Development of Algorithms for Retrieval of Chlorophyll-a in the Chesapeake Bay and other Coastal Waters Based on JPSS-VIIRS Bands

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Chlorophyll –a is an important parameter which is used for monitoring of water quality and is also used in various bio-optical and ecological models, detection of algal blooms, optimization of fishing conditions.

Multiple water parameters are monitored by Chesapeake Bay Program including concentrations of Chlorophyll-a.

Satellite observations provide a broader picture for the distribution of parameters retrievable through Ocean Color algorithms, which should be properly validated with in-situ data.
Outline

- Introduction, structure of the current Chl algorithm
- Atmospheric correction and calibration
- Data for Chl algorithm validation, Chesapeake Bay campaign
- Available approaches for algorithm development
- Algorithm development, test of performance
- Main results for Chl algorithms
- Conclusions
- Future work
The Chesapeake Bay is the largest estuary in the US with a surface area of ~11,601 km² and average water depth of 7 m (Chesapeake Bay Program, 1993).

Biological and optical properties, satellite retrievals, algorithms and climatology were heavily studied:

- Harding et al., 2004, 05, Magnuson et al., 2004, Tzotziou et al., 2006, 07, Gitelson et al., 2007, Werdell et al., 2009, Gallegos et al., 2011, Ondrusek et al., 2012, Le et al., 2012, Son and Wang, 2012, Shi et al., 2013

Magnuson et al., 2004
Joint Polar Satellite System (JPSS)  
Operational Algorithm Description (OAD)  
Document for Atmospheric Correction  
Over Ocean / Ocean Color  
Chlorophyll (ACO/OCC)  
Environmental Data Record (EDR)  
Software  
Released on July 17, 2013

1. Gaseous absorption  
2. Whitecap  
3. Rayleigh  
4. Polarization  
5. Sun glint  
6. Aerosol  
7. Chlorophyll a concentration
**Total Radiance Signal at the Top of Atmosphere**

$L_w$ - Total water-leaving radiance. $L_s$ - Radiance above the sea surface due to all surface reflection effects within the IFOV. $L_p$ - Atmospheric path radiance.

Signal from the atmospheric scattering is about 10 times stronger than from water.

Atmospheric correction utilizes NIR bands (748, 865 nm)

Gain adjustments on the sensor can change dramatically the system performance and should be considered together with atmospheric correction and retrieval algorithms.
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AERONET-Ocean Color

AERONET – Ocean Color: is a sub-network of the Aerosol Robotic Network (AERONET), relying on modified sun-photometers to support ocean color validation activities with highly consistent time-series of $L_{WN}(\lambda)$ and $\tau_a(\lambda)$.

Rationale:

• Autonomous radiometers operated on fixed platforms in coastal regions;
• Identical measuring systems and protocols, calibrated using a single reference source and method, and processed with the same code;
• Standardized products of normalized water-leaving radiance and aerosol optical thickness.

Data of the LISCO & and WaveCIS sites are used in this study.

Zibordi et al. 2009
**LISCO site**

**Platform:** Collocated multispectral **SeaPRISM** hyperspectral **HyperSAS** instrumentations

Operational since October 2009
AERONET-OC sites used in the study

SeaPRISM instrument

- Sea Radiance
- Direct Sun Radiance and Sky Radiance
- Bands: 413, 443, 490, 551, 668, 870 and 1018 nm
- Data acquisition every 30 minutes for high time resolution time series
Strong temporal agreement between the satellites and in-situ data.
Seasonal variations in the nLw data are captured well.  
Hlaing et al., 2013
Time series of normalized water leaving radiance, $nLw(\lambda)$, for LISCO site, 2012

