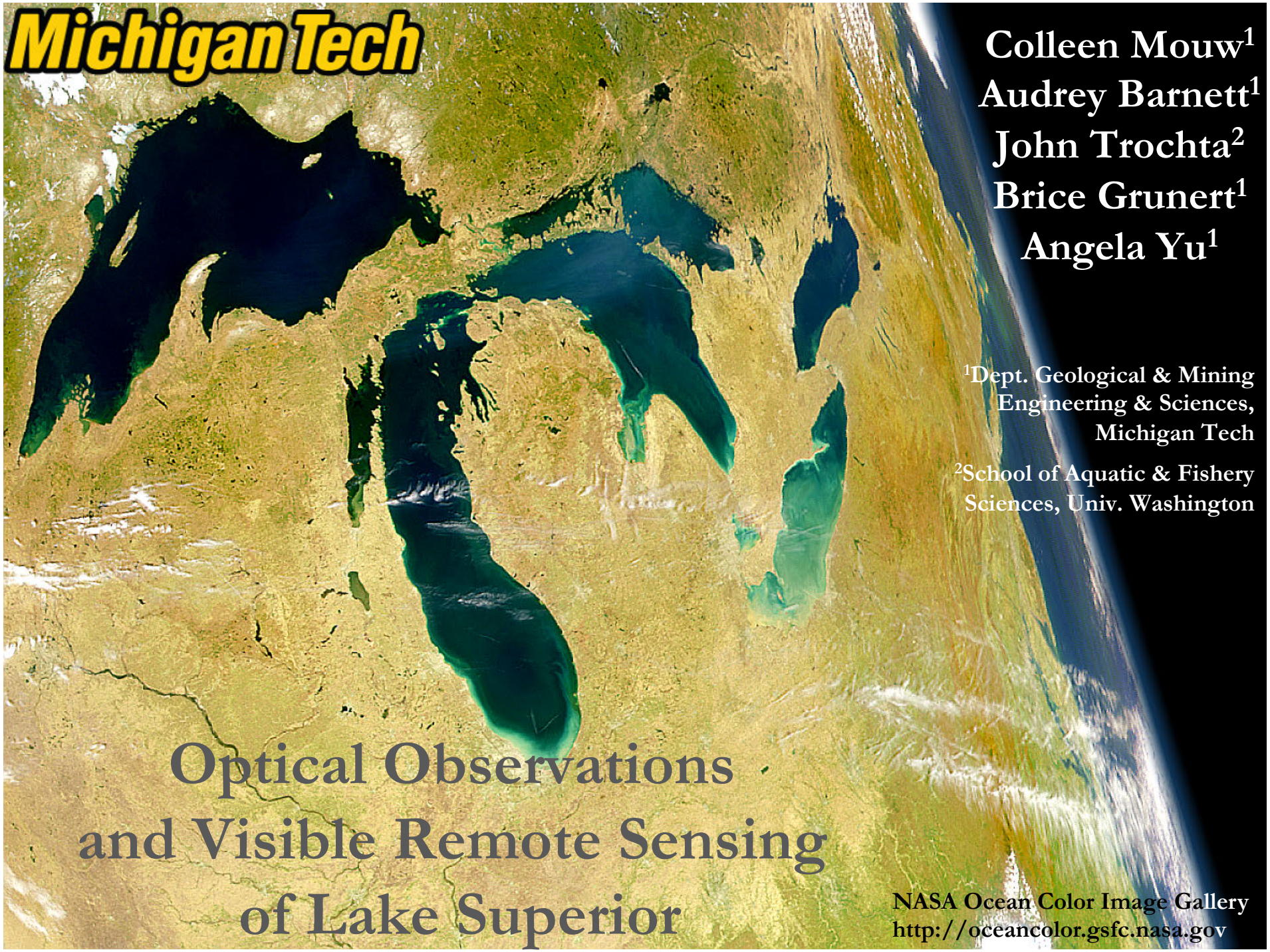


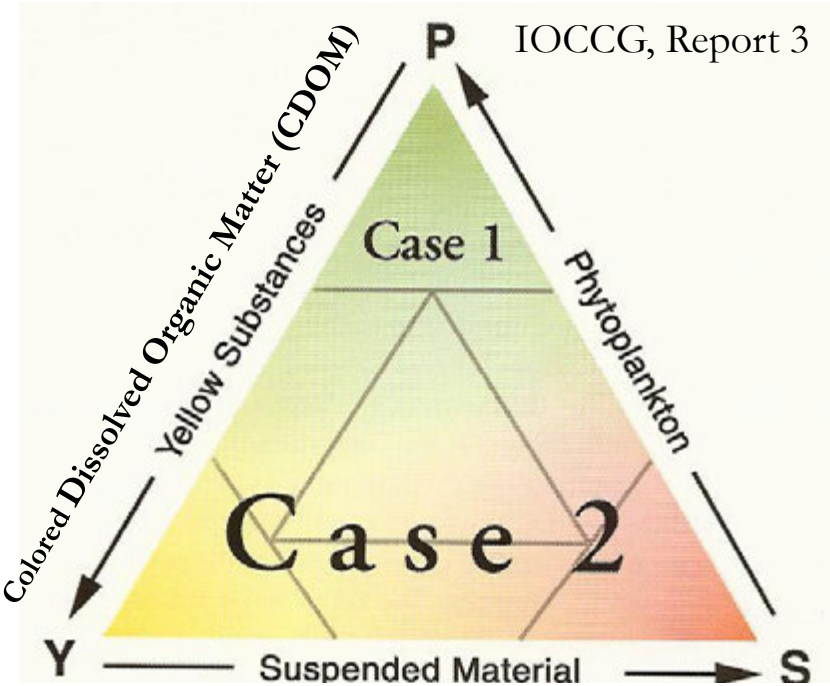
Optical Observations and Visible Remote Sensing of Lake Superior

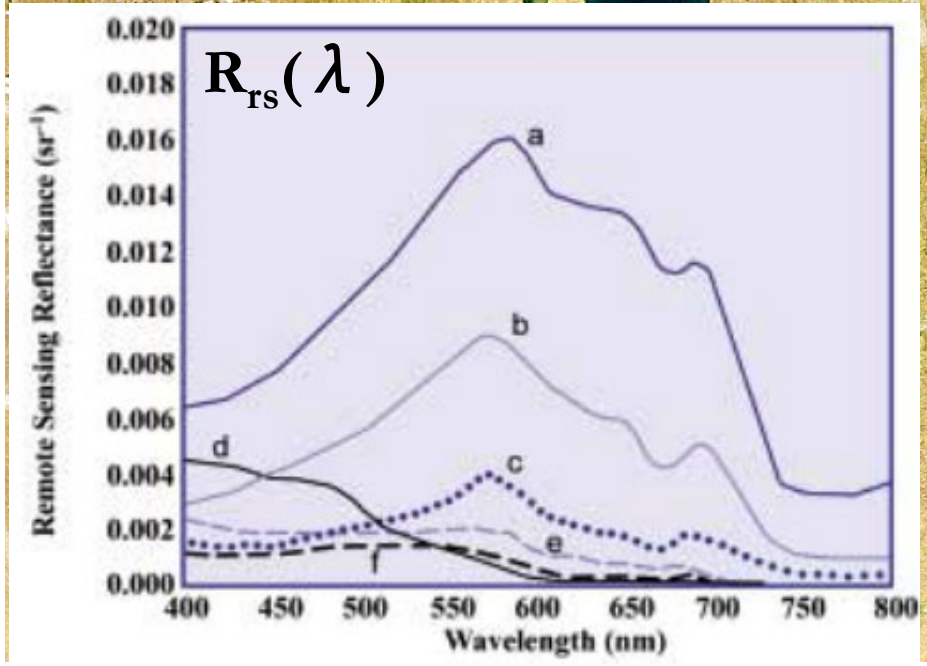
Colleen Mouw[1]
Audrey Barnett[1]
John Trochta[2]
Brice Grunert[1]
Angela Yu[1]

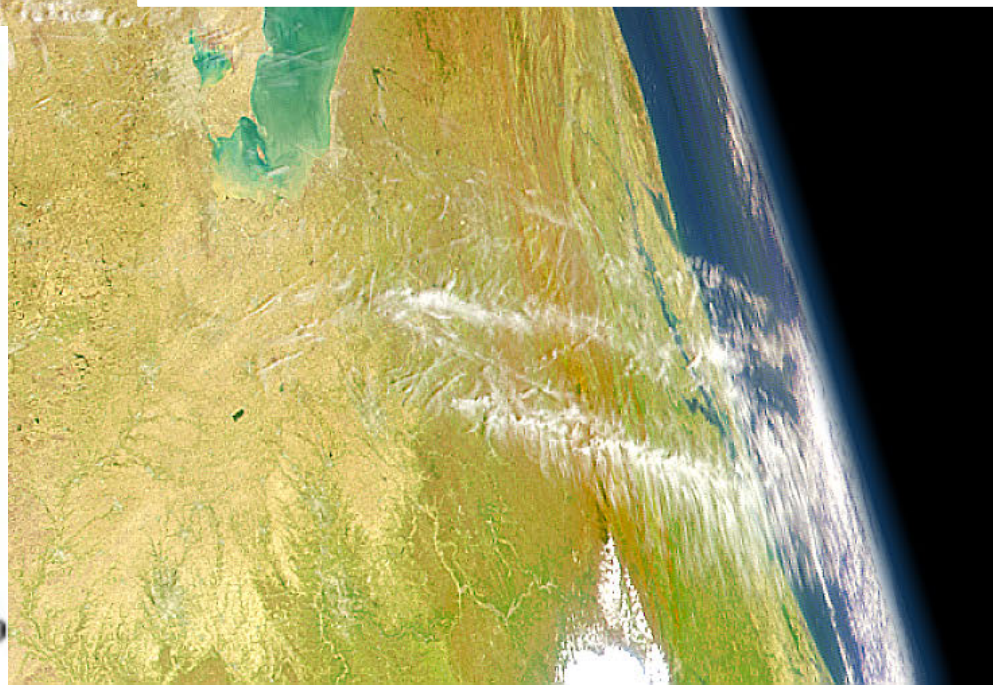
[1]Dept. Geological & Mining Engineering & Sciences, Michigan Tech

