Satellite Ocean Color Remote Sensing for Ocean Coastal and Inland Waters

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**Ocean Color Remote Sensing:** Derive the ocean water-leaving radiance spectra by accurately removing the atmospheric and surface effects.

**Ocean properties** can be derived from the ocean water-leaving radiance spectra.
At satellite altitude
~90% of sensor-measured signal over ocean comes from the atmosphere & surface!

- It is crucial to have accurate atmospheric correction and sensor calibrations.
- 0.5% error in atmospheric correction or calibration corresponds to possible of ~5% error in the derived ocean water-leaving radiance.
- We need ~0.1% sensor calibration accuracy.
The Ocean Color and Other Useful Spectral Bands for VIIRS, MODIS, and SeaWiFS

<table>
<thead>
<tr>
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<th>VIIRS</th>
<th>MODIS</th>
<th>SeaWiFS</th>
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<tbody>
<tr>
<td></td>
<td>Ocean Bands (nm)</td>
<td>Other Bands (nm)</td>
<td>Ocean Bands (nm)</td>
</tr>
<tr>
<td>412</td>
<td>412</td>
<td>645</td>
<td>412</td>
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<tr>
<td>445</td>
<td>443</td>
<td>859</td>
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<td>488</td>
<td>488</td>
<td>469</td>
<td>490</td>
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<tr>
<td>555</td>
<td>531</td>
<td>555</td>
<td>510</td>
</tr>
<tr>
<td>555</td>
<td><strong>SWIR Bands</strong></td>
<td></td>
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<tr>
<td>672</td>
<td>1240</td>
<td>667</td>
<td>1240</td>
</tr>
<tr>
<td>746</td>
<td>1610</td>
<td>748</td>
<td>1640</td>
</tr>
<tr>
<td>865</td>
<td>2250</td>
<td>869</td>
<td>2130</td>
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VIIRS has similar SWIR bands as MODIS
SeaWiFS
Sea-Viewing Wide-Field-of-view Sensor

SeaWiFS Looks at the Moon
MOBY--Vicarious Calibration Facility for Ocean Color Satellite Sensors

From D. Clark
Time Series of MODIS ocean color bands
Uncertainty ~ 5%

From D. Clark
Algorithms for Various Ocean Color Sensors
(Routine Global Ocean Color Data Processing)

- Fukushima et al. (1998) for OCTS and GLI ocean color products.
- Antoine and Morel (1999) for MERIS ocean color products.
- Deschamps et al. (1999) for POLDER ocean color products.

Assumptions:
- Ocean is black at the NIR wavelengths.
- Aerosols are non- or weakly absorbing.

SeaWiFS Chlorophyll-a Concentration
(October 1997-December 2003)
SeaWiFS Global Deep Ocean Results
(Wang et al., 2005)

Stability of Products

Mean $\tau_a (865) = 0.111$
Mean $\alpha (510) = 0.277$
Mean $[L_w(443)]_N = 1.503$ (mW cm$^{-2}$ $\mu$m$^{-1}$ sr$^{-1}$)
Mean Chl-a $= 0.193$ (mg m$^{-3}$)

Ocean Color Parameters

Aerosol Parameters

Global Deep Ocean
SeaWiFS experiences demonstrate that the atmospheric correction works well in the open oceans.
SeaWiFS Chlorophyll-a Comparison

Chlorophyll-a Unit: (mg/m$^3$)
Slope = 0.9357, Intercept = 0.0129, R = 0.9225
SeaWiFS and MODIS Experiences Show:

**High quality** ocean color products for the global **open oceans** (Case-1 waters).

**Significant efforts** are needed for improvements of water color products in the **inland & coastal regions**:

- **Turbid Waters** (violation of the NIR black ocean assumption)
- **Strongly-Absorbing Aerosols** (violation of non- or weakly absorbing aerosols)
Atmospheric Correction: SWIR Bands

(Wang & Shi, 2005; Wang, 2007)

- At the shortwave IR (SWIR) wavelengths (>~1000 nm), ocean water has much strongly absorption and ocean contributions are significantly less. Thus, atmospheric correction can be carried out for coastal regions **without using the bio-optical model.**

- Water absorption for 869 nm, 1240 nm, 1640 nm, and 2130 nm are 5 m\(^{-1}\), 88 m\(^{-1}\), 498 m\(^{-1}\), and 2200 m\(^{-1}\), respectively.