- **Strong temporal agreement** between the satellites and in-situ data at the 551 & 668 nm wavelengths.
- Seasonal variations in the $nLw$ data are also captured well.
- Data availability is **lower** for LISCO mostly due to exclusion of the pixels with atmospheric correction failure and presence of **negative** values in water leaving radiance especially at violet (413 nm) and blue (442 nm).
- 862 nm band of VIIRS is assumed to be correctly calibrated from prelaunch measurements.
- 748 nm band is adjusted by forcing the aerosol type retrievals from the South Pacific Gyre to match the aerosol type observed at the Tahiti AERONET site.
- In the initial processing (\textit{VIIRS}^{\text{initial}}), the vicarious calibration reference was derived from a sea surface reflectance model and a climatology of chlorophyll-a concentration.
- In the 2012.2 reprocessing (\textit{VIIRS}^{12.2}), the vicarious calibration is based on measurements from the Marine Optical Buoy (MOBY) near Lanai Hawaii (the same reference is currently used for SeaWiFS and MODIS).
- In this latest 2013.0 reprocessing (\textit{VIIRS}^{2013}), temporal calibration was switched from solar-diffuser-based to lunar-based, but using the solar-diffuser for detector-relative calibration. In addition the vicarious calibration was updated.
MOBY site

MOBY water leaving radiance ($L_w$) measurements at VIIRS center wavelengths for year 2014.

http://moby.mlml.calstate.edu/home
Impacts of the vicarious gain changes on retrieval of water leaving radiance

- In the atmospheric correction process, Rayleigh & glint components are estimated from the parameters such as atmospheric pressure, wind speed, sensor & solar geometries.

- Therefore, the impacts of vicarious gain changes entirely fall on the water leaving & aerosol components.

- Adjustment to 745nm channel will have direct effects on aerosol model selection and therefore impact is further amplified to shorter visible wavelengths.

- Iterative process will have compounded effects on water leaving radiance retrieval (Up to ~50% in blue & violet wavelengths).

- ± 1% change is applied to \( L_{TOA}(\lambda) \), and effects on every steps of processing are traced.

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nLw spectral consistency analysis

WaveCIS

- Matchup nLw
- average
- average ± 1 std

LISCO

- Variation ranges, and their averages & standard deviations indicates qualitative agreement between the satellites and in-situ nLw data for both sites.
- LISCO exhibits lower absolute values due to CDOM. WaveCIS generally is more dominated by sediments from delta outflows, thus higher values and variation ranges.
Matchup comparison between VIIRS and AERONET-OC $nLw(\lambda)$ for WaveCIS and LISCO site.
With VIIRS\textsuperscript{2013}, correlation at the 413 nm is greatly. Bias between the $nL_w$ data at 413 nm retrieved by two sensors almost vanishes with $PD$ value equal to 0.73\%.

Similarly, overall spectral average $PD$ value obtained for comparison between MODIS and VIIRS\textsuperscript{2013} is also lowest with its value equal to -1.01\% compared to 12.2\% obtained with VIIRS\textsuperscript{initial} and -6.2\% with VIIRS\textsuperscript{12.2}.

VIIRS\textsuperscript{2013} is most consistent with MODIS for WaveCIS whereas VIIRS\textsuperscript{initial} is for LISCO.
Average percent differences between the nLw data of VIIRS (retrieved with 3 different processing schemes) and in-situ for two AERONET-OC sites

- With each incremental adjustment of vicarious procedure, retrieval accuracies of the VIIRS nLw data of WaveCIS location are enhanced.
- On the other hand, performance degradations are observed for LISCO site.
- Impacts on the retrievals at each wavelengths are consistent with analysis from previous slide (i.e. impacts are more pronounced in shorter wavelengths).
Evaluations on the retrievals of atmospheric parameters

Matchup comparisons between the VIIRS and AERONET aerosol optical thickness ($\tau_a$) at 442 nm & 870 nm

- Strong correlation coefficient values suggest variations in $\tau_a$ data can be captured well by VIIRS.
- Overestimations in VIIRS retrieved $\tau_a$ values are observed for both sites. For WaveCIS, $PD$ values are 28% and 105% at 442nm and 870nm respectively. For LISCO, 38% and 108%.
- Relatively higher $PD$ values at 442nm for LISCO site might be at least partially explained by the mismatch between the $\gamma$ distributions of VIIRS and SeaPRISM data which in turn suggest possible inadequate aerosol (fine) mode selection for VIIRS.
- Validation study carried out for MODIS data based on the data of other coastal AERONET-OC sites (AAOT, GLT & HLT) had also displayed such discrepancy [Zibordi et. al 2009].
Evaluations on the retrievals of atmospheric parameters

