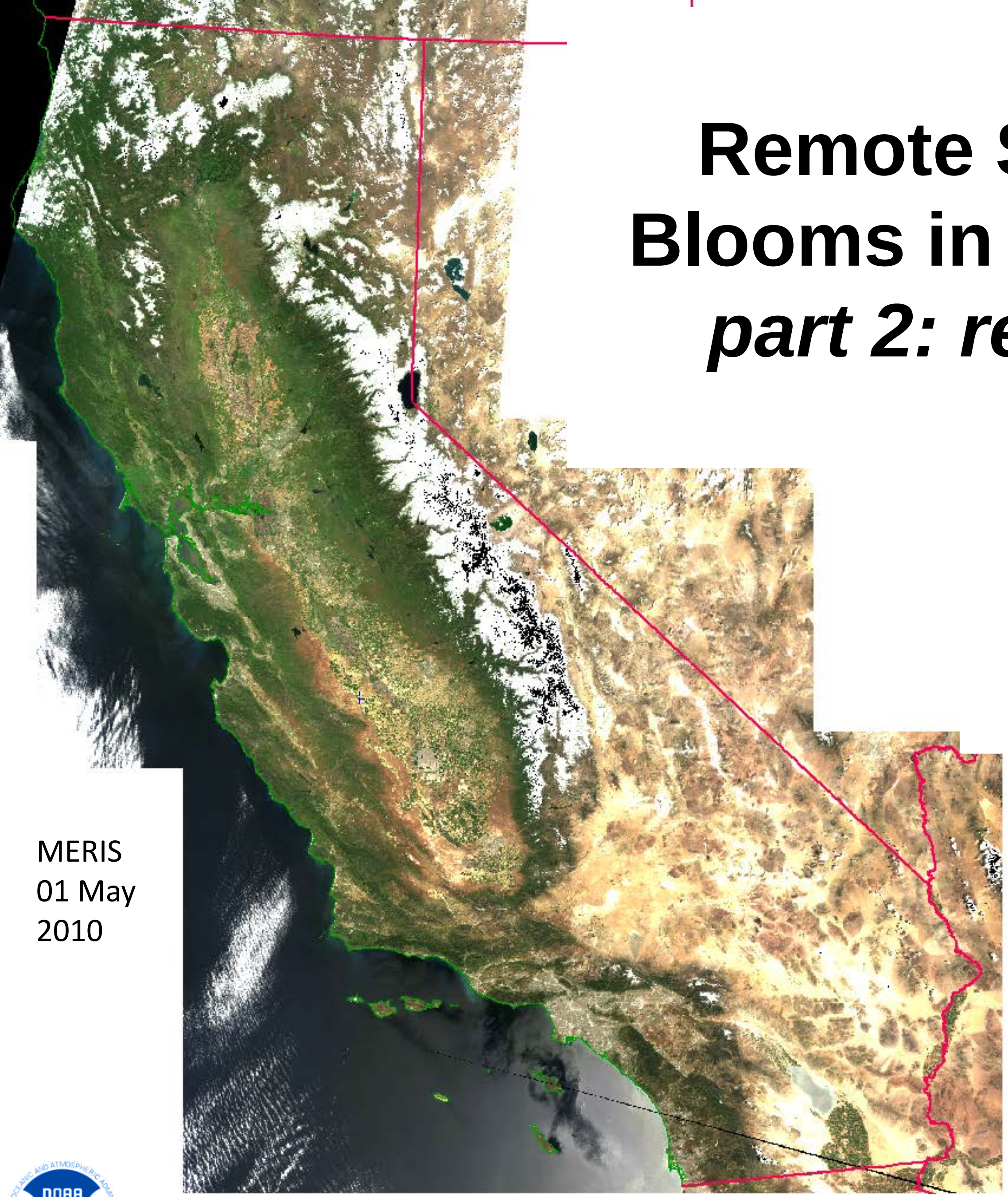


Remote Sensing for Algal Blooms in California Lakes
part 2: remote sensing

Rick Stumpf
Andrew Meredith
Shelly Tomlinson

NOAA
National Centers for
Coastal Ocean Science

MERIS
01 May
2010

Where Are We With Satellite

- We are concentrating on cyanos for this project
- Cyano blooms are observable.
- Cyano blooms are distinguishable from other blooms depending on the sensor
  - Some uncertainties on distinction between cyanos and non-cyanos
  - We are examining strategies to reduce these.
- All sensors can find scum
- Most sensors have limitations
  - Resolution trade-offs: spatial, spectral, temporal
- Experimental systems and field radiometers allow for evaluation of future high resolution strategies (not going to discuss that today).

First Remote sensing of an algal bloom, 1974

letters to nature

Nature **250**, 213 - 214 (19 July 1974); doi:10.1038/250213a0

Remote sensing and lake eutrophication

ROBERT C. WRIGLEY* & ALEXANDER J. HORNE†

An infrared photograph of part of Clear Lake, California (Fig. 1) shows beautiful, complex patterns of blue-green algal blooms which were not observed by conventional limnological techniques. Repeated observations of patterns such as these can be used to chart the surface movement of these buoyant algae and can also be used to help control algal scums in eutrophic lakes.

Resolution

- Spectral Resolution = How many bands there are.
- Temporal Resolution= how often you get an image
- Spatial Resolution = how much ground is detected in each pixel

Satellite Comparison for cyano applications

Satellite	Spatial	Temporal	Key Spectral
MERIS (2002-12) OLCI Sentinel-3 2015	300 m *OK*	2 day *good*	10 (5 on red edge) *good*
MODIS high res Terra 1999; Aqua 2002	250/500 m *OK* *poor*	1-2 day *good* *good*	4 (1 red, 1 NIR) *marginal* *OK*
MODIS low res & SeaWiFS	1 km *good*	1-2 day *poor*	7-8 (2 in red edge) *marginal*
Landsat	30 m *good*	8 or 16 day *Potential with 2*	4 (1 red, 1 NIR) *potential*
Sentinel-2 (2015)	20 m	10 day (5 day with 2nd satellite in 2017)	5 (1 red; 2 NIR, 1 in red edge)

Minimum resolution, 3 pixels across (2 mixed land/water)

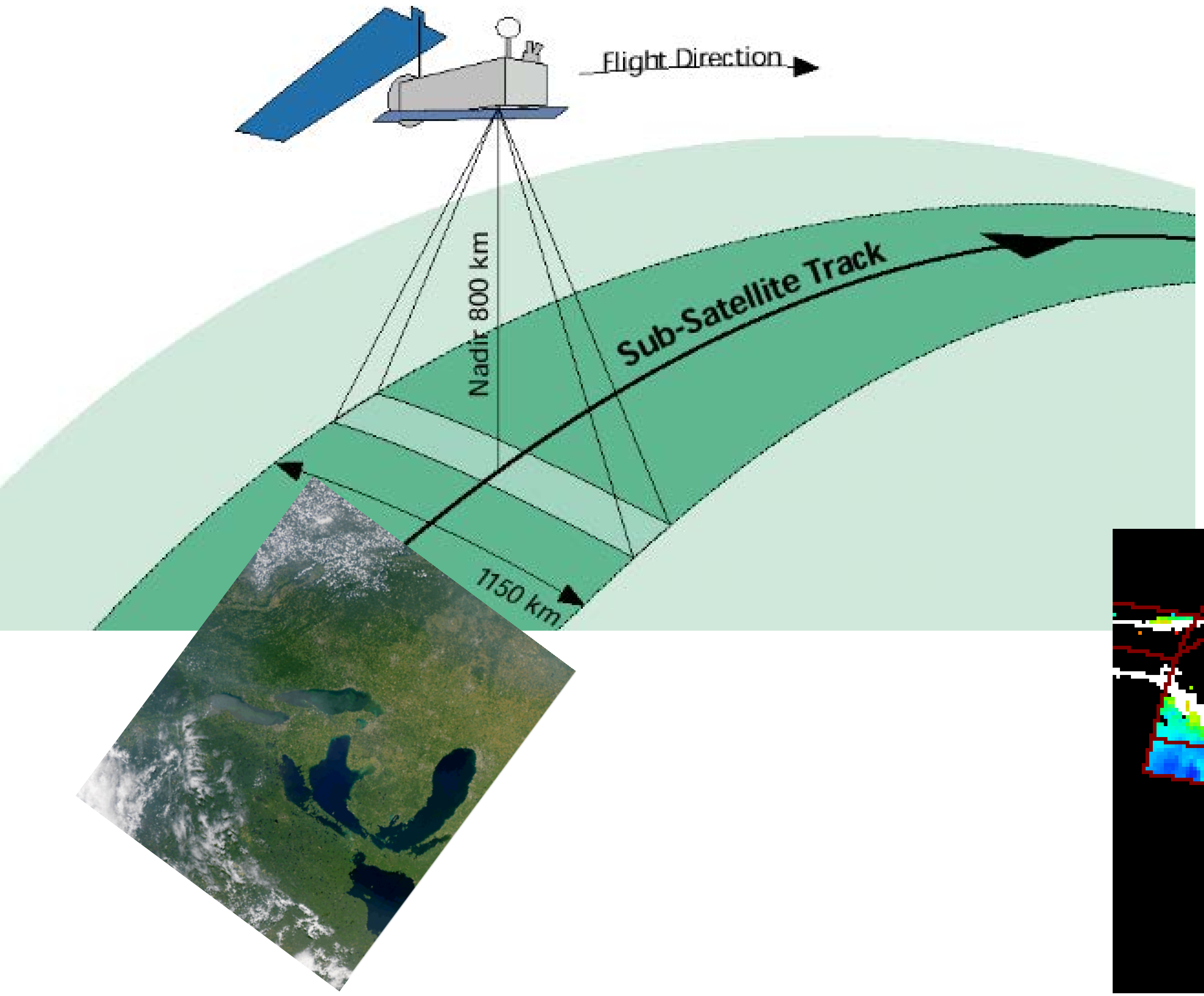
MERIS Medium Resolution Imaging Spectrometer

- Launched April 2002; Ceased operations April 2012.
- Spectral Resolution = 13 visible bands
- Spatial Resolution = 300 meters
- Temporal Resolution = 3-4 scenes a week.
- Cost = Free

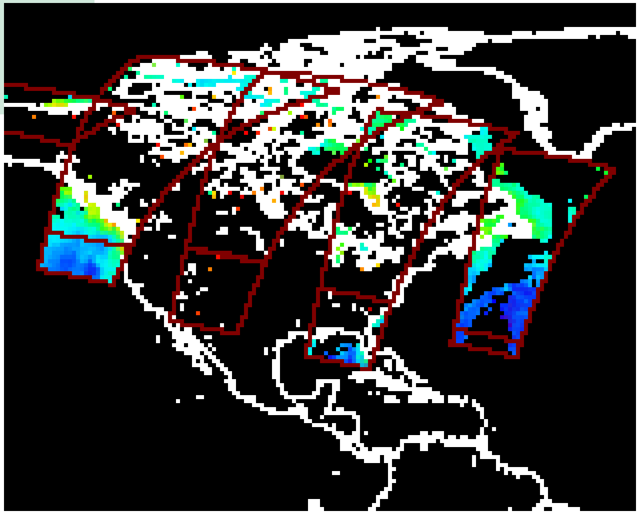
Replacement planned, launch later this year, Sentinel-3a OLCI (Ocean Land Colour Imager)

