

Breakout Workshop #4

Remote Sensing of Inland and Coastal Waters: Current Status, Challenges, Research Priorities, and End-User Engagement

PLENARY REPORT

Co-Chairs:

Wes Moses, Carsten Brockmann, Andrew Tyler, Quinten Vanhellemont, Nima Pahlevan, Steve Greb, and Paul DiGiacomo

Remote Sensing of Inland and Coastal Waters

2

Atmospheric Correction

- Current Capabilities and Challenges – [Nima Pahlevan](#)

Bio-Optical Modeling

- Do We Need Optical Water Types? – [Tim Moore](#)
- Algorithm Selection for Lakes – [Vagelis Spyrakos](#)

Sensor Characteristics

- What Do We Need for Inland and Coastal Waters? – [Wes Moses](#)

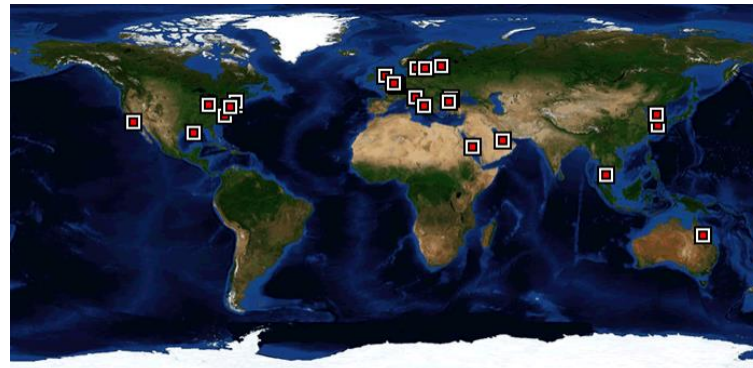
End- User Engagement

- Copernicus Inland Water Service – [Carsten Brockmann](#)
- GEO AquaWatch – [Steve Greb](#)

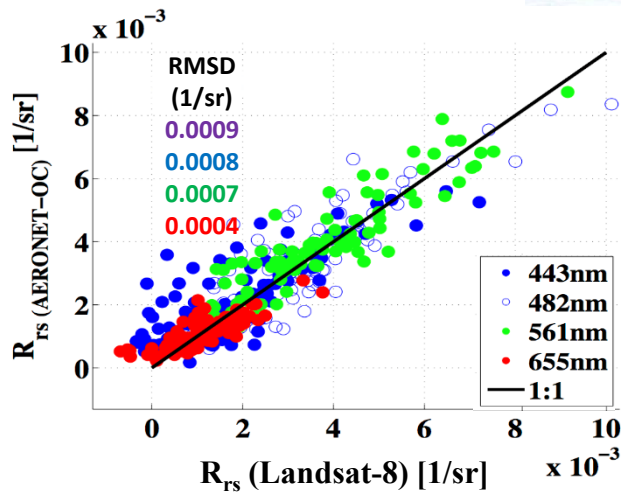
Atmospheric Correction – Capabilities & Challenges ³

Nima Pahlevan

Validations using AERONET-OC data: necessary but **NOT** sufficient

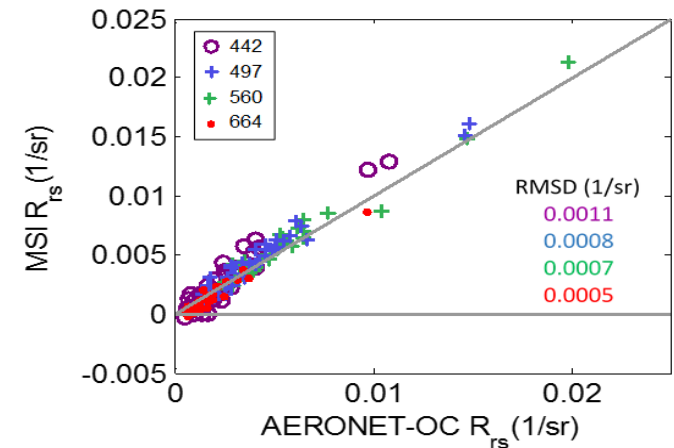


Landsat-8 (OLI)



(Pahlevan et al., 2017)

Sentinel-2A (MSI)



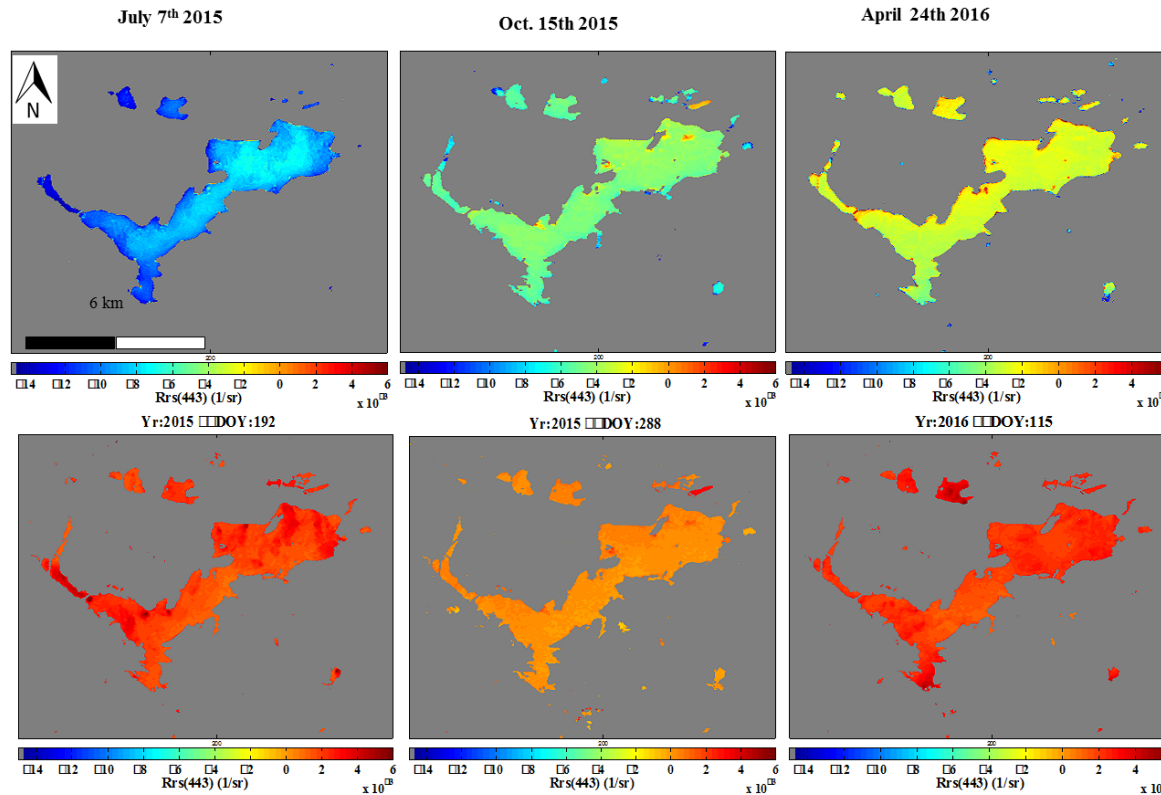
(Pahlevan et al., *submitted*)