Qualitative analysis of Angstrom (γ) coefficient distributions

- Retrieval accuracy of γ is a good indicator of the quality of atmospheric correction process.
- γ distributions suggest satellite retrievals for the location are underestimated.
- On average satellite retrieved γ values are about 0.66 (LISCO) & 0.34 (WaveCIS) lower than those retrieved from SeaPRISM.
- This probably resulted from the limited set of aerosol models used for atmospheric correction, missing extra fine mode typical of coastal areas.
- It is also possible that it is at least partially results from the iterative procedures in the atmospheric correction process in the estimation of the aerosol components in the atmospheric radiance of NIR region which assumes dark pixels in NIR in initial estimation before proceeding with correction, incorrect for coastal regions with higher suspended particulates.
Accurate algorithms for retrieval of Chl-a and IOPs in coastal waters require change of the paradigm in the sensor calibration and gain adjustments currently accepted in Ocean Color processing.

It is possible also that some adjustment in atmospheric correction procedures is required.

We work closely with Dr. M. Wang in development of new approaches, paper is in preparation, results will be presented separately.
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Field and satellite data

NOMAD (NASA bio-Optical Marine Algorithm Data)

* Rrs and chl globally – 2110 Points
* Rrs and chl with chl > 1 - 977 Points
* Rrs and chl Chesapeake Bay - 246 Points
  (Noise due to above water measurements of Lu)

* Chesapeake Bay Program Chl data (108000 points from 1999-present)
* MODIS satellite imagery (NIR (540 points) and SWIR (1003 points) atmospheric correction concurrent with Bay program data – provided by Drs. S. Son and M. Wang (NOAA-NESDIS)
* Similar filtered matchups between MODIS satellite imagery and Bay program with NIR atmospheric correction – provided by Drs. C. Hu and C. Le, University of South Florida (USF data) -1138 points
Chesapeake Bay campaign: Aug 2013

Leads: Dr. Alex Gilerson (CCNY), Dr. Michael Ondrusek (NOAA-NESDIS), Dr. Maria Tzortziou, (U. Maryland, NASA) in collaboration with Dr. Alex Chekalyuk (Columbia University)

Participants: Dr. I. Ioannou, PhD students C. Carrizo, A. El-Habashi, R. Foster, UG K. Bastani (CCNY), REU L. Lai (CityTech), Dr. E. Stengel (NOAA-NESDIS)

Goals: collection of field data for algorithm development and validation, validation of field data with satellites, intercomparison of measurement techniques, development and testing of new instrumentation
Chesapeake Bay campaign: Aug 2013
Instrumentation: in-water and above water reflectance: HyperPro and GER, water optical properties, PSD, water samples, ALFA for underway measurements
Sample stations of our Summer 2013 field Campaign (N=43) - left and NOMAD – right (246 points)
Range of absorption and attenuation coefficients measured during our summer 2013 campaign
Reflectance measured and modeled (using Hydrolight and WetLabs measurements) during our summer 2013 campaign
Field reflectance spectra capture mostly the range of the satellite reflectances, NOMAD has some higher reflectance values corresponding to more turbid waters.
Measured fields of Chl, CDOM and pigment fluorescence from ALFA instrument (WET Labs, A. Chekalyuk, Columbia University)

Chlorophyll

Colored dissolved organic matter (CDOM)

Active fluorescence signal
Mean difference in Chl values for locations 300m apart is 0.04 ug/L with a StdDev of 1.99
Mean difference in Chl values for locations 700m apart is 0.05 ug/L with a StdDev of 2.65
Mean difference in Chl values for locations 1000m apart is 0.36 ug/L with a StdDev of 3.30
Chl – CDOM relationship

Comparison between MERIS and underway measurements

Determines a range of relationship between Chl and CDOM

Strong differences in retrieved (2011) and measured fields of parameters
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## Spectral Bands for Ocean Color

