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Special Monitoring and Coastal Environmental Assessment
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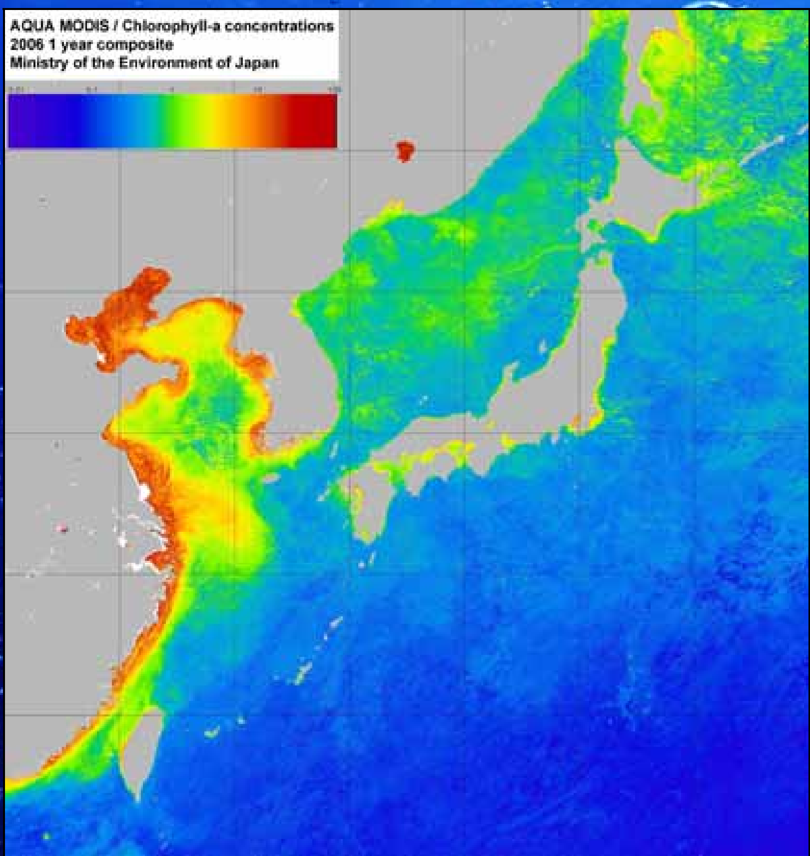
Eutrophication Monitoring Guidelines by Remote Sensing for the NOWPAP Region



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Preface

These guidelines were made aiming at coastal managers in local government and professional researchers, for translating satellite remote sensing into information and tools that are useful for monitoring of eutrophication, which represents one of the most severe and widespread environmental problems in the NOWPAP region. We hope the guidelines will contribute to proper use of satellite data for monitoring and assessment of eutrophication then, as a result, to capacity building of the NOWPAP members.

The guidelines will require ongoing revision and should be updated in accordance with the development of remote sensing technology used in marine environmental monitoring.

Any questions or comments on the guidelines should be made by contacting NOWPAP CEARAC (cearac@npec.or.jp).

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I Background and purpose

The Action Plan for the Protection, Management and Development of the Marine and Coastal Environment of the Northwest Pacific Region (NOWPAP) was adopted in September 1994 as a part of the Regional Seas Programme of the United Nations Environment Programme (UNEP). In order to support the implementation of the action plan, a network of Regional Activity Centres (RAC) was established in each member country (NOWPAP Member) in pursuit of the chosen goals and objectives. Among the RAC, a Special Monitoring and Coastal Environmental Assessment Center (CEARAC) was established in Japan and Northwest Pacific Region Environmental Cooperation Center (NPEC) was designated as the hosting body of CEARAC in 1999.

Under the CEARAC, two working groups, namely WG3 and WG4, comprised of national experts from each NOWPAP Members were established with the responsibility of implementing activities related to harmful algal blooms (HAB) including red tides (WG3) and remote sensing of marine environment (WG4).

NPEC prepared 'Guideline for Eutrophication Monitoring by Remote Sensing' in order to optimize the use of remote sensing techniques for the monitoring of eutrophication by referring to the results and lessons learned from a case study conducted in Toyama Bay. National experts of NOWPAP WG4 have reviewed and refined the guidelines prepared by NPEC in order to fit in the particular characteristics of each region and to have one integrated set of guidelines suitable for use throughout the NOWPAP Region.

The objectives of the guidelines are:

- to form a basis a common methods for the evaluation and use of satellite data,
- to promote the use of remote sensing as a marine environmental monitoring tool,
- to coordinate the implementation of an integrated marine environmental monitoring program in the NOWPAP Region.

II Eutrophication and satellite remote sensing

1 Introduction

Eutrophication is the phenomenon of aquatic ecosystem enrichment due to increased nutrient loading. Eutrophication is often caused by human activities such as the additional input of fertilizers from agriculture farming, food for aquaculture, untreated and/or treated sewage as well as industrial wastewater inputs. Eutrophication causes the deterioration of the coastal environment and typically leads to the formation of harmful algal (phytoplankton) blooms which may subsequently induce fish kill, further ecosystem damage and, at times, are directly or indirectly associated with human health problems. Eutrophication degrades the water quality by accelerating organic matter growth and decomposition as well as decreasing the light availability in the coastal waters.

Coastal areas of China, Japan and Korea are densely populated and the ability to monitor the health of these coastal systems is necessary to manage and sustain healthy coastal environments. However, the availability of continuous and synoptic water quality data, particularly in estuaries and bays in these countries, to characterize the response of water quality to human and natural impacts is lacking. Furthermore, although eutrophication is a rare event in Russian waters, due to increases in agricultural and industrial activity as well as the highly variable coastal run-off in this region, there has been an increase in the need for effective methods of water quality monitoring.

Coastal eutrophication is recognized as one of the serious marine environmental problems in Europe and US, and the need for more effective monitoring and control measures is increasing. The OSPAR Commission adopted the Common Procedure for the Identification of the Eutrophication Status of the Maritime Area in 1997. In 1999, the National Oceanic and Atmospheric Administration (NOAA) reported the first assessment on the effects of nutrient enrichment in US estuaries - National Estuarine Eutrophication Assessment (NEEA). UNEP/Mediterranean Action Plan (MAP) approved the Eutrophication Monitoring Strategy for the Mediterranean Sea in 2003. The Helsinki Commission (HELCOM) developed tools for assessment of eutrophication in the Baltic Sea, in 2006.

There are several indicators presently used to assess eutrophication in aquatic systems. Phosphate, ammonia and nitrate, in both river and coastal waters are the major constituent nutrients driving eutrophication. Chlorophyll-a (Chl-a) is an indicator of phytoplankton biomass and concentration increases due to phytoplankton growth are a result of eutrophication. Chemical oxygen demand (COD) and Biochemical oxygen demand (BOD) are used to quantify the magnitude of organic pollution, which may induce oxygen depletion in aquatic ecosystem. Suspended solid (SS) and transparency are used as an indicator of turbidity. All these indicators can be measured directly through ship-based water sampling.

Collecting water samples through ships is often costly and provides data limited in space and time. In contrast, satellite remote sensing can cover large areas (up to global) with relatively high resolution (250 m - 1 km) and without restriction of national boundaries. Additionally, remote sensing provides for long time series (nearly 10 years) of frequently measured (up to several days) data. Recent advancements in remote sensing have allowed for the collection of data and information on Chl-a concentration, SS, colored dissolved organic matter (CDOM), phytoplankton primary productivity, and sea surface temperature (SST) (CEARAC, 2005). Thus, it is reasonable to complement conventional ship-based methods of monitoring with satellite remote sensing techniques. Collectively, with regular ship monitoring, remote sensing data is able to provide a broad visual image of oceanic phenomena, aiding our understanding of eutrophication processes and the assessment of the health of coastal environments.

2 Satellite data

Among the wide range of satellite data provided by various space agencies the guidelines introduce the most cost-effective satellite data for use in the monitoring of eutrophication.

When using satellite data, factors such as the choice of monitoring parameters, sensor types, data availability and data processing methods must be carefully considered and the data must be pre-processed in order to be suitable for the monitoring of eutrophication.

2.1 Monitoring parameters

Among the parameters measured by satellite, ocean color provides the most useful information for the monitoring of eutrophication. Ocean color is the measure of the spectral characteristics of water-leaving radiance and is comparable to the visible inspection of the watercolor.

Chl-a concentration and turbidity can be retrieved from the ocean color. The retrieval algorithms are well established for the open ocean (Case 1 waters) and less accurate in the coastal areas where other materials influence the watercolor (Case 2 waters). SST can also be estimated from space by the measurement of the temperatures at the ocean surface using several wavelengths in the infrared (IR) and/or microwave ranges of electromagnetic spectrum.

a. Chl-a concentration

Chl-a is contained in all species of phytoplankton which form the base element of primary production of the ocean. It can be regarded as the total amount of phytoplankton biomass, and measures of Chl-a enables the monitoring of the mass generation of phytoplankton. If eutrophication persists phytoplankton concentrations can often increase to high levels causing the degradation of water quality and resulting in the occurrence of events such as red tides. Thus, Chl-a can be used as an indicator of eutrophication.

Satellite remote sensing provides for the estimation of oceanic Chl-a concentrations by measuring water-leaving visible radiation of each wavelength at the sea surface. Chl-a concentration is determined by the color of the water-leaving light (i.e. green color indicates high Chl-a levels because water rich in Chl-a absorbs blue light).

b. SST

SST measurements made from satellites refer to the temperature of the uppermost layer of water, less than 1 mm in thickness and are measured through the absorption of IR and microwave emissions in saline seawater. The SST field is a good indicator of the season-scale and synoptic-scale changes in surface circulation patterns and air-sea interactions. Time series of SST allow for the tracing of coastal currents and water masses of various origins as well as the identification of the location of ocean fronts, eddy-like formations, upwelling regions and the various physical features that concentrate and transport phytoplankton.

c. Turbidity (K490)

Turbidity decreases water clarity. Turbidity can be estimated from ocean color by calculation of the diffuse attenuation coefficient K490. This coefficient indicates how visible light, in the blue to green region of the spectrum, penetrates the water column.

d. Others

Other products provided by space agencies which may also be used in the monitoring of eutrophication are summarized in Table 6.1.

2.2 Sensors

Various sensors used for the measurement of each of the monitoring parameters discussed in section 2.1 have been operated by space agencies as follows. Additional sensors are summarized in Table 6.2.

a. Chl-a concentration

Satellite observations of ocean color began in 1978 with the launch of the Coastal Zone Color Scanner (CZCS) instrument on the NIMBUS-7 satellite. CZCS was a demonstration mission to establish the technological and scientific feasibility of mapping ocean phytoplankton pigment concentrations from satellite and although the frequency at which data was measured was limited (Evans and Gordon, 1994) its service continued through to June 1986. Following approximately a 10-year blank period, NASDA (predecessor of JAXA (Japan Aerospace Exploration Agency)) launched the Japanese Ocean Color and Temperature Sensor (OCTS) on the ADEOS satellite which operated from August 1996 to June 1997. NASA subsequently launched the Sea-Viewing Wide Field-of–view Sensor (SeaWiFS) in August 1997 and the satellite continues to operate in 2007. NASA also launched a Moderate Resolution Imaging Spectroradiometer (MODIS) on TERRA in December 1999 and on AQUA in May 2002. JAXA launched Global Imager (GLI) on the ADEOS-II satellite, however, operation of the GLI ceased 10 months after its launch in October 2003 due to mechanical trouble.

NASA maintains the quality and consistency of its data for all periods of operation and provides the data via the Internet. SeaWiFS data from September 1997 can be obtained free of charge by submitting an application to NASA. Methods for acquiring SeaWiFS data depend on the intended use of the data (i.e. research or commercial).

The European Space Agency (ESA) operates the Medium Resolution Imaging Spectrometer (MERIS) which was launched on Envisat-1 in March 2002. The primary mission of MERIS is the measurement of ocean color. MERIS data used for research purposes can be obtained either at reproduction costs or free of charge.

b. SST

SST is estimated through the processing of NOAA AVHRR (Advance Very High Resolution Radiometer) and NASA MODIS data. The data are received by many organizations and are made available to the public via the Internet.

c. Turbidity (K490)

SeaWiFS and MODIS provide datasets of K490 which are used to determine turbidity levels.

2.3 Obtaining data

Satellite data can be obtained from many organizations. The following list describes the satellite data most suitable for the monitoring of eutrophication. Data format specifications and the requirements necessary for obtaining data are specific to each data provider.

a. Chl-a concentration

<CZCS>
CZCS Chl-a concentration data from November 1978 through June 1986 can be obtained from the Ocean Color Web (http://oceancolor.gsfc.nasa.gov/). NASA classifies this data as an evaluation product since improvements in the accuracy of the data is still on going.

<OCTS>
OCTS Chl-a concentration data from November 1996 through June 1997 can be obtained from the Ocean Color Web via the Internet. NASA classifies this data as an evaluation product.

<SeaWiFS>
SeaWiFS Chl-a concentration data from September 1997 to 2007, can be obtained for free of charge by submitting an application to NASA. NASA provides SeaWiFS Chl-a data at a different spatial resolution to the Ocean Color Web.

<MODIS>
MODIS data is received at many organizations and is available to the public via the Internet. MODIS Chl-a data from June 2002 can be obtained from the Ocean Color Web.

JAXA also provides MODIS Chl-a data that has been received by the Earth Observation Center and processed using the JAXA GLI algorithm. A subset of the processed data has been geometrically corrected for the NOWPAP Region by the Northwest Pacific Region Marine Environmental Watch and can be downloaded from its website (the Marine Environmental Watch Homepage).

<MERIS>
MERIS Chl-a data from June 2002 can be obtained from the EOLI-WEB website (http://eoli.esa.int/servlets/template/welcome/entryPage2.vm).

b. SST

<AVHRR>
AVHRR SST from February 2002 can be obtained from the Marine Environmental Watch Homepage. The data is geometrically corrected for the NOWPAP Region and provides daily and 10-day composite images.

Marine Remote Sensing Laboratory, National Fisheries Research & Development Institute (NFRDI) also provides AVHRR SST data from November 1989.

<MODIS>
MODIS SST data from June 2002 can be obtained from the Ocean Color Web via the Internet with LAC spatial resolution. The Marine Environmental Watch Homepage also provides MODIS SST data, processed by JAXA GLI algorithm, from August 2002 onwards.

c. Turbidity (K490)

SeaWiFS and MODIS provide K490 datasets that can be used as an indicator of turbidity and are available from the Ocean Color Web.

2.4 Data processing method

The obtained data must be processed in accordance with the monitoring objective. The following section introduces some of the available software and the data processing methods available.

a. Setting up software for satellite data processing

SeaDAS (SeaWiFS Data Analysis System) is a free software developed by NASA and is the most suitable choice for the processing and analysis of Chl-a concentrations, SST and turbidity (K490) data from SeaWiFS. SeaDAS may be run on PC-Linux, thereby enabling the construction of a processing environment at a reasonable cost. WIM software is also suitable for the analysis of satellite images. WIM works on Microsoft Windows operating system and its evaluation version can be obtained via the Internet (http://www.wimsoft.com).

Microsoft Excel may be used for processing and analysis of Chl-a concentrations and SST data provided from the Marine Environmental Watch Homepage.

Other suitable software is introduced in Table 6.3.

b. Extraction of physical values

Physical values from each sensor can be extracted from the following satellite date products.

(1) Chl-a concentration

<CZCS>
Data Product: CZCS Level 2 data
Data Source: Ocean Color Web
Recommended software application: SeaDAS, TeraScan, ERDAS, ENVI, WIM

<OCTS>
Data Product: OCTS Level 2 data
Data Source: Ocean Color Web
Recommended software application: SeaDAS, TeraScan, ERDAS, ENVI, WIM

<SeaWiFS>
Data Product: SeaWiFS Level 2 data
Data Source: Ocean Color Web
Recommended software application: SeaDAS, TeraScan, ERDAS, ENVI, WIM

<MODIS>
Data Product: MODIS Level 2 data
Data Source: Ocean Color Web
Recommended software application: SeaDAS, TeraScan, ERDAS, ENVI, WIM

<MODIS processed by JAXA>
Data Product: JAXA GLI MODIS
Data Source: Marine Environmental Watch Homepage
Recommended software application: SeaDAS, TeraScan, ERDAS, ENVI, WIM, Microsoft Excel

<MERIS>
Data Product: MERIS Level 2 data
Data Source: EOLI-WEB
Recommended software application: BEAM, ERDAS, Microsoft Excel

(2) SST

<AVHRR>
Data Product: AVHRR SST
Data Source: Marine Environmental Watch Homepage, Marine Remote Sensing Laboratory, NFRDI
Recommended software application: SeaDAS, TeraScan, WIM, Microsoft Excel

<MODIS >
Data Product: MODIS SST
Data Source: Ocean Color Web
Recommended software application: SeaDAS, TeraScan, WIM

(3) Turbidity (k490)

<SeaWiFS>
Data Product: SeaWiFS Level 2 data
Data Source: Ocean Color Web
Recommended software application: SeaDAS, WIM

<MODIS>
Data Product: MODIS Level 2 data
Data Source: Ocean Color Web
Recommended software application: SeaDAS, WIM

2.5 Region-specific issues

China has been using SZ-3/CMODIS, HY-1/COCTS, HY-1/CCD and FY-1/MVIRS for open ocean and coastal environmental monitoring. These sensors are domestically used and many users have constructed their own algorithms for the monitoring of Chl-a, Total Suspended Matter and SST etc. For example, there are 16 kinds of products provided by HY-1A sensors all of which are distributed via the NSOAS website.

