National Report on Ocean Remote Sensing in Japan

Contents

1 Status of Remote Sensing Utilization in Marine Environmental Monitoring

To contribute to the conservation of the global environment, which provides a common basis for human living, Japan has so far developed and operated two earth-observing satellites, Advanced Earth Observing Satellite (ADEOS) and ADEOS-II (operation of both have been suspended due to mechanical trouble). Specifically, National Space Development Agency of Japan (NASDA) (now Japan Aerospace Exploration Agency (JAXA)), is using satellite remote sensing to enable cross border, wide, uniform and frequent observations of global phenomena.

The first earth-observing satellite produced by Japan, ADEOS, was launched in August 1996. Ocean Color and Temperature Scanner (OCTS) equipment on the ADEOS satellite took over the NIMBUS-7 Costal Zone Color Scanner (CZCS) observation mission, launched by the US in 1978, enabling global observations of ocean color and Sea Surface Temperature (SST). The data contributed to comprehensive oceanic profiles of *chlorophyll-a*, dissolved matter and SST, which were used for furthering our understanding of ocean primary production and carbon cycling, for the acquisition of information on fishing and oceanographic conditions, and for environmental monitoring. Unfortunately, ADEOS suspended its operation due to mechanical trouble in June 1997. However, the data obtained during this time resulted in the establishment of an estimation algorithm for *chlorophyll-a* concentration and contributed to ocean environmental monitoring by ocean color. In addition, OrbView-2 Sea-viewing Wide Field-of-view Sensor (SeaWiFS) was launched by the US in 1997 (Saino, 1998; Kawamura and the OCTS-team, 1998; Shimada *et al.*, 1998).

ADEOS-II was launched in December 2002, taking over the observation mission of ADEOS, to clarify the mechanisms of long-term climate change, such as global warming, and to be used for weather information and fishing. ADEOS-II was equipped with Global Imager (GLI) of high resolution and multiple wavelength channels based, on the OCTS development. It enabled frequent, accurate and global observations of various geo-physical parameters in the ocean (Ishizaka *et al.*, 2004). However, operation ceased due to mechanical trouble in October 2003, 10 months after its launch. Although the originally planned long-term and continuous monitoring of the global environment was not achieved, the data obtained by GLI produced information on *chlorophyll-a* concentrations (an important indicator of carbon cycling) and SST (an indicator of climate change) that have been available since December 2003 (section 5.1.2). GLI calibration and validation (section 3.3.1) as well as the results of algorithm development for geo-physical parameters have also been applied to Moderate Resolution Imaging Spectrometer (MODIS) for Near Real Time Data by Earth Observation Research and application Center (EORC). JAXA provides MODIS higher-level products that target the sea surrounding Japan (sections 3.2.2.1 and 5.1.1).

Products of *chlorophyll-a* concentration and SST from MODIS Near Real Time Data, and products of SST from National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometers (AVHRR), have been used for monitoring projects such as the Marine Environmental Watch Project (section 2.1) and the monitoring of areas frequently damaged by red tides. By studying specific areas of coastline, scientists have tried to develop more accurate products (sections 2.3 and 3.2.2.2) because current data have insufficient resolution for some purposes. In the open ocean, where estimates of *chlorophyll-a* concentration are accurate enough for practical use, models of primary productivity have begun to clarify seasonal and interannual variation (section 3.2.3). However, the *in situ* data necessary to validate the models is completely lacking and a system to efficiently obtain such data is under development (section 3.3.2).

While OCTS and GLI are optical sensors, Japan plans to launch Advanced Land Observing Satellite (ALOS) equipped with Phased Array type L-band Synthetic Aperture Radar (PALSAR), which is upgraded from Synthetic Aperture Radar (SAR) of Japanese Earth Resources Satellite-1 (JERS-1). PALSAR is expected to contribute to the study of the dynamics of various marine phenomena (section 3.1). In addition, Advanced Microwave Scanning Radiometer for Earth

Observing System (AMSR-E), developed by Japan and installed in Aqua, has been successfully conducting observations since its launch, and its higher-level products have been available since September 2003. Among them, SST has been used in the development by domestic and foreign researchers for building the New Generation SST (NGSST) for Open Ocean (section 3.2.1).

The present status of marine environmental monitoring by remote sensing is summarized in Table 1 according to the sensors currently in use.

Table 1. Status of Marine Environmental Monitoring by Remote Sensing
SST refers to sea surface temperature and CHLA refers to *chlorophyll-a* concentration.

Sensor	Satellite	Variables	Observation Cycle	Intended use of data
AVHRR	NOAA Series (12, 15, 17)	SST	(3-6 times/day)	• Understanding ocean dynamics • Locating fishing grounds
SeaWiFS	OrbView-2	CHLA	1 day	• Understanding red tides
MODIS	Terra/Aqua	SST CHLA	(2 times/day)	• Monitoring for water quality • Understanding red tides • Understanding ocean dynamics
AMSR-E	Aqua	SST	1 day	• Understanding ocean dynamics

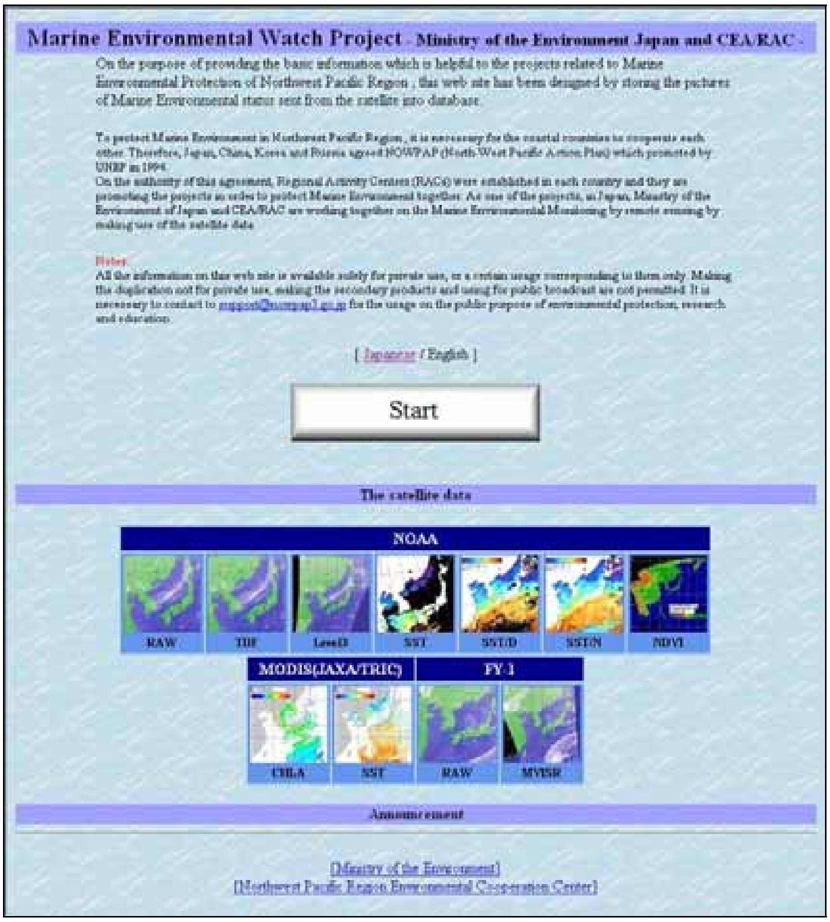
2 Case Examples of Remote Sensing Application in Marine Environmental Monitoring

2.1 Marine Environmental Watch Project

The Ministry of the Environment of Japan has contracted with the Northwest Pacific Region Environmental Cooperation Center (NPEC) since 2000 to prepare the Marine Environmental Watch Project as a Northwest Pacific Action Plan (NOWPAP) promotion project. The purpose is to provide useful basic information for marine environmental conservation, utilizing satellite remote sensing. It began operation of its receiving ground station in March 2002. The targets are NOAA AVHRR and Feng Yun-1 (FY-1) Multi-channel Visible and Infrared Scan Radiometer (MVISR), which are used for marine monitoring.

Measured data obtained by the receiving ground station are automatically processed for the NOWPAP region and saved as a database that is expected to be used in the future as baseline information. The contents are widely available through the Internet (Figure 1), providing images of clouds, SST and Normalized Difference Vegetation Index (NDVI) by search measurement date, cloud cover and region. Ten day composite images of SST for day and night are also available.

In addition to the above-mentioned data, MODIS *chlorophyll-a* concentration and SST products distributed by EORC, JAXA have been available since July 2004 to further assist and promote marine environmental conservation. Previous data delivery by regular mail has been shifted to automated distribution technologies including online order, File Transfer Protocol (FTP), etc, resulting in quick data delivery to domestic and foreign users.



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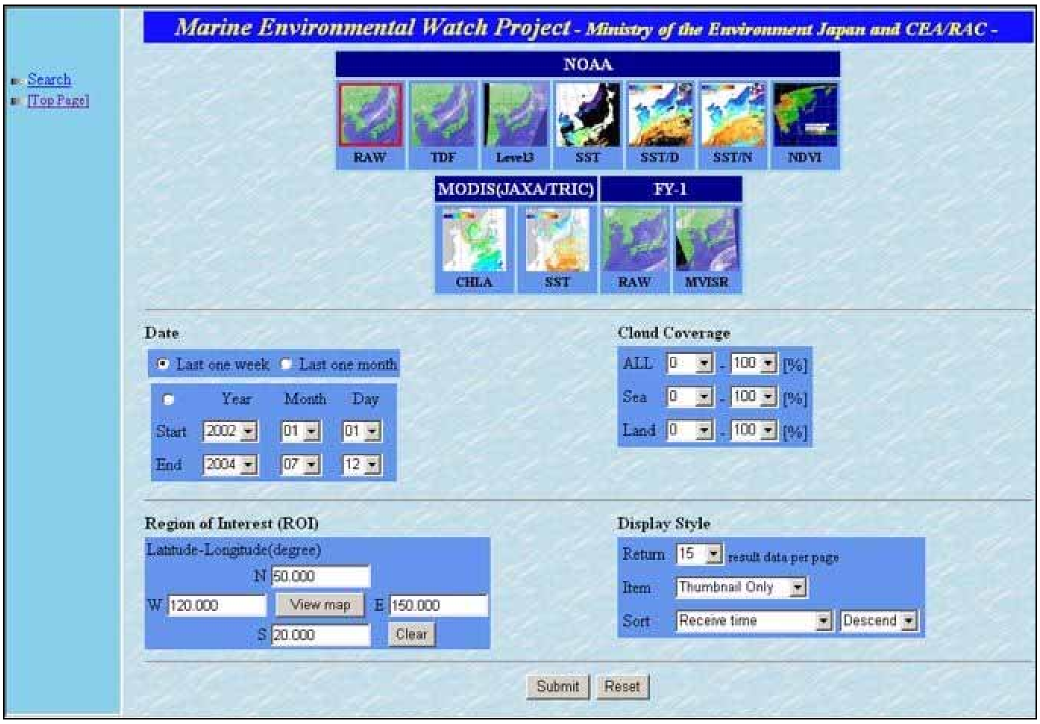


(b). Data search

Figure 1. Marine Environmental Watch Project
<http://www.nowpap3.go.jp/jsw/index.php?lang=en>

2.2 Coastal Information System of Ehime Prefecture

In the coastal area of the Uwajima Sea, water temperature varies enormously due to the intrusion of the Kuroshio Current from the Pacific Ocean. To quickly provide information on water temperature changes to fishermen and others, Ehime prefecture and the Center for Marine Environmental Studies at Ehime University collaboratively operate the Coastal Information System (Figure 2). The system broadcasts water temperature data for 5 m depths at 8 stations established along the coast of the Uwajima Sea, through the Internet, with automatic updating every 2 hours. The data are transmitted through a Low Earth Orbit satellite (Orbcomm) to recipients about 30 minutes after measurements are made.

These sea temperature data, combined with SST images of the Uwajima Sea obtained by Ehime Chuyo Fisheries Experimental Station from NOAA AVHRR, and with ocean color images by MODIS, are provided as comprehensive marine information. The ocean color images by MODIS are adopted from higher-level products provided by EORC, JAXA.