[2]School of Aquatic & Fishery Sciences, Univ. Washington

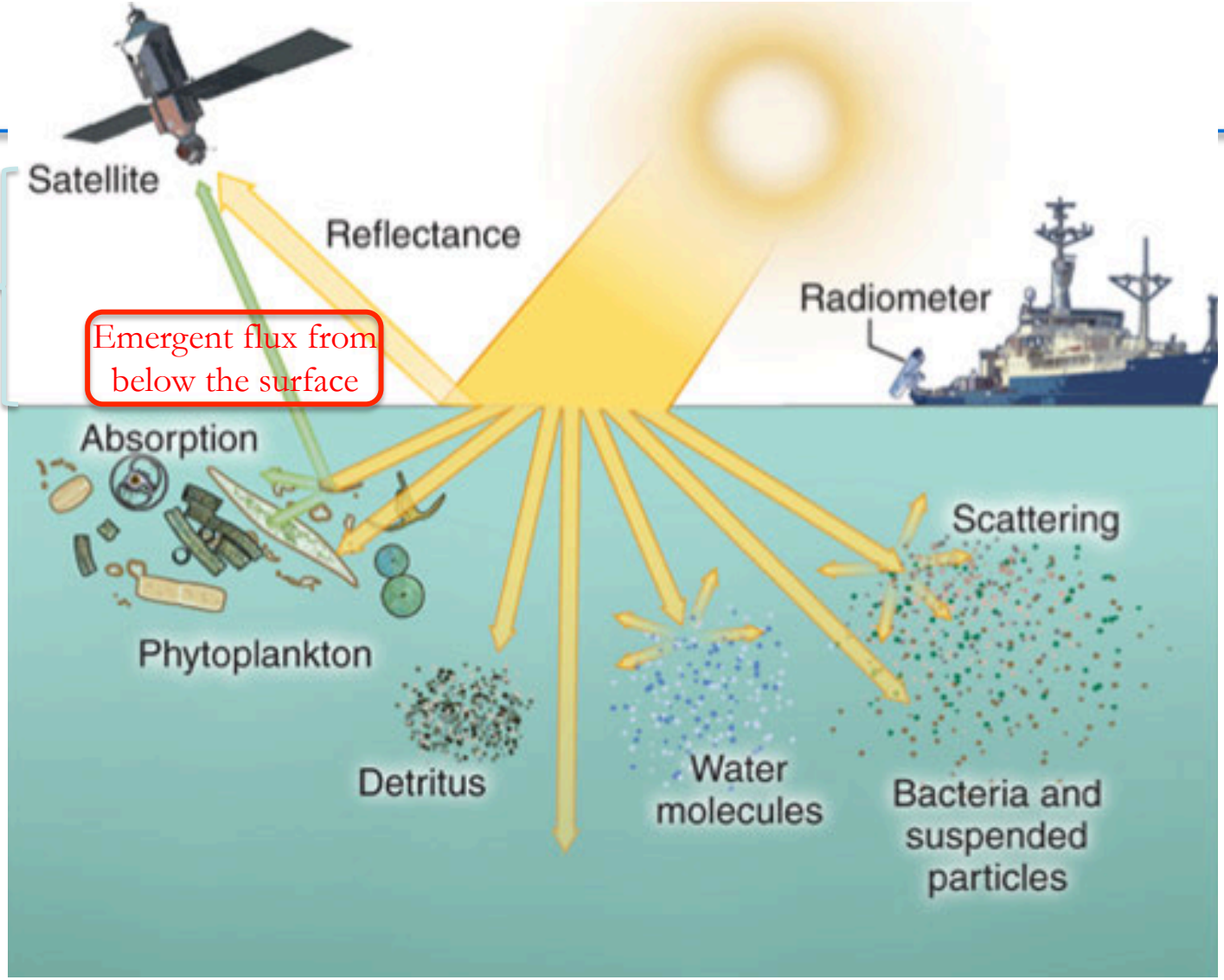
NASA Ocean Color Image Gallery
http://oceancolor.gsfc.nasa.gov


IOCCG, Report 3
P
Y
S
Case 1
Case 2
Colored Dissolved Organic Matter (CDOM)
Yellow Substances
Phytoplankton
Suspended Material
Non-algal particles (NAP)

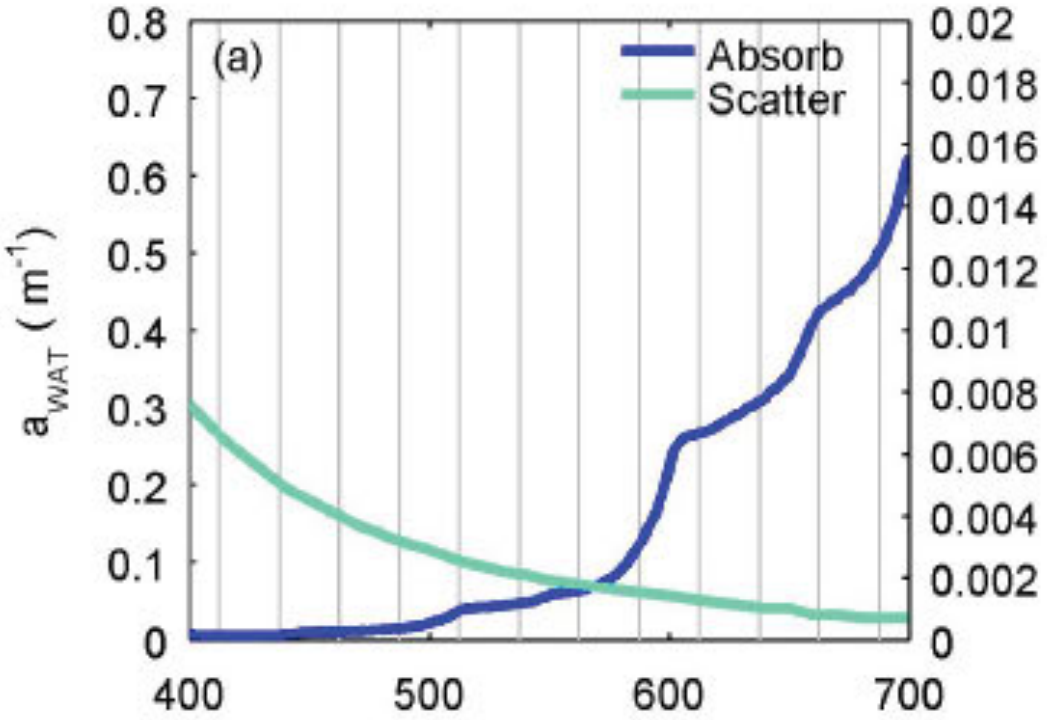

$R_{rs}(\lambda)$
Remote Sensing Reflectance (sr⁻¹)
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
400
450
500
550
600
650
700
750
800
Wavelength (nm)
a
b
c
d
e
f



What a Satellite Radiometer Sees



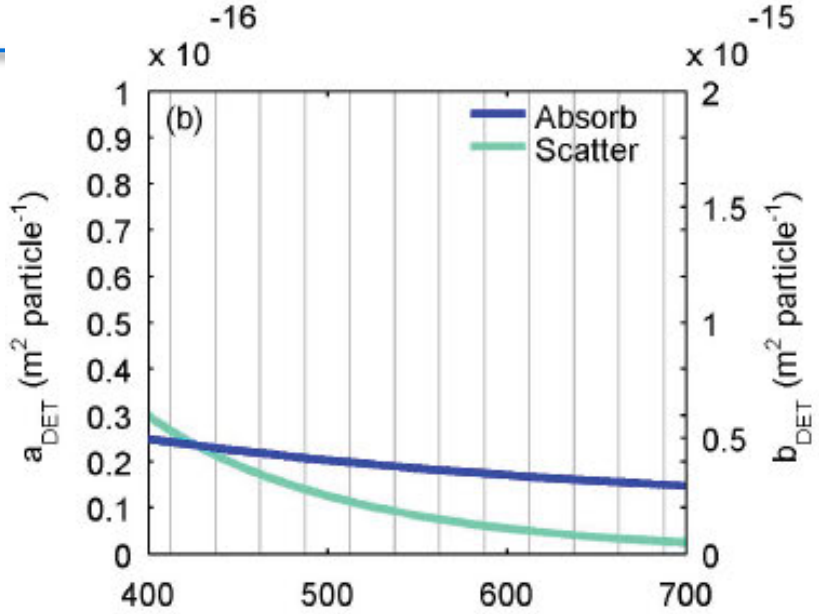
Constituents - Water

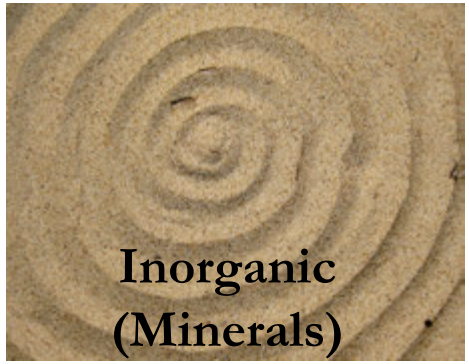


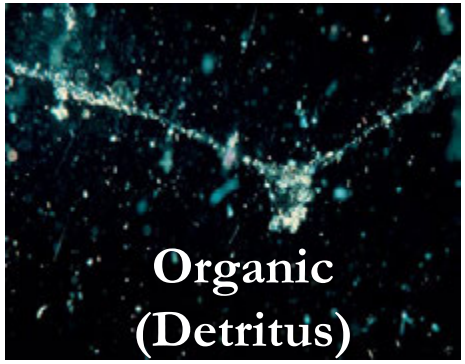
Dutkiewicz et al., 2014

Constituents – NAP & CDOM

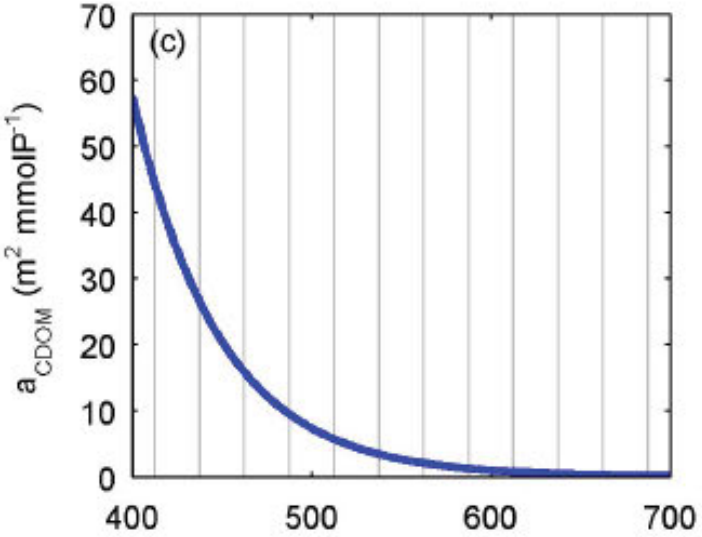
Non-Algal Particles





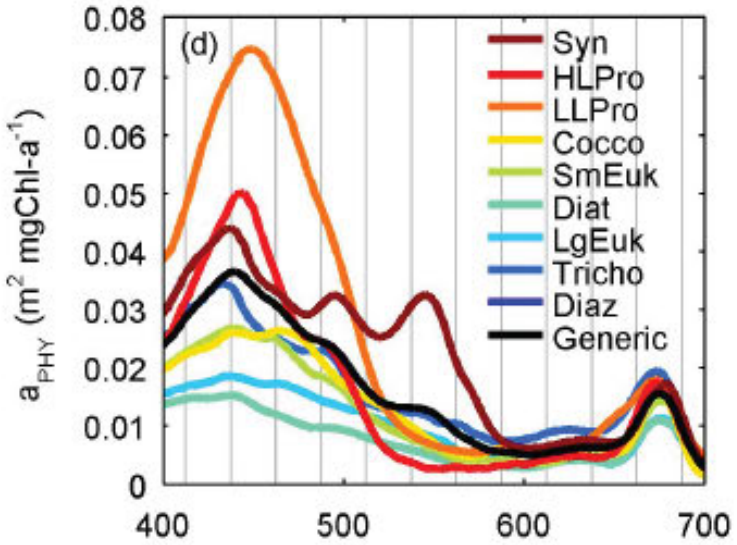


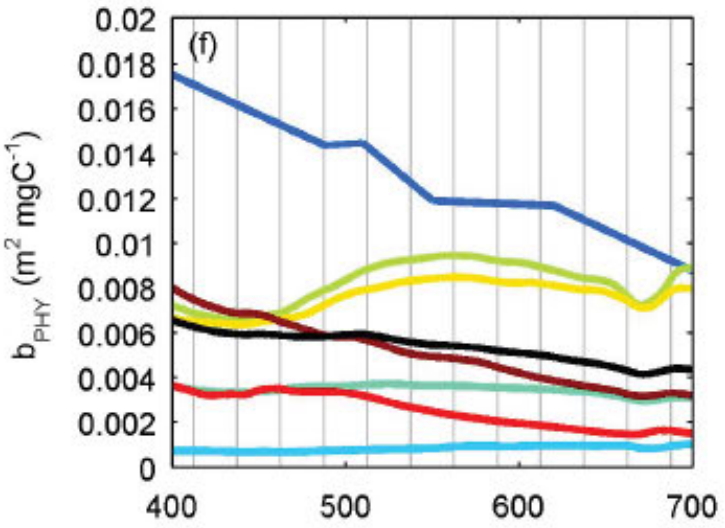
Colored Dissolved Organic Matter (CDOM)