Japan has been providing MODIS products processed using the JAXA GLI algorithm developed for GLI instrument onboard ADEOS-II. The algorithm has been validated with *in situ* data collected in seas surrounding Japan.

Korea has been using Chl-a concentration data of OCM (Ocean Color Monitor) of IRS-P4 received between May 2001 through to October 2004 at NFRDI. IRS-P4 OCM was launched on the 26th of May 1999 in India. OCM Chl-a data are processed by NASA OC2 algorithm and are used for domestic research purposes.

3 *In situ* data

To maximize the usefulness of satellite data for the monitoring of eutrophication it is essential to obtain *in situ* data. *In situ* data obtained almost simultaneously with satellite data can be used for the calibration and validation of satellite data. Furthermore, satellite data can help in the interpretation of *in situ* data by providing large spatio-temporal coverage images of oceanic phenomena that *in situ* data cannot cover.

When obtaining *in situ* data, consideration of the data requirements and the cost-effective sampling plan are necessary. The following section introduces some of the typical parameters used for the monitoring of eutrophication, their methods of measurement as well as the factors which determine the number and location of sampling points, the sampling frequency and timing and the additional prerequisites for the effective monitoring and analysis of eutrophication.

3.1 Monitoring parameters and measurement methods

It's preferable to obtain *in situ* data of the following parameters for the monitoring of eutrophication. Measurement methods for each parameter are explained in details in the NASA SeaWiFS Technical Report Series at SeaWiFS Project Information Homepage, Manual for oceanographic observation (Japan Meteorological Agency, in Japanese), and Marine Monitoring Guideline for the Correction and Validation of Satellite Sea Color Data (Earth Science and Technology Forum/Earth Monitoring Committee, Marine Environment Science Team 2001, in Japanese).

a. Chl-a concentration

In situ measurements of Chl-a concentration are used for the calibration and validation of satellite data. Chl-a concentration is a good indicator of eutrophication and correlates with measures of organic pollution such as COD, etc.

b. Nutrients

Eutrophication is often caused by the direct input of high nutrient load from land-based sources. Nutrients control phytoplankton growth and may change the taxonomic composition of plankton communities.

c. Temperature and Salinity

Temperature is a good indicator of water mass type and the condition of vertical mixing. It can also be used to estimate phytoplankton growth rate or primary production. Measurements of surface salinity levels make it possible to estimate how much fresh water, such as river outflow and precipitation, is flowing into target areas.

d. Transparency

Transparency can be used to determine the average turbidity levels in surface waters. The measurement of transparency is simple and the availability of extensive historical records can be used for comparison with the present data, particularly in the NOWPAP Region.

e. COD

COD is an indicator of organic pollution. COD may be useful to develop a greater understanding of the nature of eutrophication and organic pollution processes when combined with information of Chl-a concentration. This will make it possible to employ satellite remote sensing as a monitoring tool of organic pollution that may lead to eutrophication.

f. Suspended Solid (SS)

SS is an indicator of sediment loads derived from river inputs and/or re-suspension of bottom sediments and is considered as an indication for the level of turbidity. SS may influence satellite-derived estimates of Chl-a concentration.

g. Colored Dissolved Organic Matter (CDOM)

CDOM is a part of the dissolved organic matter and plays an important role in estimation of oxygen consumption by biological activity in coastal areas. The amount of CDOM may cause errors in the estimation of satellite-derived Chl-a concentrations. CDOM can also be used to analyze the relationship to COD or salinity.

h. Water-leaving radiance

In situ water-leaving radiance of the sea surface can be monitored by profiling methods or above-water method (especially in shallow waters). The data are used to calibrate and validate in-water algorithms.

i. Others

Vertical distributions of water temperature and salinity are good indicators of the vertical water mass structure.

Phytoplankton species and phytoplankton pigments are used as indicators of biomass or primary productivity. Phytoplankton pigments can be analyzed by high performance liquid chromatography (HPLC).

It is also advisable to keep records of the weather conditions including atmospheric temperature, cloudiness, wind speed and direction, waves and wave undulation, etc.

3.2 Determination of sampling points

The correct determination of sampling points is a vital aspect for the proper analysis of eutrophication phenomena. The spatio-temporal characteristics of the target waters should be taken into account when deciding the number and location of sampling points.

a. Criteria for selecting monitoring site

The following criteria should be considered when selecting a site for the monitoring and assessment of eutrophication.

(1) Regions receiving nutrient loads from rivers, direct discharges of domestic and industrial wastes, loads from mariculture activities and/or diffuse sources.

(2) Regions typically sensitive to eutrophication phenomena (enclosed coastal bays and estuaries, shallow water regions, limited water recycling, etc.).

(3) Regions previously identified by historical records of water quality data.

b. Number of sampling points and spatial scales

About 10 *in situ* sampling points (the more the better) are desirable per 1 measurement from satellite. It is necessary to set the sampling points within coastal and outer sea areas as well as at border regions in order to obtain a wide range of *in situ* data. Due to limited spatial resolution of satellite data sampling points need to be set at least 1 km apart from each other.

c. Distribution of sampling points

It is desirable to set fixed points if continuous *in situ* monitoring is possible; however arbitrary points are acceptable for a single measurement study. Coastal topography and sea bathymetry as well as the location of river outflow need to be considered.

3.3 Monitoring frequency and timing

When determining the monitoring frequency and timing, climatic (e.g. less cloud coverage is preferable) and oceanographic conditions (e.g. times of increased river inputs and active phytoplankton growth should not be missed), need to be considered. Regular monitoring (e.g. once a month) is necessary if temporal variations of water quality are to be captured by *in situ* monitoring. However, if more match-up datasets are needed, the monitoring shall be specialized in obtaining more sea truth data, and the monitoring timing could be focused on short terms under good conditions.

3.4 Requisites for monitoring and analysis

Vessels used for monitoring need to have a high level of seaworthiness and speed to implement the monitoring plan. Positioning system (e.g. GPS) and navigation systems are also required.

It is essential to cooperate with organizations that offer the capability and equipment for analyzing Chl-a concentration, COD, SS, CDOM and other nutrients.

3.5 Region-specific issues

In China, an above-water method for the measurements of Apparent Optical Properties directly related to the ocean color remote sensing parameters was developed. Some new methods were given for deriving the critical parameters in processing and analyzing the data from above-water method.

4 Monitoring and assessment of eutrophication

4.1 Accuracy evaluation

a. Analysis of correlation between *in situ* and satellite Chl-a concentration

The correlation between *in situ* and satellite Chl-a concentration should be determined. If a significant correlation is identified between *in situ* and satellite data, the satellite data should be calibrated in accordance with the identified correlation. The calibrated value should then be more close to *in situ* data. The calibrated value could also be considered for use as relative data.

Also, satellite Chl-a concentration may often be erroneous in comparison to *in situ* Chl-a concentration, when concentrations of SS and CDOM are significantly higher than usual (e.g. after heavy rain and inflow of turbid water). For this reason, satellite data should be used with caution under these conditions, especially when using it as an absolute value.

b. Evaluation of underwater algorithm

Correlation shall be analyzed between *in situ* and satellite Chl-a concentrations, calculated from water-leaving radiance using the underwater algorithm. This analysis can clarify if there are any discrepancies, whether in atmosphere or underwater part in the estimation algorithm of Chl-a concentration by satellite. This is essential to improve the accuracy of satellite monitoring.

4.2 Integration with the existing monitoring system

a. Understanding spatio-temporal variation of eutrophication using ocean color satellite

If no substantial temporal differences are observed between satellite data and *in situ* data, satellite data can be used for time-series analysis. As large datasets can be obtained using satellite monitoring averaging these data will smooth out erroneous values. Also, satellite monitoring can help understand the spatial characteristics of eutrophication, as data can be obtained over large area.

b. Evaluation of eutrophication

If COD or the concentration of various nutrients (e.g. phosphorus, nitrogen, etc.) is measured at the same time as Chl-a, a deeper understanding of the relationship between phytoplankton biomass and the causes of eutrophication may be developed.

c. Comparison of existing data (Chl-a, COD) to satellite data

By comparing of spatio-temporal variation of satellite Chl-a concentration data to the existing water quality data for target areas, variation patterns and reproducibility of satellite data may be evaluated.

d. Understanding the environmental impacts of eutrophication

By integrating the existing monitoring system data with geographical data, coastal use status and remote sensing data the causes as well as the environmental impact of eutrophication can be analyzed.

5 Challenges and prospects

a. Algorithm development

In ocean color remote sensing the algorithm for the estimation of Chl-a concentration in open ocean is well established and ready for practical use. However, issues still remain for coastal areas. The relationship between ocean color and coastal seawater constituents is not as simple as in the open ocean, due to the influence of SS and CDOM on the optical characteristics of seawater as well as the increased influence of light absorbing aerosols.

Eutrophication monitoring with remote sensing will be more practical with the development of an algorithm that can accurately estimate the Chl-a concentration in coastal areas. One possible approach is to develop a region-specific algorithm. China has made some progress in estimating Chl-a and CDOM concentrations in turbid waters (Case 2 water) by constructing models such as the Positive-Reverse Retrieval Model, Neural Network (NN) models, Support Vector Machines NN models, Genetic Algorithms in Search models.

b. High resolution data and information system

Application of high-resolution satellite data such as ALOS, Landsat and SPOT should also be considered for the monitoring of eutrophication in coastal areas. Although the observation frequency of these satellite data are less in comparison to the satellite data introduced in the guidelines, these data can identify events such as red tides with greater accuracy and have been widely used, in the study of small estuaries and gulfs of China. Through further accumulation of high-resolution satellite and *in situ* data future improvements in monitoring methods and our understanding of eutrophication mechanisms can be expected.

c. New sensor

China is about to launch FY-3 satellite, the second generation of Chinese polar-orbit meteorological satellites carrying the Medium Resolution Spectral Imager (MERSI), in late 2007. MERSI is a MODIS-like sensor, covering VNIR/SWIR/TIR spectral region and has 5 channels with spatial resolution of 250 m and 15 channels with spatial resolution of 1000 m. The data will be open access and is expected to contribute to environmental monitoring in the NOWPAP Region.

Korea is planning to launch the Geostationary Ocean Color Imager (GOCI) in 2008. GOCI has a spatial resolution of 500 m and a temporal resolution of 1 hour and is expected to contribute to the environmental monitoring of coastal areas in the NOWPAP Region.

d. Review of the guidelines

To maintain and improve the quality of the guidelines, it is essential that more monitoring are conducted based on the method introduced in the guidelines. The guidelines should be further updated and improved in line with the advancement of remote sensing technology for marine environmental monitoring and feedbacks from the users.

6 Appendix

Table 6.1 Free satellite data products available to marine environmental monitoring, provided by space agencies.

Agency	Product	Sensor	Description	Priority[1]
NASA	Chlor_a	SeaWiFS MODIS	Chlorophyll-a concentration. Index of total amount of phytoplankton in the surface layer.	A
	SST	MODIS	Sea Surface Temperature.	A
	K490	SeaWiFS MODIS	Index of the turbidity of the water column.	B
	PAR	SeaWiFS	Photosynthetically active radiation. Index of the amount of visible light available for photosynthesis.	B
	nLw_nnn	SeaWiFS MODIS	Normalized water-leaving radiance.	B
	Ocean Surface Topography	TOPEX Altimeter Poseidon 2	Sea surface height provides insights into ocean circulation, climate cycles, sea-level rise, and ocean tides.	C
	Ocean Vector Winds	SeaWinds	Near sea surface wind speed and direction.	C

1. Products are prioritized by the importance for the monitoring of eutrophication (A>B>C).

Table 6.2 Sensors available for monitoring of marine environment.

Sensor	Satellite	Operation	Space agency[1]	Spatial resolution	Monitoring target[2]
CZCS	NIMBUS-7	1978/10 - 1986/12	NASA	825m	Ocean color, Chla
OCTS	ADEOS	1996/8 - 1997/7	NASDA	700m	Ocean color, Chla, SST
SeaWiFS	OrvView-2	1997/8 - 1997/6	NASA	1.1km	Ocean color, Chla, Turbidity, PAR
OCM	IRS-P4	1999/5 -	ISRO	360m	Ocean color
MODIS	Terra Aqua	1999/12 - 2002/5 -	NASA	1km	Ocean color, Chla, SST, Turbidity
MERIS	Envisat-1	2002/3 -	ESA	300m / 1.2km	Ocean color
COCTS	HY-1A	2002/5 - 2004/4	CNSA	1.1km	Ocean color, Chla, SST, Turbidity
MVIRS	FY-1D	2002/5 -	CMA	1.1km	SST
S-VISSR	FY-2C	2004/10 -	CMA	1.25km / 5km	SST
GLI	ADEOS-II	2002/12 - 2003/10	JAXA	250m / 1km	Ocean color, Chla
AVHRR	NOAA 6-18	1979/6 -	NOAA	1.1km	SST
AMSR	ADEOS-II	2002/12 - 2003/10	JAXA	5 - 50km	SST
AMSR-E	Aqua	2002/5 -	NASDA	5 - 50km	SST
ASAR	Envisat-1	2002/3 -	ESA	30m - 1.2km	Ocean dynamics
SAR	ERS-1 ERS-2	1991/7 - 2000/3 1995/4 -	ESA	30 - 50m	Ocean dynamics
TOPEX Altimeter	TOPEX/POS EIDON	1992/9 - 2006/1	NASA	-	SSH
Poseidon 2	Jason-1	2002/1 -	NASA	-	SSH
SeaWinds	QuikSCAT ADEOS-II	1999/6 - 2002/12 - 2003/10	NASA JAXA	25km	SSW

1. NASA: National Aeronautics and Space Administration (US), JAXA: Japan Aerospace Exploration Agency, NASDA: National Space Development Agency of Japan (now JAXA), ISRO: Indian Space Research Organisation, ESA: European Space Agency, CNSA: China National Space Administration.
2. Chla: Chlorophyll-a concentration, SST: Sea Surface Temperature, PAR: Photosynthetically Active Radiation, SSH: Sea Surface Height, SSW: Sea Surface Wind.

Table 6.3 List of software for satellite data analysis.

Software	Publisher	Description	System requirements
SeaDAS	The SeaDAS Development Group at NASA GSFC	The SeaWiFS Data Analysis System. A comprehensive image analysis package for the processing, display, analysis, and quality control of ocean color data. Supported satellite sensors are MODIS, SeaWiFS, OCTS, and CZCS.	Mac, Linux, Solaris, IRIX
GRASS	GRASS Development Team	A Geographic Information System (GIS) used for geospatial data management and analysis, image processing, graphics/maps production, spatial modeling, and visualization.	Windows, Mac, Linux
HyperCube	US Army Corps of Engineers	Tool for the analysis and display of multispectral and hyperspectral imagery. Sample data and manuals are available.	Windows, Mac
MultiSpec	Purdue University	Tool for the analysis and display of multispectral and hyperspectral imagery. Tool can be used to analyze data in a variety of formats.	Windows, Mac
WIM (License Fee)	WimSoft	Windows Image Manager. General-purpose image display and analysis program with special features for analyzing satellite images. There many ways and formats to store digital images.	Windows
ENVI (License Fee)	Research Systems, Inc.	Tool can be used to analyze data in a variety of formats. Cross-platform, written in IDL, customizable, and ability for program creation.	Windows, Mac, UNIX, Linux
IDL (License Fee)	Research Systems, Inc.	Tool used to analyze and display scientific data. General numeric analytical tool. Cross-platform. Tool is distributed free of charge.	Windows, Mac, UNIX, Linux
ERDAS IMAGINE (License Fee)	Leica Geosystems Geospatial Imaging, LLC	The raster-centric software GIS professionals use to extract information from satellite and aerial images. The vast array of tools allowing users to analyze data from almost any source. High degree of data Interchangeability with ArcGIS.	Windows, Solaris
ViewFinder	Leica Geosystems Geospatial Imaging, LLC	A viewing tool. It provides basic image viewing and manipulation capabilities. Supported image formats are ERDAS IMAGINE .IMG, TIFF, GeoTIFF, etc.	Windows
ER Mapper (License Fee)	Earth Resource Mapping	Simple-to-use geospatial imagery processing application. A wide range of image formats is supported.	Windows, Solaris
ER View	Earth Resource Mapping	An easy to use image viewer featuring interactive roaming and zooming with very large image files. A wide range of image formats is supported.	Windows
BEAM	BEAM Development Team at Carsten Brockmann Consult	The Basic ERS & Envisat (A)ATSR and MERIS toolbox. A collection of executable tools and an application programming interface which have been developed to facilitate the utilisation, viewing and processing of ESA MERIS, (A)ATSR and ASAR data.	Windows, Mac, Linux, Solaris

7 References

1. NOWPAP CEARAC (2005), Integrated Report on Ocean Remote Sensing for the NOWPAP Region.

2. Evans, R. H., and H. R. Gordon (1994), Coastal zone color scanner “system calibration”: A retrospective examination, *J. Geophys. Res.*, 99(C4), 7293–7308.

