Remote Sensing of Water Quality: Can Hyperspectral Imagery Improve Public Health?

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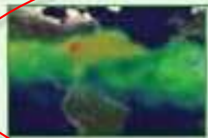
University of California, Santa Cruz

International Ocean Colour Science Meeting 2015 | Advancing Global Ocean Colour Observations

Breakout Session 7:

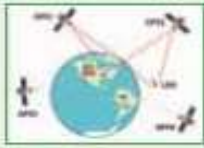
Advances in Hyperspectral Remote Sensing Science



Launch 2022

Identification of human versus natural sources for aerosols and ozone precursors

Observation of air pollution transport in North, Central, and South America



GPSRO

Launch 2010-2013

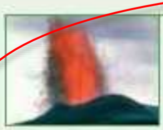
Pressure, temperature, water vapor profiles

SWOT

Launch 2013-2016

Sea-level measurements extended into coastal zones

Ocean eddies and currents

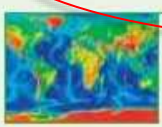


HYSPIRI

Launch

Nutrients and water status of vegetation, soil type and health

Processes indicating volcanic eruption



LIST

Launch 2016-2020

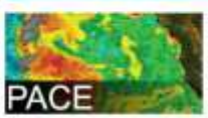
Global high-resolution topography

Detection of active faults

PATH

Launch 2016-2020

PACE



The Pre-ACE (PACE) mission is a recent addition to the NASA flight program manifest as recommended in the report, "Responding to the Challenge of Climate and Environmental Change: NASA's plan for a Climate-Centric Architecture for Earth Observations and Applications from Space", published in June 2010. As described in the report, the primary objective is to "make essential global ocean color measurements, essential for understanding the carbon cycle and how it both affects and is affected by climate change...". The report also suggested that a contributed polarimeter for aerosol and cloud research be accommodated provided a partner could be found who would provide an instrument at no expense to NASA.

In the fall of 2011, NASA selected a science definition team (SDT) via an open solicitation that is composed of ocean, aerosol, and cloud scientists. The SDT is supported by an engineering team who is tasked with conducting instrument and mission design studies. Four members of the Ocean Ecology Laboratory were selected for the SDT. The SDT held three open community workshops in the fall of 2011 and spring of 2012. As of August 2012, the SDT has drafted a report for NASA Headquarters that outlines the science objectives and measurement requirements for ocean, aerosol, and cloud research. At present, PACE is scheduled for launch in the 2019 time frame.

For further information, go to the PACE website. http://decadal.gsfc.nasa.gov/pace.html

Harmful Algal Blooms
Water-borne diseases
Hypoxia

increased temporal coverage coastal & inland lakes at mid-lats

SOCIETAL CHALLENGE: EXTREME-EVENT WARNINGS

Longer-term, more reliable storm track forecasts, storm intensification predictions, and volcanic eruption and landslide warnings to enable effective evacuation planning

SOCIETAL CHALLENGE: HUMAN HEALTH

More reliable forecasts of outbreaks of infectious and vector-borne disease for disease control and response

Land-ocean interface
Marine Forecasts
Malaria Risk
Run-off (nut. Loading?)
via hydrodynamic models
Cholera (*Vibrio*) Risk
Droughts/Floods

Improved ocean color for C, climate, WQ

Earth Science and Applications from Space National Imperatives for the Next Decade and Beyond, National Research Council

HABs and Water Quality are Linked

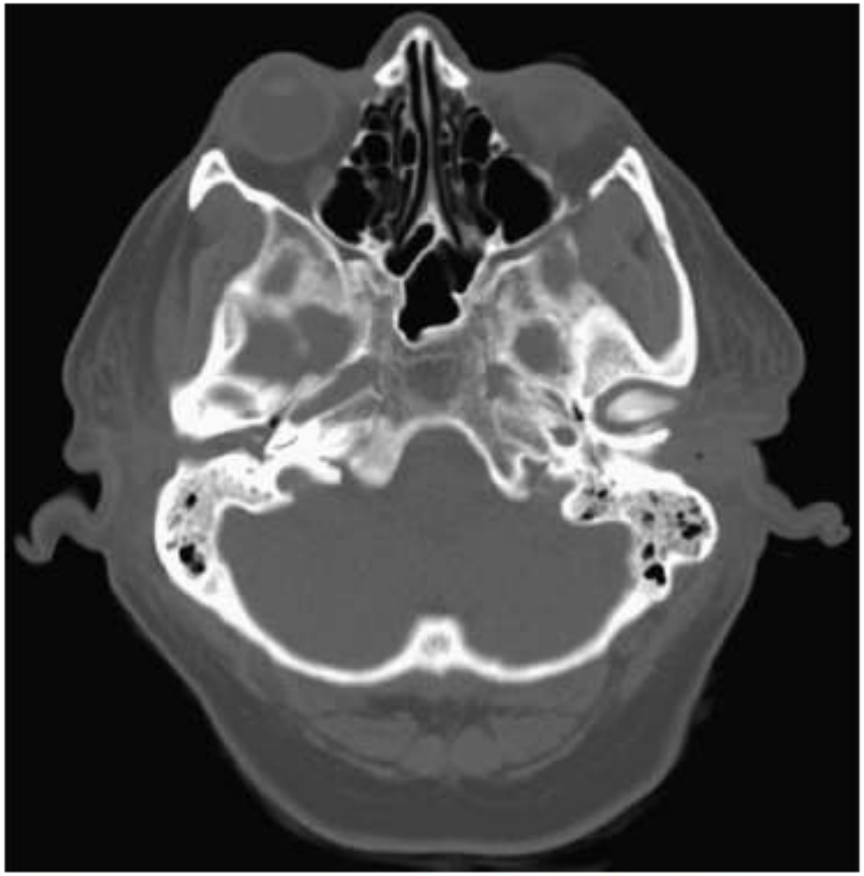


Figure 2. Computed tomography scan showing opacification of the bilateral mastoid air cells.

September 2009—53 year old woman diving in Monterey suffered from bilateral mastoiditis (ear infections penetrating to the brain).

Retrospective analysis linked high pathogen loads to red tides.

Honner, Kudela & Handler (2012), J. Emergency Medicine

World Health Organization

Table 2.5. Advantages and shortcomings of biological and chemical water quality monitoring

Biological monitoring	**Chemical monitoring**
Advantages	
Good spatial and temporal integration	Possibility of very fine temporal variations
Good response to chronic, minor pollution events	Possibility of precise pollutant determination
Signal amplification (bioaccumulation, biomagnification)	Determination of pollutant fluxes
Real time studies (in-line bioassays)	Valid for all water bodies, including groundwaters
Measures the physical degradation of the aquatic habitat	Standardisation possible
Shortcomings	
General lack of temporal sensitivity	High detection limits for many routine analyses (micropollutants)
Many semi-quantitative or quantitative responses possible	No time-integration for water grab samples
Standardisation difficult	Possible sample contamination for some micropollutants (e.g. metals)
Not valid for pollutant flux studies	High costs involved in surveys
Not yet adapted to groundwaters	Limited use for continuous surveillance

Remote Sensing of Coastal & Inland Water Bodies

MULTI- & HYPERSPECTRAL SENSORS APPLIED TO WATER QUALITY ASSESSM

SeaWiFS	GOCI
MODIS	HICO
MERIS	Hyperion
VIIRS	Landsat*

*30m res, not optimized for water

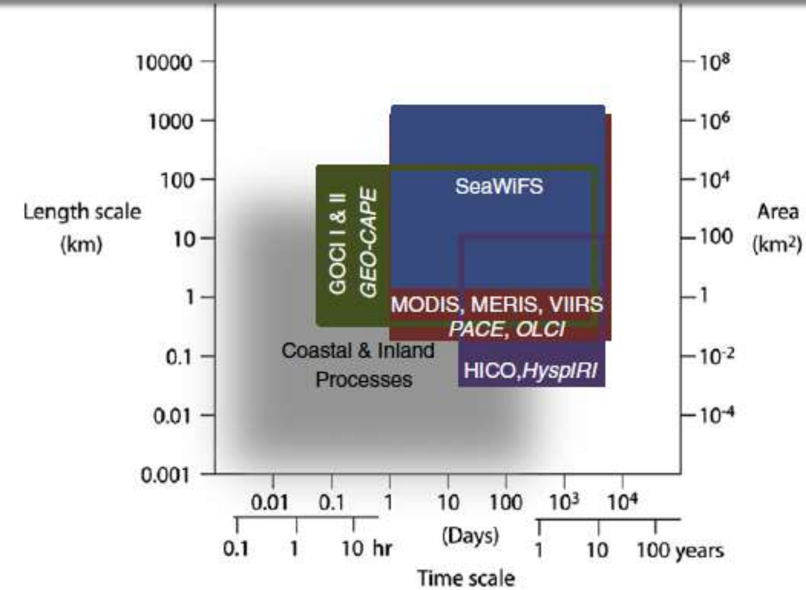


Fig. 2. Length- and timescales of coastal and inland processes in relation to heritage, current and planned aquatic color sensors (SeaWiFS, MODIS, MERIS, VIIRS, HICO, GOCI, OLCI) and missions (PACE/ACE, GEO-CAPE, HyspIRI). Planned sensors and missions are italicized.
Adapted from Robinson (2010).

