constant implementation of the initial calibration and validation work, constant monitoring of the telemetric and calibration data, brightness temperature of such specified areas as tropical forests, ice sheets, oceans and others will be conducted to evaluate the long-term stability of the sensor performance. The trend evaluation results of the geophysical quantities may be inversely used for the calibration of the brightness temperature.

6.1.3.2 Validation

(1) Integrated Water Vapour

Validation of the integrated water vapour will primarily be conducted using the worldwide radio-sonde network. When judged necessary, validation will also be conducted using ground-based microwave radiometers on remote islands, ground-based GPS receivers and LEO GPS occulation observation. A quality survey will also be conducted by means of comparison with other GPM satellite observation data and the use of operational numerical weather forecasting system data.

(2) Cloud Liquid Water

The planned activities include comparative validation with the remote sensing observation data provided by ground-based microwave radiometers, radars and ceilometers to measure the cloud bottom height. Comparison will also be conducted with the analysis results provided by operational numerical weather forecasting systems.

(3) Precipitation

Precipitation is characterised by considerable temporal-spatial fluctuations and is one of the geophysical quantities which is difficult to directly compare with ground observation data. In principle, the existing operational ground-based radar network and a group of ground-based hydrometers will be used for validation. Comparison of the AMSR2 data with the data provided by satellite-based precipitation radars if the observation periods converge will be important because of questions regarding the accuracy and uniformity of ground-based data.

(4) Sea Surface Temperature

Validation will basically be conducted by comparison with the water temperature observation data supplied by globally deployed fixed and drifting buoys. Comparison with the sea surface temperature data simultaneously produced by satellite-based infrared radiometers will assist the validation, especially in the initial observation period, of the global sea surface temperature and evaluation of the characteristics and error distribution of different datasets.

(5) Sea Surface Wind Speed

Validation will primarily be conducted by comparison with the wind speed data supplied by globally deployed fixed buoys. If a satellite-based microwave scatterometer is operational during the same observation period, comparison with its data will also be important.

(6) Sea Ice Concentration

Validation data based on various types of sea ice, seasons and sea areas will be required to adjust the algorithm parameters and to validate the AMSR2 observation data. In particular, validation of the data for the Sea of Okhotsk will be important to validate data for thin ice areas. To be more precise, validation datasets starting from ground level must be developed through synchronised multi-stage observation involving ships, airplanes and satellites. The comparison of satellite data with a high resolution of several to several tens of meters will be particularly important.

(7) Snow Depth

Validation must be conducted under three different conditions to improve and validate the algorithm as mentioned earlier in the section explaining the Level 2 algorithm for snow depth. Firstly, highly accurate physical validation will be conducted through observation by ground-based microwave radiometers at sites where the snow cover conditions, characteristics of the bottom face of the snow cover and vegetation conditions can be quantitatively established. Next, the AMSR2 data will be actually validated through the intensive observation of the snow parameters in satellite footprint size validation areas. Finally, the observation will move to the long-term validation phase while continuing observation at sites of different climate, vegetation and soil types.

(8) Soil Moisture

The validation of soil moisture data must consider three points for the purpose of improving and validating the relevant algorithm. Firstly, the validation must take the microwave radiation transmission characteristics which differ depending on the soil moisture conditions, ranging from dry to wet, into consideration. Next, the validation must consider the different soil types (ground surface roughness and texture). The difference in roughness greatly affects the ground surface scattering while the difference in texture greatly affects the volumetric scattering in soil. Finally, the validation must consider the different vegetation conditions (amount of vegetation, type of vegetation and unevenness of vegetation cover). Evaluation of the vegetation conditions is extremely important as the AMSR2 uses the C band which is susceptible to the state of vegetation.

6.2 SGLI (Hiroshi Murakami: Japan Aerospace Exploration Agency)

6.2.1 Objective of the Development of GCOM-C/SGLI Algorithms

The primary objective of the GCOM-C/SGLI is to produce products which will be used as input data to contribute to the understanding of the physical processes and prediction of climate change as part of the GCOM's overall objective of monitoring and understanding climate change. These products are also essential for various monitoring activities, including the retrieval of highly accurate data on the physical quantities of vegetation, determination of the global distribution of aerosols over land, detailed observation of rapidly changing coastal areas and detection of signals for climate change emerging in the cryosphere. For this reason, emphasis will be placed on the long-term continual observation of the changing values of the parameters for global observation, such as the global radiation balance and plant production which affects the carbon cycle and food production, and also on observation of the impacts of human activities as well as climate change utilising such characteristics of the SGLI as the wide observation wavelength range from near ultraviolet to thermal infrared, spatial resolution of 250 m and multi-directional observation. The objective of the development of GCOM-C/SGLI algorithms is to produce the above-mentioned products with sufficient accuracy (the target accuracy level is described in the Calibration and Validation Plan document) for the application purposes.

6.2.1.1 Algorithm Development Policies

- The target algorithms will be efficiently developed utilising <u>the development outcomes and experience of the ADEOS-II/GLI.</u>

  - Actual satellite data from the ADEOS and ADEOS-II and the relevant data processing algorithms will be utilised to efficiently develop algorithms for the GCOM-C/SGLI, including improvement of the existing algorithms. Advance research using ground-based observation data and simulation data will be conducted in relation to the development of new algorithms.

  - A system capable of analysing, modifying and making improvement proposals will be established within the JAXA to ensure efficient algorithm development, achievement of the required accuracy and feedback for the development of products in the future (similar to the GLI Algorithm Integration Team (GAIT) of the ADEOS-II mission).