8 Glossary

ADEOS-II
Japan satellite launched in October 2002 with Global Imager (GLI), Advanced Microwave Scanning Radiometer (AMSR) and scatterometer

Algae
comparatively simple chlorophyll-bearing plants, most of which are aquatic, and microscopic in size

Ambient
surrounding

Aqua
American satellite launched in May 2002 with spectroradiometer MODIS and Advanced Microwave Scanning Radiometer (AMSR-E) and ASTER

Aquatic ecosystem
any water environment from small to large, from pond to ocean, in which plants and animals interact with the chemical and physical features of the environment

AVHRR
Advanced very high-resolution radiometer, operational instrument on US NOAA series satellites. AVHRR has 2 visible channels and 3 infrared channels.

Biochemical oxygen demand (BOD)
the decrease in oxygen content in a sample of water that is brought about by the bacterial breakdown of organic matter in the water

Bloom
an unusually large number of organisms of one or a few species, usually algae, per unit of water

BOD
Biochemical oxygen demand

Calibration
establish the link between sensor output signal (voltage, digital numbers) and absolute physical values at sensor input, i.e. describe the overall transfer function of the sensor
Calibration is a part of sensor characterization, in particular with respect to spectral and radiometric parameters. Parameters to be determined during calibration process depend on:

- sensor principle
- detector type
- application.

CDOM
Colored Dissolved Organic Matter is colored dissolved substances (commonly called “yellow substances” or “Gelbstoff”). CDOM contributes to the absorption spectrum of phytoplankton.

Chemical oxygen demand (COD)
the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant

CEARAC
Special Monitoring and Coastal Environmental Assessment Regional Activity Centre

Chlorophyll (Chl)
is the pigment common to all marine photosynthetic organisms.

Chl-a
Chl *a* is an indicator of phytoplankton biomass and can be estimated on a global or regional scale using remotely sensed ocean color techniques.

COD
is chemical oxygen demand, the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. COD is an indicator of organic pollution.

Concentration
the quantifiable amount of a substance in water, food or sediment

Contaminants
biological or chemical substances or entities, not normally present in a system, capable of producing an adverse effect in a biological system, seriously injuring structure or function

Control
part of an experimental procedure that is ideally exactly like the treated part except that it is not subject to the test conditions. It is used as a standard of comparison, to check that the outcome of the experiment is a reflection of the test conditions and not of some unknown general factor.

Criteria (water quality)
scientific data evaluated to derive the recommended quality of water for different uses

CZCS
Coastal Zone Color Scanner installed aboard the NIMBUS-7 satellite.

Detection limit
method detection limit is the concentration of a substance which, when processed through the complete analytical method, produces a signal that has a 99% probability of being different from the blank

EC (Electrical conductivity)
the ability of water or soil solution to conduct an electric current; commonly used as a measure of salinity or total dissolved salts

Environmental values
particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and that require protection from the effects of contaminants, waste discharges and deposits. Several environmental values may be designated for a specific water body.

Eutrophication
enrichment of waters with nutrients, primarily phosphorus, causing abundant aquatic plant growth and often leading to seasonal deficiencies in dissolved oxygen

GLI
Global Imager an optical sensor aboard ADEOS-II

Indicator
measurement parameter or combination of parameters that can be used to assess the quality of water

JAXA
Japan Aerospace Exploration Agency

K490
diffuse attenuation coefficient at wavelength of 490 nm, which indicates how blue visible light is.

Measurement parameter
any parameter or variable that is measured to find something out about an ecosystem.

MODIS
Moderate Resolution Imaging Spectroradiometer installed aboard Terra and Aqua satellites.

NASA
National Aerospace Agency

NOWPAP
the Action Plan for the Protection, Management and Development of the Marine and Coastal Environment of the Northwest Pacific Region.

NPEC
Northwest Pacific Region Environmental Cooperation Center.

Nutrients
chemical elements known to be essential for the growth of living organisms, including nitrogen, sulfur, phosphorus, and carbon.

OCTS
Ocean Color and Temperature Sensor which was installed aboard ADEOS-I satellite

Organism
any living animal or plant; anything capable of carrying on life processes

Oxidation
the combination of oxygen with a substance, or the removal of hydrogen from it, or, more generally, any reaction in which an atom loses electrons

PAR
Abbreviated PAR - photosyntetically active radiation - designates the spectral range of solar light from 400 to 700 nm that is useful to terrestrial plants in the process of photosynthesis. This spectral region corresponds more or less with the range of light visible to the human eye. Photons at shorter wavelengths tend to be so energetic that they can be damaging to cells and tissues; fortunately they are mostly filtered out by the ozone layer in the stratosphere. Photons at longer wavelengths do not carry enough energy to allow photosynthesis to take place.

Parameter
a measurable or quantifiable characteristic or feature

Penetration depth
depth from within which 90% of the water-leaving radiance originates.

pH
the intensity of the acidic or basic character of a solution, defined as the negative logarithm of the hydrogen ion concentration of a solution

Plankton
plants (phytoplankton) and animals (zooplankton), usually microscopic, floating in aquatic systems

Precipitation
the settling out of water from cloud, in the form of rain, hail, fog, snow, etc. (also the formation and settling out of solid particles in solution)

Protocol
a formally agreed method and procedure for measuring an indicator, including sampling, sample handling procedures and sample analysis

Quality control (QC)
the implementation of procedures to maximize the integrity of monitoring data (e.g. cleaning procedures, contamination avoidance, sample preservation methods)

Reference condition
an environmental quality or condition that is defined from as many similar systems as possible and used as a benchmark for determining the environmental quality or condition to be achieved and/or maintained in a particular system of equivalent type

Reflectance
is the ratio between the irradiance upwelling just under the surface of the water, $E_u(\lambda)$, to the down-welling irradiance just penetrating the surface, $E_d(\lambda)$.

Salinity
the presence of soluble salts in water

SeaDAS
SeaWiFS Data Analysis System, free software developed by NASA

SeaWiFS
the Sea–Viewing Wide Field–of–view Sensor launched in August 1997 aboard SeaStar satellite.

Sediment
unconsolidated mineral and organic particulate material that is suspended or has settled to the bottom of aquatic environments

Sensor
A device that measures or detects a real-world condition, such as motion, heat or light and converts the condition into an analog or digital representation. An optical sensor detects the intensity or brightness of light, or the intensity of red, green and blue for color systems.

Species
generally regarded as a group of organisms that resemble each other to a greater degree than members of other groups and that form a reproductively isolated group that will not normally breed with members of another group. (Chemical species are differing compounds of an element.)

SS
Suspended Solid is an indicator of sediment load. It is also considered as an indicator of turbidity. SS is responsible for an increase in turbidity

SST
Sea Surface Temperature

Suspension
very small particles (solid, semi-solid, or liquid) more or less uniformly dispersed in a liquid or gaseous medium

Terra
American satellite launched in 1999 with spectroradiometer MODIS and ASTER

Transparency
Transparency can be used to get a rough estimation of average turbidity of the sea water.

True colour
the colour of water resulting from substances that are totally in solution; not to be mistaken for apparent color which includes the effects of colloidal or suspended matter

Turbidity
Turbidity can be estimated from ocean color data provided by SeaWiFS and MODIS by calculation of diffuse attenuation coefficient K490 at wavelength $\lambda = 490$ nm. This coefficient indicates how blue visible light is. Turbidity decreases water clarity.

Upwelling
is an oceanographic phenomenon that involves wind-driven motion of dense, cooler, and usually nutrient-rich water towards the ocean surface, replacing the warmer, usually nutrient-deplete surface water.

Validation
establish the link between measurements in orbit and measurements made on ground (sensor validation) as well as verification of models, algorithms, derived parameters and data products (algorithm validation). It is essential procedure to utilizate „ground truth“ measurements, to understand and quantify the quality and accuracy of data products.

Water color
the spectral variations of the diffuse reflectance of the upper ocean, R(λ), λ is wavelength.

Water Leaving Radiance
In situ Water-Leaving Radiance of sea surface can be monitored by measuring profile of reflectance in water. The data are used to calibrate and validate in-water algorithms.

WG4
Working Group 4 on remote sensing at CEARAC

WIM
Windows Image Manager

Zooplankton
see plankton

A case study in China

Annex 1 A case study in China

1 Objective and Background

Since its launch, ocean color remote sensing satellite has been widely used in monitoring ocean environment and assessing its water quality. Many parameters such as SST, Chl-a concentration can be calculated directly or indirectly by using ocean color remote sensed data. The great successes have been achieved in the application of ocean color remote sensing to estimation of open ocean environmental parameters by remote sensing techniques. But there are still lots of issues and problems to be solved to achieve such a success in coastal waters. This case study aimed to evaluate the usefulness of ocean color remote sensing techniques in environmental monitoring and assessment of Case 2 water along the coastal zone. Bohai sea was selected as the study area (Fig.1).

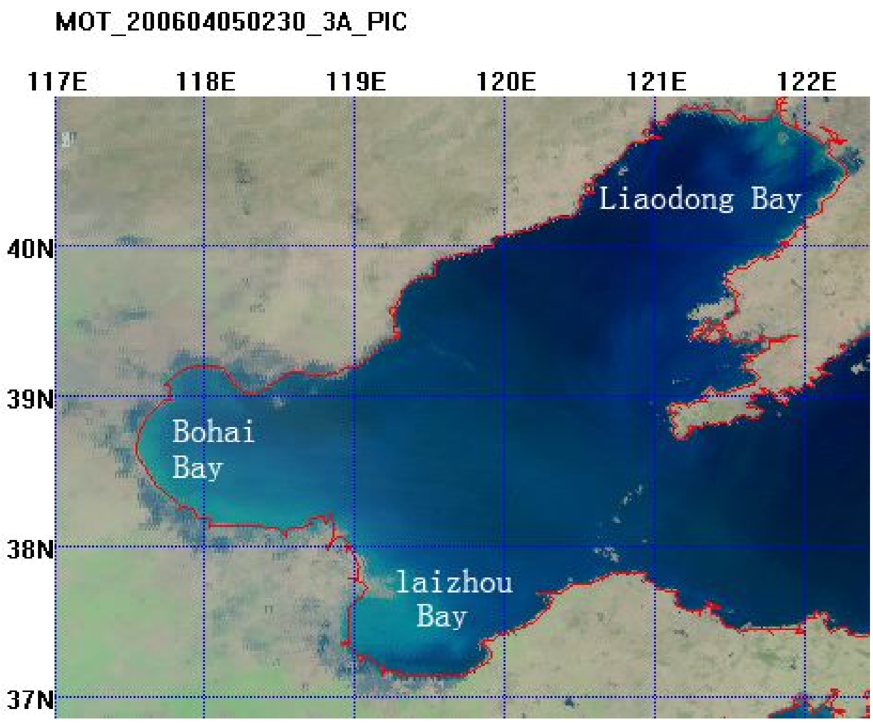

Fig.1 Bohai Sea (false color image of MODIS)

2 Data and Methods

2.1 *In situ* data collection and lab analysis

During the period from June to September 2006, several field surveys were conducted in the Liaodong Bay. 173 water samples were collected in the complex Case 2 water area with high concentration of sediment and high frequency of red tide occurrence. Fig.2 shows the distribution of the sampling points.

In the laboratory, fluorometric measurement and high-performance liquid chromatography (HPLC) measurement were adopted to analyze all the water samples collected in Liaodong Bay. It is believed that HPLC method will give the true data of Chl-a. Hitachi Fluorometer 650260 was used. The wavelength of the pulse laser is 436 nm and emission laser 670nm.

Fig.2 Sample points distribution

2.2 Satellite data and calibration

In this case study, the MODIS, SeaWiFS and AVHRR images were used. All the images were preprocessed by the Second Institute of Oceanography, State Ocean Administration. They developed special calibration models which are effective in Case 2 water area.

3 Results and discussion

3.1 Relationship between fluorometric and HPLC measurements

In situ Chl-a concentration is important for calibration and validation of ocean color algorithm of remote sensing. Theoretically, the different protocols will affect the uncertainties of Chl-a concentration retrieved from remote sensing data. The lab test results indicated a difference between fluorometric and HPLC measurements. The average value of Chl-a concentration given by fluorometer was 15.62 mg/m^3 and the concentration varied from 0.215mg/m^3 to 147mg/m^3, while average by HPLC was 10.12 mg/m^3 and varied from 0.18mg/m^3 to 177.6mg/m^3. However there existed a significant linear relationship with the coefficient of 0.85 when concentrations were in log scale (Fig.3).

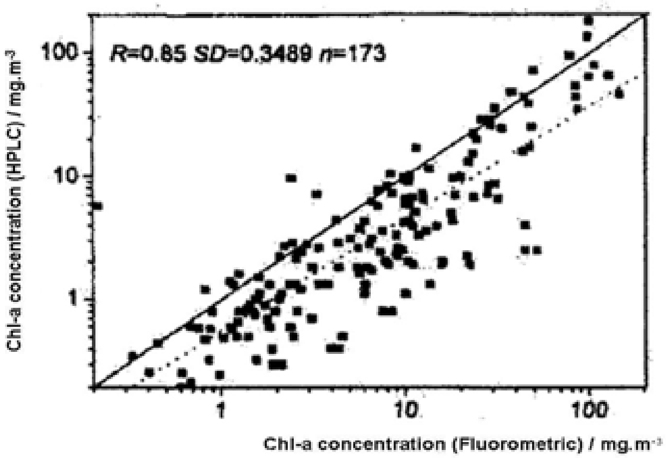

Fig.3 Regression of Chl-a from HPLC and Fluorometer

3.2 Detecting red tide in Liaodong Bay on Sept 8,1998

Many case studies have approved that AVHRR images are very helpful in detecting red tides. In this case study, we developed a method to detect red tide by plankton cell number. During the period from August 18, 1998 to Sept 30, 1998, serious red tides occurred in Liaodong Bay. The lab sample analysis indicated that Ceratium furca was the main plankton type. We rectified the AVHRR images and calculated the cell number of plankton using the relationship between Chl-a and cell number. Fig.4 showed the possible red tide area.

In order to reflect the process of red tide development during this period, we also used a series of SeaWiFS images to calculate Chl-a concentration and classified the red tide area. Table.1 listed the retrieval results and Fig.5 showed the distribution of red tide on Sept 18, 1998. This case approved the usefulness of ocean color remote sensing techniques in monitoring marine environment of Case 2 water.