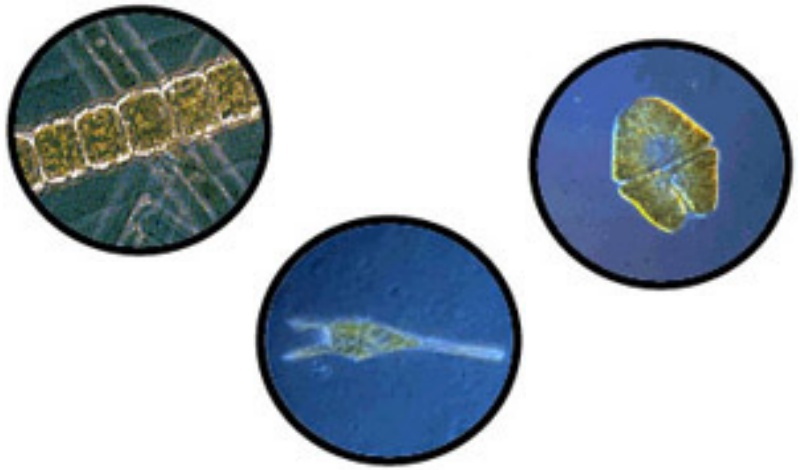
Dutkiewicz et al., 2014

Constituents - Phytoplankton



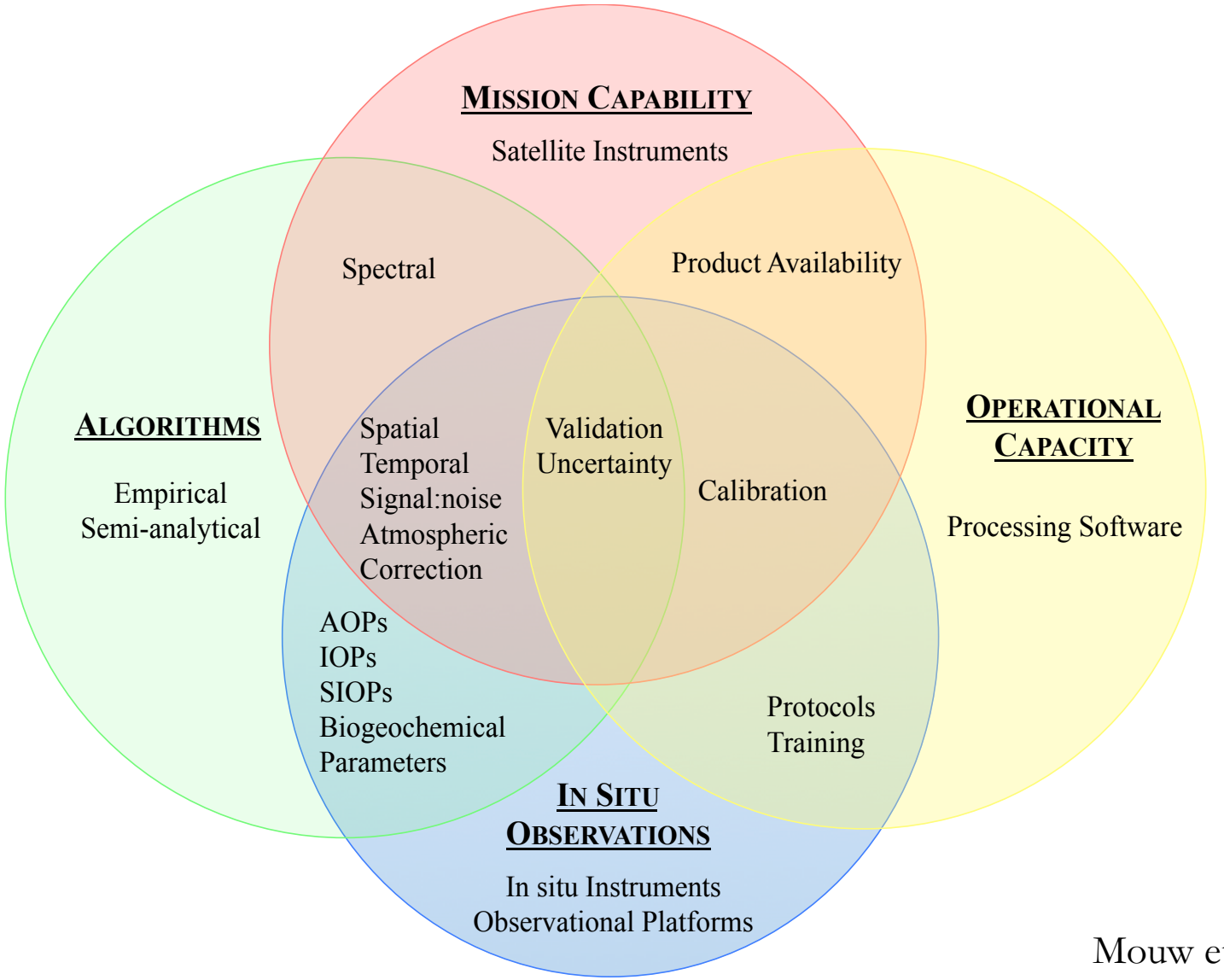


- **Pigment composition**
- **Taxonomic composition**
- **Physiological status**
- **Cell size**