- Examples using the MODIS Aqua **1240** and **2130 nm** data to derive the ocean color products are provided.

- We use the SWIR band (1240 nm) for the cloud masking. This is necessary for coastal region waters.

- Require sufficient **SNR** characteristics for the SWIR bands and the SWIR atmospheric correction has slight larger noises at the short visible bands (compared with those from the NIR algorithm).
Water Absorption

(a)

Water Absorption (1/cm)

Wavelength (nm)

- Hale & Querry (1973)
- Segelstein (1981)
- Kou et al. (1993)

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Results from SWIR Atmospheric Correction for turbid ocean waters in US east coastal

MODIS-Aqua True Color Image

U.S. East Coastal

April 6, 2004
Ocean Spectra from Visible to NIR for Various Ocean Waters

\( nL_w(645) \)

\[ \tau_a(869) \sim 0.3 \]
Comparisons of MODIS Ocean Color Products from NIR, SWIR, and NIR-SWIR Combined Methods

Example: U.S. East Coast

Chlorophyll-a Comparison Results in Chesapeake Bay

MODIS Matchup with CBnet Chl-a (< +/-3hrs)

Valid NIR only

Valid BLEND only

In Situ

MODIS (NIR)

In Situ

MODIS (NIR-SWIR)

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SWIR-based Global Ocean Color Data Processing at NOAA/STAR

Chlorophyll-a 0.01-10 (mg/m³) (Log scale)


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Development of New Water Diffuse Attenuation Coefficient Kd(490) Algorithm for the Chesapeake Bay and Turbid Coastal Waters Using the MODIS Data


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Composite Images of MODIS Kd(490) (July 2002-Dec. 2007)

(a) Mueller (2000) Model
(b) New Model: R(667)
(c) New Model: R(645)

Old  New  New

Kd(490) (m⁻¹)

0.01  0.10  1.00  3.00

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Validation Kd(490) Results for Chesapeake Bay

(a) Mueller (2000) Model, Chesapeake Bay Data
   MODIS SWIR Derived Kd(PAR)
   291 Data: Mean Ratio = 0.394
   Old

(b) Lee et al. (2002) Model, Chesapeake Bay Data
   MODIS SWIR Derived Kd(PAR)
   291 Data: Mean Ratio = 0.515
   Old

(c) New Model, Chesapeake Bay Data
   MODIS SWIR Derived R(667) for Kd(PAR)
   291 Data: Mean Ratio = 0.951
   New

(d) New Model, Chesapeake Bay Data
   MODIS SWIR Derived R(645) for Kd(PAR)
   291 Data: Mean Ratio = 0.958
   New
Ocean Color Retrievals In the Turbid Coastal Region

MODIS-derived ocean color products along the China east coastal region

MODIS-Aqua Climatological Monthly Chl-a Images in YECS (April)

Chlorophyll-a

Composite from April 2002-2007 Data
The SWIR-based Ocean Color Products for Various Applications

- **Coastal Phytoplankton Bloom Study:** Observations of Hurricane Katrina-induced phytoplankton bloom in the Gulf of Mexico (Shi and Wang, 2007; Liu et al., 2009).

- **Ecosystem Responses to Major Weather Event:** Three-dimension observations from MODIS and CALIPSO for ocean responses to Cyclone Nargis in the Gulf of Martaban (Shi and Wang, 2008).