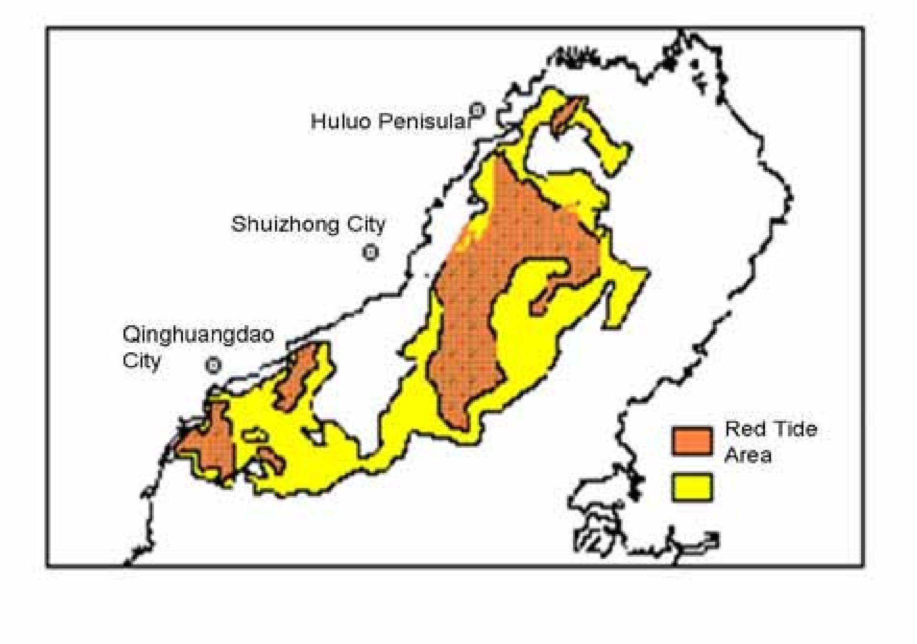

Fig.4 Distribution of red tide on September 18,1998 from AVHRR

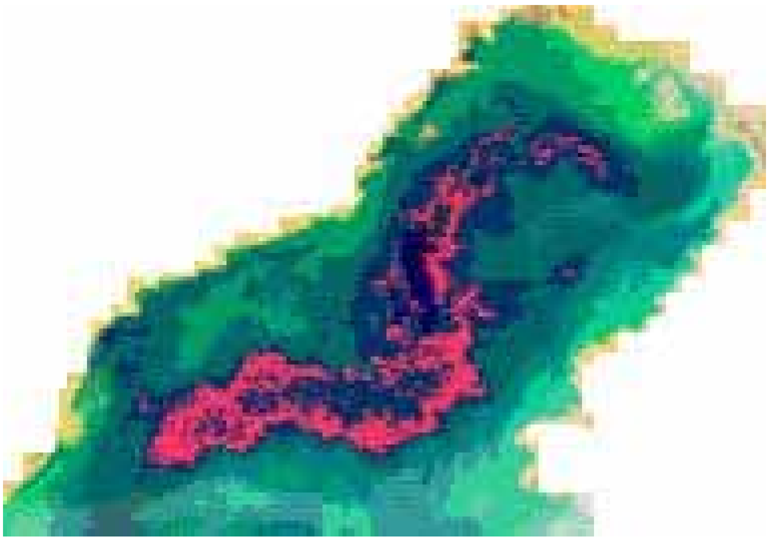

Fig.5 Distribution of red tide on September 18,1998 from SeaWiFS image

Table.1 The area of red tide during August to October, 1998

Date	Aug 25	Aug 27	Sept 2	Sept 11	Sept 15	Sept 18	Sept 21	Sept 22	Sept 27	Oct 3
Area (km^2)	1400	4000	4050	3700	2200	3400	3500	3020	2800	1020

3.3 Precise retrieval of Ocean color parameters in Case 2 water

Since MODIS images are available, a particular use in red tide monitoring are found, and some successful case studies further confirm it. But it is hard to get a precise result from satellite images in the area of Case 2 water along the coastal zone. We developed a semi-analytical inversing model of water transparency by using the theory of radiative transfer in water. The accuracy of this semi-analytical inversing model was validated by using the larger scale *in situ* data, and the result showed that the correlation coefficient was 0. 84 with the relative error of 22.6 % and absolute error of 4.7 m. Fig.6 showed that the water transparency was lower than 2 meters in most of Bohai Sea on April 5, 2006.

In order to retrieve SST, Chl-a concentration and other parameters, we modified the models developed by Deluo Pan by replacing the water-leaving radiation equation which was applicable to Bohai Sea. Fig.7, 8 and 9 were the results by the modified model from MODIS images on April 5, 2006. All these results were well consistent with *in situ* data.

4 Results and discussion

Bohai Sea is a typical Case 2 water body. This case study showed that ocean color remote sensed data were effective and useful in monitoring the environment and detecting the environmental hazards such as red tide. Integration of all kinds of images from different satellites such NOAA, Terra/Aqua, SeaWiFS will be more advantageous for retrieval of environmental parameters. Therefore making full use of existing satellite data will make it possible to real-time monitor ocean environment and predict the change and developing trend.

This case study also revealed that there was non universal models for calibration and validation of retrieved results in the situation of Case 2 water. Therefore it needs to have wider cooperation among regions and countries to jointly set up ocean environment monitoring systems.

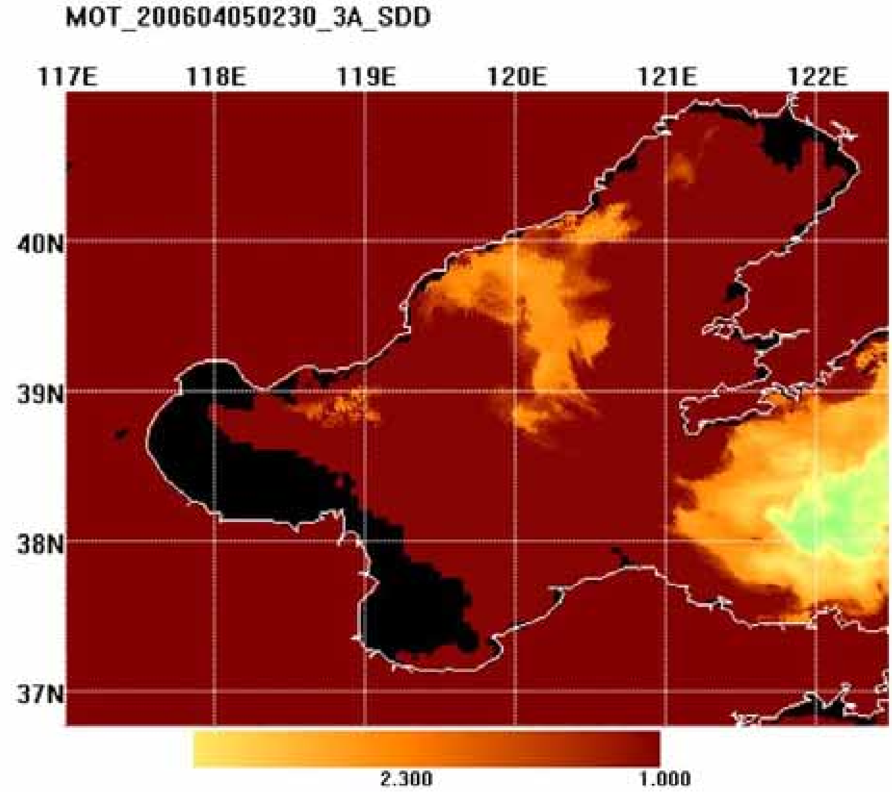

Fig.6 Bohai Sea MODIS water transparency on April 5, 2006

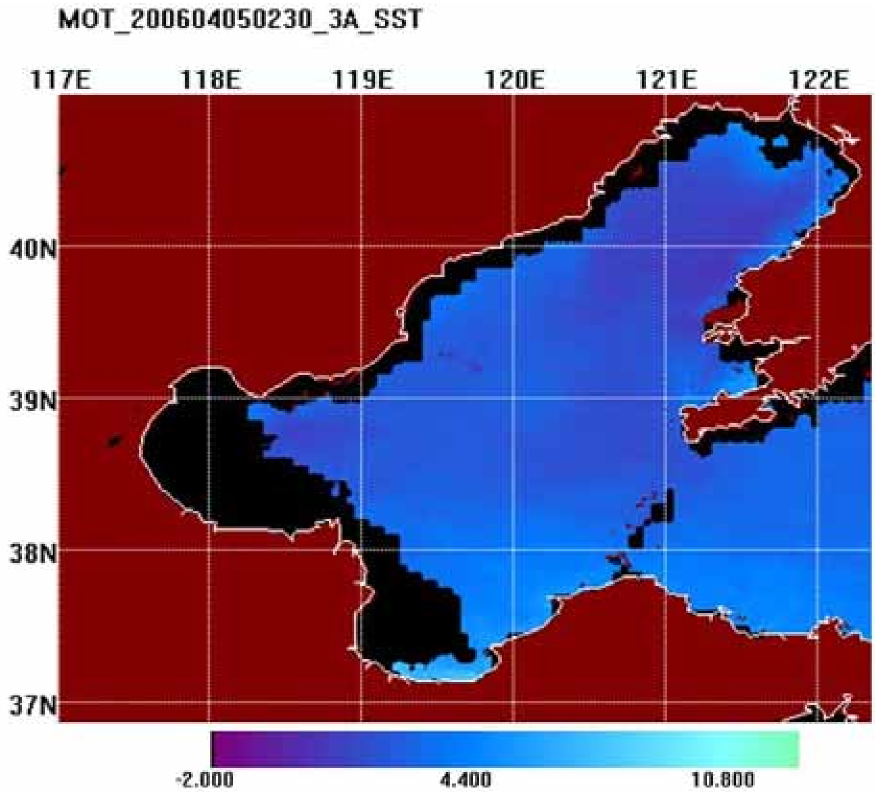

Fig.7 Bohai Sea MODIS SST on April 5, 2006

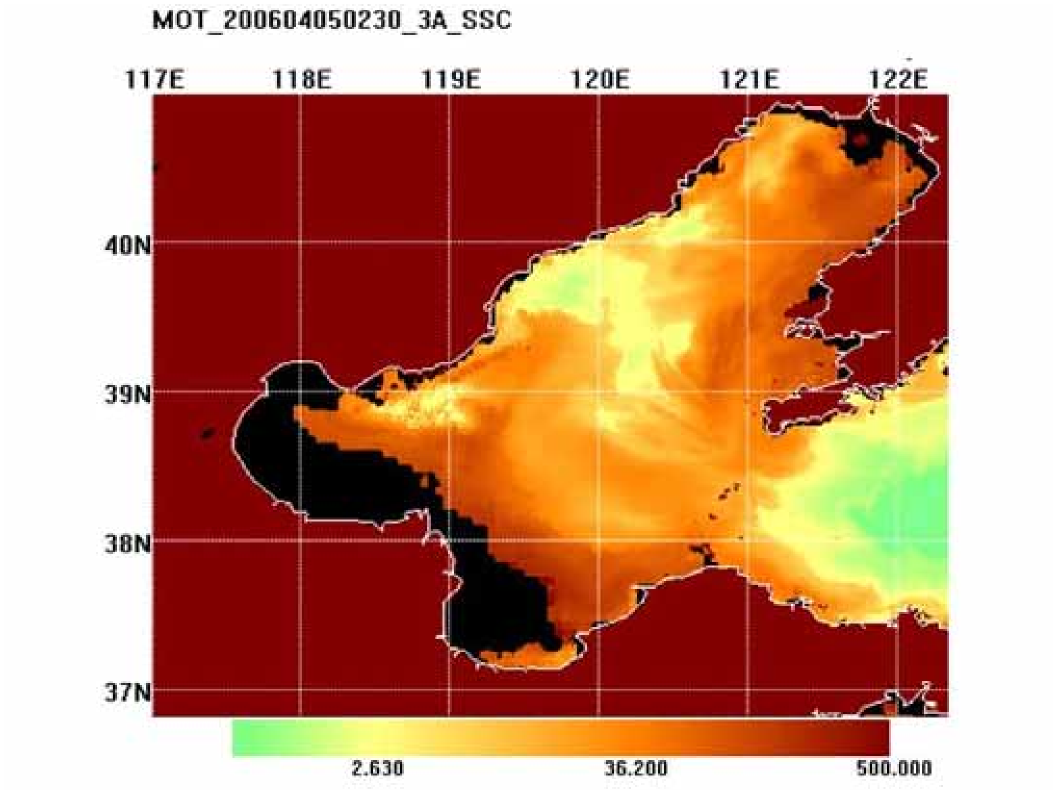

Fig.8 Bohai Sea MODIS suspended sediment concentration on April 5, 2006

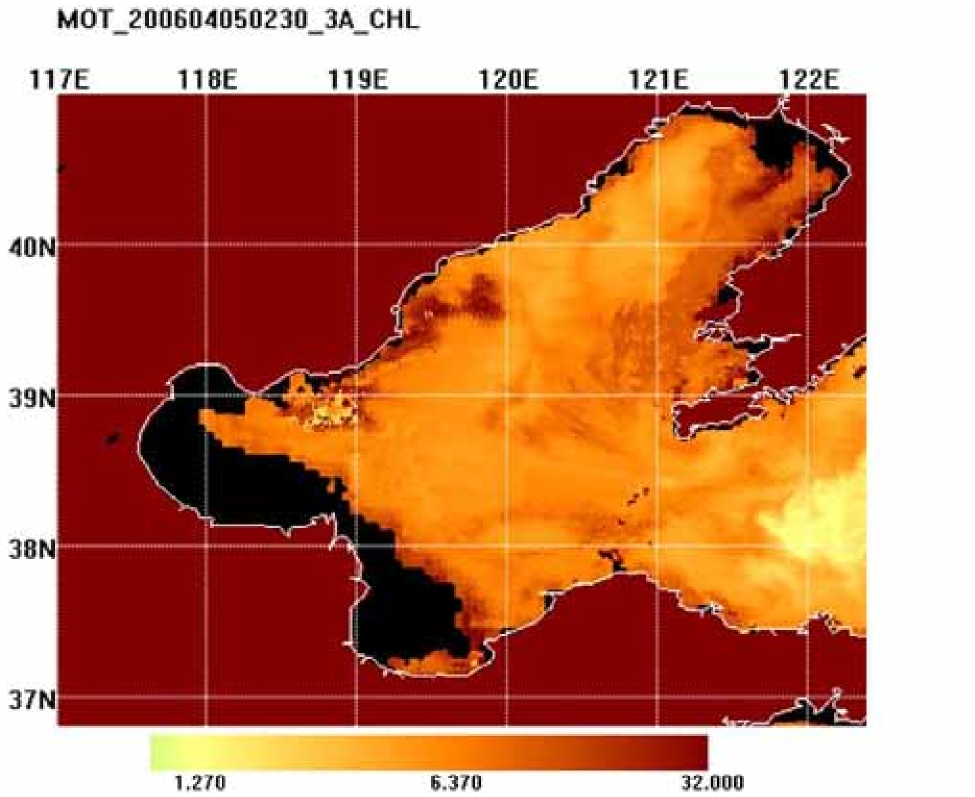

Fig.9 Bohai Sea MODIS Chl-a concentration on April 5, 2006

A case study in Japan

Annex 2 A case study in Japan

1 Objective and Background

In order to evaluate the effectiveness of remote sensing techniques as a monitoring tool for the marine and coastal environment, a case study was conducted in Toyama Bay. In this study, MODIS Chl-a concentration was analyzed with sea-truth data for validating in-water algorithms for estimating Chl-a concentration.

In addition, SeaWiFS Chl-a concentration data were analyzed to understand spatio-temporal variation of water quality in Toyama Bay. The correlation between phytoplankton and seawater pollution (COD; Chemical Oxygen Demand, classified phosphate) were studied to understand the process of pollution.

2 Method

2.1 Monitoring survey of Toyama Bay

a. Observed variables with vessel
   pH, temperature, salinity, water color, transparency, underwater radiances (measured by Profiling Reflectance Radiometer (PRR) 600)

   Temperature and salinity (measured by CTD)

b. Analyzed variables in lab
   DO (Dissolved Oxygen), Chl-a, SS, CDOM, classified phosphate, silicate, total nitrogen, COD etc.

2.2 Obtaining ocean color satellite data

MODIS Chl-a data was obtained through Marine Environmental Watch System. The data was processed based on the algorithm, which was developed by JAXA for GLI, a sensor on board on ADEOS-II satellite.

SeaWiFS Chl-a data of Toyama Bay from 1998 to 2003 was also obtained and processed for the coverage from longitude 136.5 to 138.5 degrees east and latitude 36.5 to 38.0 degree north. (Fig.1)

Fig.1 Location of study area.

3 Analysis and discussion

3.1 Analysis of time series satellite Chl-a concentration

a. Analysis of daily Chl-a concentration image

Chl-a concentration patterns of Toyama Bay in May 2003 were observed (Fig.1). As described later, satellite Chl-a concentration tended to be over estimated than *in situ* Chl-a concentration data, when high concentration of SS and CDOM caused by discharge of murky waters was detected. Few rainfall and river discharge, however, was measured in studied period shown in Fig.2, and it was considered that high Chl-a concentration was moved with the anti-clockwise flowage pattern, which was previously suggested in Toyama Bay (Uchiyama 1993).

By this means, remotely sensed Chl-a images are useful but not limited to detect its concentration and its transition pattern with the flowage pattern.

b. Analysis of monthly Chl-a concentration image

The monthly average SeaWiFS Chl-a concentration image below indicates two peaks of Chl-a concentration every year, one in early spring (March and April) and the other in fall (October and November). It also shows that the Chl-a concentration of the inner area of the bay is higher every summer (June, July and August) and fall (September and October) than in the other seasons (Fig.3).

c. Seasonal variability of Chl-a concentration in three different areas

Time series of daily SeaWiFS Chl-a concentration in three different areas showed different characteristic of seasonal variation (Fig.4). There were two apparent peaks of Chl-a concentration in spring and fall every year in outer area. This corresponds to the timing of seasonal phytoplankton bloom offshore or in the NOWPAP Region (excluding Yellow Sea) (Yamada *et al.*, 2004), and it is expected that the land source nutrient input is minimum. On the other hand, Chl-a concentration in inner area was higher in summer and fall and radically changed in short period of time. This may be caused by nutrient input from river, and possible eutrophication by human activity is suspected. It is clear that the middle part of the bay is also influenced by river discharge but the influence is relatively smaller than the inner part.

