Validation of Ocean Color RS Data in Korea

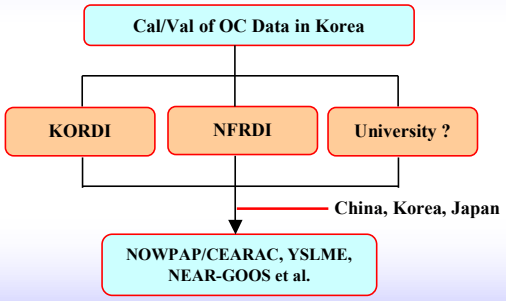
Case studies in Korea

Sang-Woo Kim

National Fisheries Research & Development Institute
(NFRDI)

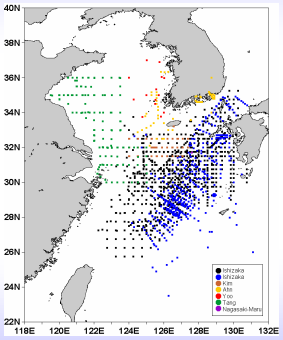
1

International Cooperation



2

Locations of YOC-shared chlorophyll a data (China, Korea, Japan)



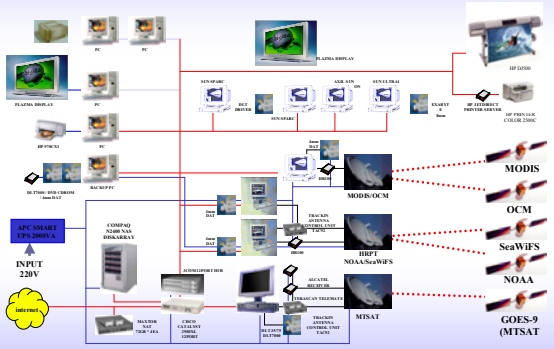
Total data : 3,397

- Item : Chlorophyll a
- Period : 1998 ~ 2007 (Jan. – Nov.)
- Number of data : 3,481 (including error data)
- Data source : China, Korea, Japan

3

Present Status of RS Data in the NFRDI

Operation of the Satellite Remote Sensing System



System of Satellite Ocean Information Lab. in the NFRDI

Operation of the Satellite Remote Sensing System

Thermal observation | **Ocean color observation**

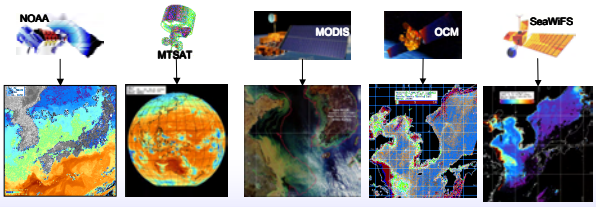
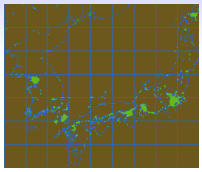
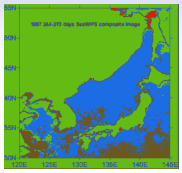


Fig. . Real time information on SST from NOAA and MTSAT / Ocean color from SeaWiFS, MODIS and OCM.

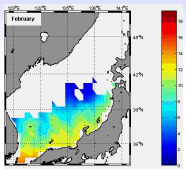
Monitoring of the fishing ground using satellite data



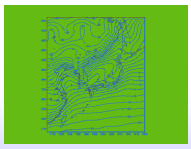
Nighttime fishing boats



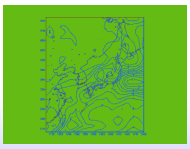
Pigment concentration



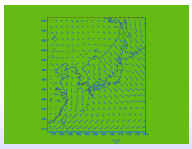
Temperature



Air temperature



Rainfall



Wind

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The First NEARGOOS-NOWPAP Training Course on RS Data Analysis

Validation of OC Data in the NFRDI

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The First NEARGOOS-NOWPAP Training Course on RS Data Analysis

Monitoring of the East China Seas

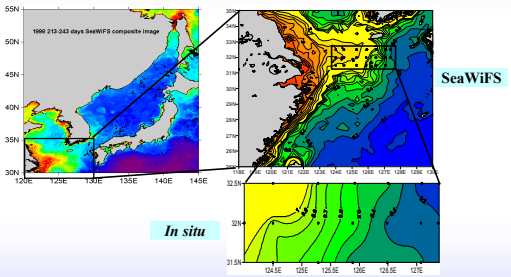

Fig. . Study area in the East China Sea

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Change of oceanic environment in the southern part of Korean peninsula by the construction of three gorges dam

Oceanic conditions monitoring around the East China Sea and Korean waters related to the construction of Three Gorges Dam

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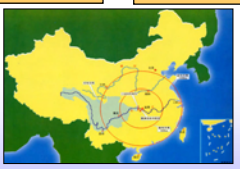
CDW (Changjiang Diluted Water) monitoring using the satellite remote sensing data



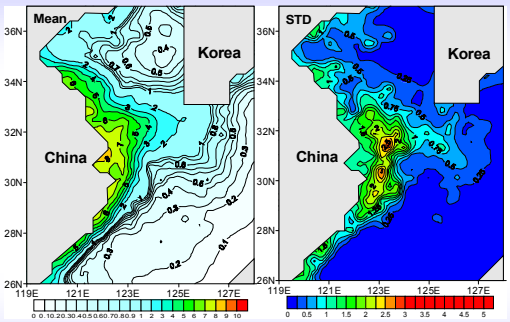


Fig. . Yearly mean and standard deviation of Chl-a derived from SeaWiFS images in August from 1998 to 2006. Unit is mg/m^3.

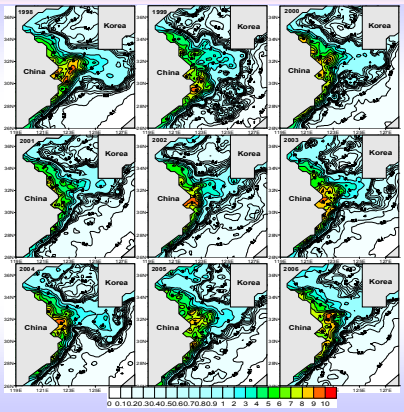
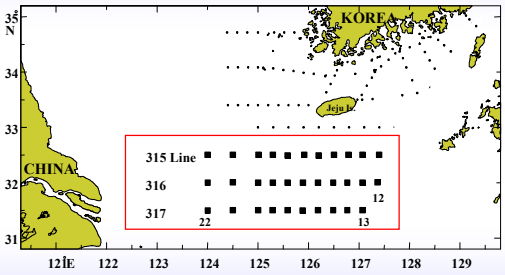


Fig. . Horizontal distributions of Chl-a derived from SeaWiFS in August from 1998 to 2006.