Sentinel-3b in two years

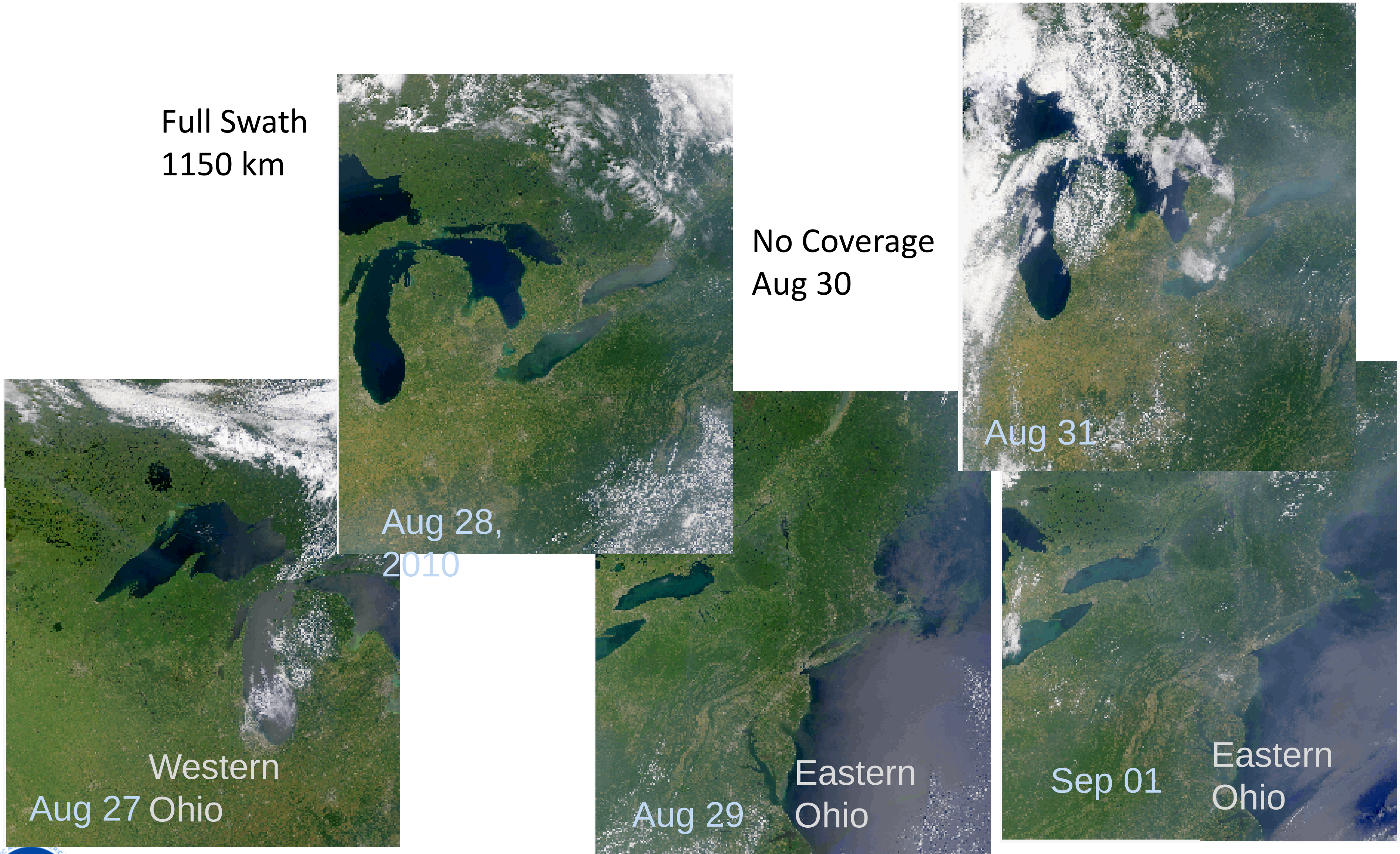
MERIS data collection



swaths over North America on Aug 28



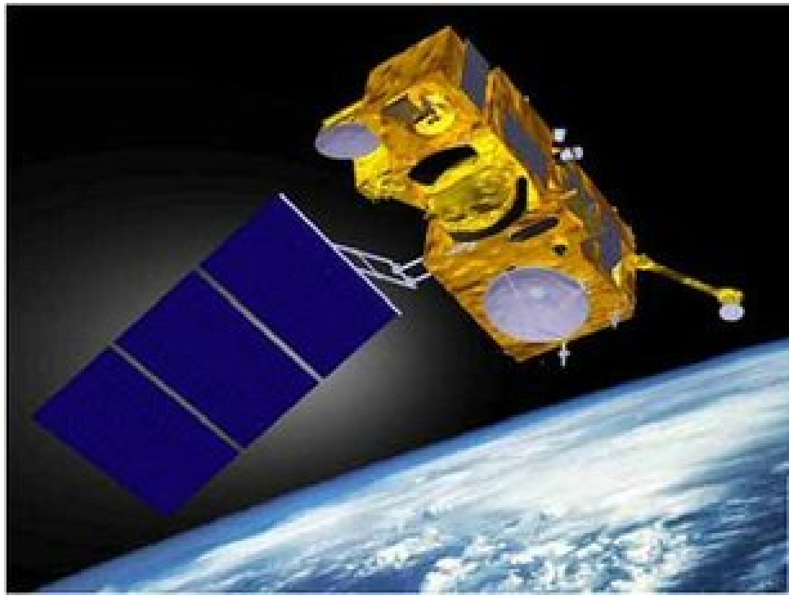
Satellite Coverage: “Swaths” move around



MERIS replacement in 2015: OLCI

Ocean Land Colour Imager on Sentinel-3

Satellite Launch due
for late 2015.

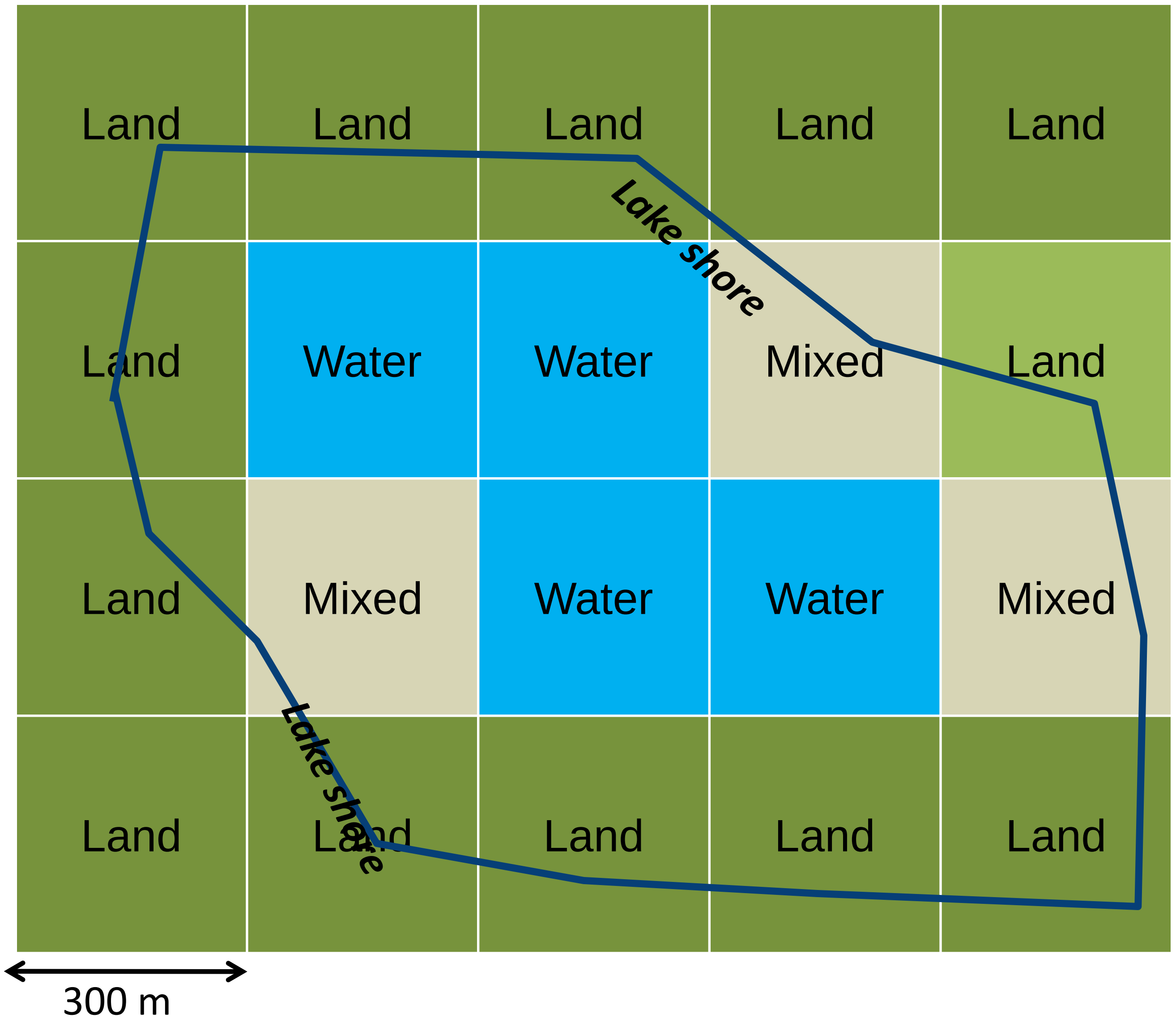


1270 km swath 300-m data
will be routine

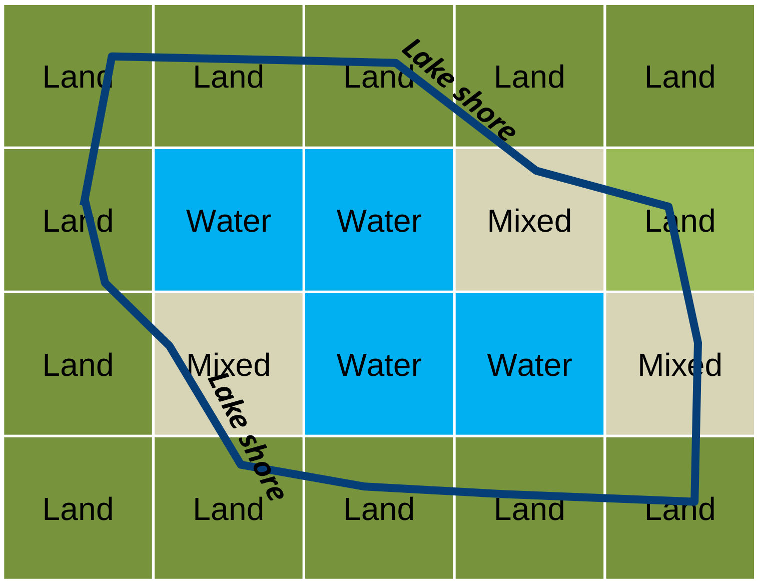
2nd satellite planned for launch two years later

