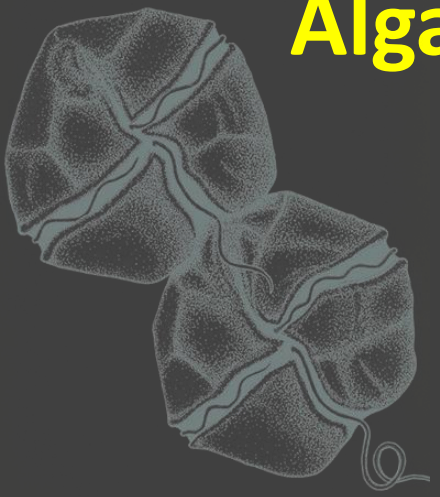
What Have We Learned About Harmful Algal Blooms From Ocean Colour?

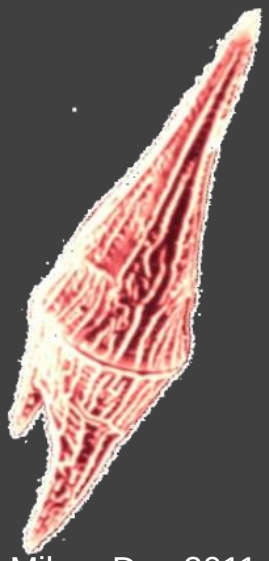


Raphael Kudela

University of California – Santa Cruz

Ocean Colour & Harmful Algal Bloom Working Group

International Ocean-Colour Coordinating Group
IOCCG
&
Global Ecology and Oceanography of Harmful Algal Blooms
GEOHAB



Second WG Meeting, Milan, Dec 2011

First Meeting, August 2010
Schulphoek, South Africa

Collaborators

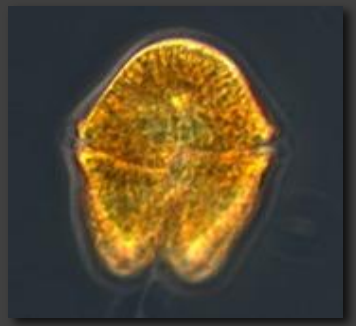
- HyspIRI/HQ2O Projects (NASA)
  - Liane Guild
  - Sherry Palacios
  - Juan Torres-Perez
- NASA Student Airborne Research Program
  - David Austerberry
  - Emma Accorsi
  - Kimee Moore
  - Noah Tuchow
- HAB Forecasting (NOAA, NASA)
  - Clarissa Anderson
  - Mati Kahru
  - Yi Chao
- COAST HES-CW
  - Curt Davis
  - Paul Bissett
  - Rick Reynolds
  - Derek Gray

All these programs include large teams of investigators who are not listed—Thank You!

What Can Ocean Colour Provide to the HAB Research/Monitoring Community?

- Typical Answer:
  - Nothing. You must identify species… my organism is low-biomass but highly toxic… my organism is in the subsurface.
- What would you like?
  - HAB species, abundance, toxicity. Predictions of where HABs will be. And I want it now!

The Rogue's Gallery– California HABs



Akashiwo sanguinea

- Dinoflagellate
- massive bird mortality from foam production

Pseudo-nitzschia spp.

- Cosmopolitan
- Causes Amnesic Shellfish Poisoning

Microcystis (blue-green algae)

- Previously a freshwater problem
- Recently monitored in coastal waters

Harmful Algal Bloom: any phytoplankton that is toxigenic, or has been linked to detrimental impacts

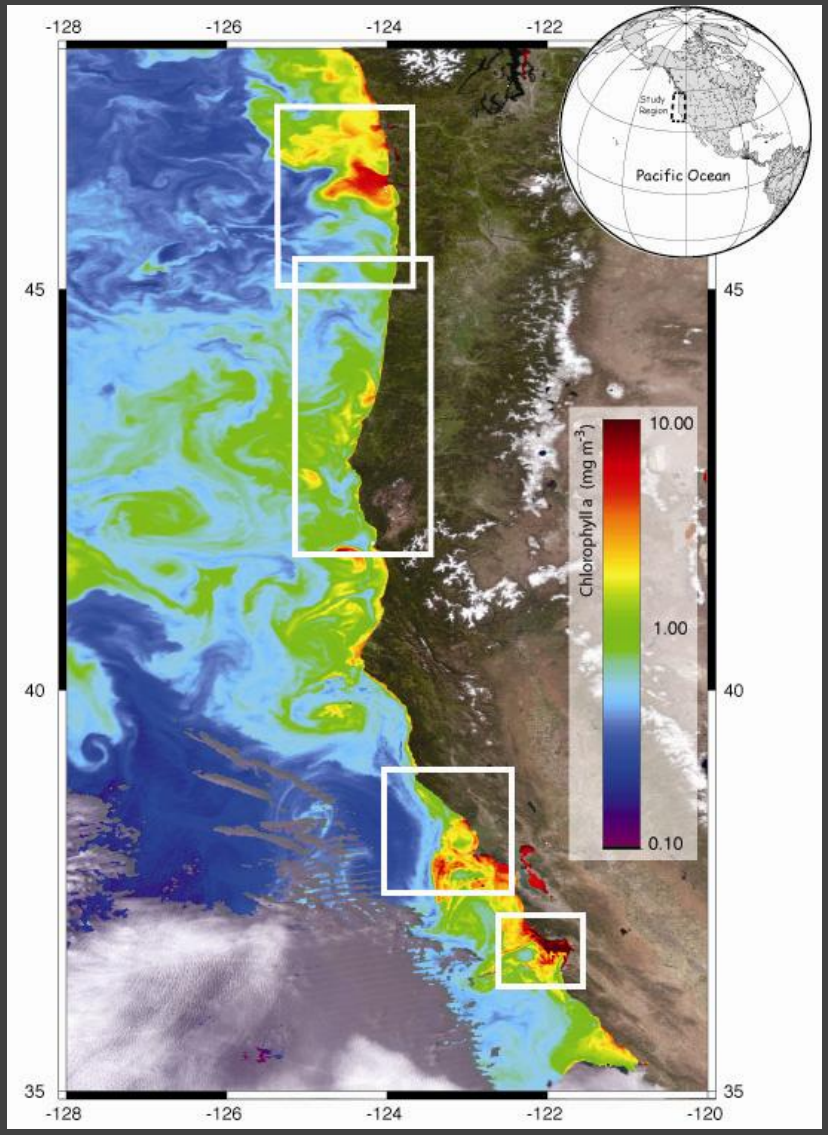
Three Examples

1) Using PFTs to detect Dinoflagellates

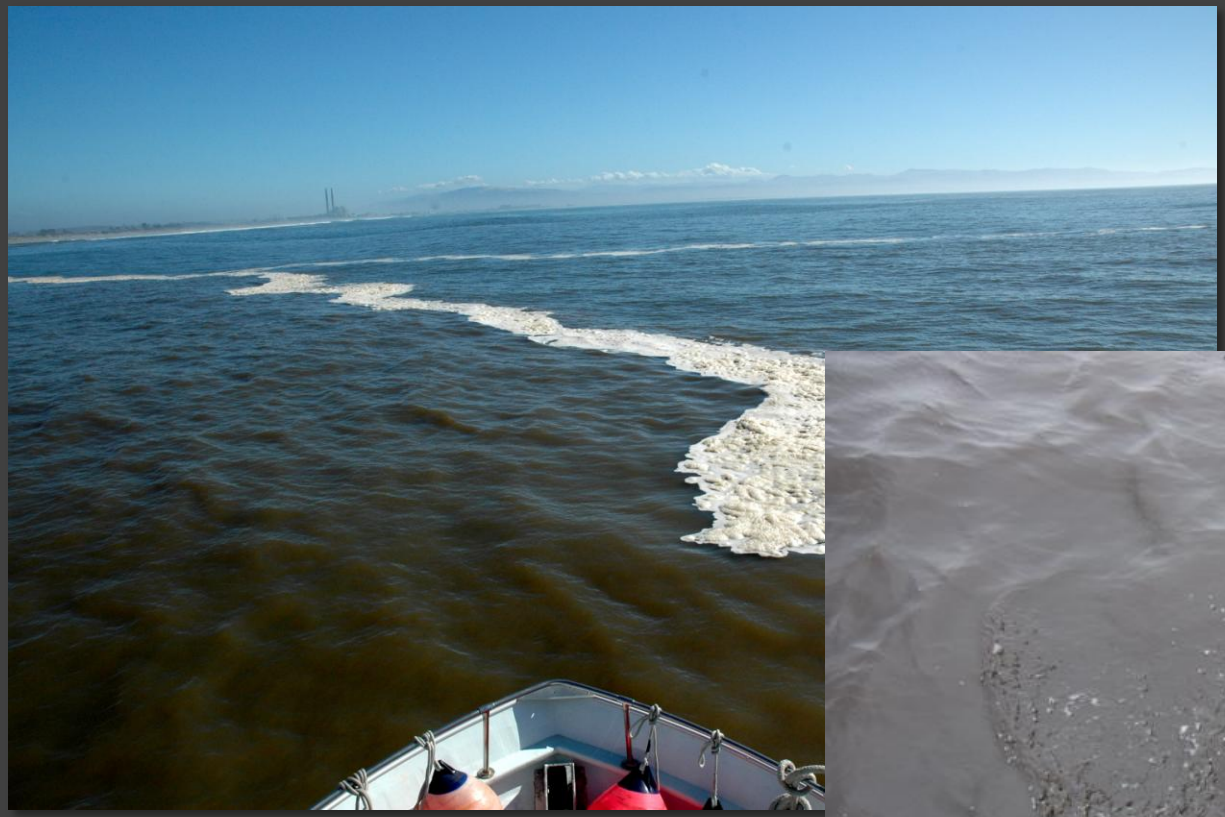
2) Blue-Green Algae—an Emerging Threat

1) Operational Forecasting of Domoic Acid

- Focus on Monterey Bay
- Not including high-biomass



Case Study 1: PFTs

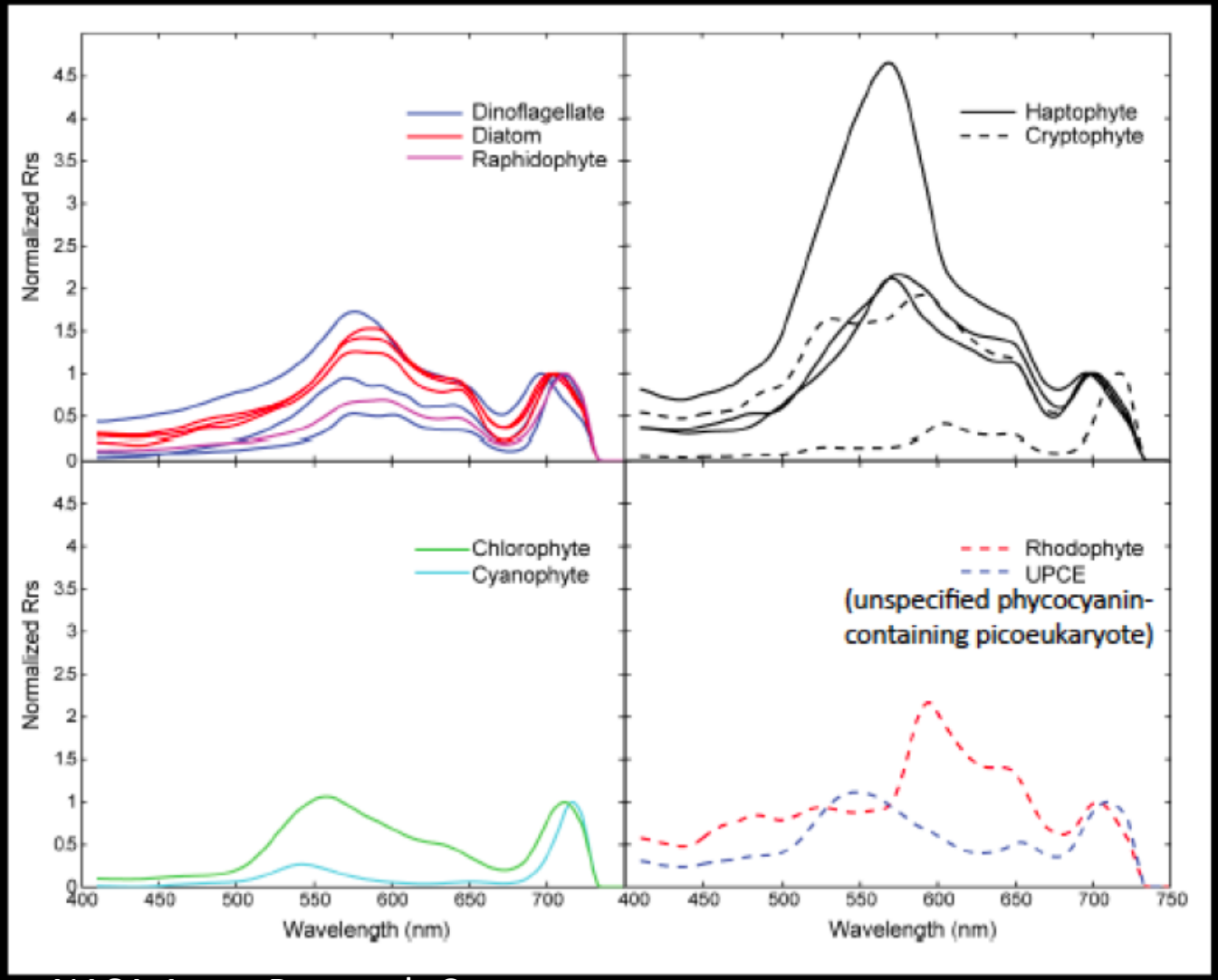


What would a patch of pure phytoplankton culture look like in the ocean?