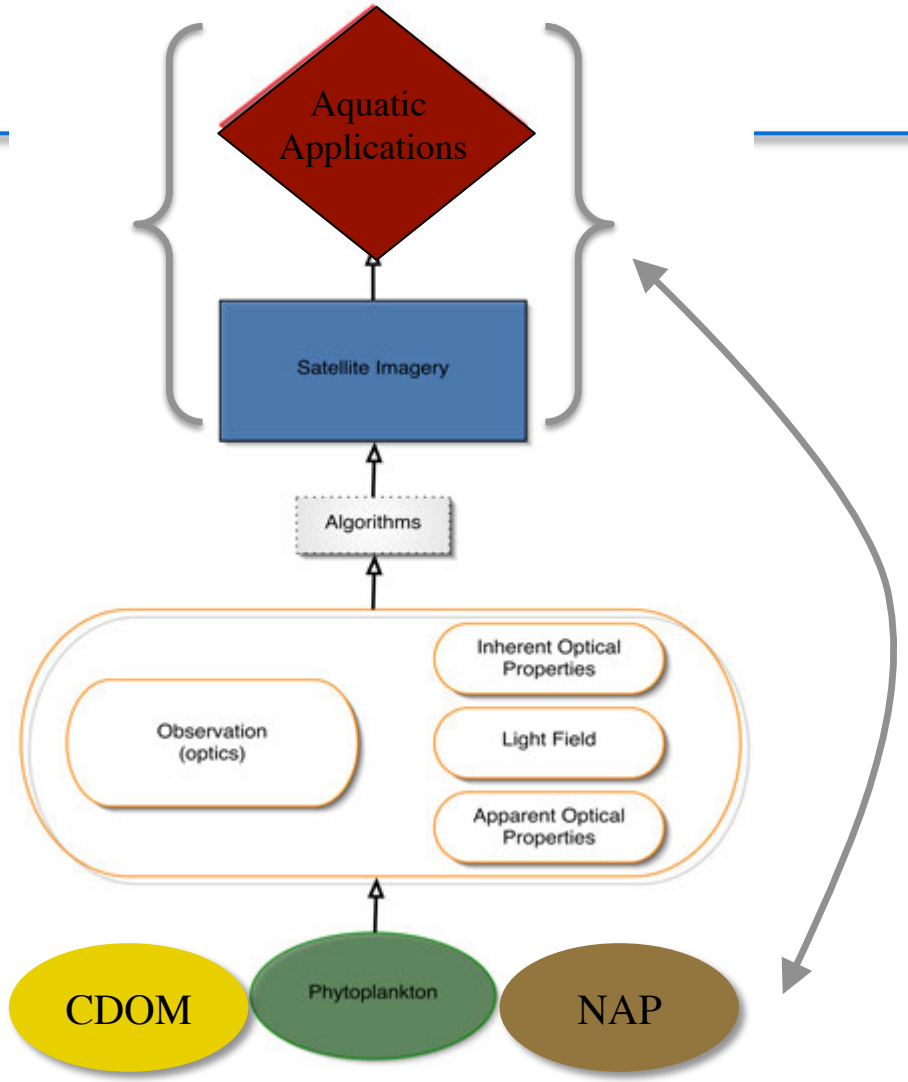
Dutkiewicz et al., 2014

Fundamental Elements of Satellite Remote Sensing

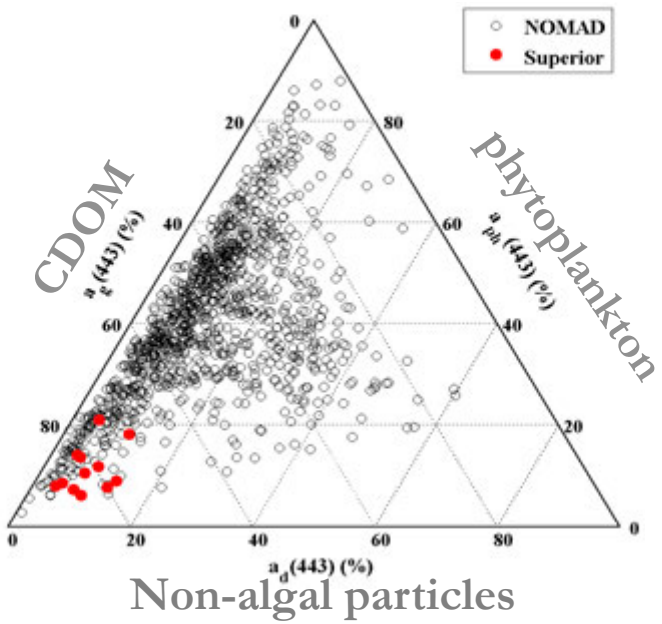


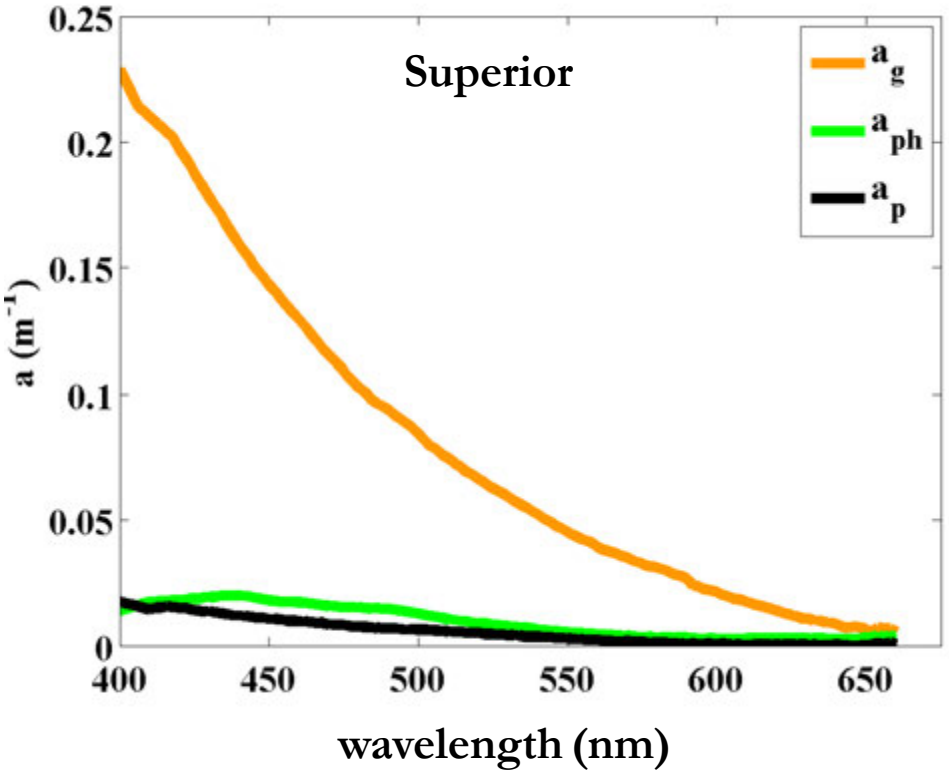
Mouw et al., 2015

Components of Aquatic Color Remote Sensing



Lake Superior – Optics





- High CDOM absorption (>75%)
- Oligotrophic, small chlorophyll dynamic range in the open lake (0.4 – 0.8 mg m^{-3})

a_{CDOM} is 10x greater

Mouw et al., 2013
Effler et al. 2010

JOURNAL OF GEOPHYSICAL RESEARCH: OCEANS, VOL. 118, 1696–1714, doi:10.1002/jgrc.20139, 2013

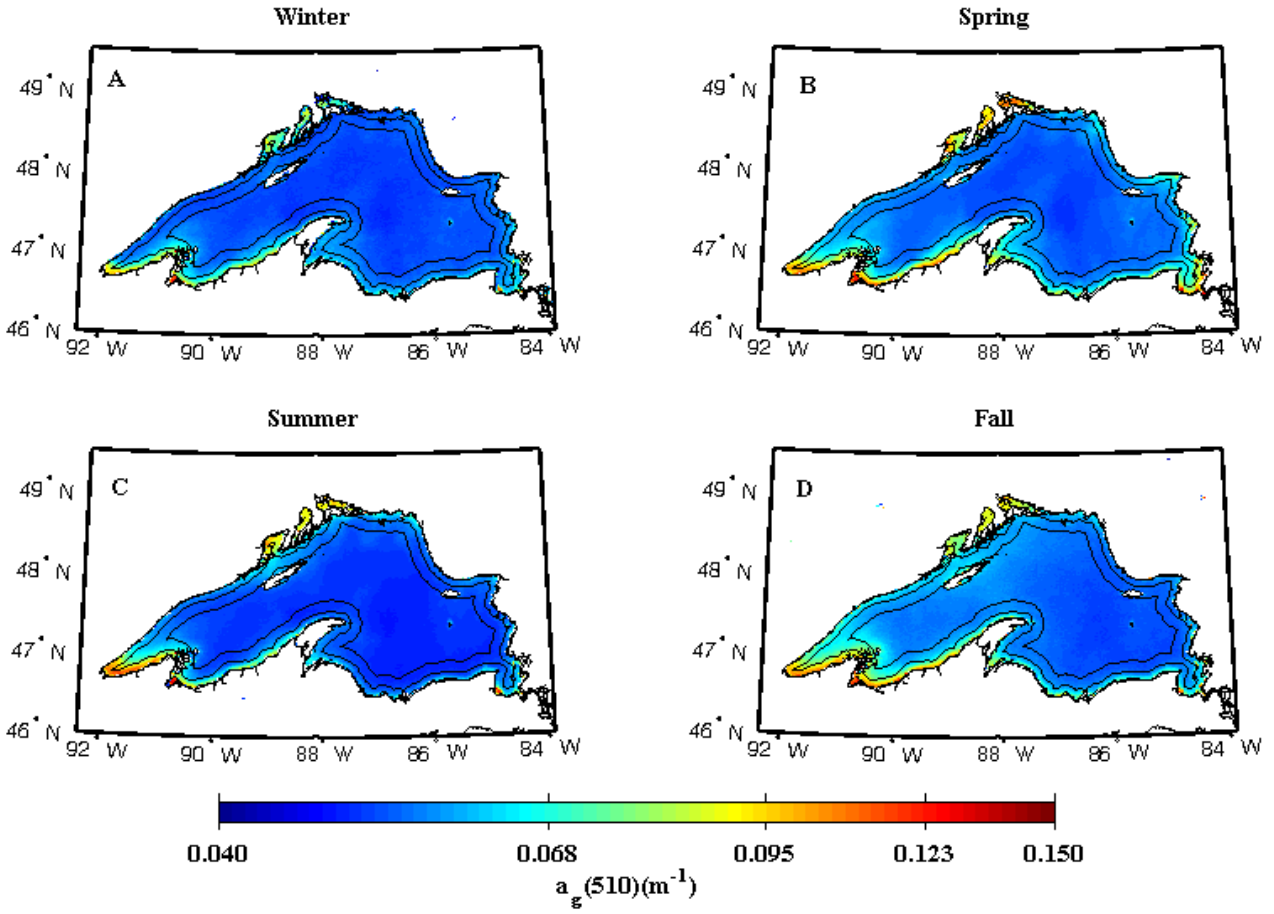
Evaluation and optimization of bio-optical inversion algorithms for remote sensing of Lake Superior's optical properties

Colleen B. Mouw,[1,4] Haidi Chen,[2] Galen A. McKinley,[2] Steven Effler,[3] David O'Donnell,[3] Mary Gail Perkins,[3] and Chris Strait[3]

Retrieval of chlorophyll concentration from an inversion algorithm approach was unsuccessful. The very large contribution of absorption due to CDOM to total absorption and the error in derived CDOM absorption being greater than phytoplankton absorption values make the deconvolution of absorption due to phytoplankton and consequently chlorophyll concentration from $R_{rs}(\lambda)$ difficult.

CDOM Absorption Imagery

Spatial / temporal understanding of a_{CDOM} lends insight into carbon inputs and cycling within the lake as well as optical limitations for satellite retrievals of other biogeochemical parameters.

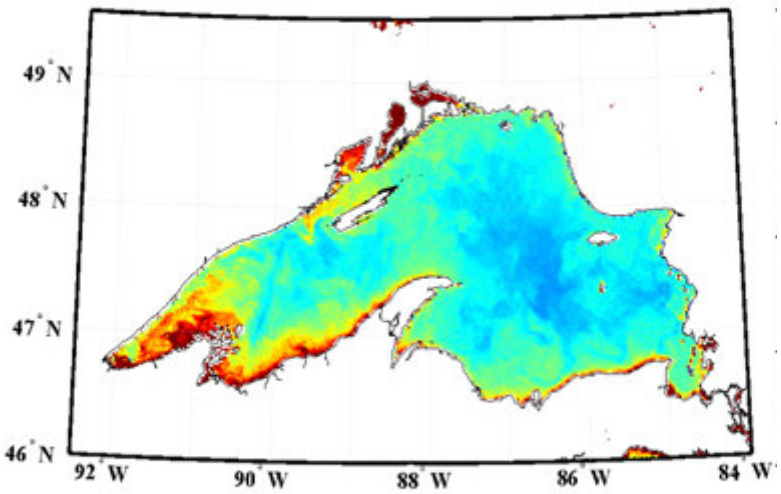


Buffer zones based on the distance from shore: <10 km, 10 to 25 km, and > 25 km

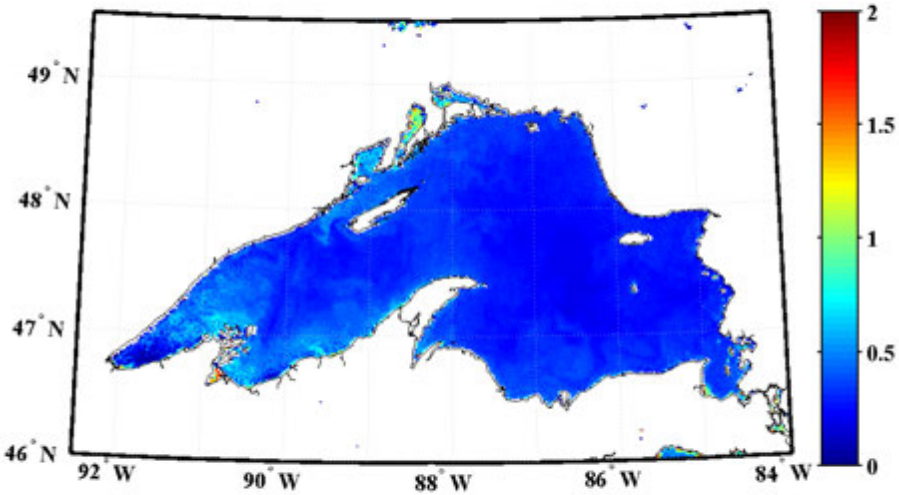
Mouw et al., 2013

Imagery Example

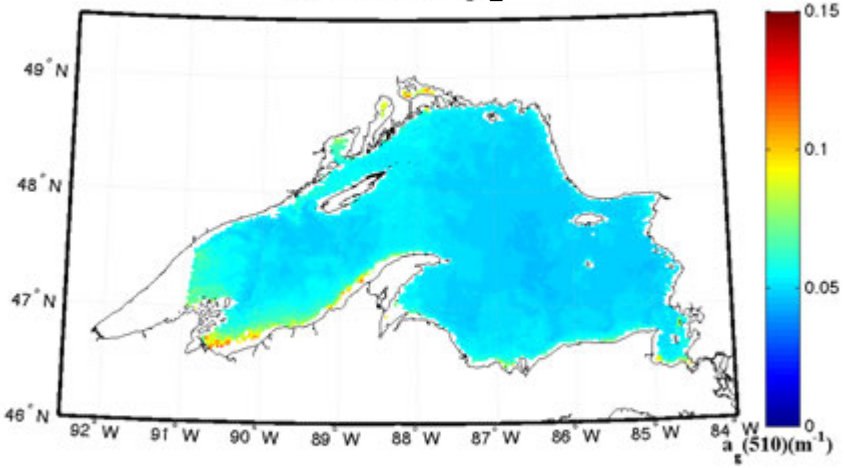
OC4 [Chl]



CDOM corrected [Chl]