- <u>External researchers will be recruited as principal investigators (PIs)</u> so that efficient joint R & D work with researchers of the JAXA will achieve the development of new algorithms, application of existing algorithms to the SGLI and improvement of the product accuracy in an assured and effective manner.
- For the monitoring of and research on climate change, the developed algorithms will have <u>taken into consideration the need to establish uniform, stable and highly accurate datasets covering a long period</u> with GCOM (three generations) data at the core.

  - For the establishment of the datasets mentioned above, the calibration and validation results, particularly the mutual calibration and validation results for data supplied by three generations of GCOM satellites and related satellites, will be fed back to improve the algorithms.

- Algorithms will be developed with the practical use of products in mind.

  - The integrated use of products will be facilitated in consideration of their general contribution to the GEOSS-GEO information system and others. To be more precise, the development efforts will include compounding with data supplied by related satellites using GCOM data as the core data, definition of and data structure for physical quantities in consideration of compatibility with numerical models and intimate information sharing with organizations developing models and development of interfaces for such information sharing.

  - Various activities will be conducted to facilitate the practical use of products. These will include improvement of the data reliability, supply of detailed data to organizations using products for operational purposes, development of interfaces with such organizations and proposal for advanced product application methods.

  - The feasibility of the practical use of satellite data will be demonstrated using actual examples of the use of data for the prediction of climate change and other purposes. The identified needs and obtained knowledge through such demonstration will be fed back for algorithm development.

  - The user confidence in the datasets will be enhanced through the continual preparation of datasets.

- Processing software capable of conducting steady processing will be prepared for the smooth distribution of data for swift analysis.

- New data analysis and utilisation methods will be developed to expand the application scope of satellite remote sensing in the future observation of the global environment.

- As the accuracy and quality of products reflect the overall performance of the process from satellite-based data gathering to processing on the ground, algorithms reflecting the design and development results of satellite-based sensors will be developed if necessary. The development outcomes of such algorithms may be fed back to the development process of satellite-based sensors.

6.2.1.2 Algorithm Development Procedure

(1) Basic Procedure

There are three types of algorithms at present. The first type determines output values by empirically linking input data and output data (first generation of algorithms). The second type determines output values using the radiation process in a positive manner (such as a radiation transmission model) (second generation of algorithms). The third type determines output values by making the physical, biological and chemical processes into a formula or model (third generation of algorithms). While the weight of an individual step of algorithm development differs depending on the type of algorithm, an algorithm is generally developed in accordance with the steps described below. In line with the progress of algorithm development, an algorithm theoretical basis document (ATBD) will be prepared and revised.

1) Creation of Basic Database

The data for quantities to be developed as products will be directly observed in-situ and will be linked to the radiance of each wavelength channel. When the in-situ measurement of a target quantity is difficult (cloud characteristics, etc.), the direct satellite remote sensing of the radiance will be used as a substitute observation method. When dealing with such a complicated system as the ecosystem, multiple steps may be combined based on a theoretical model or a numerical model may be used. At this step, the feasibility of the algorithm under development and the likely level of accuracy of the satellite products can be confirmed to a certain extent.

2) Correction of Atmospheric Effects

When physical quantities on the ground surface are targeted, the radiation transmission codes of the RSTAR and 6S will be used to establish links between the in-situ radiance affected by the geometric conditions of observation, atmospheric modules, aerosols and clouds and the radiance observed by satellite. For the processing codes, a look-up table showing the calculation results under the geometric conditions for all satellites and the sun will have been prepared in advance and will be referred to when the actual radiance data observed by satellite is to be processed.

3) Processing Test

The practicality of the developed algorithms will be tested using existing satellite data and in-situ observation data as simulation data. The check items will be the resolution, scaling up or down of the processing range, processing time, abnormal values generated by processing, flag mask and impacts of the sensor characteristics and any necessary corrections/modifications will be made.

(2) Development Phases

1) Initial Development Phase

- The feasibility of developing new algorithms will be examined along with improvement of any problems encountered by the existing algorithms to be inherited from the ADEOS-II/GLI.

- Algorithms will be developed using ADEOS-II and other satellite data and in-situ observation data already available.

- In regard to the satellite sensor design outcomes, a study on the impacts on product quality and measures to ensure the product quality will be conducted if necessary.

2) Performance Development Phase

- All of the targeted SGLI algorithms will be developed.

- The necessary basic data will be gathered.

- Development, validation and actual usage demonstrations will be conducted using data from other satellites and the above-mentioned basic data.

- Based on the outcomes of the demonstrations, a pre-launch implementation test-1 (PLI-1) will be conducted to evaluate the performance of each algorithm proper and the applicability of satellite data.

- In regard to the estimated satellite sensor performance, a study on the impacts on the product quality and measures to improve the product quality will be conducted if necessary.

- Suitable algorithms will be evaluated and selected in accordance with the following sequence.

  ① As part of the First Research Announcement (RA #1) at this phase, researchers will be invited to submit an algorithm proposal document (equivalent to a provisional ATBD). The principal investigator (PI) to lead the development of each selected algorithm will be selected based on the theoretical validity and past performance in data processing of the proposed algorithm.

  ② When more than one algorithm is selected for the same product, the performance (theoretical validity, estimation accuracy using the test data and operational stability of the algorithm) will be evaluated at this phase. The evaluation results will be discussed at Science Workshop #4 and will be reflected in the Second Research Announcement (RA #2).

  ③ In principle, one standard algorithm will be selected for each standard product in preparation for the implementation of an operational algorithm. When it is judged to be preferable to keep more than one candidate algorithm, selection will be made based on the evaluation results at the time of pre-launch or at the time of the release of Ver. 1.