Satellite Spatial Resolution, limits on detection

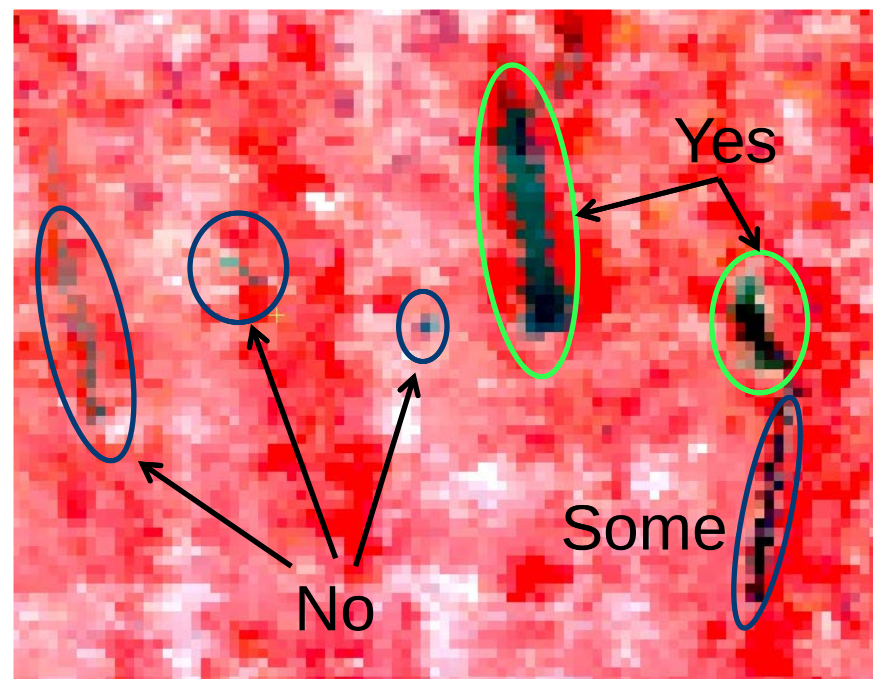
3 Pixels minimum width



Resolution and water bodies

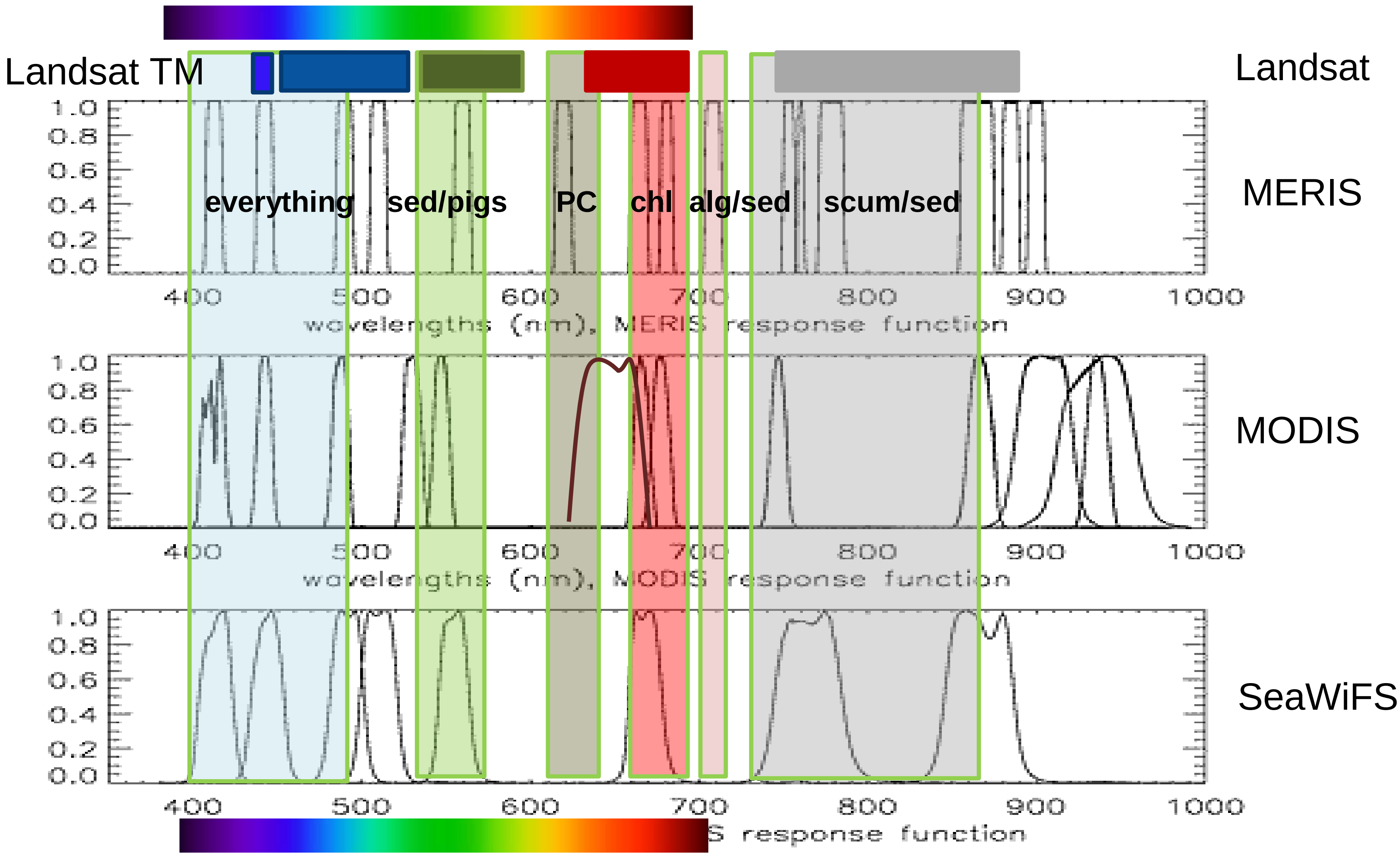


Mixed pixels limit our ability to monitor small water bodies

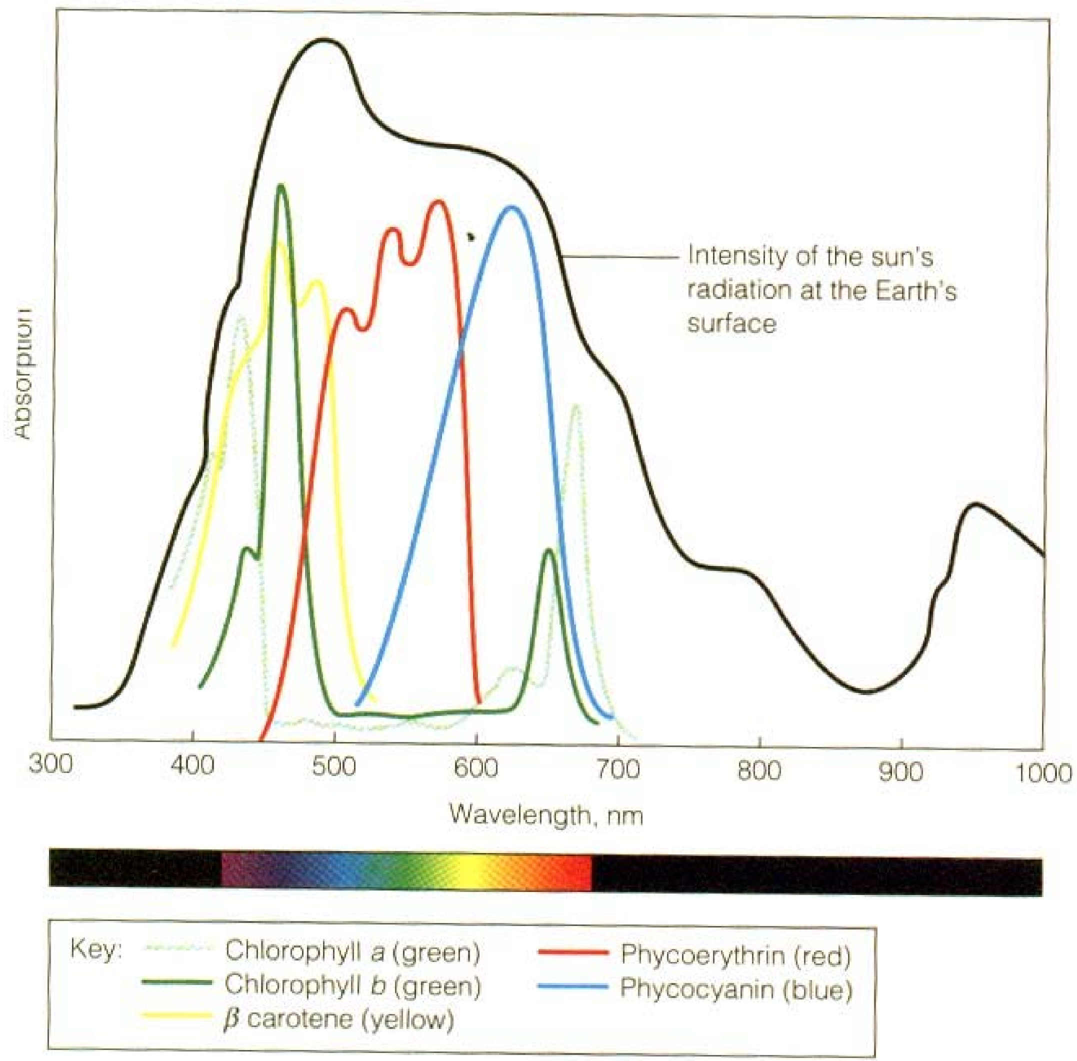


Note: in this case false color sharpens distinction between land and water. Reddish pixels at right include land.

Satellite bands and sensitivity to materials in the water

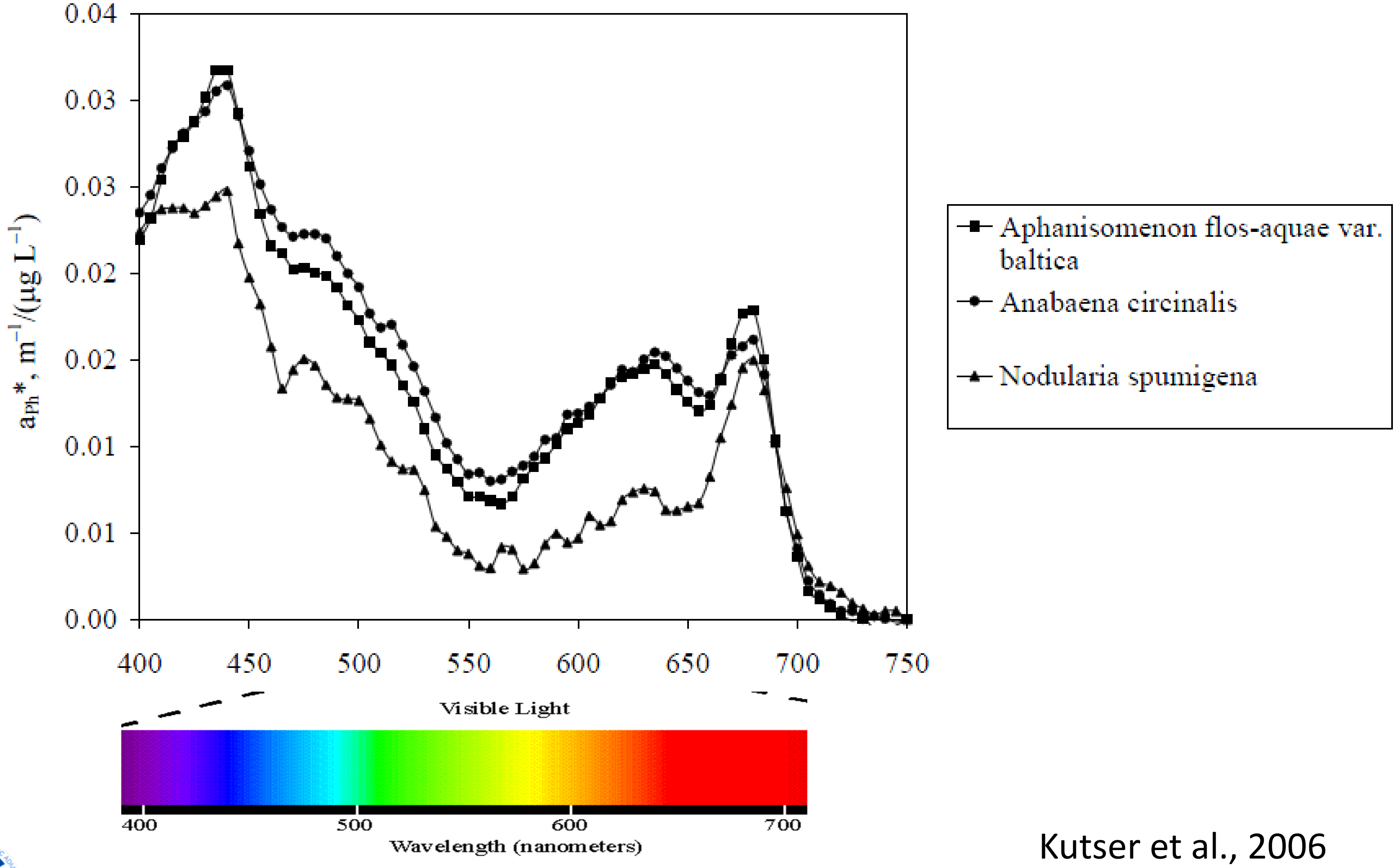


Various pigments in algae



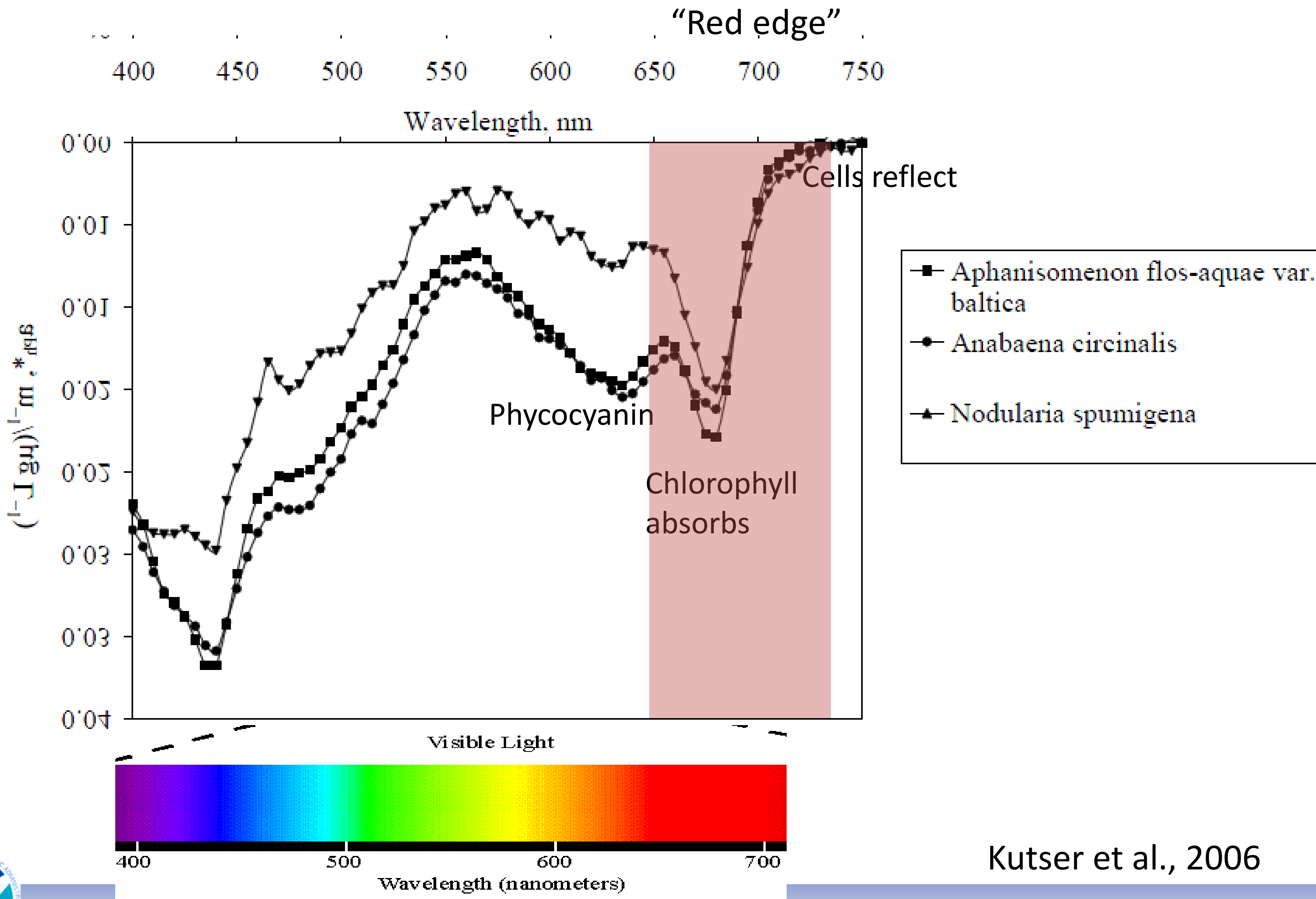
S. Berg Winona State
http://course1.winona.edu/sberg/Fac_sb.htm