Serial Oceanographic Observation in the Northern East China Sea (ECS)



- Stations : East China Sea (32 sta.)
- Frequency : 4 times/year (Feb., May, Aug., Nov.)
- Vessels : Tamgu-1 (East China Sea, 2180 G/T),

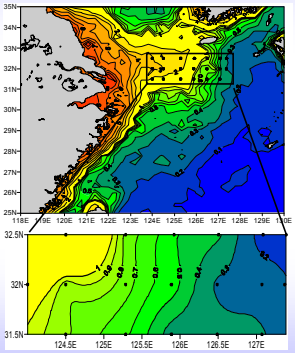
Serial Oceanographic Observation in the ECS

- Period : 1995 ~ Present
- Items : Temperature, Salinity, Dissolved Oxygen, Nutrients, Zooplankton Phytoplankton, Chl-a, Transparency, Meteorological conditions, ARGOS drifter buoy and so on.
- Frequency : 4 times/year (February, May, August, November)
- Stations : 32 stations
- Vessels : Tamgu-1 (2,810G/T) or Tamgu-3 (369G/T)
- Objectives
  - To understand the relationship between physical oceanographic factors and biogeochemical factors
  - To understand the behavior of low salinity waters

Relationship between in situ Chl-a and SeaWiFS Chl-a

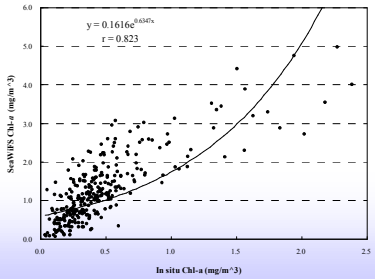
SeaWiFS Chl-a

In situ Chl-a



Improvement of Chl-a algorithm derived from OC data

- Relationship between SeaWiFS Chl-a and In situ Chl-a in the southern area of Korean Peninsula (ECS and South Sea) from April 2000 to August 2005.
  Estimation equation : $y = 0.1616e^{0.6347x}$, R=0.82



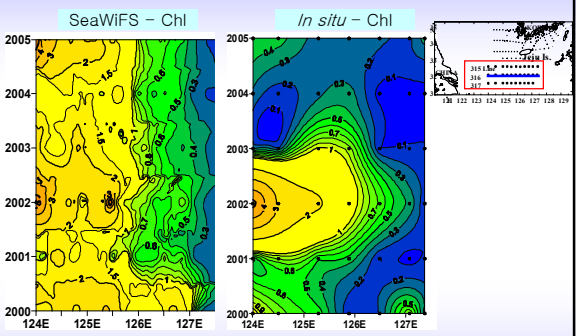
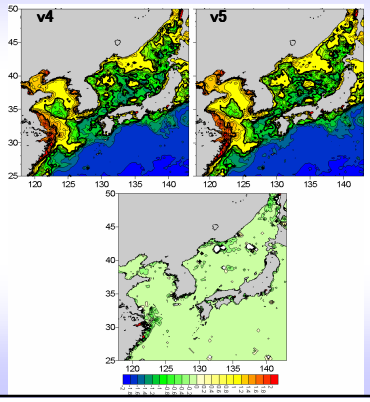


Fig. . Temporal and spatial distributions of SeaWiFS Chl-a and in situ Chl-a along the 32 N in August from 2000 to 2005.

Chl-a concentrations in near the coast of China appear the range of 1.5-5.0 mg/m3, 0.2-1.0 mg/m3 in the eastern areas of ECS.
The Chl-a concentrations by satellite data are 2-10 times higher than that by in-situ data.

Comparison between v4 and v5 data



In-situ bio-optical measurements in the ECS in the NFRDI

In situ bio-optical observation in the ECS

- **Period : 5 years (2000 – 2004)**
- **Frequency : 4 times/year (February, May, August, November)**
- **Optical sensor : PRR-800 spectral radiometer**
  Data were collected from freefall castings of the PRR-800

- Absorption coefficient by particulate suspended sediment , $a_p(\lambda)$
  - Sea water filtration by 25mm Whatman GF/F → spectrometer (300 ~800nm: 1nm interval) → calculation of absorption coefficient
- Absorption coefficient by detritus, $a_d(\lambda)$
  - Pigment remove : filtrated 100% methanol washing (one hour)
  - ☞ Measurement of spectrometer (300 ~800nm)
- Absorption coefficient by phytoplankton, $a_{ph}(\lambda)$ ∴ $a_{ph}(\lambda) = a_p(\lambda) - a_d(\lambda)$
- Specific light absorption coefficient (m^{-1}/mg chl-a/m^3)
  - ※ $a^*_{ph}(\lambda) = a_{ph}(\lambda)$/Chl-a

※ **Wet Filter method (Kishino et al., 1985)**

- chlorophyll_a
- Ap, Ad, As

(a) (b)

Fig. . The facility form measuring (a) particle absorption (Ap), detritus absorption (Ad), and (b) soluble absorption (As).

Understand Ocean Optical Properties(1)

(Optical Properties in the northern ECS)
Data were corrected from freefall castings of the PRR-800 spectral radiometer.

Fig. The PRR-800 casting

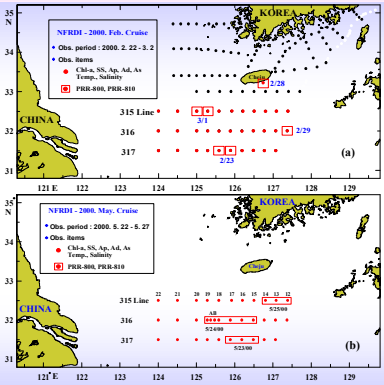
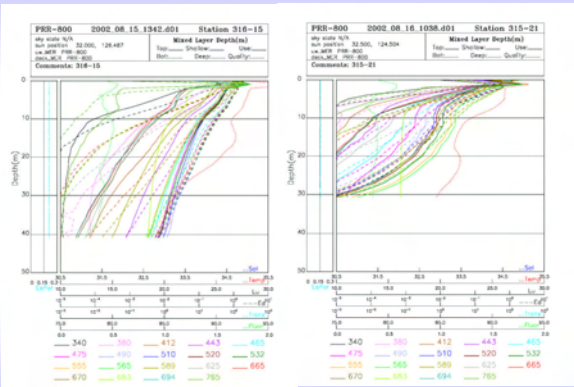


Fig. . Bio-optical observing stations related to the Cal/Val of the OC satellite data in February and May, 2000.