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<tr>
<td>———</td>
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<td>410 (M1)</td>
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<td>443 (M2)</td>
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<td>551 (M4)</td>
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<td>671 (M5)</td>
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<td>745 (M6)</td>
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<td>862 (M7)</td>
<td>869</td>
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<td>1240 (M8)</td>
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<td>1610 (M10)</td>
<td>1640</td>
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</table>
Evaluation of performance of the blue-green MODIS OC3M algorithm on simulation and field data in coastal waters.

\[ y = 1.01x + 8.424 \]
\[ R^2 = 0.3785 \]

\[ y = 0.437x + 25.5 \]
\[ R^2 = 0.132 \]

Gilerson et al. 2010
Two- and three-band red/NIR Chl algorithms

Two-band algorithms are known for more than 20 years

\[ R2 = \frac{R_{rs}(753)}{R_{rs}(665)} \]

Stumpf and Tyler, 1988

\[ R2 = \frac{R_{rs}(708)}{R_{rs}(665)} \]

Gitelson, 1992

Three-band algorithm was suggested and used recently

\[ R3 = \left[ R_{rs}(665)^{-1} - R_{rs}(708)^{-1} \right] * R_{rs}(753) \]

Dall’Olmo and Gitelson, AO, 2005, 2006

Gitelson, et al. 2007-2010, Gilerson et al., 2010

Algorithms are appropriate for hyperspectral data – not for VIIRS

753/665 (745/671 for VIIRS) are usually not reliable but combinations with other bands in blue-green can be considered
Simple correlations for two band algorithms

Tzortziou et. al., 2007

Table 2
Regression relationships betweeny IOPs and $R_{rs}$ in the mid Chesapeake Bay

<table>
<thead>
<tr>
<th>Parameters (Y vs X)</th>
<th>Regression relationship</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{rs}(412)/R_{rs}(554)$ vs [chl-a]</td>
<td>$\log_{10}(Y) = -0.1261 \cdot \log_{10}(X) - 0.4508$ ($N = 40$)</td>
<td>0.24</td>
</tr>
<tr>
<td>$R_{rs}(443)/R_{rs}(554)$ vs [chl-a]</td>
<td>$\log_{10}(Y) = -0.1537 \cdot \log_{10}(X) - 0.2933$ ($N = 40$)</td>
<td>0.39</td>
</tr>
<tr>
<td>$R_{rs}(488)/R_{rs}(554)$ vs [chl-a]</td>
<td>$\log_{10}(Y) = -0.1299 \cdot \log_{10}(X) - 0.1074$ ($N = 40$)</td>
<td>0.32</td>
</tr>
<tr>
<td>$R_{rs}(510)/R_{rs}(554)$ vs [chl-a]</td>
<td>$\log_{10}(Y) = -0.1168 \cdot \log_{10}(X) - 0.0339$ ($N = 40$)</td>
<td>0.36</td>
</tr>
<tr>
<td>$R_{rs}(532)/R_{rs}(554)$ vs [chl-a]</td>
<td>$\log_{10}(Y) = -0.0728 \cdot \log_{10}(X) + 0.0068$ ($N = 40$)</td>
<td>0.23</td>
</tr>
<tr>
<td>$R_{rs}(670)/R_{rs}(554)$ vs [chl-a]</td>
<td>$\log_{10}(Y) = 0.166 \cdot \log_{10}(X) - 0.5467$ ($N = 40$)</td>
<td>0.48</td>
</tr>
<tr>
<td>$R_{rs}(677)/R_{rs}(554)$ vs [chl-a]</td>
<td>$\log_{10}(Y) = 0.1725 \cdot \log_{10}(X) - 0.5117$ ($N = 40$)</td>
<td>0.54</td>
</tr>
<tr>
<td>$a_{r-w}(677)$ vs [chl-a]</td>
<td>$Y = 0.0166 \cdot X + 0.0603$ ($N = 137$)</td>
<td>0.92</td>
</tr>
</tbody>
</table>
Performance of the neural network on the part of our simulated dataset that was not used in the training stage, with 20% uniform noise added at each Rrs.
Performance of the Neural Network algorithm on NOMAD

\[
\begin{align*}
R^2 = 0.938 & \quad \text{RMSE} = 0.16 \\
\text{error} = 0.45
\end{align*}
\]