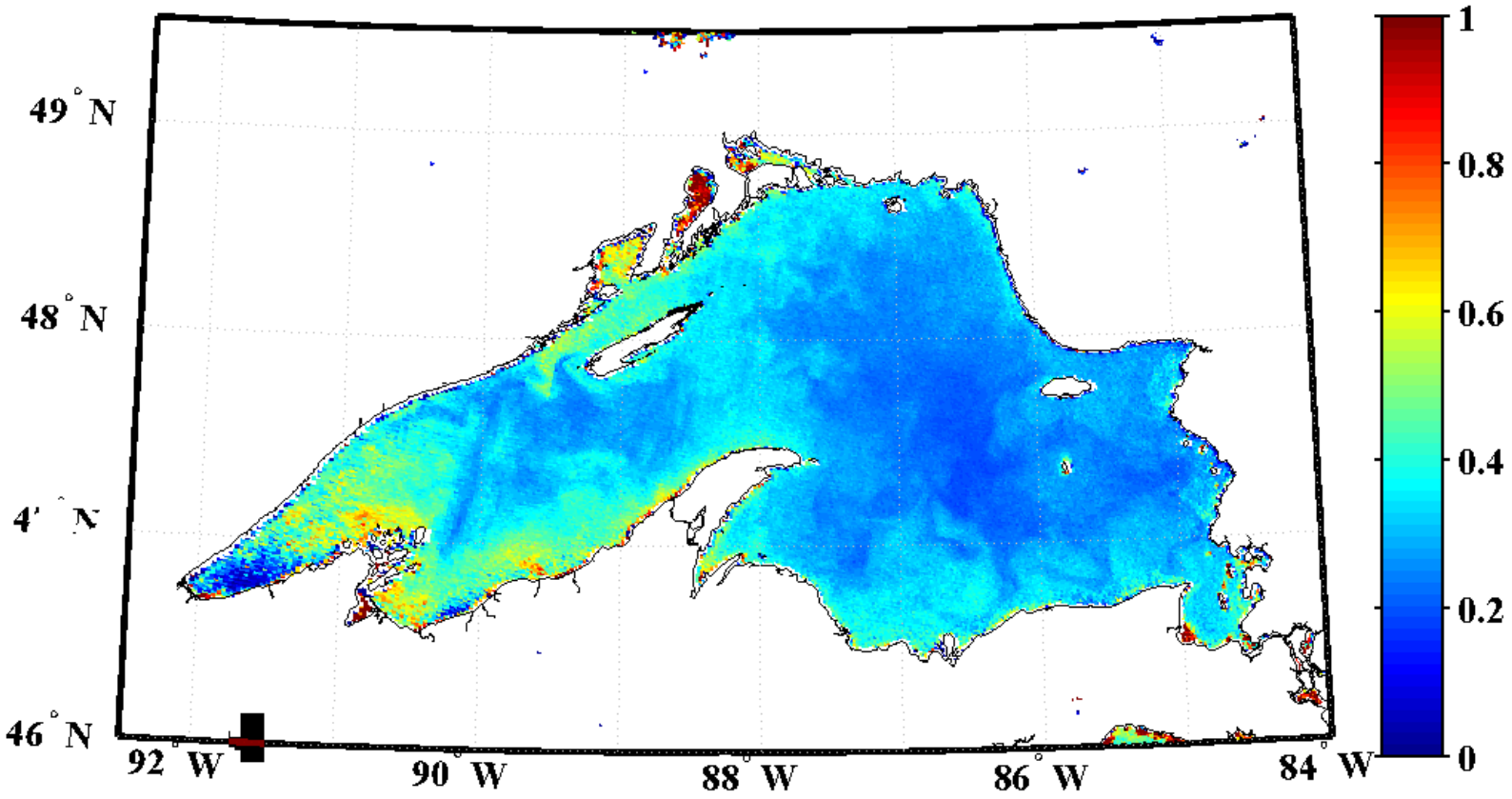
CDOM Absorption



SeaWiFS
8/31/2006

Mouw et al., 2013
Mouw et al., in prep

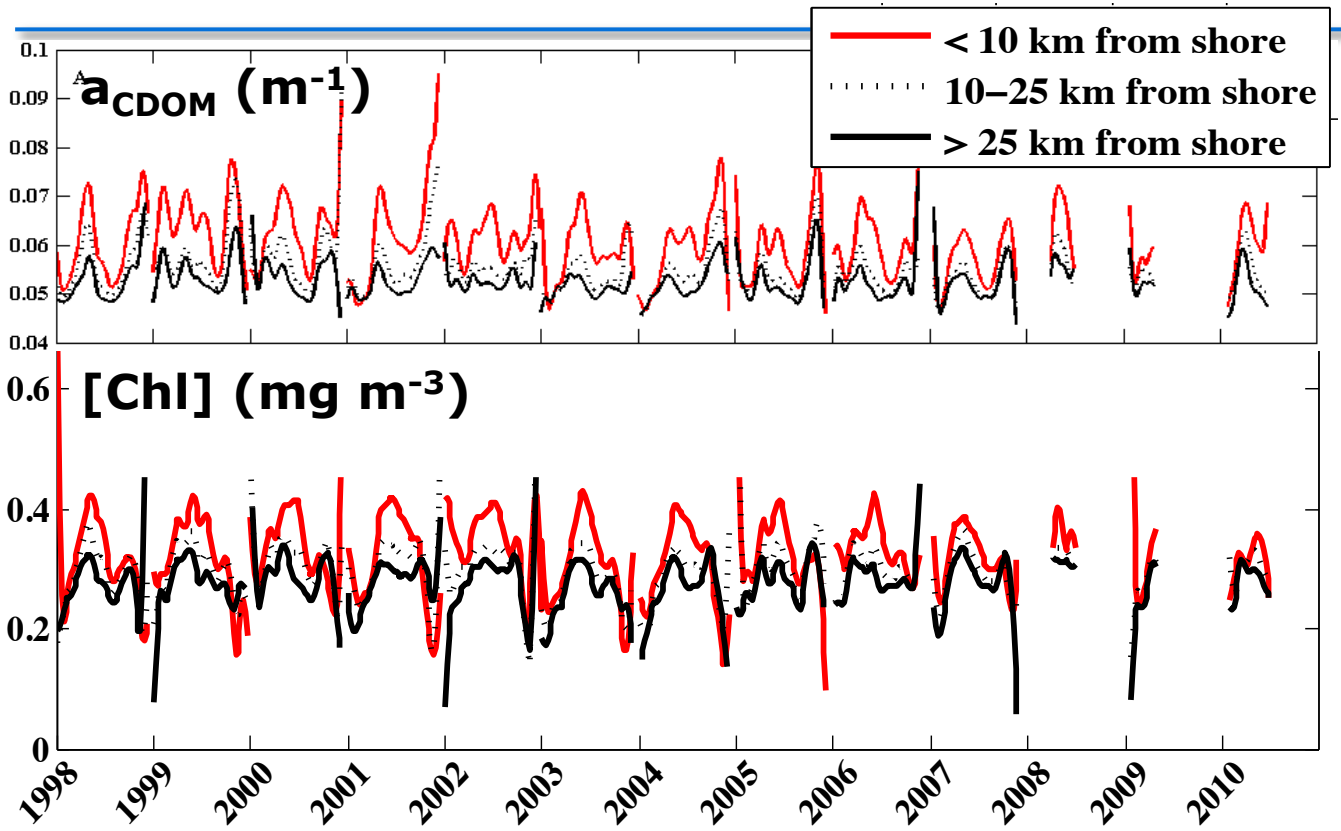
CDOM Corrected [Chl]



SeaWiFS, August 31, 2006

Mouw et al., in prep

a_{CDOM} & [Chl] Time Series

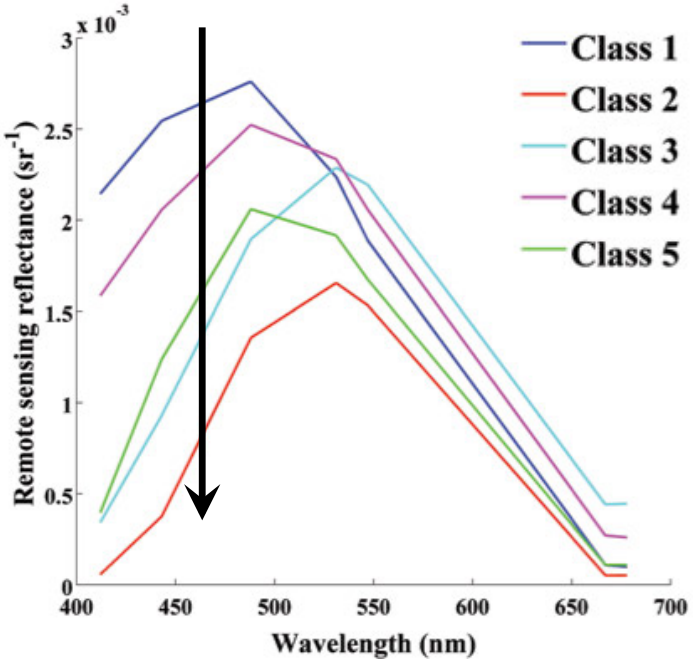


- a_{CDOM} bimodal annual distribution: Greatest peak in fall smaller peak in spring
- Mixing deep CDOM reservoirs back into the surface
- Summer: Photochemical degradation and microbial utilization.

- **[Chl]** bimodal annual distribution: Greatest peak in spring smaller peak in fall
- Looking into drivers of interannual bloom variability.

