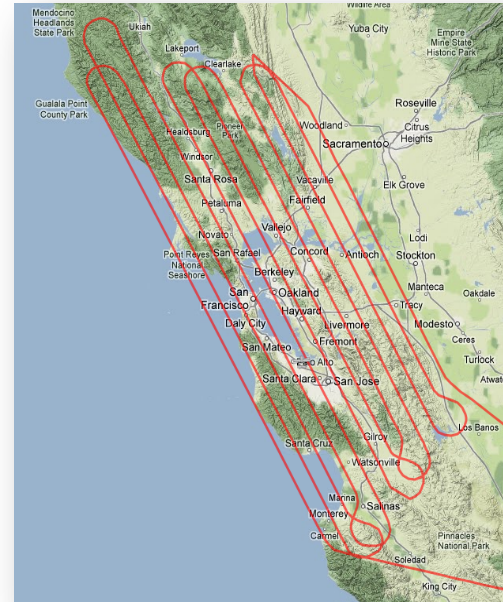
Using HyspIRI at the Land/Sea Interface to Identify Phytoplankton Functional Types (PFTs): AKA Hyperspectral Studies of Coastal and Inland Waters of California

Raphael Kudela[1] (PI, UCSC), Liane Guild[2] (Co-PI, NASA ARC)
Sherry Palacios[3], Juan Torres-Pérez[3]
Kendra Negrey[1]

1 UC – Santa Cruz, 2 NASA ARC, 3 Bay Area Environmental Research Institute/NASA ARC

HyspIRI Science and Applications Workshop October 2015

Outline



- Science Goal and Questions
- Data Collected (2013-2015)
  - *In situ*
  - Imagery
  - Ongoing issues
- Some of our Science
  - *Application of hyperspectral remote sensing to cyanobacterial blooms in inland waters – Raphe's work*
  - *Remote sensing of phytoplankton functional types in the coastal ocean from the HyspIRI Preparatory Flight Campaign – Sherry's work*
- *Lessons Learned*
- *Data Management*

Science Goal and Questions

The primary goal of this project is to demonstrate the utility of an airborne HyspIRI simulation to address the biological properties of coastal California, within the context of the long-term monitoring programs ongoing in the area.

1) Can we use PHYDOTax (a PFT algorithm) for coastal and inland waters?
2) Do Spectral Shape algorithms provide “good enough” data?
3) How does this relate to coastal water quality?
4) How best to provide cal/val data for airborne missions
    - Comparison of in-water instruments
    - Comparison with airborne sensors
    - Evaluation of atmospheric correction schemes
    - Development of new spectral end-member algorithms
    - Development of a size-resolving Net Primary Production model

In Situ Plumes & Blooms Observations

Pigments (e.g. chl-a)

IOPs

- absorption (a_p, a_d, a_{CDM})
- backscattering

AOPs

- water-leaving radiance
- remote sensing reflectance

Water

- salinity
- temperature

In Situ Monterey Bay Observations

Ocean: Red Tide Incubator (RTI), Pajaro River Mouth (PRM), M0 Legacy Mooring

HPLC measured pigments (e.g. chl-a)

Phytoplankton cell counts

IOPs

- absorption (a_p, a_d, a_{CDM})
- ac-s measured total absorption and attenuation
- backscattering

AOPs

- water-leaving radiance
- remote sensing reflectance

Water

- salinity
- temperature

Pinto Lake:

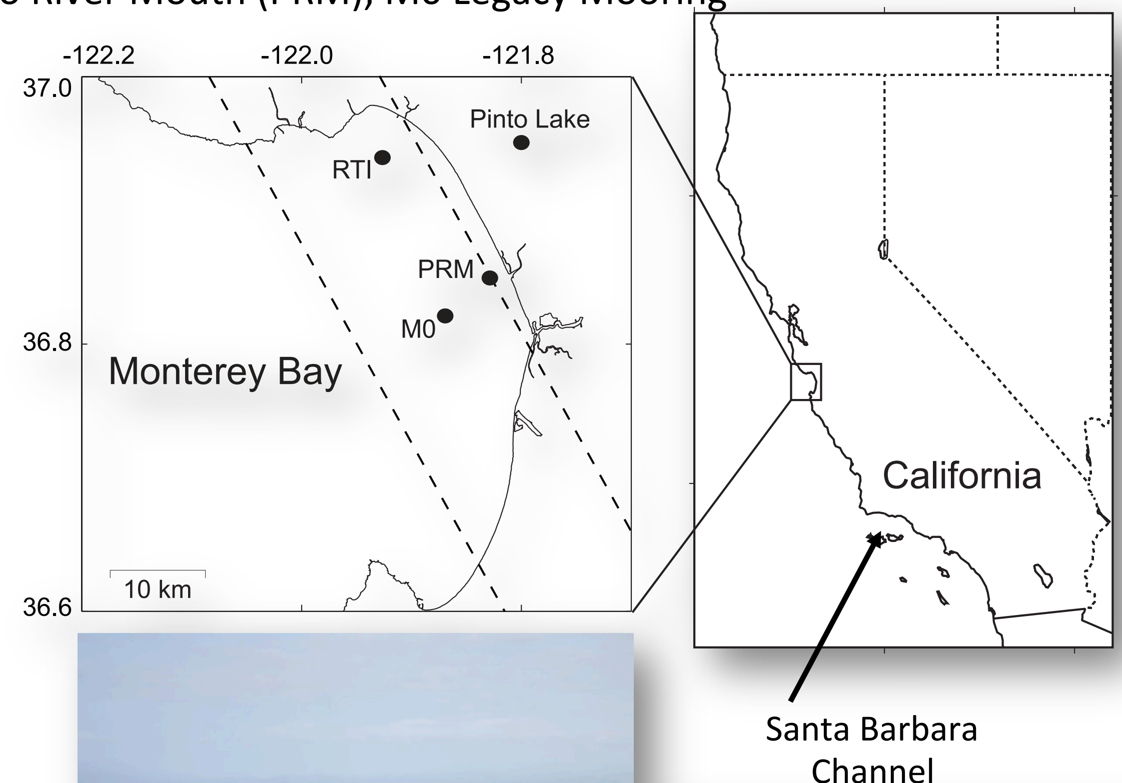
Pigments (chl-a)

Backscattering

AOPs

Spectroscopy – GER 1500, ASD

Aerosol Optical Depth (AOD) - Microtops sun photometer



In situ Monterey Bay Observation Dates

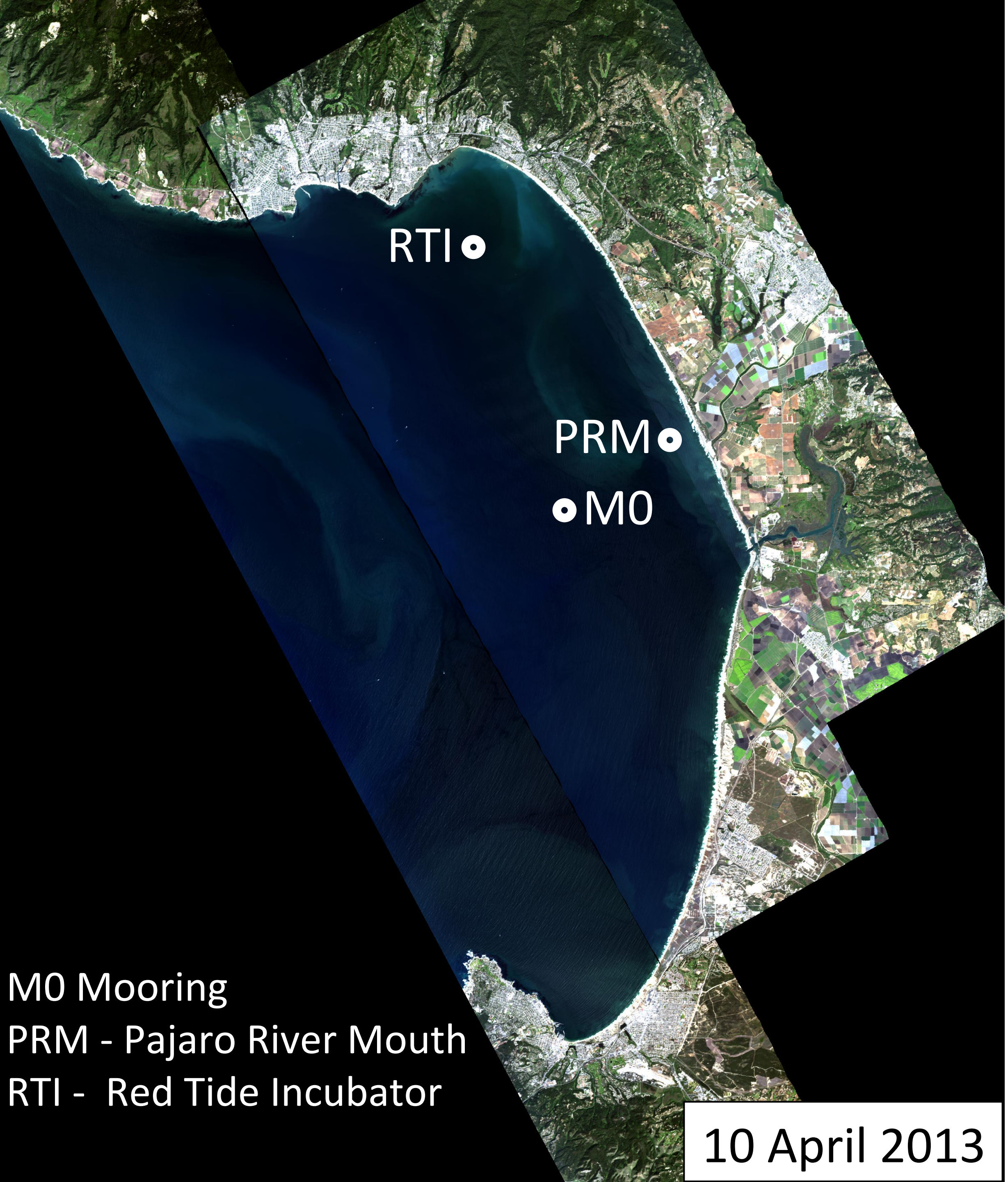
Field Season	Flight Date(s)	Location (box)	In-water Measurements	RTI	PRM	M0	SCW	Pinto	White Plains
Spring 2013	4/10/13	SF Bay	y	x	x	x		x	x
Summer 2013	6/7/13	SF Bay	y	x	x	x		x	x
Autumn 2013	10/30/13	SF Bay	y	x	x	x			
	10/31/13	SF Bay	y	x	x	x		x	
	11/5/13	SF Bay	no imagery	x	x	x			
	11/22/13	SF Bay	n						
	12/5/13	SF Bay	y	x	x	x		x	
Spring 2014	4/23/14	SF Bay	no imagery	x	x	x		x	x
	4/28/14	SF Bay	y	x	x	x		x	x
	5/7/14	SF Bay	y				x		
Summer 2014	5/28/14	SF Bay	Pinto only					x	
Autumn 2014	10/6/14	SF Bay	y					x	
	10/23/14	SF Bay	no imagery	x	x	x			
	10/27/14	SF Bay	y	x	x	x		x	
	10/30/14	SF Bay	no imagery		x				
	11/24/14	SF Bay	n						
Spring 2015	4/17/15	SF Bay	no imagery	x	x	x		x	
	4/30/15	SF Bay	y				x	x	
	4/30/15	Monterey Bay & Pinto Lake	y					x	
Summer 2015	No data	SF Bay							
Autumn 2015	10/2/15	SF Bay	TBD	x	x	x		x	