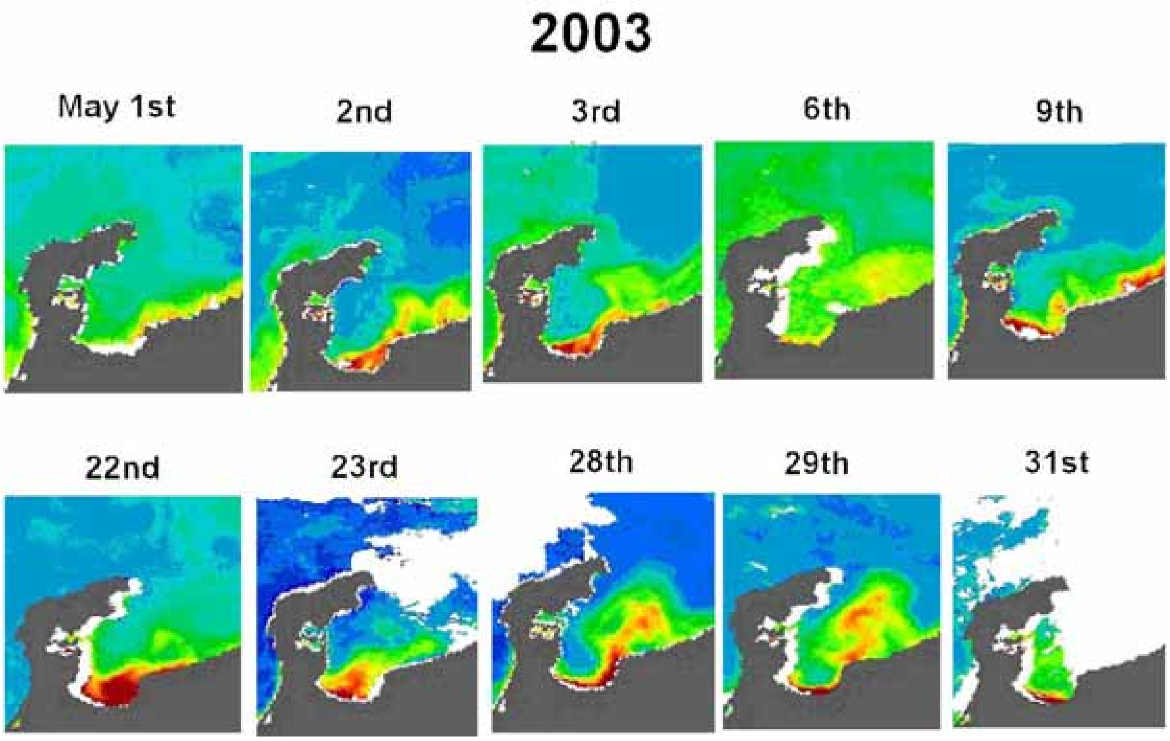

Fig.2 Chl-a concentrations pattern of May 2003 observed by MODIS in Toyama Bay.

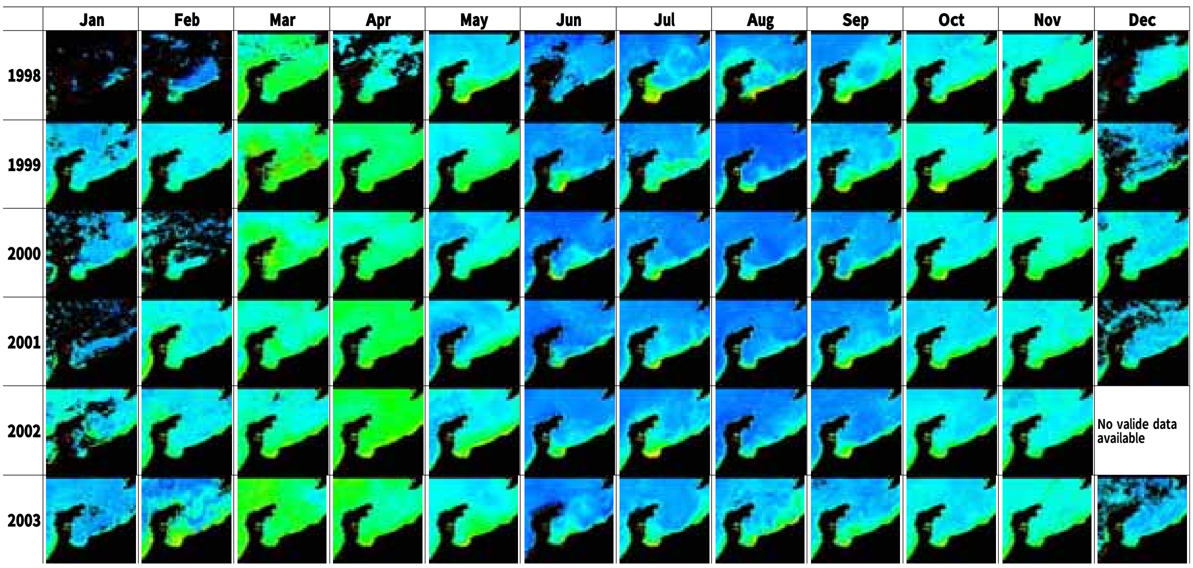

Fig.3 Monthly average SeaWiFS Chl-a image of Toyama Bay.

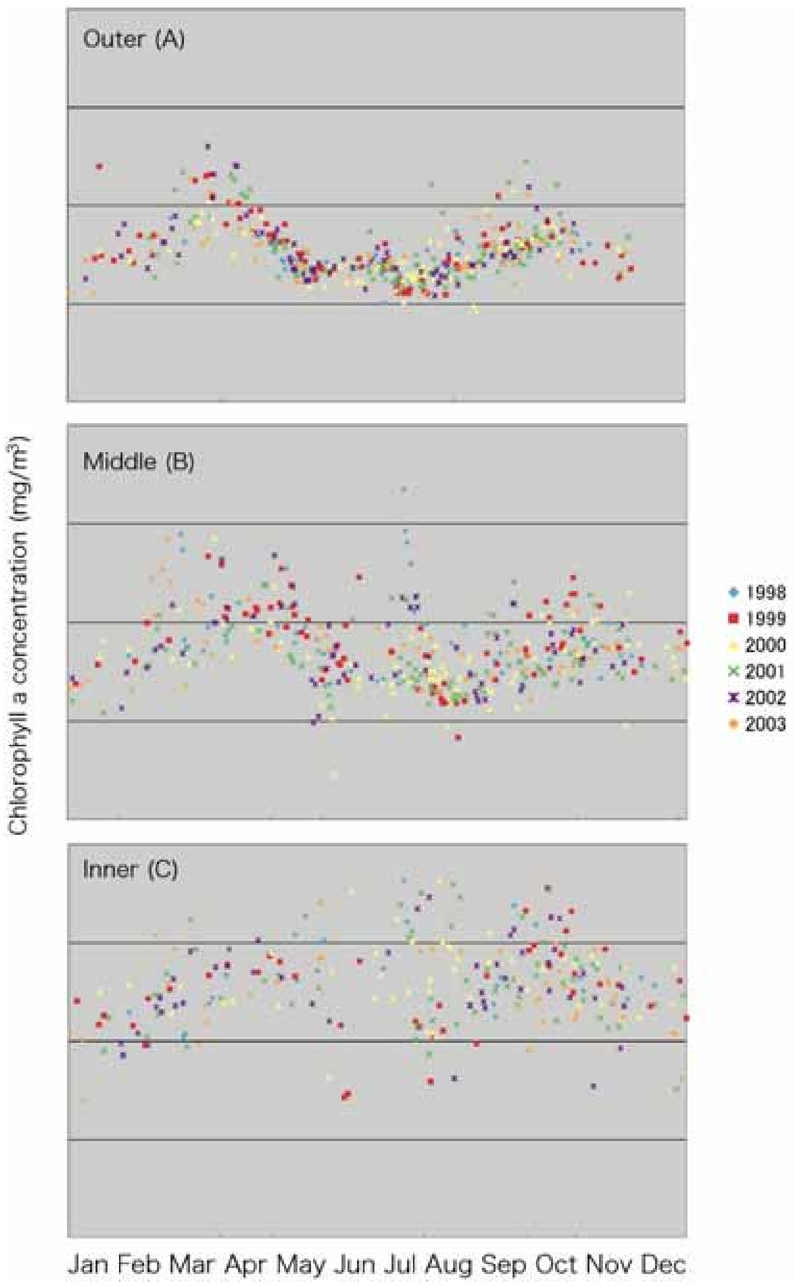

Fig.4 Seasonal variability of Chl-a concentration in three different areas.
Each area, outer (A), middle (B) and inner (C), is corresponding to the location in Fig.1.

3.2 Validation of satellite Chl-a concentration

a. Validation of in-water algorithms

The correlation between *in situ* Chl-a concentrations and one derived from three existing in-water algorithms of SeaWiFS, MODIS and GLI were investigated, using data observed in Isahaya, Ariake (Kyushu Region), East China Sea (ECS), Wakasa Bay (Japan sea) and Toyama Bay (Fig.5). The results showed strong relationship in ratio 1:1, varying coefficient of correlation 0.85 to 0.88 and square error of 0.015 to 0.016 in all data. When investigating data of Toyama Bay solely, the coefficient of correction, the coefficient of correlation varied 0.55 to 0.58, however square error was 0.052 to 0.057. The above results indicate that there is no unique characteristic in Toyama Bay, thus, existing in-water algorithms can be applied to estimate Chl-a concentration in Toyama Bay. It also suggested that there might be a problem in atmospheric correction.

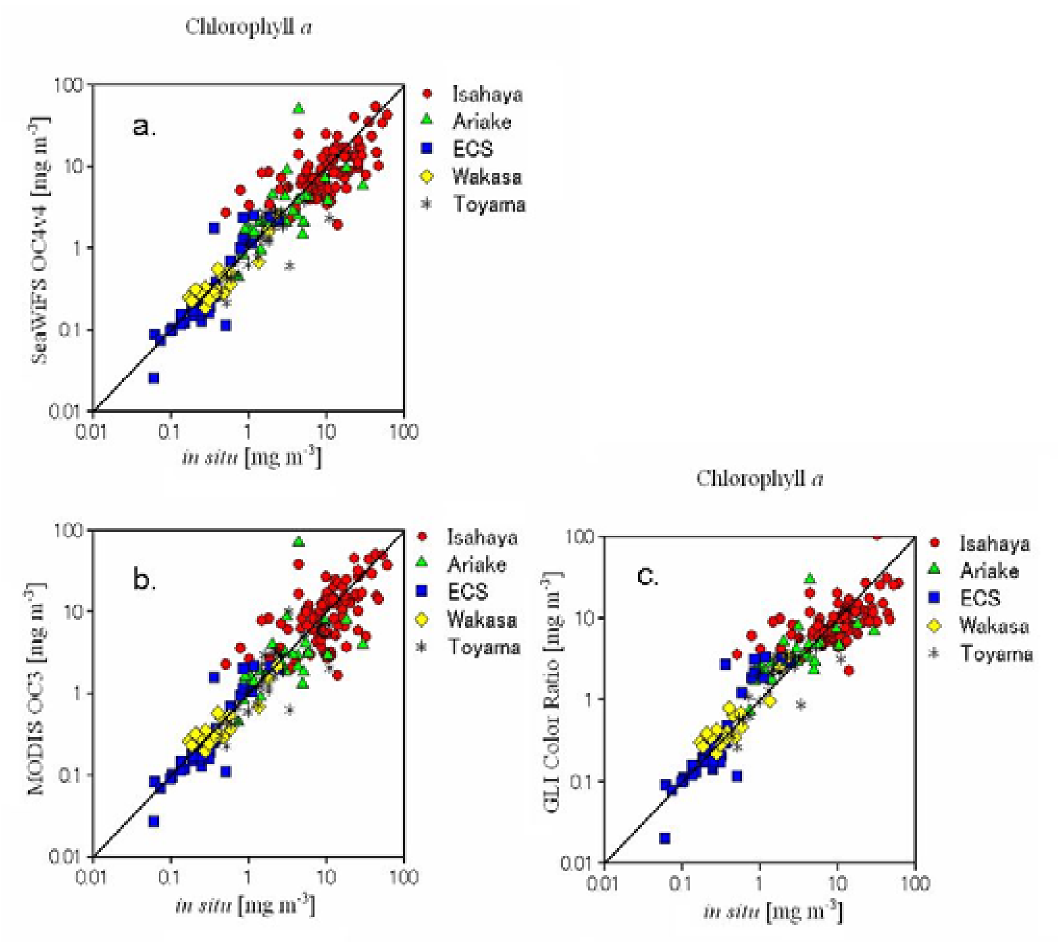

Fig.5 Relationships *in situ* Chl-a and one derived from three existing in-water algorithms SeaWiFS, MODIS and GLI.

b. Correlation of Chl-a concentration between *in situ* and MODIS

The correlation between *in situ* and MODIS Chl-a concentration processed by JAXA GLI algorithm was investigated using match up data of 4 cruises (Fig. 6). Liner regression was found in all cases. MODIS Chl-a concentration was slightly underestimated in one case (July 23, 2004), while strong positive correlation (R=0.88, N=9) was found. In contrast, MODIS Chl-a concentrations for other three cases tended to be overestimated. It was suggested that the underestimation of MODIS Chl-a concentration of July 23, 2004 may be affected by anomaly of mirror on MODIS instrument, which was reported by NASA.

c. Analysis of MODIS Chl-a concentration with SS and CDOM

The difference between *in situ* and MODIS Chl-a concentration and its relationship with SS and CDOM were studied. It was found that MODIS Chl-a concentration tends to be overestimated when the concentration of SS and CDOM become higher (Fig. 7).

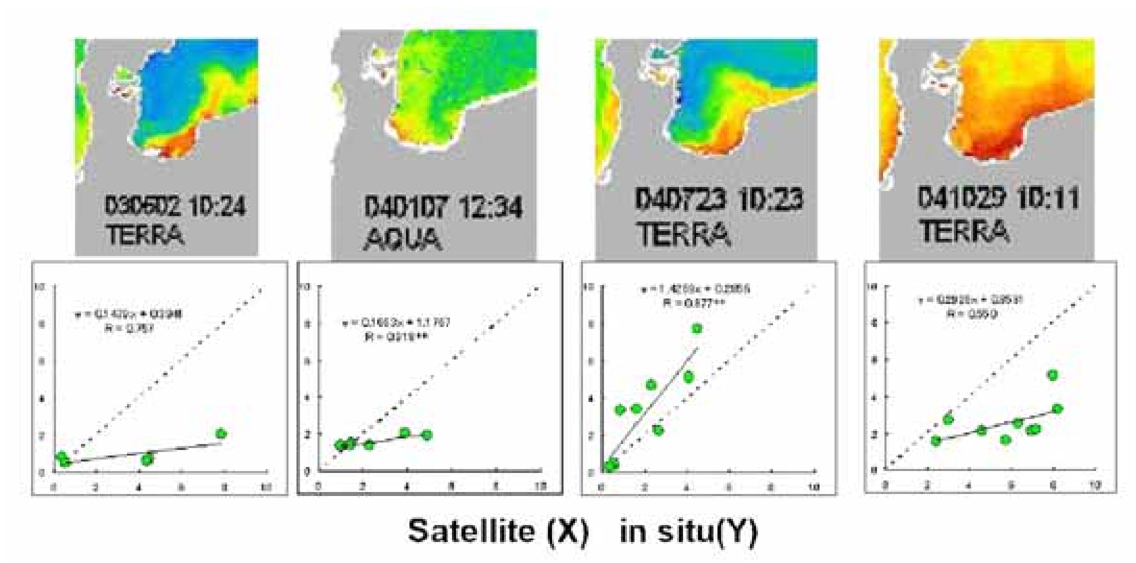

Fig.6 Relationship between satellite and *in situ* Chl-a.

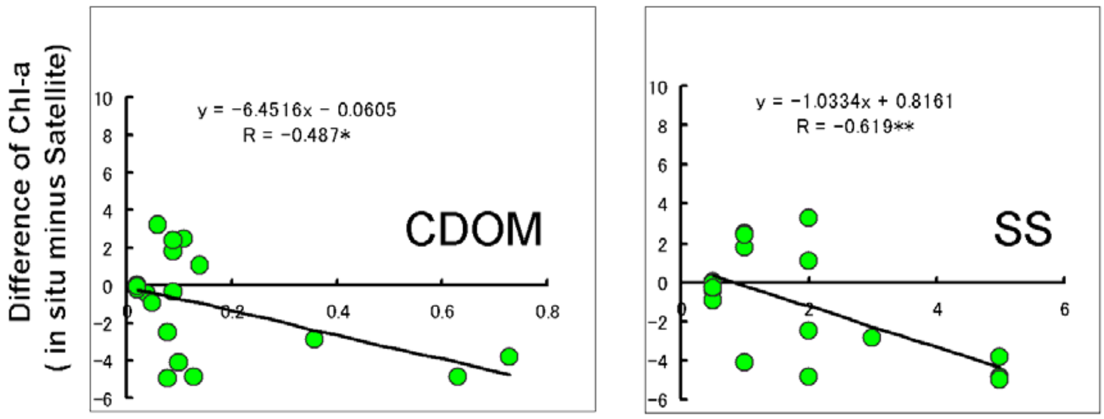

Fig.7 Analysis of MODIS Chl-a concentration with SS and CDOM.