Absorption coefficient of phytoplankton

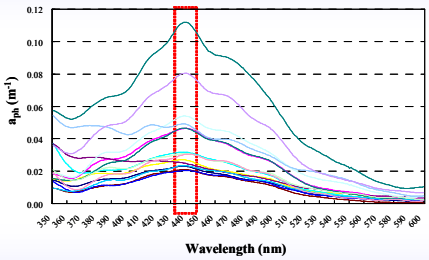


Fig. Absorption spectra of phytoplankton measured in the ECS in May, 2000.

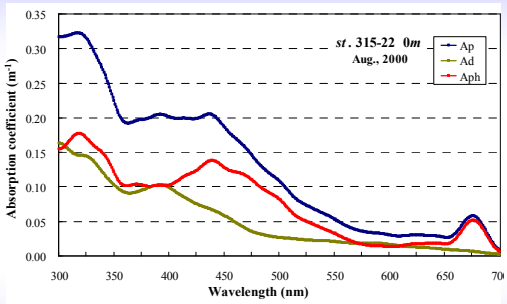


Fig. . Spectrum of absorption coefficient of Ap, Ad, Aph in the ECS in August, 2000

Ap : absorption coefficient by particulate suspended sediment, Ad : absorption coefficient by detritus,
Aph : absorption coefficient by phytoplankton, ∴ Aph = Ap-Ad

Status of Retrieval Algorithms of the OC in the KORDI

Algorithms/current problems/future directions in case-II water:

Due to the complexity in optical state of Yellow Sea waters, the global algorithms developed based on measurements from oceanic waters are often reported to have significant errors in these waters, and therefore, the more appropriate regional algorithms are needed to be developed based on measurements resulting from the regional waters.

Current problems are in turbid coastal waters, where accurate retrieval of water-leaving radiance (in other term, atmospheric correction), estimation of phytoplankton pigment concentrations, and red tide detection/monitoring/forecasting remain challenging.

Future research should focus on these issues in addition with integration of various in-situ data to develop algorithms that are commonly used and to validate them in this regional water.

(After, Dr. Yu-Hwan Ahn from KORDI)

Ocean Color: Relationship between absorption and scattering

$Rrs(\lambda) = L_u(\lambda) / E_d(\lambda)$ (just above water or depth 0+)
$Rrs(\lambda)$ "Remote Sensing" Reflectance
$E_d(\lambda)$ and $L_u(\lambda)$ are downwelling irradiance and upwelling radiance

$Rrs1(\lambda) = 0.519 * L_u(\lambda) / E_d(\lambda)$ (measured below surface or depth 0-)
$Rrs2(\lambda) = 0.54 * L_u(\lambda) / E_s(\lambda)$ (E_s measured above surface)
Lwn (or nLw) = Rrs*Fobar (λ) (Neckel & Labs, 1984)
Lwn is normalized water-leaving radiance

$Rrs(\lambda) = c\, bb(\lambda) / (bb(\lambda) + a(\lambda))$
Where c is approximately constant, a(l) is the volume absorption coefficient, and $bb(\lambda)$ is the volume backscattering coefficient

Since a and bb are inherent optical properties, they may be partitioned into their respective additive components:
$a(\lambda) = a_w(\lambda) + a_p(\lambda) + a_s(\lambda)$
$a_p(\lambda) = a_{ph}(\lambda) + a_d(\lambda) + a_i(\lambda)$
$bb(\lambda) = bb_w(\lambda) + bb_p(\lambda)$
$bb_p(\lambda) = bb_{ph}(\lambda) + bb_d(\lambda) + bb_i(\lambda)$
w- water, p- particulates, s- soluble, ph- phytoplankton, d- detritus,
i- inorganic sediments
$bb(\lambda)$ is relatively flat spectrally, controls albedo
$a(\lambda)$ has large spectral structure, controls "ocean color"

Pigment Specific Absorption: $a_p(\lambda) = a^*_p(\lambda)$ [chl]

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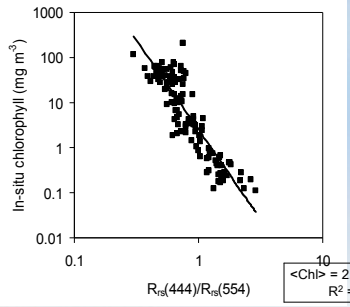
The fundamental algorithms needed for the Case-II region are as follows:

- **Chlorophyll, SS and DOM algorithms**
- **Atmospheric correction algorithm**
- **Red tide index algorithms**
- **Optical properties : k, a & b_b**
- **Transparency/visibility of water algorithms**

(After, Dr. Yu-Hwan Ahn from KORDI)

Chlorophyll Retrieval Algorithms

(1) Band ratio approach:



Reference:
Ahn, Y.H., and Shanmugam, P, (2007). Derivation and analysis of the fluorescence algorithms to estimate phytoplankton pigment concentrations in optically complex waters. **Pure and Applied Optics,** 9, 352-362.

Applications:

Ecosystem modeling
Water quality / Pollution
Transparency of water
Tropical water classification
Primary productivity
Fishing ground information

$$\langle Chl \rangle = 2.50[R_{rs}(444)/R_{rs}(554)]^{-3.97}$$
$$R^2 = 0.79$$

(After, Dr. Yu-Hwan Ahn from KORDI)

Red tide detection Algorithms

asic Red tide Index (RI) Equation

$$I = \frac{[L_w(510)/L_w(555) - L_w(443)]}{[L_w(510)/L_w(555) + L_w(443)]}$$

erived Red tide Index (RI) Equation

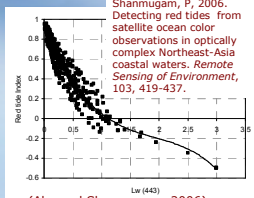
$$RI = 10^{(-0.1069\times X^3 + 0.6259\times X^2 - 1.3936\times X + 0.919)}$$

ed tide Chlorophyll Algorithm

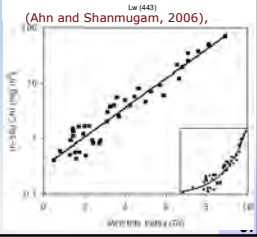
$$< Chl > (mgm^{-3}) = 0.316e^{(0.61\times RI_{(Derived)})}$$

10% of the total light detected by a satellite aimed at the ocean is leaving radiance, while the other 90% of the light is due to pheric effects.
ctions must be applied to the data to remove this atmospheric radiance. the radiance signal has been corrected for atmospheric light scattering, nal is then corrected for the solar zenith angle. This gives us the lized water leaving radiance (nLw), which is the radiance that would asured exiting the flat surface of the ocean with the Sun at zenith tly overhead) and the atmosphere absent. The normalized water- g radiances are then used in algorithms to produce geophysical values, s chlorophyll concentration.