Data Collected

Coastal Imagery Dates

Field Season	Flight Date(s)	Location (box)	AVIRIS	MASTER	In-water Measurements
Spring 2013	4/10/13	SF Bay	y	y	y
	4/11/13	SB Channel	y	y	n
Summer 2013	6/7/13	SF Bay	y	y	y
	6/6/13	SB Channel	y	y	n
Autumn 2013	10/30/13	SF Bay	y	y	y
	10/31/13	SF Bay	y	n	y
	11/22/13	SF Bay	y	y	n
	11/25/13	SB Channel	y	y	n
	12/5/13	SF Bay	y	y	y
Spring 2014	4/16/14	SB Channel	y	y	y
	4/28/14	SF Bay	n	y	y
	5/7/14	SF Bay	y	y	y
Summer 2014	5/28/14	SF Bay	y	y	n
	6/4/14	SB Channel	y	y	n
	6/6/14	SB Channel	y	y	n
Autumn 2014	8/29/14	SB Channel	y	y	n
	10/6/14	Monterey Bay & Pinto Lake	AVIRIS-NG	n	y
	10/21/14	SB Channel	y	y	y
	10/27/14	SF Bay	y	y	y
	11/24/14	SF Bay	y	y	n
Spring 2015	4/16/15	SB Channel	y	y	y
	4/17/15	SF Bay	n	y	y
	4/30/15	SF Bay	y	y	y
	4/30/15	Monterey Bay & Pinto Lake	AVIRIS-NG	n	y
Summer 2015	6/2/15	SB Channel	y	y	n
	No Data	SF Bay			
Autumn 2015	10/2/15	SF Bay			