Atmospheric Correction – Capabilities & Challenges ⁴

Nima Pahlevan

Issues with Aerosol Removal - Representativeness

Landsat-8
derived $R_{rs}(443)$
over **Wachusett
Reservoir**
in Massachusetts



Automated
removal of
aerosols using
**existing
aerosol LUTs**

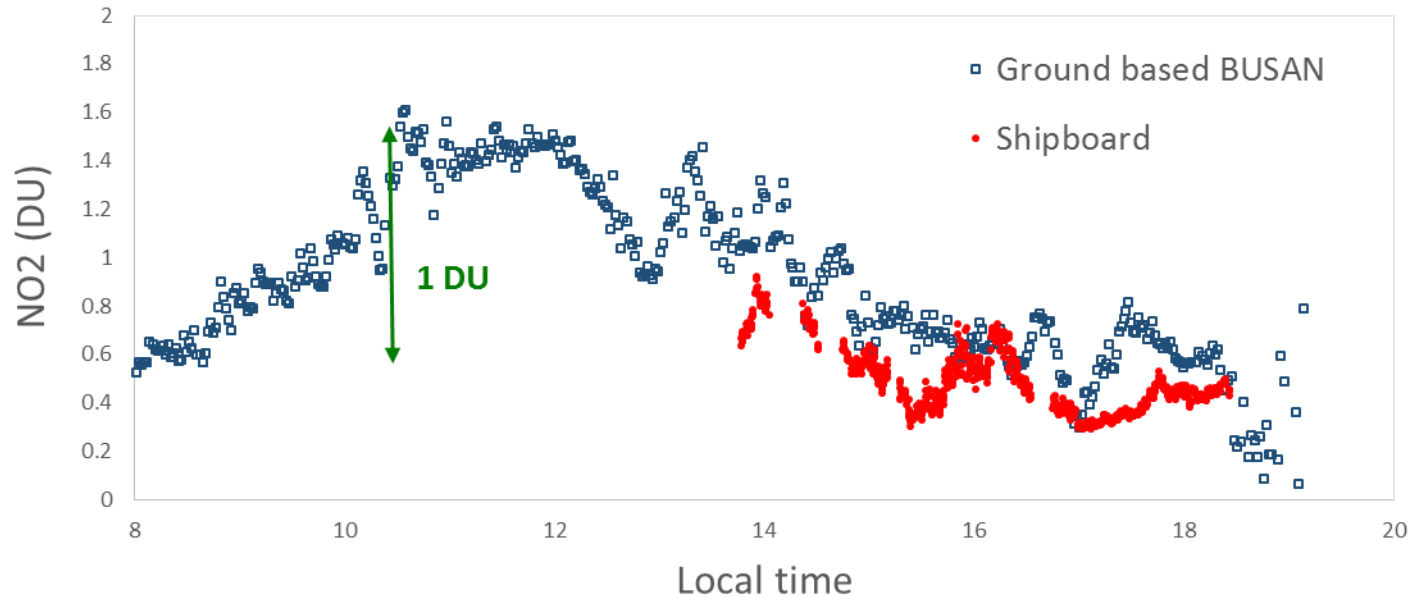
Manual
removal of
aerosols using
**observed AOT
spectra**

Atmospheric Correction – Capabilities & Challenges ⁵

Nima Pahlevan

Issues with Trace Gas Removal - Representativeness

Busan, 18 May 2016



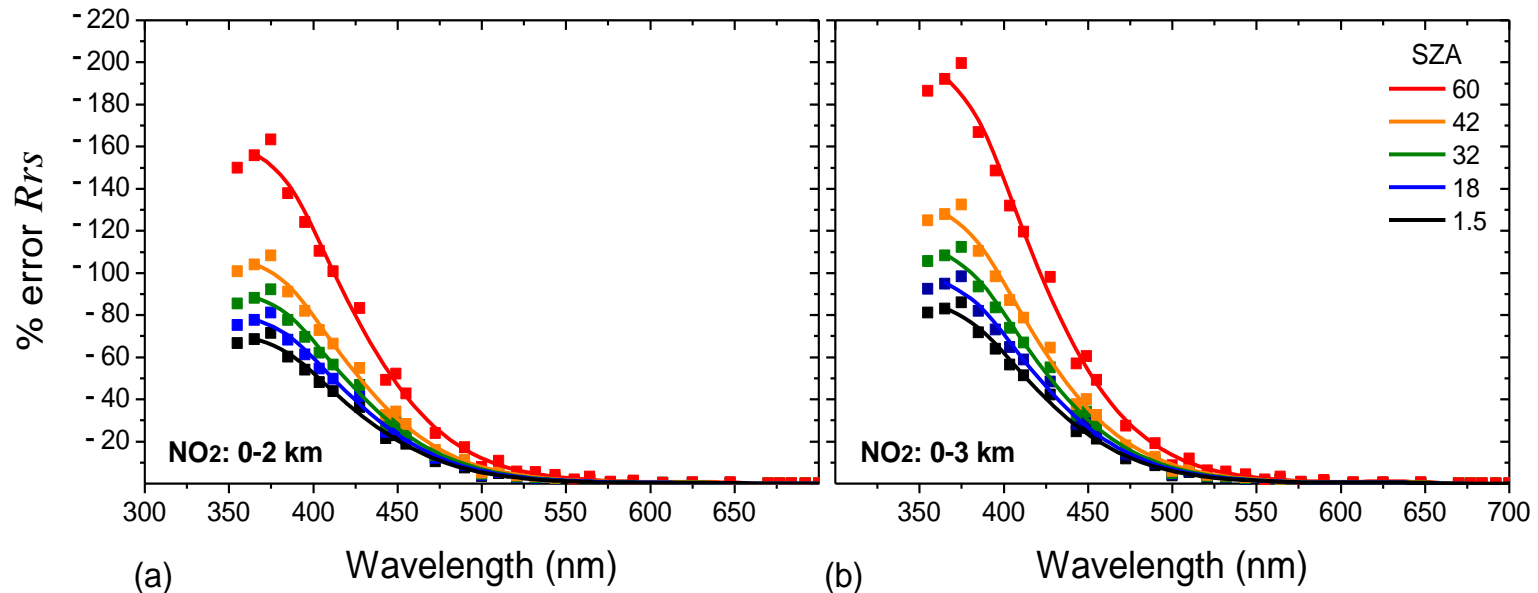
Credit: Maria Tzortziou (KORUS–OC field campaign)

Atmospheric Correction – Capabilities & Challenges ⁶

Nima Pahlevan

Issues with Trace Gas Removal - Representativeness

1 DU error results in large errors in R_{rs} in the UV and blue



(Tzortiou et al., 2017)

Atmospheric Correction – Capabilities & Challenges ⁷

Nima Pahlevan

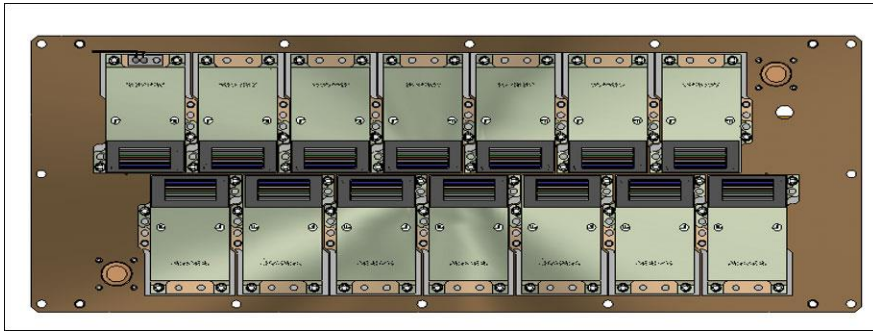
Adjacency Effects



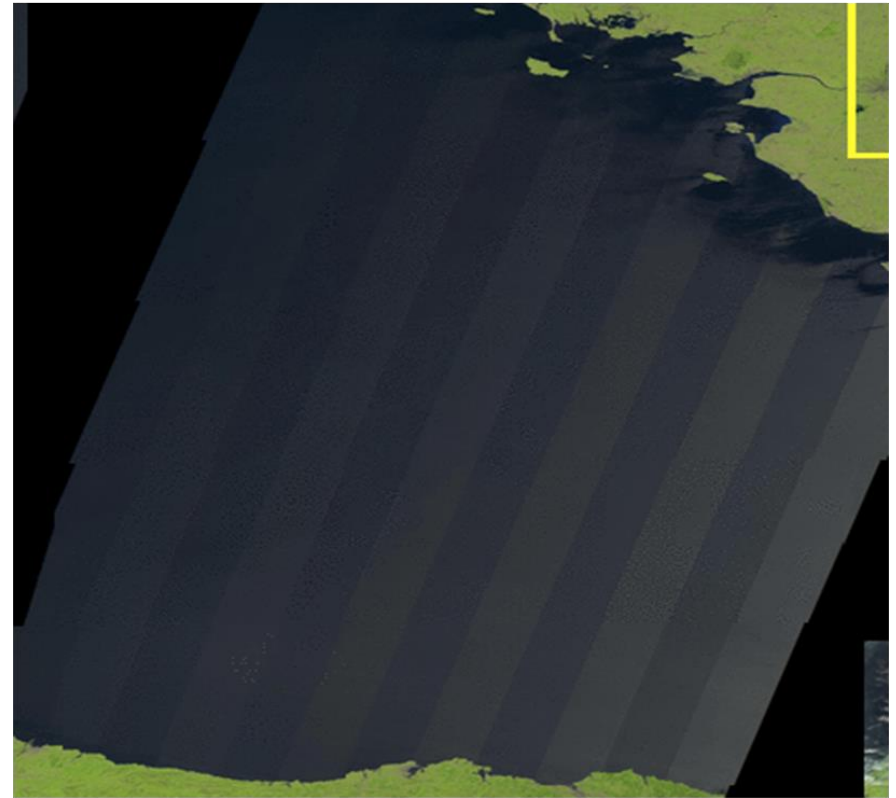
Atmospheric Correction – Capabilities & Challenges ⁸

Nima Pahlevan

Sun Glint



Sentinel-2A



Q1. Atmospheric Correction – Discussion

Q1A. How can we improve validation of aerosol retrievals in inland/coastal waters?