3) Operational Algorithm Development Phase

- Based on the PLI-1 results, the coding, evaluation and improvement of the pre-launch algorithms will be conducted to match the brightness data (including sensor characteristics) to be observed by the SGLI and the SGLI data processing system.

- The pre-launch implementation test 2 (PLI-2) will be conducted to reproduce the flow of processing work at the launch and to check the operational performance of the algorithm.

- The ATBD Ver. 0 will be prepared.

- The evaluation of the performance of the research algorithms and examination of their potential upgrading to standard algorithms will be continued.

4) Post-Launch Development and Improvement Phase

- An algorithm evaluation, validation, improvement and utilisation test will be conducted using real GLI data in view of the upgrading of the version and the correction of algorithm errors at an appropriate time.

- The basic data and validation data required for algorithm improvement will be gathered.

- The improved algorithms will be used for a follow-up sensor. After the launch of the second GCOM-C satellite, the products of the GCOM-C1 satellite will be compared with the products of the GCOM-C2 satellite.

- The development, validation and demonstration of the research products will be conducted and new applications for the products will be clarified.

6.2.1.3 Product List and Classification of Products

The target products for development will be those listed in the GCOM Requirements Document (a table of the products and required accuracy and a table of correspondence between the products and the SGLI channels to be used are added to this document as Attached Table 1 and Attached Table 2 for reference purposes).

Products can be classified in various ways, such as ① importance for the GCOM, ② feasibility of algorithm development and ③ mode of data processing and supply. In connection with the mission objectives, some products are part of such mission objectives while new knowledge to be obtained through algorithm development can also be a mission objective. For the SGLI, an effective development system and modes of data processing and supply (A: production and distribution in accordance with the retrieval of satellite data; B: publication after the processing and evaluation of data for a certain period of time; C: publication as research outcomes) to achieve the mission objectives based on the experience of product development and data supply in the ADEOS and ADEOS-II mission are necessary.

The distinction between standard products and research products will be based on three criteria, i.e. importance, feasibility and effective data processing and supply mode. For example, standard products include cloud/aerosol characteristics, sea surface temperature, sea colour, snow depth and vegetation, all of which are demanded by a GCOS, which are important to achieve the mission objectives, the feasibility of which has been fully confirmed by the ADEOS-II mission and others and which are suitable for the systematic supply of data. In contrast, the research products so far identified are those at the research stage of development or practical use or those of which the importance is high but of which the outcome is acquired knowledge rather than the systematic supply of data. The product processing and supply system must be efficient and effective in consideration of the three aspects of the products.

6.2.1.4 Practical Use of Data

Algorithm development must take the following issues into consideration along with the trends of the GEO information system and guarantee of accuracy.

- Combined use with the GCOM framework
- Combined use with other satellite data
- Consideration of long-term fluctuation analysis (calibration; analysis of past data)
- Application for numerical models

6.2.1.5 Publicity and Diffusion

It is necessary for the SGLI products to be used by as many researchers and organizations as possible and for their outcomes to be known by as many people as possible to successfully achieve the mission. The following matters are very important in this regard.

(1) Maintenance and Improvement of Product Quality

The product accuracy must be sufficient in the light of the planned product use and the product quality must be equivalent to or even better than that of comparable sensor products produced abroad. To ensure this, pre-launch sensor calibration on the ground, algorithm development and post-launch calibration and validation will be thoroughly implemented. If a quality flag attached to each pixel of a product is effective from the viewpoint of securing data reliability, such flags will be attached to the product.

(2) Continual Data Supply

Long-term continual data supply is essential for the detection of long-term fluctuations and also for the operational system developed by each data (product) user using its own resources. The GCOM aims at the continual supply of data for more than 10 years and it will be essential to ensure the consist operation of the on-orbit sensors to create the data products. A feature of GCOM products which allows their combined use with the products of other sensors should help the acquisition of many users at an early stage after the launch of the first GCOM satellite as users will be able to use their own processing and analysis infrastructure to obtain useful data using this feature.

(3) Easy Access to Data

One effective way of achieving positive outcomes from climate change observation data is to make the thresholds for access to and use of the data as low as possible so that the data can be used by many users. For this purpose, a simpler Web/FTP/search/supply system will be developed to match the characteristics of the data. To facilitate the access to actual data, there is an additional need for the supply of format descriptions or a sample reading tool (for example, binary dump or text output) for easy data use and also for the spread of techniques to use the data through the distribution of a user guidance document, etc. (customisation for individual users should be conducted by private enterprises specialising in data analysis and system technology).

In addition to data access, information disclosure will be required in regard to data quality information (ATBD, state of calibration and validation and list of reference materials), data usage (format descriptions and simulation data to check the format), data supply sources, data processing and release schedule and mission schedule (research announcement, launch and data release). Such information will be made available on the EORC's website in line with the progress of the GCOM.

(4) Publicity

Academic societies involved in climate change research and international science groups will be informed of the availability of data/products for practical/research use through the communication network of these organizations and meetings to report the research achievements, etc. Moreover, effective publicity in the press and others will be attempted at climate change-related events.

6.2.1.6 Development System

(1) Collaboration Between the JAXA and PIs/Data Users

(Science Team Management)

The objectives of the GCOM/SGLI mission include items in such wide-ranging fields as the development of sensors, development of algorithms, calibration and validation, data analysis and data application (to numerical model, environmental assessment and prediction). The effective division of the work and cooperation with external researchers and research organizations will be essential to achieve the mission objectives. For this reason, contracts will be signed to appoint PIs (principal investigators) to be responsible for algorithm development, verification and applied research in line with each mission phase. Joint research will be conducted when necessary with external organizations which are involved in the development of numerical models and the practical application of products, etc. in the fisheries and other industries or the combined use of data from other satellites.