$$C \frac{b_b}{a + b_b} = R_{rs}$$

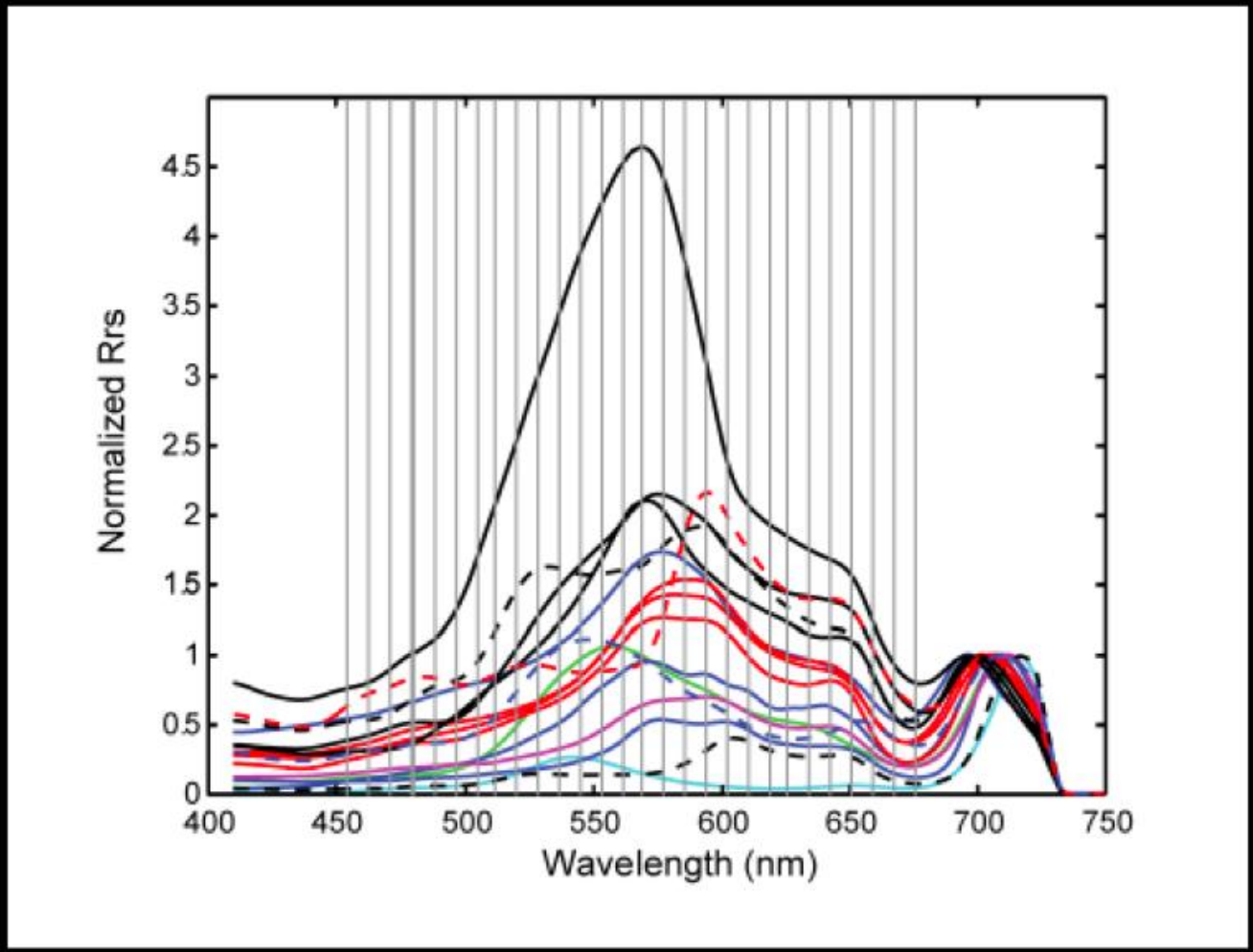
Sherry Palacios, NASA Ames Research Center

R_{rs} Signature Library



Sherry Palacios, NASA Ames Research Center

Building Signature Library Matrix



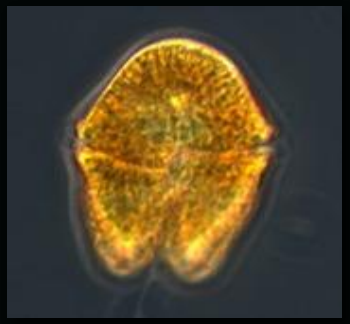
Sherry Palacios, NASA Ames Research Center

Diatoms
Dinoflagellates
Haptophytes
Cryptophytes
Chlorophytes
Cyanophytes
UPCE

PHYDOTax

$$m = S^{-1} \bullet u$$

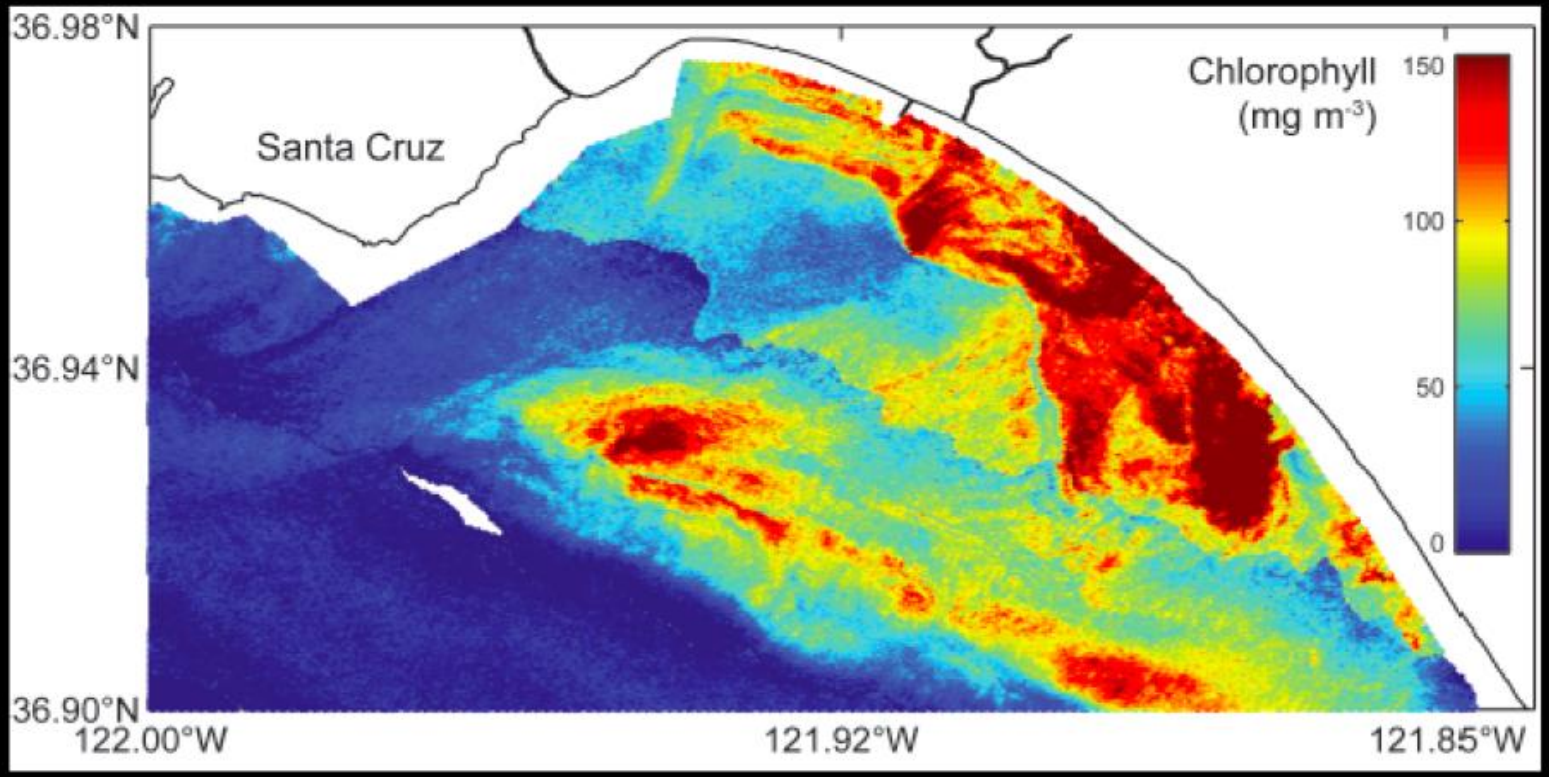
$$p = \frac{m}{\sum m}$$



S = Signature Library matrix
u = Unknown sample vector
m = Vector of "scores" per taxon
p = Vector of proportions of each taxon for unknown sample

Sherry Palacios, NASA Ames Research Center

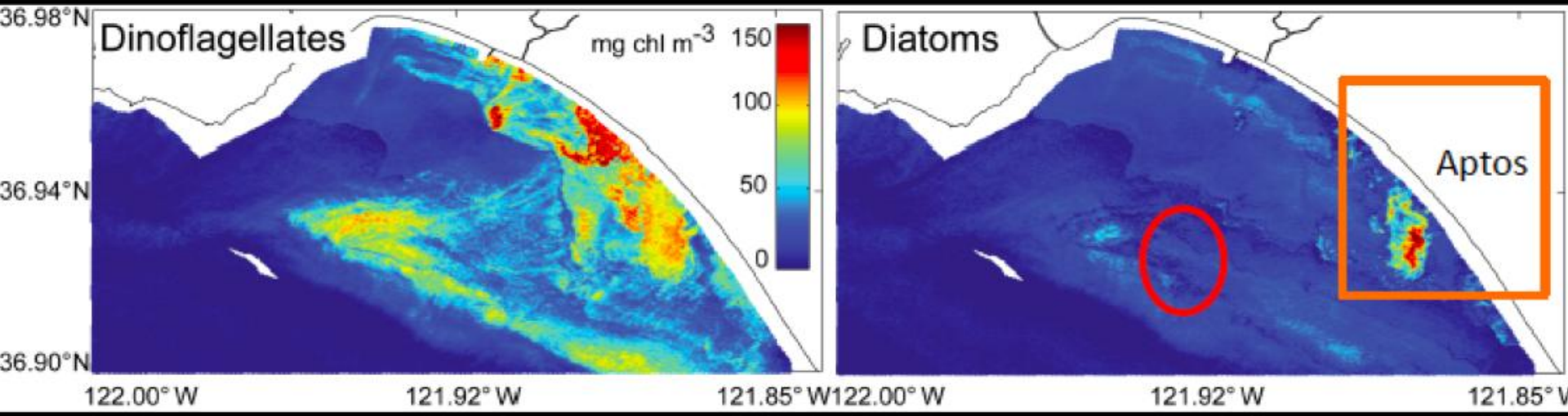
Chlorophyll concentrations were extremely high in the red-tide incubator in 2006