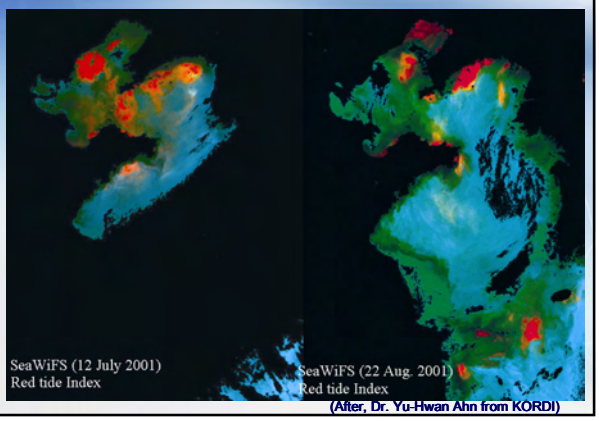
Reference:
Ahn, Y.H., and Shanmugam, P, 2006. Detecting red tides from satellite ocean color observations in optically complex Northeast-Asia coastal waters. *Remote Sensing of Environment*, 103, 419-437.



(Ahn and Shanmugam, 2006),

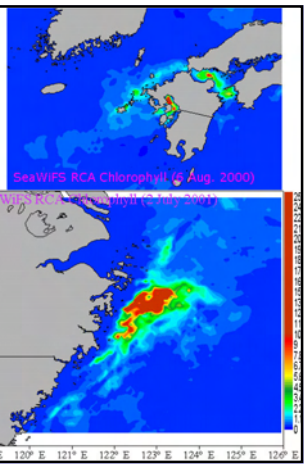


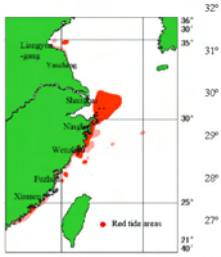
Red tide Index (RI) in Chinese Coastal waters



(After, Dr. Yu-Hwan Ahn from KORDI)

Results of Red tide Chlorophyll Algorithm (RCA) in Chinese and Japanese Coastal waters



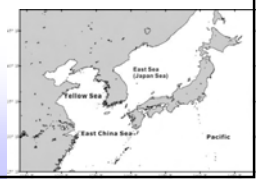


(After, Dr. Yu-Hwan Ahn from KORDI)

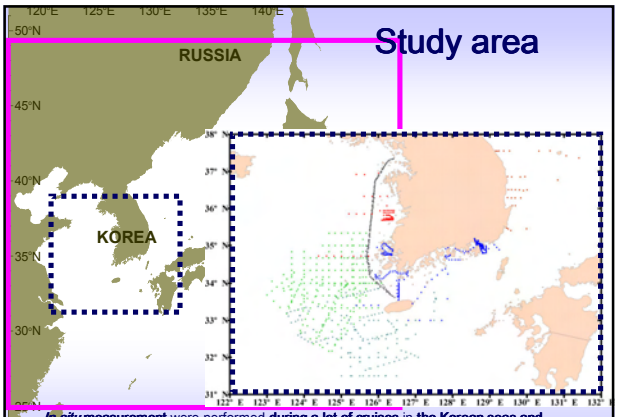
In situ bio-optical measurements in the YS and adjacent Seas in the KORDI

Main goals

- In the GOCI swath,
  - The coastal area of Korea & China and the ECS is a typical Case-2 waters
  - East/Japan Sea, central YS & Pacific come under the Case-1 water
- Main Goals :
  - to understand the optical properties of the Seas around Korean peninsula
  - to develop the new bio-optical algorithms suitable for complex optical properties considering Case-1 & Case 2 waters
  - to make a GOCI Data Processing System (GDPS)

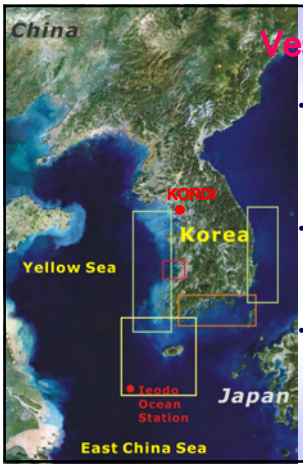


(After, Dr. Joo-Hyung Ryu from KORDI)



In-situ measurement were performed during a lot of cruises in the Korean seas and neighboring waters during 1998-2006 onboard the KORDI research vessel and fishing boats.

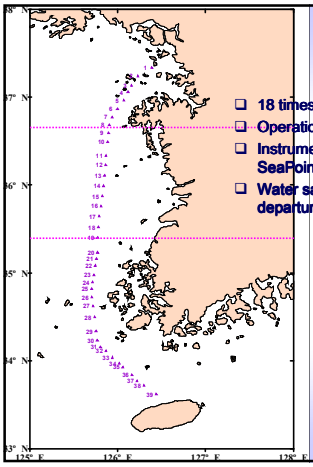
(After, Dr. Joo-Hyung Ryu from KORDI) 39



Vessels & Stations

- KORDI research vessels and fishing boats
  - Onnuri(1,500 ton), Eardo(500 ton), JangMok(150 ton)
- Fixed stations
  - KORDI at Ansan
  - IEODO station in the ECS
- Ferryboats
  - Chunghaejin (Incheon-Jeju)
  - Ohamana (Incheon-Jeju)