(Roles of the JAXA, PIs and External Organizations)

The JAXA must aim at successfully achieving the mission objectives in terms of the global observation system through effective collaboration with Japanese and foreign organizations using the global observation data products of which the production and supply are the primary objectives of the GCOM. Among the wide-ranging work items, the development and verification of algorithm, where innovation is an important requirement, and the observation/gathering of in-situ data must be conducted in close collaboration with the PIs to be publicly recruited for the GCOM, data users and operational/research organizations constantly conducting in-situ observation in view of the reliable and effective implementation of this work. The division of the roles between JAXA staff and the PIs will be determined to ensure “reliable and effective” outcomes, taking the performance of similar development phases in the past into consideration for the planned deployment of human resources for the GCOM into consideration.

(2) Linkage with Calibration and Validation Activities

Algorithm development, calibration and validation will be implemented as an integral unit. As the in-situ data required for algorithm development falls in practically the same category as the in-situ data required for post-launch validation, the know-how and equipment for in-situ observation will be fully inherited and used for algorithm development and validation.

6.2.2 Calibration and Validation

6.2.2.1 Objectives

The SGLI is a multi-purpose, multi-channel optical sensor to be used for the observation of and research on land, atmosphere, oceans and cryosphere. It has 11 non-polarised visible to near infrared channels, four short-wave infrared channels, two thermal infrared channels and two polarised near infrared channels with three different polarisation azimuth angles and observes radiance in each channel reaching the on-orbit sensor. Through the combination of the radiance of multiple channels based on scientific knowledge, products related to geophysical quantities will be created using algorithms developed for each sphere.

The primary objective of the SGLI is to conduct frequent global observation with a view to supplying global-scale observation data which can contribute to the prediction of long-term climate change. For this reason, it will be necessary for the SGLI to supply observation data based on absolute criteria of no regional dependence for geophysical quantities of which the fluctuation values differ from one region or ocean of the earth to another. Moreover, the values for the geophysical quantities to be supplied must be compatible with similar data/products supplied by similar optical sensors on other satellites which will be in operation during the GCOM period.

When satellite observation products are used for the monitoring and analysis of climate change, their absolute values and changing patterns must be highly accurate along with the supply of information relating to accuracy. While the accuracy of the radiance observed by the sensor and the accuracy of sensor monitoring (geometric accuracy) are calibrated (measured and evaluated) on the ground before launch, post-launch checking and modification will be required for those of which checking can only be conducted on-orbit, those of which the accuracy cannot be sufficiently determined on the ground and those which can change during launch and in space while in operation.

The objectives of the calibration and validation activities are to achieve the necessary accuracy level for each product to fulfil the relevant requirements under the GCOM and to release accurate products.

6.2.2. 2 Policies

(1) Product Accuracy

(Definitions of Accuracy)

Three definitions of accuracy have been established for the products to be made available under the GCOM as described below and these are linked to the success criteria for the mission which will be evaluated approximately one year and five years after launch.

1) Minimum accuracy for release (evaluation criterion for minimum success which will be evaluated approximately one year after launch)

This refers to the minimum level of accuracy of the data to be released as data which can contribute to the analysis of climate change. The yardstick is for such data/products to be useful for the mission objective (contribution to the monitoring and process analysis of changes of the global environment and improved accuracy of numerical models).

2) Standard accuracy (evaluation criterion for full success which will be evaluated approximately five years after launch)

This refers to the useful as well as standard level of accuracy in view of the performance of the relevant sensor of the ADEOS-II and other missions. The yardstick is equivalent or better values (in terms of accuracy, resolution and coverage of observation) than those of similar data/products.

3) Target accuracy (evaluation criterion for extra success which will be evaluated approximately five years after launch)

This refers to the level of accuracy of which the achievement will depend on progress of the research on improvement of the algorithm performance, improvement of the calibration accuracy and others.

(2) Required Accuracy Levels

The standard accuracy and target accuracy of the SGLI have been set through discussions involving organizations to use the data/products for research or operational purposes and the GCOM Committee based on the past results of the use of satellite sensor data, including those for the GLI, and product validation while taking the future prospects of algorithm improvement into consideration. The product accuracy is determined as the combination of (i) calibration error of the brightness data, (ii) error due to the inclusion of various observation targets within the pixels, (iii) error originating from the theoretical assumptions used for the algorithms and error inherent in atmospheric pressure and other supplementary data and (iv) error contained in the in-situ data used for comparison. The degree of contribution of each error depends on the product (algorithm) and observation conditions. It has, therefore, been decided that "values based on past results" will be used as indicators which can be evaluated to determine the standard accuracy and target accuracy as these past results contain various error elements. The theoretical errors were checked as part of the GLI validation work using algorithms and simulation exercises.

The specifications of the SGLI sensor have been determined to achieve the standard/target accuracy explained above.

(3) Calibration Policies and Accuracy Targets

Brightness calibration is a type of work to accurately establish the values of the spectral-radiance reaching the sensor opening based on the sensor output values. This work involves evaluation of the general response characteristics of each observation component (mirror tube for each VNI channel, mirror tube for each polarised channel and IRS), each wavelength channel and each pixel, the effects of the incidence angle on the scanning mirror reflectance and the polarisation sensitivity characteristics from the design and prototype stages for the purpose of improving and maintaining the accuracy (absolute accuracy and relative accuracy) of the observation data. The target brightness calibration accuracy is set for each mission phase as a system-calibrated satellite observed radiance product (Level-1B).