Mouw et al. (2015), *RS*

PARAMETERS: CDOM, Total Suspend Material, Turbidity, Harmful Algal Bloom CyanoHABs

LIMITATIONS:

- Difficult to separate out independently varying constituents given the low spectral/radiometric resolution
- Low spatial & temporal resolution does not capture appropriate scales of variability in coastal and inland water bodies

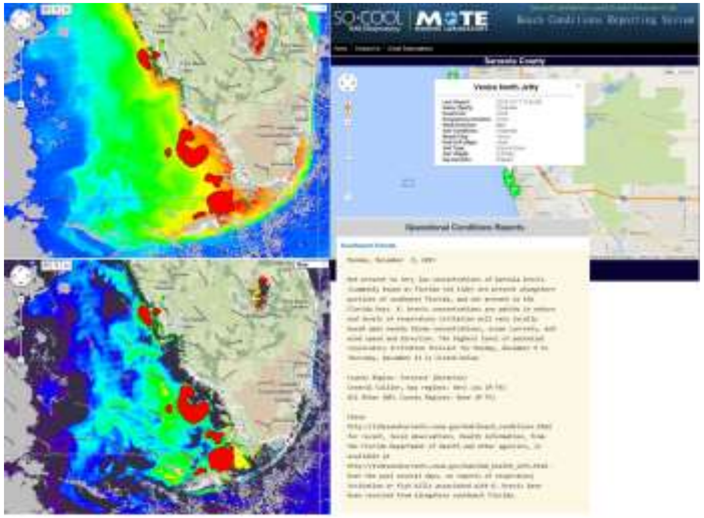
Powerful Constellation

FUTURE

GEO-CAPE
(410-2130nm, 10-40nm)
HyspIRI
(380-2500nm, 10nm)
PACE
(340-1100nm, 10nm)

OLCI/Sentinel-3
(spectral res)
Sentinel-2
(spatial res)

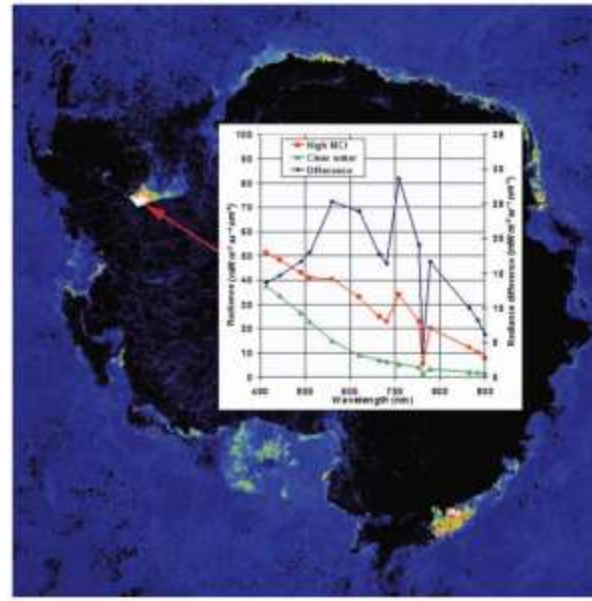
Chlorophyll has been most reliable proxy for Harmful Algal Bloom



Multispectral Sensors

MODIS

MERIS



Operational HAB Forecasting in the Gulf of Mexico relies on chlorophyll anomaly product from MODIS to detect *K. brevis*

Maximum Chlorophyll Index (MCI) for MERIS
(e.g. Gower et al. 2008)

Maximum Peak Height (MPH)
for MERIS
(e.g. Matthews & Odermatt, 2015)

Hyperspectral Sensors

1) Algorithms that better discriminate **HAB-derived chlorophyll**
(especially in optically complex waters)

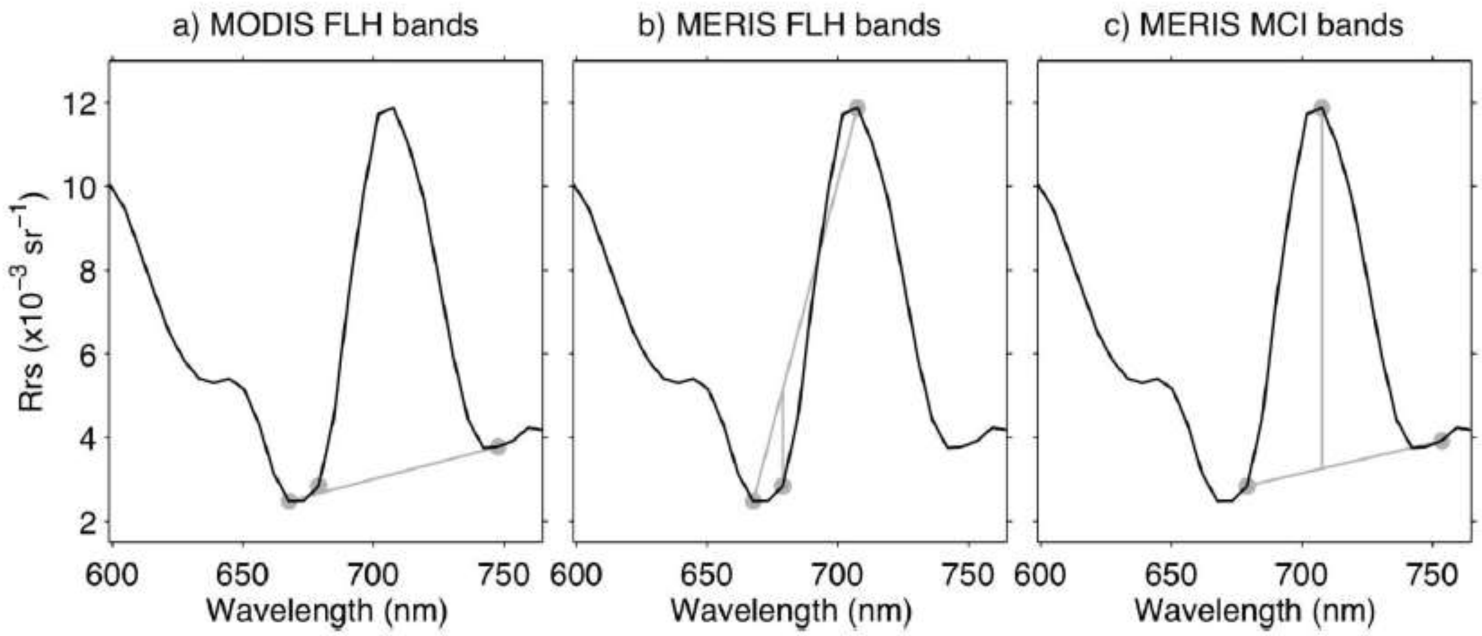
2) Application of PFT algorithms, detection of taxa/pigments/toxins
via high-resolution spectral information and **spectral shape analysis**
(**potential for reduced sensitivity to atmos correction issues**)

Application of the Hyperspectral Imager for the Coastal Ocean to Phytoplankton Ecology Studies in the Monterey Bay, CA, USA

LINEAR BASELINE ALGORITHMS

Table 1. Center wavelengths of Hyperspectral Imager for the Coastal Ocean (HICO) bands used in algorithm computations.

	Chlorophyll	QAA IOP	MODIS FLH	MERIS FLH	MERIS MCI
Multispectral bands (nm)	443, 490, 510, 555	411, 443, 490, 555, 667	665, 677, 746	665, 681, 709	681, 709, 754
HICO bands (nm)	444, 490, 507, 553	410, 444, 490, 553, 668	668, 679, 748	668, 679, 708	679, 708, 753

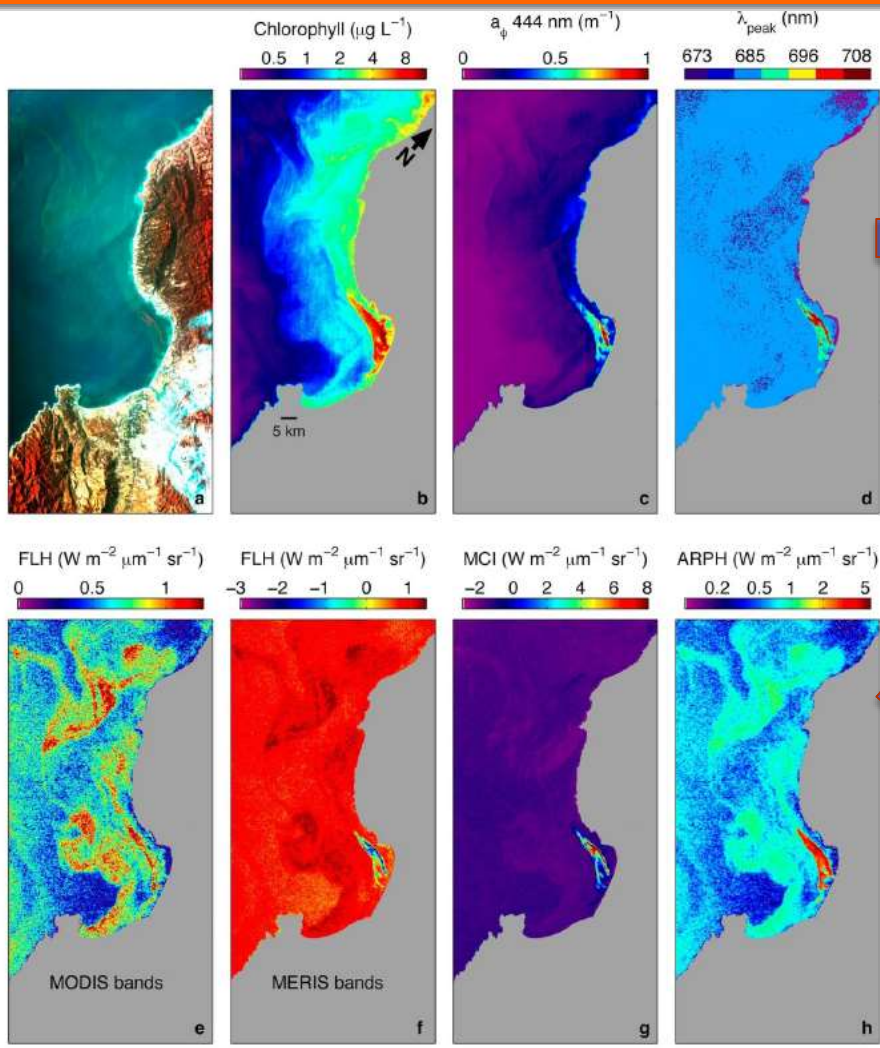


Application of the Hyperspectral Imager for the Coastal Ocean to Phytoplankton Ecology Studies in the Monterey Bay, CA, USA