(After, Dr. Joo-Hyung Ryu from KORDI) 40

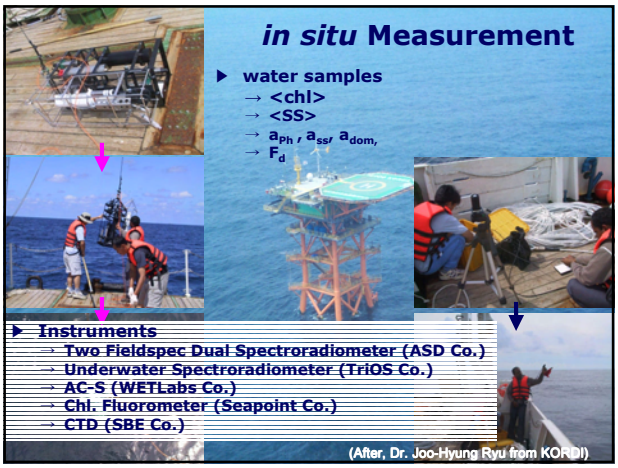


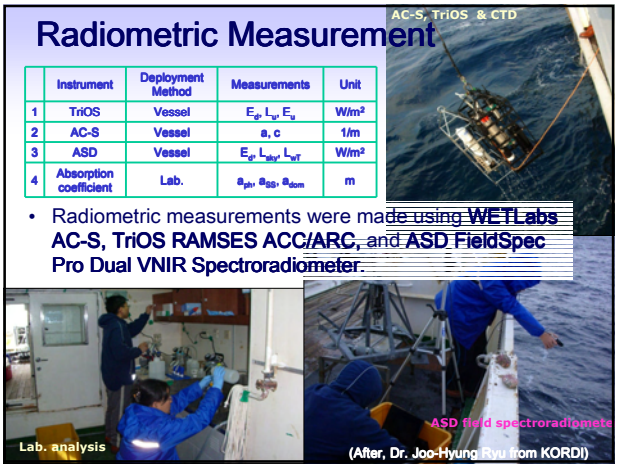
Ferrybox

- 18 times during 4 years
- Operation time : 19:00-10:00(next day)
- Instruments : YSI(SS, chl, T, S, DO), ChelSea(chl), SeaPoint(chl), McVan(SS)
- Water sample : about 40 (every 20 min after departure) <SS>, <chl>, a_{dom}

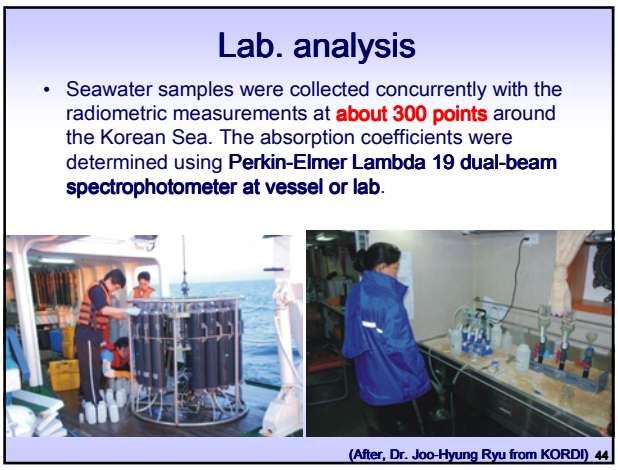
Year	Month	Vessel
2001	5,7,8,9,10	Chunghaejin
2002	6,7,8,9,10	Chunghaejin
2003	5,7,9,10,11	Chunghaejin
2004	8,9,11	Ohamana

(After, Dr. Joo-Hyung Ryu from KORDI) 41





	Instrument	Deployment Method	Measurements	Unit
1	TriOS	Vessel	E_d, L_u, E_u	W/m²
2	AC-S	Vessel	a, c	1/m
3	ASD	Vessel	E_d, L_{sky}, L_{wT}	W/m²
4	Absorption coefficient	Lab.	a_{ph}, a_{ss}, a_{dom}	m



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Methods

- <chl> : Spectrophotometric Method (Jeffery and Humphrey, 1975)
- <SS> : Dry Weight Method using 25 mm GF/F
- F(d) : using Multisizer 3 Coulter Counter (BECKMAN COULTER Co.)
- a_{ph} & a_{ss} : Filter Technique Method using 25 mm GF/F (β = 2)

$$a_{(ph,ss)}(\lambda) = \frac{O.D_{(ph,ss)}(\lambda) \times 2.3025}{(\frac{V}{S}) \times \beta} \times 100 [m^{-1}]$$

- a_{dom} : using 10cm optical cell

$$a_{dom}(\lambda) = \frac{O.D_{dom}(\lambda) \times 2.3025}{0.1} \times 100 \ [m^{-1}]$$

(After, Dr. Joo-Hyung Ryu from KORDI) 45

Ieodo Ocean Research Station

- Ocean Monitoring Systems (22)
  - Spectroradiometer
  - Wave radar
  - Directional Waverider
  - Self Contained Ultrasonic Sensors
  - Sea Level Monitor
  - Acoustic Doppler Velocimeter
  - ADCP
  - CTD
  - CTR7
  - Ultraviolet Fluorometer
  - Chlorophyll Fluorometer
  - Current Profiler
  - Ultrasonic Level Meter
  - etc.
- Meteorological Instruments (13)
  - Wind monitor-MA
  - Wind speed sensor
  - Temp & Humidity sensor
  - Digital barometric sensor
  - Pyranometer
  - Sunshine duration meter
  - Vaporimeter
  - Optical precipitation sensor
  - Rain guage
  - Quartzonix pressure standard
  - 3D sonic anemometer
  - etc.
- Environment Observing Systems (6)

(After, Dr. Joo-Hyung Ryu from KOR

Satlantic HyperSAS OCR-3000

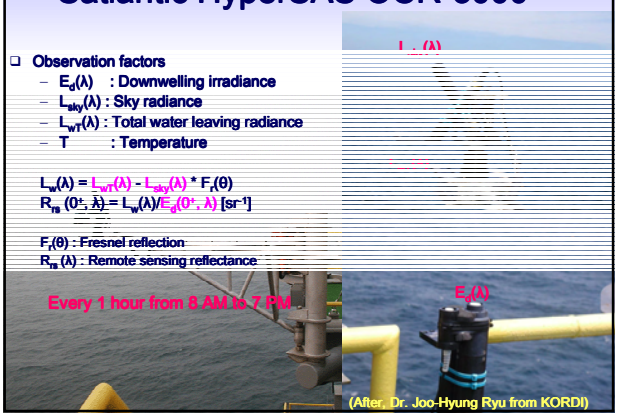
- Observation factors
  - $E_d(\lambda)$: Downwelling irradiance
  - $L_{sky}(\lambda)$: Sky radiance
  - $L_{wT}(\lambda)$: Total water leaving radiance
  - T : Temperature

$L_w(\lambda) = L_{wT}(\lambda) - L_{sky}(\lambda) * F_r(\theta)$

$R_{rs}(0^{\pm}, \lambda) = L_w(\lambda)/E_d(0^+, \lambda)$ [sr^{-1}]