- Set up AERONET/AERONET-OC-like stations (some sites may not meet the criteria)
- Encourage researchers to collect aerosol optical thickness using sun photometers and share data (after quality control) on databases such as SeaBASS

Q1. Atmospheric Correction – Discussion

Q1B. How do we deal with complex atmospheres?

- Interact with more and learn from the land community

Q1. Atmospheric Correction – Discussion

Q1C. What is the best approach to correct for adjacency effects?

- Use spectral information
- Might be challenging in near-shore shallow-water regions

Q1. Atmospheric Correction – Discussion

Q1D. How do we mitigate sun glint effects?

- Explore shifting satellite orbital paths for the northern hemisphere
- Explore taking advantage of sun glint signal

Bio-Optical Modeling – Optical Water Types

Tim Moore

Complex optics with large range in conditions create challenges to remote sensing applications for inland lakes.



Bio-Optical Modeling – Optical Water Types

Tim Moore

Cyanobacteria colony surface formation – July 23, 2016 (Part 1)

9:16 AM



10:16 AM



11:16 AM



12:16 PM



1:16 PM



2:16 PM



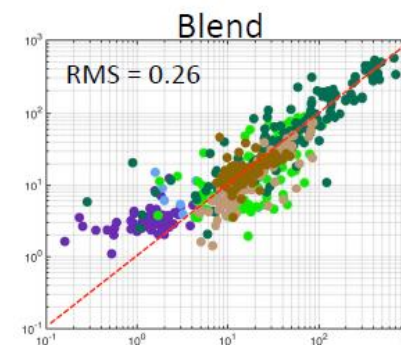
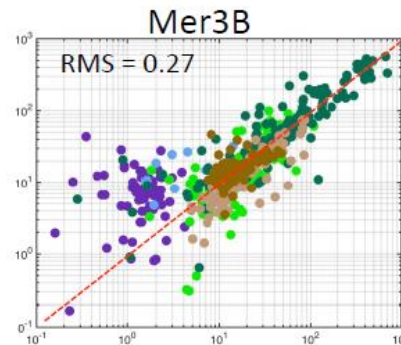
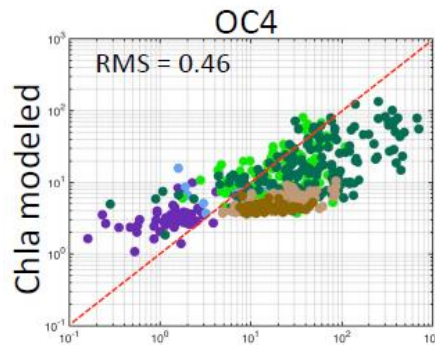
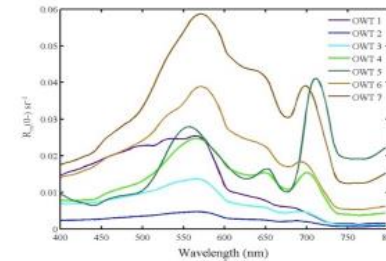
Bio-Optical Modeling – Optical Water Types

Tim Moore

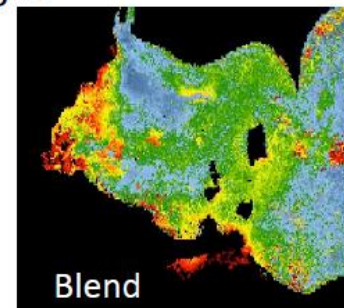
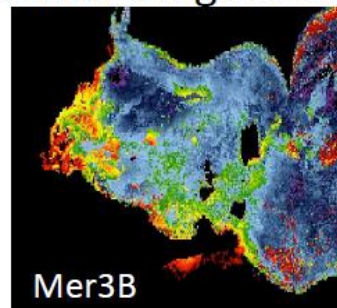
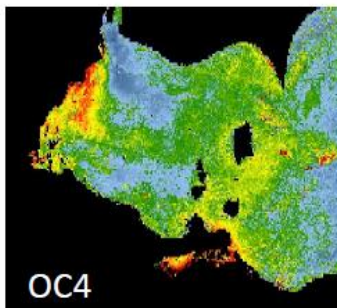
- 7 optical water types used to classify RS imagery
- Water type represents an optical state
- Allows for tuning specific models/parameters to optical conditions

(Moore et al 2014, RSE)

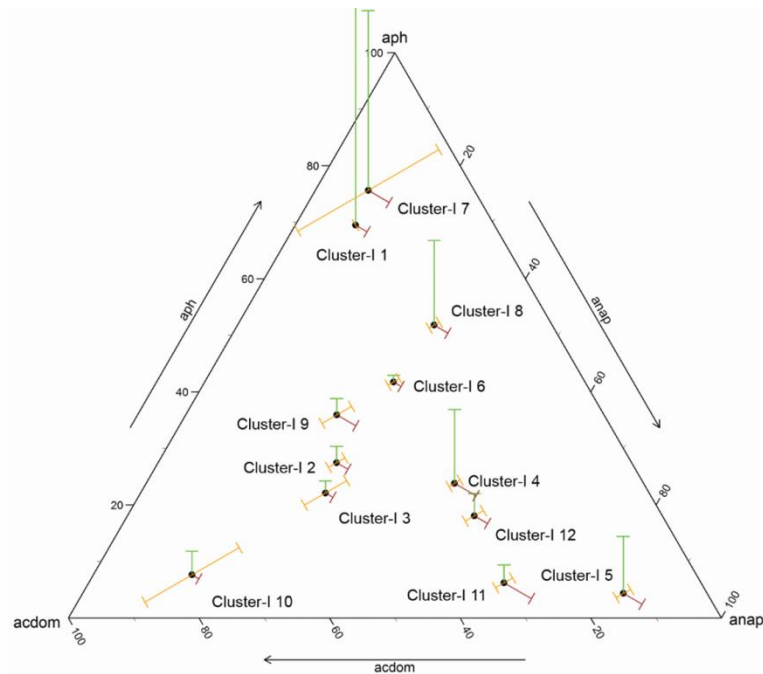
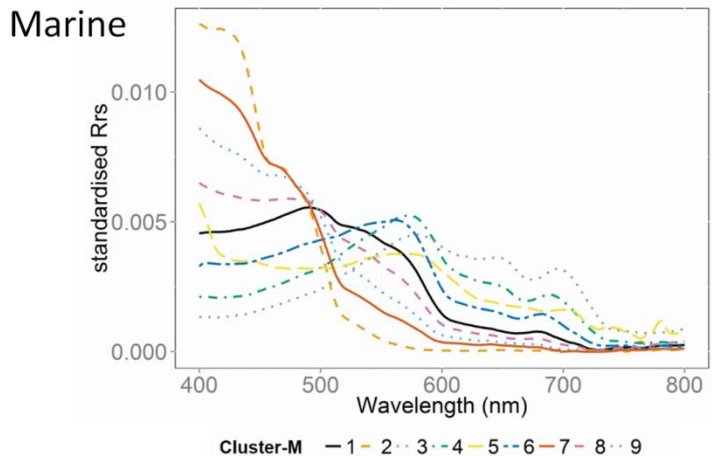
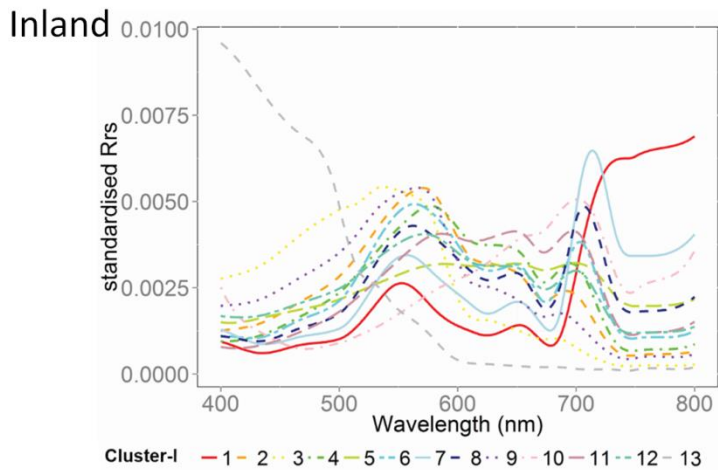
Algorithm Blending