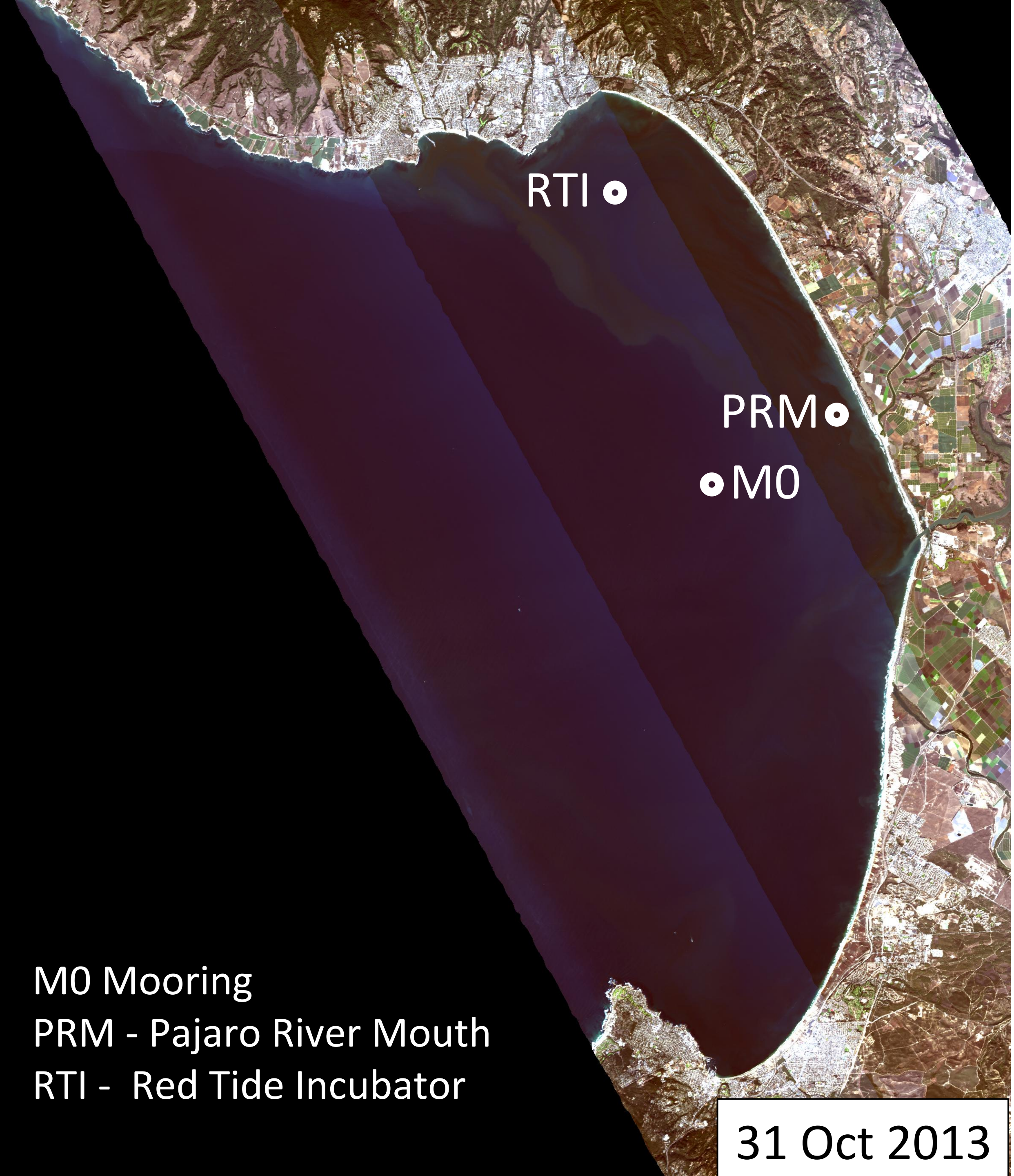
☹ Rosette lines



Spring 2013

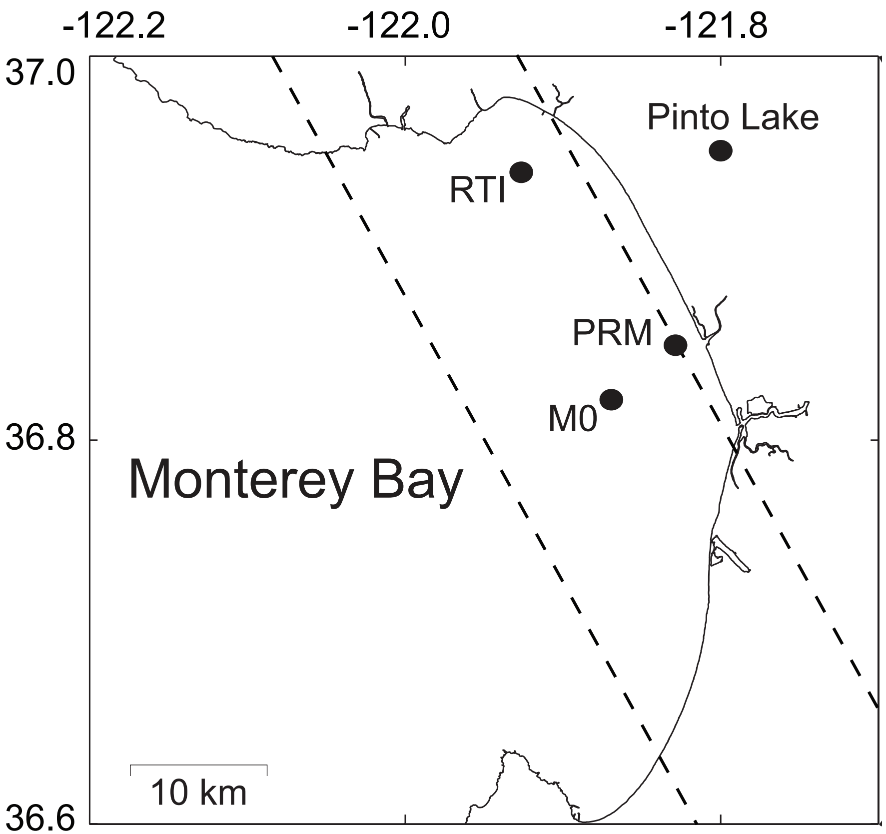
- period of upwelling
- patchy phytoplankton bloom (~ 60 mg m^{-3})
- diatom dominated
- calm sea-state
- seasick post-docs

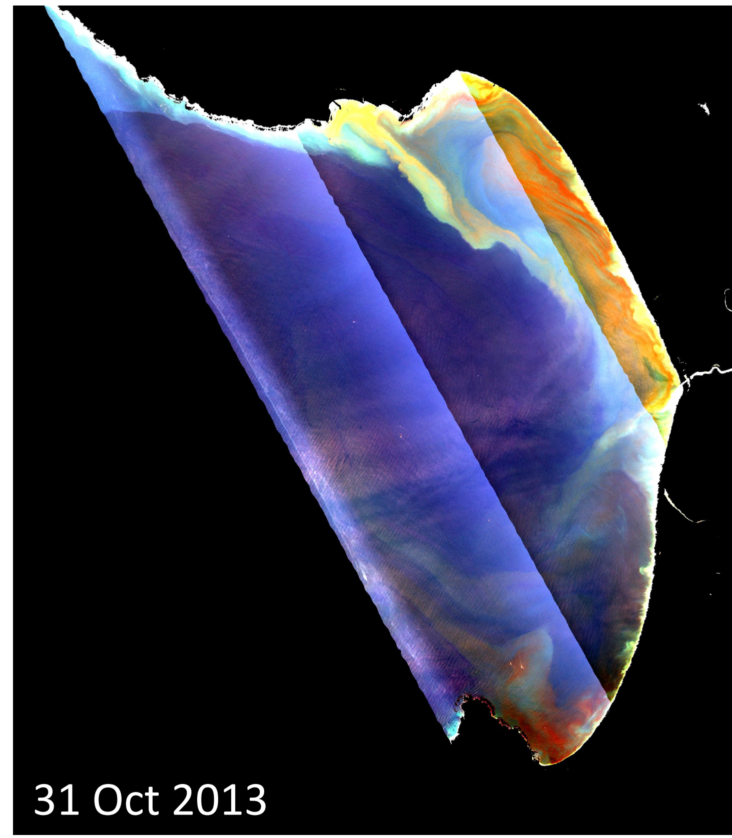
Autumn 2013



- period of relaxation
- red tide (~ 50 mg m^{-3})
- dinoflagellates
- calm sea-state
- widespread whale and seabird foraging

"Remote sensing of phytoplankton functional types in the coastal ocean from the HyspIRI Preparatory Flight Campaign"