Sherry Palacios, NASA Ames Research Center

SAMSON Hyperspectral Imager

Dinoflagellates dominated most of northern bay
Diatoms were also present in low levels throughout bloom
Diatoms dominated in a small bloom near Aptos, CA



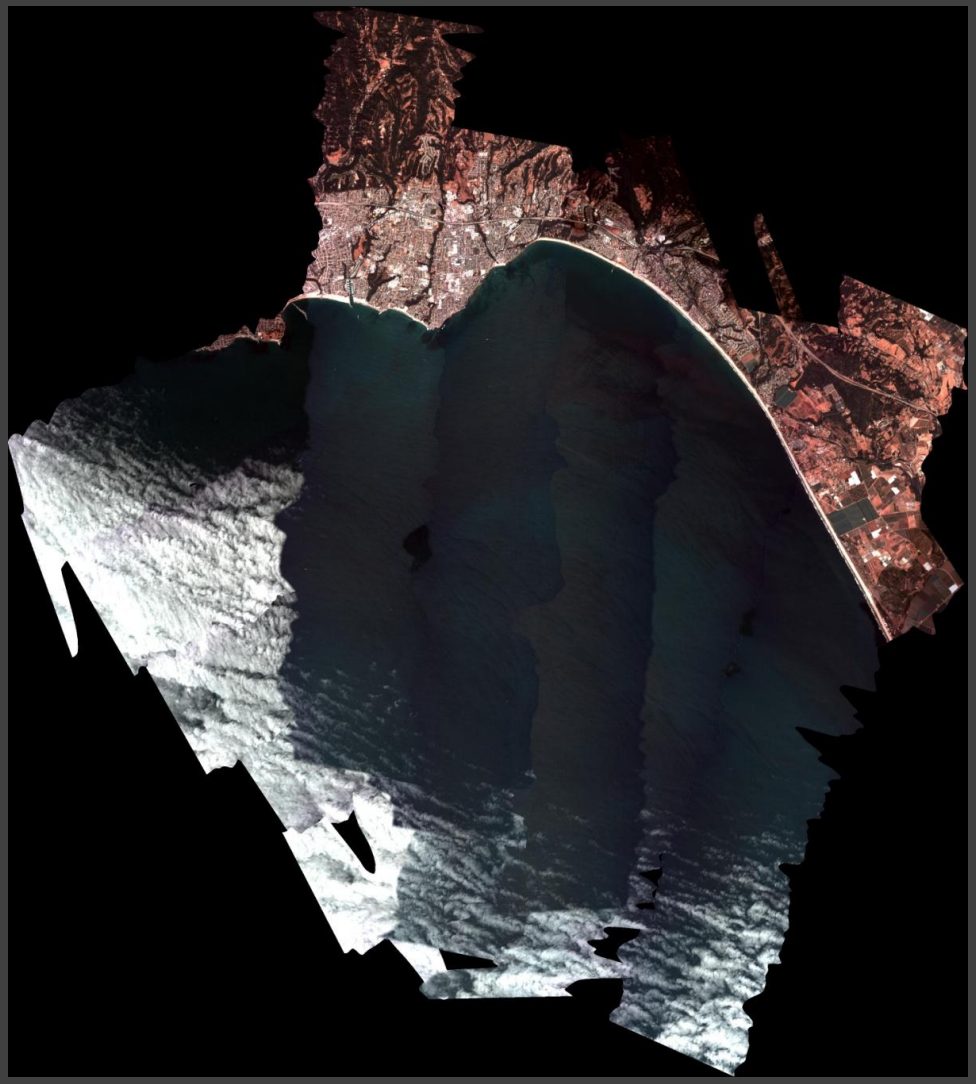
PHYDOTax Predictions

This algorithm is the first to distinguish dinoflagellates from diatoms using ocean color data

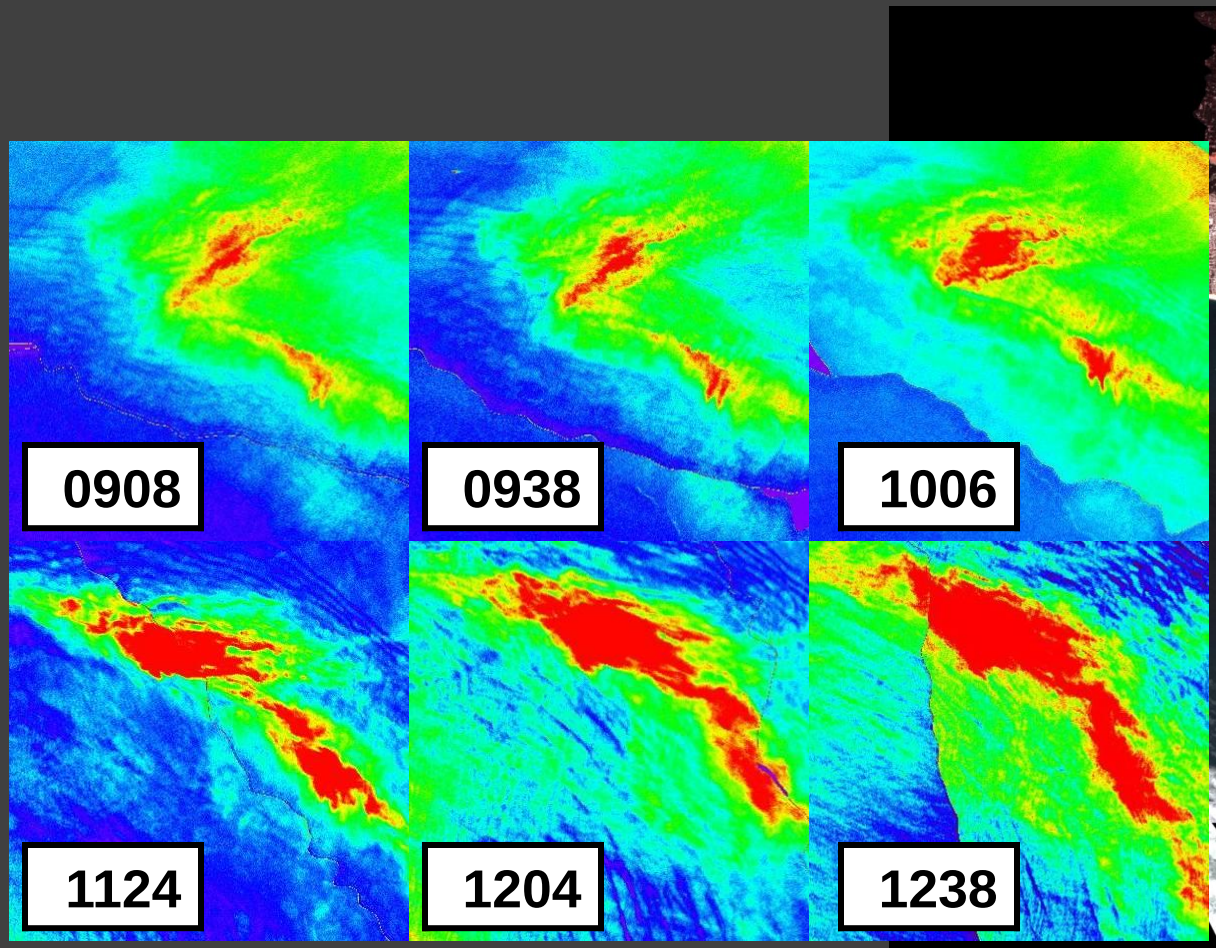
Sherry Palacios, NASA Ames Research Center

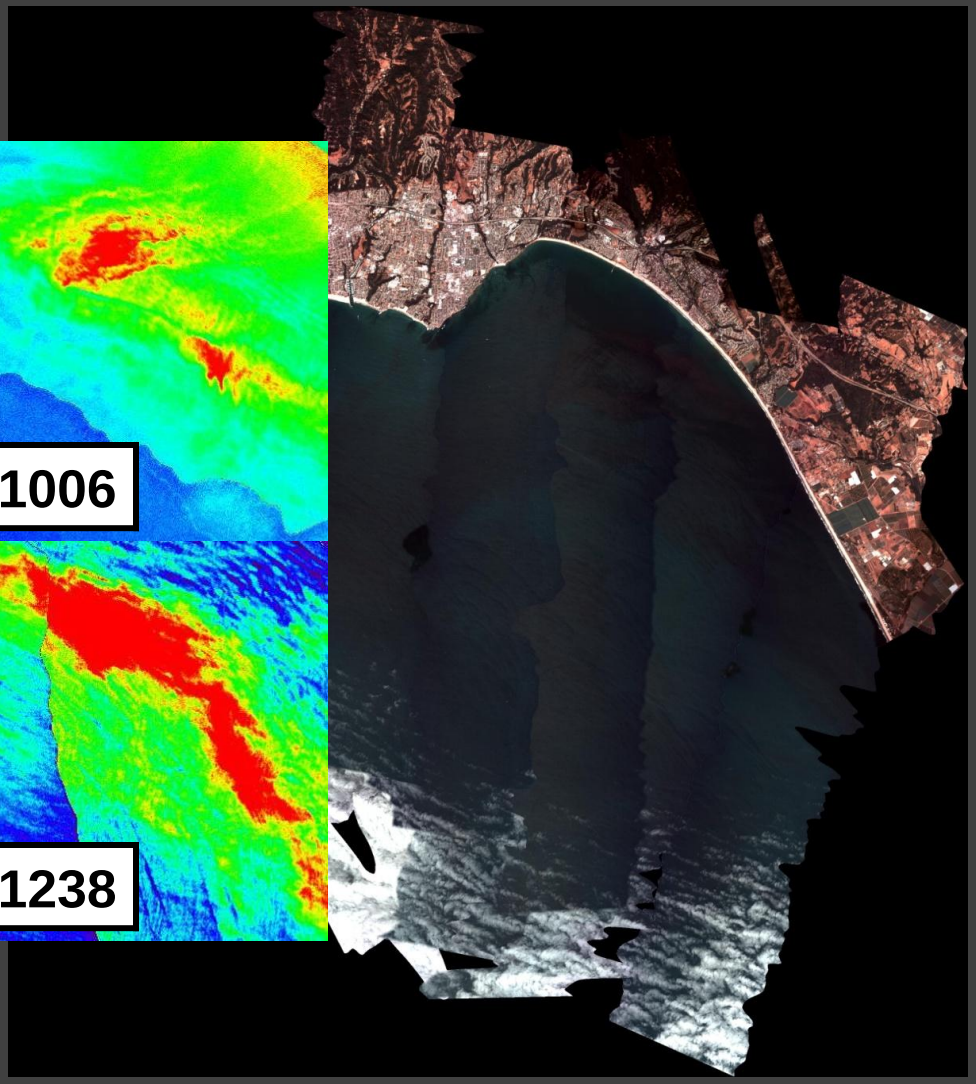
Extending PHYDOTax to Depth

- RGB image of Monterey Bay during a red tide event (dominated by *Akashiwo sanguinea*)
- COAST 2006, 9/05
- PHILLS SAMSON