Chla in situ
MERIS August averages

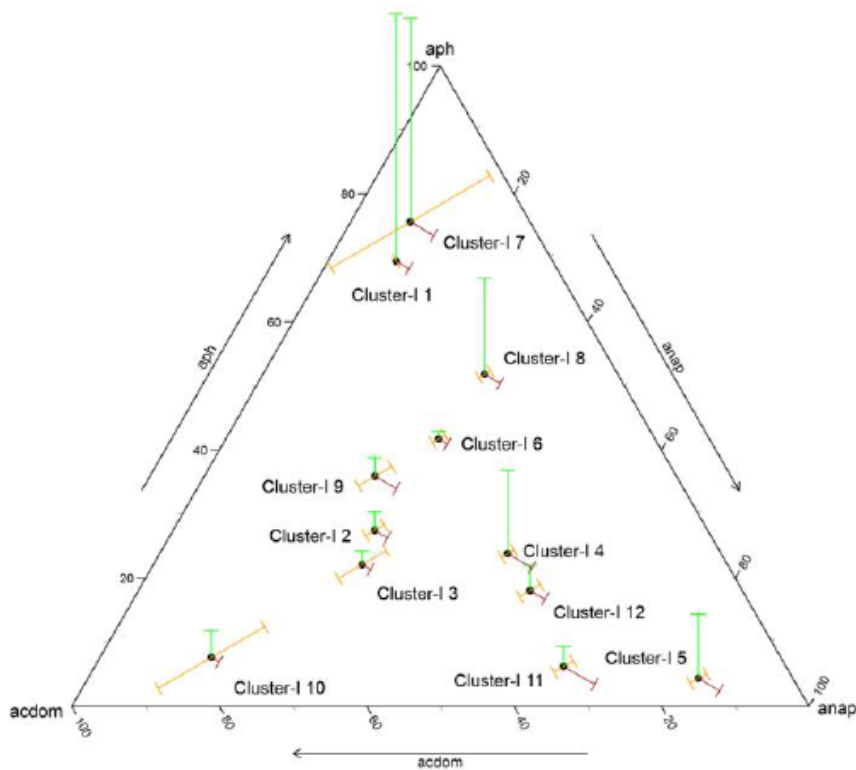


Optical Water Type Classification through Clustering



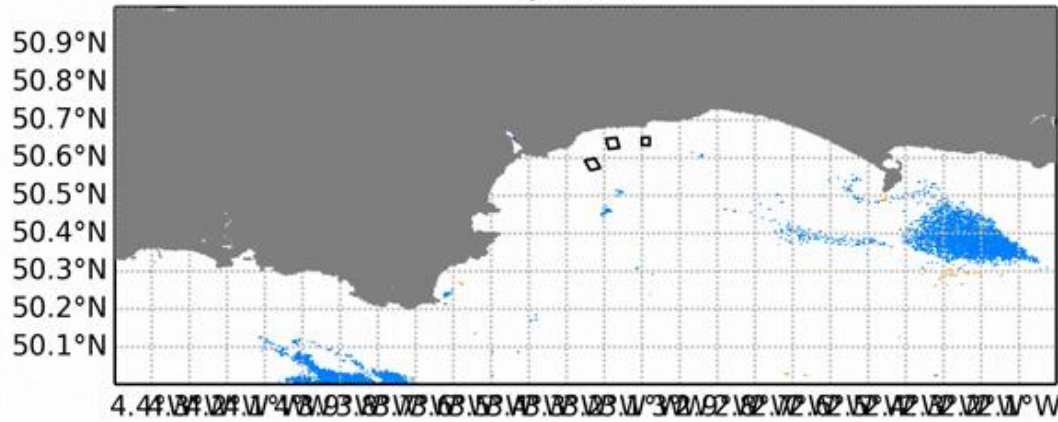
E. Spyrakos et al.: Optical types of natural waters. Submitted to Limnology and Oceanography.

Optical Water Type Classification through Clustering

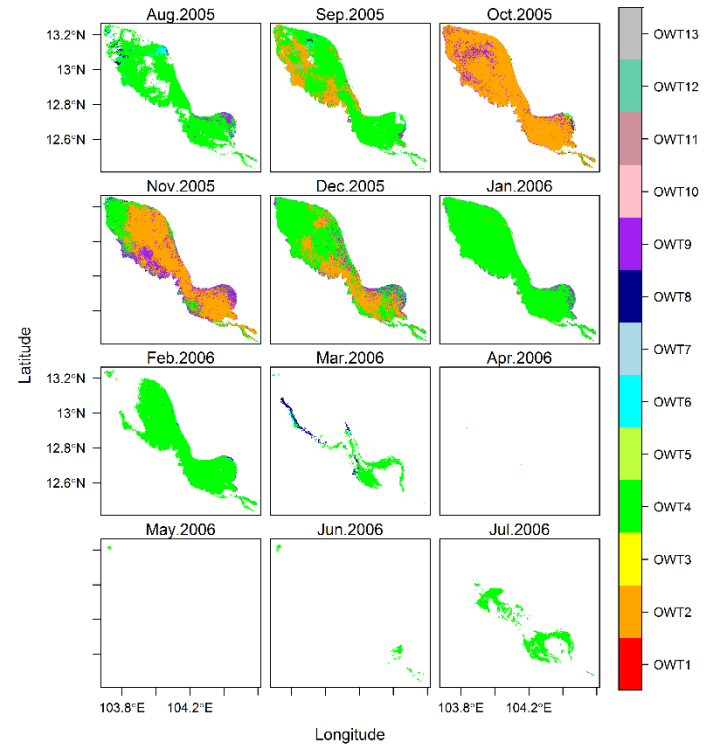
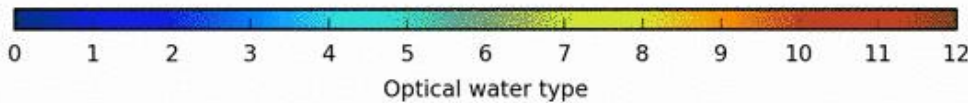


OWT	Dominant characteristics
OWT1	Hyper-eutrophic waters with cyanobacteria scum and vegetation-like reflectance
OWT2	Common case waters with diverse reflectance shape and marginal dominance of pigments and CDOM over inorganic suspended particles
OWT3	Clear waters
OWT4	Turbid waters with high organic content
OWT5	Sediment-laden waters
OWT6	Balanced effects of optically active constituents at shorter wavelength
OWT7	Highly productive waters with reflectance peak with elevated reflectance at red/near-infrared spectral region
OWT8	Productive waters with reflectance peak close to 700 nm
OWT9	Optically neighbouring to OWT2 waters but with higher reflectance at shorter wavelengths
OWT10	CDOM-rich waters
OWT11	High in CDOM waters with cyanobacteria presence and high absorption efficiency by NAP
OWT12	Turbid, moderately productive waters with cyanobacteria presence
OWT13	Very clear blue waters

Jul 2002



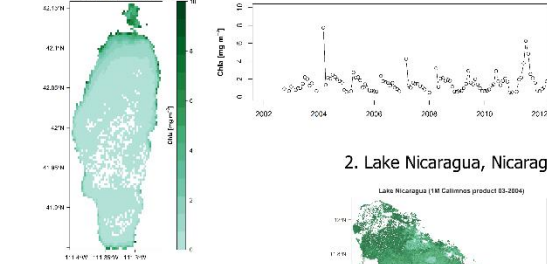
Credits to: Plymouth Marine Laboratory
and H2020-TAPAS project



GloboLakes Sites

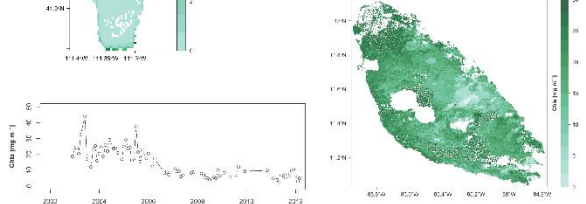
1. Bear Lake, USA

Bear Lake (1M Calimnos product 10-2008)