When you add them together for cyanobacteria



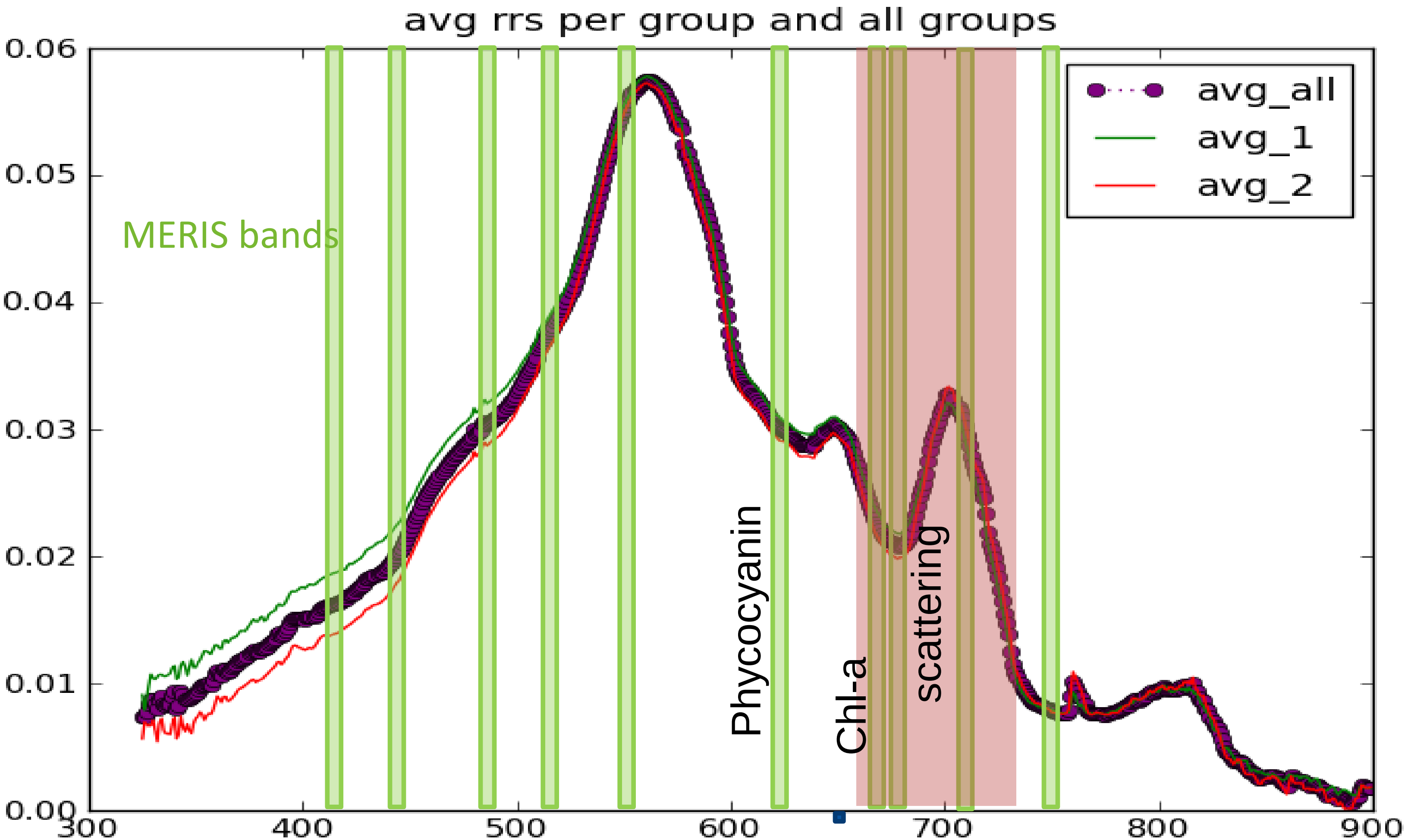
Kutser et al., 2006

Reflectance is the inverse of absorption

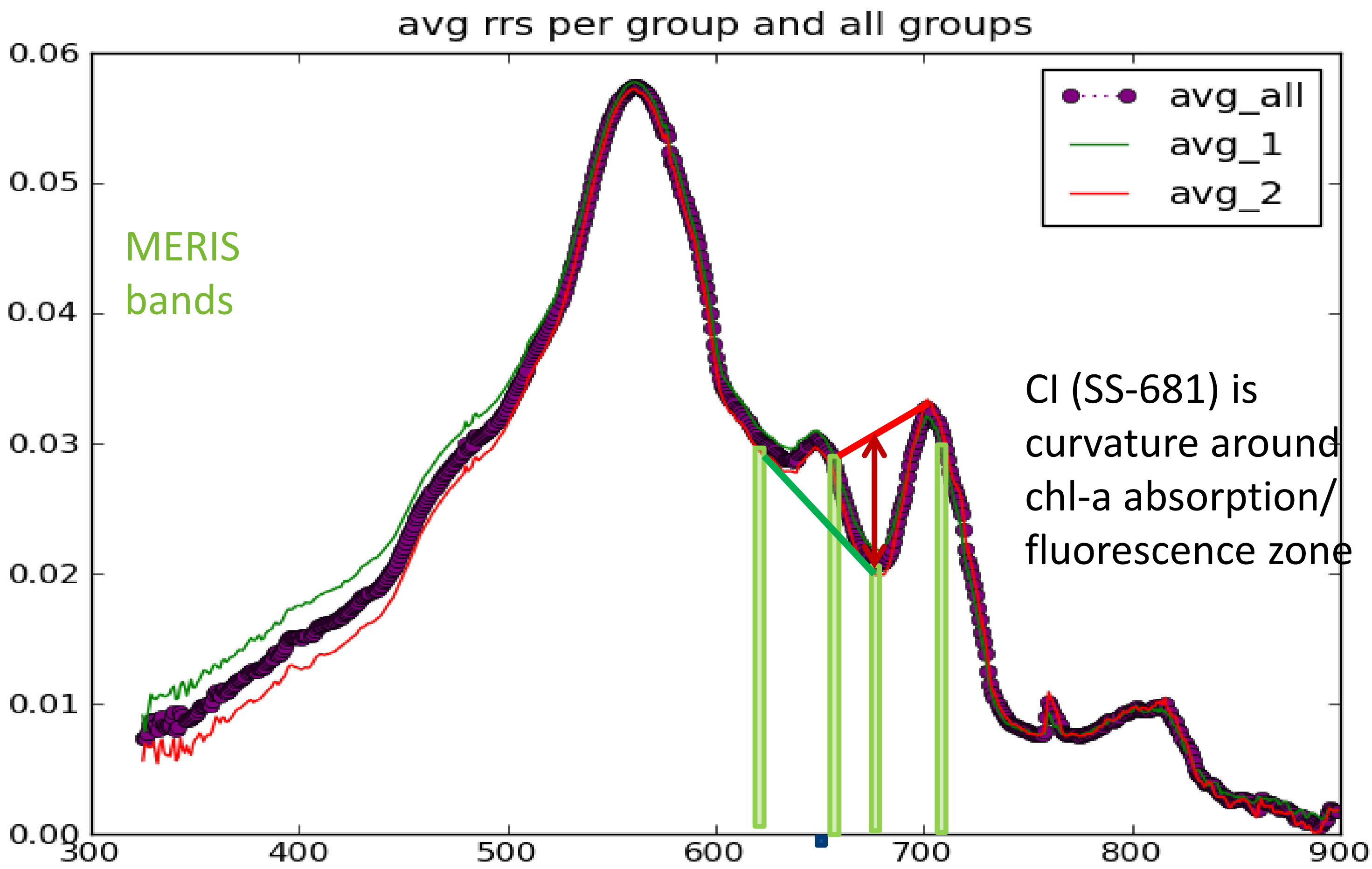


Kutser et al., 2006

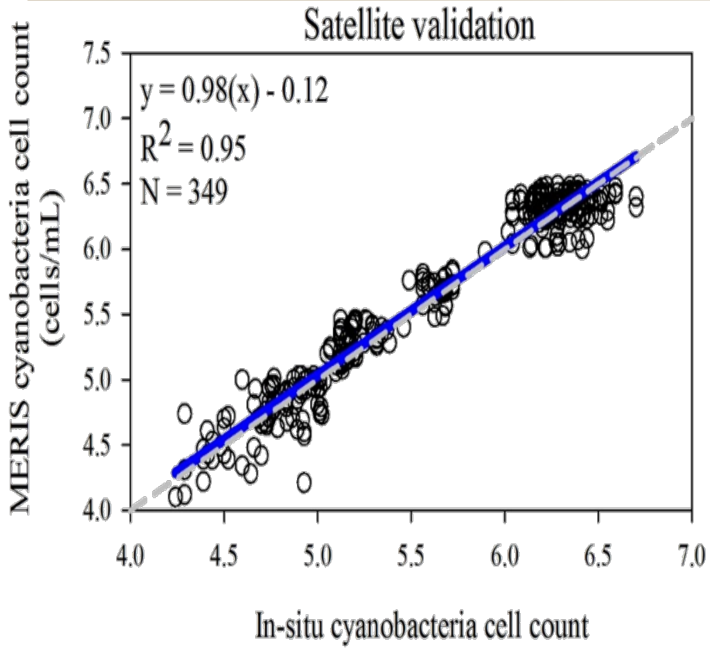
Intense blooms in water, red/NIR bands provide discrimination