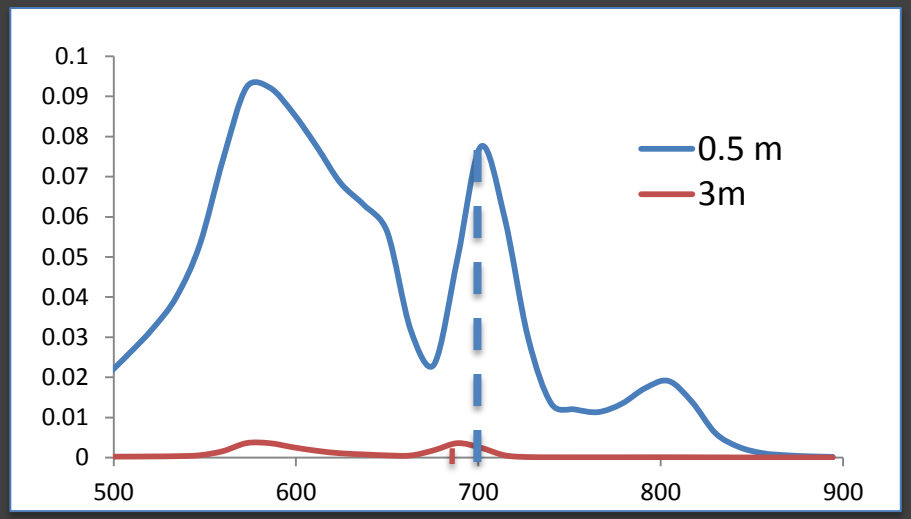
Extending PHYDOTax to Depth





Source: Curt Davis

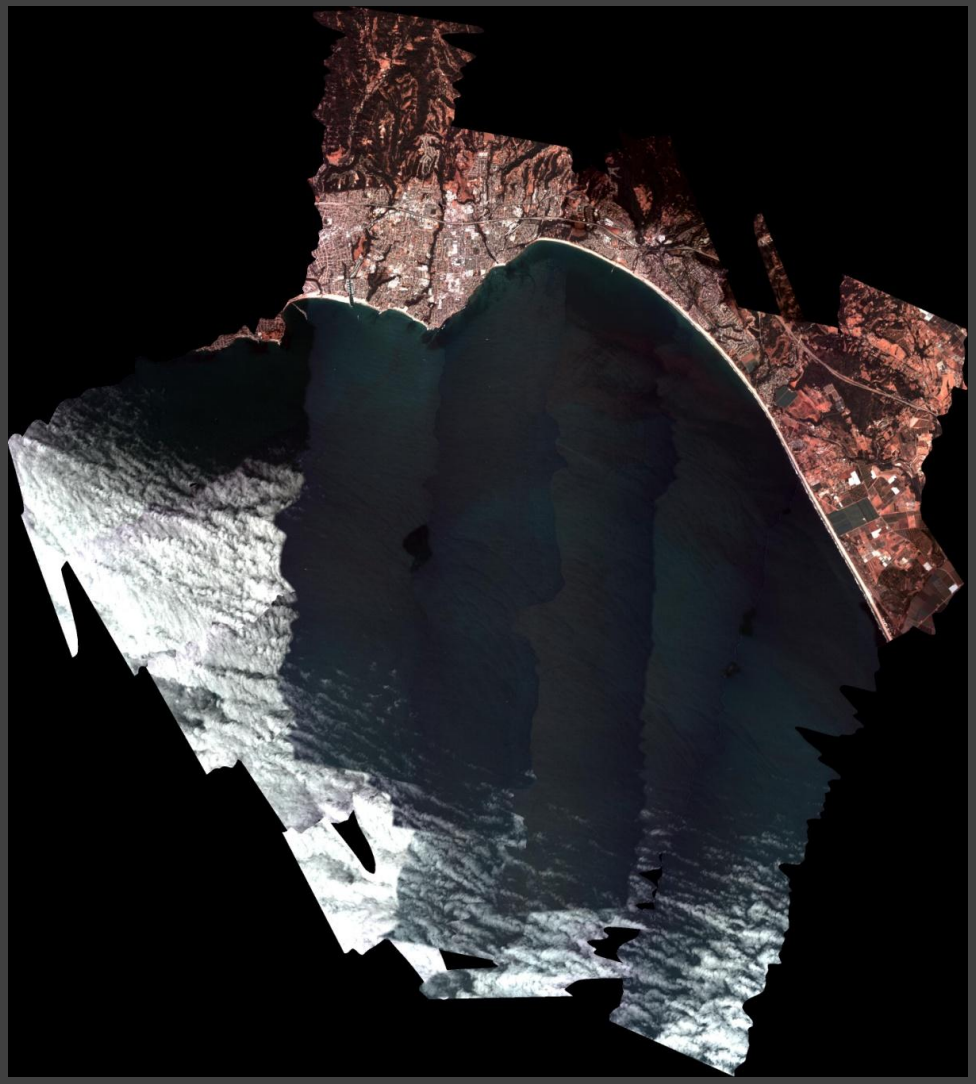
Extending PHYDOTax to Depth



- The Phase Function (and other properties) was estimated from in-water data (Noah Tuchow, SARP)

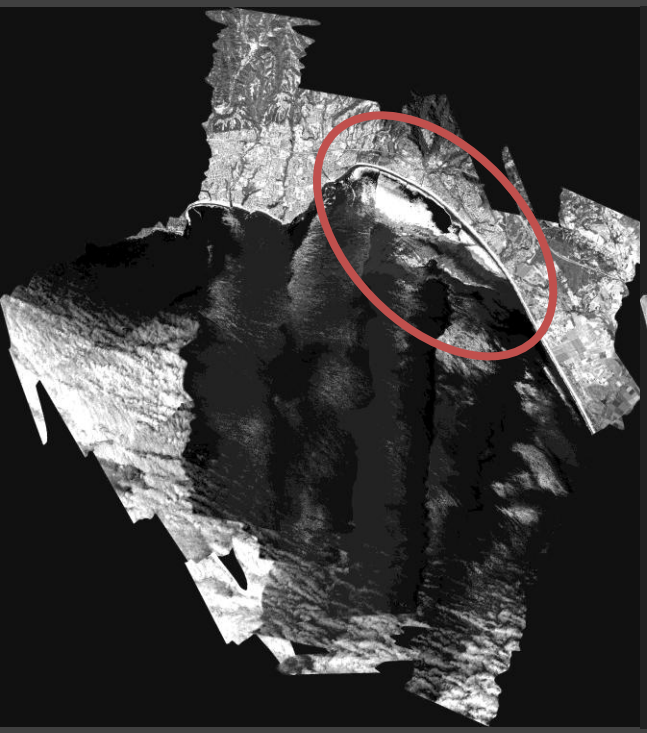
- Spectral shifts in *Rrs* were modeled in Hydrolight as a function of depth

- Layers of *Akashiwo* were identified

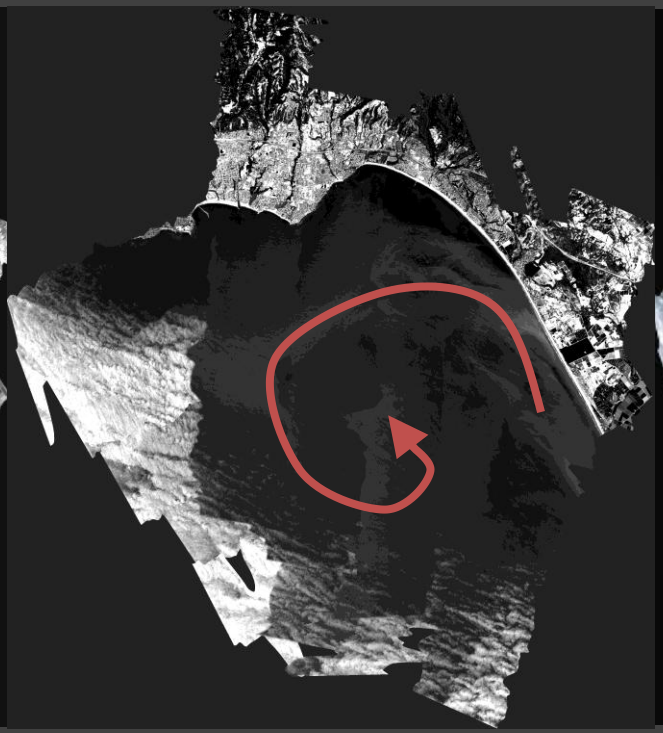


Kimee Moore, NASA SARP

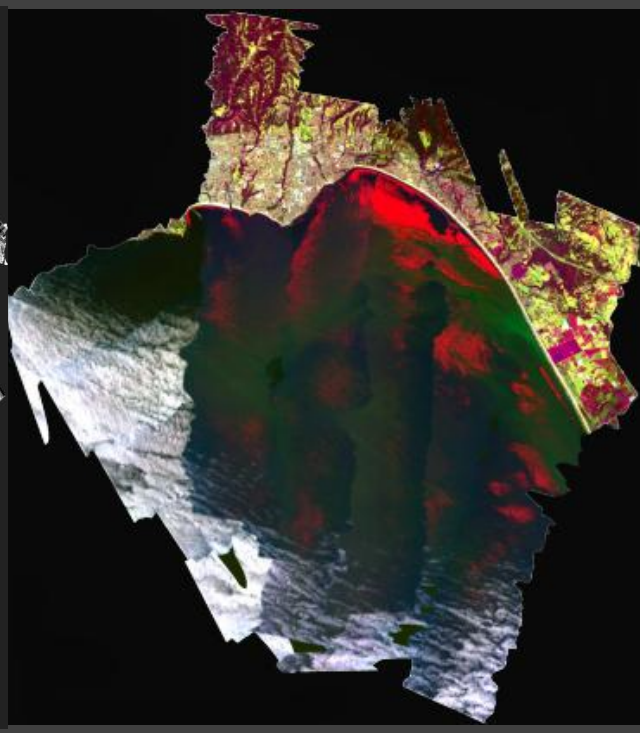
Extending PHYDOTax to Depth



Surface (0-3m)



Depth (7.5m)