John Ryan, Curtiss Davis, Nicholas Tufillaro, Raphe Kudela, Bo-Cai Gao

2014 *Remote Sensing*

ADAPTIVE REFLECTANCE PEAK HEIGHT ALGORITHM



Characterizing phytoplankton density with HICO data

MONTEREY BAY

Adaptive Reflectance Peak Height (ARPH)

Application of Hyperspectral Remote Sensing to Cyanobacterial Blooms in Inland Waters

Raphe Kudela, Sherry Palacios, David Austerberry, Emma Accorsi, Liane Guild, Juan Torres-Perez

SPECTRAL SHAPE ALGORITHMS

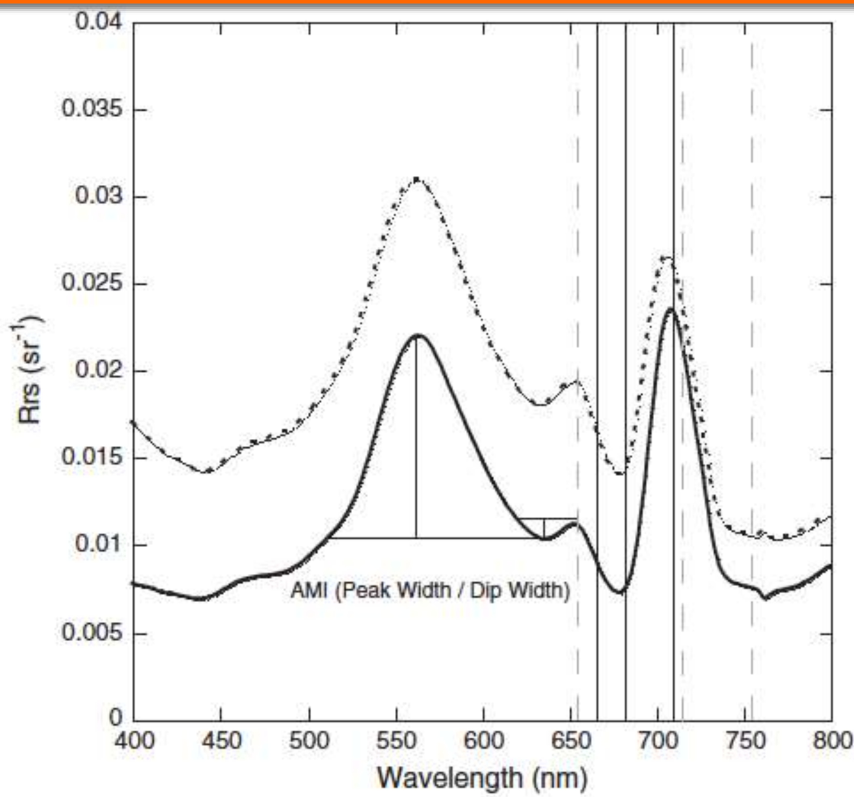


Fig. 2. Example spectra for blooms of *Microcystis* (solid) and *Aphanizomenon* (dashed) from Pinto Lake, CA collected on 13 September and 10 July 2012, respectively. Vertical solid lines indicate the wavelengths used for the CI, vertical dashed lines indicate wavelengths used for SLH. The AMI is based on the ratio of the peak width at ~565 nm and peak trough at ~620 nm.

Cyanobacteria Index (CI) – **Wynne et al. 20**
optimized for MERIS

$$SS(681) = Rrs_{681} - Rrs_{665} - (Rrs_{709} - Rrs_{665}) * \frac{(681-665nm)}{(709-665nm)}$$

Scattering Line Height (SLH)

$$Rrs_{714} - [Rrs_{654} + \frac{Rrs_{754} - Rrs_{654}}{754nm - 654nm}(714-654nm)]$$

Aphanizomenon-Microcystis Index (AMI)

$$\text{peak width/dip width} = \frac{640 - 510\ nm}{652 - 625\ nm}$$

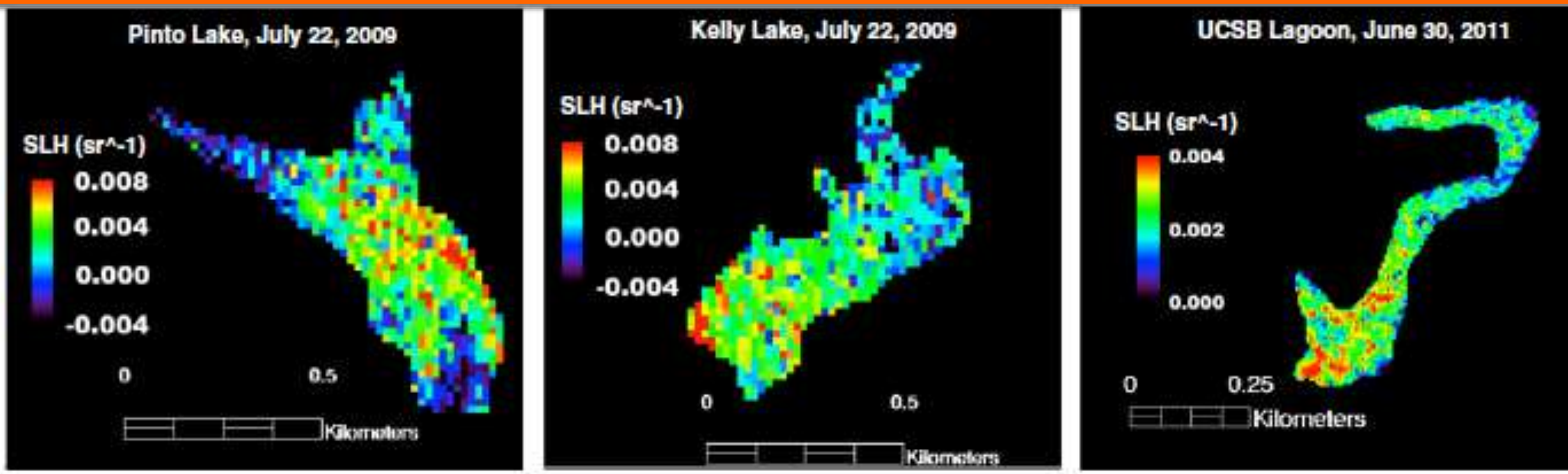
Applied to:

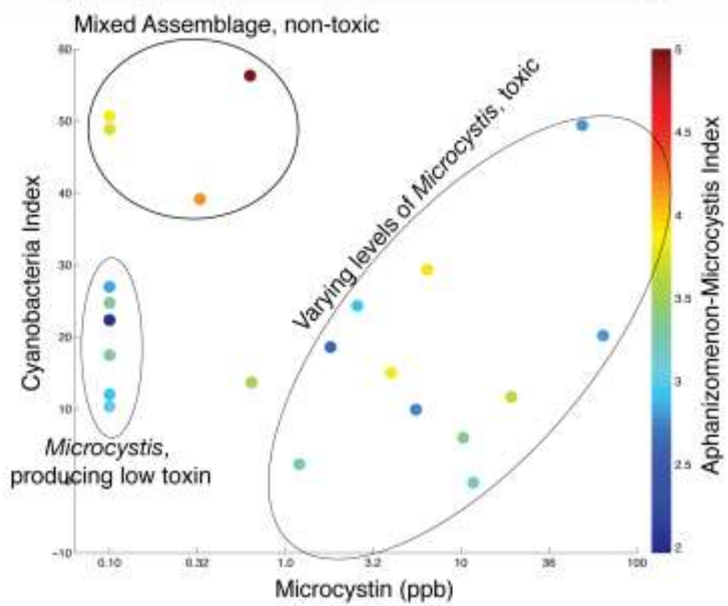
1) HICO imagery
2) Airborne MASTER
3) GER and ASD

Application of Hyperspectral Remote Sensing to Cyanobacterial Blooms in Inland Waters

Kudela et al. (2015) *RSE*

SPECTRAL SHAPE ALGORITHMS



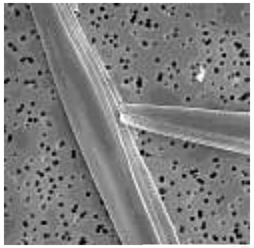


HARMFUL ALGAL BLOOMS ON THE U.S. WEST CO

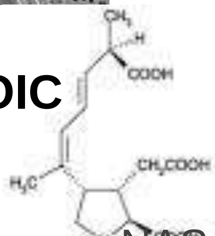
- Annual recreational fishery closures associated with *Pseudo-nitzschia*
- Risk to public health from Amnesic Shellfish Poisoning
- Widespread ecosystem impacts from domoic acid poisoning

Is there a characteristic spectral shape associated with toxic *Pseudo-nitzschia* events?