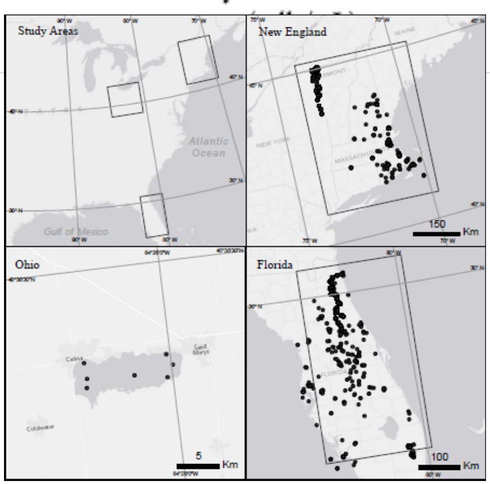


CI/SS681, intense blooms, more cyano sensitive

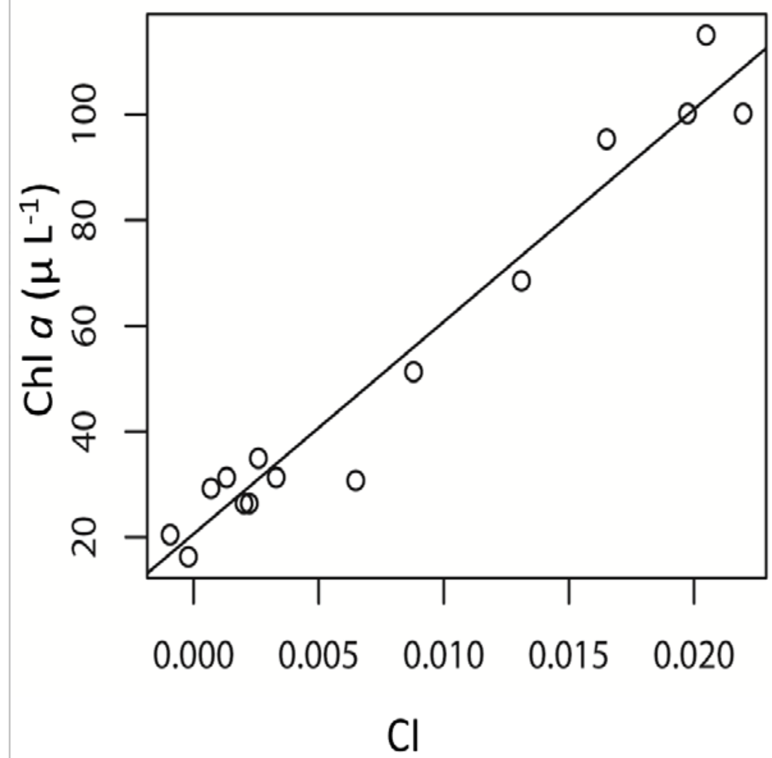


Example quantification for CI, Lake Erie transferred to many other lakes



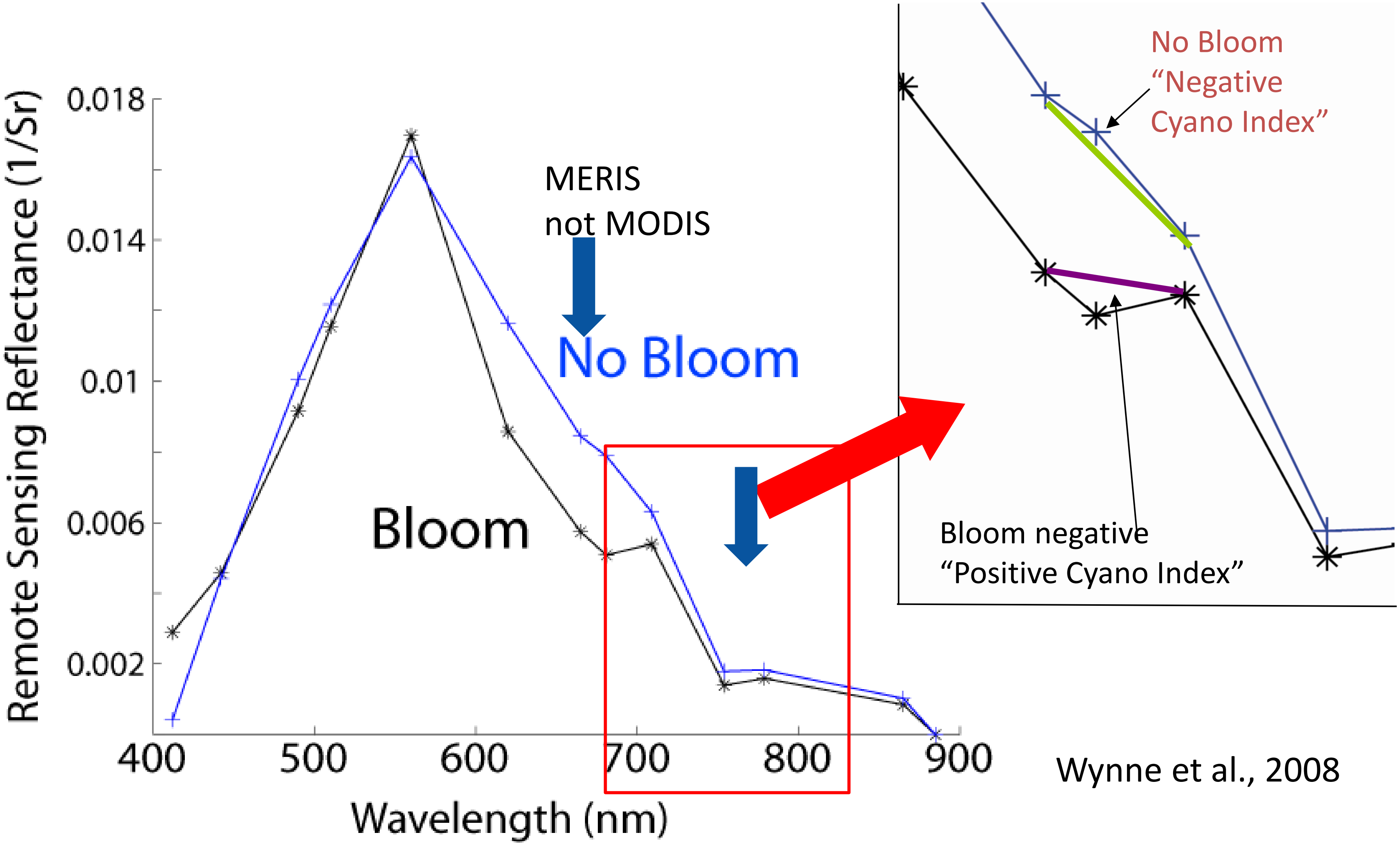


Lunetta et al., 2014



Relationship to chl-a
Tomlinson et al., submitted

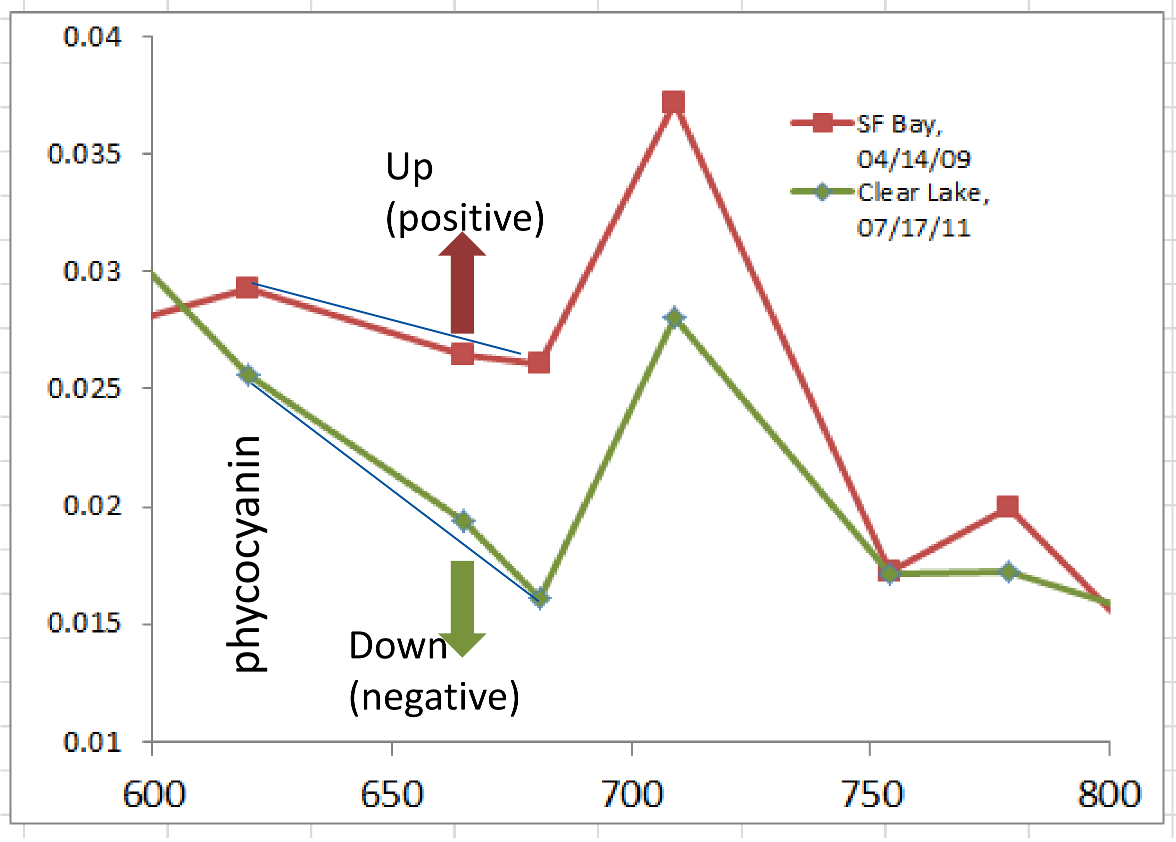
MERIS, CI SS-681 is the shape of the red edge



Wynne et al., 2008

Separation of cyanos and non-cyanos

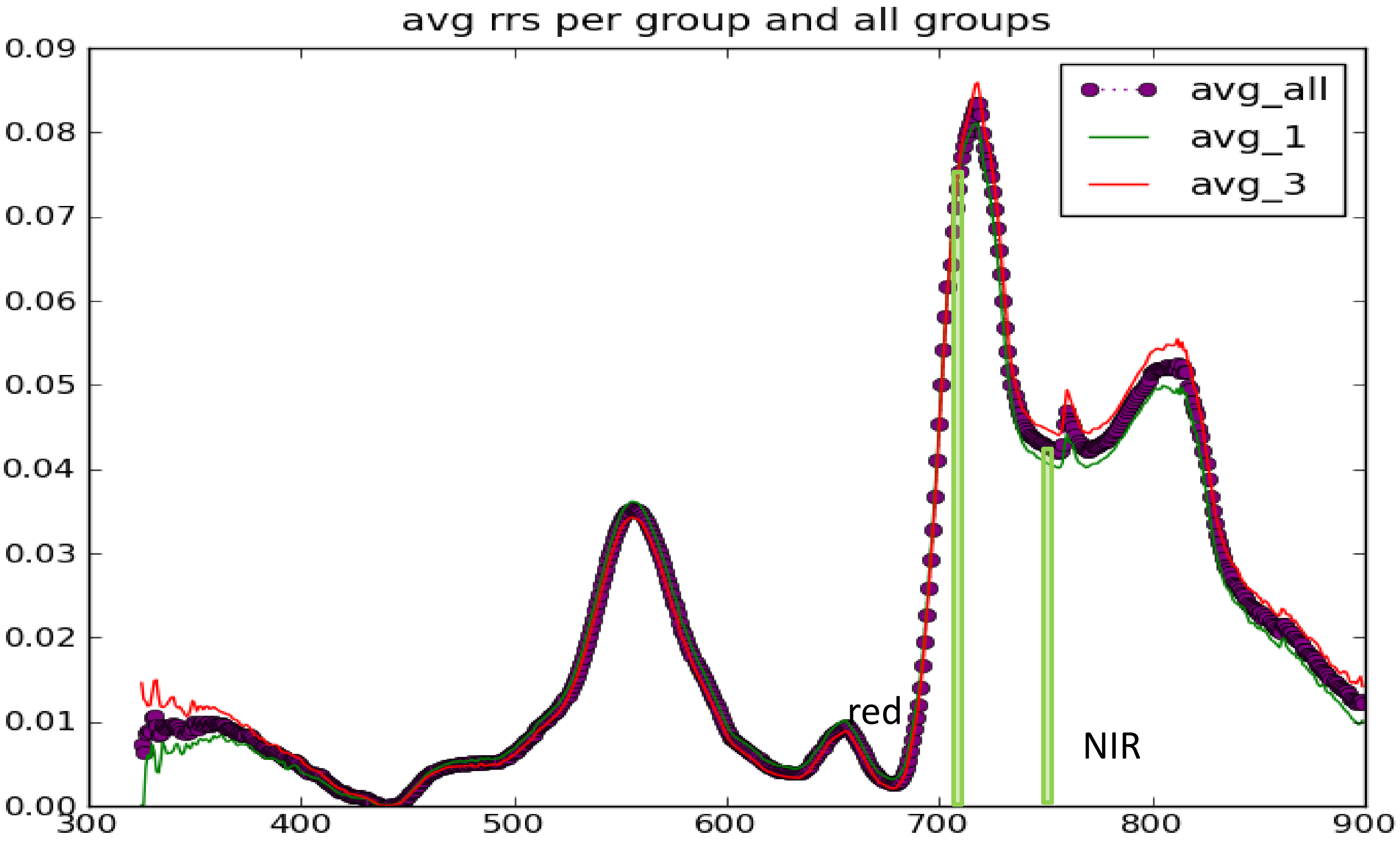
Phycocyanin depresses 620 band, changes curvature around 665 nm from “up” to “down” for cyanos



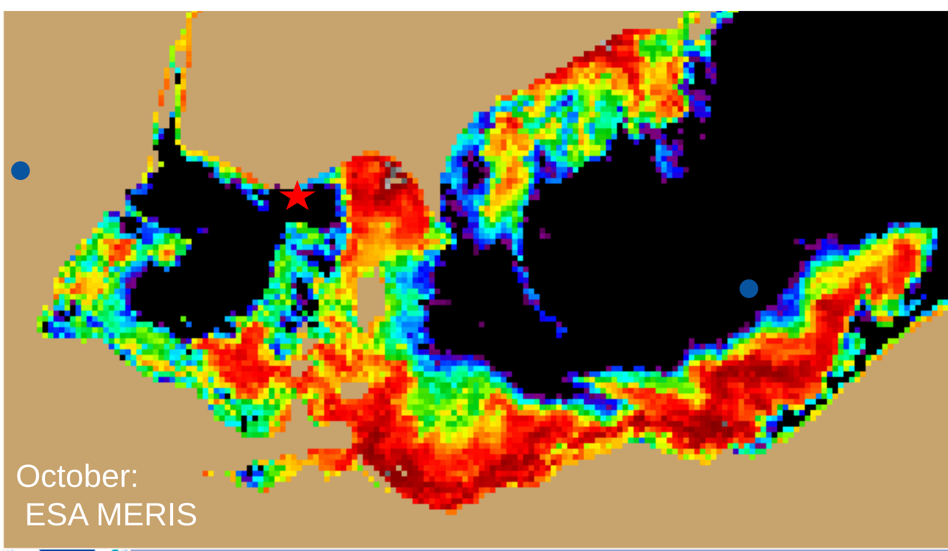
Caveat, this is “presence/absent”, with potential uncertainty.
We will be refining this to identify a clearer probability.

