Validation of Ocean Color RS Data in Korea

Case studies in Korea

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International Cooperation

Cal/Val of OC Data in Korea

KORDI, NFRDI, University?

China, Korea, Japan

NOWPAP/CEARAC, YSLME, NEAR-GOOS et al.

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

- Item: Chlorophyll a
- Number of data: 3,481 (including error data)
- Data source: China, Korea, Japan

Total data: 1,397
Present Status of RS Data 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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Validation of OC Data in the NFWRI

Monitoring of the East China Seas

SeaWiFS

In situ

Fig. - Study area in the East China Sea
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

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/m³.
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: Tamgo-T1 (East China Sea, 2180 G/T)

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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: Tamgo-1 (2,810 G/T) or Tamgo-3 (369 G/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
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. 1. Temporal and spatial distributions of SeaWiFS Chl-a and In situ Chl-a along the 32° N in August from 2000 to 2005.

Comparison between v4 and v5 data
In situ bio-optical measurements in the ECS in the NFRDI

Absorption coefficient by particulate suspended sediment, \( a_p(\lambda) \)
- Sea water filtration by 25mm Whatman GF/F spectrometer (300 – 800nm: 1nm intervals) \( \rightarrow \) 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, \( a_{ph}(\lambda) \)
- Specific light absorption coefficient (\( \text{m}^2/\text{mg chl a/m}^3 \))

\[ a_{ph}(\lambda) = a_p(\lambda)/a_{ph} \]
- Wet Filter method (Kishino et al., 1985)

Period: 5 years (2000 – 2004)
Frequency: 4 times/year (February, May, August, November)
Optical sensor: PRRT800 spectral radiometer

Data were collected from freefall castings of the PRRT-800

Fig. The facility form measuring (a) particle absorption \( (A_p) \), detritus absorption \( (A_d) \), and (b) soluble absorption \( (A_s) \).
Understand Ocean Optical Properties(1)

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

Fig. The PRRT-800 casting

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

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

Absorption coefficient of phytoplankton

Wavelength (nm)

0.00 0.02 0.04 0.06 0.08 0.10 0.12
350 360 370 380 390 400 410 420 430 440 450 460 470 480 490 500 510 520 530 540 550 560 570 580 590

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 = WApx Ad

Status of Retrieval Algorithms of the TOC 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.

(The authors, Yu Hwan Ahn from KORDI)

Ocean Color: Relationship between absorption and scattering

\[ R_{rs}(\lambda) = \frac{L_u(\lambda)}{E_d(\lambda)} \]

where \( R_{rs}(\lambda) \) is the remote sensing reflectance, \( L_u(\lambda) \) is the upwelling radiance, and \( E_d(\lambda) \) is the downwelling irradiance.

\[ R_{rs1}(\lambda) = 0.519 \cdot \frac{L_u(\lambda)}{E_d(\lambda)} \]  
\[ R_{rs2}(\lambda) = 0.54 \cdot \frac{L_u(\lambda)}{E_s(\lambda)} \]

where \( E_s(\lambda) \) is measured above surface.

\[ L_{wn}(\lambda) = R_{rs}(\lambda) \cdot F_o(\lambda) \]

where \( L_{wn}(\lambda) \) is the normalized water-leaving radiance.

\[ R_{rs}(\lambda) = \frac{c_{bb}(\lambda)}{a(\lambda) + b(\lambda)} \]

where \( c \) is approximately constant, \( a(\lambda) \) is the volume absorption coefficient, and \( b(\lambda) \) is the volume backscattering coefficient.

Since \( a \) and \( b \) are inherent optical properties, they may be partitioned into their respective additive components:

\[ a^w(\lambda) = a_p^w(\lambda) + a_p^p(\lambda) + a_s^w(\lambda) \]
\[ b(\lambda) = b_p(\lambda) + b_p^d(\lambda) + b_i(\lambda) \]

where \( b_p(\lambda) \) is particulate, \( a_p^w(\lambda) \) is soluble, \( a_p^p(\lambda) \) is phytoplankton, \( a_s^w(\lambda) \) is detritus, \( a_i(\lambda) \) is inorganic sediments.