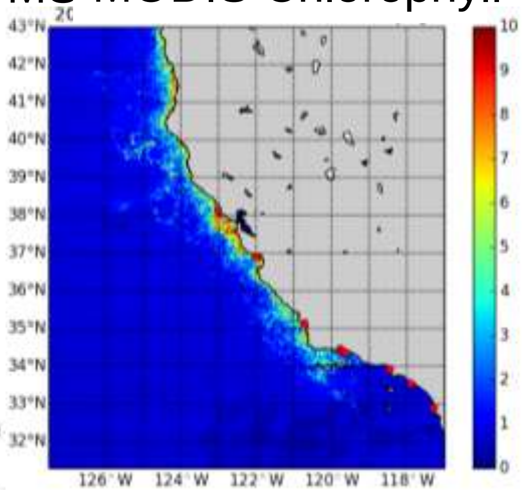
Microscopy& LC-MS



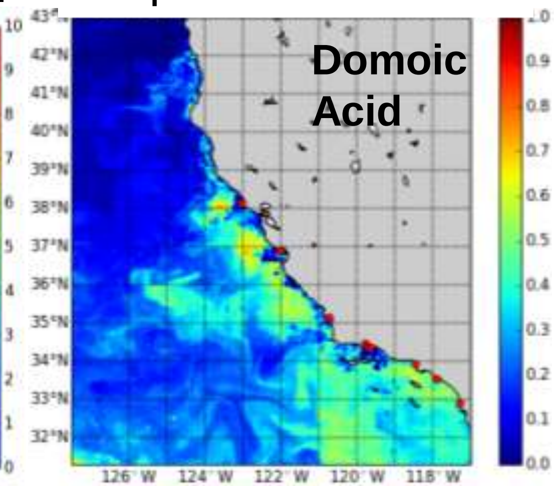
DOMOIC ACID



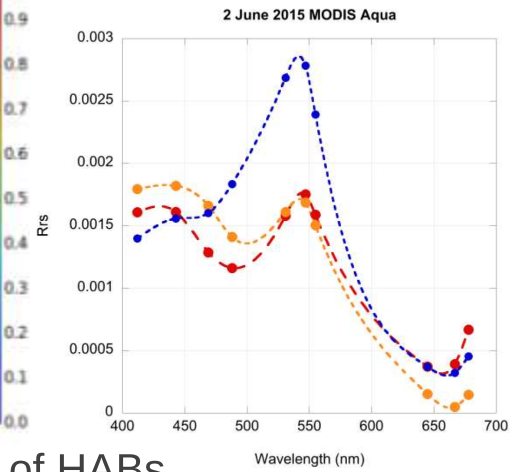
MODIS Chlorophyll



Empirical HAB Models



Spectral Shape

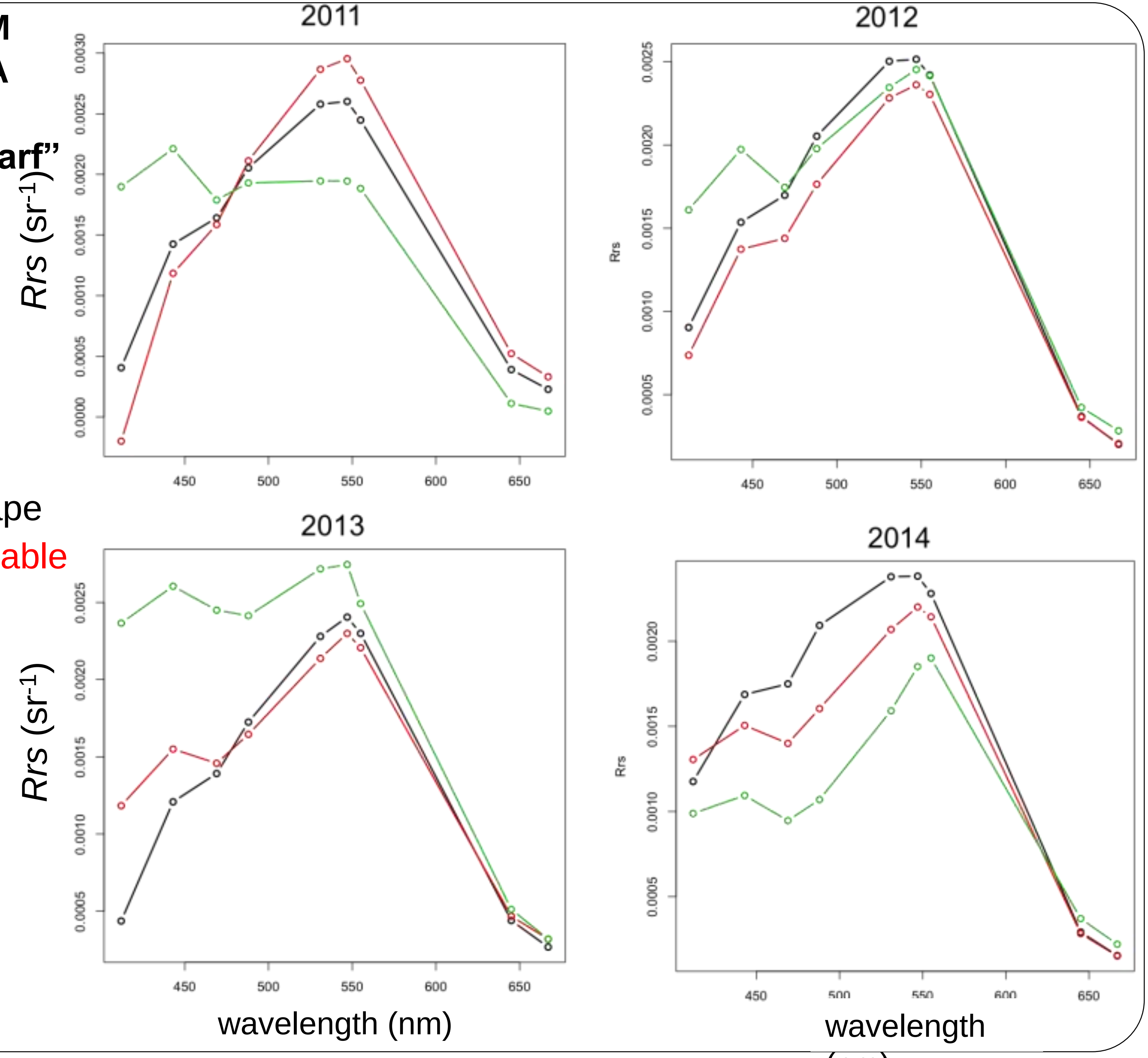


NASA Applied Sciences Program, Operational Forecasting of HABs

PIs: C. Anderson, R. Kudela, CeNCOOS, D. Robinson, R. Stumpf

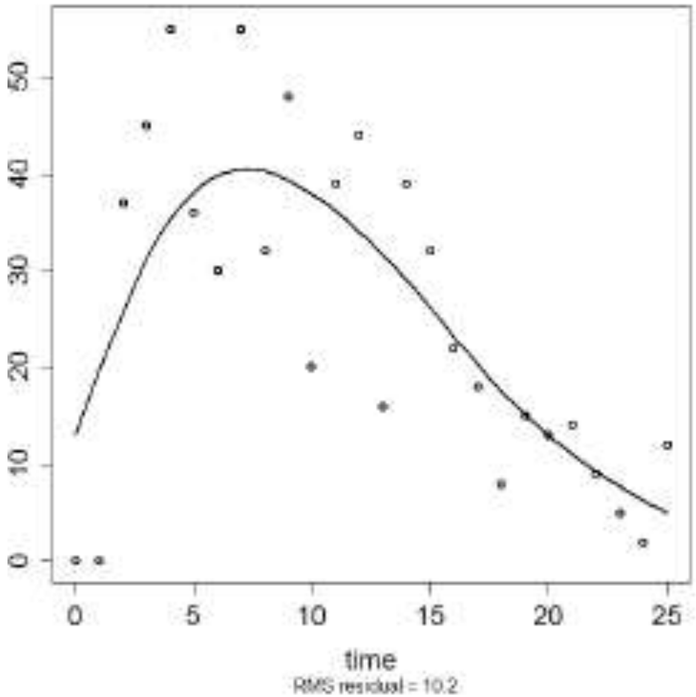
Collaboration with Raphe Kudela - ECOHAB & HyspIRI tea

GIOVANI 4KM MODIS AQUA at "Santa Cruz Wharf"