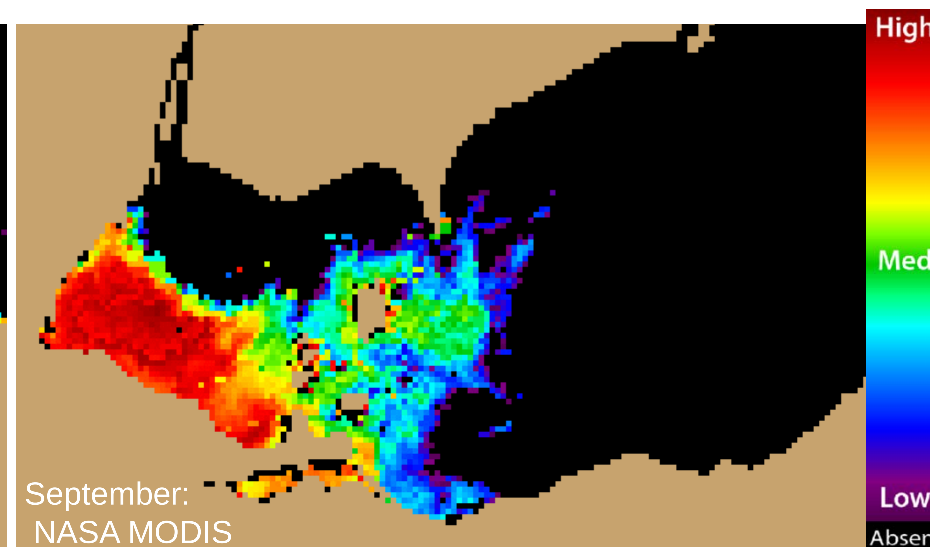
Some cyanos maybe identified as non-cyanos.

Spectra of *Microcystis* “scum”
High in NIR, low in red



How do we get analysis of where the bloom is
You’re familiar with the top images.

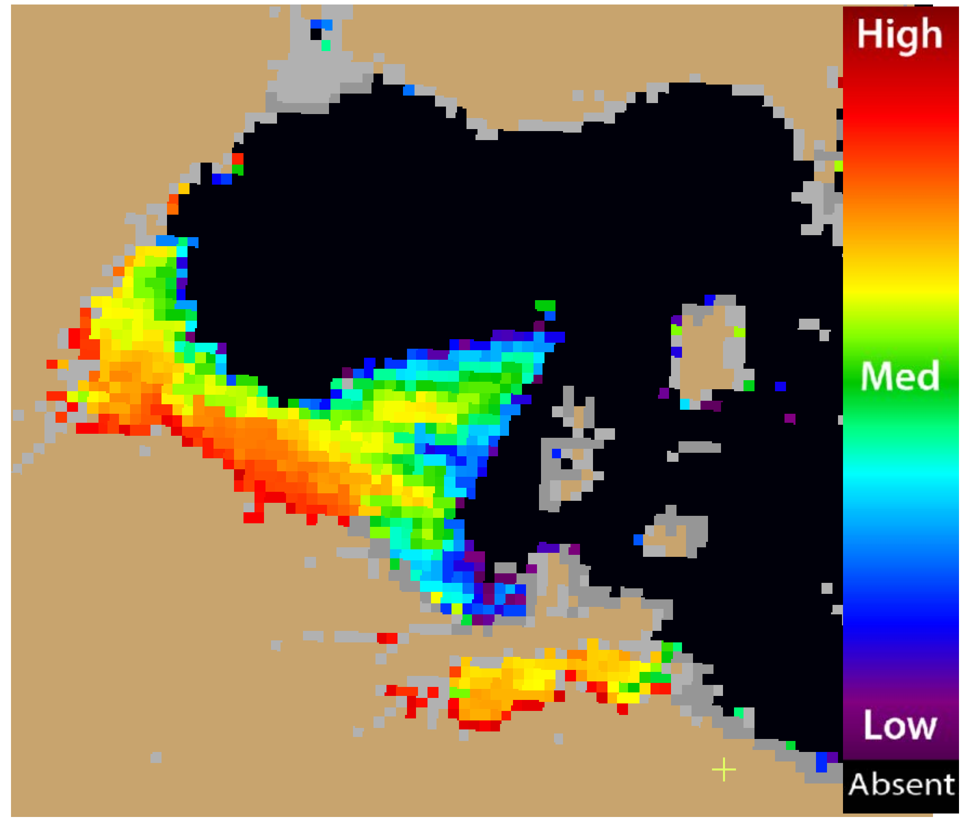




Find the bloom. This is not straightforward.

Enhanced true color, Aug 16, 2014

Cyano index



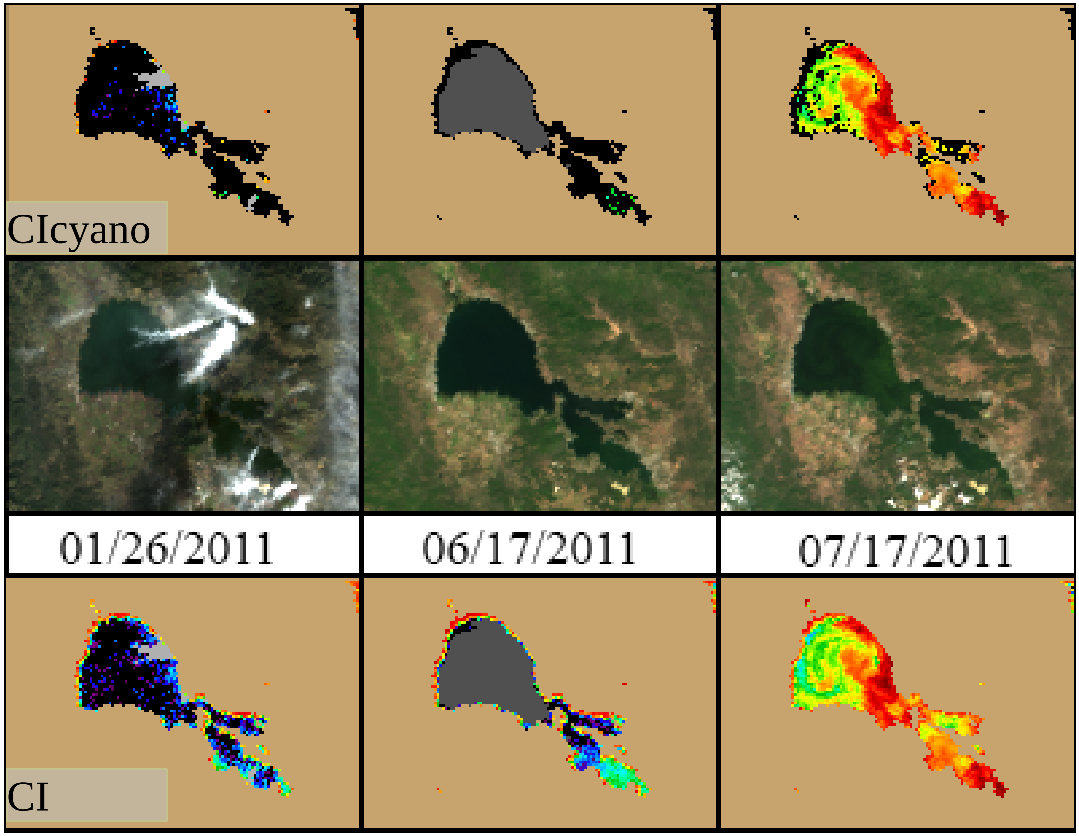
MODIS Cyano Index (CI)

Proof-of-of Concept example Clear Lake

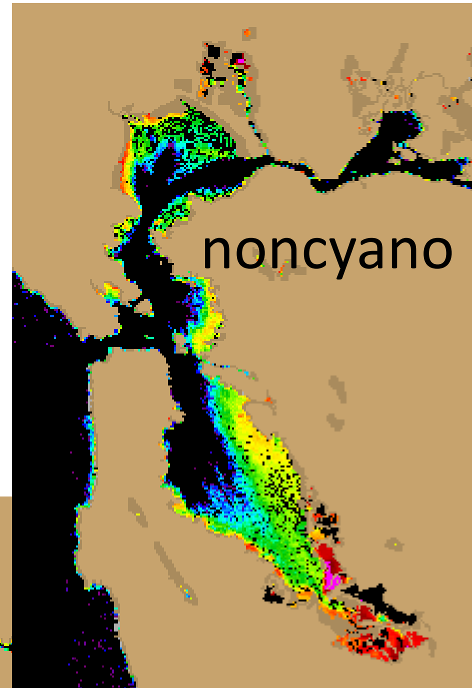
(Imagery shows intensification of chlorophyll-a in June)

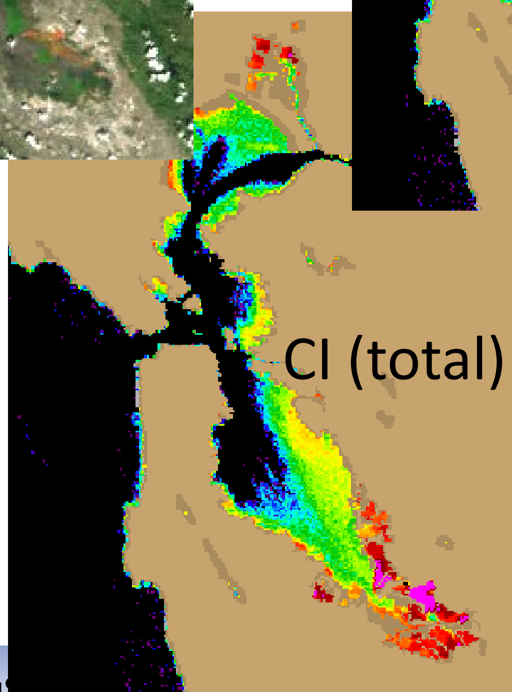
In mid June chlorophyll increased dramatically Clear Lake Lower Arms on June 16th, 2011. Clear Lake subsequently suffered a devastating cyanobacteria bloom that continue through the summer. Early June chlorophyll ~3 ug/L in NW, 15 ug/L in Lower Arms.

60 and 130 ug/L in mid July.

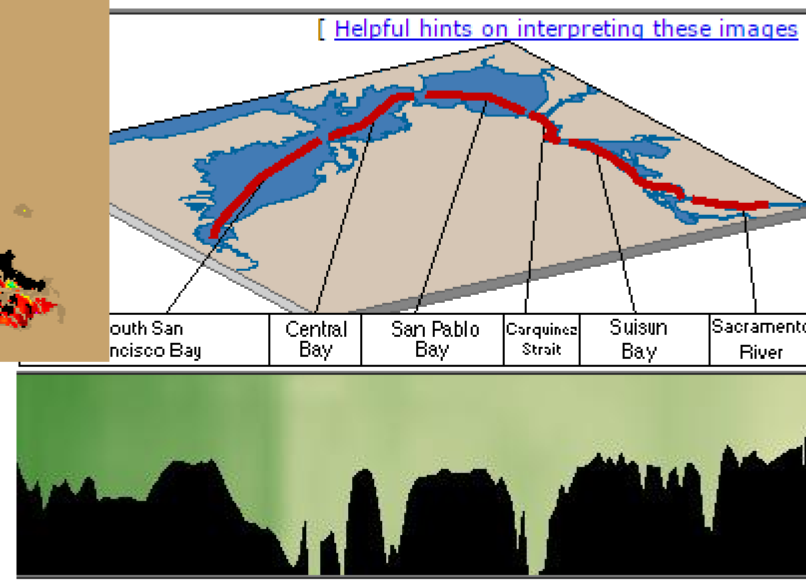


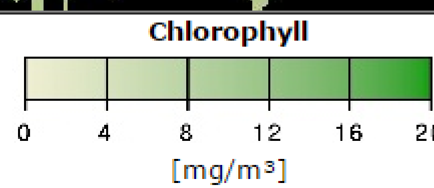
Example of non-cyano





2009Apr14 image showing “noncyano” spring bloom in south SF Bay.