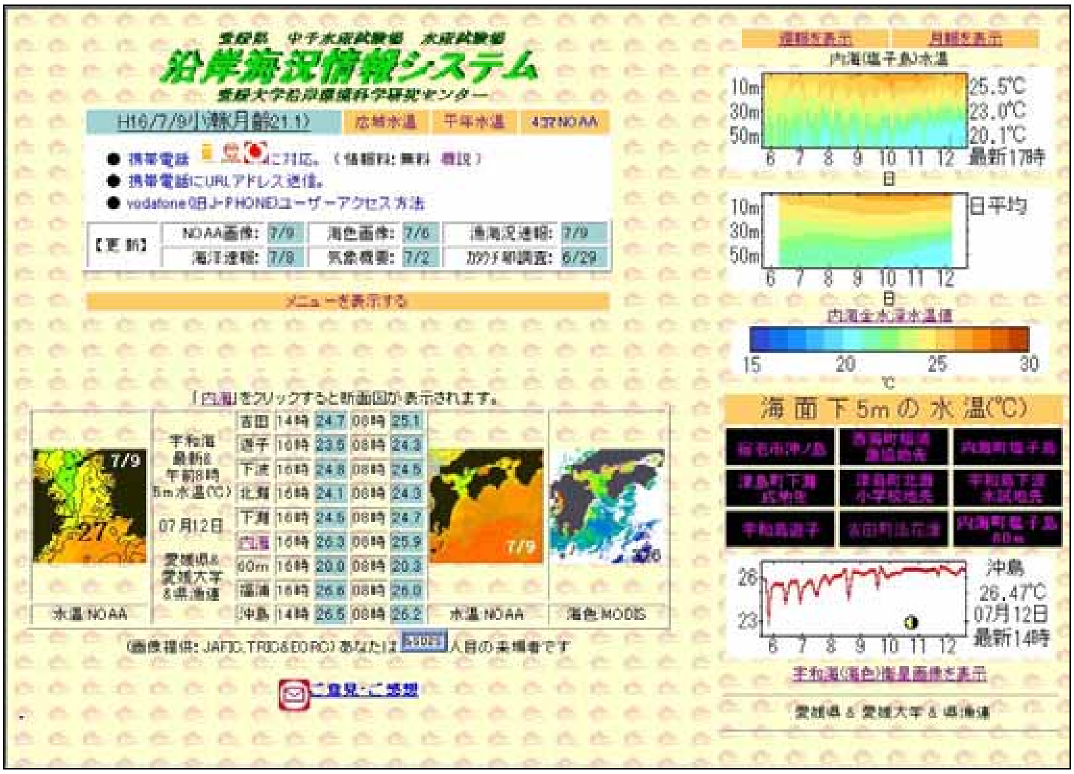


Figure 2. Ehime Prefecture Coastal Information System
<http://www8.ocn.ne.jp/~ehchusui/>

2.3 Ariake Sea Project

The Ariake Sea is a representative shallow coastal area in western Japan that has long been known for its many marine resources. In recent years, however, the numbers of fishes and shellfish, including the short-necked clam and pen shell, have rapidly declined. The increasing frequency and scale of red tides have caused serious ecosystem damage, initiated through the bleaching of laver macroalgae (Nakata, 2003).

To tackle the issue, researchers in the faculty of fisheries at Nagasaki University organized a project entitled 'Research and study on changes of environment, ecosystem, and fisheries in Ariake Sea'. Its core project is called 'Comprehensive study on the impact on fishery resources caused by the environmental change in Ariake Sea' and has been underway since 2001. The final goal of the project is to provide concrete proposals on the expected future conservation and utilization of the environment and fisheries resources in the Ariake Sea. This is to be achieved by systematically clarifying the process of change in the environment and in fisheries production in the Ariake Sea by considering it as a single-cycling ecosystem. To achieve this goal, researchers are studying the characteristics and processes of the environment and ecosystem of the Ariake Sea. Measurements being made include physical parameters, such as sedimentation at the bottom of the sea, and oxygen depletion rates and sources, the impacts of endocrine disrupters, plankton production, including red tides, and long-term changes in tidal-flat communities (Nakata, 2003).

According to the Ariake Sea Project, one of the studies headed by Professor Joji Ishizaka, Faculty of Fisheries at Nagasaki University, is conducting the following activities to clarify the dynamics and processes of low-level production by phytoplankton and zooplankton in the Ariake Sea.

1) Collection of existing knowledge of past red tides
2) Monthly surveys in Isahaya bay of the standing crops of phytoplankton and zooplankton, taxonomic composition, sea temperature, salinity, transparency and nutrient concentrations
3) Further development of a remote sensing method for estimating *chlorophyll-a* concentration, suspended solids (SS) concentration, transparency, and SST
4) Continuous monitoring of chlorophyll fluorescence by mooring systems

Ishizaka (2003, 2005) considered the cause of red tides, based on reviewing *chlorophyll-a* concentration images in the Ariake Sea from 1998 to 2001 from SeaWiFS together with *in situ* data taken by Nagasaki University. The images showed red-tide growth and senescence from December 2000, resulting in damaged laver. They also showed seasonal trends of *chlorophyll-a* that peaked from June to July and again in November during 1998-2001 across the entire Ariake Sea, including Isahaya Bay. The results reveal that monitoring *chlorophyll-a* concentration by satellite is effective for red-tide detection. The remaining issues for *chlorophyll-a* concentration are possible over estimation and the lack of measurements at the head of the Ariake Sea.

Efforts are currently being made to accumulate daily images of *chlorophyll-a* concentrations in the Ariake Sea, derived from MODIS higher-level products distributed by EORC, JAXA. The goal of this work is to clarify red-tide dynamics through the analysis of these data (Figure 3).

Figure 3. Links to *Chlorophyll-a* Images of the Ariake Sea by MODIS
<http://w3.fish.nagasaki-u.ac.jp/FISH/KYOUKAN/ISHIZAKA/MODIS/>

3 Status of Research and Development on remote sensing technology for the marine environment

3.1 Sensors and Satellites

ALOS

The Japanese earth observing satellite program consists of two satellites, one mainly for atmospheric and marine observation, and one mainly for land observation. The aim of using ALOS, the Advanced Land Observing Satellite, is to improve the land observing technologies of JERS-1 and ADEOS by collecting global land-observation data with high resolution. Also, ALOS may be useful for the marine environment by:

1) Providing maps for Japan and other countries, including those in the Asian-Pacific region (Cartography)
2) Performing regional observation for ‘sustainable development’ - harmonization between the Earth’s environment and development (Regional Observation)
3) Conducting disaster monitoring around the world (Disaster Monitoring)
4) Surveying natural resources in domestic and foreign countries (Resources Surveying)
5) Developing the technology necessary for future Earth-observing satellites (Technology Development)

ALOS, as shown in Figure 4 and Table 2, has three earth observing sensors: the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) for digital elevation mapping; the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) for precise land coverage observation; and PALSAR for day and night and all-weather land observations. In order to fully utilize the data obtained by these sensors, ALOS was designed with two advanced technologies: the former is the high speed and large capacity mission data-handling technology, and the latter is the precision spacecraft position and attitude determination capability. They will be essential to high-resolution remote sensing satellites in the next decade.

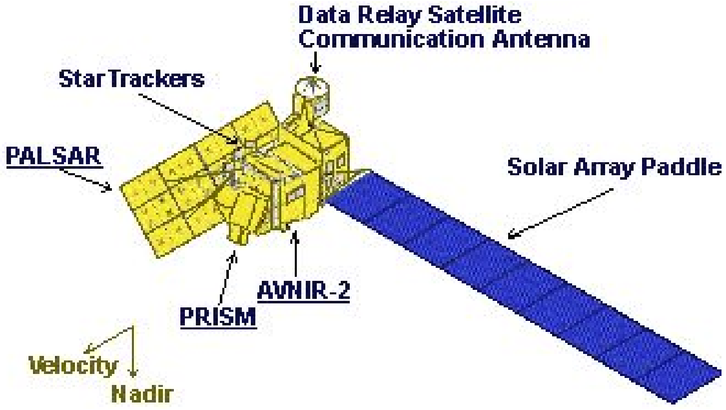


Figure 4. ALOS - Overview -
Source: ALOS@EORC

Table 2. ALOS Characteristics
Source: ALOS@EORC

Date	2004 -
Launch Vehicle	H-IIA
Launch Site	Tanegashima Space Center
Spacecraft Mass	Approx. 4 tons
Generated Power	Approx. 7 kW (at end of life)
Design Life	3-5 years
Orbit	Sun-Synchronous Sub-Recurrent Repeat Cycle: 46 days Sub Cycle: 2 days Altitude: 691.65 km (at Equator) Inclination: 98.16 deg.
Attitude Determination Accuracy	2.0×10^{-4} deg. (with Ground Control Point (GCP))
Position Determination Accuracy	1 m (off-line)
Data Rate	240 Mbps (via Data Relay Technology Satellite) 120 Mbps (Direct Transmission)
Onboard Data Recorder	Solid-state data recorder (90Gbytes)

Various products derived from ALOS are expected to contribute widely to the advancement of basic science as well as to applied fields, such as natural resource management, disaster monitoring and damage mitigation, and regional development and planning. The ALOS science program seeks to promote basic and applied research. Applied research is expected to provide data products and algorithmic products for near-term practical uses. The ALOS science program sets research development targets, as follows, for ALOS data utilization and its algorithm development for data products.

1) Land use and land cover research
2) Topography and geology
3) Terrestrial (vegetation) ecosystem, agriculture and forestry research
4) Climatic system, hydrological processes and water resources related research
5) Oceanography and coastal zone related research
6) Disasters and earthquakes
7) Resource exploration
8) Development of spatial data infrastructure
9) Basic studies on scattering and interferometric characteristics
10) Basic studies for accurate observation with high-resolution optical sensors

The Oceanography and Coastal Zone Related Research program aims to provide information to assist economic activities, including sea traffic, pollution control and fisheries in coastal areas. For this purpose it is necessary to develop an algorithm for products from PALSAR data, such as data sets for sea-surface wind and wave-height, sea ice, oil spills, and so on. It is also necessary to extract high-resolution digital elevation model (DEM) for combination with existing depth data.

For oil spill detection, the possible identification of the spilled area by PASLAR and AVNIR-2, using the pointing function which can change its observation area, could make information a spill and its dispersion widely and immediately available. It is expected to contribute to effective surveillance, collection and reduction of oil-spill damage. PALSAR ScanSAR mode data will be used to extract information on large-scale ocean currents (Kuroshio, etc.), cold and warm water masses, coastal-water currents and internal waves. In addition to the above-mentioned ongoing data collection, the information extracted from these data is expected to make large contributions to studies on air-sea interactions, sea waves and the dynamics of phenomena in the coastal and open ocean. Once ocean dynamics are understood in more detail, it is expected to accelerate clarification of the mechanisms and modeling of eutrophication and related red tides, resulting in damage prevention in fisheries.

Measuring ocean phenomena such as surface-wind waves, internal waves, sea-surface roughness and other features is dependent on characteristics of synthetic aperture radar, including observation frequency, polarization and off nadir angle. Table 3 shows the major characteristics of ALOS PALSAR and JERS-1 SAR. J-ERS-1 made observations primarily over land from 1992 to 1998. The off nadir angle of JERS-1 SAR was set to 35 deg., which was an intermediate angle between the best land-observation angle and the best marine angle. The lower off nadir angle is sensitive to land features and the higher off nadir angle is sensitive to ocean phenomena. Although the off nadir angle was set to 35 deg., JERS-1 SAR provided many unique images over the ocean and provided oceanic information on surface-wind waves, eddies, currents and surface roughness, which is dependent on micro films (Asanuma *et al.*, 2003b). It is expected that ALOS PALSAR will take over JERS-1 SAR for producing the data for marine applications. In particular, the higher off nadir angle of 51 deg. will produce an image that is more sensitive to ocean phenomena.

Table 3. Major characteristics of SAR

	ALOS PALSAR		JERS-1 SAR
Major observation mode	High resolution	ScanSAR	-
Observation frequency	L-band (1.27 GHz)		L-band (1.275 GHz)
Polarization	HH, VV, HH&HV, VV&VH	HH, VV	HH
Spatial resolution	10 m	100 m	18 m
Number of looks	2	8	3
Scan width	70 km	250-350 km	75 km
Off nadir angle	10-51 deg.		35 deg.

Symposiums and workshops were organized by JAXA, as follows, to help create an international and interdisciplinary community of researchers on data use ready for the ALOS launch after 2004.

- March 2000 ALOS Data Use International Symposium 2000
- March 2001 ALOS Data Use Industrial Symposium 2001
- February 2003 ALOS Data Use Symposium 2003
- January 2004 ALOS PI (Principal Investigator) Workshop and Report on Public Subscription Results of JERS-1 Research

3.2 Algorithms for Geo-physical Parameters

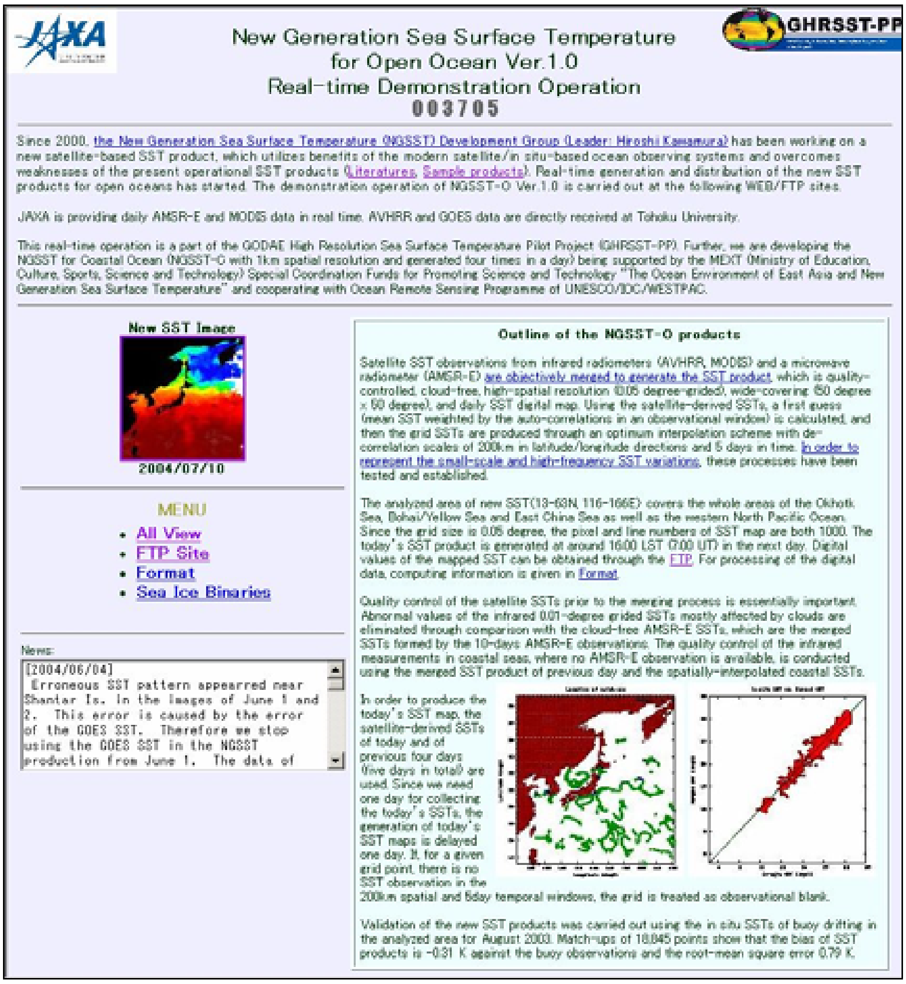
3.2.1 Sea Surface Temperature

New Generation Sea Surface Temperature for Open Ocean Ver. 1.0 Real-time Demonstration Operation

Since 2000, the NGSST Development Group, represented by Professor Hiroshi Kawamura, the Center for Atmospheric and Ocean Studies, Tohoku University, has been working on a new satellite-based SST product that utilizes the benefits of both modern satellites and *in situ*-based ocean observing systems, overcoming the weakness of the present operational SST products. The group opened the website of ‘New Generation Sea Surface Temperature for Open Ocean Ver. 1.0 Real-time Demonstration Operation’ in June 2003 and started real-time generation and distribution of the NGSST products for the open ocean (Figure 5). This real-time operation is part of the Global Ocean Data Assimilation Experiment (GODAE) High Resolution Sea Surface Temperature Pilot Project (GHRSST-PP).