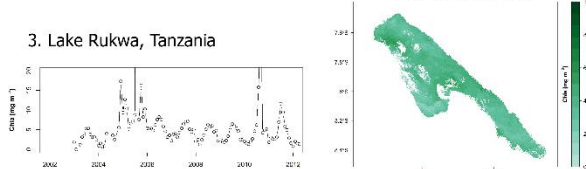
2. Lake Nicaragua, Nicaragua

Lake Nicaragua (1M Calimnos product 03-2004)



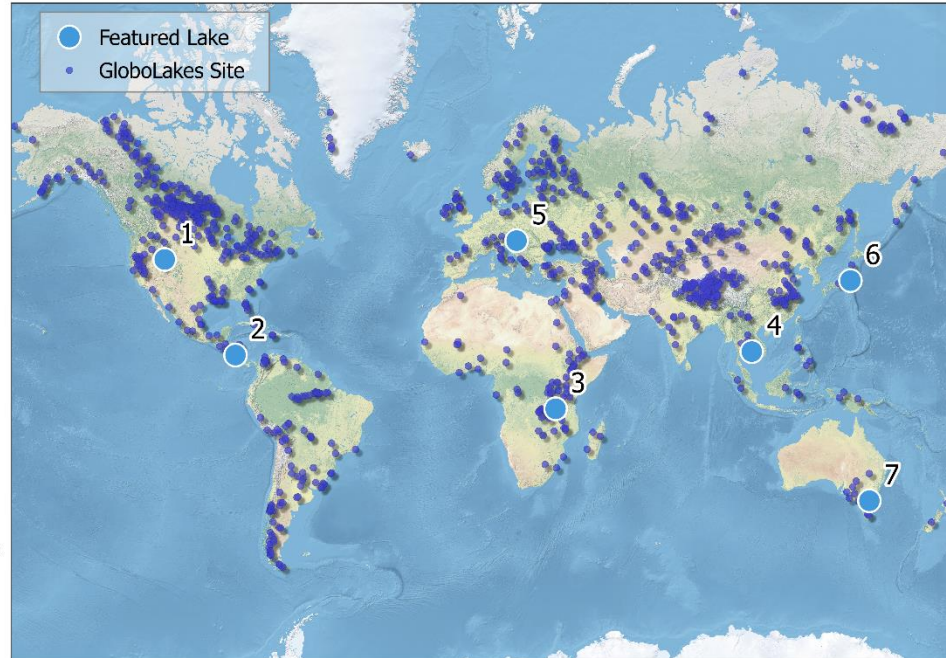
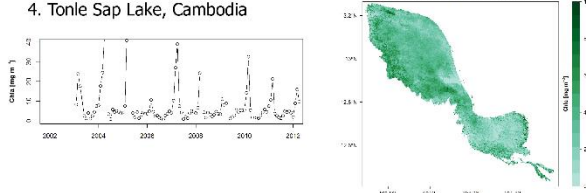
3. Lake Rukwa, Tanzania

Lake Rukwa (1M Calimnos product 02-2006)



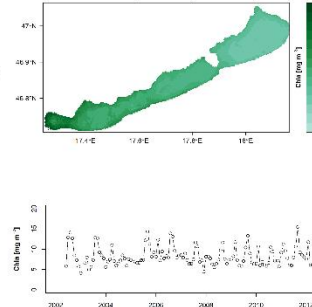
4. Tonle Sap Lake, Cambodia

TONLE SAP Lake (1M Calimnos product 10-2003)



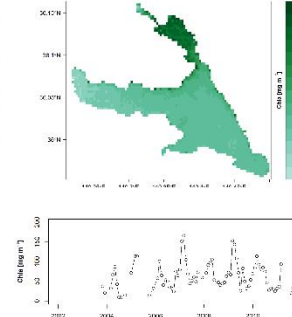
5. Lake Balaton, Hungary

Lake Balaton (1M Calimnos product 07-2007)



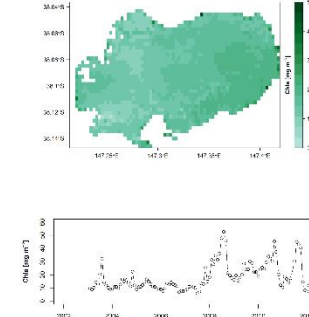
6. Lake Kasumigaura, Japan

Lake Kasumigaura (1M Calimnos product 03-2005)



7. Lake Wellington, Australia

Wellington (1M Calimnos product 02-2007)



Q2. Bio-Optical Modeling – Discussion

Q2A-D. What is the best approach for applying algorithms to coastal/inland waters?

- Globally developed, locally applied algorithms
- Need for more *in situ* data for evaluating global vs. local relationships
- Standardized data-collection procedures needed, but they are difficult to adopt
- Need for sIOP measurements

Q2. Bio-Optical Modeling – Discussion

Q2E. What are the most critical products sought for water quality monitoring?

- Chl-*a* concentration, by a long shot

Sensor Characteristics

Wes Moses

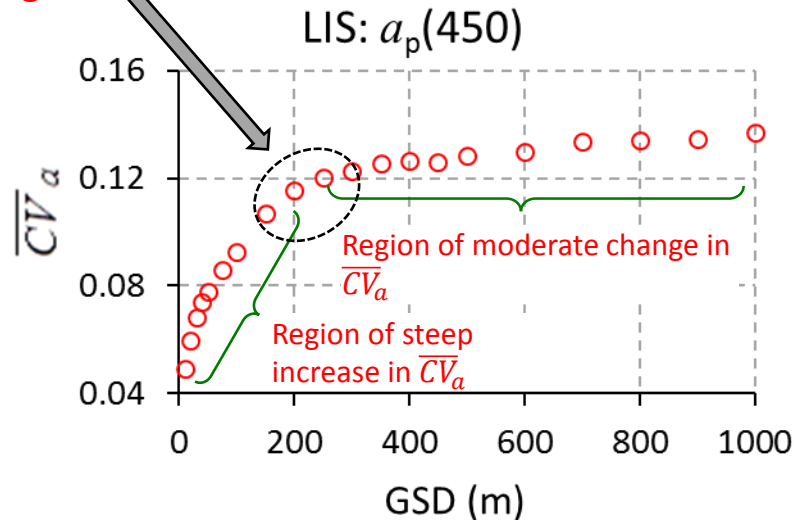
- Spatial Resolution
- Spectral Resolution
- Signal-to-Noise Ratio
- Temporal Resolution

Sensor Characteristics – Spatial Resolution

Wes Moses

(for coastal waters)

Transition
Region



Does not imply that 200 m is sufficient; it simply means that beyond 200 m there is a significant loss in the ability to capture spatial variability

- Bases on analysis of sub-pixel variability, a resolution **no coarser than 200 m** needed to resolve bio-optical features in coastal waters
- A finer resolution needed for inland waters

Sensor Characteristics – Spectral Resolution

Wes Moses



Determining the Optimal Spectral Sampling Frequency for Various Water Types



Ryan Vandermeulen, Antonio Mannino, and Aimee Neeley



What are the scales of spectral variability?

RESULTS – SPECTRAL VARIABILITY OF PHYTOPLANKTON ABSORPTION

METHODS

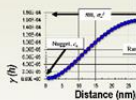
Empirical variograms, $\gamma(h)$, are correlated with "distance" as

$$\gamma(h)$$

Where:

h is a spatial distance between two POCs, n is the number of all possible z and z' are the data values at loc. Proceed to calculate $\gamma(h)$ for 1 m

In a nutshell: We measure the variance measured at different averaging distance h , each averaged at different data structure is no longer range describes the distance h represents the uncertainty, or r



Gaussian fit $\rightarrow \sigma$



MODIFY

In this analysis, we are variogram, but rather the emphasis shows the location of the words, below this point of spectral resolution in

DATA COLL

Hyperspectral data were collected in environment filter pad above water

Four cultures (see Results) were filtered onto ODF filters. Spectrophotometer equipped with 0.3125, 0.625, 1.00, and 5.0 absorbance values are normal

Above-water remote sensing were taken using Anali Spectroradiometers. These instruments using uncalibrated radiance or reflectance (ρ_r) relative to reflectance is a 10% grey card and is assumed to be a semi-computed as:

$$R_{0.5}$$

For this analysis, $R_{0.5}$ is normalized to maximum values and compared. Empirical variograms were individually calculated for each scenario, and results were averaged according to water-type.

Types (PT) from space, which will require more spectral bands and finer spectral resolution than present ocean color sensors.

nm resolution), with the possibility of subsampling pre-defined regions at a higher spectral resolution, if deemed relevant. This trade study aims to determine the optimal sampling frequency for OCL.