\[
\begin{align*}
R^2 = 0.62 & \quad \text{RMSE} = 0.13 \\
\text{error} = 0.35
\end{align*}
\]

\[
\begin{align*}
R^2 = 0.906 & \quad \text{RMSE} = 0.24 \\
\text{error} = 0.75
\end{align*}
\]

\[
\begin{align*}
R^2 = 0.87 & \quad \text{RMSE} = 0.24 \\
\text{error} = 0.75
\end{align*}
\]

\[
\begin{align*}
R^2 = 0.78 & \quad \text{RMSE} = 0.31 \\
\text{error} = 1.03
\end{align*}
\]

\[
\begin{align*}
R^2 = 0.87 & \quad \text{RMSE} = 0.3 \\
\text{error} = 0.99
\end{align*}
\]
Neural Networks

Inputs times weights for each node are summed and passed through the transfer function:

\[ Y_i = \sum \omega_{jm} \sigma(\omega_{nj}X_n) \]

Result is a matrix of coefficients plus error:

\[ \bar{Y} = G(\bar{X}) + \bar{e} \]

Example:

\[
\begin{bmatrix}
    \text{Chl} \\
    \text{CDOM} \\
    \text{Bbp} \\
    a_{ph} \\
    \vdots \\
    G_{n1} \\
    G_{n2} \\
    G_{n3} \\
    G_{n4} \\
    \vdots \\
    G_{nm}
\end{bmatrix} =
\begin{bmatrix}
    G_{11} & G_{12} & G_{13} & G_{14} & \cdots & G_{1m} \\
    G_{21} & G_{22} & G_{23} & G_{24} & \cdots & G_{2m} \\
    G_{31} & G_{32} & G_{33} & G_{34} & \cdots & G_{3m} \\
    G_{41} & G_{42} & G_{43} & G_{44} & \cdots & G_{4m} \\
    \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\
    G_{n1} & G_{n2} & G_{n3} & G_{n4} & \cdots & G_{nm}
\end{bmatrix}
\begin{bmatrix}
    R_{RS412} \\
    R_{RS443} \\
    R_{RS488} \\
    R_{RS530} \\
    R_{RS555}
\end{bmatrix}
\]
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Operational OC3 [Chl] Algorithms

\[ \log_{10}[\text{max}\{\text{Rrs}(443),\text{Rrs}(488)\}/\text{Rrs}(547)] \rightarrow 4^{\text{th}} \text{ order polynomial} \rightarrow [\text{Chl}] \]

Rrs1 = blue wavelength Rrs (e.g., 443, 490, or 510-nm)
Rrs2 = green wavelength Rrs (e.g., 547, 555, or 565-nm)
X = \log_{10}(\text{Rrs1} / \text{Rrs2})

\[ \text{chlor}_a = 10^{(a_0 + a_1X + a_2X^2 + a_3X^3 + a_4X^4)} \]

OC3M-551  MODIS  443>489  550  0.2424 -2.5828 1.7057 -0.3415 -0.8818

OC3V  VIIRS  443>486  550  0.2228 -2.4683 1.5867 -0.4275 -0.7768

oceancolor.gsfc.nasa.gov

Operational established algorithms for MODIS and VIIRS were used as benchmarks in comparison with other approaches.
## Selection of algorithms