The new SST product, ‘Merged SST’, is generated from objectively merged SST data obtained by AVHRR, MODIS and AMSR-E. Using these SST data, a first guess (mean SST weighted by auto-correlations) is calculated, and then the final product is produced through a simple optimum interpolation scheme (Guan and Kawamura, 2004). This method enables the provision of proper SST data on a relatively small scale and with a quick response time. Also, it requires strict quality control of the SST data to be merged. Abnormal values of SST from AVHRR and MODIS are eliminated through comparison with the 10-day composite SST (AMSR-E Merged SST) data prior to the generation of Merged SST. The quality control, where no AMSR-E SST observation is available, is conducted using the Merged SST of the previous day or the spatially interpolated values. Merged SST needs data of the target day and its previous 4 days. The delay to its broadcast is one day.

Currently, the NGSST is under development and is targeting coastal areas with a spatial resolution of 1 km and a distribution frequency of 4 times per day. This NGSST is a project of the Ocean Remote Sensing Programme of United Nations Educational, Scientific and Cultural Organization (UNESCO)/ The Intergovernmental Oceanographic Commission (IOC)/ IOC Sub-Commission for the Western Pacific (WESTPAC), and is supported by IOC and the Special Coordination Funds for Promoting Science and Technology for the ‘New Generation Sea Surface Temperature’.



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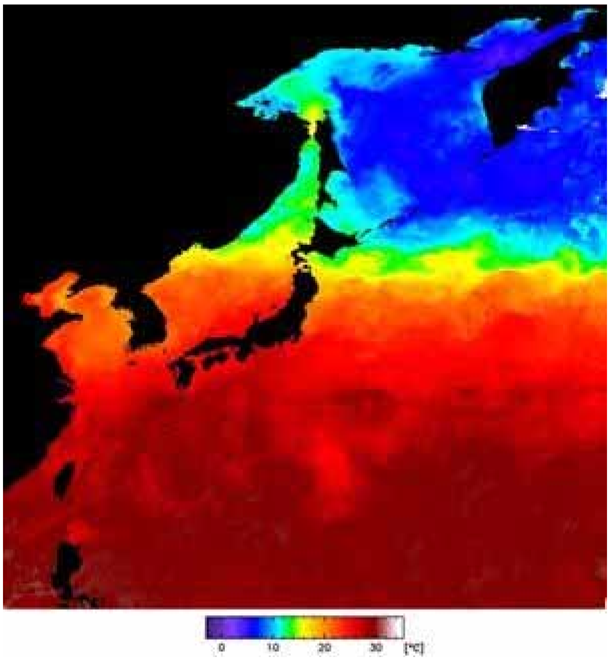


Produced by the NGSST Development Group.

(b). Merged SST on July 12, 2004

Figure 5. New Generation Sea Surface Temperature
<http://www.ocean.caos.tohoku.ac.jp/~merge/sstbinary/actvalbm.cgi?eng=1>

3.2.2 *Chlorophyll-a* Concentration

3.2.2.1 Improvement of algorithms for Near Real-time MODIS Processing

For the estimation of physical quantities of *chlorophyll-a* concentration, EORC, JAXA has not been using the standard algorithm provided by National Aeronautics and Space Administration (NASA) since 2002, when the center started near real-time processing of MODIS data, but rather has been using an algorithm prepared for ADEOS-II GLI. After the launch of ADEOS-II at the end of 2002, calibration, verification and algorithms were made for GLI. In 2004, the results were applied to MODIS higher-level products to improve their accuracy.

According to Murakami *et al*. (2004), the major changes of the algorithm for ADEOS-II before and after the launch are in the atmospheric correction and in-water algorithm. For the atmospheric correction algorithm, the MODIS specific Look Up Table (LUT) was applied because conversion from MODIS radiance to GLI radiance could have caused errors due to perturbations from the land or atmosphere. In addition, an aerosol model was selected for the in-water optical model (Tanaka *et al*., 2004) during the development process to improve the atmospheric correction in turbid coastal water. No data areas and outlier data problems in coastal areas are expected to improve as a result. For the in-water algorithms, empirical equation coefficients on *chlorophyll-a* concentration were adjusted in accordance with the adoption of LUT. The empirical equations used in the in-water algorithms are shown in Table 4.

Table 4. In-water algorithms used in the MODIS NRT processing (Murakami *et al*., 2004)

Parameter	Equation nlwX: Normalized water-leaving radiance at Xnm
CHLA: *Chlorophyll-a* concentration	CHLA = 10^(0.36786 -2.3450*r +1.0645*r2 -0.53167*r3) -0.035 r = log10(max(nlw443,nlw470,nlw490)/nlw551)
SS: Suspended solid concentration	SS = 10^(-0.2977 -1.5537*r +0.42439*r2) r = log10(nlw443/nlw551)
CDOM: Colored dissolved organic matter absorption at 440 nm	CDOM = 10^(-1.4952 -1.5020*r) r = log10(nlw443/nlw531)

The improved algorithms were verified in ocean color observations by *Kaiyo*, the marine observation vessel of Japan Marine Science and Technology Center (now Japan Agency for Marine-Earth Science and Technology) (JAMSTEC), in the East China Sea from February to March 2004 (Figures 6 and 7). As a result, the estimated radiance spectrum and *chlorophyll-a* concentration by both Terra and Aqua MODIS agreed well with the *in situ* data, although there was some discrepancy between the estimated values and *in situ* data. This was due to an atmospheric correction error caused by aerosol absorption, and will be a future research topic.

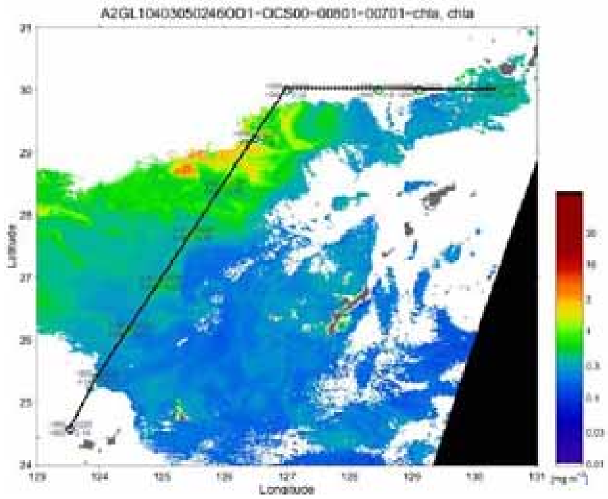
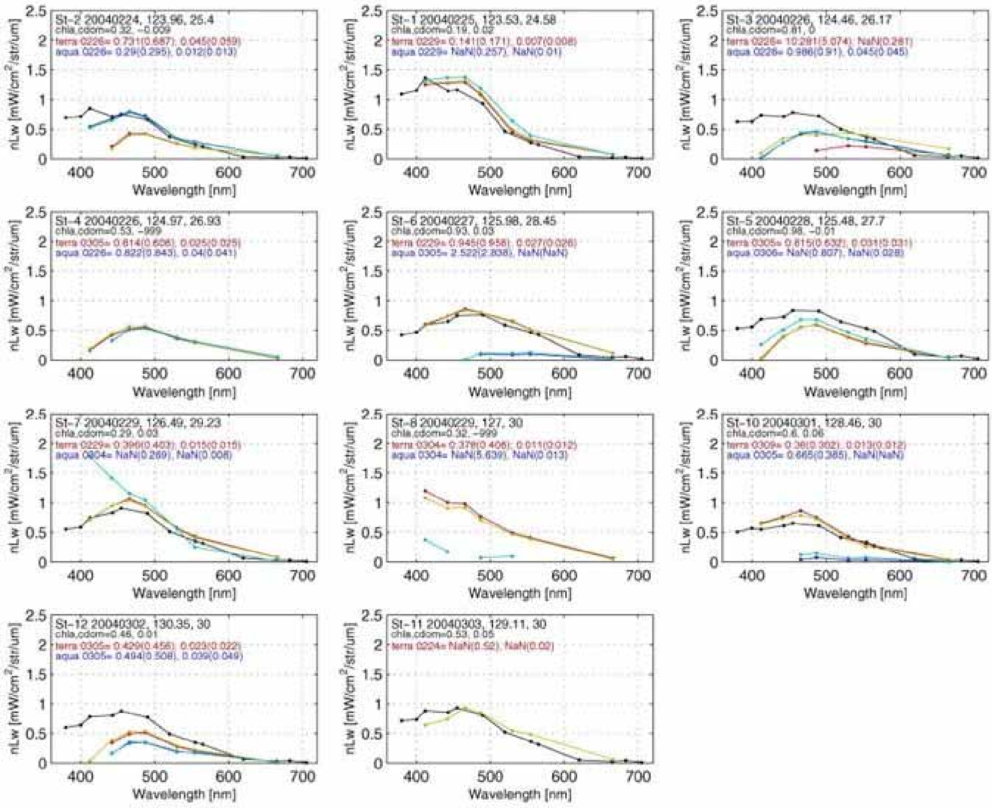
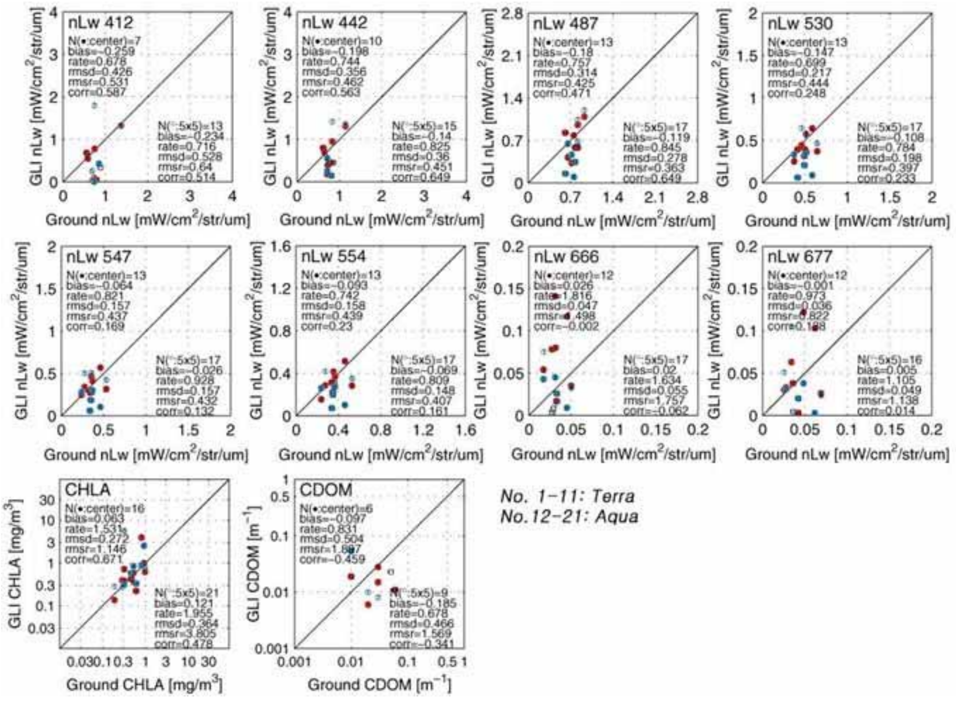


Figure 6. Navigation Route and *Chlorophyll-a* Image on March 5, 2004
(Murakami *et al*., 2004)



(a). Spectrum

Black lines in the graphs show the *in situ* data. Red and yellow lines show the recent observation data of Terra and their 5 x 5 spatial averages, respectively. Blue and sky blue lines show recent observation data by Aqua and their 5 x 5 spatial averages, respectively. Black characters show the *in situ* observation points, date, longitude, latitude, CHLA and CDOM respectively. Red characters show the Terra observation dates for CHLA and CDOM respectively and blue characters show the Aqua observation dates for CHLA and CDOM, respectively.



(b). nLw, CHLA, CDOM

X-axis shows *in situ* data. Y-axis shows data estimated by MODIS. Red dots show Terra. Blue dots show Aqua.

Figure 7. Comparison between *in situ* and estimated data (Murakami *et al*., 2004)

3.2.2.2 Toyama Bay Project

The project aims at using Toyama Bay as a model to develop algorithms for producing precise measurements of *chlorophyll-a*, SS and CDOM. It also aims to show NOWPAP members (China, Korea and Russia) the effectiveness of remote sensing as a monitoring technique for the marine environment. The project is to be conducted over 3 years (commenced 2003) with the cooperation of the Ministry of the Environment of Japan, NPEC, Nagasaki University, Toyama University, Toyama Prefectural Fisheries Experimental Station and Toyama Prefectural Environmental Science Research Center. In the fiscal year 2003, the following studies were conducted in Toyama Bay for water-quality characteristics and the estimations of SST and *chlorophyll-a* concentration by remote sensing.