Mouw et al., 2013; Mouw et al., in prep

Optical Water Types



Highest to lowest constituent composition

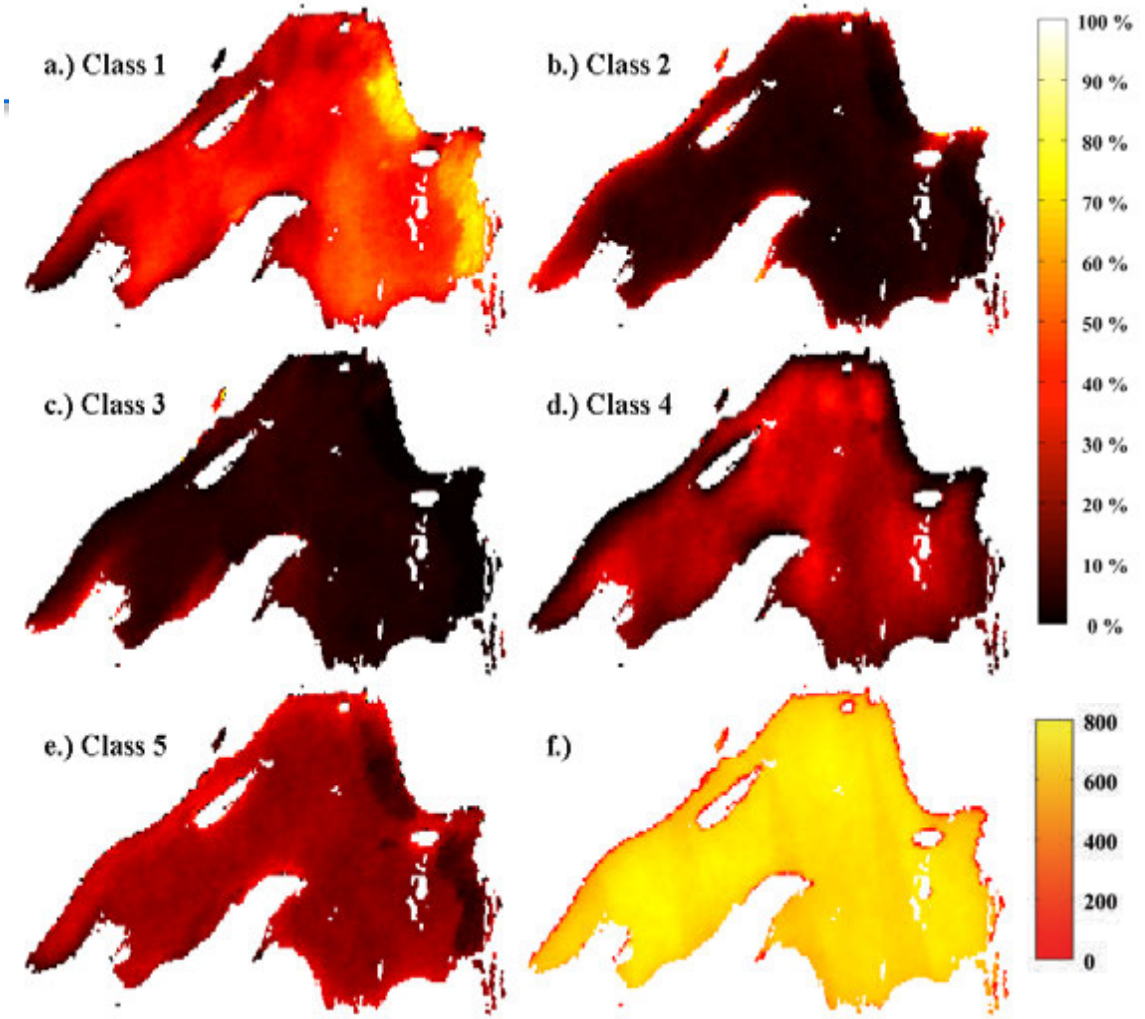
HEAVIEST

HEAVIER

MODERATE

CLEARER

CLEAREST



Frequency of classification – how often pixels had high membership in each class

Trochta, Mouw & Moore, submitted

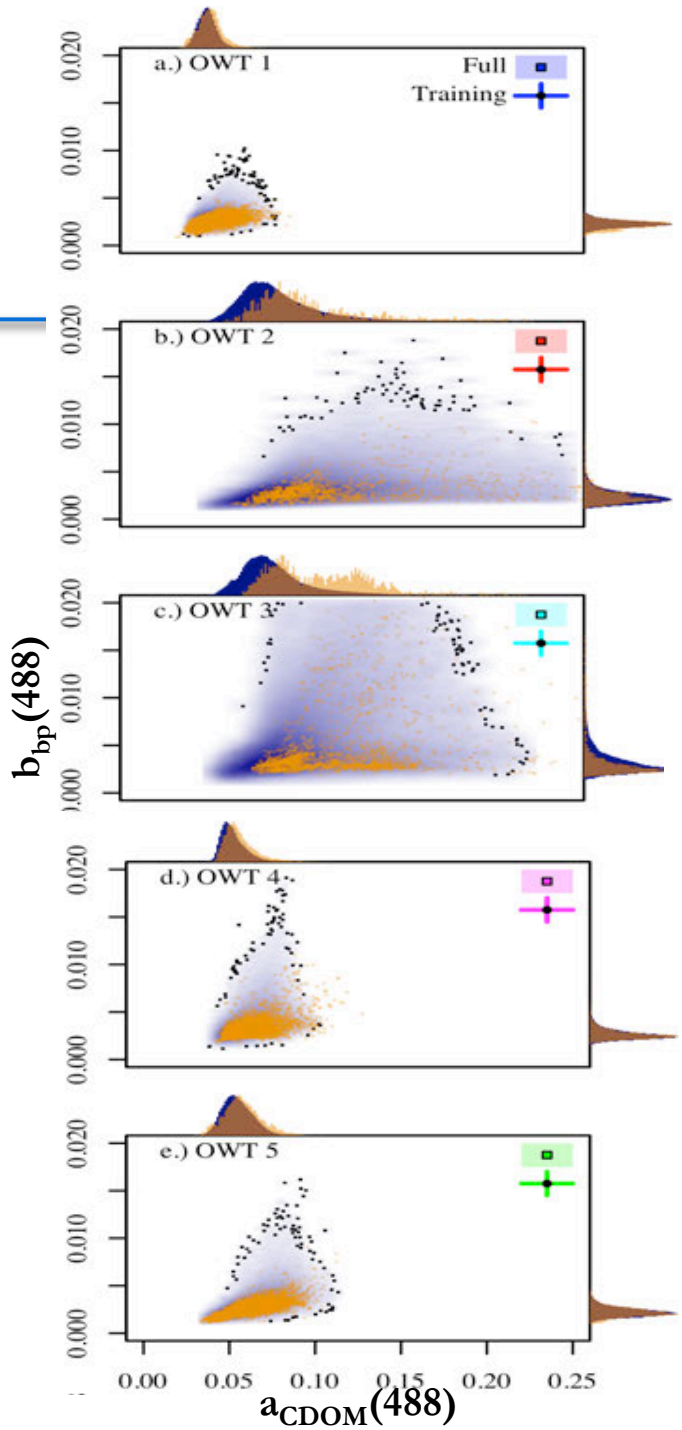
Bluest with lowest CDOM & particles **(CLEAREST)**

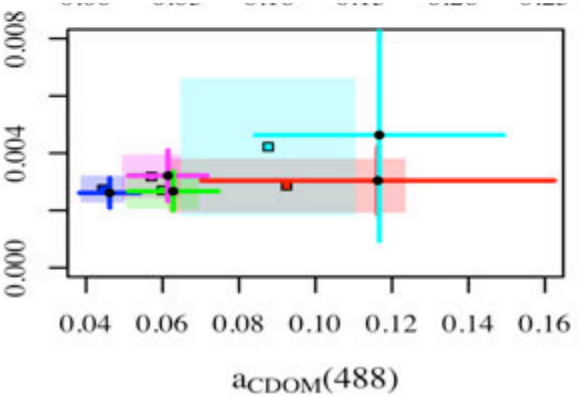
Greener class with high CDOM & moderate particles **(HEAVIER)**