References:

Duan, H.T. et al. (2009) "Fluorescence peak shift corresponding to high chlorophyll concentrations in inland water." *Limnology* 29: 161-4

CONCLUSIONS

1

A **MINIMUM** of 5 nm spectral resolution is required to resolve variability across mixed spectrum

2

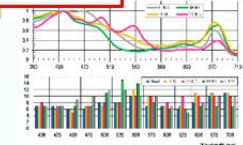
Certain spectral regions may benefit from enhanced spectral subsampling (e.g. fluorescence channel)

3

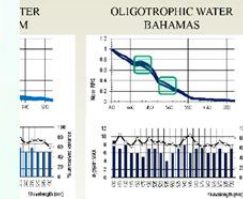
Results show that even most sensitive regions of the spectrum are resolved at ~4 nm, but does not account for capturing the location of shifting peaks.

4

At 5 nm spectral resolution, SNR may be ultimate limiting factor for distinguishing fine scale peaks



spectrum of four distinct cultures (top) and the corresponding dy(h)dh MAX (below), indicating the spectral resolution at which the most information is gained. Results show most features are resolved at ~6 nm.



from open ocean (left) and oligotrophic waters in the Bahamas (top), and the corresponding dy(h)dh MAX optimization (bottom). Spectral optimization variance is shown that some areas that require 5 nm or less to resolve (475 and 535 nm).

IONS

of 5 nm spectral resolution is required to distinguish mixed spectrum

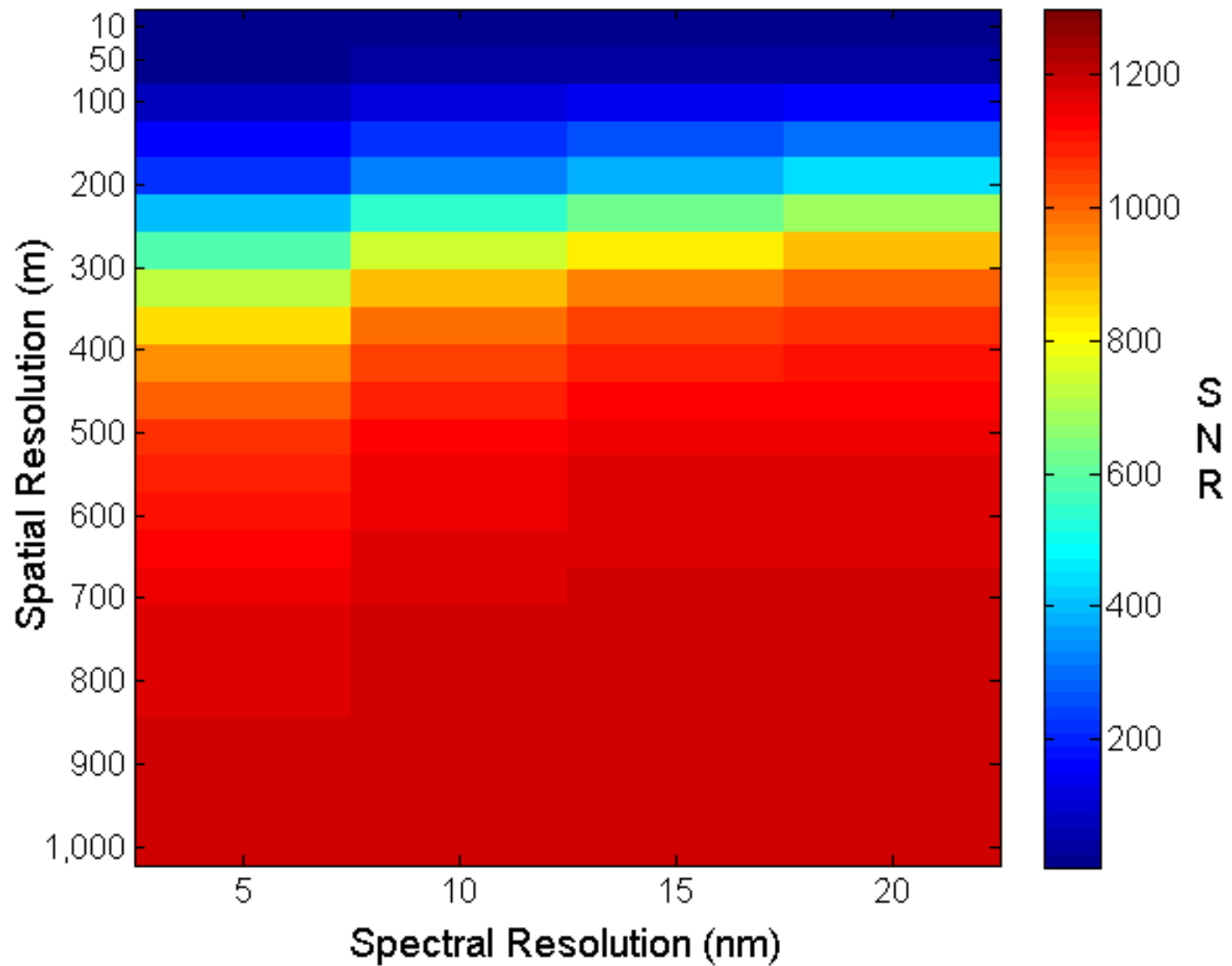
regions may benefit from enhanced sampling (e.g. fluorescence channel)

that even most sensitive regions of the spectrum are resolved at ~4 nm, but does not account for the location of shifting peaks.

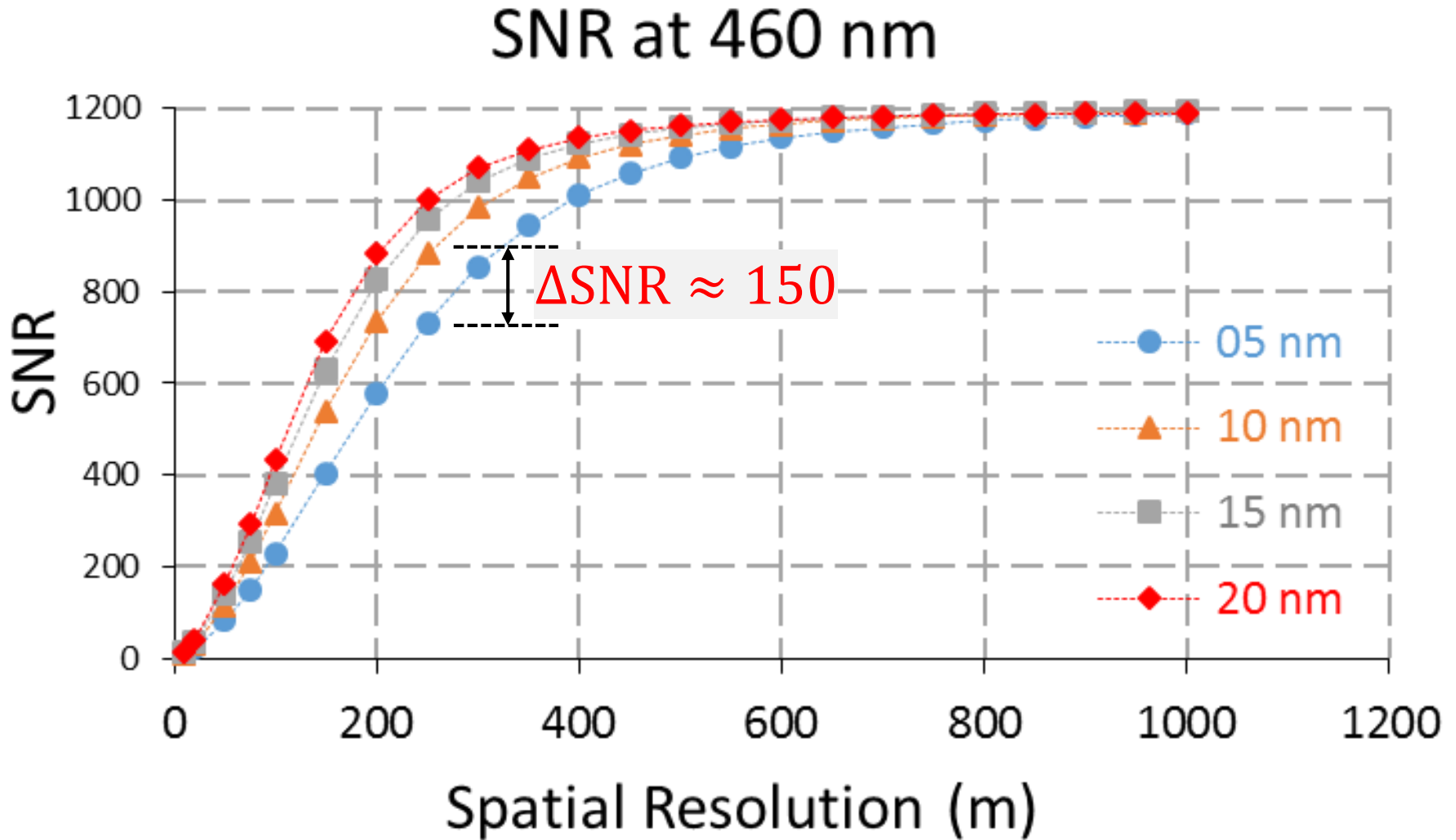
spectral resolution, SNR may be ultimate limiting factor for distinguishing fine scale peaks

understanding from NASA PACE mission, NOAA JPSS and other satellite sensors for Coastal and River Dominated Ecosystems

Trade-off



Trade-off



What does $\Delta\text{SNR} \approx 150$ mean for retrievals?