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: \( k, a \) & \( b \)
- Transparency/visibility of water algorithms

(The authors, Yu Hwan Ahn from KORDI)
Chlorophyll Retrieval Algorithms

(1) Band ratio approach:

\[ \text{Chl} = 2.50 \left( \frac{R_{rs}(444)}{R_{rs}(554)} \right) - 3.97 \]

\[ R^2 = 0.79 \]

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

Reference:

Red tide detection Algorithms

Basic Red tide Index (RI) Equation

\[ RI = \frac{L_{(510)} - L_{(555)}}{L_{(510)} + L_{(555)}} \]

Derived Red tide Index (RI) Equation

\[ RI = 10^{-0.1068 \times \lambda^3 - 0.6259 \times \lambda^2 - 1.9353 \times \lambda + 2.919} \]

Red tide Chlorophyll Algorithm

\[ \text{Chl} > (\text{mgm}^{-2}) = 0.316 \times (L_{\text{obs}} - L_{\text{atm}}) \]

10% of the total light detected by a satellite aimed at the ocean is leaving radiation, while the other 90% of the light is due to atmospheric effects. Data correction applied to the data to remove the atmospheric radiance; the radiance observed has been corrected for atmospheric light scattering and then corrected for the water zenith angle. This gives us the

\[ \text{Red water leaving radiance (Lw), which is the radiance that would exit the flat surface of the ocean with the sun directly overhead and the atmosphere removed. The normalized water leaving radiance are then used algorithms to produce geophysical values, chlorophyll concentration}. \]
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 (G DPS)
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)

Vessels & Stations
- KORDI research vessels and fishing boats
  - Omuri(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)

Study area

Ferrybox
- 18 times during 4 years
- Operation time: 19:00-10:00(next day)
- Instruments: YSI(SS, chl, T, S, DO), ChellSea(chl), SeaPoint(chl, DO), McVan(SS)
- Water sample: about 40 (every 20 min after departure) <SS>, <chl>, <T, S, DO>
**in situ Measurement**

- water samples
  - $<\text{chl}>$
  - $<\text{SS}>$
  - $a_{\text{phy}}, a_{\text{SS}}, a_{\text{dom}}$
  - $F_d$

**Instruments**

- Two FieldSpec Dual Spectroradiometer (ASD Co.)
- Underwater Spectroradiometer (TriOS Co.)
- AC-S (WETLabs Co.)
- Chl. Fluorometer (Seapoint Co.)
- CTD (SBE Co.)

**Radiometric Measurement**

<table>
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<tr>
<th>Instrument</th>
<th>Deployment Method</th>
<th>Measurements</th>
<th>Unit</th>
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<tr>
<td>TriOS</td>
<td>Vessel</td>
<td>$E_L, E_R$</td>
<td>W/m²</td>
</tr>
<tr>
<td>AC-S</td>
<td>Vessel</td>
<td>$a_{\text{phy}}, a_{\text{SS}}, a_{\text{dom}}$</td>
<td>W/m²</td>
</tr>
<tr>
<td>ASD</td>
<td>Vessel</td>
<td>$E_L, E_R$</td>
<td>W/m²</td>
</tr>
<tr>
<td>Absorption coefficient</td>
<td>Lab.</td>
<td>$a_{\text{phy}}, a_{\text{SS}}, a_{\text{dom}}$</td>
<td>m</td>
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</tbody>
</table>

- Radiometric measurements were made using WETLabs AC-S, TriOS RAMSES ACC/ARC, and ASD FieldSpec Pro Dual VNIR Spectroradiometer.

**Lab. analysis**

- Seawater samples were collected concurrently with the radiometric measurements at about 300 points around the Korean Sea. The absorption coefficients were determined using Perkin-Elmer Lambda 19 dual-beam spectrophotometer at vessel or lab.
**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_s** & **a_o**: Filter Technique Method using 25 mm GF/F (β = 2)
  \[ a_{\text{s/sph}}(d) = \frac{OD_{\text{s/sph}}(d) \cdot 2.3025}{S \cdot \beta} \cdot 100 \text{ [mg L}^{-1} \text{]} \]
- **a_\text{seas}**: using 10cm optical cell
  \[ a_{\text{seas}}(d) = \frac{OD_{\text{seas}}(d) \cdot 2.3025}{0.1} \cdot 100 \text{ [mg L}^{-1} \text{]} \]

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**Ieodo Ocean Research Station**

- **Ocean Monitoring Systems (22)**
  - Spectroradiometer
  - Wave meter
  - Directional Wave meter
  - Sea Level Monitor
  - Acoustic Doppler Velocimeter
  - AADP
  - CTD
  - CTR
  - Ultraviolet Fluorometer
  - Chlorophyll Fluorometer
  - Current Profiler
  - Ultrasonic Level Meter
  - etc.