<table>
<thead>
<tr>
<th>Data source</th>
<th>Independent variable ((x))</th>
<th>Regression relationships</th>
<th>(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USF measured (Rrs) ((\lambda)) and Chla ((N = 32)) ((\text{Chla: } 7.4-54.3 \text{ mg m}^{-3}))</td>
<td>(\log_{10}(Rrs (488)/Rrs (547)))</td>
<td>Chla = 10((-2.15x+0.59))</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>(\log_{10}(Rrs (667)/Rrs (531)))</td>
<td>Chla = 10((3.25x+2.09))</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>(\log_{10}(Rrs (667)/Rrs (547)))</td>
<td>Chla = 10((3.57x+2.41))</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>(\log_{10}(Rrs (510)/Rrs (555)))</td>
<td>Chla = 10((-3.21x+0.61))</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>(\log_{10}(Rrs (670)/Rrs (490)))</td>
<td>Chla = 10((2.45x+1.2))</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>(\log_{10}(Rrs (670)/Rrs (510)))</td>
<td>Chla = 10((2.96x+1.59))</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>(\log_{10}(Rrs (670)/Rrs (555)))</td>
<td>Chla = 10((4.38x+2.83))</td>
<td>0.69</td>
</tr>
<tr>
<td>CBP measured Chla: ((N = 1079)) ((1-50 \text{ mg m}^{-3}))</td>
<td>MODIS (Rrs) ((\lambda))</td>
<td>Chla = 10((1.76x+1.61))</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>SeaWiFS (Rrs) ((\lambda)) ((N = 1132))</td>
<td>Chla = 10((1.76x+1.43))</td>
<td>0.43</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VIIRS bands</th>
<th>410</th>
<th>443</th>
<th>486</th>
<th>551</th>
<th>671</th>
</tr>
</thead>
</table>

Masked algorithms are available only for MODIS bands  

Le et al., 2013
Bio-optical model and radiative transfer simulation for the generation of datasets

**Four Components Bio-optical Model**
- Algal Particles [Chl]
- Non-Algal Particles [C_NAP]
- CDOM
- Pure Sea-water

**Inherent Optical Properties (IOP)**
- Absorption ($a$)
- Scattering ($b$, $b_b$)

**Radiative transfer simulations (Hydrolight)**

**Remote-sensing Reflectance $Rrs(\lambda)$**

Generated as *random* variables in the prescribed ranges typical for *coastal and oceanic water* conditions

Particle Scattering Phase Function Varied with particle Concentration & Composition
Neural Network Algorithm description for retrieval of IOPs (NN IOPs)

Input to the neural networks is the log$_{10}$ of above water Reflectance $R_{rs}$ at the visible MODIS wavelengths 412, 443, 488, 531, 547 and 667nm

Retrieved parameters
- $a_{pg}$: the particulate and dissolved absorption coefficient
- $b_{bp}$: particulate backscattering coefficient
- $a_{phy}$: phytoplankton absorption coefficient
- $a_{dm}$: non-phytoplankton particulate absorption coefficient
- $a_{g}$: dissolved absorption coefficient

Ioannou et al., 2011 & 2013
Neural network [Chl] Algorithms

1) Rrs NN ([Chl]_{NN}) Global

Input MODIS Bands: \( \log_{10} R_{rs} \) at 412, 443, 488, 531, 547 and 667nm

Trained based on the NOMAD

NN Chl Global

2) Rrs NN for Chesapeake Bay ([Chl]_{NN(CB)})

Input VIIRS Bands: \( \log_{10} R_{rs} \) at 443, 486, 551 and 671nm

Trained based on a simulated dataset

NN ChBay VIIRS
Sample Seasonal [Chl], Spring

Seasonal Chlorophyll Concentration (NN[Chl]) starting 2003-03-22

[Map showing seasonal chlorophyll concentration globally with color scaling from 0.01 to >20 mg/m³, with a graph overlay showing fluctuations over years 2003 to 2012.]

[Graph showing time series of chlorophyll concentration with two lines: OC3-Chl and NN-Chl (Ioannou, 2013).]
Outline

* Introduction, structure of the current Chl algorithm
* Atmospheric correction and calibration
* Data for Chl algorithm validation, Chesapeake Bay campaign
* Available approaches for algorithm development
* Algorithm development, test of performance
* Main results for Chl algorithms
* Conclusions
* Future work
Main results for MODIS bands – NOMAD

<table>
<thead>
<tr>
<th>$R^2$</th>
<th>NOMAD Global (N=2110)</th>
<th>NOMAD, $[\text{Chl}] &gt; 1$ (N=977)</th>
<th>NOMAD, Chesapeake Bay (N=247)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OC3M</td>
<td>0.83</td>
<td>0.51</td>
<td>0.17</td>
</tr>
<tr>
<td>667/531</td>
<td>0.61</td>
<td>0.22</td>
<td>0.13</td>
</tr>
<tr>
<td>NN IOPs</td>
<td>0.84</td>
<td>0.58</td>
<td>0.2</td>
</tr>
<tr>
<td>NN Chl Global</td>
<td>0.89</td>
<td>0.7</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Performance of all algorithms consistently degrades from Global data to Coastal and then to Chesapeake Bay.
Performance of OC3M algorithm