1) Marine monitoring survey

To monitor currents and water quality of Toyama Bay, monthly regular sampling and *in situ* surveys were conducted at nine stations (seven coastal stations, central Bay station and an outside station). An outline of the findings on water quality in Toyama Bay is as follows.

- *Chlorophyll-a* concentration had a relatively strong negative correlation with dissolved oxygen (DO) and a positive correlation with pH, SS and SST.
- Phosphorus had a large influence on the increase and decrease of phytoplankton, whereas silicic acid had little influence.
- The increase of phytoplankton related to the increase of chemical oxygen demand (COD).

2) Environmental monitoring survey by satellite

To develop and validate in-water algorithms for estimating *chlorophyll-a* and SS concentrations in the coastal area of Toyama Bay, SeaWiFS and MODIS data were acquired and analyzed. Also, accuracy verification was conducted for SST and *chlorophyll-a* concentration of AVHRR and MODIS using data provided by the Marine Environmental Watch Project. An outline of the results is as follows.

- Water with a high *chlorophyll-a* concentration was observed along the coast of Toyama Bay and was carried out of the bay by a counterclockwise current (Figure 8).
- The accuracy of SST, estimated by AVHRR, was high even in the coastal area.
- The *chlorophyll-a* concentration estimated using the GLI algorithm did not match well with *in situ* data in Toyama Bay, although a good correlation with *in situ* data was observed in the other areas as a whole.
- The reverse computation algorithm of the radiative transfer model by a neural network is not currently accurate enough to be useful for estimating *chlorophyll-a* concentration.

In the fiscal year 2004, the project continued the same surveys and obtained more *in situ* data to improve the in-water algorithms that estimate *chlorophyll-a* and SS concentrations. In order to demonstrate the effectiveness of remote sensing, the project will attempt to develop more accurate in-water algorithms using past SeaWiFS data.

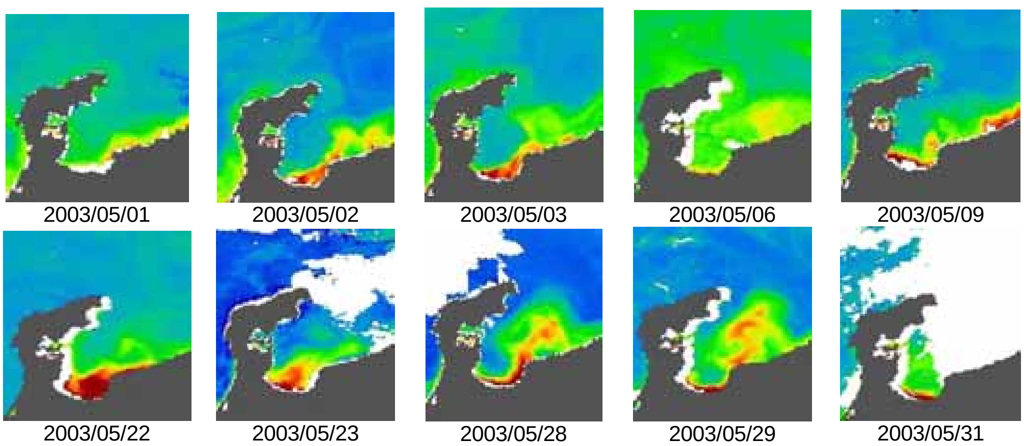


Figure 8. Continuous Images of Ocean Color in Toyama Bay

3.2.3 Primary Productivity

3.2.3.1 Algorithm to estimate primary productivity using a two-community phytoplankton model

Kameda and Ishizaka (2000) reconsidered the depth-integrated algorithm of Behrenfeld and Falkowski (1997) by adding observational data for the coast of Japan, and showed that primary productivity was overestimated in high *chlorophyll-a* concentration areas and underestimated in low *chlorophyll-a* concentration areas. They also showed that P^B_{opt}, the maximum photosynthesis rate per unit *chlorophyll-a*, depends not only on SST but also on *chlorophyll-a* concentration. P^B_{opt} was expressed as a function of SST and *chlorophyll-a* concentration, assuming that there are two types of phytoplankton: one that has large individuals in a population of high biomass but with slow primary productivity; and the other that has small individuals in a population of low biomass but with fast primary productivity. Global primary production was estimated by applying this algorithm to OCTS/SeaWiFS data. As a result, the overestimation in high *chlorophyll-a* concentration area was corrected and the annual total primary productivity estimates obtained from monthly *chlorophyll-a* concentrations matched existing estimates, but the underestimation in low *chlorophyll-a* concentration areas, such as the west equatorial Pacific Ocean, was not corrected. This latter problem was because the surface values estimated from the satellite data were used instead of the vertical distributions of *chlorophyll-a* that should have been used.

These algorithms have been developed by targeting open ocean areas. In coastal areas, sea surface *chlorophyll-a* concentrations estimated from ocean color remote sensing continue to have large errors, due to SS and CDOM that add to or mask the optical signal from the phytoplankton. In addition, a difficulty that remains is the assumption used in ocean areas that phytoplankton concentration determines Photosynthetically Available Radiation (PAR) (Ishizaka, 2002).

Yamada *et al*. (2005) verified the model in the eastern NOWPAP region with a few *in situ* data and found the estimated value was very close to the *in situ* data. They estimated the annual primary production of 170, 161, 191 and 222 gC/m^2/year in the Russian coast, middle of the Japan Basin, the southeastern area and the southwestern area, respectively.

3.2.3.2 Time and Depth Resolved Primary Productivity Model

Asanuma *et al*. (2000) proposed a time and depth resolved primary productivity model, taking into account the vertical distribution of PAR and *chlorophyll-a* concentration, as well as varying carbon fixation rate with time. Their model provided a vertical distribution of PAR and *chlorophyll-a* concentration as an empirical equation, resulting in a fairly good agreement between its estimated values and the *in situ* data of primary production in equatorial areas and along the Pacific coast of Japan. However, an overestimation in case II water was confirmed during the validation process. It was pointed out that the main reason for the overestimation was that the vertical estimates of PAR were based solely on the surface *chlorophyll-a* concentrations estimated from satellite data.

To improve the accuracy in case II water, Asanuma *et al*. (2003a) introduced the concept of a diffused attenuation coefficient, corresponding to *chlorophyll-a* concentration after accounting for optical attenuation by SS and CDOM. As a result, the estimated values and *in situ* data had good agreement as a whole, and its practical use is about to be realized. There were some exceptions for individual points, where *in situ* data exceeded the estimated values (Matsumoto and Asanuma, 2003). This study was part of a comprehensive study called ‘Cooperative research on the global mapping of carbon cycle and its advancement’, which was funded by Special Coordination Funds for Promoting Science and Technology.

Figure 9 shows the global distribution of ocean primary productivity that was estimated through applying the model to GLI data. A characteristic of the model was that ocean primary productivity was overestimated in the middle-to-high latitude coastal regions and equatorial areas where photosynthesis by phytoplankton is high.

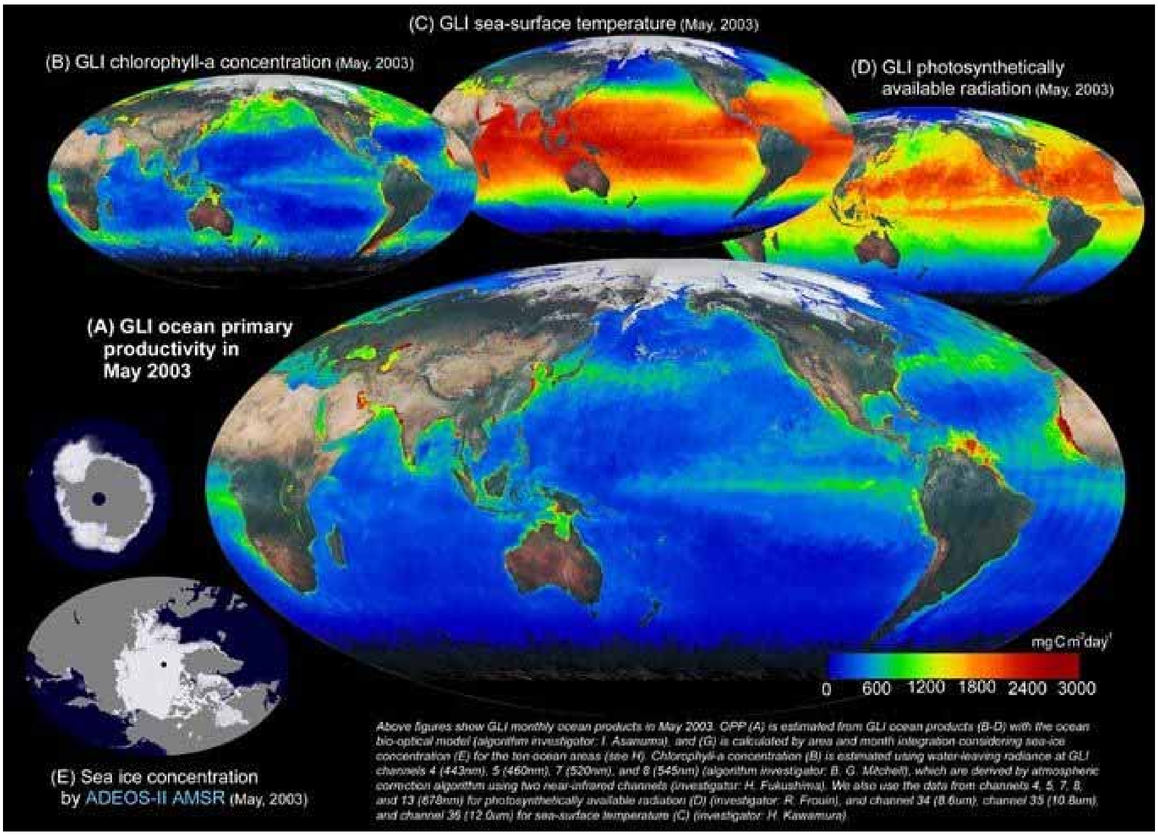


Figure 9. GLI Ocean Primary Productivity in May 2003
Source: EORC, JAXA

3.3 Validation of Geo-physical Parameters

3.3.1 GLI Match-up Analysis

The JAXA/EORC GLI ocean group has been validating various physical quantities estimated from GLI data by match-up data sets since GLI was launched. Match-up data sets consist of the *in situ* data and the clipped data from GLI when observed in the same position at the same or nearly the same time. By comparing both data sets, efforts have been made to recognize errors in higher-level products, to adjust parameters and to improve the algorithms.

In situ data to be used in validation are collected through two approaches, one from the global level and the other from Asia, where the users are concentrated. For the global level, data are collected from areas such as offshore of California and Hawaii, where atmospheric and oceanographic conditions are good, and in the Atlantic Ocean, to make the best use of international cooperation, particularly with PI, Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS), etc.

In Asian oceans, data from the East China Sea, the Ariake Sea, offshore of Sanriku, Tokyo Bay, Toyama Bay, etc., are maintained by a field campaign involving the cooperative observations of Nagasaki University, Tokyo University of Fisheries (now Tokyo University of Marine Science and Technology), Hokkaido University, the Fisheries Agency of Japan, the Japan Coast Guard and NPEC. These data sets are managed by JAXA. Some of the data can only be used for calibration and validation or algorithm development. Figure 10 shows all of the locations where *in situ* data have been obtained.