Similar to 2, but with high particles **(HEAVIEST)**

Bluer class with moderate CDOM & particles **(MODERATE)**

Similar to 4, but with lower particles **(CLEARER)**

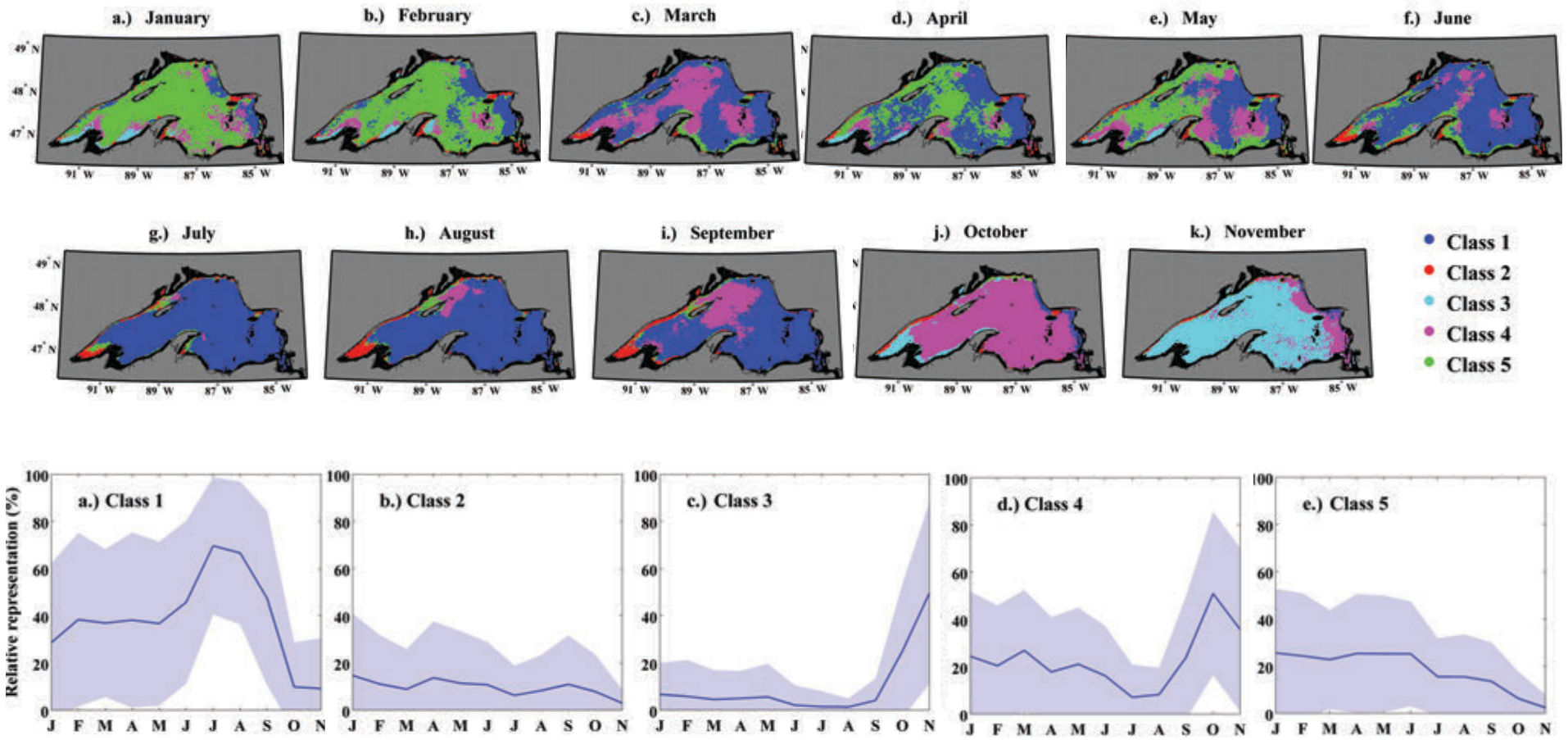




Trochta, Mouw & Moore, submitted

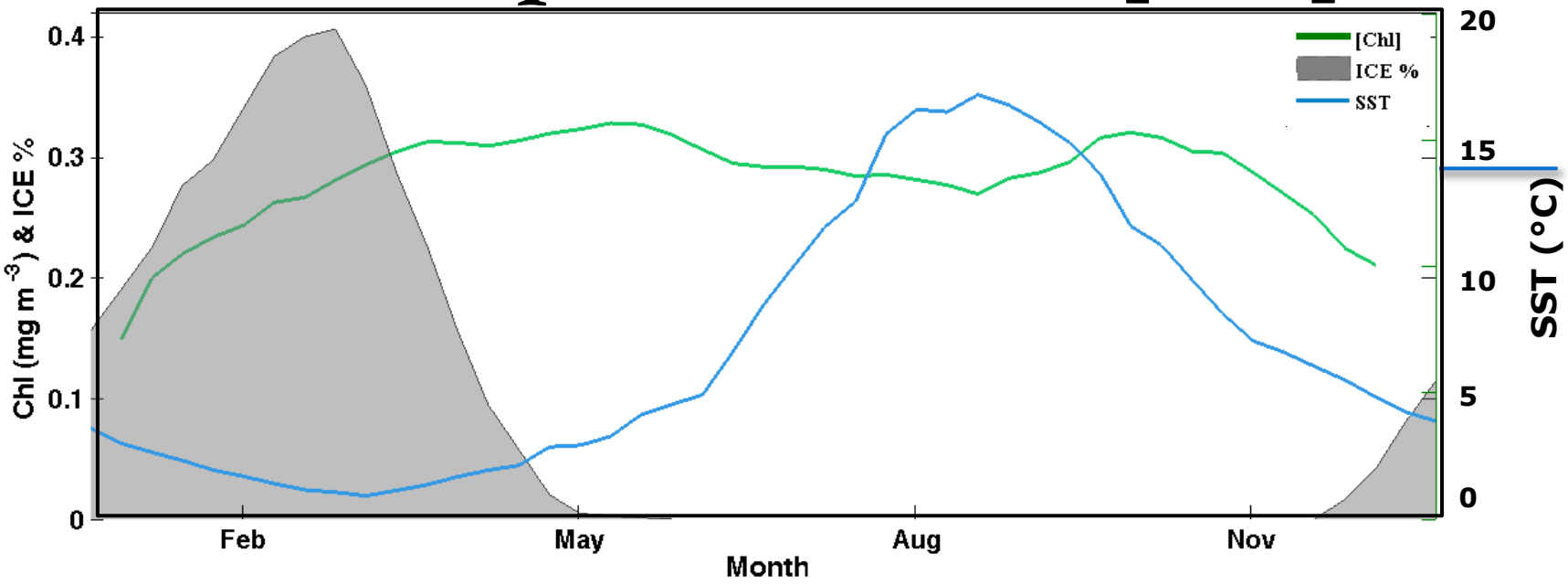
Temporal Evolution

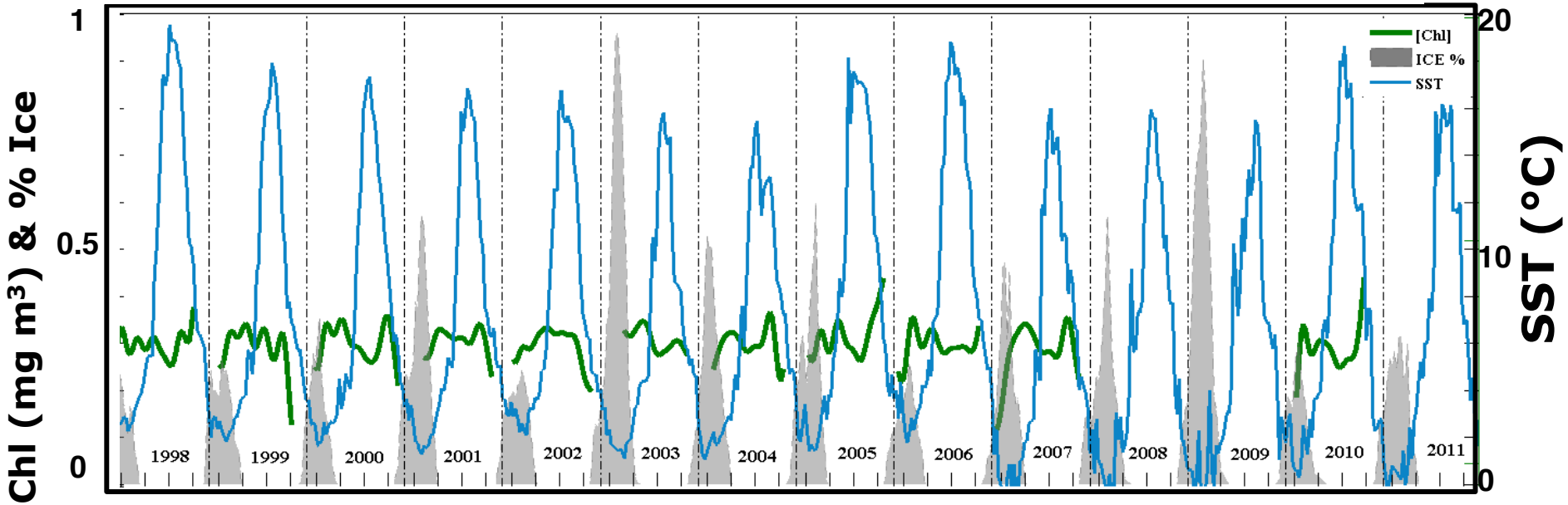
Highest to lowest constituent composition
HEAVIEST
HEAVIER
MODERATE
CLEARER
CLEAREST



Trochta, Mouw & Moore, submitted

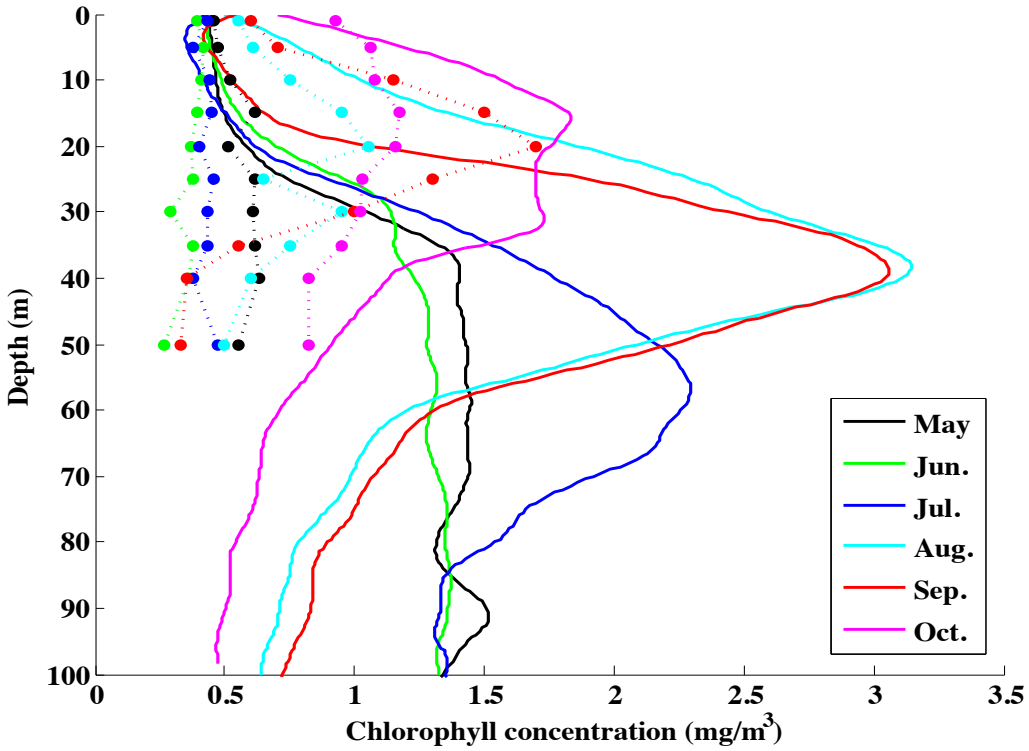
Ice, Temperature and [Chl]





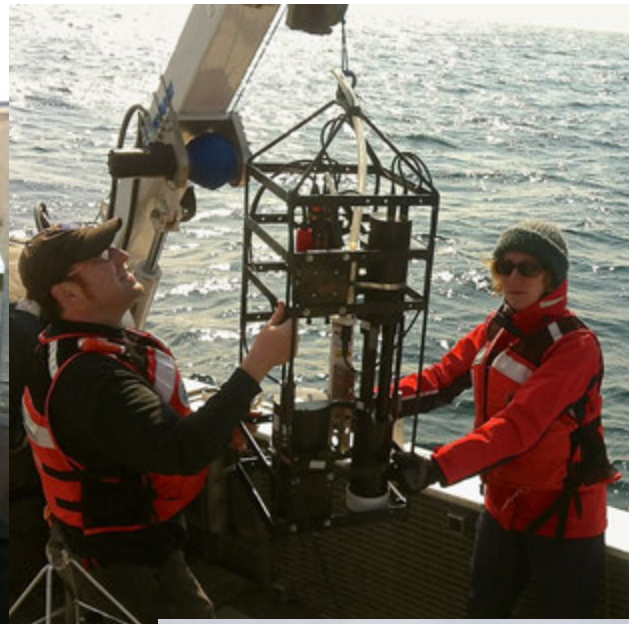
Mouw et al., in prep

Deep Chlorophyll Layer



Comparison of [Chl] profiles between a very cold high ice year (1979, dotted line; Fahnenstiel and Glime, 1983) and a warm year (2013, solid line)

Optical Observations

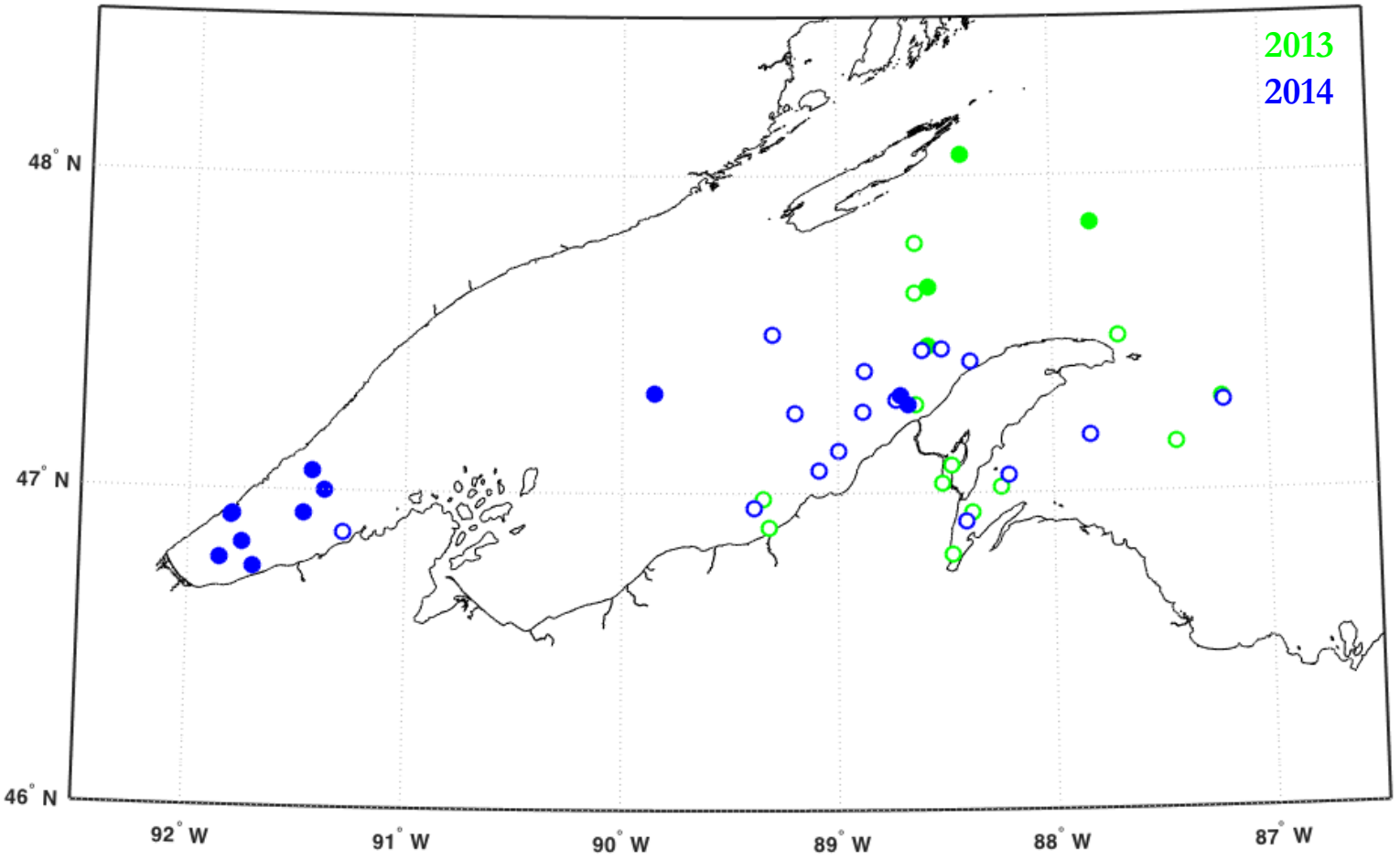


Full characterization of optical properties needed for algorithm development and validation