There are various means to calibrate the brightness, including pre-launch ground-based calibration (measurement and deduction of parameters for character evaluation and for the preparation and calibration of a sensor model), on-orbit calibration using internal lamp, black body, moon, deep space, dark period and night observation data, vicarious calibration using the SGLI's global observation data, ground-based spectral radiance observation data and observation data of other satellites and analysis of the Yaw manoeuvre for the correction of sensitivity deviation. As each of these offers excellent accuracy for some items but requires some assumptions for other, sufficiently reliable accuracy cannot be determined by a single means. To rectify this situation, cooperation will be sought with sensor development and ground system operating divisions for comprehensive analysis of the calibration results to evaluate, improve and maintain the accuracy of the products on radiance observed by the SGLI in operation.

Geometric system calibration means the decision on the position of each earth observation pixel using information on the position and attitude of the satellite and sensor alignment. The target geometric accuracy has been determined for each mission phase as system-calibrated radiance products of satellite observation. Positional error can be caused by the on-orbit thermal distortion of the satellite and sensor, secular distortion and error in the decisions relating to the position or attitude. Short-term (up to one year) fluctuations will be corrected by geometric system calibration. In the case of components of long-term (longer than one year) periodic fluctuations, these components will be statistically retrieved as mean values for each period of a certain length by mean of matching the GCP and SGLI observation image patterns for correction through the Level-1 processing. Such geometric correction work will be conducted in collaboration with the satellite, sensor and ground system development divisions.

(4) Validation Policies and Accuracy Targets

Validation means the work to validate the accuracy of the geophysical quantity which is estimated from the spectral radiance value for each channel. The target accuracy level is set for each geophysical quantity in each mission phase. In general, there are two types of accuracy validation methods. One is based on the in-situ observation data supplied by ground stations, ships and others. The other is based on theoretical values estimated in view of the inherent temporal-spatial fluctuation characteristics of each geophysical quantity or empirical values (including meteorological values).

Validation based on in-situ observation data will be conducted mainly using match-up data sets which consist of in-situ observation data on the same points at the same or similar times and SGLI cut-out data. Although the method, period and frequency of in-situ observation vary depending on the targeted physical quantity, the accuracy of a higher SGLI product will ultimately be computed through comparison between the values of the physical property in question calculated from these two types of data.

In regard to those physical quantities of which ground observation is difficult, the relationship between the target physical quantity and the observed radiance or another geophysical quantity not subject to validation will be estimated in advance based on theoretical computation, a numerical model or past observation data by airplane or satellite so that the accuracy of the target physical quantity can be estimated on the basis of the accuracy of the radiance (based on vicarious calibration, etc.) or another physical quantity.

Based on this estimated accuracy, the higher algorithm used for the retrieval of a physical quantity will be revised if necessary.

(5) Combined Use of Data

For the combined use of data, the accuracy of each data must be sufficiently high. It will also be necessary to announce the evaluation results along with the evaluation method or to make it possible to compare the evaluation results of different sensors (for example, use of common in-situ data and partial integration of the computation process to produce numerical values which can be used as accuracy evaluation results). For these purposes, such existing international frameworks as the GEOSS and CEOS/WGCV will be utilised.

6.2.2.3 Systems

(1) Calibration System

Calibration of the SGLI, including on-orbit brightness calibration and lunar calibration, will primarily be conducted by those responsible for the SGLI in the JAXA's satellite sensor development, mission management and applied research divisions with the participation of representatives of the equipment/instrument manufacturers and other contractors and also the PIs who will be recruited through the research announcements.

In consideration of the nature of calibration where various factors affect the data quality in a complex manner, an interdisciplinary group will be formed within the JAXA to deal with specific themes if necessary. The actual calibration work will be conducted by individual divisions of the JAXA in coordination with this group. The JAXA-SGLI calibration committee will be established as an umbrella body and the SGLI-Cal working group will be introduced as a calibration-related group of PIs. The GCOM-C1 mission manager will have ultimate responsibility for calibration as indicated in the configuration of the GCOM-C1 Project.

The themes identified through the calibration work of the GLI are listed below.

1) Solar calibration and lamp calibration (on-orbit calibration of visible and short-wave infrared data)
2) Black body calibration and deep space calibration (on-orbit calibration of thermal infrared data)
3) Geometric calibration (evaluation of geometric accuracy using the GCP and modification of the alignment table)
4) Sensor characteristics and image quality evaluation (strip pattern noise, stray light, transient response and saturation)
5) Vicarious calibration and mutual calibration (vicarious calibration using in-situ data and mutual calibration with MODIS or SeaWiFS data)
6) LI processing software (reflection of methods and coefficients obtained by the above calibration exercises for improvement on products)

In addition, lunar calibration and analysis of the polarised observation performance will be conducted with the SGLI.

(2) Validation System

Validation of the SGLI products will be conducted through collaboration between JAXA staff working for application and research projects and the PIs. JAXA staff and the PIs will form four groups in charge of land, atmosphere, oceans and cryosphere respectively and will conduct the actual validation work within each group. If necessary, the SGLI-Val working group will be set up to coordinate the work of the four different spheres.

Important decisions on calibration and validation which will affect the entire science project will be made at meetings of the SGLI science team consisting of JAXA staff and the PIs.

(3) Announcement of Calibration and Validation Results

The calibrated and validated accuracy of each product will be disclosed on the science research project's website and will also be externally presented through lectures and academic papers.