$F_r(\theta)$: Fresnel reflection

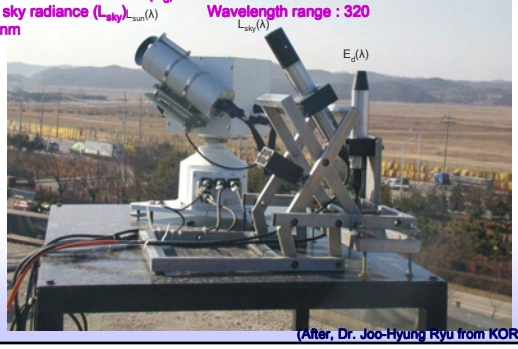
$R_{rs}(\lambda)$: Remote sensing reflectance



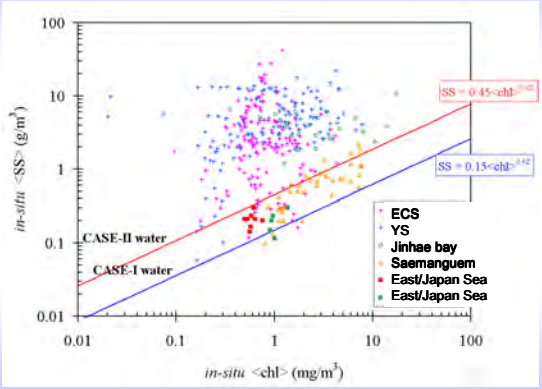
(After, Dr. Joo-Hyung Ryu from KORDI)

Instrument at KORDI

Grating sunphotometer (PGS 100) (350-1050nm)
Hyperspectral radiometer RAMSES-
ACC : downward irradiance (E_d) RAMSES-
ARC : sky radiance (L_{sky})$L_{sun}(\lambda)$ Wavelength range : 320 – 950 nm



(After, Dr. Joo-Hyung Ryu from KORDI) 48



(After, Dr. Joo-Hyung Ryu from KORDI) 49

The First NEARGOOS-NOWPAP Training Course on RS Data Analysis

Local OC algorithms for Primary Productivity of YS in the KORDI

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Thank you for your attention !!

Local OC algorithms for Primary Productivity of YS in KORDI, Korea

Primary productivity of YS (limitation of current knowledge)

- It is known to vary in the range of 11.78 ~ 3,175 ㎎ C m^{-2} d^{-1} depending on time and space.
- Some of estimates on annual production are ~150 gC m^{-2} y^{-1}, which is small compared to fish landings.
- Uncertainty is significant
- Seasonal phytoplankton blooms are known to occur but there are few time-series to show the interannual variation in the timing and intensity of the blooms.

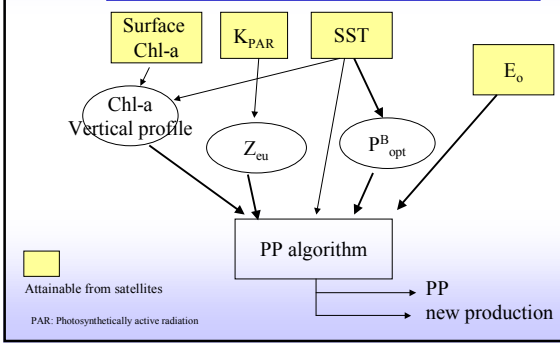
(After, Dr. Shin-Jae Yoo from KORDI) 54

Methodological limitations

- Spatial and temporal variability of major variables of primary productivity, such as chlorophyll and turbidity is too high to deal with traditional ways of observation.
- Satellite data can be potentially utilized to solved such variability.

(After, Dr. SinJae Yoo from KORDI) 55

Variables and parameters



PAR: Photosynthetically active radiation

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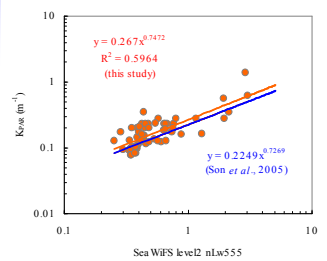
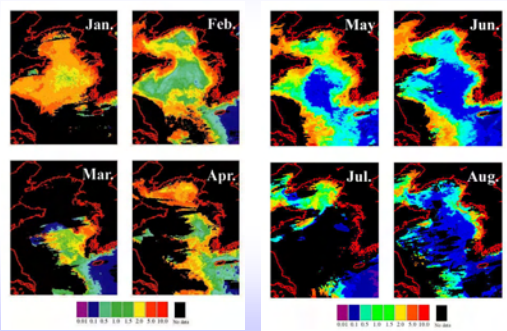
SeaWiFS nLw555 vs. measured K_{PAR}



- The relationship between K_{PAR} and SeaWiFS nLw555 shows a reasonable agreement.
- Therefore, this relationship was used for deriving K_{PAR} from nLw555.

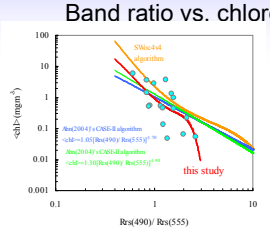
(After, Dr. SinJae Yoo from KORDI) 57

Are ocean color CHL data reliable in case 2 water?



(After, Dr. SinJae Yoo from KORDI) 58

Band ratio vs. chlorophyll concentration



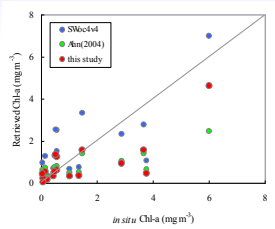
$$Chl = 10^{y}$$

$$y = -0.552 \cdot x^3 + 2.818 \cdot x^2 - 5.202 \cdot x + 2.903$$

- 17 in-situ optic data were used check the accuracy of chlorophyll algorithms (SeaWiFS standard algorithm and Ahn's (2004) regional algorithm.
- The empirical algorithm was adjusted using our data set, and used for calculating PP.

(After, Dr. SinJae Yoo from KORDI) 59

Comparison of in situ and retrieved chlorophyll a



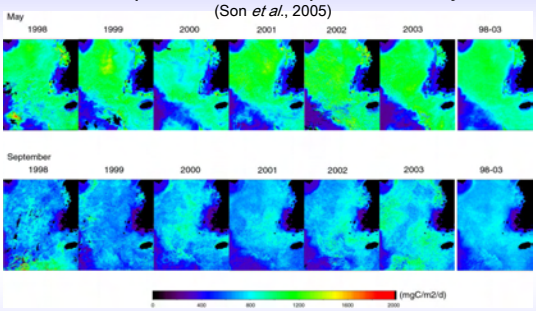
	SWoc4v4	Ahn(2004)	This study
RMS error	2.05	1.12	1.50

- RMS errors were not significantly different among the algorithms. However, The algorithm was less biased throughout the range.