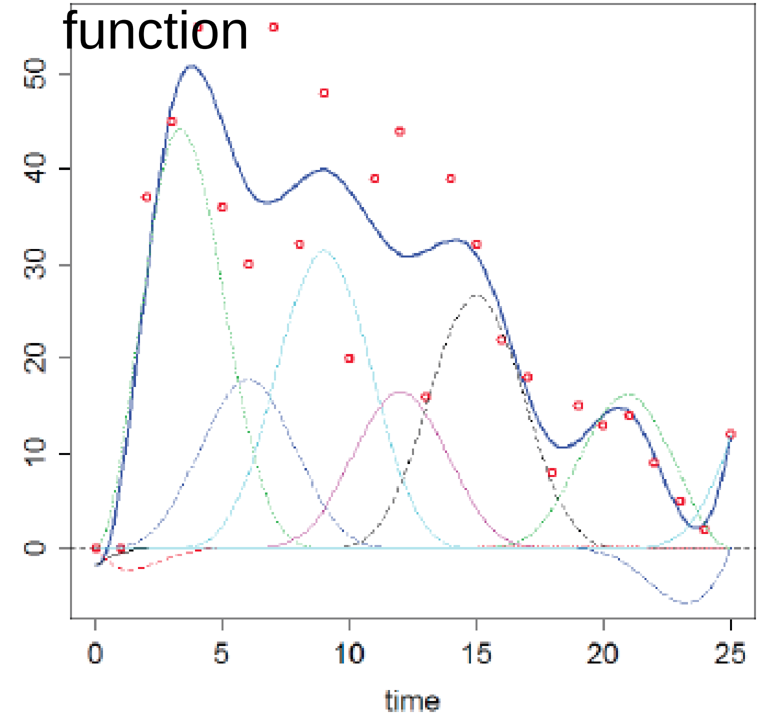


Functional Principal Components Analysis (fPC

Estimate functional data from discrete, noisy observations

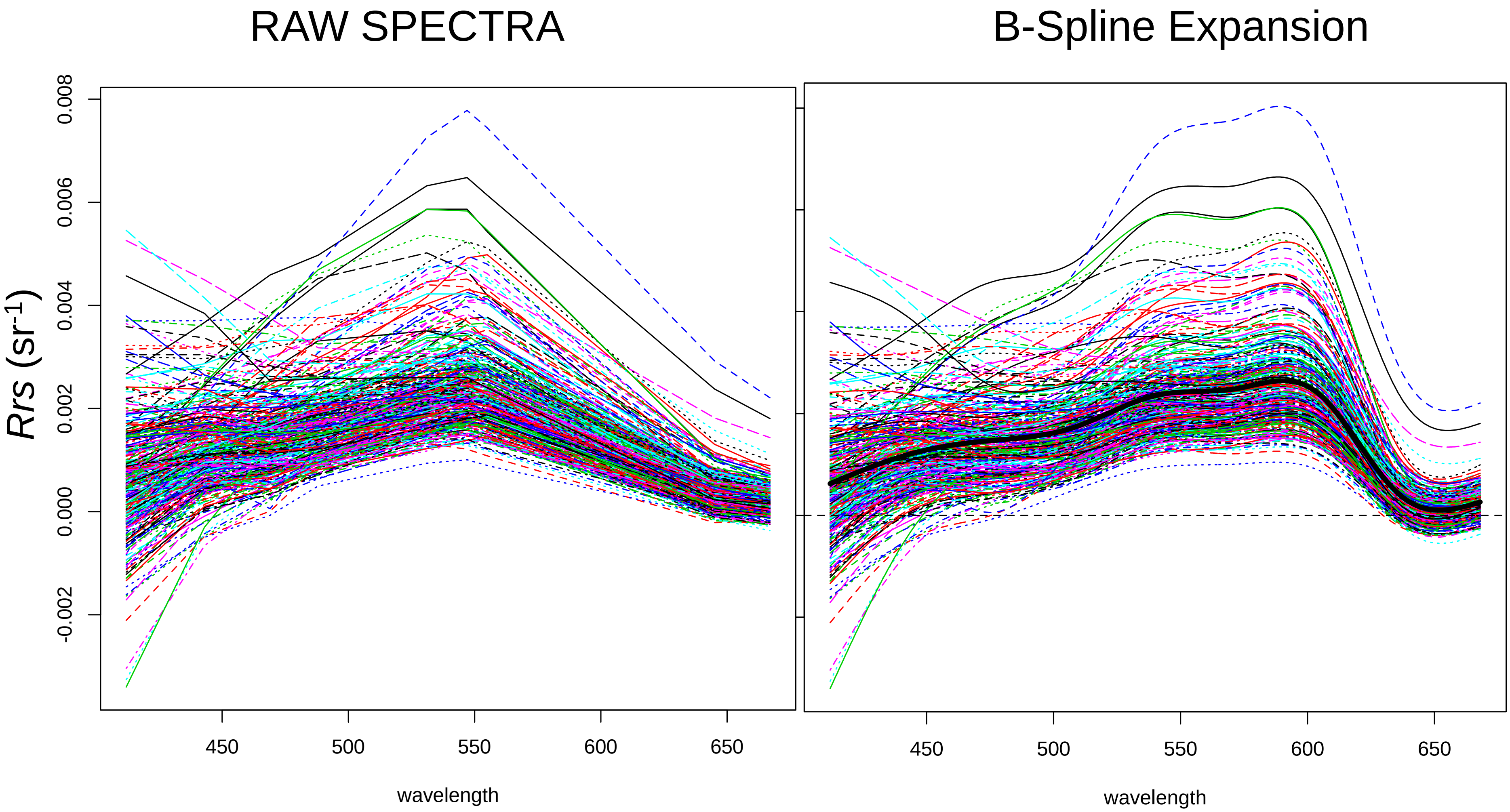


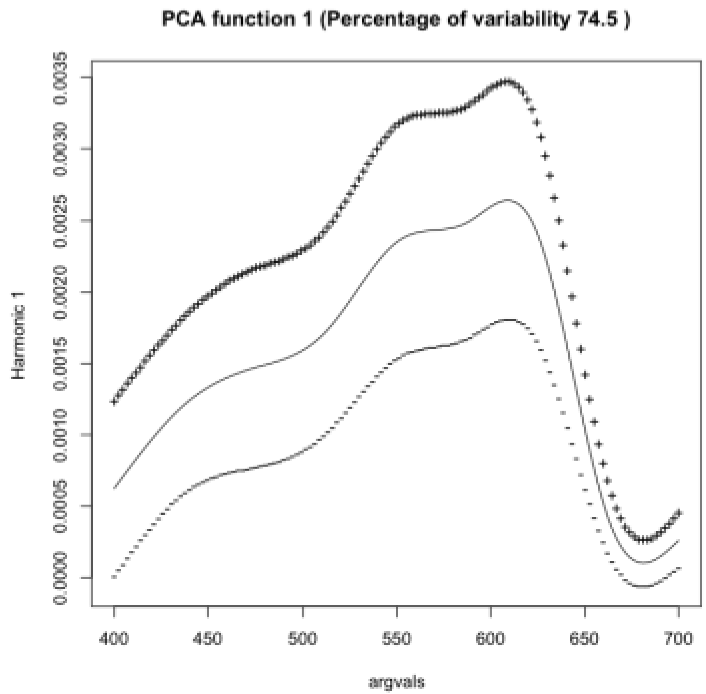
Basis Expansion to transform discrete data to a continuous function

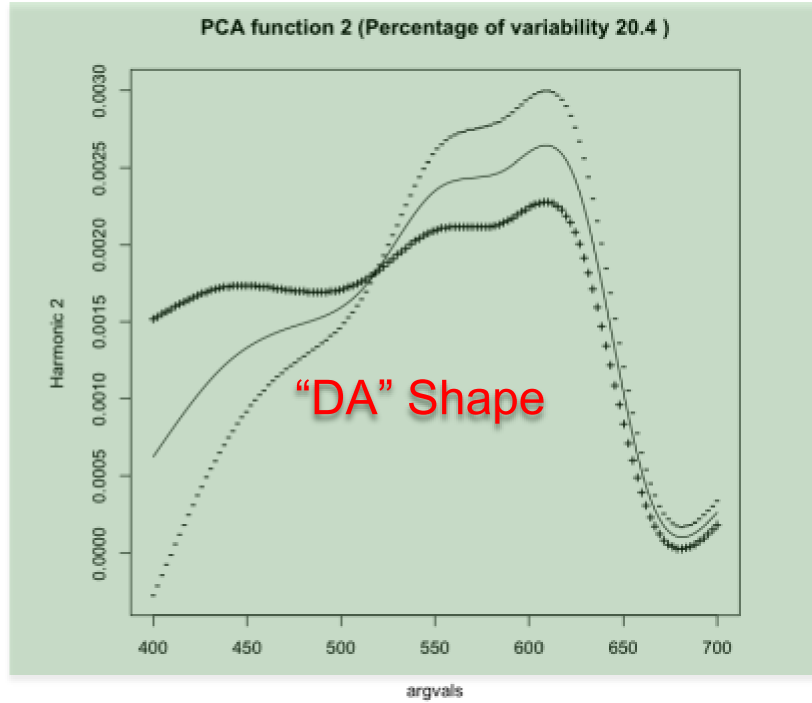


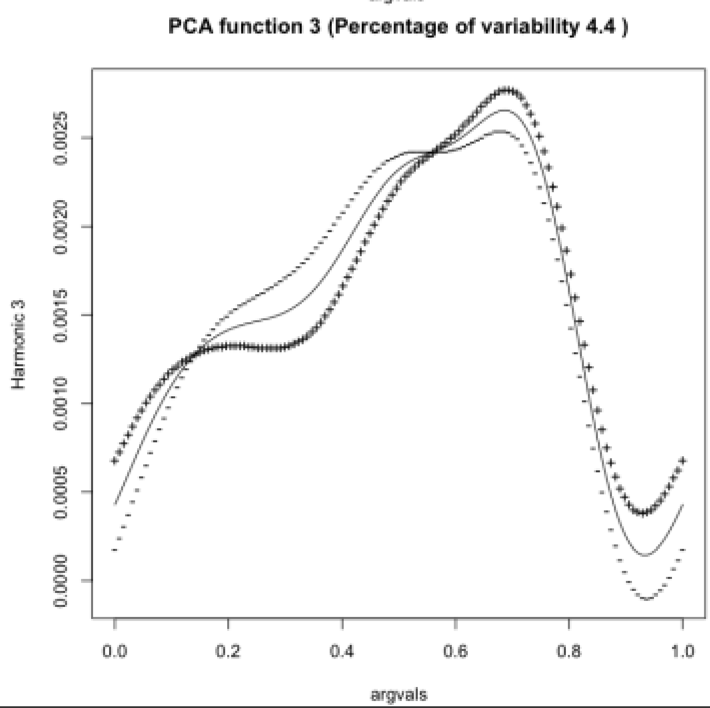
Element	In PCA	In FPCA
Data	$X \in \mathbb{R}^p$	$X \in L^2(\mathcal{T})$
Dimension	$p < \infty$	∞
Mean	$\mu = \mathrm{E}(X)$	$\mu(t) = \mathrm{E}(X(t))$
Covariance	$\mathrm{Cov}(X) = \Sigma_{p \times p}$	$\mathrm{Cov}(X(s), X(t)) = G(s, t)$