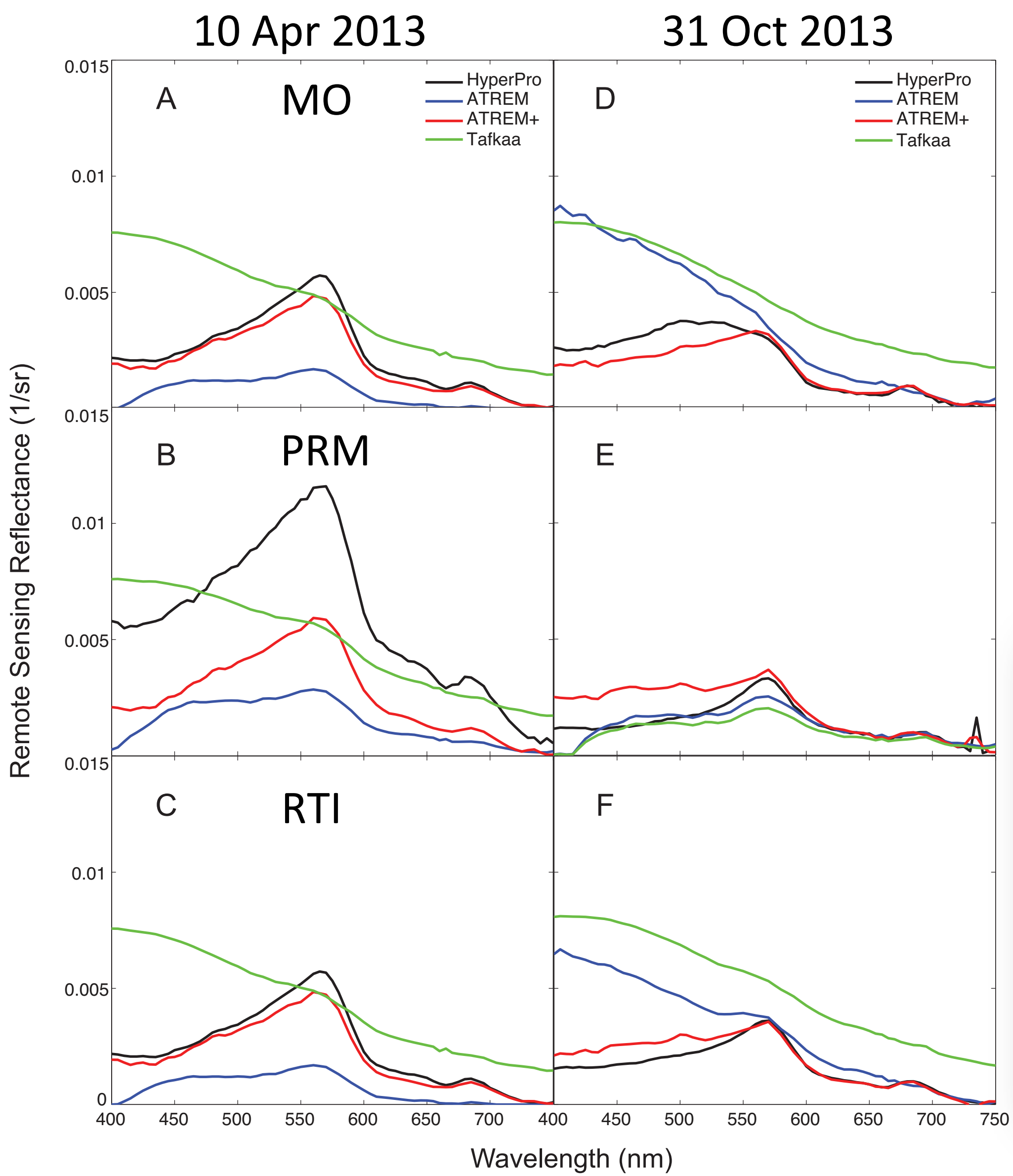


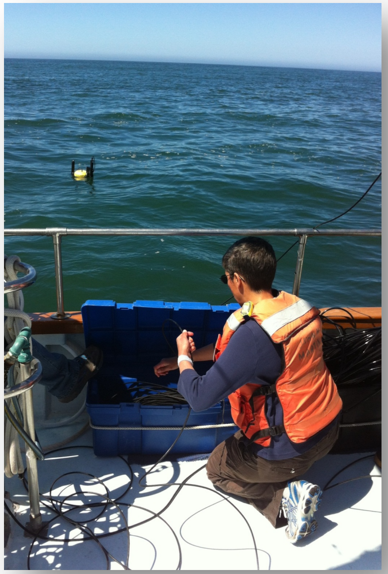


RTI = Red Tide Incubator, PRM = Pajaro River Mouth, M0 Legacy Mooring

Data Collected

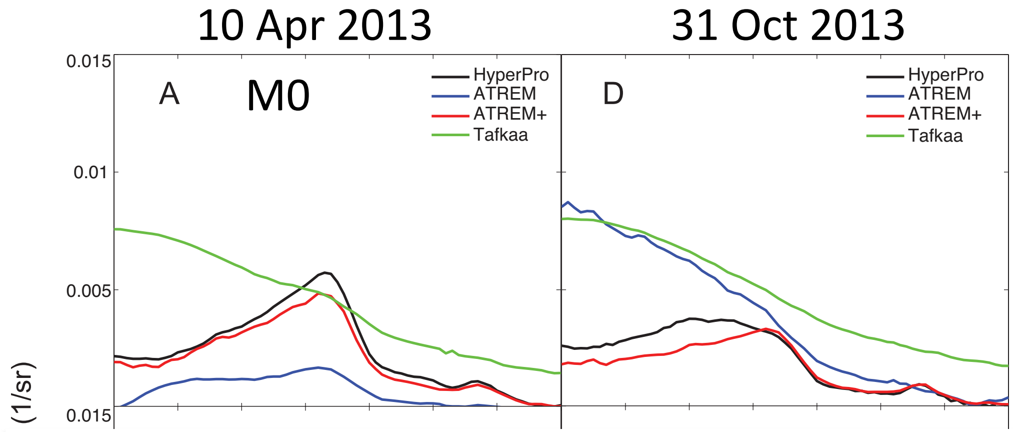
Ongoing Issues with Imagery

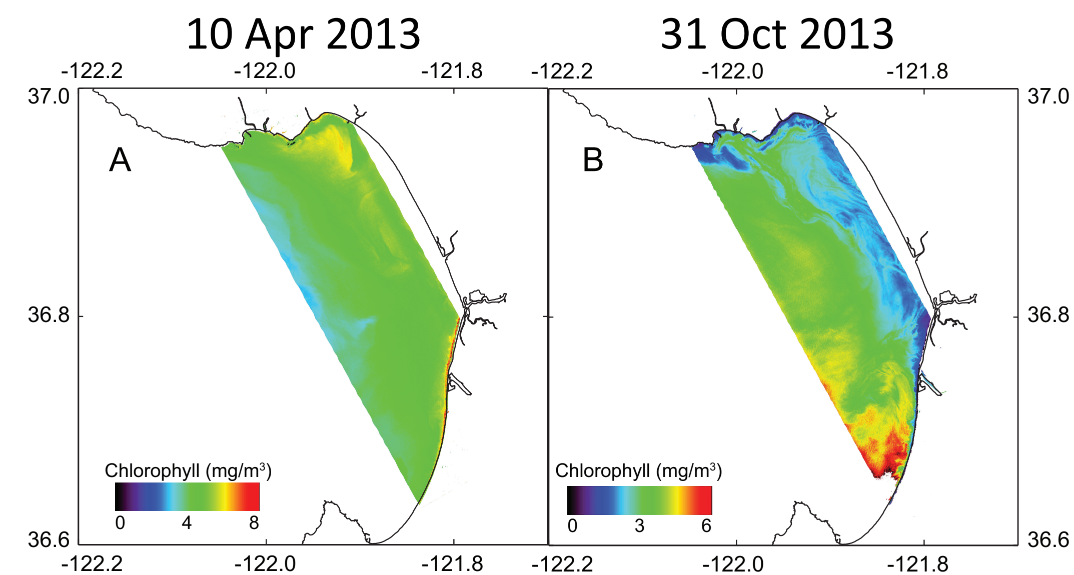




Oct. 2013 red tide and marine mammals!