(After, Dr. SinJae Yoo from KORDI) 60

Comparison with our previous study

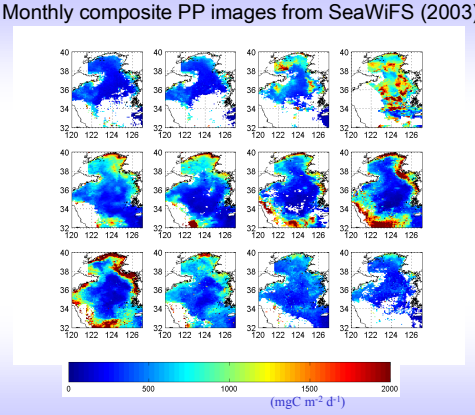
(Son *et al.*, 2005)



Monthly composite PP images and 6-year composite images from SeaWiFS

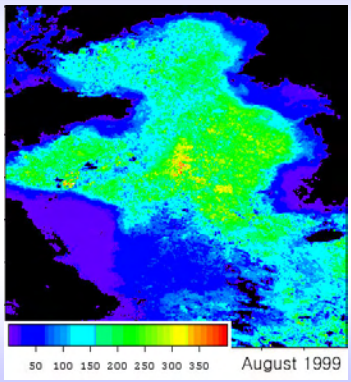
(After, Dr. SinJae Yoo from KORDI) 61

Monthly composite PP images from SeaWiFS (2003)



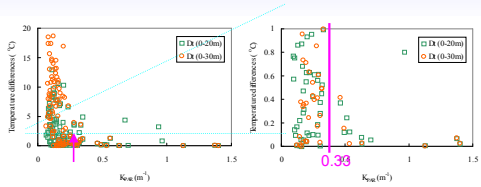
(After, Dr. SinJae Yoo from KORDI) 62

Example of PP map of YS



(After, Dr. SinJae Yoo from KORDI) 63

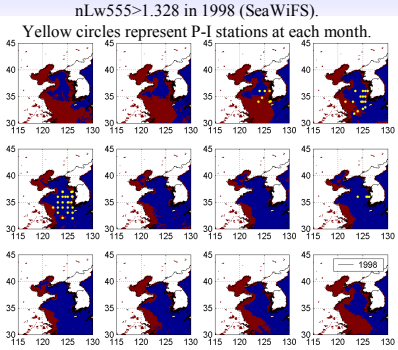
Temperature differences (between surface and subsurface) vs. K_{PAR}



- Temperature differences are taken as stratification strength. While coastal waters with high tidal mixing show small temperature differences and high K_{PAR}, open waters show variable range of temperature differences.
- The cluster with lower K_{PAR} seems to separate from high K_{PAR} stations and we use this criterion for dividing into two sub-regions (K_{PAR} > 0.33 or nLw555 > 1.328).

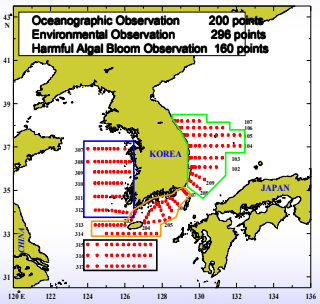
(After, Dr. SinJae Yoo from KORDI) 64

Monthly distribution of two sub-regions which is divided by nLw555>1.328 in 1998 (SeaWiFS).
Yellow circles represent P-I stations at each month.



(After, Dr. SinJae Yoo from KORDI) 65

Stations of the NFRDI's Serial Oceanographic Observation



- East Sea Institute at the NFRDI
- South Sea Institute at the NFRDI
- West Sea Institute at the NFRDI
  - ※Frequency : 6 times/year (Feb., Apr., Jun., Aug., Oct., Dec.)
- Ocean research team
  - ※Frequency : 4 times/year (Feb., May, Aug., Nov.)

Obs., factors : Temperature, Salinity, DO, Nutrients, Zooplankton, Phytoplankton, Chl-a, Transparency, SS Meteorological conditions, ARGOS drifter buoy etc.

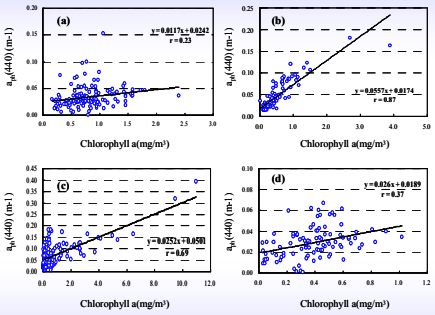


Fig. . Relationship between $a_{ph}(440)$ and Chl-a in (a) February, (b) May, (c) August and (d) November during 3 years (2000 ~ 2002).

Summary

- ♦ NFRDI has been carrying out investigation of OC factors (Chl-a, SS, etc) for the improvement of OC algorithms in the ECS from 2000 to present.
- ◆ Relationship between SeaWiFS Chl-a and In situ Chl-a showed high correlation (0.82) in the southern area of Korean Peninsula from April 2000 to August 2005.
- ◆ In case of the ECS, the Chl-a by OC satellite are 2-10 times higher than that by in-situ Chl-a in August during 2000-2005. The correlation was low (0.53).
- ◆ Relationship between SeaWiFS Chl-a and In situ Chl-a showed relatively high correlation (R^2=0.62) in the West Sea of Korea from Oct., 1999 to Aug., 2001.
- ◆ To extend the regional OC algorithms (Case I and Case II) in other geographical area, we need a larger in-situ database from other adjacent countries.

Division of areas by optical properties

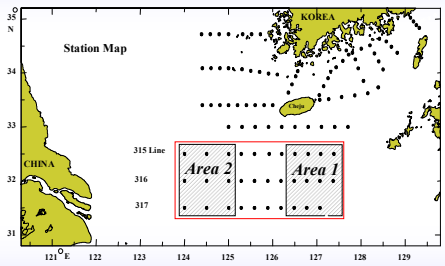


Fig. Area 1 water and Area 2 water in this study.

Relationship between specific absorption coefficient, a*ph(440), and Chl-a

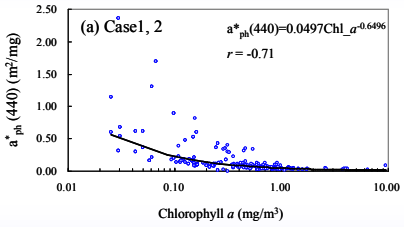
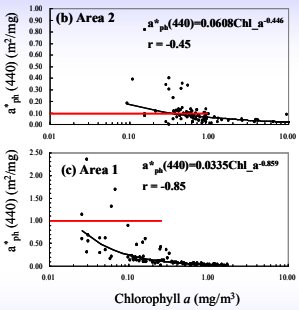


Fig. . Relationship between the specific absorption coefficient, $a^*_{ph}(440)$ and chlorophyll a in area 1 and area 2 areas.