Son et al. 2012
Our overall estimation $R^2 < 0.1$
NIR/Red algorithm on field data, Chesapeake Bay

Chl, NIR/red bands ratio algorithm, Gilerson et al, 2010 (Rrs708/Rrs665)

Confirms high consistency of our field data
Main results for MODIS bands, Chesapeake Bay

<table>
<thead>
<tr>
<th>R²</th>
<th>CCNY field (N=43)</th>
<th>NOMAD (N=247)</th>
<th>USF data (N=889)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OC₃M</td>
<td>0.6</td>
<td>0.17</td>
<td>0.02</td>
</tr>
<tr>
<td>667/531</td>
<td>0.64</td>
<td>0.13</td>
<td>0.35</td>
</tr>
<tr>
<td>667/510</td>
<td>0.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NN IOPs</td>
<td>0.69</td>
<td>0.2</td>
<td>0.17</td>
</tr>
<tr>
<td>NN Chl</td>
<td>0.52</td>
<td>0.37</td>
<td>0.29</td>
</tr>
</tbody>
</table>

While NN are trained on all available bands they are not efficient enough on satellite and NOMAD data because of vulnerability of the blue bands.
NN are trained on all available bands, they are not efficient enough on satellite and NOMAD data because of vulnerability of the blue bands, especially 412nm.
Multi-band algorithm

\[ Chl = a_0 + a_1 \times \left[ \frac{R_{rs}(745)}{R_{rs}(672)} \right] + a_2 \times \left[ \frac{R_{rs}(443)}{R_{rs}(555)} \right] + a_3 \times \left[ \frac{R_{rs}(672)}{R_{rs}(488)} \right] \]

Algorithm was originally developed on the synthetic dataset, then further tuned separately on the CCNY field and USF data.
Main results for VIIRS bands, Chesapeake Bay

<table>
<thead>
<tr>
<th></th>
<th>CCNY field (N=43)</th>
<th>NOMAD (N=247)</th>
<th>USF data (N=889)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OC3V</td>
<td>0.64</td>
<td>0.1</td>
<td>0.079</td>
</tr>
<tr>
<td>671/486</td>
<td>0.73</td>
<td>0.37</td>
<td>0.29</td>
</tr>
<tr>
<td>671/551</td>
<td>0.51</td>
<td>0.20</td>
<td>0.22</td>
</tr>
<tr>
<td>Multi-band</td>
<td>0.88</td>
<td>-</td>
<td>0.31</td>
</tr>
<tr>
<td>NN VIIRS</td>
<td>0.71</td>
<td>0.22</td>
<td>0.34</td>
</tr>
</tbody>
</table>

NN CB VIIRS trained on VIIRS bands excluding 412nm band perform well on both field and satellite data.
Main results for VIIRS bands: examples

CCNY, field

USF data

NN CB VIIRS trained on VIIRS bands excluding 412nm band perform well on both field and satellite data
Retrieval of Chl from VIIRS satellite imagery (August 5, 2013)
Conclusions

• Current Ocean Color calibration – atmospheric correction approach is focused on the open ocean retrievals and should be refined for the proper retrievals in the coastal waters
• Retrieved Rrs spectra are inaccurate in the blue bands which limits utilization of these bands in the algorithms
• Algorithms which contain all available bands typically perform worse than simple ratio algorithms, with the current calibration and atmospheric correction approaches 412nm bands should be excluded from the algorithms
• Several approaches are proposed for VIIRS chlorophyll algorithm in Chesapeake Bay which should be further evaluated
Future work

• Development of approaches for improvement of gain adjustment – atmospheric correction in the application to VIIRS
• Collection of VIIRS satellite imagery matching available in-situ data
• Evaluation of performance of the algorithms on these data
• Refinement of available algorithms
Thank you