3.3 Correlation between *in situ* Chl-a concentration and COD

Strong positive correlation (R=0.87, N=86) was found between *in situ* Chl-a and COD (Fig. 8). Less variability was found especially in spring and summer, when seasonal stabilization of upper water layer is promoted. This result suggested that the satellite monitoring of Chl-a is possible for monitoring of organic pollution indicated COD.

It was considered that the section of regression formula is indicating whole organic matter other than phytoplankton, such as detritus, dissolved organic matter and zooplankton. Further analysis of the constituent of the section is necessary to understand the process of organic pollution.

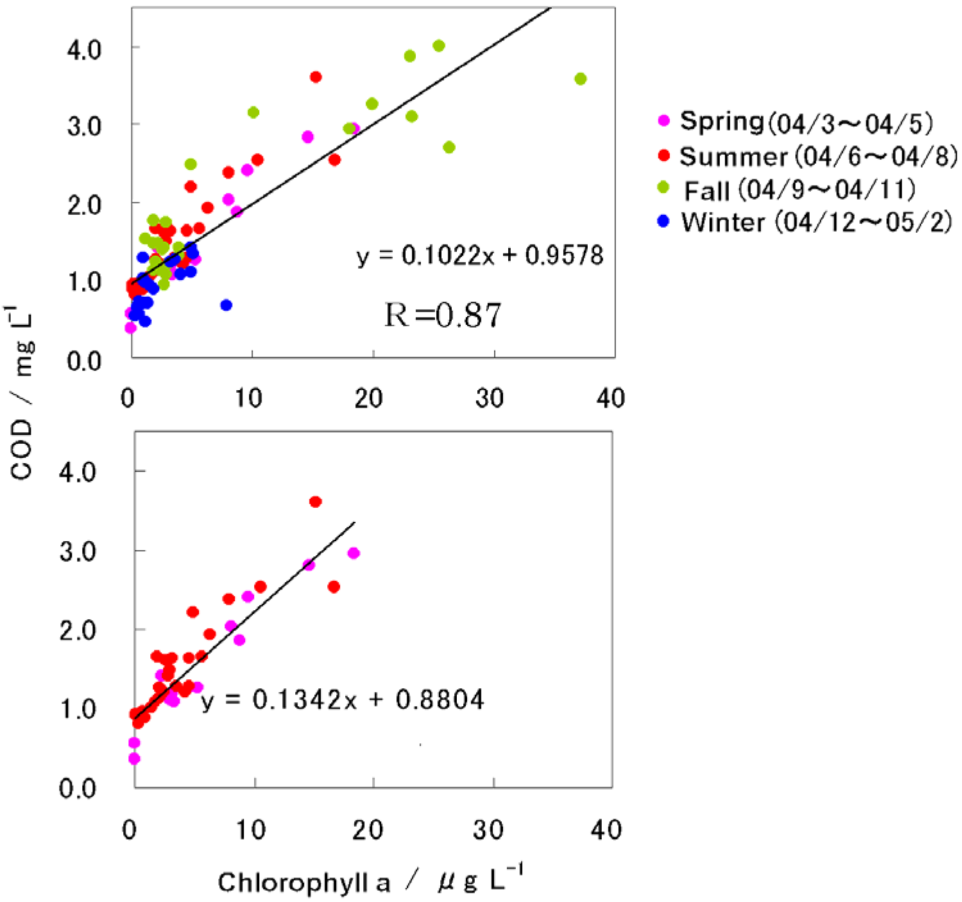

Fig.8 Correlation between Chl-a concentration and COD in Toyama Bay.

4 Assessment of eutrophication with remote sensing

4.1 Detecting spatio-temporal variation of eutrophication by ocean color satellite

Liner regression was found in relationship between *in situ* and MODIS Chl-a concentration data (Fig.5). The characteristics of variation pattern were represented well, as Chl-a concentration in inner area of the bay is higher every summer and fall, through analyzing of time series of satellite Chl-a concentration data (Fig.2). Thus, it is possible to detect eutrophication by using ocean color satellite data as relative value in Toyama Bay.

4.2 Evaluation of eutrophication from *in situ* investigation

Since strong positive correlation (R=0.87, N=86) was found between *in situ* Chl-a concentration and COD, as an indicator of eutrophication, monitoring of Chl-a concentration by satellite may be useful to find the characteristics of eutrophication and organic pollution in coastal area.

4.3 Others

Monitoring by satellite is more economical than vessel survey, and it also can estimate the conditions regularly even when there is no vessel survey. In addition, we can discuss the characteristics of eutrophication further through analyzing satellite Chl-a concentration data with other environmental elements such as river discharge or sea temperature and salinity.

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A case study in Korea

Annex 3 A case study in Korea

1 Objective and Background

In order to evaluate the usefulness of remote sensing techniques as a monitoring tool for the marine environment including coastal area, a case study was conducted in the southern waters of the Korean Peninsula and northern part of the East China Sea. In this study, SeaWiFS chlorophyll-a (Chl-a) data were analyzed with sea-truth data for validating in-water algorithms for estimating Chl-a concentration and for understanding spatio-temporal variations of water qualities in these regions.

2 Method

2.1 Monitoring survey

a. Observed factors with vessel
   Temperature, Salinity, SS, Transparency, DO, Chl-a, Nutrients (Phosphate, Silicate, Nitrogen etc), Phytoplankton, Zooplankton etc.

2.2 Obtaining ocean color satellite data

SeaWiFS Chl-a data were obtained through KEOC (Korea Earth Observation Center). The data was processed based on the OC2 algorithm, which was developed by NASA.

SeaWiFS Chl-a data in the South Sea of the Korean Peninsula and northern part of the East China Sea from 1998 to 2005 were also obtained and processed for the coverage with the South Sea (125-130ºE, 32.5-36.5ºN) in the northern part of the East China Sea (120-128ºE, 28-36ºN) (Fig.1).

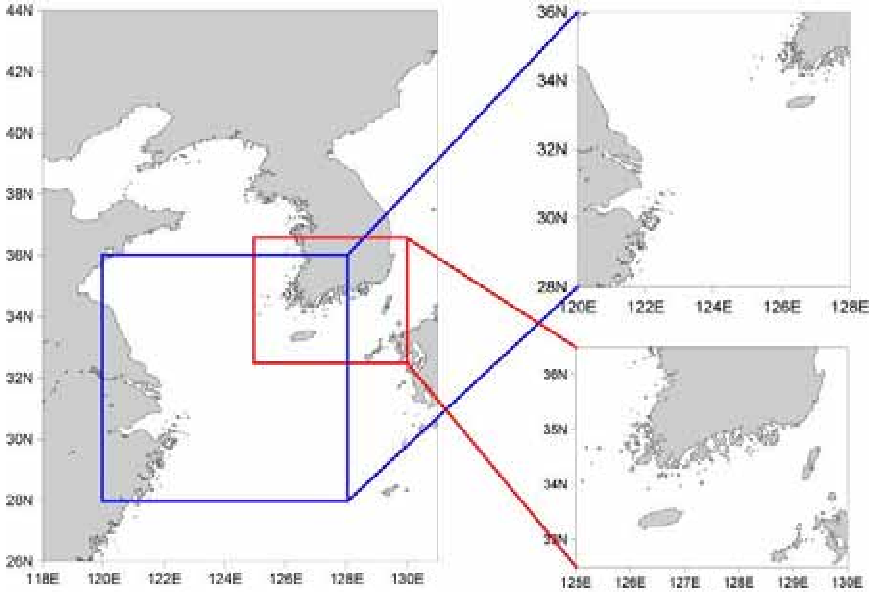


Fig.1 Location of study area.

3 Analysis and discussion

3.1 Analysis of time series Chl-a concentration derived from ocean color satellite

a. Analysis of ten days Chl-a concentration imageries

   Chl-a concentration patterns in the South Sea of the Korean Peninsula from January to December of 2000 were observed. Fig.2 shows the calendar of the Chl-a using SeaWiFS data from the early in January to the last ten days in December 2000. We can detect the spring bloom of phytoplankton in April and May of 2000. However, we cannot notice any special features from August to September while the *Cochlodinium polykrikoides* red tide blooms occurred frequently (Suh *et al.*, 2004a). As described later, satellite Chl-a concentrations tended to be over estimated than those of *in situ* data, when high SS concentration occurred from the discharge of murky waters in the southern coast of Korea.

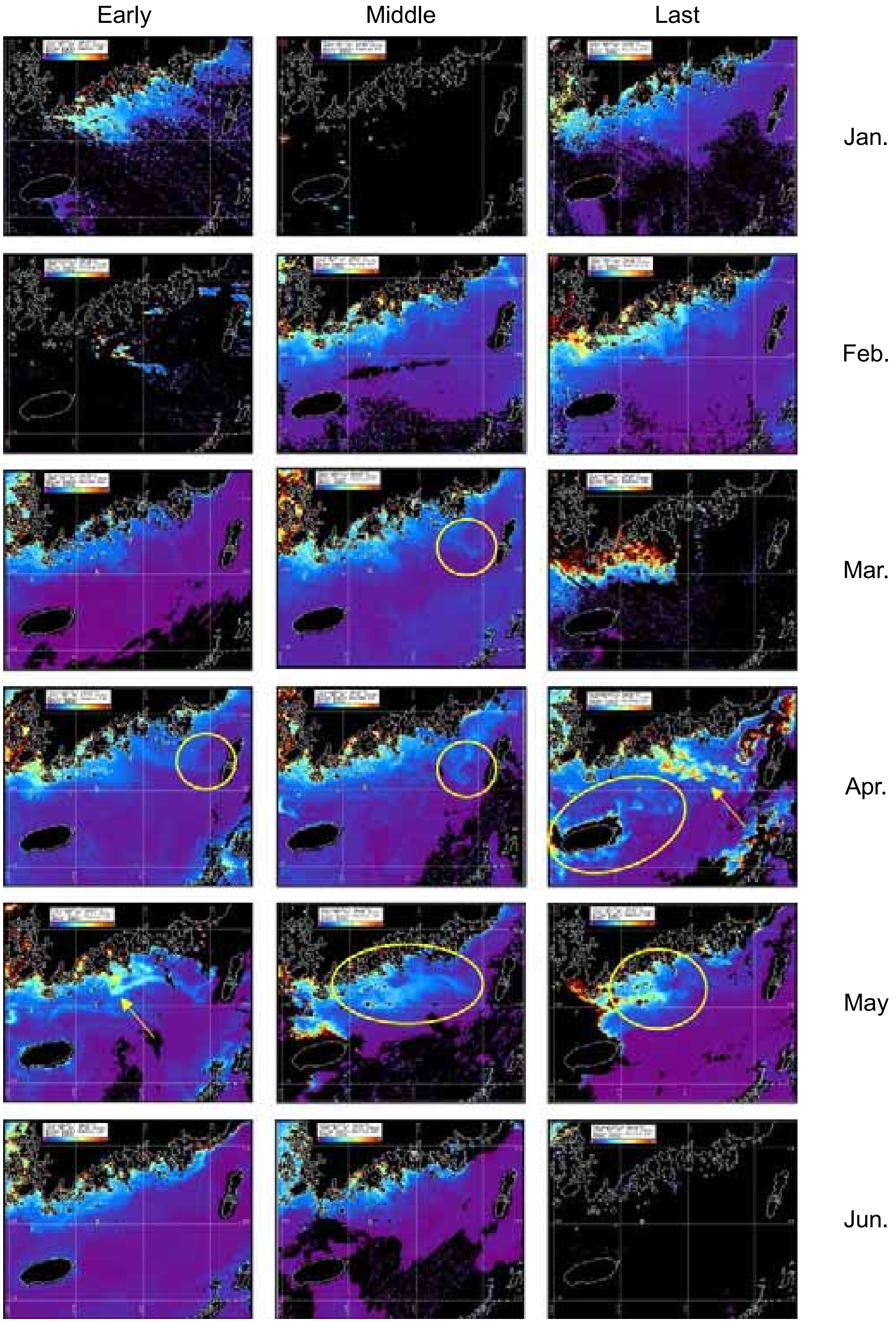


Fig.2a Ten days images of the estimated Chl-a derived from SeaWiFS from January to June 2000 in the South Sea of Korea (Suh *et al.*, 2004a).

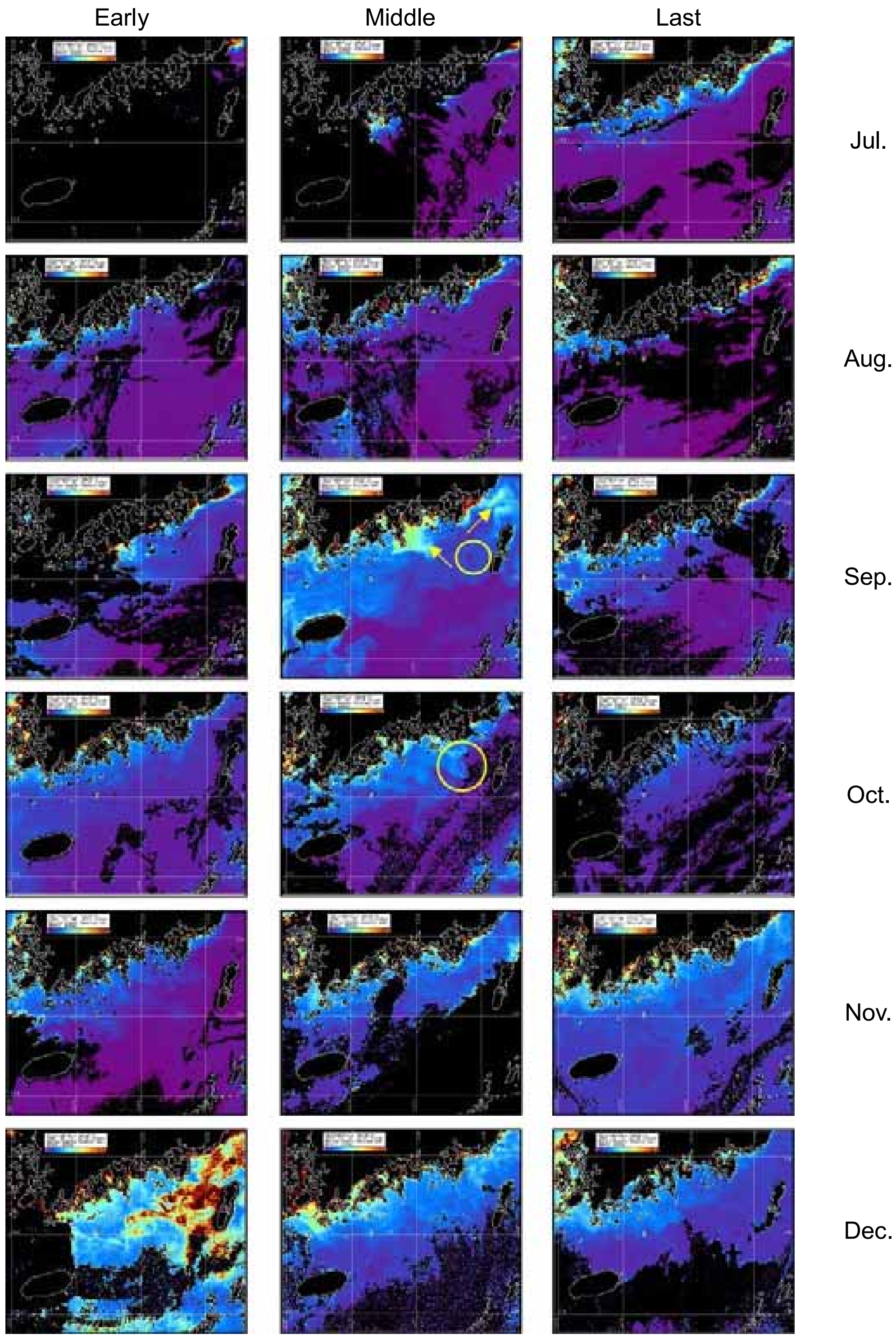


Fig.2b　The same as Fig.2a, except for July to December 2000.

b. Analysis of monthly Chl-a concentration imageries

The monthly average SeaWiFS Chl-a concentration images are as below Fig.3. The high Chl-a concentrations more than 5 mg/m^3 occurred in the coast water of China every year. In the northern part of the East China Sea, the Chl-a concentrations are higher in summer (July, August and September) than those in the other seasons.

Fig.4 shows temporal and spatial distributions of Chl-a derived from SeaWiFS and *in situ* Chl-a along the 32 ºN and 124-127.5 ºE in August from 2000 to 2005. The high Chl-a concentrations more than 2mg/m^3 appeared in the near the coast of China (32 ºN, 124-125 ºE), low Chl-a concentrations less than 1mg/m^3 appeared in the eastern parts of 126 ºE. The satellite Chl-a concentrations tended to be over estimated than those of *in situ* Chl-a.