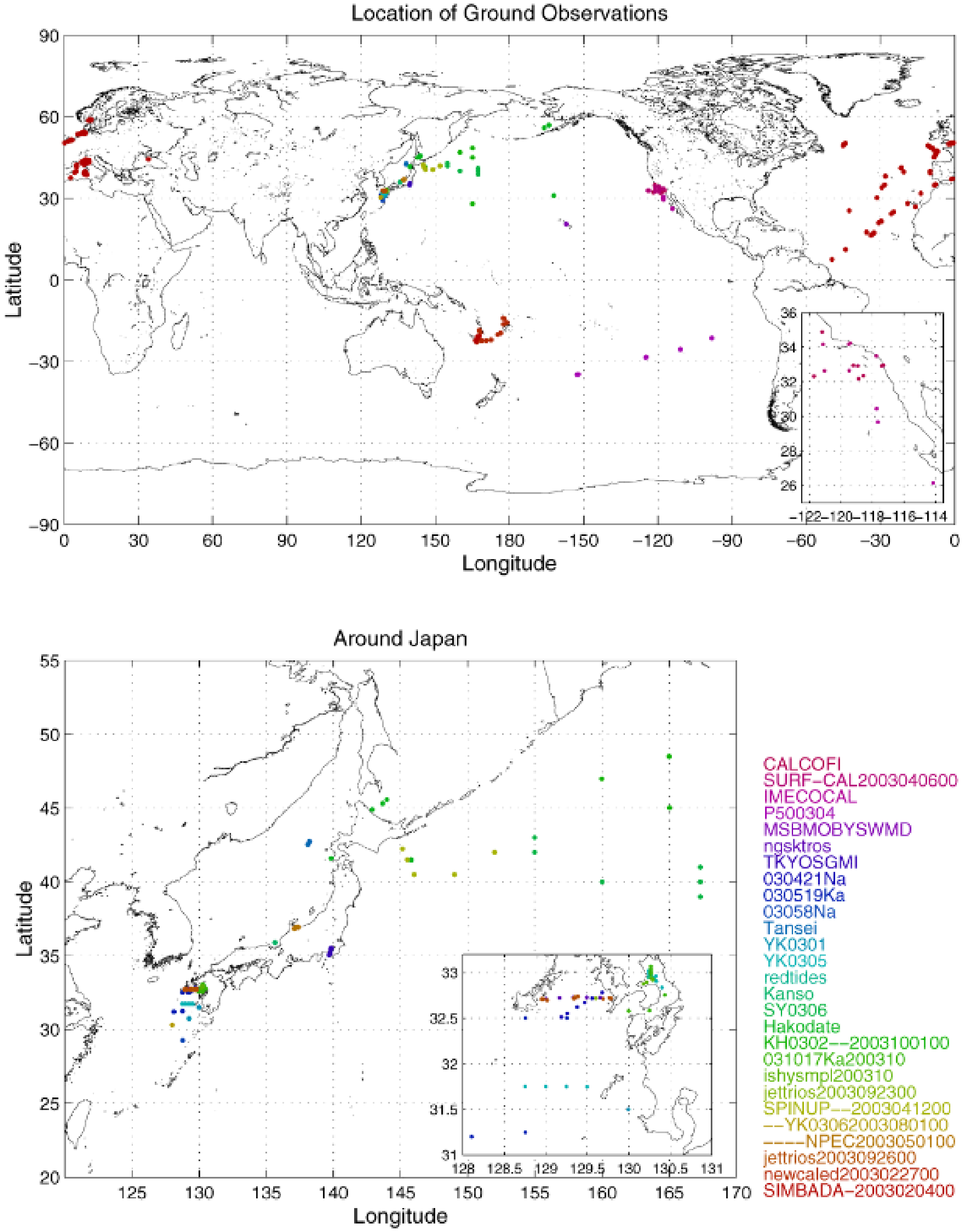


Figure 10. All locations of *in situ* observations
Source: Ocean Home GLI EORC JAXA

Validated results of the product by match-up data are shown in Table 5. The results suggest that the accuracy of *chlorophyll-a* concentration is good as a whole, but it is not good enough in coastal waters. They also suggest that CDOM is underestimated. This is probably due to differences in CDOM concentrations among the various target areas that occurred during algorithm development and validation. In addition, it has been confirmed that the distribution and values of each product are generally in good agreement with the validated products of SeaWiFS and Geostationary Meteorological Satellite (GMS).

Table 5. Summary of GLI Validation (version 1 products)
(JAXA/EORC GLI Ocean Group, 2004 with modification)

Parameter code	Parameter name	Final target	Ver. 1 Accuracy	Notes
NWLR	normalized water leaving radiance	-35-+50% (offshore) -50-+100% (coastal area)	16-47% (CH01-09) 84-284% (CH10-12)	- Select vicarious calibration coefficients (vical coef.) of SeaWiFS Apr-Jul base - Bad results longer the 565nm are due to low (<1/20) nLw over the ocean - looks better than the early OCTS - problem under absorptive aerosol
PAR	photosynthetically available radiation	-10-+10% (10 km/month)	11%	- agrees well with SeaWiFS PAR and Tropical Atmosphere Ocean (TAO) solar irradiance
CHLA	*chlorophyll-a* concentration	-35-+50% (offshore) -50-+100% (coastal area)	130%	- large scatter is caused by coastal points - comparable quality to OCTS
CDOM	colored dissolved organic matter absorption at 440 nm	-50-+100%	(82%)	- insufficient sample size (now increasing)
SS	suspended sediment concentration	-50-+100%	(34%)	- insufficient sample size
K490	attenuation at 490 nm	-35-+50%	(78%)	- insufficient sample size (now increasing)
SST	bulk sea surface temperature	0.6 K	0.6 K	- cloud detection problem - Electric noise on Middle and Thermal Infrared (MTIR) image

3.3.2 Project on Ocean Productivity Profiling System

To understand material cycling in the ocean, it is necessary to clarify the geographical distribution and variation of biological pump activity. For this clarification, measurements of phytoplankton quantity and primary production by ocean color remote sensing are expected to be a practical method for observation. However, present data sets are not large or accurate enough to validate phytoplankton quantity and primary production. In particular, the lack of primary production data is likely to remain a serious problem because these measurements must be made by *in situ* experiments based on vessels.

The ‘Project on Ocean Productivity Profiling System’, represented by Professor Toshiro Saino of the Hydrospheric Atmospheric Research Center at Nagoya University, aims at providing data for real-time validation of estimated primary productivity by ocean color remote sensing (Saino, 2001). The project started as a 5-year plan (November 1999 to October 2004) and will continue as a new 5-year plan named ‘Ocean Primary Productivity Monitoring by Satellite’ from November 2004. The Japan Science and Technology Agency supports these projects as part of the Core Research for Evolutional Science and Technology.

As shown in Figure 11, the underwater automatic escalation buoy is composed of an underwater winch below the euphotic zone and a measurement buoy that rises from the winch to the water’s surface. The measurement buoy has a Fast Repetition Rate Fluorometer (FRRF) and Profiling

Reflectance Radiometer (PRR) for obtaining vertical profiles. The system can be kept at calm depth to reduce the influence of waves and minimize the attachment of organisms. It can also transfer the measured data in real time, and the winch can be controlled in real time by acoustic and radio communications. Model 1 has recently been repeatedly tested in the ocean.

The essential fundamental data required to validate methods for primary production estimated by ocean color remote sensing are daily- and depth-integrated net primary productivities. Accurate algorithms have been developed to estimate daily- and depth-integrated total primary productivities, making the best use of vertical profiles of phytoplankton photosynthetic characteristics, measured by the FRRF and phytoplankton-abundance data, estimated from the PRR measurements, and the solar radiation time series, estimated from the GMS data.

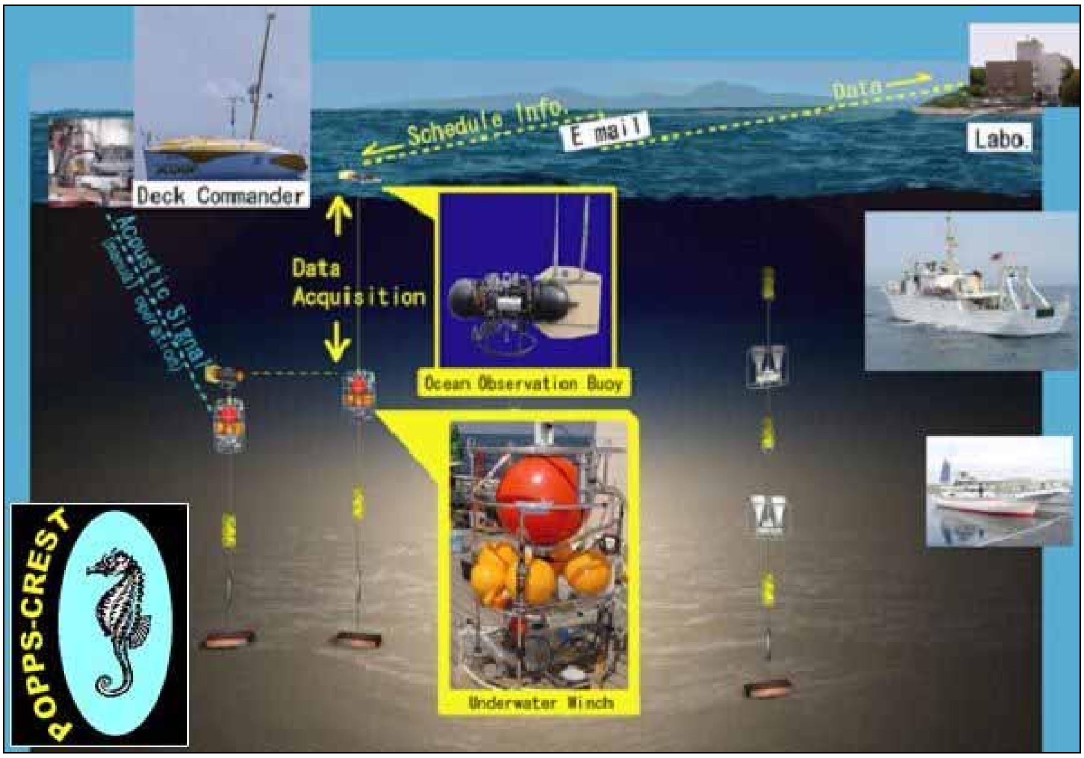


Figure 11. Project on Ocean Productivity Profiling System (POPPS)

4 Introduction of latest findings

4.1 Remote sensing oceanography of harmful algal blooms off the coast of southeastern Vietnam

Harmful algal blooms (HABs) in the southeastern Vietnamese coastal waters have caused large economic losses in aquaculture and wild fisheries in recent years. However, there have been few oceanographic studies on these HAB events. The present study reports an extensive HAB off southeastern Vietnamese waters during late June to July 2002, using *in situ* observations and analysis of the oceanographic conditions using satellite remote sensing data. The HAB had high *chlorophyll-a* concentrations, up to 4.5 mg/m^3, and occurred about 200 km off the coast and about 200 km northeast of the Mekong River mouth for a period of about 6 weeks. The bloom was dominated by the harmful algal haptophyte *Phaeocystis* cf. *globosa* and caused a very significant mortality of aquacultured fish and other marine life. During the same period, SST imagery showed a cold water plume extending from the coast to the open sea, and QuikScat data showed strong southwesterly winds blowing parallel to the coastline. This study indicated that the HAB was induced and supported by offshore upwelling that brings nutrients from the deep ocean to the surface, as well as from the coastal water to offshore water. This upwelling was driven by strong wind through Ekman transport when winds were parallel to the coastline. This study demonstrated the possibility of utilizing a combination of satellite data of *chlorophyll-a* concentration, SST and wind velocity, together with coastal bathymetric information and *in situ* observations, to give a better understanding of the biological oceanography of HABs (Tang *et al.*, 2004).

4.2 Seasonal and interannual variability of sea surface *chlorophyll-a* concentration in the NOWPAP region

Seasonal and interannual variability of *chlorophyll-a* concentration in the NOWPAP region was detected spatially by ocean color satellite remote sensing. The starting time of the spring bloom was spatially variable. The spring bloom started from south of the subpolar in March, and moved north of the subpolar front, the Primorye coast and off Hokkaido in April, and into the middle of the Japan Basin in May. The start of the spring bloom showed interannual variability that corresponded to wind speed in the area.

The spring blooms in 1998 and 2002 appeared about 4 weeks earlier than the other spring blooms between 1997 and 2002. These early blooms corresponded to periods of weak winds that led to an early development of the thermocline. The bloom was late in 1999 and 2001 in the Japan Basin and along the Primorye coast. It was also late in the southern area in 2000. It corresponded with stronger than average wind stress that delayed seasonal thermocline formation. The bloom along the Primorye coast appeared later in 1999, corresponding to stronger wind stress, and at the same time seemed to be related to the delay of the melting of sea ice in Mamiya Strait. The fall bloom appeared from early October to early December, and did not have a clear temporal transition. The area where *chlorophyll-a* concentration exceeded 0.8 μg/L was wider in the western area than in the eastern area every year. The magnitude of the fall bloom differed between years, but did notcorrelate with average wind speed in this season. These results indicate that the timing of the seasonal bloom in the NOWPAP region is largely affected by the variability in global climate, such as El Nino/Southern Oscillation (ENSO) events (Yamada *et al.*, 2004).

4.3 Wind jets and wind waves off the Pacific coast of northern Japan during the winter monsoon as captured by combined use of scatterometer, SAR and altimeter

Wind jets and wind waves off the Pacific coast of northern Japan during the East Asian winter monsoon are investigated using a scatterometer, SAR and altimeters. This study indicates the important role of coastal topography in air-sea interactions by tracking wind-wave developments. During the monsoons, strong winds blow over the Japanese archipelago toward the Pacific Ocean and form distinct wind jets and wakes over the ocean. First, we depicted two prevailing wind-flow patterns associated with the northwesterly winter monsoon. They are derived by averaging Quick Scatterometer (QuikSCAT) wind vectors when the 850-hPa pressure level wind directions are within 260 ° - 290 ° and 290 ° - 330 ° , respectively. In the two wind-flow patterns, wind jets and wakes are formed in different regions in connection with the line of strike of the topography. Then, using high-resolution satellite observations of QuikSCAT and European Remote Sensing Satellite-2 (ERS-2) SAR for wind, and TOPEX/Poseidon and ERS-2 Radar Altimeter (RA) for significant wave height, we present two case studies corresponding to the two prevailing wind-flow patterns in order to investigate wind-wave development under topographically modified winds. The combined use of QuikSCAT and ERS-2 SAR allow us to capture the surface wind transition from the shore to the offshore. The SAR-derived wind fields reveal smaller-scale wind jets and lower-wind regions in near-shore regions. They verify that the wind jets and wakes are extensions of terrestrial gaps and blockages. The coastal wind jets extending from Uchiura Bay, Mutsu Bay and the Tsugaru Straits are noticeable. Variations of significant wave height observed by TOPEX/Poseidon and ERS-2 RA are compared with those of surface winds derived from QuikSCAT and ERS-2 SAR along the altimeter ground tracks. As a result, the positions of the local maximum and minimum of significant wave heights and squares of wind speeds coincide with each other. This demonstrates the important role of coastal topography in wind modification and the resulting offshore wind-wave development (Shimada and Kawamura, 2004).