- **River Estuary, River Dynamics and River Plume:** Satellite observations of flood-driven Mississippi River plume in the spring 2008 (Shi and Wang, 2009).

- **Stormwater Plume Detection:** Stormwater plume detection in the southern California coastal ocean (Nezline et al., 2008).

- **Coastal and Inland-water Hazard Monitoring:** Satellite-observed blue-green algae blooms in China’s Lake Taihu (Wang and Shi, 2008).

- **Environmental Responses to a Land Reclamation Project:** Satellite-observed drastic changes in marine environment in response to the Saemangeum Reclamation Project in South Korea (Son and Wang, 2009).

- **Monitoring Green Macroalgae Blooms in Yellow Sea:** Satellite observation and monitoring of green macroalgae blooms in the Yellow Sea during the spring and summer of 2008 (Shi and Wang, 2009).
Results from Inland Lake Taihu

Using the SWIR algorithm, we have derived the water optical properties over the Lake Taihu using the MODIS-Aqua measurements during the spring of 2007 for monitoring a massive blue-green algae bloom, which was a major natural disaster affecting several millions residents in nearby Wuxi city.


➤ The work was featured in the NASA 2008 Sensing Our Planet (http://nasadaacs.eos.nasa.gov/articles/2008/2008_algae.html)
Blue-Green Algae (Microcystis) Bloom Crisis in Lake Taihu (Spring 2007)
Time Series of Chlorophyll-a (index) and $nL_w(443)$ at Wuxi Station (bloom) and Central Lake (non-bloom)

Normalized Water-leaving Radiance at 443 nm

Chlorophyll-a

Bloom Location

Central Lake

Date (2007)

March 21 April 10 April 30 May 20 June 9

<table>
<thead>
<tr>
<th>Date</th>
<th>Chlorophyll-a (mg m$^{-3}$)</th>
<th>$nL_w(\lambda)$ (mW/cm$^2$ µm sr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 21</td>
<td>3</td>
<td>0.1</td>
</tr>
<tr>
<td>April 10</td>
<td>10</td>
<td>0.8</td>
</tr>
<tr>
<td>April 30</td>
<td>10</td>
<td>1.0</td>
</tr>
<tr>
<td>May 20</td>
<td>5</td>
<td>1.0</td>
</tr>
<tr>
<td>June 9</td>
<td>3</td>
<td>0.1</td>
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</table>

Normalized Water-leaving Radiance at 443 nm
The Saemangeum Reclamation Project in South Korea

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Current Research and Development Activities

- **Transition of Research to Operational for the SWIR-Based Algorithms:**
  - Working with the NOAA data operational partners, we have been working on implementing the SWIR-based ocean color data processing system into the NOAA operational data processing system.
  - Near real time ocean color products will be produced using the SWIR-based algorithms for the U.S. coastal regions in the NOAA CoastWatch Program.
  - Improved ocean color data, e.g., new Kd(490) product for turbid waters, will be generated.

- **NPOESS (NPP)-VIIRS Ocean Color Cal/Val:**
  - On-orbit Vicarious Calibration for the VIIRS ocean color products.
  - NOAA VIIRS ocean color data processing.
  - VIIRS ocean color product validation.

- **Algorithm Development and Ocean Color Data Applications:**
  - Algorithms development (e.g., for dealing with the absorbing aerosols in coastal region) and refinement for ocean coastal and inland waters.
  - Various ocean color data applications for ocean coastal and inland waters.
  - Chesapeake Bay TSM (total suspended matter) work and COCE (coastal ocean characterization experiment) in STAR

- **Future Ocean Color Satellite Missions:**
  - NASA Aerosol, Cloud, and Ecosystem (ACE) Mission.
  - NASA Geostationary Coastal and Air Pollution Events (GEO-CAPE) Mission.
The SWIR Algorithm Related Publications (1)
(Algorithms and Validations)


The SWIR Algorithm Related Publications (2)
(Various Applications)


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Thank You!