The Chl-a concentrations around the bay in the South Sea of Korea are higher in summer and early fall (October) than those in the other seasons (Fig.5). Two peaks of Chl-a concentration occurred, one was in spring (March, April and May) and the other was in fall (October and November).

c. Seasonal variability of Chl-a concentration in five different areas

Time series of ten days SeaWiFS Chl-a concentration in five different areas showed different characteristic of seasonal variations (Fig.6). The stations as below were selected to extract the time series data from the SeaWiFS Chl-a images from 2000 to 2001. Chl-a values are averaged in 18x18km area to avoid some noise on the images. It is also quantified the seasonal variations of SeaWiFS Chl-a. It was able to detect the spring bloom in March, May and the late fall bloom in December 2000-2001. However, it was not able to detect the high Chl-a density during the summer even though huge red tides occurred in 2000 and 2001 (Suh *et al.*, 2004b).

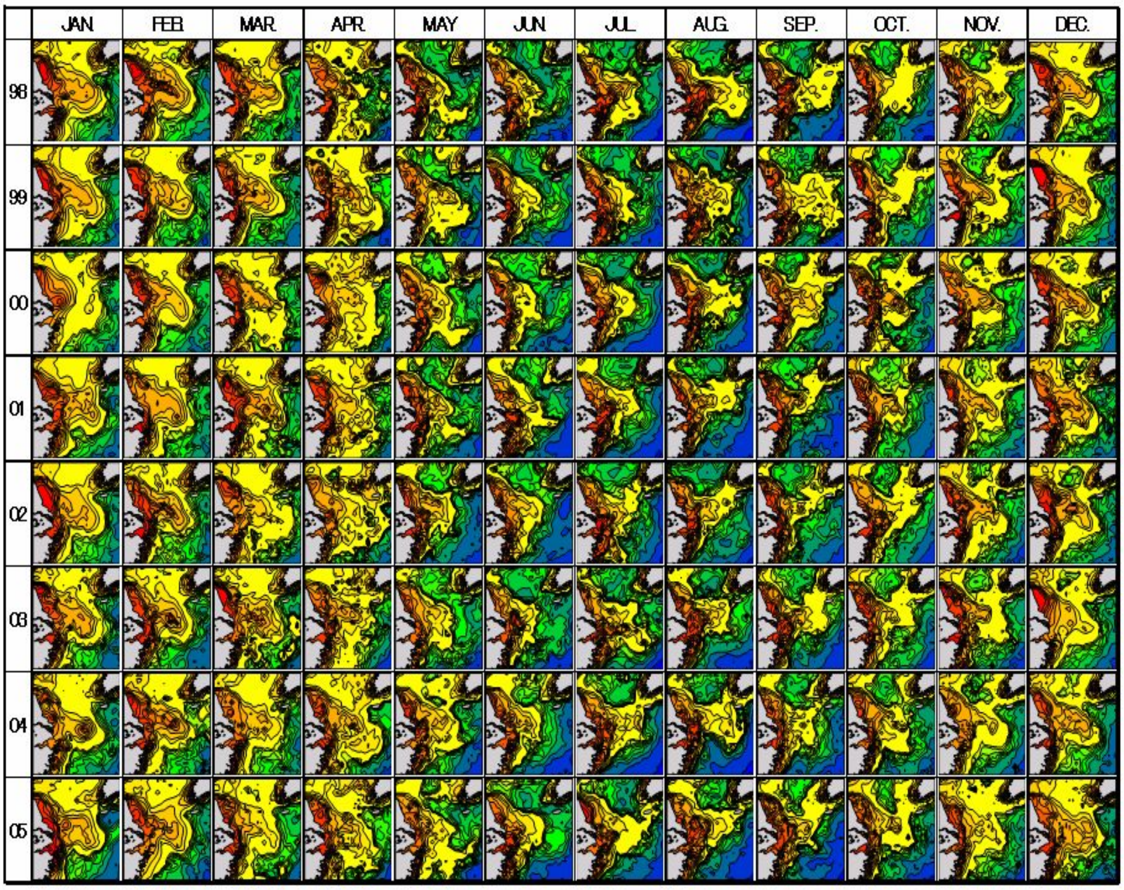


Fig.3 Monthly average SeaWiFS Chl-a images in the East China Sea from 1998 to 2005.

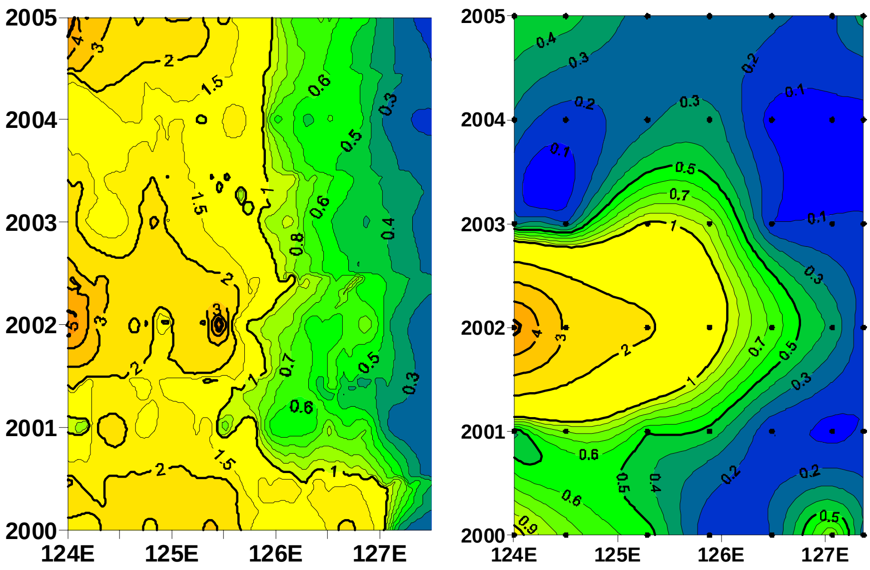


Fig.4 Temporal and spatial distributions of Chl-a derived from SeaWiFS and *in situ* Chl-a along the line (32 ºN, 124-127.5 ºE) in August form 2000 to 2005.

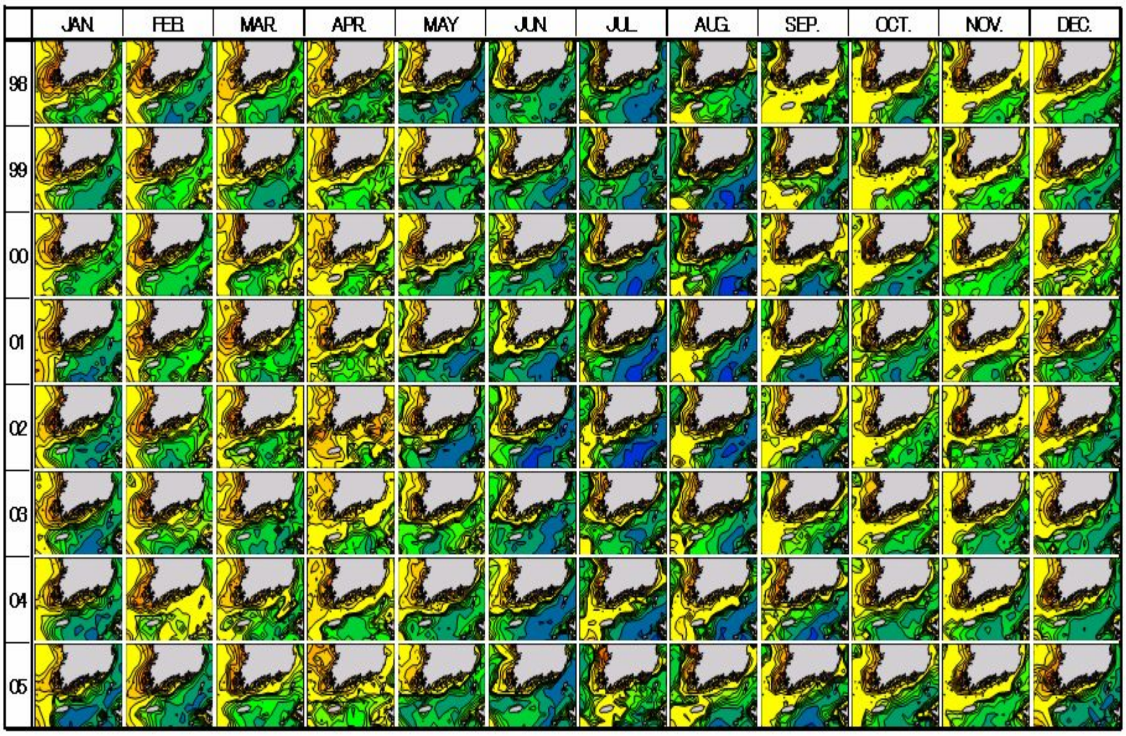
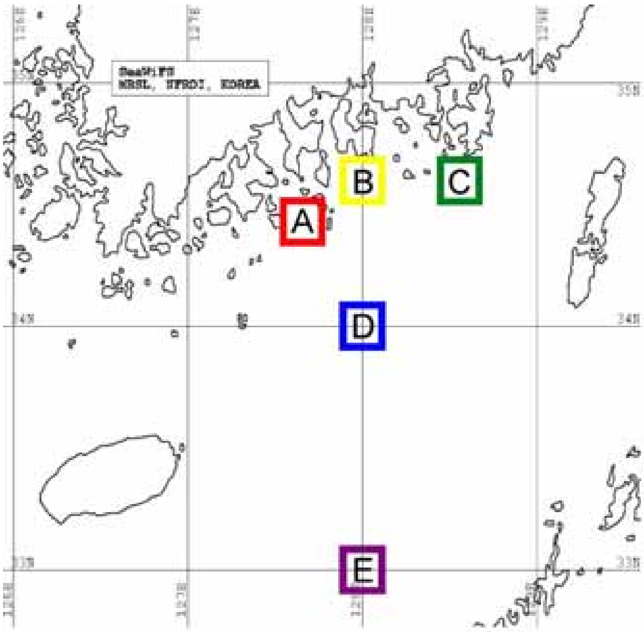
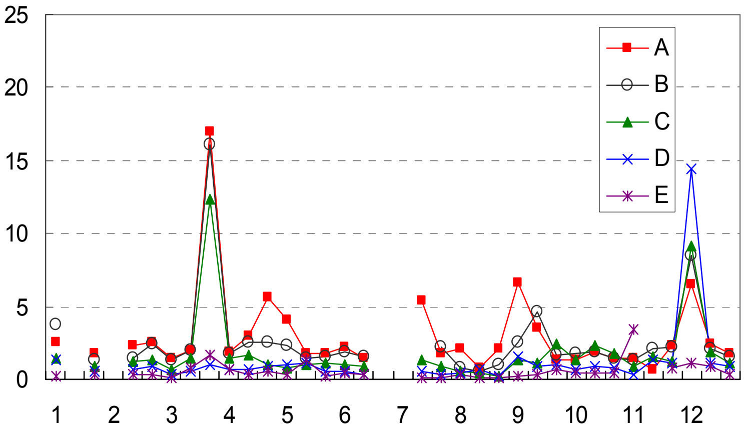


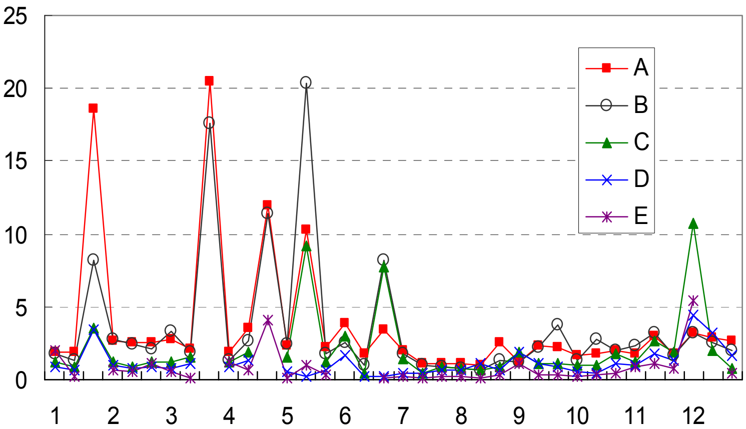
Fig.5 Monthly average SeaWiFS Chl-a images in the South Sea of Korea from 1998 to 2005.



(a)



(b)



(c)

Fig.6 (a) Study map in the southern part of the Korean waters. Ten days variations of the estimated Chl-a derived from SeaWiFS in (b) 2000 and (c) 2001 (Suh *et al.*, 2004b).

3.2 Validation of satellite Chl-a concentration

The correlation between *in situ* Chl-a concentrations and those derived from three existing in-water algorithms of SeaWiFS was investigated, using data observed in the southern coastal region of Korea, the northern part of the East China Sea (Fig.7-8). The results showed good the coefficient of correlation 0.56 and 0.82 in all data. The above results indicate that there is no unique characteristic in the Korean waters, thus, existing in-water algorithms can be applied to estimate Chl-a concentration in southern coastal waters of Korea. It also suggested that there might be a problem in atmospheric correction.

We would like to talk about the estimated SS in the southern part of Korean waters. We developed the empirical formula from the relationship between the *in situ* SS and SeaWiFS band ratio (nLw490/nLw555) as in Fig.9. We were able to regenerate the SS distributions in the southern part of Korean waters using the empirical formula [Estimated SS=-11.51Ln(x)+14.38, R^2=0.58, here x is the SeaWiFS band ratio (normalized water leaving radiance 490nm/555nm)].

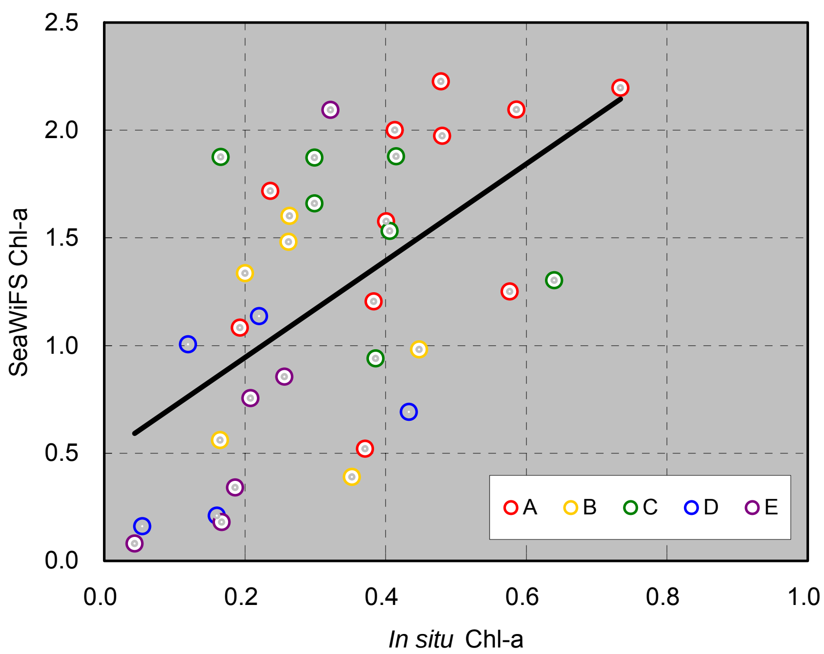


Fig.7 Relationship between the *in situ* Chl-a and Chl-a derived from SeaWiFS in the areas as shown in Fig.6 (a) for four years (1999-2002).

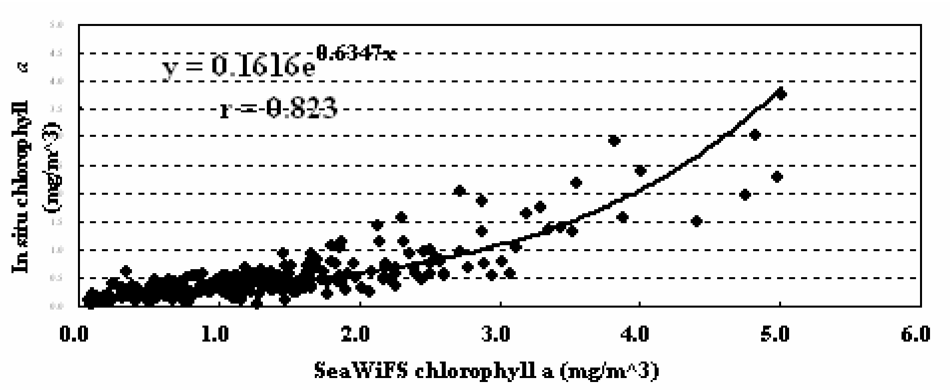


Fig.8. Relationship between the *in situ* Chl-a and Chl-a derived from SeaWiFS in February, May, August, and November for 6 years (2000-2005).