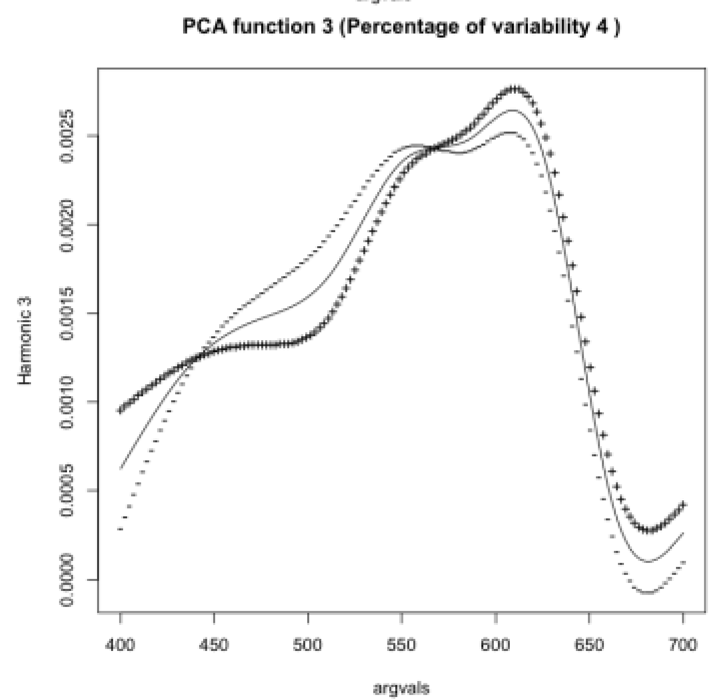
2003-2014 (MARCH-OCTOBER)
GIOVANNI 4KM BINNED MODIS AQUA
Mean Santa Cruz Wharf Pixel



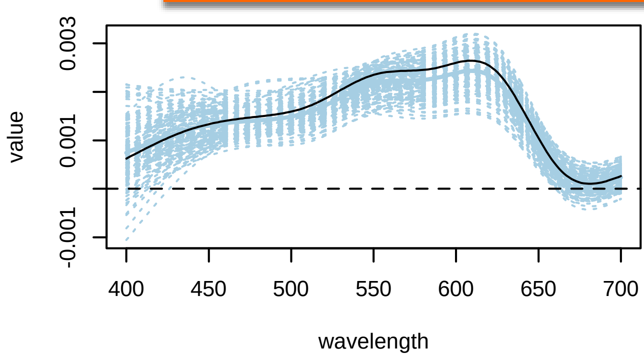

PCA function 1 (Percentage of variability 74.5)
Harmonic 1
argvals
0.0000 0.0005 0.0010 0.0015 0.0020 0.0025 0.0030 0.0035
400 450 500 550 600 650 700

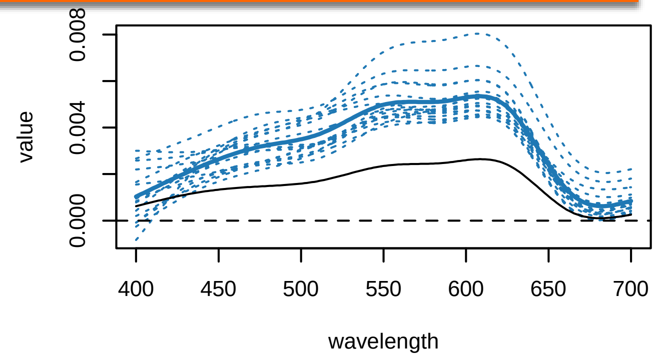

PCA function 2 (Percentage of variability 20.4)
"DA" Shape
Harmonic 2
argvals
0.0000 0.0005 0.0010 0.0015 0.0020 0.0025 0.0030
400 450 500 550 600 650 700

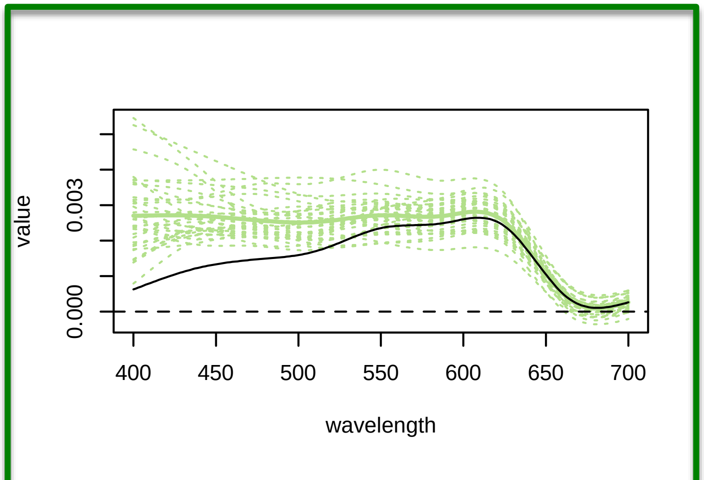

PCA function 3 (Percentage of variability 4.4)
Harmonic 3
argvals
0.0000 0.0005 0.0010 0.0015 0.0020 0.0025
0.0 0.2 0.4 0.6 0.8 1.0

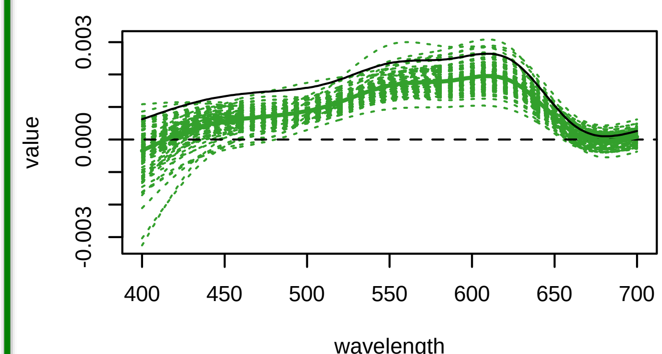

PCA function 3 (Percentage of variability 4)
Harmonic 3
argvals
0.0000 0.0005 0.0010 0.0015 0.0020 0.0025
400 450 500 550 600 650 700