(4) Linkage with Algorithm Development

The higher algorithms used for the retrieval of physical quantities will be revised if necessary based on the estimated accuracy of each physical quantity by the validation work.

(5) Required Manpower, Computers and In-Situ Observation Equipment

The necessary manpower, computers and in-situ observation equipment for due operation of the SGLI will be fully in place.

6.2.2.4 Observation Requirements for Calibration and Validation

When observation using modes which differ from the standard SGLI observation modes is required for the calibration/validation observation to be conducted by the PIs and/or JAXA staff members, the requirements will be adjusted and put together within the research project framework for inclusion in the mission operating system approximately every three months.

6.2.2.5 Schedule

Observation on the ground, etc. prior to the launch of the SGLI will be conducted as part of the algorithm development. The calibration and validation phase of the SGLI products will start with the launch. Table 5-1 shows the major milestones for the SGLI-related calibration and validation activities.

6.2.2. 6 Calibration Plan

(1) Sensor Design and Prototype Phase

In line with the design and prototype fabrication of the sensor, the sensor characteristics (brightness and geometry) believed to affect the product accuracy and quality will be identified for examination of their possible correction if necessary. This work will simultaneously take place with the sensor development. The examination results will be reflected on the basic brightness and geometric conversion models to be primarily developed by the sensor development division in the BBM phase.

(2) Sensor Performance Evaluation Phase

Based on the performance evaluation results of the actual sensor, the sensor characteristics (brightness and geometry) believed to affect the product accuracy and quality will be identified and their correction methods will be examined if necessary. The examination results will be reflected on the Level-1 algorithms to be used for the post-launch initial processing. This work will be jointly conducted with the sensor development and ground processing development divisions. This phase will correspond to the EM and PFM phases of sensor development. The sensor development, ground processing development and research divisions will cooperate to conduct the development of the Level-1 algorithms as part of the ground processing of the SGLI data in the EM phase. In the PFM phase, a PFM table (database) will be prepared for its use for algorithm improvement and post-launch initial processing by means of analysing the sensor PFM calibration test data in combination with the relevant algorithms.

(3) Initial Calibration and Validation Phase

1) On-Orbit Brightness Calibration

On-orbit calibration (dark period, night-time, black body, solar diffusion and internal lamp calibration) can be expected to produce stable calibration results as known light sources will be used as the target data. Using such data, correction coefficients will be prepared if necessary by means of evaluating the temporal fluctuations of the overall sensitivity. The brightness range and geometric conditions for observation will, however, be restricted because of the need for several assumptions in terms of the light intensity of the internal lamps after launch, reflectance of the diffuser plate and others. For this reason, the calibration reliability will be improved through the complementary use of lunar calibration, vicarious calibration using earth observation data and/or mutual calibration. This work will be jointly conducted with the sensor development and ground processing development divisions.

2) Evaluation of Sensor Characteristics and Image Quality

The relative accuracy of sensitivity deviations between pixels, channels and mirror tubes and of the scan angle will be improved using on-orbit calibration and the SGLI's earth observation data. The sensitivity deviation between pixels, channels and mirror tubes under specific observation conditions will be estimated very accurately using such on-orbit calibration sources as black body, diffuser plate and internal lamps. In regard to other observation conditions, suitable earth observation data and data of other satellites will be used to evaluate the characteristics and to determine the correction coefficients. Although individual samples of earth observation data have a high level of error due to changes of the atmosphere and ground surface, such relative sensitivity as differences between the mirror tubes, angle of view deviation and scan angle dependency of the IRs can be statistically evaluated by means of using a large volume of observation data for such relatively stable ground surface areas as snow and ice covered area, desert and open ocean in the required brightness range. Because of the existence of uncertainties regarding the calibration accuracy of deviation in the field of view of other satellite data, atmospheric conditions and bidirectional reflectance distribution function (BRDF) of the ground surface reflectance, evaluation must be conducted in combination with fixed point observation through manoeuvring. The sensor characteristics and image quality evaluation will also feature stray light, transitional response, MTF and noise. If necessary and possible, development of the correction methods will be conducted for their application to Level-1 processing. The work described here will be jointly conducted with the sensor development and ground processing development divisions.

3) Vicarious Calibration and Mutual Calibration

Vicarious calibration using ground targets and mutual calibration between satellite sensors mean estimation of the ground surface reflectance using in-situ reflectance observation values or partially calibrated data from other satellites (a previous generation GCOM satellite can serve as such a satellite for the next generation GCOM satellite) and its comparison with the satellite observation values for the targets. Because of the need to consider the characteristics of the ground surface and the radiative transfer process in the atmosphere (atmospheric molecules and aerosols), this vicarious calibration will primarily be conducted by the research division. This method has such advantages as evaluation with various observation conditions in terms of brightness range and scan angle because of its ability to use various targets and also the gathering of many samples in a short period of time after the commencement of operation when using data from other satellites. However, there is a problem in regard to the estimated error of the ground surface reflectance (question of the accuracy of brightness data supplied by other satellites and question of representativeness of the ground observation points for comparison targets). Moreover, calculation errors of the atmospheric influence (estimation errors regarding aerosols, atmospheric pressure, temperature and water vapour) can constitute estimation errors. It is, therefore, essential for absolute calibration to improve the evaluation results in general and the reliability of the correction methods, taking the advantages and disadvantages of the individual calibration methods outlined above into consideration.

In-situ data is not necessarily required for mutual calibration with the observation data of other satellites on points which are spatio-temporally stable. However, to obtain results which are not dependent on the accuracy of other satellite data, vicarious calibration requiring in-situ brightness (reflectance) observation for data comparison purposes is necessary.