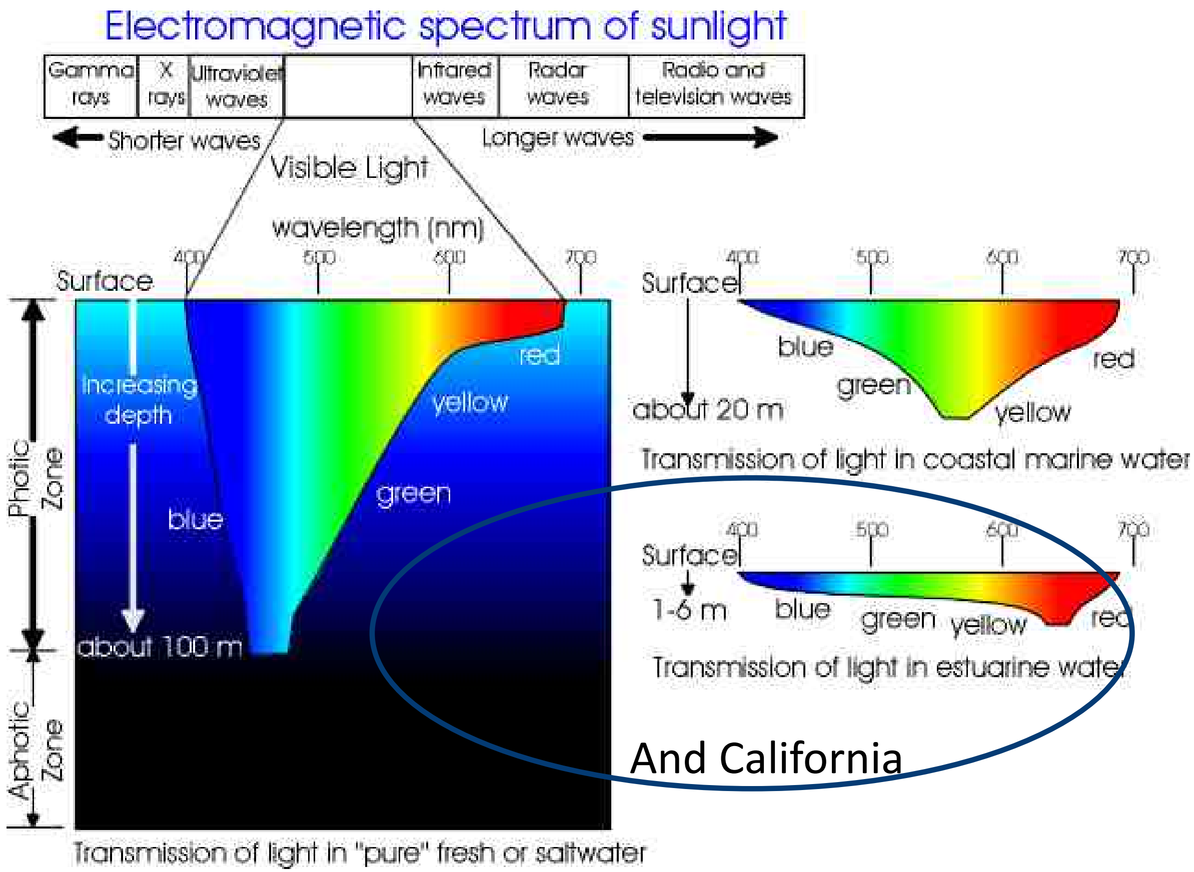




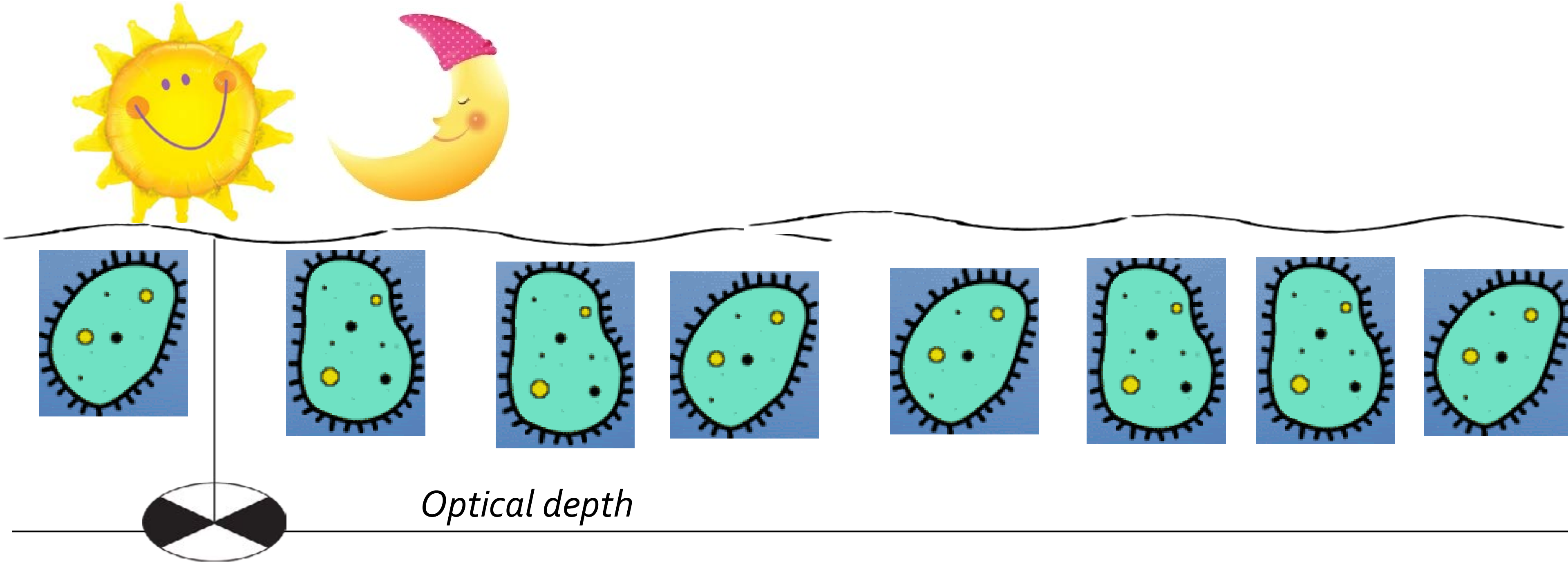
Cruise
Apr 16

Light penetration into the water.

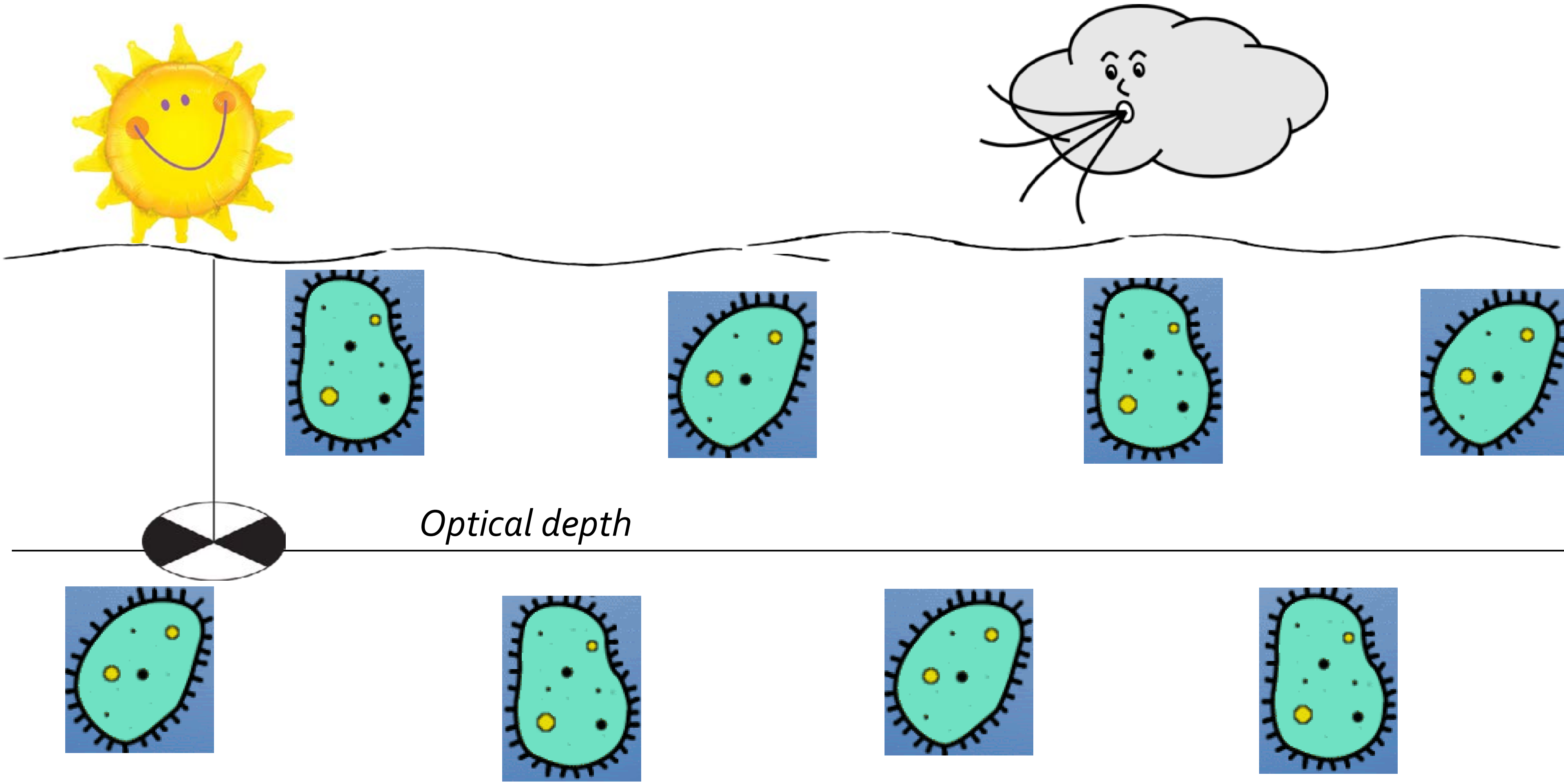
Blue light is scattered by clear water, red light is absorbed. Algae and tannins absorb blue and green. Rules of thumb: in clear water, light from 1-2 m at the red-NIR edge; in turbid, tens of cm. (Blue-green light from 1 Secchi depth).



Conceptual diagram no wind

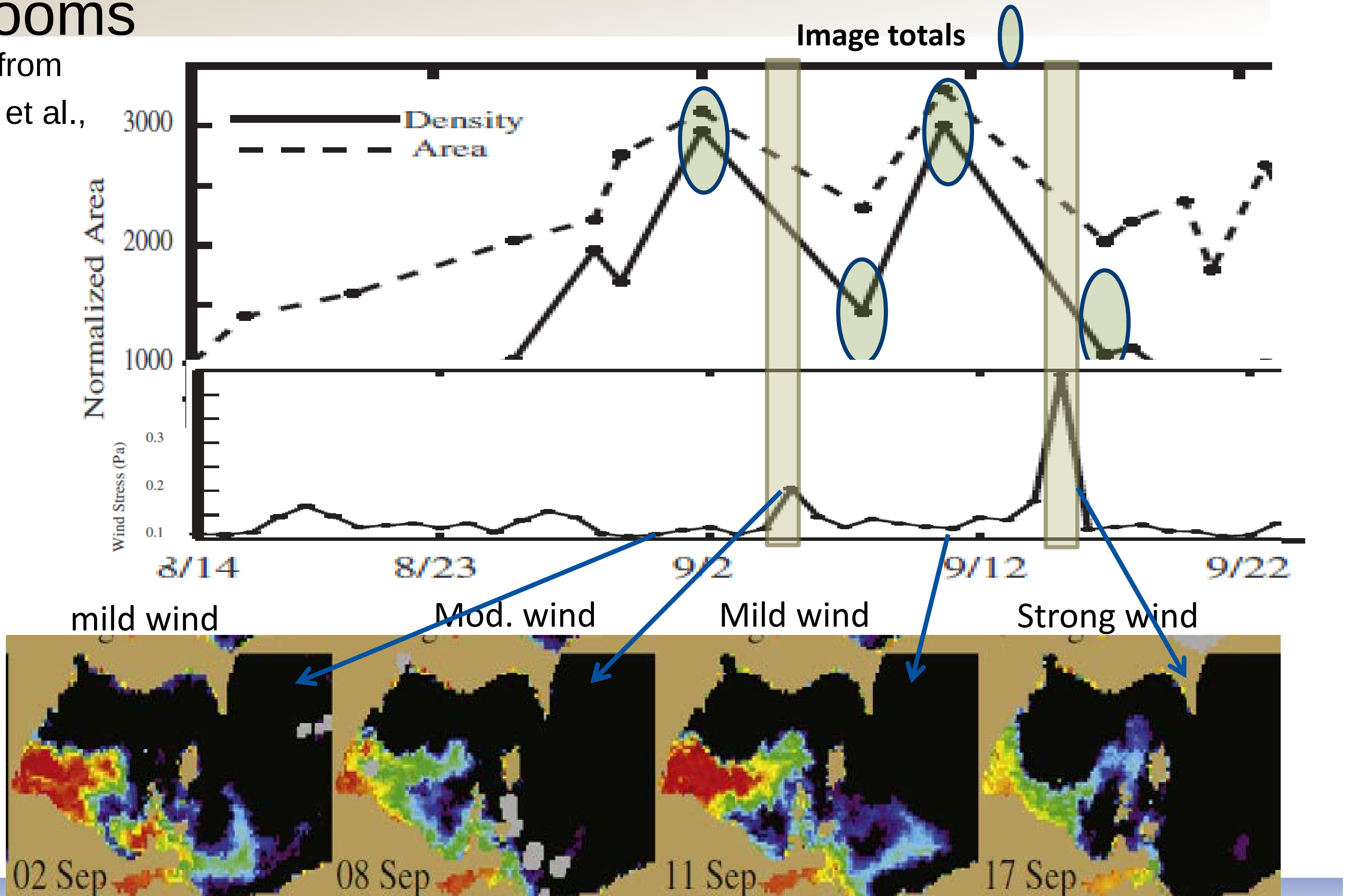


Conceptual diagram with wind



Satellite sees either surface scum or surface concentration. Caution on "averaging" buoyant blooms