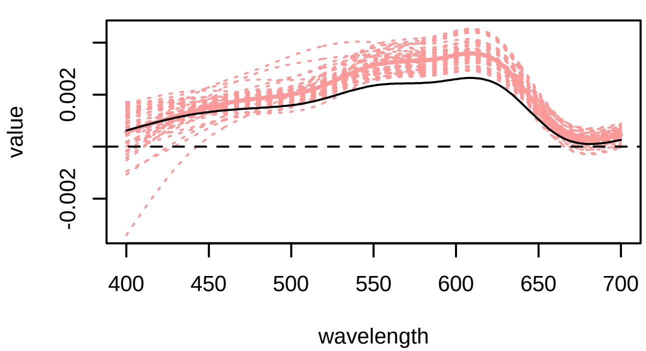
K MEANS CLUSTERING on fPCA SCORES









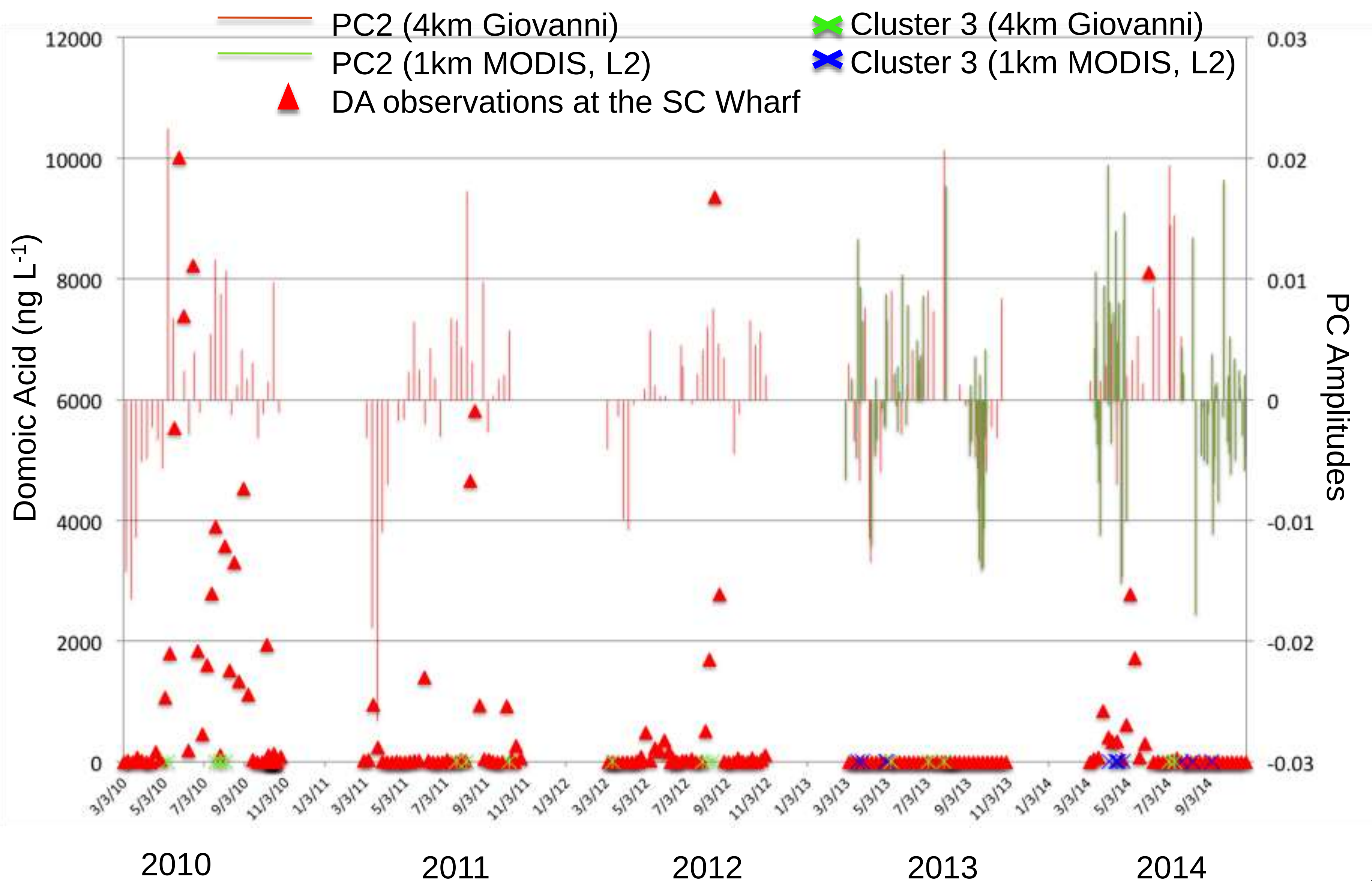


5 clusters selected with Calinski cri

Cluster 3 most resembles “DA” sha

2010-2014 : SANTA CRUZ WHARF

TIME SERIES OF DOMOIC ACID, 2ND PC FUNCTION, AND 3RD K MEANS C



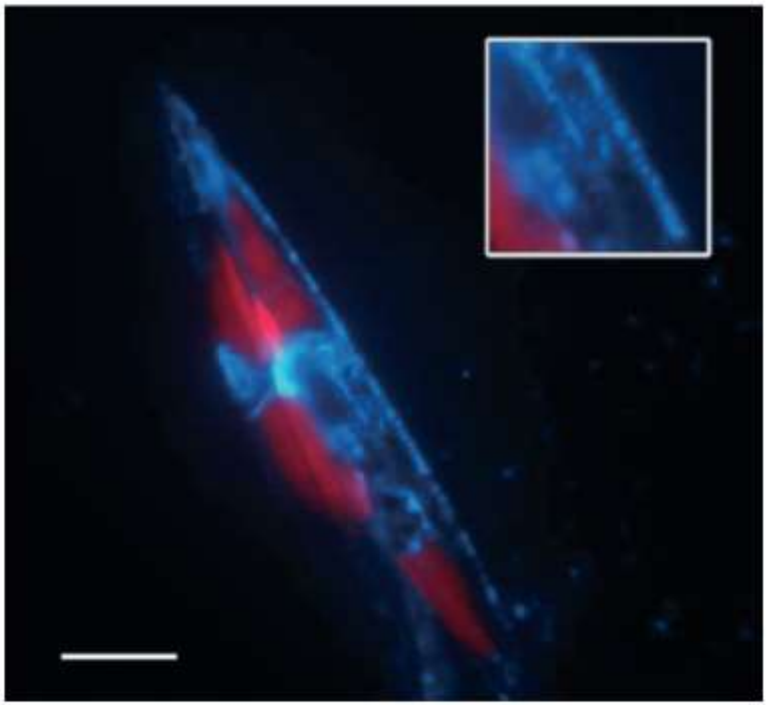
J. Phycol. 40, 705–710 (2004)

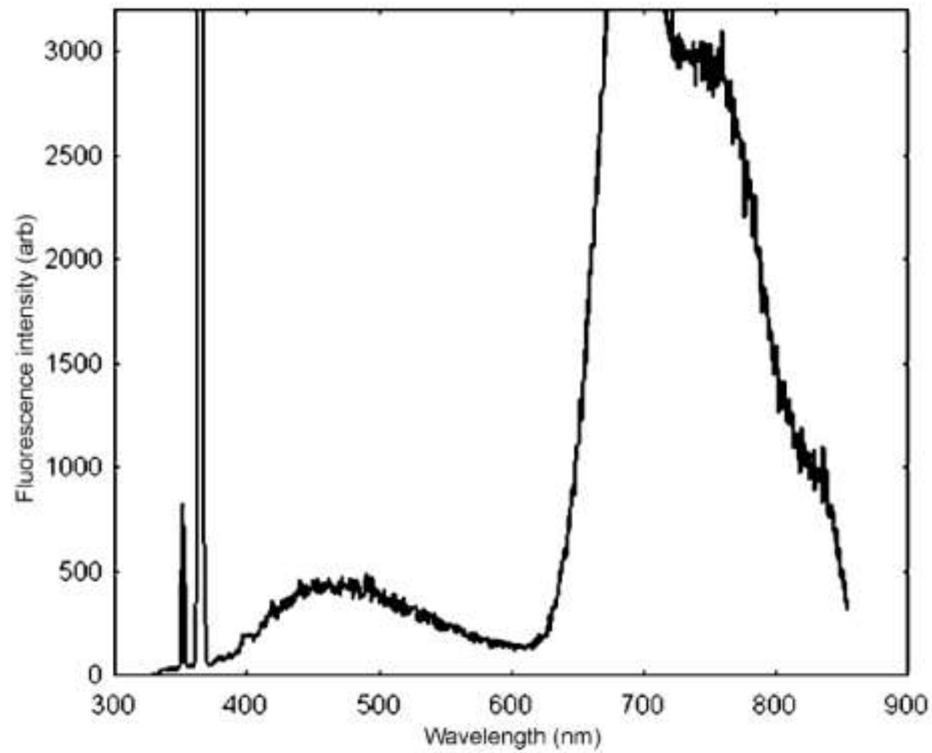
DOI: 10.1111/j.1529-8817.2004.03226.x

NOTE

UV-EXCITED BLUE AUTOFLUORESCENCE OF *PSEUDO-NITZSCHIA MULTISERIES* (BACILLARIOPHYCEAE)[1]

Mónica V. Orellana,[2] Timothy W. Petersen, and Ger van den Engh
Institute for Systems Biology, 1441 North 34th Street, Seattle, Washington 98103, USA





Would natural UV be enough to induce fluorescent emission in the blue if enough *Pseudo-nitzschia* are concentrated in surface waters?

2015: MASSIVE TOXIC DA EVENT on the WEST COAST

CNBC

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Huge bloom of toxic algae hits West Coast

Robert Ferris | @RobertoFerris

22 Hours Ago

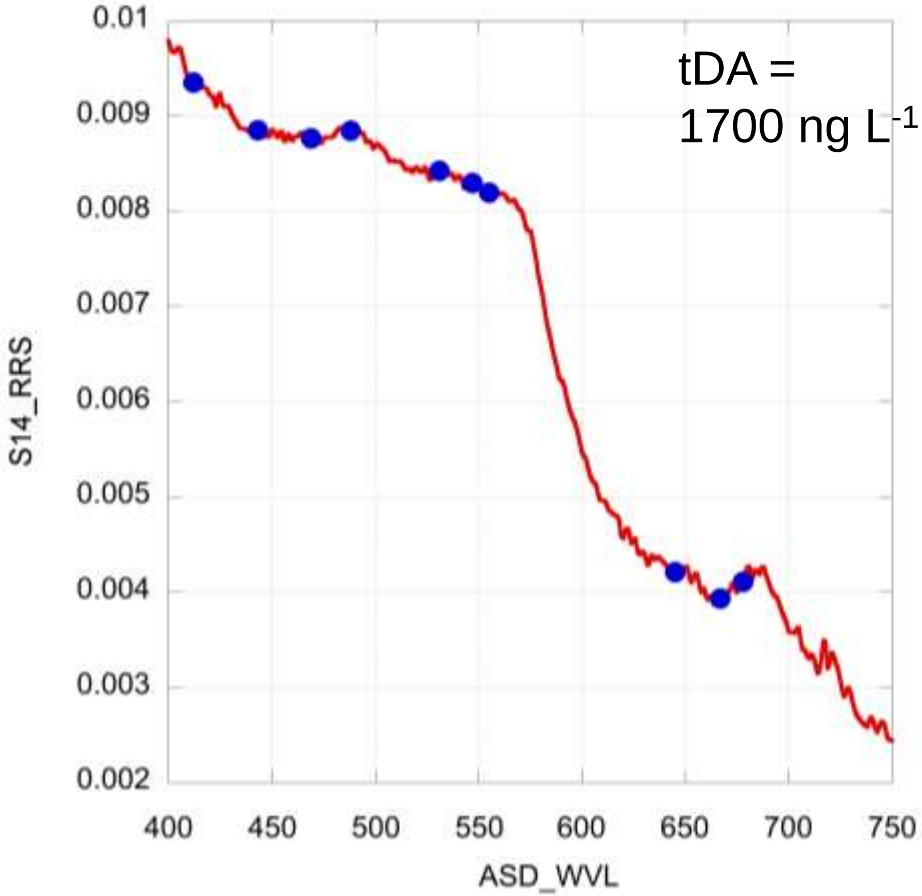
An extraordinarily large mass of toxic algae off the West Coast of the United States has prompted state agencies to shut down crab and clam fisheries in at least two states, and is posing risks to recreational fishing and marine life.