All depths

R: dinoflagellates at 0-3m

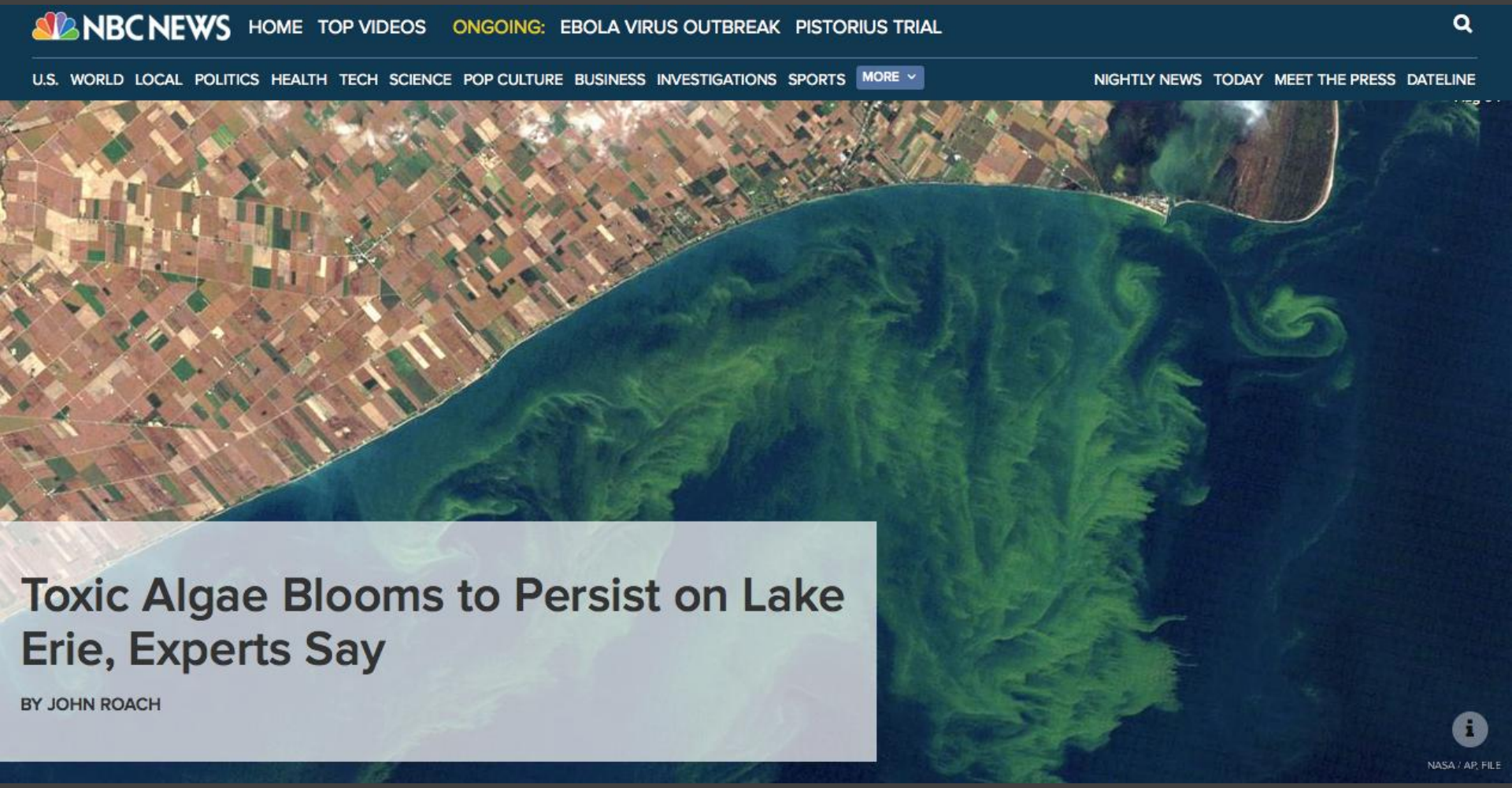
G: dinoflagellates at 7.5m

B: open water

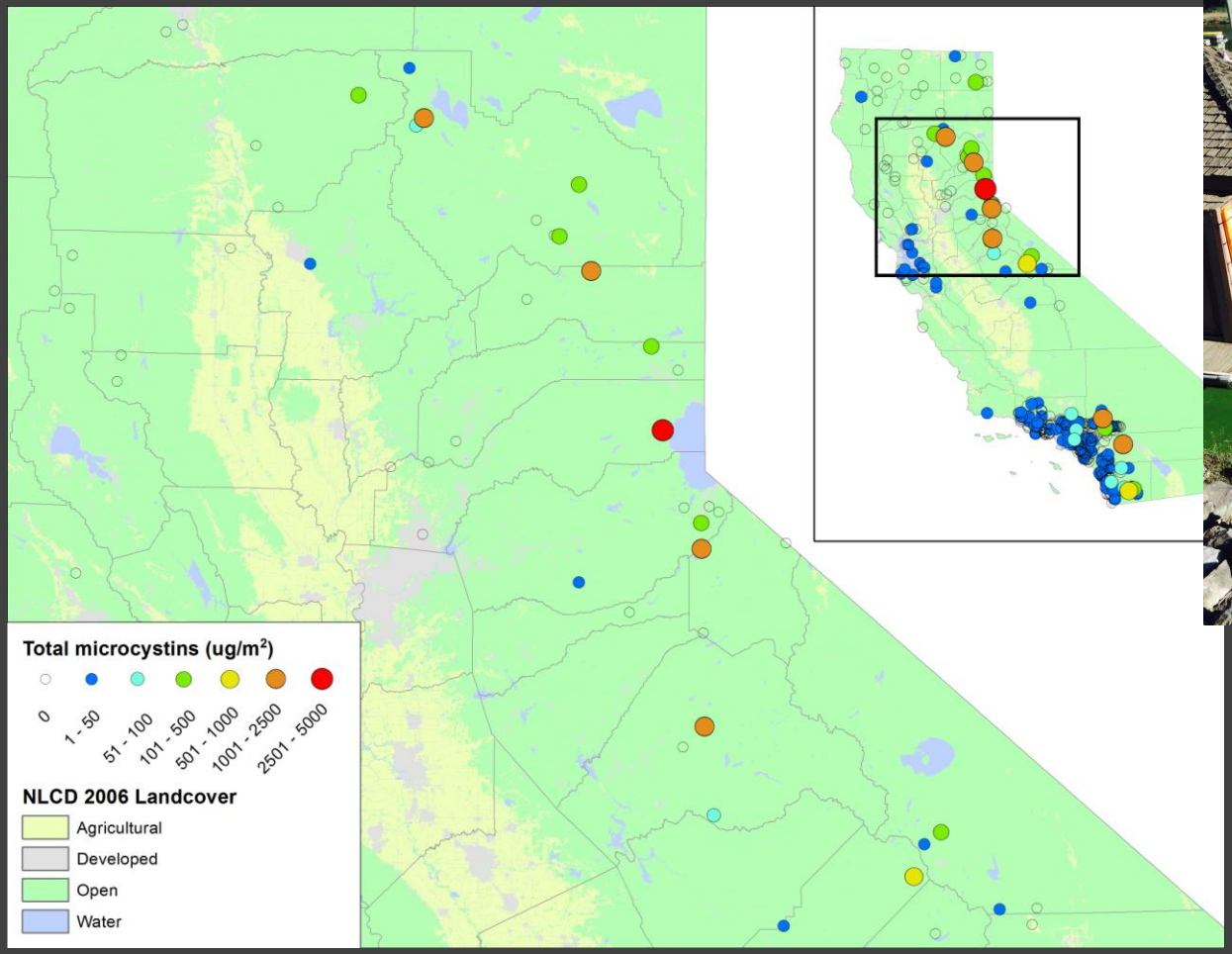
White is clouds

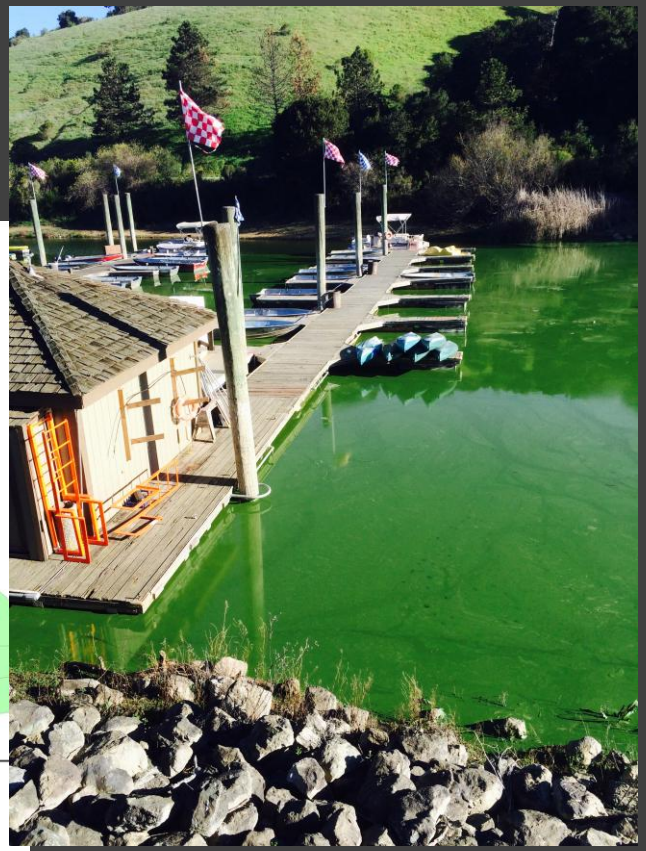
Kimee Moore, SARP 2013

Case Study 2: Blue Green Algae

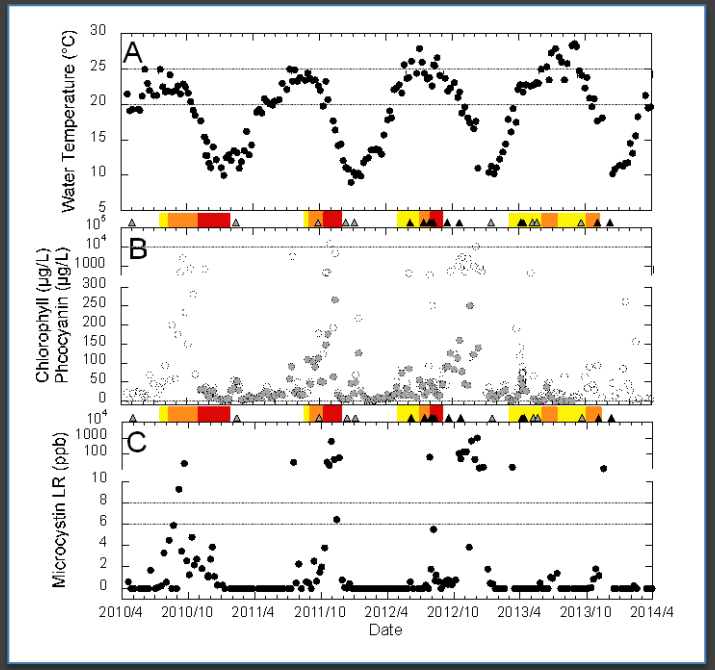


California is NOT Lake Erie

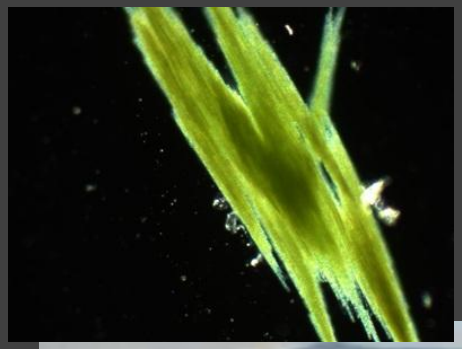


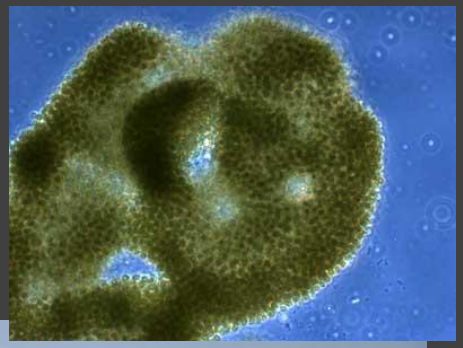


Pinto Lake, Our Favorite Toxic Cesspool



Challenge: two optically similar species

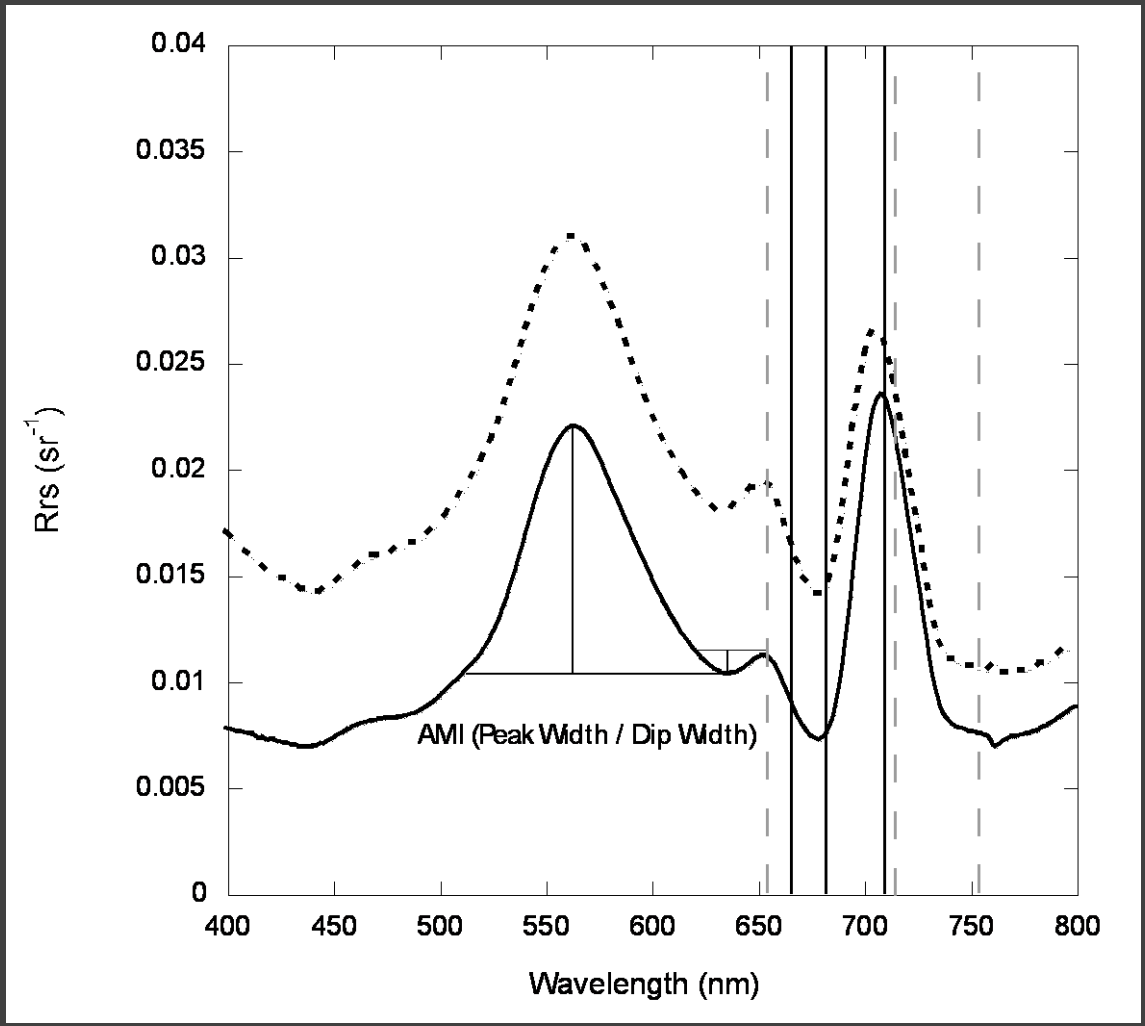




Aphanizomenon flos-aquae

Microcystis spp.