- $E_d(\lambda)$, $L_u(\lambda) \rightarrow R_{rs}(\lambda)$
- $a(\lambda)$, $a_g(\lambda)$, $c(\lambda)$
- $b_b(\lambda)$
- Chl, CDOM, PC fluor.
- CTD

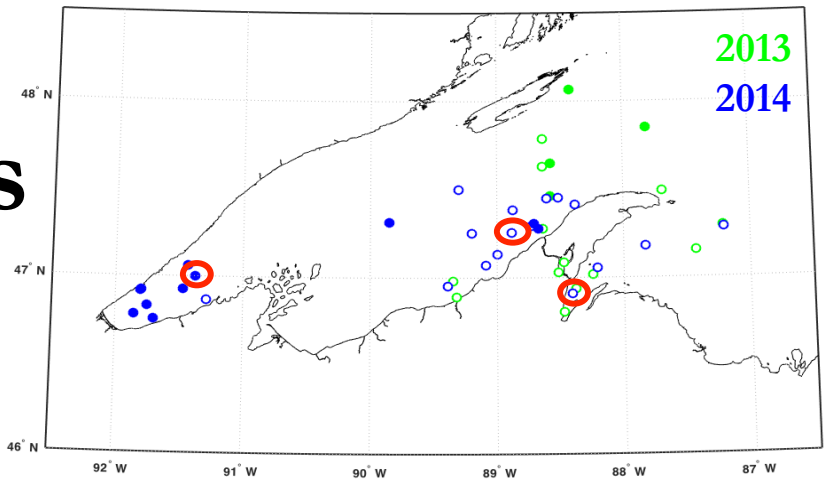
SATLANTIC WET Labs

Optical Sampling Locations

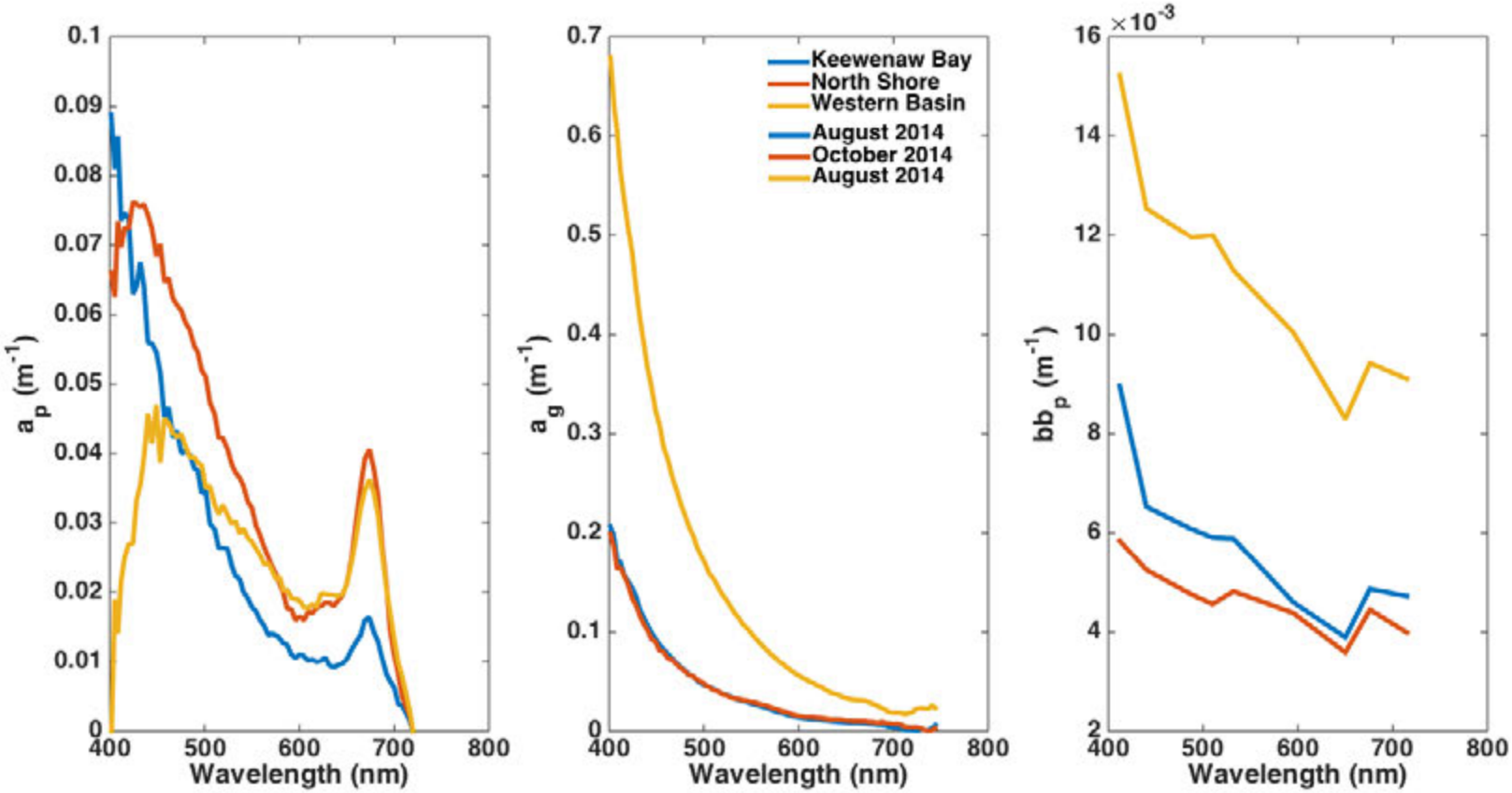


solid symbols - stations sampled more than once in a given year
open symbols - stations sampled once in a given year

Optical Observations



5 m



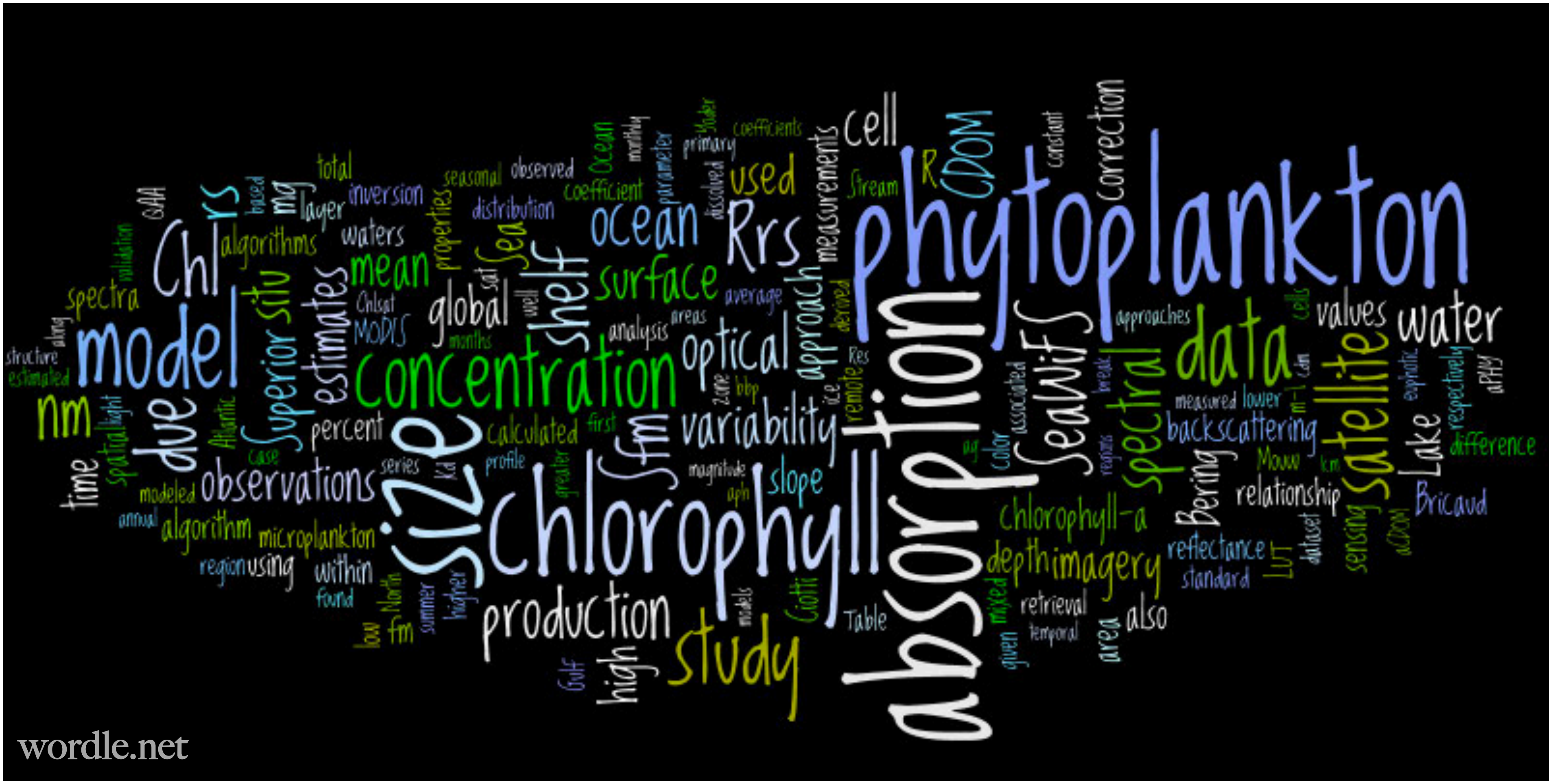
Particulate Absorption
CDOM Absorption
Keewenaw Bay, August 2014
North Shore, October 2014
Western Basin, August 2014
Depth (m)
Wavelength (nm)
a_p (m^{-1})
a_g (m^{-1})

Acknowledgements

- Gary Fahnenstiel (Michigan Tech U.)
- Tim Moore (U. New Hampshire)
- Mike Twardowski, Jim Sullivan (WET Labs)
- Galen McKinley, Haidi Chen (U. Wisconsin-Madison)
- Steve Effler, David O'Donnell, MaryGail Perkins, Chris Strait (Upstate Freshwater Inst.)
- SeaWiFS, MODIS: NASA Ocean Biology Processing Group
- Ice: National Snow and Ice Data Center

Photo credit: Chris Strait

Mouw Optics and Remote Sensing Laboratory



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http://www.geo.mtu.edu/~cbmouw