◆ Specific absorption coefficient

- Area 2 area : High Chl-a, low specific absorption coefficient.
- Area 1 area : Low Chl-a, high specific absorption coefficient .
- Light available rate (efficient) by phytoplankton : east area higher than the west area.

Fig. . Relationship between the specific absorption coefficient, $a^*_{ph}(440)$ and chlorophyll a in area 2 (a) and area 1 (b).

Validation of ocean color satellite in the South Sea of Korea

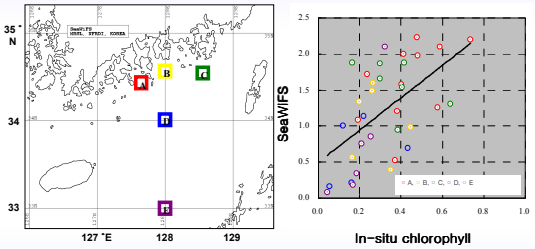


Fig. Relationship between the in situ Chl-a and Chl-a derived from SeaWiFS in the five areas from 1999 to 2002 (Suh *et al.*, 2004).

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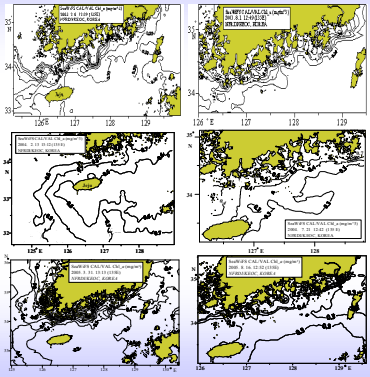
Validation of ocean color satellite data



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Phytoplankton pigment data in the ECS

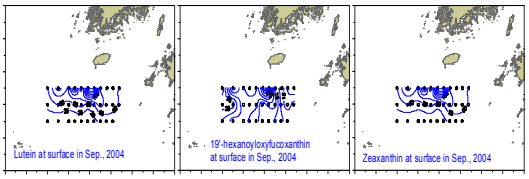

Fig. Distribution of phytoplankton Pigment using HPLC

Detecting the high concentration Lutein,19'-hexanoyloxyfucoxanthin, zeaxanthin, violaxanthin in the Northern ECS

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Cal/Val data of OC satellite in the ECS

	JRC	Abs.	Color	SS
2000-Feb				
2000-May				
2000-Aug				
2000-Nov				
2001-Feb				
2001-May				
2001-Aug				
2001-Nov				
2002-Feb				
2002-May				
2002-Aug				
2002-Nov				
2003-Feb				
2003-May				
2003-Aug				
2003-Nov				
2004-Feb				
2004-May				
2004-Aug				
2004-Nov				
2005-Feb				
2005-May				
2005-Aug				
2005-Nov				
2006-Feb				
2006-May				
2006-Aug				
2006-Nov				

Cal/Val data in the southern area of Korea

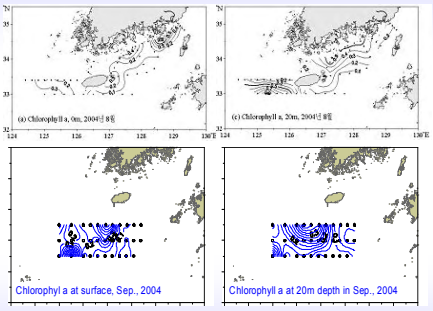

Fig. Chl-a distributions at surface and 20m in August and September, 2004

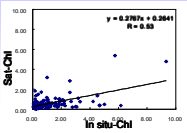

Fig. . Relationship between in situ Chl-a and Chl-a derived from SeaWiFS in August from 2000 to 2005.

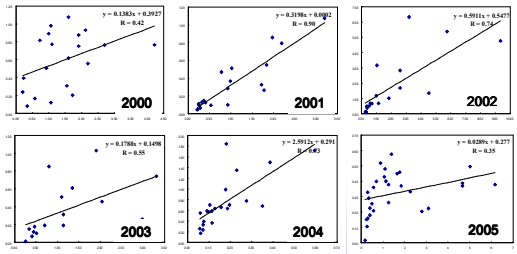

Fig. . Relationship between in situ Chl-a and Chl-a derived from SeaWiFS in August from 2000 to 2005.

Relationship between $a_{ph}(440)$ and Chl-a

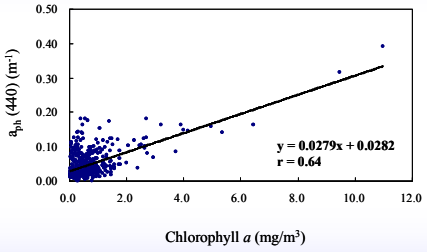

Fig. . Relation between the absorption coefficient, $a_{ph}(440)$ and Chl-a during 3 years (2000～2002).

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Bio-optical in situ data in the East China Sea

	PRR	Abs.	Chlor	SS
2000-Feb	■	■	■	■
2000-May	■	■	■	■
2000-Aug	■	■	■	■
2000-Nov	■	■	■	■
2001-Feb			■	■
2001-May	■	■	■	■
2001-Aug		■	■	■
2001-Nov			■	■
2002-Feb	■	■	■	■
2002-May			■	■
2002-Aug	■	■	■	■
2002-Nov	■		■	■
2003-Feb	■	■	■	■
2003-May	■	■	■	■
2003-Aug	■	■	■	■
2003-Nov	■		■	■
2004-Feb	■	■	■	■
2004-May	■	■	■	■
2004-Aug			■	■
2004-Nov			■	■
2005-Feb			■	■
2005-May			■	■
2005-Aug			■	■
2005-Nov			■	■
2006-Feb			■	■
2006-May			■	■
2006-Aug			■	■
2006-Nov				

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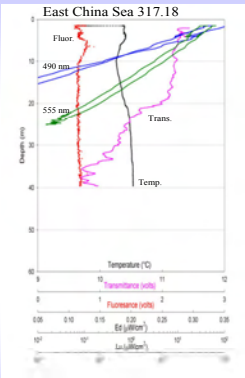

Fig. . Vertical profiles of optical properties from the PRR-800 spectral radiometer collected in the East China Sea in February at NFRDI station 317-18.

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