Detecting Blue-Green Algae



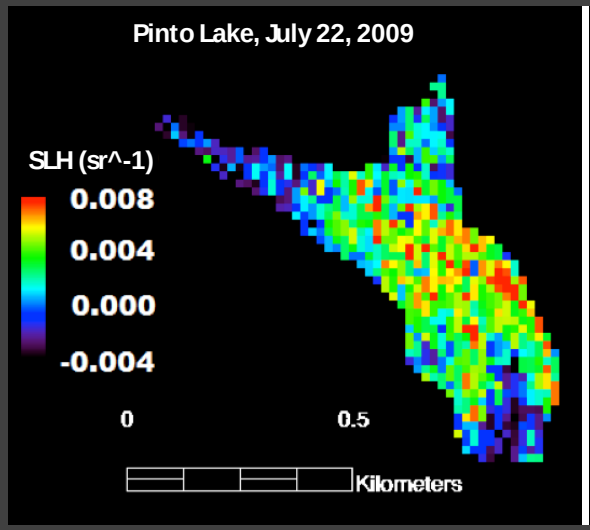
Several algorithms have been developed, including the Cyanobacterial Index (CI) and various phycocyanin absorption methods.

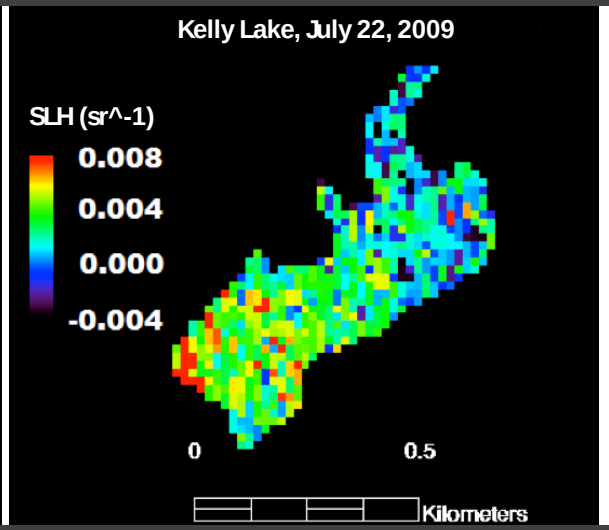
We generalized the spectral shape methods to take advantage of hyperspectral data, and also developed a Scattering Line Height (SLH) algorithm which works with almost any sensor, including MASTER

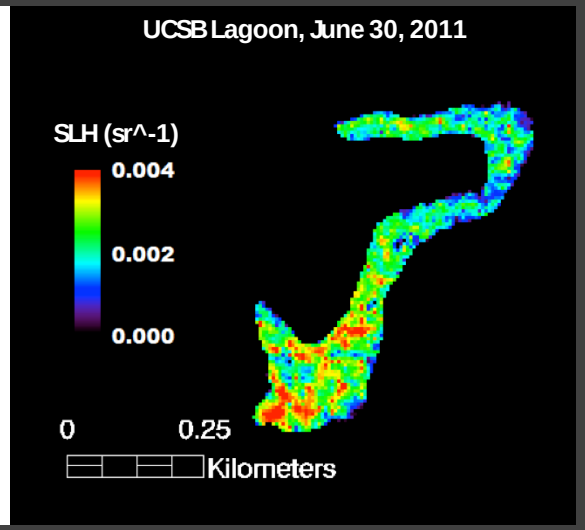
Kudela et al. RSE 2015

Remote Sensing Data

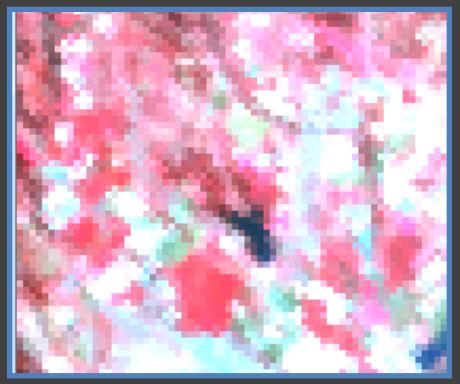
Application with MASTER



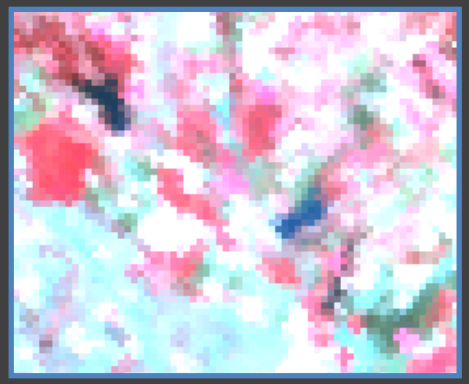




Application with HICO



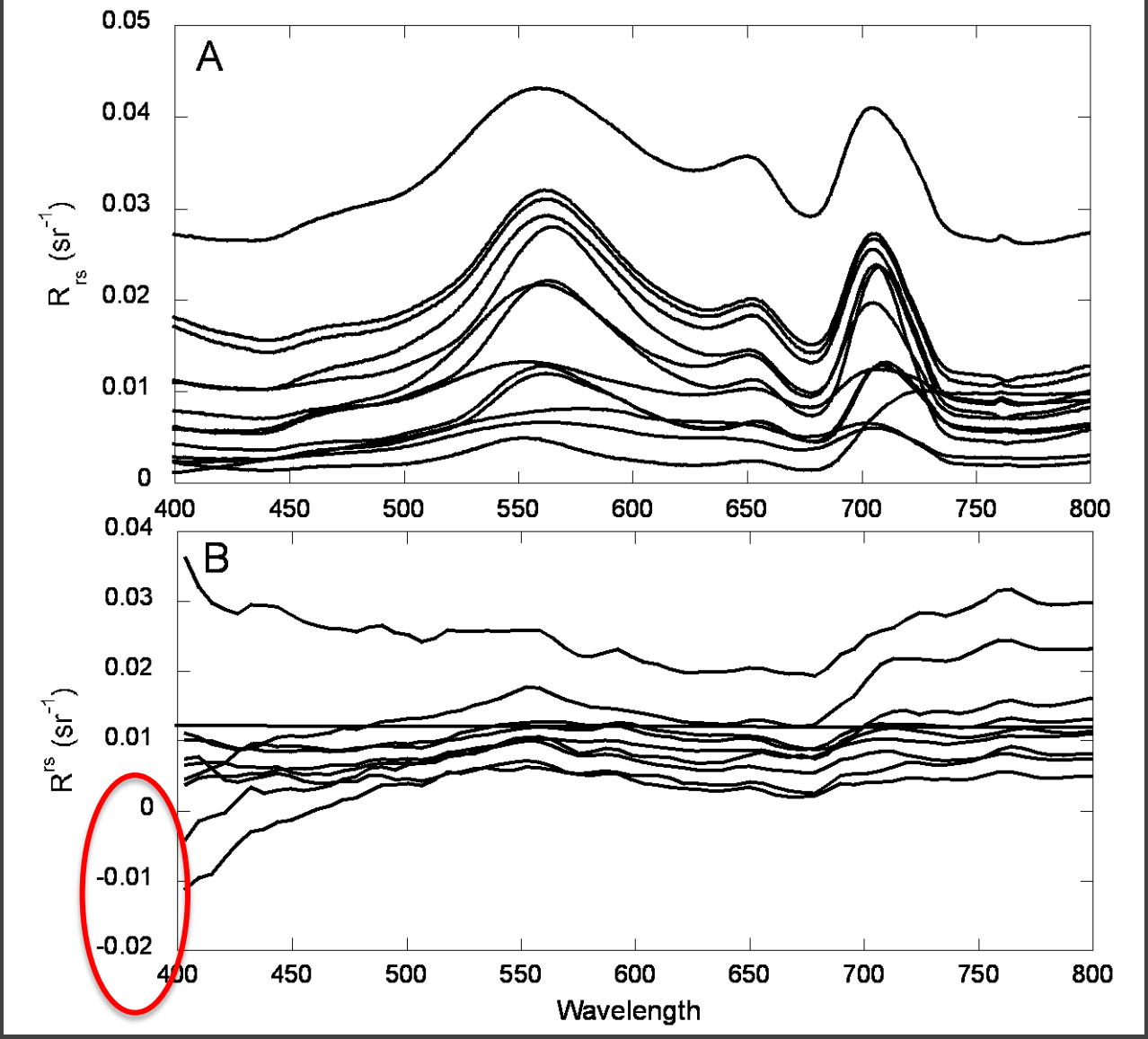
Pinto Lake



Kelly Lake

Kudela et al. RSE 2015

Spectral Data



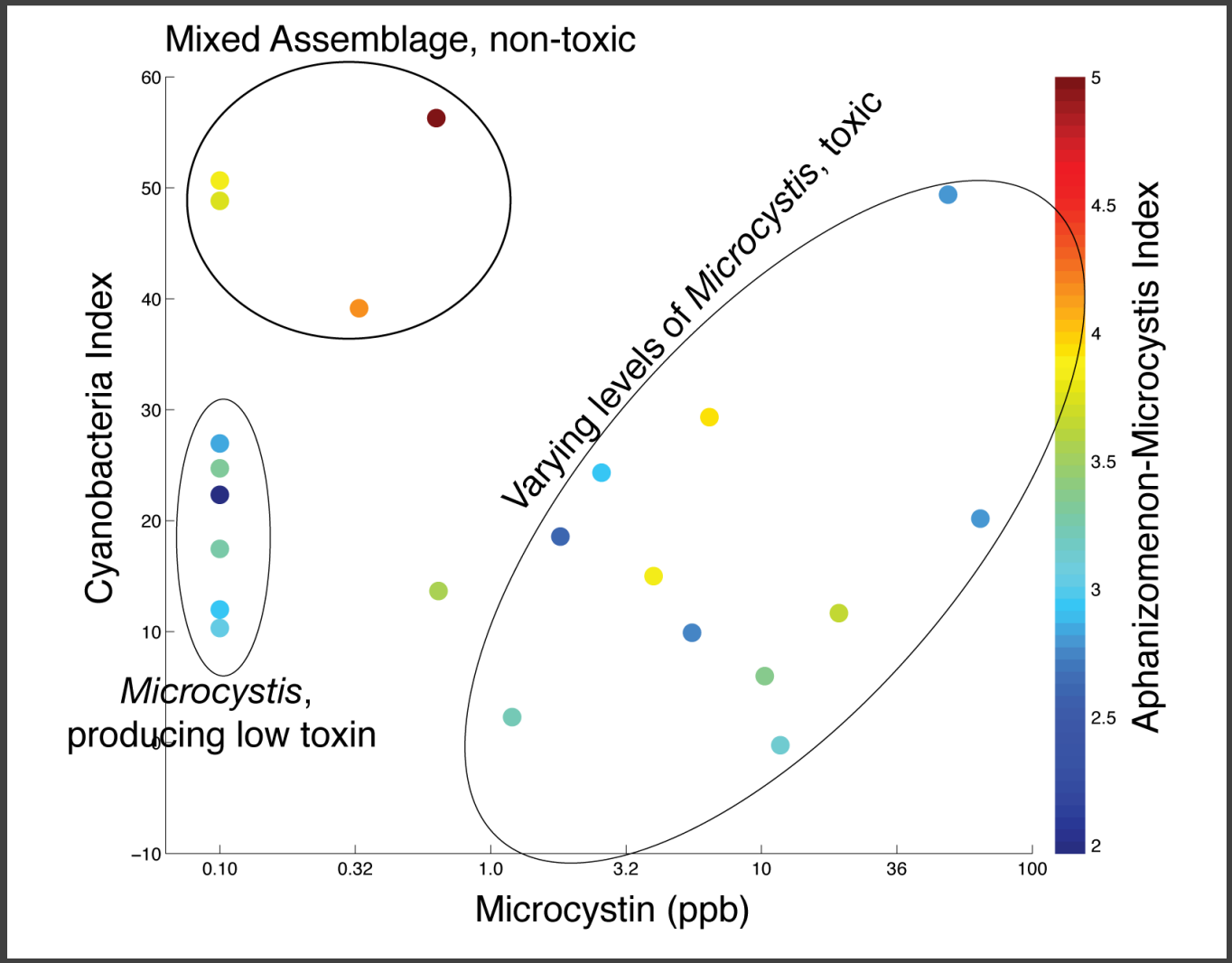
ASD & GER validation data

Hyperspectral Imager for the Coastal Ocean (HICO)