5 Strategies/Plans for Remote Sensing related activities

5.1 Satellite data supply and distribution

5.1.1 MODIS Near Real Time Data

EORC, JAXA has been providing higher-level products, including *chlorophyll-a* concentration and SST, processed since July 2002 from MODIS observation data through the Internet on a near real-time basis (Figure 12). Tokai University Space Information Center receives MODIS observation data. Tokai University Research and Information Center processes Level 1B files, and then EORC estimates the physical quantity. This procedure took a half to one day to provide products to users, due to data transmission time among stations. In July 2004, JAXA developed a new system in which Earth Observation Center (EOC) receives data and conducts Level 1B processing. This system started its operation in parallel with the existing system. These are alternatives to the products from the Terra and Aqua MODIS and Aqua AMSR-E for the users who were going to use ADEOS-II GLI/Advanced Microwave Scanning Radiometer (AMSR) products. The latter suspended its operation at the end of October 2003 due to mechanical troubles. In the new system, a transmission line with a huge capacity has been prepared between EOC and EORC, enabling product distribution in an average of about 4 hours.

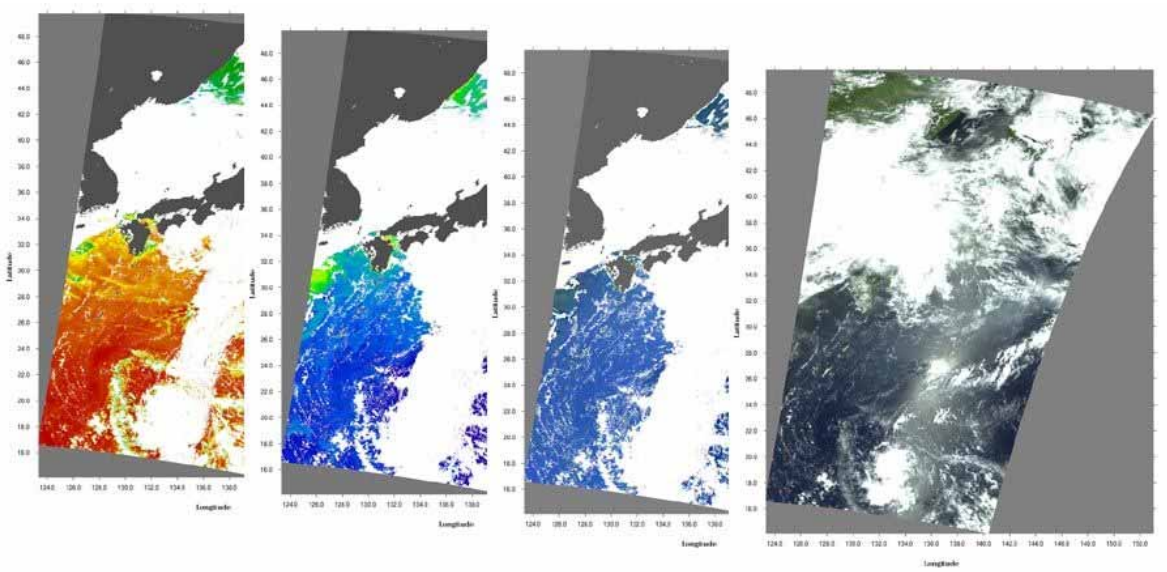
EORC uses the ADEOS-II GLI algorithm which was improved in accuracy by calibration, verification and algorithm development after its launch. This is used instead of the standard NASA algorithm. The use of GLI Version 2 is now under preparation.

The currently available high-order products are shown Table 6 and Figure 13. All products are free of charge. Simple registration, including user name, organization, etc., is necessary when using Binary Data.

Figure 12. MODIS Near Real Time Data
<http://kuroshio.eorc.nasda.go.jp/ADEOS/mod_nrt/>

Table 6. Products in MODIS Near Real Time Data

Spatial Resolution	Product	
	Image	Binary
1 km	Geometrically corrected: Rayleigh corrected reflectance (RcRefl) Normalized water-leaving radiance (nLw) Sea surface temperature (SST) *Chlorophyll-a* concentration (CHLA)	SST CHLA
500 m	Geometrically corrected	-
250 m	Geometrically corrected	-



Courtesy of JAXA/TOKAI UNIVERSITY

Figure 13. Sample of 1 km Images Supplied by MODIS Near Real Time Data: SST, CHLA, nLw and RcRefl on July 12, 2004.

5.1.2 RESTEC

The Remote Sensing Technology Center of Japan (RESTEC) was established in August 1975 to promote social economy and the well being of the nation's citizenry. To these ends, RESTEC utilizes satellites and conducts basic and general research development related to remote sensing. Remote sensing encompasses earth resources and phenomena investigation. Furthermore, RESTEC promotes the diffusion of remote sensing and other space-development.

The institutional mandate of RESTEC is to continuously provide data, including that from past observations. Table 7 shows some of the data that Japan is involved in obtaining, developing and providing. Various products of Aqua AMSR-E have been provided since September 2003; and those of ADEOS-II AMSR and GLI have been provided since December 2003. Regarding ALOS, which was planned to launch in 2004, the 'ALOS Use Committee' was established to promote data use and dissemination, and to contribute to data supply.

Table 7. Satellite data related to Japan provided by RESTEC

Satellite	Sensor	Operational period
MOS-1, 1b	MESSR (Multispectral Electronic Self-scanning Radiometer) VTIR (Visible and Thermal-Infrared Radiometer) MSR (Microwave Scanning Radiometer)	1987/02-1996/04
JERS-1	VNIR (Visible and Near Infrared) SWIR (Shortwave Length Infrared) SAR	1992/09-1998/10 1992/09-1993/12 1992/09-1998/10
ADEOS	AVNIR (Multi-Band) AVNIR (Panchromatic-Band) OCTS	1996/10-1997/06
TRMM (Tropical Rainfall Measuring Mission)	PR (Precipitation Radar) VIRS (Visible and Infrared Scanner) TMI (TRMM Microwave Imager)	1997/11 -
Aqua	AMSR-E	2002/05 -
ADEOS-II	GLI VNIR SWIR MTIR AMSR	2002/12-2003/10
ENVISAT (Environment Satellite)	ASAR (Advanced Synthetic Aperture Radar)	2002/03 -
ALOS	PRISM AVNIR-2 PALSAR	Planned

Users need to submit order forms to RESTEC to obtain the satellite data shown in Table 7. To fill out the order forms, users should obtain the necessary information from EOC operated by JAXA. Earth Observation data and Information System (EOIS) is a comprehensive online information service (Figure 14) that is integrated as a common interface for various services, including scene search, data-set search, etc., provided by JAXA and NASA. Users can decide what they order by inputting observation date, cloud amount, etc. to EOIS.

Users permitted to do so by EOC, JAXA can order data directly through EOIS without submitting order forms to RESTEC.

Figure 14. Earth Observation Data and Information System
<https://isswww.eoc.jaxa.jp/iss/en/index.html>

5.1.3 Agropedia-SIDaB

The Satellite Image Database System in AFF (SIDaB) has been operated by the Computer Center for Agriculture, Forestry and Fisheries Research of the Ministry of Agriculture, Forestry and Fisheries of Japan since 2000. The system accumulates universal observation data, such as NOAA, Defense Meteorological Satellite Program (DMSP), GMS, etc., and provides product processing, search functions and data. SIDaB is accessible through the Internet as part of ‘Agropedia’, an agricultural information resource system that intends to provide for effective use of research results. The system began to receive MODIS data in December 2002, and has provided products of Level 1B, Level 3B, and NDVI since February 2003 (Figure 15). The *chlorophyll-a* concentration product is now under consideration for distribution.

Users can obtain target products by searching for observation date, cloud cover and region, and can obtain custom processed products free of charge, such as for specifically requested areas, format specifications, etc. User registration in ‘Agropedia’ is required for use.

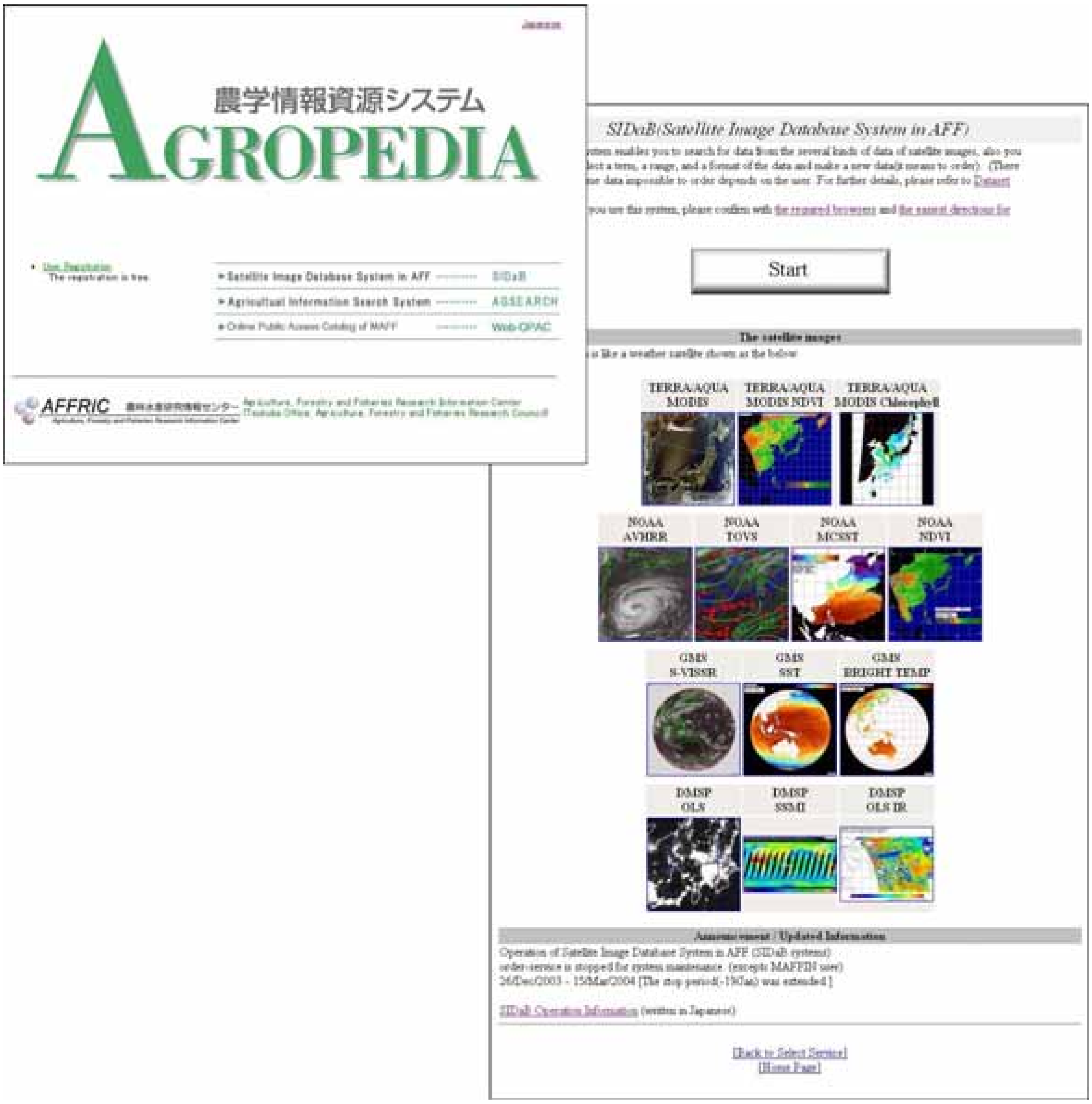


Figure 15. Agropedia - SIDaB
<http://rms1.agsearch.agropedia.affrc.go.jp/menu_en.html>

5.1.4 WebPaNDA and WebMODIS

The Institute of Industrial Science at the University of Tokyo was the earliest adopter in Japan and has been receiving NOAA AVHRR observation data since 1984. It has been operating an online distribution system (WebPaNDA) for Level 1B data and Quicklook images, using FTP, since February 2002. PaNDA, which stands for Package for NOAA Data Analysis, is a software package that has functions for format conversion, radiation correction, atmospheric correction and precise geometric correction by GCP, etc. While it is often the case that costly commercial software is used for the processing of AVHRR data, PaNDA is freeware capable of making the precise geometric correction that is considered to be the most difficult part of the processing (Takeuchi *et al*., 2002).

In parallel with receiving AVHRR data, the Institute started to receive Terra MODIS data in May 2001 and has been operating WebMODIS since September 2002, which pre-processes MODIS data by HDFLook and distributes it to users such as WebPaNDA. In 2003, the Institute also started to receive Aqua MODIS data and is now working on adding functions that include atmospheric corrections, Bidirectional Reflectance Distribution Function (BRDF) corrections and radiation corrections by Second Simulation of the Satellite Signal in the Solar Spectrum (6S). The institute set its final goal as providing higher-level products such as NDVI, land surface temperature, SST and Leaf Area Index (LAI) (Takeuchi *et al*., 2003).

Both WebPaNDA and WebMODIS provide data free of charge. The sample use method of WebMODIS is as follows. Table 8 shows the available data.