A single case study

- Add noise to Rrs spectrum at SNR = 700 and 850
- Estimate chl-*a* for both cases and compare to the estimate from noiseless Rrs spectrum to determine the uncertainty due to noise, U_{SNR}
- Effects of SNR on atmospheric correction not considered here
- $U_{\text{SNR}=700} = 0.17 \pm 4.5\%$
- $U_{\text{SNR}=850} = 0.15 \pm 3.7\%$

Q3. Sensor Characteristics – Discussion

Q3A. What are the desired sensor characteristics?

- Depends on the water body and the application
- Spatial resolution may be more important than the others
- Need to quantitatively evaluate the impact of various spatial resolutions on retrievals

Q3. Sensor Characteristics – Discussion

Q3B. What is the best approach for designing an inland/coastal water mission?

- Multiple sensors with different characteristics used in a complementary manner; blend data to generate products that may not be produced from just one sensor
- CubeSats are interesting, but questions on radiometric fidelity remain
- Include UV/SWIR bands

Q3. Sensor Characteristics – Discussion

Q3C,D. Should future sensor design be influenced by data product continuity/consistency considerations?

- Spectrally convolve hyperspectral data to create multispectral legacy data products
- Need to identify core spectral bands critical for inland/coastal waters
- Numerical modeling for data continuity (to fill missing data and simulate data for future missions)

Q3. Sensor Characteristics – Discussion

Q3E. What are the agency responsibilities for ensuring product consistency?

- Develop guidelines for quality assurance of products
- Promote consistency in sensor calibration across multiple missions (e.g., lunar calibration)

End-User Engagement – Copernicus

Carsten Brockmann

Copernicus Global Land Service

Monitoring the vegetation, the water cycle and the energy budget at global scale

Bio-geophysical products

- status and evolution of land surface
- at global scale
- at mid and low spatial resolution.
- delivery “in a timely manner”
- complemented by the constitution of long term time series



<http://land.copernicus.eu/global/>

End-User Engagement – Copernicus

Carsten Brockmann

Lake Water Products

Software
readiness

Metadata

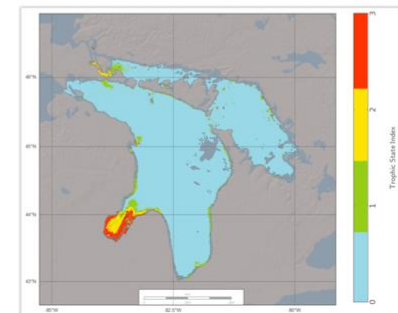
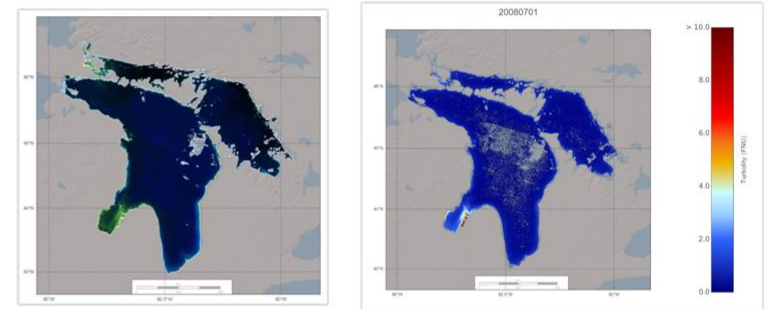
User Doc.

Uncertainty
Charact.

Public Access
Feedback

Usage

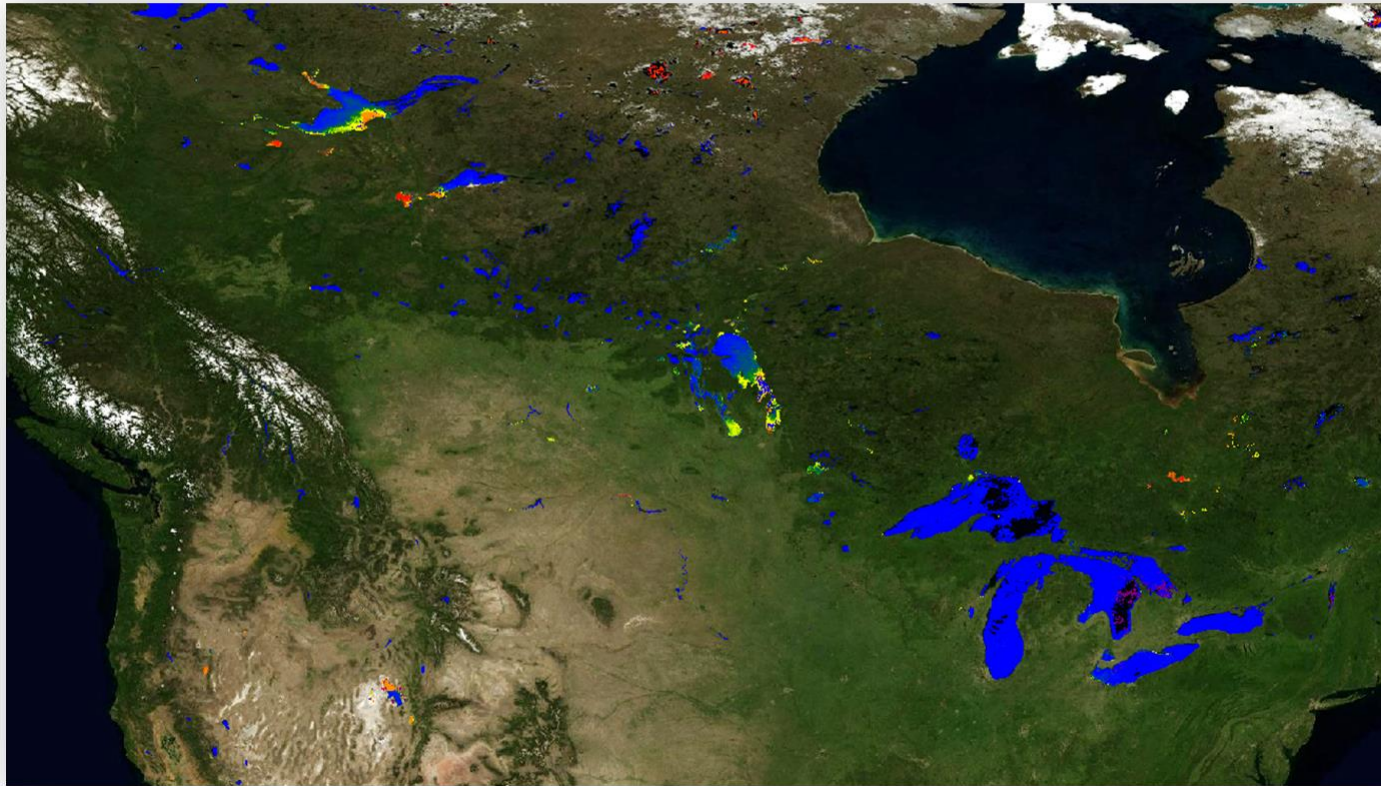
- Parameters:
 - Lake Surface Temperature (LSWT)
 - Lake Surface Reflectances (LSR)
 - Turbidity (TUR)
 - Trophic State Index (TSI)
- Inputs:
 - MERIS (REPROCESSING 300m, 1km)
 - OLCI (NRT 300m, 1km)
 - S-2 MSI (100m)
- Outputs:
 - 10days averages, best pixel