Figure from Wynne et al., 2013)



OLCI data

- Improvements over MERIS
  - Less glint (points slightly away from sun)
  - About 2 day repeat with one satellite
    - 1-day repeat with two satellites
  - Routine 300 m data over land/coast
    - (MERIS 300 m had time gaps, esp. 2002-2008)
- Availability
  - CyAN project (NOAA-NASA collaboration).
  - Initial product type same as MERIS for cyanos
  - Current products do not require long validation

Cyanobacteria Assessment Network (CyAN)

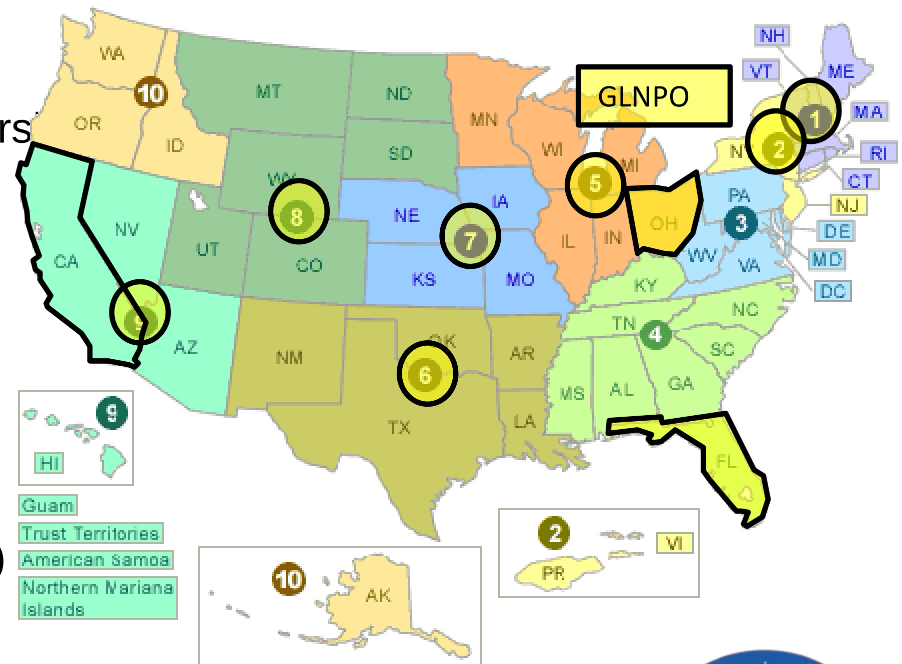
Getting satellite ocean color capabilities into U.S. water quality mgmt decisions

Starting fall 2015, multi-year project

collaboration of EPA Office of Water; NOAA Natl Centers Coastal Ocean Science; NASA; USGS

Partners

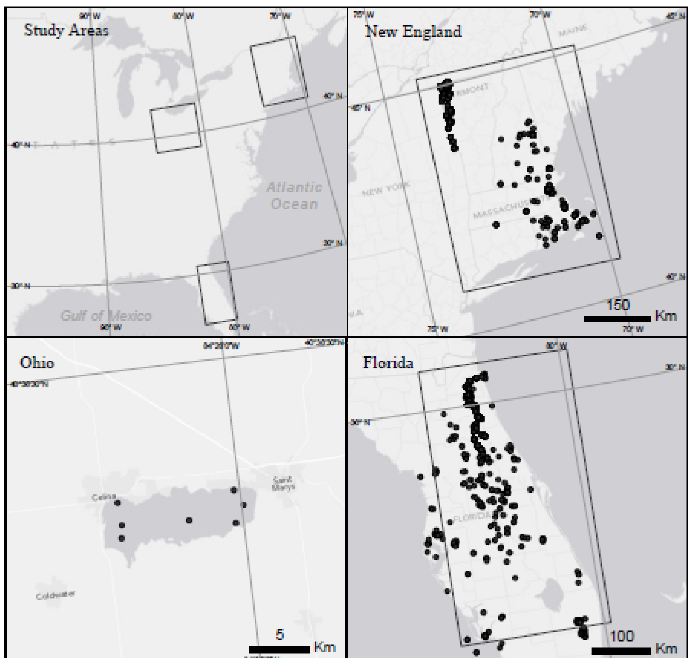
- EPA Office of Water
  - Office of Wetlands, Oceans, and Waters
  - Office of Wastewater Management
  - Office of Science and Technology
- EPA Regions
- U.S. Army Corps of Engineers
- States
  - Ohio EPA
  - Florida (St Johns R, & S Florida WMD)
  - California

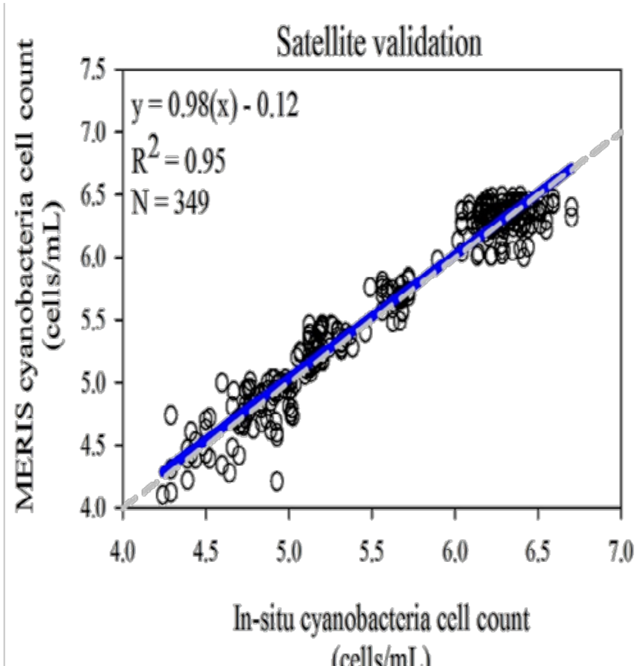


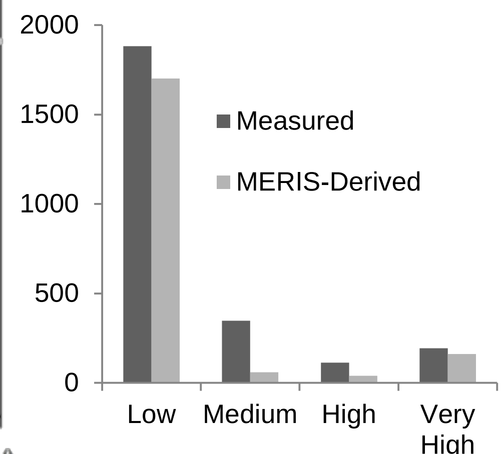
Validation of Lake Erie algorithm for other areas with EPA; start of Cyanobacteria Assessment Network

- **Remote Sensing**
  - *Uniform and systematic approach for identifying cyanobacteria blooms.*
    - Second derivative spectral shape algorithms (SS; Wynne et al. 2008)

$$SS(\lambda) = \rho_s(\lambda) - \rho_s(\lambda_-) + \{\rho_s(\lambda_-) - \rho_s(\lambda_+)\} * \frac{(\lambda - \lambda_-)}{(\lambda_+ - \lambda_-)}$$







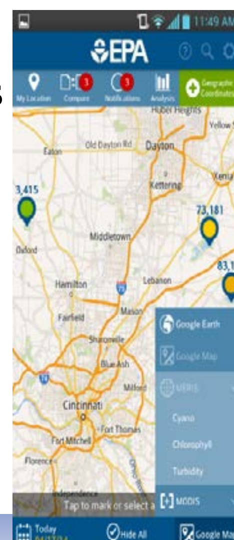
Lunetta, Schaeffer, Stumpf et al. Remote Sensing of Environment

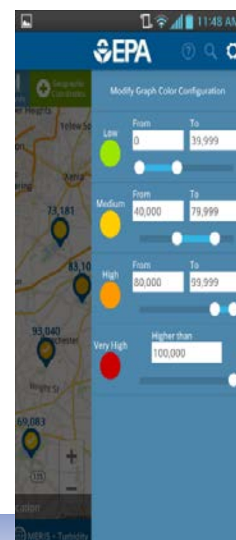
Technical Approach

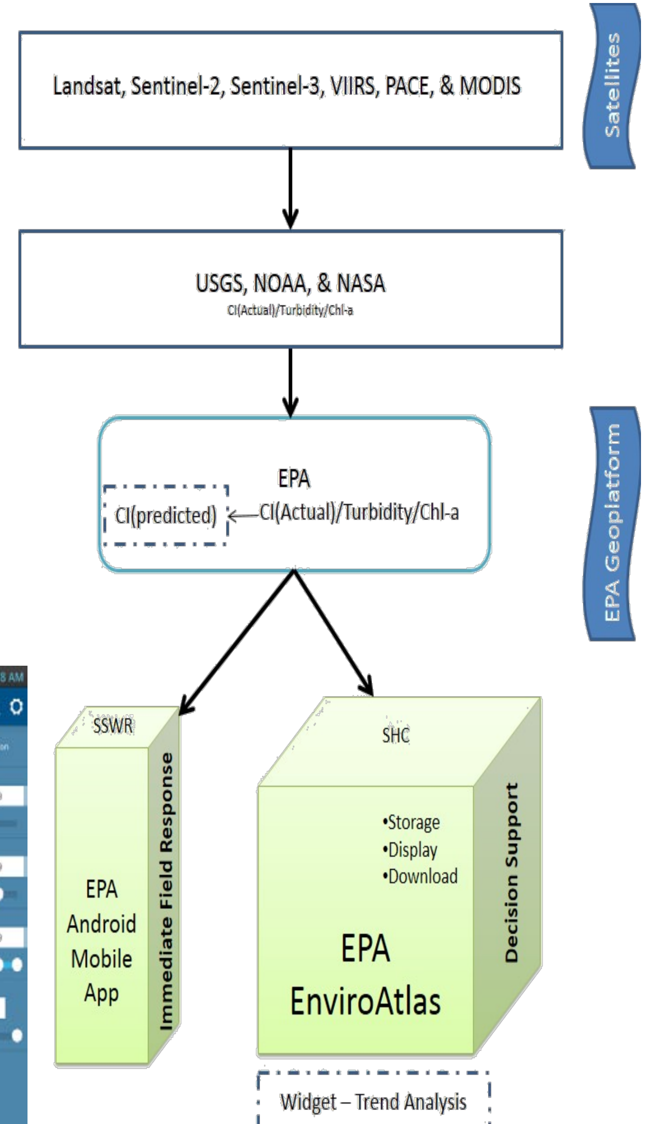
- ***Remote Sensing***
  - *Uniform and systematic approach for identifying cyanobacteria blooms.*
  - *Strategy for evaluation and refinement of algorithms across platforms.*
- ***Environment***
  - *Identify landscape linkages causes of chlorophyll-a and cyanobacteria.*
- ***Health***
  - *Exposure and human health effects in drinking and recreational waters.*
- ***Economics***
  - *Behavioral responses and economic value of the early warning system.*
- ***Notifications***
  - *Bring the technology to EPA, states and tribal partners.*

Technical Approach

- **Notifications**
  - *Bring the technology to EPA, states and tribal partners.*
  - Bring Ocean color satellite data to stakeholders in a manner that demonstrates its practical value to daily life (Schaeffer et al. 2013).
  - Multiple Approaches
    - Data pushed from NOAA, NASA and USGS to EPA Mobile Android Platform on weekly time-steps.
    - Data can be pulled by states







Impacts

- Informed decision making under the Clean Water Act and Safe Drinking Water Act.
- Complement National Aquatic Resource Surveys.
- Applied novel sophisticated tool to assist in management of events that may involve significant risk to the public.
- Increased use of remotely sensed water quality data to improve decision support in EPA and state agencies.
- Decrease costs of monitoring, improve resource allocations, and reduce exposures.