In the GCOM, vicarious calibration based on validated geophysical quantity data and higher level algorithms will be conducted to check the data accuracy under different observation conditions (Murakami, H., Yoshida, M., Tanaka, K., Fukushima, H., Toratani, M., Tanaka, A. and Senga, Y., Vicarious Calibration of ADEOS-2 GLI Visible to Short-Wave Infrared Bands Using Global Database, IEEE Transactions on Geoscience and Remote Sensing, Vol. 43, No. 7, pp. 1571 – 1584, 2005). For mutual calibration, the international frameworks listed in (7) below will be used. Details of the in-situ observation plan will be described in the calibration plan. A rough calibration plan will be prepared some two years before the planned launch and more details of the calibration work will have been determined approximately one year before the planned launch taking the trends of other missions into consideration. These details will be incorporated in the calibration plan.

4) Lunar Calibration

Using lunar data obtained through lunar calibration pitch manoeuvring, the absolute accuracy and its changes in time will be evaluated to develop correction coefficients if necessary. While hardly any uncertain factors are believed to exist for lunar calibration, it is predicted that the continual evaluation of fluctuations caused by the aspect of and distance to the moon will be necessary for a period of three to five years to ascertain the reliability of this relatively new calibration method. Mutual calibration through comparison will be conducted if lunar observation data of other earth observation satellites for the same period is available. MTF and stray light will also be evaluated using the edge of the moon. This work will be jointly conducted with the sensor development division.

5) Post-Launch Geometric Correction

The geometric system accuracy will be evaluated through comparison of the observation data of each mirror tube/channel and GCP data. The registration accuracy between wavelengths and between mirror tubes will be evaluated using the observation data. Based on the evaluation results, geometric changes with a repetition cycle of one year or longer will be corrected through modification of the alignment table and others. This work will be conducted in concert with the validation of the precise geometrically corrected reflectance and the work to determine the position and attitude of the on-orbit satellite sensor system.

6) Modification of Level-1 Processing Software

To supply highly accurate products, it will be necessary to efficiently and swiftly reflect the calibration results, coefficients and correction methods proposed through the series of work described above on the Level-1 processing. For this reason, the work described in ① through ⑤ above will be conducted in consideration of the application of their results to the Level-1 processing (formatting of the correction coefficients, correction methods corresponding to the processing flow and others).

(4) Constant Evaluation Phase

The accuracy of long-term data will be secured by means of constantly evaluating the matters referred to in ① through ⑤ of 3) above and applying the evaluation results to data processing. In particular, changes of the sensitivity in time, for which data is required for the analysis of climate change, will be evaluated by combining detailed analysis of the beta effect of solar calibration, the effect of lunar age and vicarious calibration. If the next generation GCOM/SGLI is on orbit, mutual calibration will be conducted with the GCOM-C1/SGLI. The evaluation and correction of fluctuations of noise and relative sensitivity will be continually conducted. While it is predicted that evaluation of the polarisation sensitivity of the polarisation observation function will be difficult on orbit, evaluation using a vicarious calibration technique using the observation results for temporal-spatial changes by a higher algorithm (aerosols) will be considered. Such evaluation and correction methods of the sensor characteristics will be inherited by subsequent climate change observation missions.

6.2.2.7 Cooperation with International Calibration and Validation Frameworks

The following international frameworks will be utilised for effective mutual calibration and the exchange of vital information.

- CEOS/IVOS
- RSL/APEX

Definitions of GCOM-C Products (Baseline)

(1) Land

1) Standard Products

- Precise Geometrically Corrected Image (PGCI): radiance data of which the pixel positions are determined using the ground control points for each processing unit taking the pixel altitude into consideration

- Atmospherically Corrected Land-Surface Reflectance (ACLR): estimated ground surface reflectance after the correction of atmospheric effects, such as scattering affecting the radiance data

- Vegetation Index (VI): index parameter to express the density and activity of green vegetation, including the Normalised Difference Vegetation Index (NDVI) calculated from the red and near-infrared channel reflectances and the Enhanced Vegetation Index (EVI) using the visible channel reflectance

- Vegetation Roughness Index (VRI): index indicating the three-dimensional structure of vegetation based on "differences of the observed light between different observation angles" as derived from multi-angle observation

- Shadow Index (SI): estimated "fraction of vegetation shadow resulting from its three-dimensional structure" using the wavelength characteristics of observed light

- Fraction of Absorbed Photosynthetically Active Radiation (FAPAR): fraction of photosynthetically active radiation of 400 to 700 nm absorbed by canopies

- Leaf Area Index (LAI): ratio of the total upper leaf surface of vegetation to the surface area of the land on which the said vegetation is growing

- Above-Ground Biomass (AGBIO): dry weight of above-ground biomass

- Land-Surface Temperature (LST): temperature of the land surface

2) Research Products

- Land Net Primary Production (LNPP): net carbon amount fixed by land vegetation as the difference between photosynthetic production and vegetation respiration
- Water Stress Trend (WST): estimated "degree of impediment of water supply to vegetation" using the diurnal variation of the surface temperature

- Fire Detection Index (FDI): positions of fires detected using radiation data in the thermal and short-wave infrared bands

- Land Surface Albedo (LALB): "ratio of upward reflected radiation energy to downward solar radiation energy" estimated from the type of land cover and surface reflectance in each spectral band of the SGLI

- Land Cover Type (LCT): estimated state of land cover using vegetation indices and the surface reflectance in each channel

(2) Atmosphere

1) Standard Products

- Cloud Flag (CLFG): cloud/clear discrimination and type/phase of cloud cover for each pixel