**Environment Observing Systems (2)**

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**Satlantic HyperSAS OCR-3000**

- **E_i(d)**: Downwelling irradiance
- **L_d(d)**: Sky irradiance
- **L_w(d)**: Total water leaving radiance
- **T**: Temperature

  \[ L_w(d) = L_d(d) \cdot L_w(d) \cdot F_i(d) \]
  \[ R_w(\theta, \varphi) = L_w(\theta, \varphi) \cdot [\text{sr}^2] \]

**F_i(d)**: Fresnel reflection

**R_w (θ)**: Remote sensing reflectance

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(All, Dr. Jae-Hyung Ryu from KOARD)
Thank you for your attention!

In situ bio-optical measurements in the East China Sea

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 g 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.

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.

Variables and parameters

- Surface Chl-a
- Vertical profile
- \( K_{par} \)
- \( E_r \)
- SST
- PP algorithm

Attainable from satellites

PP: New production
The relationship between $K_{\text{PAR}}$ and SeaWiFS nLw555 shows a reasonable agreement. Therefore, this relationship was used for deriving $K_{\text{PAR}}$ from nLw555.

\[ y = 0.267x^{0.7472} \]
\[ R^2 = 0.5964 \] (this study)

\[ y = 0.2249x^{0.7269} \] (Son et al., 2005)

Are ocean color CHL data reliable in case 2 water?

Band ratio vs. chlorophyll concentration

\[ Chl = 10^7 \]
\[ y = -0.332 - 2.019x - 5.302 \]

17 in-situ optic data were used to 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.
Comparison of in situ and retrieved chlorophyll a

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

Comparison with our previous study (Son et al., 2005)

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

Monthly composite PP images from SeaWiFS (2003)
Example of PP map of YS

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).

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.
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 (R²=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 (R²=0.53).
- Relationship between SeaWiFS Chl-a and In situ Chl-a showed relatively high correlation (R²=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, \( a^\text{ph}(440) \), and Chl-a

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

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

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.
Validation of ocean color satellite in the South Sea of Korea

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

Validation of ocean color satellite data

Phytoplankton pigment data in the ECS

Fig. Distributions of phytoplankton Pigment using HPLC

Detecting the high concentration Lutein, 19'-hexanoyloxyfucoxanthin, etc. in the Northern ECS

SeaWiFS CAL/VAL Chl_a (mg/m^3) 2005. 3.31.13:13 (135E) NFRDI/KEOC, KOREA

SeaWiFS CAL/VAL Chl_a (mg/m^3) 2005. 8.16.12:52 (135E) NFRDI/KEOC, KOREA

SeaWiFS CAL/VAL Chl_a (mg/m^3) 2004. 7.21.12:42 (135E) NFRDI/KEOC, KOREA

SeaWiFS CAL/VAL Chl_a (mg/m^3) 2004. 2.13.13:12 (135E) NFRDI/KEOC, KOREA

SeaWiFS CAL/VAL Chl_a (mg/m^3) 2004. 7.21.12:42 (135E) NFRDI/KEOC, KOREA

Lutein at surface in Sep., 2004
19'-hexanoyloxyfucoxanthin at surface in Sep., 2004
Zeaxanthin at surface in Sep., 2004

Fig. Distribution of phytoplankton Pigment using HPLC

Detecting the high concentration Lutein, 19'-hexanoyloxyfucoxanthin, etc. in the Northern ECS
Cal/Val data of OC satellite in the ECS

Cal/Val data in the southern area of Korea

Fig. Chl 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 2008.
Relationship between $a_{ph}(440)$ and Chl-a

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

Bio-optical in situ data in the East China Sea

Fig.: Vertical profiles of optical properties from the PRR-400 spectral radiometer collected in the East China Sea in February at NFRDI station 317.18.