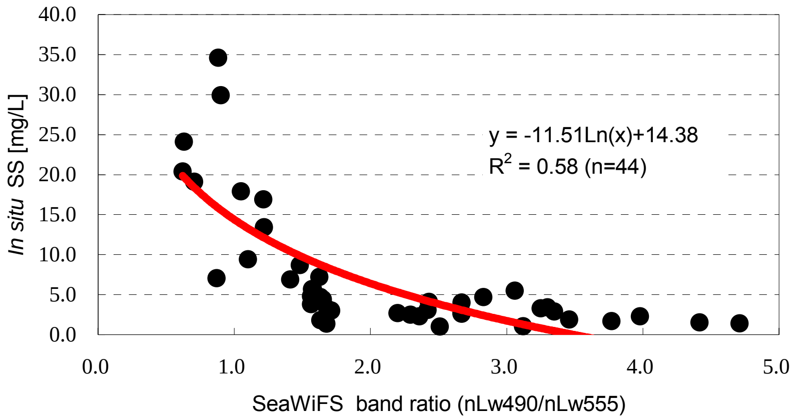


Fig.9 Empirical relationship between *in situ* SS in the southern part of the Korean waters and the band ratio of SeaWiFS satellite from October 1999 to June 2002.

4 Assessment of eutrophication with remote sensing

Liner regression was made in relationship between *in situ* and SeaWiFS Chl-a concentration data (Fig.7-9). The characteristics of variation pattern were represented well, as Chl-a concentrations in inner area of the bay in the South Sea of Korean Peninsula and the eastern coast of China are higher every summer, through analyzing of time series of satellite Chl-a concentration data (Fig.3-5).

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A case study in Russia

Annex 4 A case study in Russia

Satellite and *in situ* measurements of Chl-a concentration in Russian coastal zones

Satellite data from the ocean color sensors enable us to derive a set of bio-optical parameters such as Chl-a concentration, the particle backscattering and yellow substance absorption coefficients which manifest spatial and temporal variability of three important seawater constituents - photosynthetic phytoplankton, particulate and colored organic matter. Such work was made, in particular, for the NOWPAP Region with SeaWiFS data in 1998-2004 [1-4].

The starting data for the calculations were SeaWiFS Level-1A GAC data with spatial resolution at nadir of 4.4 x 4.4 km obtained from GSFC DAAC. SeaDAS 4.7 version of SeaWiFS Data Analysis System [5] was used to process all data (POI specialists used both OC2 and OC4 algorithms and SeaDAS4.6 software). As standard output products of Level-2, the values of normalized water-leaving radiance L_{WN}, aerosol optical thickness t_a, diffuse attenuation coefficient at 490 nm $K_d(490)$, and chlorophyll concentration Chl_OC4 were generated by the SeaDAS msl12 processing program; the subsequent processing was performed using the software developed by Shirshov Institute of Oceanology (SIO) RAS specialists [4]. The modified algorithms providing much better agreement between *in situ* and satellite-based values of bio-optical characteristics were developed on the basis of the ship measured data [1-4].

Level-2 products are derived from the Level-1 data with no remapping, so Level-2 data correspond to the original pixel position. The developed software allows us to perform the spatial and temporal averaging Level-2 data, to create Level-3 files and calculate various statistical characteristics for any distribution constructed. The daily Level-3 values were generated by averaging the Level-2 values within a given bin of 9 x 9 km and for a given day. Monthly or other Level-3 files were created by averaging the daily Level-3 values over the corresponding period. The monthly mean values for a given region were calculated by averaging the monthly "bin" values of a considered characteristic over the area of a given region. The seasonal and annual mean values were calculated by averaging the monthly mean values over a corresponding period.

The available data of field measurements show that the operational algorithm OC4 and the simplified algorithm for the particle backscattering coefficient provide quite reasonable results in the NOWPAP Region. Application of OC4 may be explained by the absence there of a significant riverine runoff delivering yellow substance and suspended matter.

In situ Chl-a concentrations in the NOWPAP Region were determined by POI specialists during 8 cruises [6-9]. Total number of stations was equal to 595. Water samples the volume of 1-1.5 l were taken by Niskin bathometer from standard depths of 0, 5, 10, 15 and 20 m that allowed to determine the variations of vertical distribution of Chl-a. Water transparence was estimated with Sechi disk. Amount of sediments was calculated by filtration of water samples the volume of 300-400 mL through lavsan nuclear filters the diameter of 35 mm with the size of pores of 0.4 mkm.

In situ measurements of Chl-a concentration in Peter the Great Bay and in Aniva Bay were carried out during special ship expeditions in 1999-2004. One of the main tasks was to develop regional algorithms to improve accuracy of satellite-derived Chl-a values. Satellite-derived Chl-a concentrations were used to study the relationships between the spatial and temporal Chl-a variations and the changes of environmental conditions. Fig.1 demonstrates development of autumn phytoplankton bloom in Peter the Great Bay in autumn 2003.

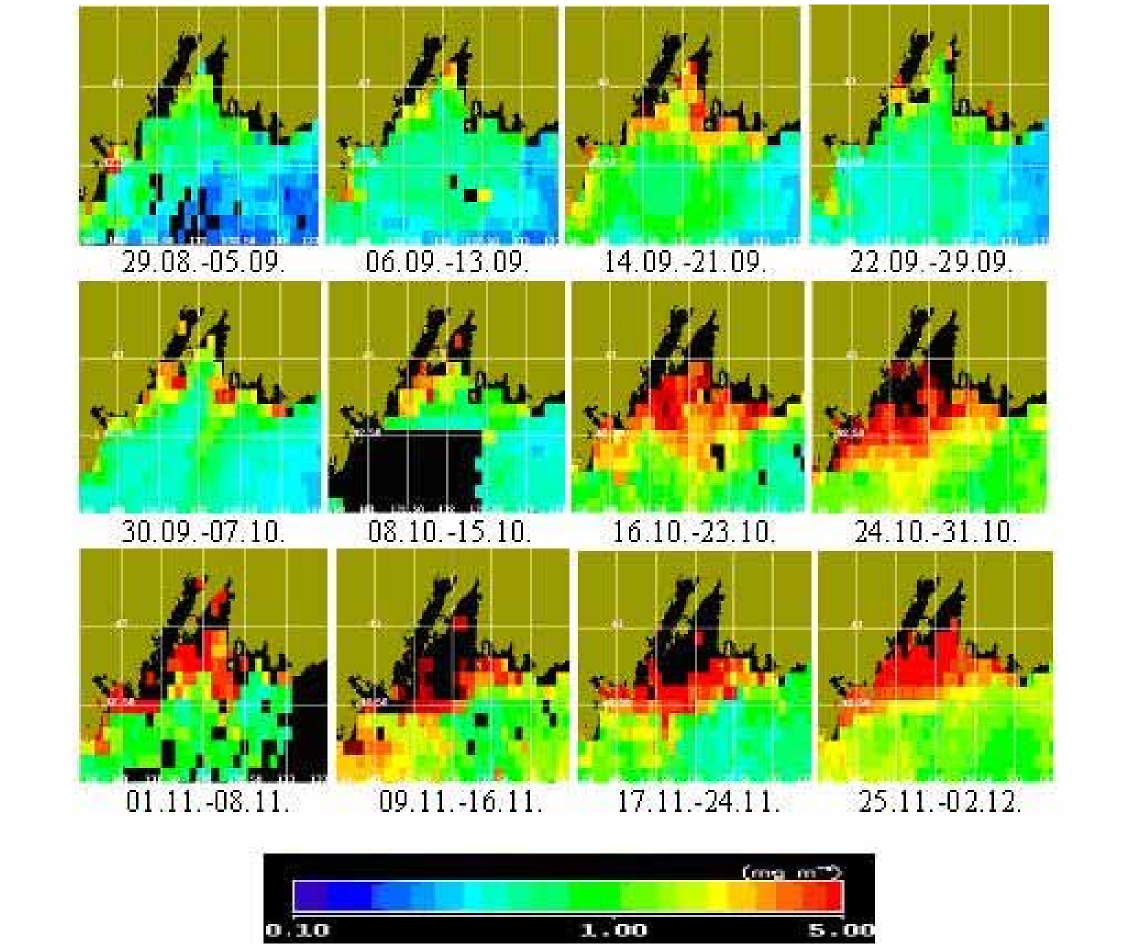


Fig.1 Chl-a distribution in Peter the Great Bay in autumn 2003 constructed from satellite 8-day averaged estimates (dark color denotes the absence of data).

In Peter the Great Bay spring bloom of phytoplankton begins in March and its minimum concentration is observed in July (Fig.2). Chl-a concentration varied from 0.04 mg/m^3 measured during cruise in March in an open area of the Bay to 8.1 mg/m^3 recorded in autumn at the same area. Satellite-derived Chl-a values determined with the use of OC2 algorithm were compared with 210 *in situ* ship data. In 109 cases, satellite values exceeded *in situ* data more than on 35%. Large overestimations were usually found for the coastal stations. It can be caused by the increased light absorption by dissolved organic matter (DOM) compare to absorption by pigments of phytoplankton. DOM content of waters in the coastal area of Peter the Great Bay varied from 3.4 mg/L to 20.55 mg/L and in the open area of the Bay it decreased to 0.4 mgr/L. Fig.3 shows the locations of hydrobiological stations where Chl-a measurements were performed during two ship cruises.

Sometimes satellite values were lower than *in situ* data. Maximum underestimating reached 70% and was observed near the coast and was likely caused by the increased turbidity of the coastal waters under high wind/waves conditions. At Chl-a concentration varied from 0,04 to 1 mg/m^3 discrepancy between satellite and *in situ* Chl-a data was less when satellite estimates were computed using OC2 algorithm. At Chl-a concentration larger than 3 mg/m^3, estimates obtained by application of OC4 algorithm were closer to ship determinations compare to OC2 algorithm.

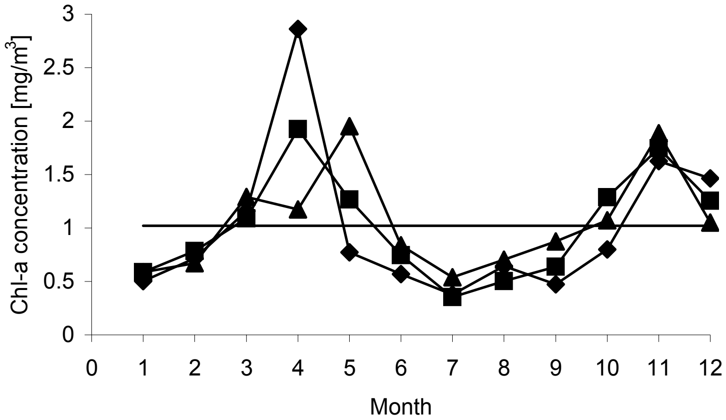
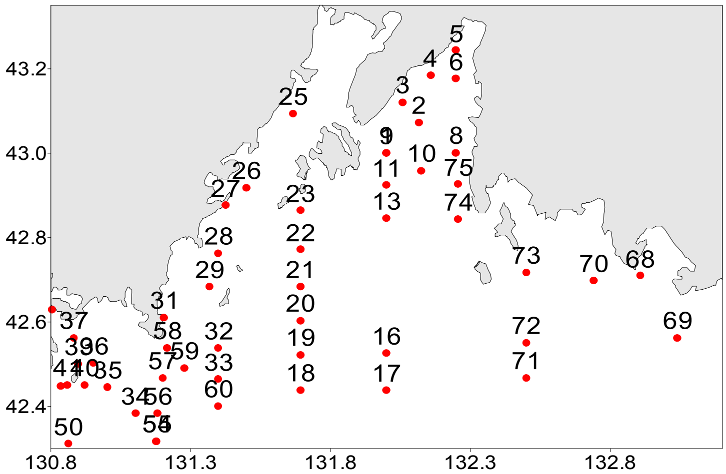
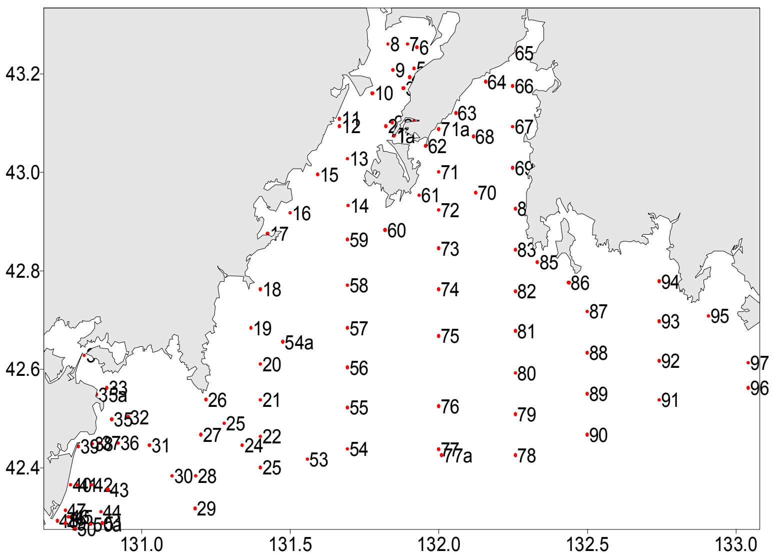


Fig.2 Season variations of average Chl-a concentration in the area bounded by coordinates 42.0-43.4ºN, 130.5-133.5ºE in 1999 (■), 2000 (▲) and 2001(◆).



(a) Research Vessel "Lugovoe", 1-12 March 2000.



(b) Research Vessel "Lugovoe", 23 November -3 December 1999.

Fig.3 Location of hydrobiological stations.

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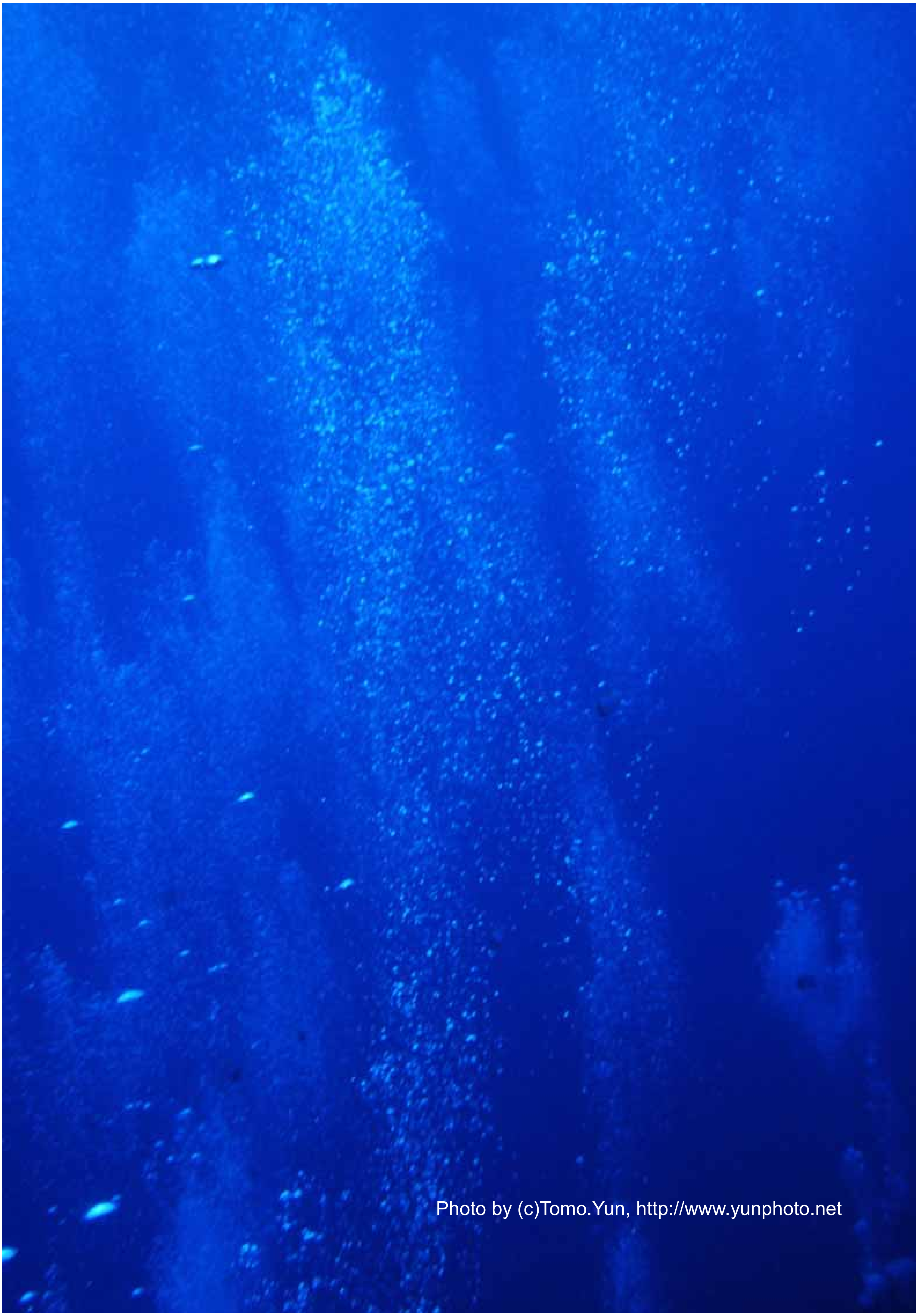
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