End-User Engagement – Copernicus

Carsten Brockmann

Globally distributed Lakes



End-User Engagement – Copernicus

Carsten Brockmann

Validation

Software
readiness

Metadata

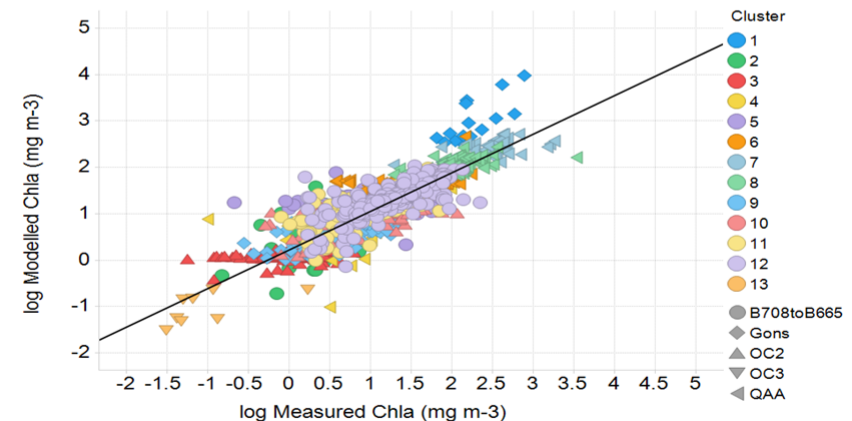
User Doc.

Uncertainty
Charact.

Public Access
Feedback

Usage

- Visual inspection
 - Plausibility of spatial patterns → mapping
 - Plausibility of temporal patterns → time series
 - Identification of Artefacts → mapping
 - Assessment of values in known lakes
- Comparison with in situ data
 - In situ data sources LIMNADES
 - US data bases for lake assessment (EPA)
 - National lake monitoring programs



In situ data: LIMNADES, Globolakes

End-User Engagement – Copernicus

Carsten Brockmann

Documents

Software
readiness

Metadata

User Doc.

Uncertainty
Charact.

Public Access
Feedback

Usage

Copernicus Global Land Operations – Lot 2
Date Issued: 28.04.2017
Issue: 11.00



Copernicus Global Land Operations
“Vegetation and Energy”
“CGLOPS-2”
Framework Service Contract N° 199496 (JRC)

QUALITY ASSESSMENT REPORT

LAKE WATER QUALITY
300M PRODUCT, HISTORIC
VERSION 1.1.0

Issue 11.00

Organization name of lead contractor for this deliverable: Brockmann Consult GmbH

Book Captain:	Kerstin Stelzer, BC
Contributing Authors:	Dagmar Müller, BC Stefan Simis, PML

Copernicus Global Land Operations – Lot 2
Date Issued: 28.04.2017
Issue: 11.00



Copernicus Global Land Operations
“Cryosphere and Water”
“CGLOPS-2”
Framework Service Contract N° 199496 (JRC)

ALGORITHM THEORETICAL BASIS DOCUMENT

LAKE WATERS
300M PRODUCT, HISTORIC
VERSION 1.1.0

Issue 11.00

Organization name of lead contractor for this deliverable:

Book Captain:	Stefan Simis (FML)
Contributing Authors:	Kerstin Stelzer (BC), Dagmar Müller (BC)

Copernicus Global Land Operations – Lot 2
Date Issued: 28.04.2017
Issue: 11.00



Copernicus Global Land Operations
“Cryosphere and Water”
“CGLOPS-2”
Framework Service Contract N° 199496 (JRC)

PRODUCT USER MANUAL

LAKE WATERS
300M PRODUCT, HISTORIC
VERSION 1.1.0

Issue 11.00

Organization name of lead contractor for this deliverable:

Book Captain:	Kerstin Stelzer, BC
Contributing Authors:	Stefan Simis, PML

End-User Engagement – GEO AquaWatch

Steve Greb

GEO AquaWatch

The AquaWatch Mission:

To improve water quality in coastal and inland waters through more effective monitoring, management and decision making.

The AquaWatch Goal:

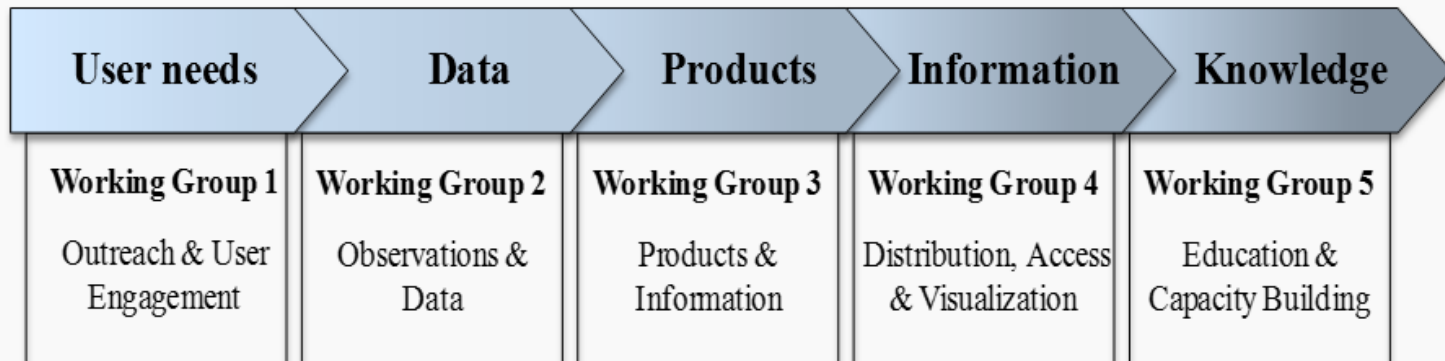
To develop and build the global capacity and utility of Earth Observation-derived water quality data, products and information to support water resources management and decision making.

End-User Engagement – GEO AquaWatch

Steve Greb

GEO AquaWatch

AquaWatch has formed and populated five working groups. These groups, which correspond to the five objectives, carry out the needed tasks (work packages) to complete the AquaWatch mission.



Q4. End-User Engagement – Discussion

Q4A-E. What are the gaps in existing technology and the measures needed to improve uptake of remote sensing products by end-users?

- Developing/under-developed countries have a greater need
- Capability exists to generate products for these regions, but validation is a challenge
- Citizen science measures for generating *in situ* data for product validation (examples of success in Brazil and Peru)

Acknowledgement

Note-Takers

- Henry Houskeeper
- Andrea Hilborn
- Brice Grunert
- Christiana Ade
- Jeremy Kravitz



Bio-optical Modeling and Remote Sensing of Inland Waters



Edited by
D.R. Mishra, I. Ogashawara, and A.A. Gitelson

Chapter 1: Remote Sensing of Inland Waters: Background and Current State-of-the-Art

Igor Ogashawara, Deepak R. Mishra and Anatoly A. Gitelson

Chapter 2: Radiative Transfer Theory for Inland Waters

Peter Gege

Chapter 3: Atmospheric Correction for Inland Waters

Wesley J. Moses, Sindy Sterckx, Marcos Montes, Liesbeth De Keukelaere and Els Knaeps

Chapter 4: Bio-Optical Modeling of Colored Dissolved Organic Matter

Tiit Kutser, Sampsa Koponen, Kari Y. Kallio, Tonio Fincke, and Birgot Paavel

Chapter 5: Bio-Optical Modeling of Total Suspended Solids

Claudia Giardino, Mariano Bresciani, Federica Braga, Ilaria Cazzaniga, Liesbeth De Keukelaere, Els Knaeps and Vittorio E. Brando

Chapter 6: Bio-Optical Modeling of Phytoplankton Chlorophyll-a

Mark William Matthews

Chapter 7: Bio-Optical Modeling of Sun-Induced Chlorophyll-a Fluorescence in Inland and Coastal Waters

Alexander Gilerson and Yannick Huot

Chapter 8: Bio-Optical Modeling of Phycocyanin

Linhai Li and Kaishan Song

Chapter 9: Bio-Optical Modeling and Remote Sensing of Aquatic Macrophytes

Tim J. Malthus



remote sensing



Special Issue

Remote Sensing of Water Quality

Manuscript Submission: **Now – 31 Dec 2017**

Manuscripts will be reviewed and published soon after they are submitted (i.e., manuscripts may be published before 31 Dec 2017)