~ 100 m pixels, processed using standard (minimal optimization) Tafkaa atmospheric correction

Kudela et al. RSE 2015

Predicting Toxic Blooms



Kudela et al. RSE 2015

Case Study 3: Operational Forecasting

Domoic acid poisoning alert along Washington, Oregon coastline

BY KAREN GRAHAM MAY 10, 2015 IN FOOD

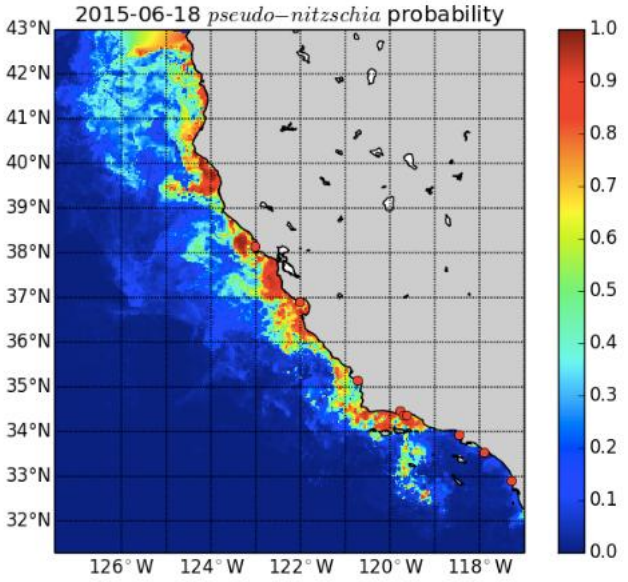
Oregon and Washington state health officials issued a warning on Friday asking recreational and commercial diggers of razor clams taken from selected beaches on Thursday and Friday to be destroyed due to high levels of the marine toxin, domoic acid.

The Seattle Times

Toxic algae bloom might be largest ever

Originally published June 15, 2015 at 9:05 pm | *Updated June 16, 2015 at 11:41 am*

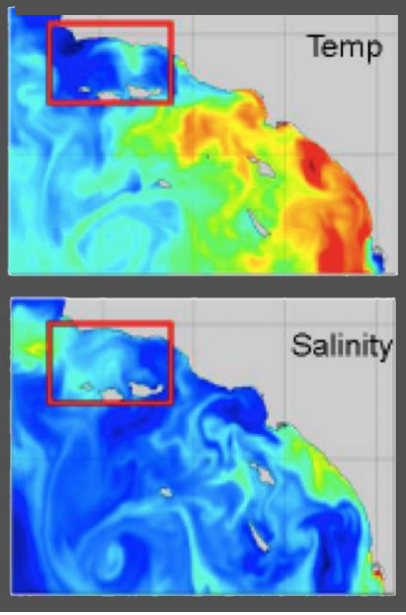
CeNCOOS DATA LEARN ABOUT COMMUNITY



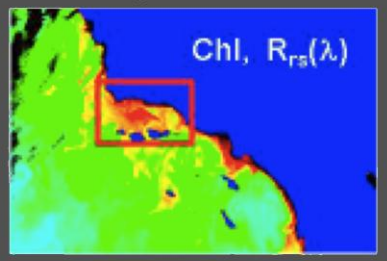
The map image displays the probability that the abundance of toxin-producing species of the diatom Pseudo-nitzschia in coastal waters is at or above the "bloom" threshold of 10,000 cells per liter. A value of 0.7, for example, means there's a 70% predicted probability of Pseudo-nitzschia blooms in that pixel.

http://www.cencoos.org/data/models/habs

ROMS Simulations

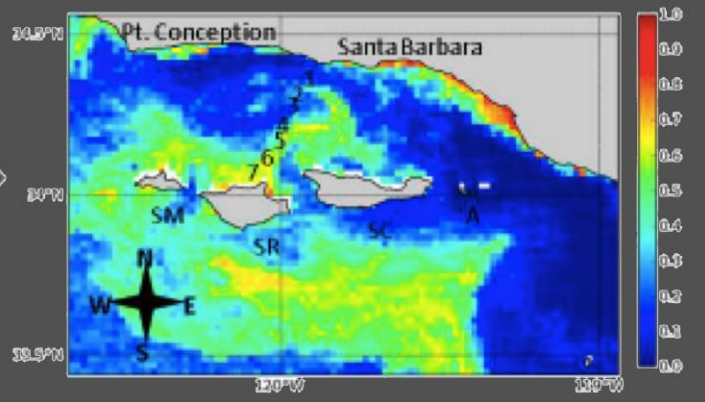


MODIS AQUA Data



Remote-Sensing HAB Model

Predicted HAB Probability



HAB Variable (Threshold)	Best-fit Logistic GLM - RS $P_{bloom} = e^{(logit)}/[e^{(logit)} + 1]$
Pseudo-nitzschia (10^4 cells mL^{-1})	**(i)** logit = 8.54 - 10.84*[R_{rs} (510/555)] – 0.216*[Month] + 4.67*[R_{rs}(490/555)]
	(ii) logit = 5.32 – 2.87*[R_{rs} (490/555)] – 0.165*[Month]
pDA (500 ng L^{-1})	logit = -134.3 + 0.253[Chl] + 4.0*[Sal] – 502*[R_{rs} (555)]
cDA (10 pg $cell^{-1}$)	logit = -90.0 - 0.35*[Temp] – 666*[R_{rs} (555)] + 2.87*[Sal]

Remote Sensing Reflectance
Salinity
Temperature
Chlorophyll

Nitrate
Phosphate
Silicic Acid

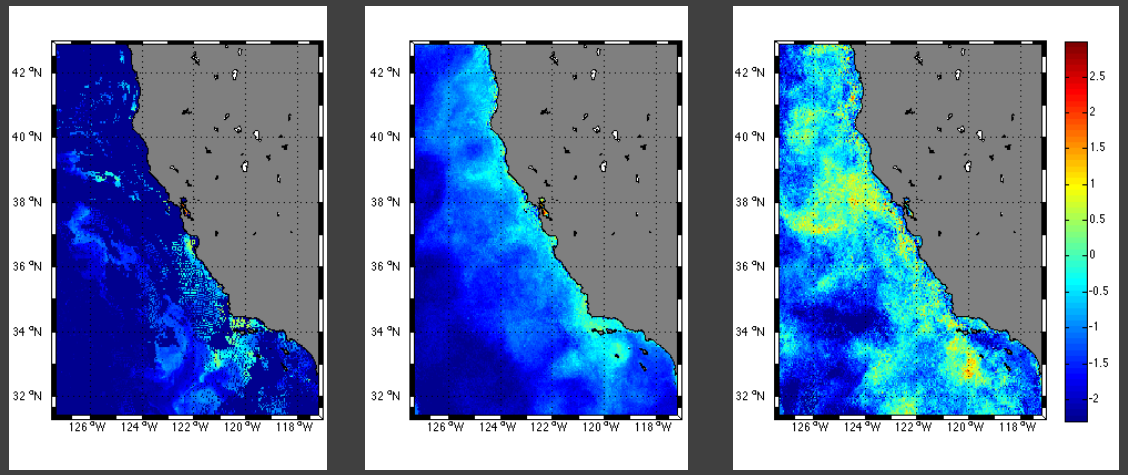
Anderson et al. 2011, Detecting diatom blooms from ocean color and a regional ocean model. Geophysical Research Letters L04603

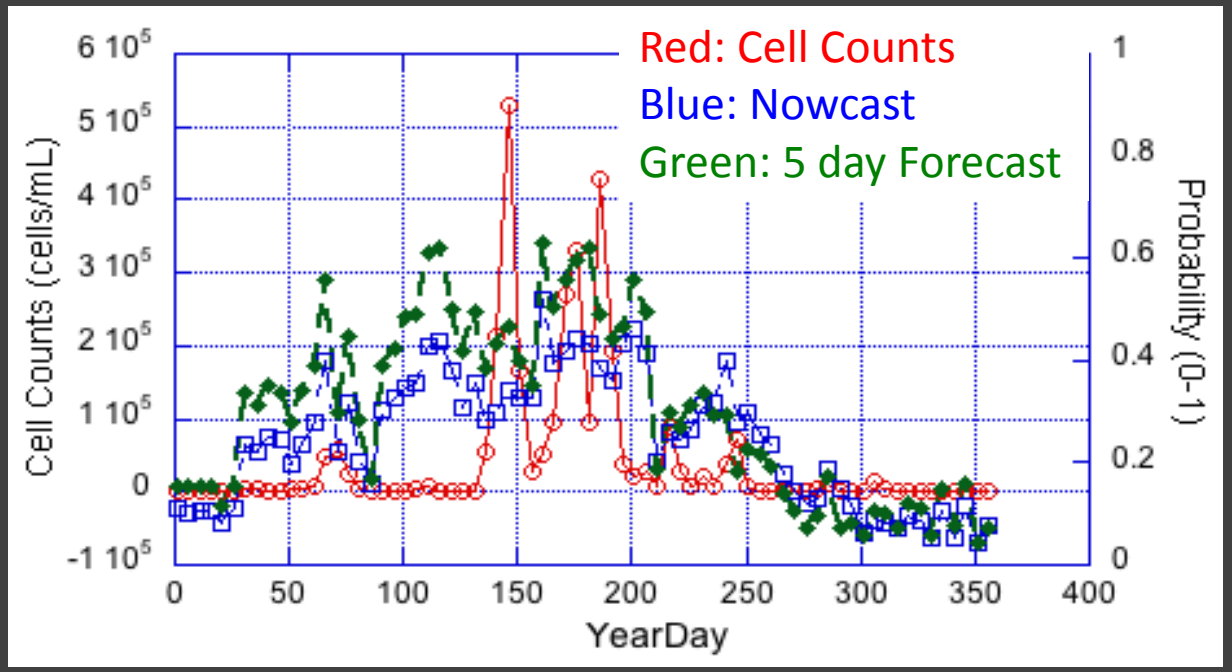
Forecasting *Pseudo-nitzschia*

For each forecast time-step, CHL, Rrs, SST, and Salinity is estimated (CHL shown @ right)

Each 5-day interval was forecast with 6 months of historical data and compared to the nowcast (@ right)