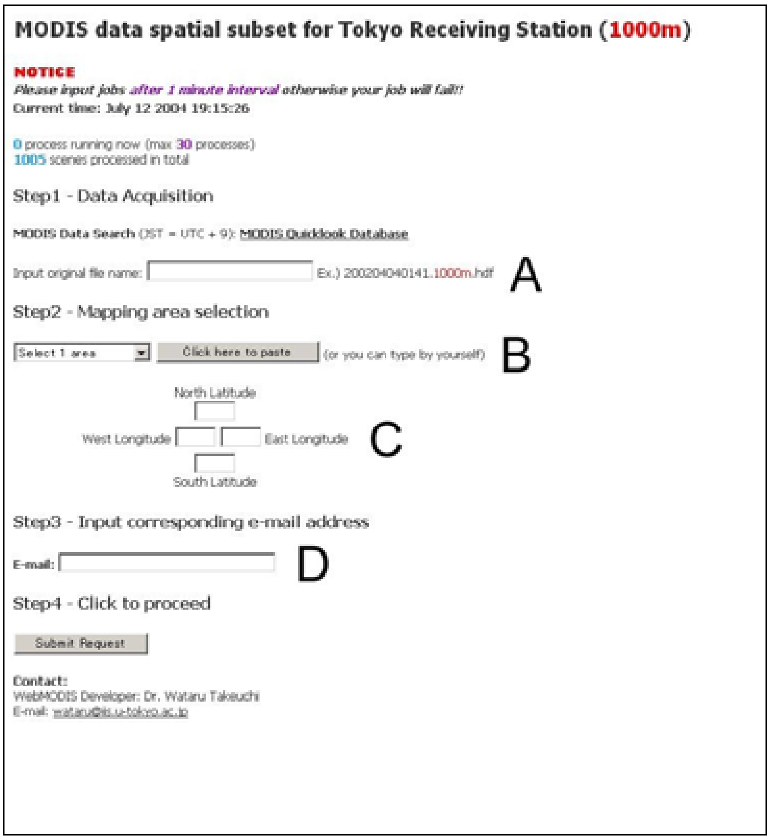
1) Select special resolution from 250, 500 or 1000 m (Figure 16-(a)-A).
2) Select the date of the required data by file name (Figure 16-(b)-A).
3) Input longitude and latitude of the required area (Figure 16-(b)-C) or select from the prepared options (Figure 16-(b)-B).
4) Input e-mail address to receive the information on data processing completion and download procedure (Figure 16-(b)-C).
5) Receive the e-mail informing the FTP site about 20 minutes after completing procedures 1) to 4). Download data from the FTP site. The data will be deleted 72 hours after the e-mail notice.

Table 8. Available file list processed on WebMODIS in terms of spatial resolution (Takeuchi *et al*., 2003)

FNAME expresses the data acquisition date in the form of YYYYMMDDHHMM (Year, Month, Day, Hour and Minute in UTC). Reflectance values are in radiance, thermal values in brightness temperature (°C) and zenith/azimuth angles in radians. HDF data are in 32-bit floating values.

Spatial Resolution	File	Note
250 m (QKM)	FNAME QKM RefSB.hdf	Image of Visible and Near-infrared (channels 1, 2)
	FNAME QKM QuickLook.jpg	Quicklook image of Visible and Near-infrared
	FNAME QKM.met	Meta-information (ASCII)
500 m (HKM)	FNAME QKM AggrHKM RefSB.hdf	Image of Visible and Near-infrared (channels 1, 2)
	FNAME HKM RefSB.hdf	Image of Visible and Near-infrared (channels 3-7)
	FNAME HKM QuickLook.jpg	Quicklook image of Visible and Near-infrared
	FNAME HKM.met	Meta-information (ASCII)
1000 m (1KM)	FNAME QKM Aggr1KM RefSB.hdf	Image of Visible and Near-infrared (channels 1, 2)
	FNAME HKM Aggr1KM RefSB.hdf	Image of Visible and Near-infrared (channels 3-7)
	FNAME 1KM RefSB.hdf	Image of Visible and Near-infrared (channels 8-9, 26)
	FNAME 1KM Emissive.hdf	Image of Thermal Infrared (channels 20-25, 27-36)
	FNAME SensorAzimuth.hdf	Sensor Azimuth Angle
	FNAME SensorZenith.hdf	Sensor Zenith Angle
	FNAME SolarAzimuth.hdf	Solar Azimuth Angle
	FNAME SolarZenith.hdf	Solar Zenith Angle
	FNAME 1KM QuickLook.jpg	Quicklook image of Visible and Near-infrared
	FNAME 1KM.met	Meta-information (ASCII)

(a). Home Page



(b). Data Search

Figure 16. WebMODIS
<http://webmodis.iis.u-tokyo.ac.jp/>

5.2 Study Network and Assistance Activity

5.2.1 International Workshop on Remote Sensing of the Marine Environment in the Northwest Pacific Region

Workshops have been organized by the NPEC, the host of the NOWPAP Special Monitoring and Coastal Environmental Assessment Regional Activity Center (CEARAC) since April 1999. The aim is to contribute to the development of marine environmental monitoring technologies derived from remote sensing. In the workshop, relevant countries (Japan, China, Korea and Russia), including NOWPAP Working Group 4 (NOWPAP WG4) members, attend to make presentations on remote sensing application, see examples of marine environmental monitoring, research and development trends, etc., and to exchange information.

The first workshop, held in Toyama from March 31 to April 1 in 2000, recommended that NOWPAP and NPEC should organize regular workshops and training courses, as well as promote the development of real-time information systems of the NOWPAP region (NPEC, 2000).

The second workshop, held in Toyama from March 25-26 in 2002, focused mainly on ocean color remote sensing, which made it different from the broad topics of the first workshop. Reports were presented on the status of ocean color remote sensing in each country, and there was general discussion on the atmospheric correction and in-water algorithms. Specifically, the methods discussed pertained to marine environmental remote sensing in Asia. Asian researchers expressed the expectation that Japan should take a leadership role and establish a cooperation system in Asia for the use of ocean color remote sensing based on their experience with ADEOS OCTS for coastal environmental monitoring. The workshop discussion produced the following results (NPEC, 2000; NPEC, 2003). The third workshop was held in October 2004 in Beijing.

1) It is very important to continue monitoring using CZCS, OCTS, FY-1 and SeaWiFS.
2) *In situ* surveys are necessary to improve the atmospheric correction and in-water algorithms.
3) It is important to undertake cooperative research to collect *in situ* observation data for the improvement of model calibration and validation.
4) Regular data collection by each regional organization is useful.
5) Quality control of *in situ* data is important and must always be carried out. Establishment of standardized protocols is necessary to accurately accumulate quality data from different organizations and projects.
6) Consideration of the land-ocean system is important for monitoring, modeling and reducing pollution in the NOWPAP region. Specifically, coastal and river basin monitoring are necessary.
7) NOWPAP is expected to have cooperative activities with international marine environmental monitoring programs, including IOC, The Global Ocean Observing System (GOOS), etc.
8) It was proposed that workshops and training courses should be continued, and their results and the satellite data managed and operated by NPEC should be made widely available.

5.2.2 Red Tide Watcher Project

Along the Asian coast, large-scale red tides have frequently occurred, resulting in social issues that include increased damage to fisheries, deterioration of tourism resources and poisoning of people due to polluted fish and shellfish. To prevent such damage, it is necessary to have regular and large scale monitoring programs. However, the collection of information on red tides in Asian coastal countries still primarily relies on survey vessels. The establishment of more monitoring systems is expected due to the increasing occurrence of red tides. The 'Red Tide Watcher Project', presented by Professor Ken Furuya of the Graduate School of Agricultural and Life Sciences at The University of Tokyo, started in October 2002. The project's primary aim is the establishment of red-tide monitoring infrastructure based on the mutual understanding among related countries, including the integration of existing efforts and the latest technology, such as remote sensing. This project is supported by the Special Coordination Funds for Promoting Science and Technology of the Ministry of Education, Culture, Sports, Science and Technology, Japan.

Red tides involve many species of phytoplankton, depending on sea area and season. Thus, wide-area monitoring requires the cooperation of researchers who are studying each area. Also, communication between red-tide researchers and remote-sensing researchers, which was rare in the past, has become very important. Based on such observations, the Red Tide Watcher Project initiated an international ocean color observation forum to promote partnership among organizations and specialists relating to red tides along the Asian coast, the marine environment and the remote sensing of ocean color. The outlines of the activities are as follows (Red Tide Watcher Project, 2003).

1) Monitoring red tides that spread widely along Asian coasts
   Establishing an international ocean color observation forum of organizations and researchers in Asia relating to red tides, the marine environment and remote sensing of ocean color. Initiating a wide area red-tide monitoring system, Red Tide Watcher, that integrates the forum activities as well as the database development and operation of red-tide events.
2) Ecology of red tides
   Reviewing ecological information by studying red-tide plankton classification and ecology, and collecting information from each country's researchers through holding symposia on red-tide ecology.
3) Ocean color observation by satellites
   Establishing an algorithm for estimating *chlorophyll-a* concentration for the highly turbid water that is dominant along the Asian coast, by studying the optical characteristics of seawater. Also, investigating the efficient operation of red-tide monitoring systems by ocean color remote sensing thorough satellite workshops.
4) Asian Intensive Local Area Coverage (I-LAC) database
   Taking a role in basic infrastructure development, including the Asian I-LAC database, its maintenance and operation.

In March 2003, a workshop was held that combined the international ocean-color satellite and red-tide symposia, in which about 30 researchers of remote sensing and red tides from Asia, Europe and America gathered to share their common understandings, and present conditions and issues regarding the establishment of a red-tide monitoring system (Red Tide Watcher Project, 2003).

6 Challenges and Prospects

6.1 Real-time Performance and Continuity of Observation

To proceed with the development of algorithms for practical use, infrastructure establishment and subsequent project formation, it is necessary to achieve a real-time performance that provides status and continuity of the observations so that long-term variation can be understood. Real-time performance, as shown in section 5.1.1, is ready for practical use and is expected to provide products in the near future. The continuity will be achieved more than 10 years from now by observation plans such as the Global Change Observation Mission of JAXA and the National Polar-orbiting Operational Environment Satellite System (NPOESS) Preparatory Project of NASA that follow the presently operating SeaWiFS and MODIS. However, to analyze long-term variations using products of OCTS, SeaWiFS, MODIS and GLI, which have a range of 8 years, product compatibility between sensors will be an issue due to the inevitable changes in sensors.

Global Change Observation Mission

To systematically observe global environmental variations in time and space, JAXA is considering a long-term earth observation program, called Global Change Observation Mission (GCOM). This will record the necessary parameters taking over the role of ADEOS II. The program plans to launch two earth observation satellites, based on the Integrated Global Observing Strategy (IGOS). One is the GCOM-A1 satellite that observes ozone and greenhouse gases, and the other is the GCOM-B1 satellite that observes material and energy cycles. GCOM-B1 will be equipped with a second generation GLI (S-GLI), which has multiple wavelength-channels as a successor of GLI, with the goal that Japan takes a leading role in the observation of ocean color and marine primary production.

It is very important to conduct such coastal monitoring for understanding and predicting the impacts of human activities on the marine environment. This is especially true for Japan, which has a long coastline and high population and industrial density, combined with rapid coastal development. S-GLI is a sensor that is expected to contribute to advancing this understanding. High-resolution daily observations at 250 m and high signal to noise ratio (SNR) ocean color observations are considered vital, although they are still in the preliminary stages of development. The final goal is as follows.

Understanding coastal-area processes
- Input and output of materials (carbon, soil, pollutants, etc.) and heat
- Process of primary production (contribution in the carbon cycle)
- Interaction between coast and open ocean

Coastal area monitoring
- Pollution of material and heat due to urbanization and industrialization
- Eutrophication (e.g. red tides) in the coastal and in-land waters
- Natural disasters (abnormal wind, rain, influence of an earthquake, etc.)
- Estimation of productivity (fishery locations and fish catch)
- High-resolution sea-ice position and displacement
- Near real-time inputs of high-resolution numerical (physical, biological and chemical) models in the coastal area

In addition, based on the experience of ADEOS-II, which suspended its operation due to mechanical troubles, the mission is now considering launching a S-GLI ALOHA version sensor (ALOHA: Atmosphere, Land and Ocean Harmonized Answer) in 2008.

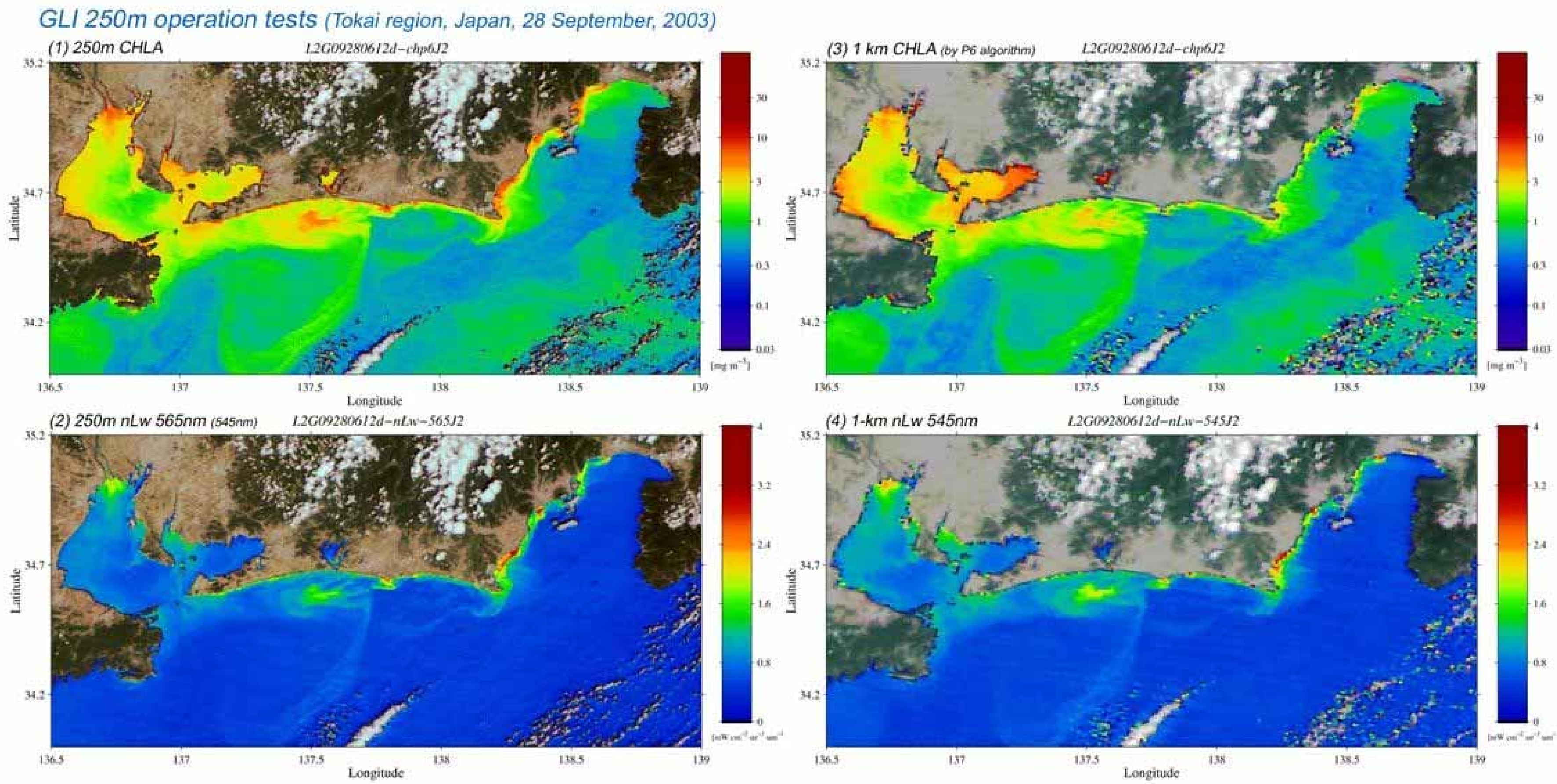
6.2 Practical Use of Ocean Color Remote Sensing Along the Coast