2015: MASSIVE TOXIC DA EVENT on the WEST COAST

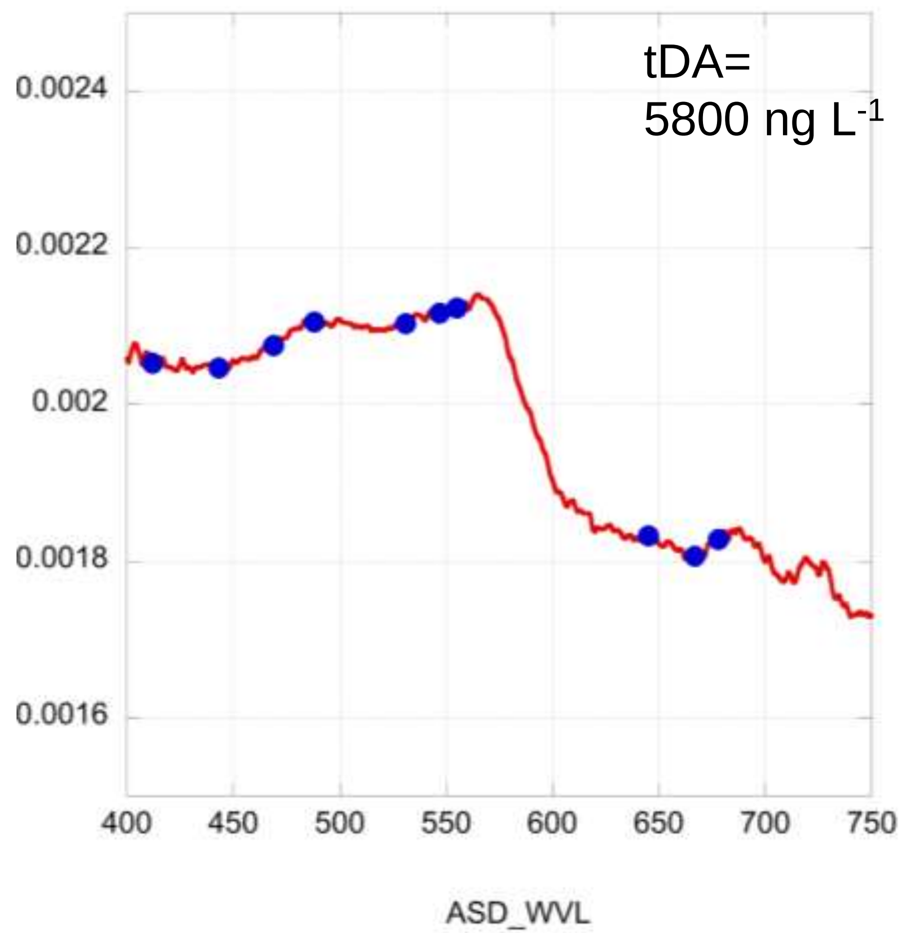
ASD SPECTRA FROM TWO STATIONS in MONTEREY BAY

NOAA ECOHAB & NASA HyspIRI PROJECTS

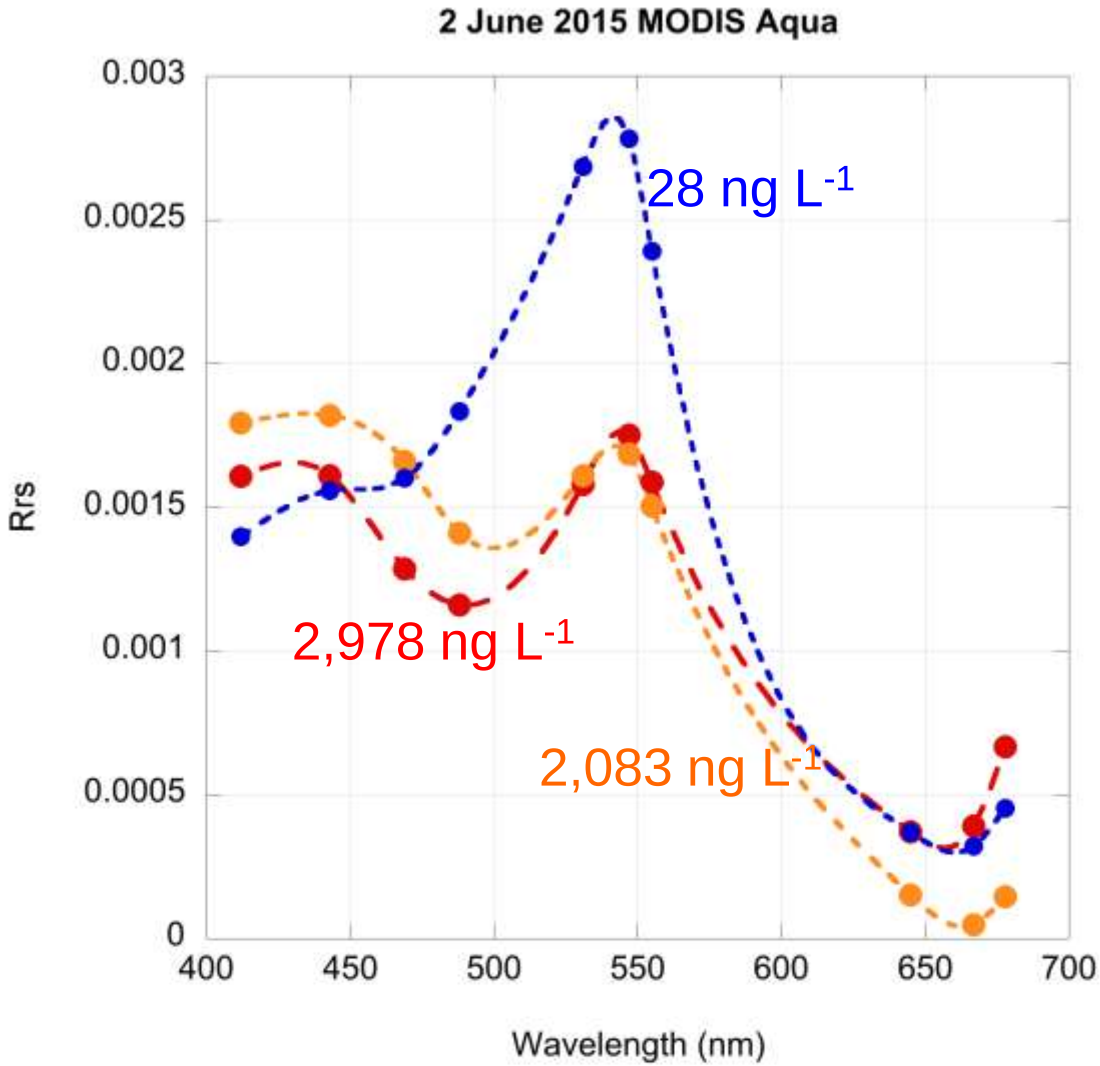
Stn 14 – "Low" Domoic Acid

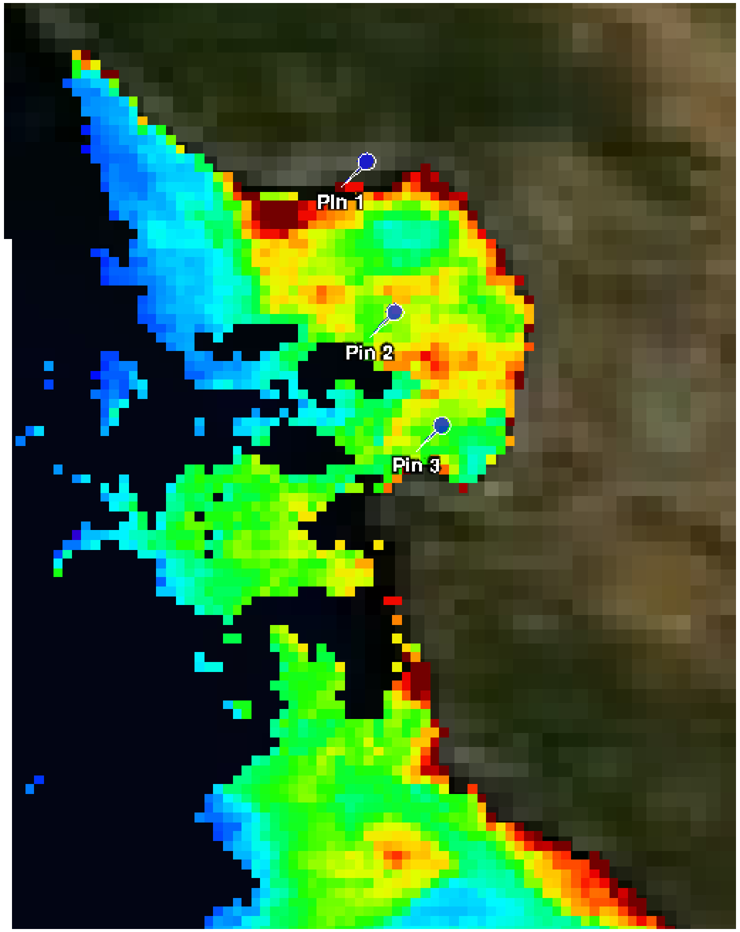


Stn 15 - High Domoic Acid



MODIS Aqua Spectra versus Measured Toxin





Chlorophyll (μg L^{-1}):

Blue = 11.07

Orange = 1.43

Red = 1.88

Hyperspectral Science & Next Decadal Survey
Can we improve public health?

1) Major science questions pertaining to HABs and other water-borne pathogens:

- Can we discriminate between taxa and estimate physiological condition?
  -includes toxin production

ANSWER: Need increased spectral resolution (overlap in bands/# bands)

- Can we assimilate EO data into end-to-end modeling frameworks to improve
  water quality/public health predictions?

ANSWER: Biological data assimilation possible, but we need adequate mechanistic models to reflect the biological processes driving the production of key by-products.

2) How will hyperspectral data help to address those questions?

ANSWER: "It is our only hope." -Dave Siegel, 16 June 2015

3) What is the smallest measurement 'scale' needed to address your scien

REPHRASE: What is the largest scale that is still useful? ANSWER: 1 km, 1 da
But nearshore HAB dynamics and lake processes really require scales ~ 100-50

4) What other space-based measurements or modeled data would you like to have to obtain more out of ocean color?

ANSWERS: LIDAR – physiological status? Physical-biogeochemical models at sub- mesoscales, coupled w/empirical detection algorithms