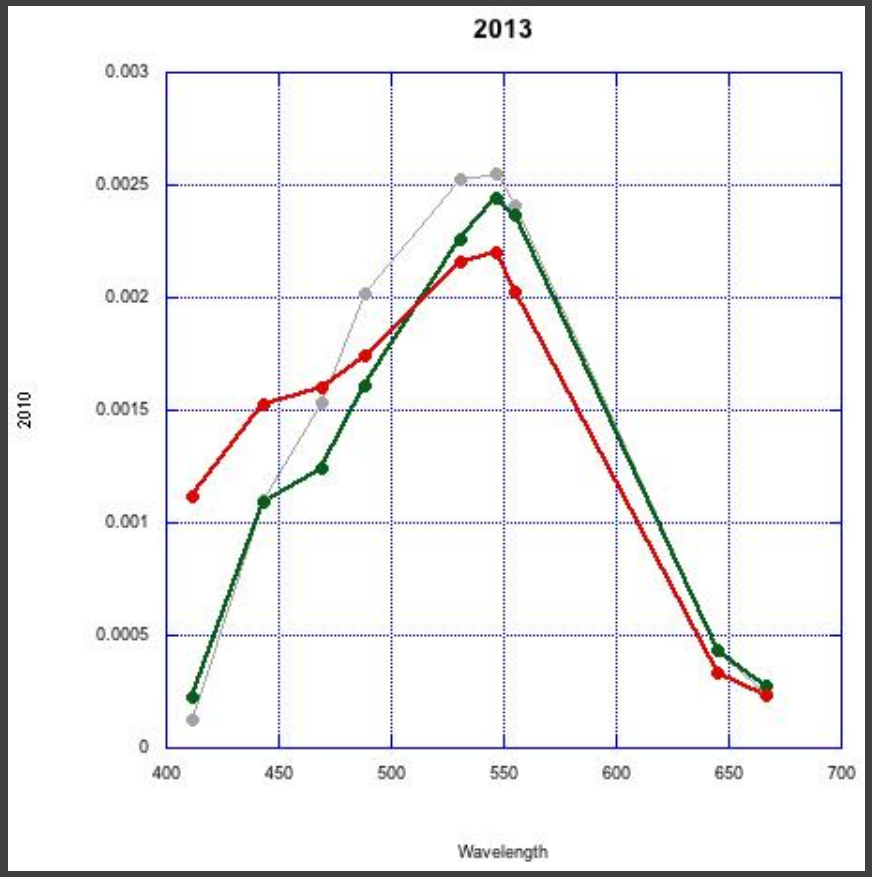
Original log(CHL) DINEOF log(CHL) Forecast log(CHL)



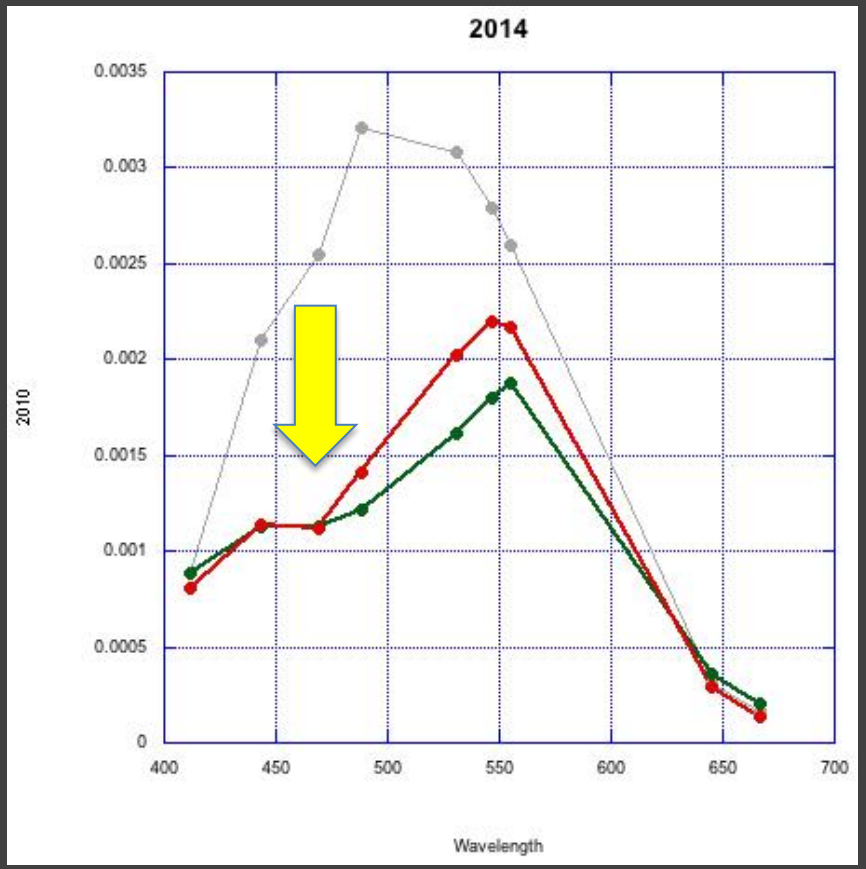


Is There a Spectral Signature for Toxin?

2013
Abundant *Pseudo-nitzschia*,
~ no toxin

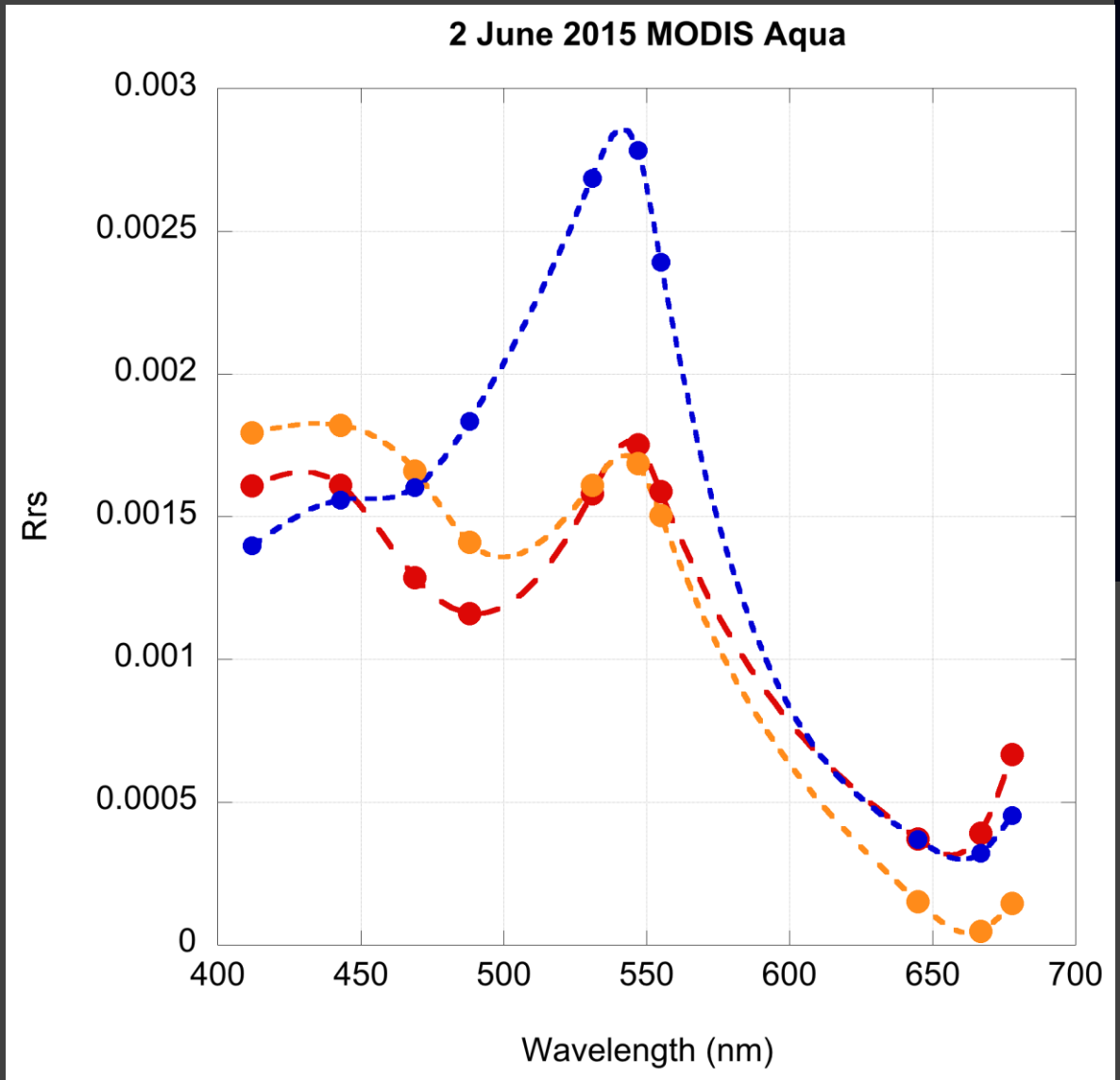


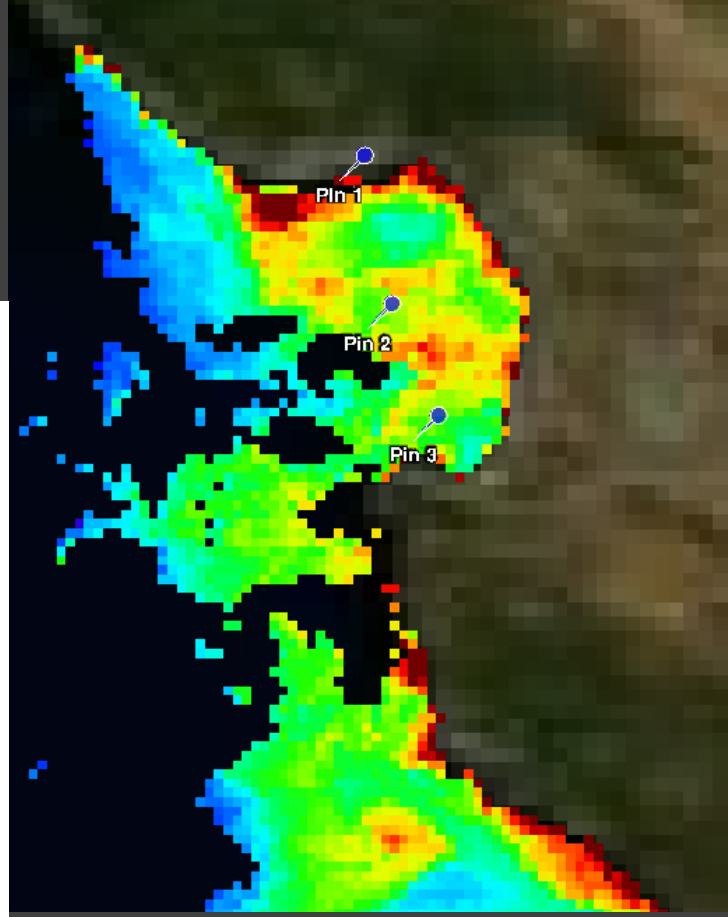
2014
Abundant *Pseudo-nitzschia*,
Very High Toxin



Grey: no *Pseudo-nitzschia* Green: *Pseudo-nitzschia* dominant; Red: highest abundance

MODIS Aqua Spectra versus Measured Toxin

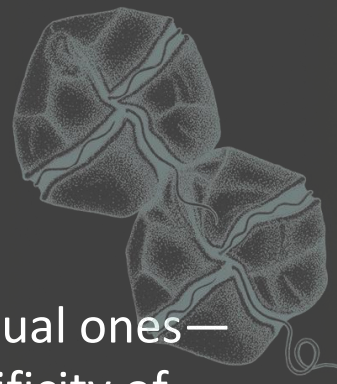




Blue: 28 ng/L domoic acid
Orange: 2083 ng/L
Red: 2978 ng/L

Chlorophyll:
Blue = 11.07
Orange =1.43
Red = 1.88

Summary



Challenges

- The primary challenges for effective use of ocean color are the usual ones—poor atmospheric correction, optically complex waters, non-specificity of algorithms, spatial and spectral resolution

Progress

- We have successfully extended spectral shape algorithms to multiple sensors
- We can separate non-toxic and toxic species, providing predictive capability;
- Remote Sensing data are being used for semi-operational applications in challenging systems

Opportunities

- Sensors are getting better—there are promising applications for HABs
- Spectral Shape functions provide rapid, sensitive detection
- IOCCG/GEOHAB Monograph provides an opportunity to bridge communities
- **We MUST take an ecosystem perspective!**

Thank You!

What would you like?

HAB species, abundance, toxicity.

Predictions of where HABs will be.

And I want it now!

Funding:

- NASA HyspIRI Project, Ecological Forecasting (Woody Turner)
- NASA HQ20 Project (Paula Bontempi)
- NASA Student Airborne Research Program (Rick Shetter)
- NOAA ECOHAB & MERHAB Programs
- Central and Northern California Ocean Observing System
- California Sea Grant
- California Ocean Protection Council