- Classified Cloud Fraction (CLFR): statistical fraction of appearance of cloud-pixels by type of cloud

- Cloud-Top Temperature and Height (CLTTH): cloud-top temperature and height estimated from brightness temperature data in the thermal infrared channels

- Water Cloud Optical Thickness and Particle Effective Radius (CLOTER_W): optical thickness of water cloud and size of cloud droplets

- Ice Cloud Optical Thickness (CLOT_I): optical thickness of ice cloud

- Aerosols Over the Ocean (ARV): optical amount of aerosols (optical thickness of aerosols), particle size (expressed in angstrom exponent which indicates the wave characteristics of aerosols) and aerosol classification (such as soot and sea salt particles)

- Land Aerosols by Near Ultra Violet (ARU): aerosol optical thickness and aerosol absorption coefficient

- Aerosols by Polarisation (ARP): optical thickness and angstrom exponent as derived from polarisation observation
  (Multi-Channel Aerosol Products: candidate for a future algorithm unifying ocean and land algorithms to estimate the aerosol size distribution and component ratio)

2) Research Products

- Water Cloud Geometrical Thickness (CLGT_W): geometrical thickness of water cloud expressed in the unit of length; the combined use of this parameter with the cloud-top height makes it possible to estimate the cloud bottom height, contributing to an improved retrieval accuracy of the long-wave radiation flux at the ground surface

- Long-Wave Radiation Flux (LWRF): downward and upward long-wave radiation flux at the ground surface, indicating the balance of the earth's radiation energy; upward flux in cloudy weather conditions is estimated using the surface temperature data provided by the AMSR2, etc.

- Short-Wave Radiation Flux (SWRF): downward and upward short-wave radiation flux at the ground surface, indicating the balance of solar radiation energy

(2) Ocean

1) Standard Products

- Normalised Water-Leaving Radiance (NWLR): sea colour (radiance of each channel) at the ocean surface after correction of the atmospheric effects, such as scattering, on the radiance observed by the SGLI
- Atmospheric Correction Parameters (ACP): aerosol properties, etc. necessary for correction of the atmospheric effects, including scattering
- Photosynthetically Available Radiation (PAR): downward radiation at wavelengths of 400 to 700 nm at the ocean surface that is available for phytoplankton
- Chlorophyll-a Concentration (CHLA): concentration of phytoplankton chlorophyll-a, a main pigment in photosynthesis
- Suspended Solid Concentration (SS): dry weight of suspended solids which are not dissolved in water; defined as the total of organic matters, such as plankton, and inorganic matters, such as soil
- Coloured Dissolved Organic Matters (CDOM): attenuation coefficient (unit: 1/m) of coloured dissolved organic matters in the ocean surface layer
- Sea Surface Temperature (SST): bulk sea surface temperature

2) Research Products

- Euphotic Zone Depth (EZD): depth of an euphotic zone suitable for plant growth
- Inherent Optical Properties (IOP): optical properties of ocean water, such as the absorption coefficients of plankton pigment, SS and CDOM, and the scattering coefficients of SS, all of which are estimated using the normalised water-leaving radiances
- Ocean Net Primary Productivity (ONPP): net primary productivity of phytoplankton for the absorption of carbon produced by ocean phytoplankton minus the carbon consumed by respiration
- Phytoplankton Functional Type (PHFT): phytoplankton existence rate for every function, such as nitrogen fixation, silicon fixation and carbon dioxide discharge, in connection with the NWLR

- Red Tide (RTD): discrimination of red tide using the characteristics of ocean colour

- Multi-Sensor Merged Ocean Colour Parameters (MOC): data sets which combine the products of other sea colour sensors, such as the NPOESS/VIIRS, for the same observation period

- Multi-Sensor Merged Sea-Surface Temperature (MSST): data sets which combine the products of other sensors, such as the AMSR-2 and NPOESS/VIIRS, for the same observation period

(4) Cryosphere

1) Standard Products

- Snow and Ice-Covered Area (SICA): snow and ice discrimination by each pixel

- Okhotsk Sea Ice Distribution (OKID): sea ice distribution in the Sea of Okhotsk in quasi-real time
- Snow and Ice Surface Temperature (SIST): temperature at the snow and ice surface

- Snow Grain Size in Shallow Layer (SNGSL): snow grain size retrieved with the reflectance in the 865 nm channel

2) Research Products

- Snow and Ice Classification (SIC): snow and ice cover types, such as new snow and old snow or first year ice or multi-year ice

- Snow-Covered Area in Forest and Mountain (SCMFM): snow-covered area in forest and mountain regions where the vegetation cover is likely to be mixed with snow

- Snow Grain Size of Sub-Surface Layer (SNGSS): snow grain size retrieved with the reflectance in the 1050 nm channel; the retrieved sizes represent the snow properties in a shallower layer than that of the SMGSL

- Snow Grain Size of Top Layer (SNGST): snow grain size retrieved with the reflectance of 1640 nm channel; the retrieved sizes represent the snow properties of the top snow layer

- Snow and Ice Albedo (SIALB): "ratio of upward reflected radiation energy to downward solar radiation energy" estimated using the snow-surface reflectance in each channel and taking the atmospheric effects suggested by the radiance values into consideration

- Snow Impurity (SNIP): ratio of such impurities as soot and dust in snow

- Ice Sheet Surface Roughness (ISRGH): roughness of an ice sheet defined as the ratio of the height to the width of the roughness estimated by multi-angle observation

- Ice Sheet Boundary Monitoring (ISBM): monitoring data on the positional changes of specific ice sheet boundaries