In ocean color remote sensing by OCTS, SeaWiFS, GLI and MODIS, the estimation algorithm of *chlorophyll-a* concentration that targets the open ocean has almost been established and put into practical use. However, issues still remain for targeting the coast. The relation between ocean color and materials in coastal seawater is not as simple as in the open ocean, due to the influence of SS and CDOM on the optical characteristics of seawater. Complications also arise due to the influence of absorbing aerosols, particularly those that are man-made. In addition, the assumption used in the open ocean that the water-leaving radiance in the near infrared is negligible is not applicable for the coast due to high turbidity.

New algorithms are currently under development to solve these issues. Regarding atmospheric correction, neural-network use was proposed for in-water algorithms (described later) to estimate water-leaving radiance by analytical methods that take account of absorption coefficients for *chlorophyll-a*, SS and CDOM, rather than the use of empirical methods using regression formulas. The method is expected to be an effective approach, even for correcting light absorbing aerosols, because it has the advantage that it includes the optical interaction between air and water. Such optical interaction is difficult to identify with the existing algorithm that uses an in-water algorithm after atmospheric correction. Regarding the in-water algorithm, a reverse computational method using neural networks is under study. It first analyzes the water-leaving radiance of *chlorophyll-a*, SS and CDOM with a radiative transfer model, and then the neural network back computes these parameters. To make the algorithm ready for practical use, it will be important to develop and validate the radiative transfer model, based on enough *in situ* measurements of water-leaving radiance, *chlorophyll-a*, SS and CDOM (Ishizaka, 2001). To further increase accuracy, region specific algorithm development should supplement the current practice of using a uniform algorithm.

Another issue is the coarse (1 km) resolution of the existing data in estimating parameter distributions along coastlines with more complicated topography. To tackle this issue, the processing methods are under study on GLI products with that combine 250 m and 1 km resolution (Figure 17), as well as on MODIS products that combine 500 m and 1 km resolution (Sakuno, 2004).

At the end of October 2003, ADEOS-II terminated its operation due to mechanical troubles. Although the observation period was short, valuable high-resolution products at multiple wavelengths have contributed to the great progress in coastal ocean color remote sensing. Based on such progress by ADEOS-II and more *in situ* data, it is highly probable that ocean color remote sensing by MODIS, as a leading sensor, will be used for practical applications in near future.



Produced by EORC, JAXA.

Figure 17. GLI 250m operation tests #3 (Tokai region, Japan, 26 September, 2003)

7 Suggested Activities for the NOWPAP region

7.1 Remote Sensing Information Network in Future

It was pointed out during discussions at the first meeting of NOWPAP WG4 and the second CEARAC Focal Points Meeting (FPM) that common understanding and information sharing should be promoted on application and interpretation, the status and future prospects of research and development, and the real use of remote sensing in marine environmental monitoring. Based on such observations, NOWPAP WG4 considered the development of a remote sensing information network and started a portal site on the Internet. However, the portal site's role of navigating locations of scattered information and data is limited in its quality and quantity, and its role as a useful remote sensing information network will not last long. Thus, it is necessary to consider step-by-step procedures to develop a remote sensing information network, taking account of realistic limitations, such as development cost, content provision, etc. Figure 18 illustrates the concept for developing a remote sensing information network step-by-step.

The development has two steps, depending on target information, accumulated data quantity and sharing level. The first step is the development of an ongoing portal site that reviews and provides locations of scattered information and data. The second step is the development of a digital library that also provides the information and data. The Marine Environmental Watch Project, which is currently expanding its functions, is worth considering as a base for the digital library.

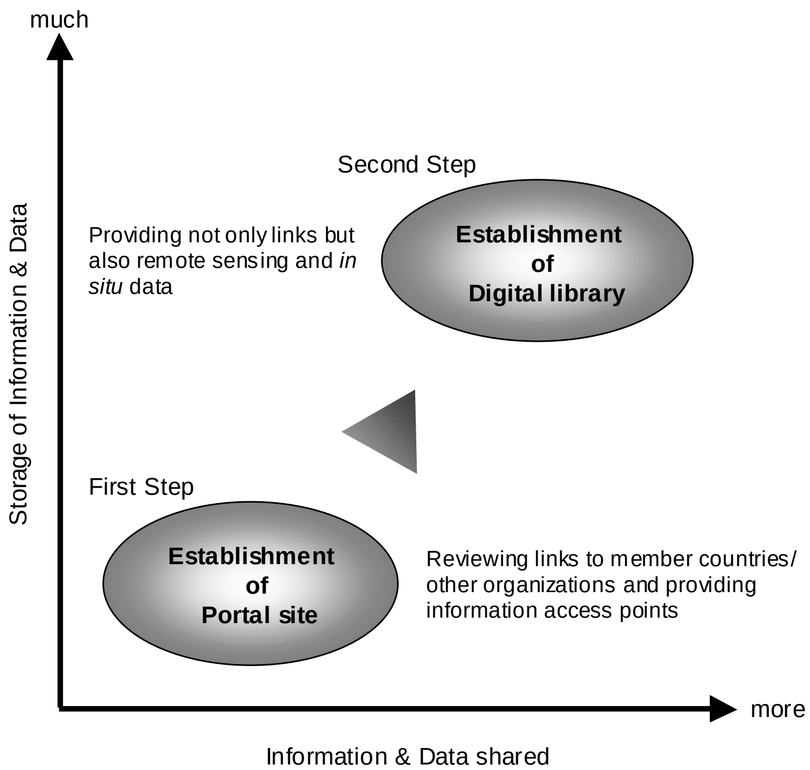


Figure 18. Steps for the Development of a Remote Sensing Information Network System

7.2 Sustainable ocean observing system and regional cooperation

During the Earth Observation Summit II (Tokyo, April 2004), the Group on Earth Observations (GEO) adopted the position that observing and understanding the earth more completely and comprehensively will expand worldwide capacity and a means to achieve sustainable development. It will also yield advances in many specific areas of socio-economic benefit, including: (1) reducing loss of life and property from natural and human-induced disasters; (2) understanding environmental factors affecting human health and well being; (3) improving management of energy resources; (4) understanding, assessing, predicting, mitigating and adapting to climate variability and change; (5) improving water-resource management through a better understanding of the water cycle; (6) improving weather information, forecasting and warning; (7) improving the management and protection of terrestrial, coastal and marine ecosystems; (8) supporting sustainable agriculture and combating desertification; and (9) understanding, monitoring, and conserving biodiversity (GEO, 2004). The implementation of NOWPAP activities, including monitoring eutrophication and oil spills, should be made with due consideration of these social benefits.

GOOS has been developed by UNESCO/IOC, United Nations Environment Programme (UNEP), World Meteorological Organization (WMO) and International Council for Science (ICSU). Its coastal module is designed by an advisory group, the Coastal Ocean Observations Panel, and its strategic design plan is now available (UNESCO, 2003). The sustainable coastal observing system should have the ability to rapidly detect and provide timely predictions of changes in a broad spectrum of marine phenomena that affect: (1) the safety and efficiency of marine operations; (2) the susceptibility of human populations to natural hazards; (3) the response of coastal ecosystems to global climate change; (4) public health and well being; (5) the state of marine ecosystems; and (6) the sustainability of living marine resources. Because of these overlapping working areas between GOOS/COOP and NOWPAP, cooperative activities in the development of the regional ocean observing system will be promoted.

The National GOOS Programmes and GOOS Regional Alliances (GRAs) provide the primary venue for identifying user groups, specifying data and information requirements and refining data products over time, based on user feedback and new knowledge. The North-East Asian Regional GOOS (NEAR-GOOS) is one of the GRAs. Its region is almost the same as that of NOWPAP, and its member countries are also the same. In order to promote the space-based monitoring systems of NOWPAP and achieve its goals, close collaborations with NEAR-GOOS may be important and necessary.

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Group on Earth Observations <http://earthobservations.org/>

JAXA <http://www.jaxa.jp/index_e.html>

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Marine Environmental Watch Project <http://www.nowpap3.go.jp/jsw/index.php?lang=en>

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List of Acronyms

6S	Second Simulation of the Satellite Signal in the Solar Spectrum
ADEOS	Advanced Earth Observing Satellite
ALOS	Advanced Land Observing Satellite
AMSR	Advanced Microwave Scanning Radiometer
AMSR-E	Advanced Microwave Scanning Radiometer for Earth Observing System
ASAR	Advanced Synthetic Aperture Radar
AVHRR	Advanced Very High Resolution Radiometers
AVNIR-2	Advanced Visible and Near Infrared Radiometer type-2
BRDF	Bidirectional Reflectance Distribution Function
CDOM	Colored Dissolved Organic Matter
CEARAC	Coastal Environmental Assessment Regional Activity Center
CZCS	Coastal Zone Color Scanner
DEM	Digital Elevation Model
DMSP	Defense Meteorological Satellite Program
ENSO	El Nino/Southern Oscillation
ENVISAT	Environment Satellite
EOC	Earth Observation Center
EOIS	Earth Observation Data and Information System
EORC	Earth Observation Research and application Center
ERS-2	European Remote Sensing Satellite-2
ESA	European Space Agency
FPM	Focal Points Meeting
FRRF	Fast Repetition Rate Fluorometer
FTP	File Transfer Protocol
FY-1	Feng Yun-1
GCOM	Global Change Observation Mission
GCP	Ground Control Point
GEO	Group on Earth Observations
GHRSST-PP	GODAE High Resolution Sea Surface Temperature Pilot Project
GLI	Global Imager
GMS	Geostationary Meteorological Satellite
GODAE	Global Ocean Data Assimilation Experiment
GOOS	The Global Ocean Observing System
GRAs	GOOS Regional Alliances
HABs	Harmful Algal Blooms
ICSU	International Council for Science
IGOS	Integrated Global Observing Strategy
IOC	The Intergovernmental Oceanographic Commission
I-LAC	Intensive Local Area Coverage
JAMSTEC	Japan Marine Science and Technology Center (now Japan Agency for Marine-Earth Science and Technology)
JAXA	Japan Aerospace Exploration Agency
JERS-1	Japanese Earth Resources Satellite-1
LAI	Leaf Area Index
LUT	Look Up Table
MESSR	Multispectral Electronic Self-scanning Radiometer
MODIS	Moderate Resolution Imaging Spectrometer
MSR	Microwave Scanning Radiometer
MTIR	Middle and Thermal Infrared
MVISR	Multi-channel Visible and IR Scan Radiometer
NASA	National Aeronautics and Space Administration

NASDA	National Space Development Agency of Japan (now JAXA)
NDVI	Normalized Difference Vegetation Index
NEAR-GOOS	North-East Asian Regional GOOS
NGSST	New Generation Sea Surface Temperature
NOAA	National Oceanic and Atmospheric Administration
NOWPAP	Northwest Pacific Action Plan
NPEC	Northwest Pacific Region Environmental Cooperation Center
NPOESS	National Polar-orbiting Operational Environment Satellite System
OCTS	Ocean Color and Temperature Scanner
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PaNDA	Package for NOAA Data Analysis
PAR	Photosynthetically Available Radiation
PI	Principal Investigator
PR	Precipitation Radar
PRISM	Panchromatic Remote-sensing Instrument for Stereo Mapping
PRR	Profiling Reflectance Radiometer
QuikSCAT	Quick Scatterometer
RA	Radar Altimeter
RESTEC	Remote Sensing Technology Center of Japan
S-GLI	Second generation-GLI
SAR	Synthetic Aperture Radar
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SIDaB	Satellite Image Database System in AFF
SIMBIOS	Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies
SS	Suspended Solid
SST	Sea Surface Temperature
SWIR	Shortwave Length Infrared
TAO	Tropical Atmosphere Ocean
TMI	TRMM Microwave Imager
TRMM	Tropical Rainfall Measuring Mission
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
vical coef.	vicarious calibration coefficients
VIRS	Visible and Infrared Scanner
VNIR	Visible and Near Infrared
VTIR	Visible and Thermal-Infrared Radiometer
WESTPAC	IOC Sub-Commission for the Western Pacific
WG4	Working Group 4
WMO	World Meteorological Organization