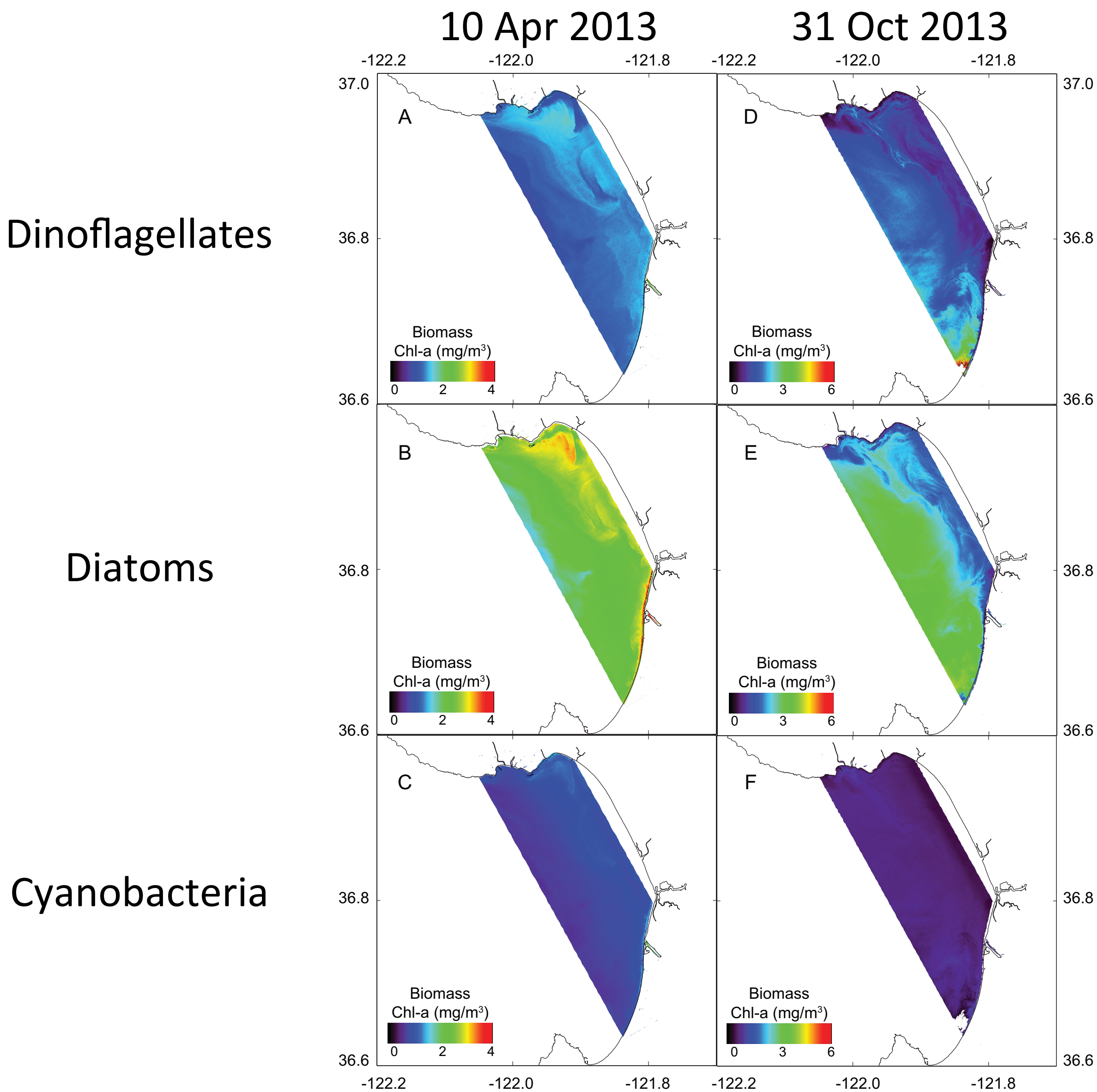
First Rule of Ocean Color Remote Sensing: Accurate Retrievals





Results suggest that chlorophyll can be estimated from ATREM+ retrievals, but only weakly

First Rule of Ocean Color Remote Sensing: Accurate Retrievals



PHYDOTax failed to accurately estimate population structure in spectra with low biomass/signal, but accurately predicted it under high biomass conditions

Coastal Imagery Dates

Data Collected

- A robust *in situ* data set collected in Monterey Bay and Pinto Lake for all years and seasons: 2013, 2014, 2015
- Matchups for Santa Barbara Channel Plumes & Blooms cruises on 4/16/14 & 10/21/14
- Currently, only **two dates** of experimentally processed "scientific quality" AVIRIS images for Monterey Bay (4/10/2013 & 10/31/2013)

Lessons Learned

- Hyperpsectral imagery has special needs with respect to instrument calibration, signal-to-noise, and atmospheric correction
- It is possible to forecast blooms of the toxic cyanobacterium, *Microcystis*, using hyperspectral data

Data Management

- Preparing *in situ* data to target upload to SeaBASS in winter 2016
- AVIRIS over water targets, needs further work with JPL

2015: We live in interesting times…

Large bloom of toxic algae under way in Monterey Bay and beyond

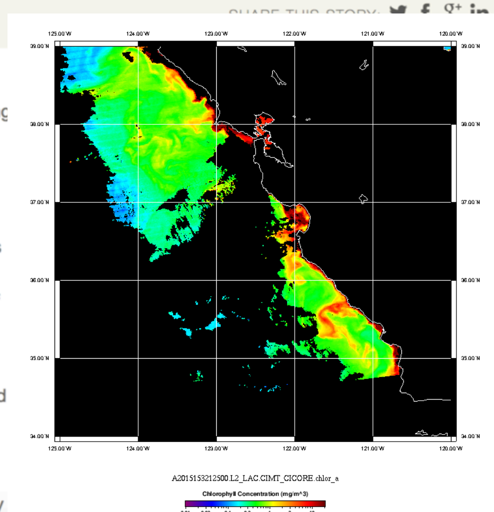
Monitoring program led by UC Santa Cruz has detected high levels of the toxin domoic acid in Monterey Bay; more blooms reported elsewhere along the west coast

June 02, 2015
By Tim Stephens

SHARE THIS STORY:

Researchers have detected large blooms of toxin-producing algae in Monterey Bay, raising concerns about potential effects on marine mammals and seabirds. The bloom involves microscopic algae called *Pseudo-nitzschia* (a type of diatom), which produce a potent neurotoxin called domoic acid. The toxin was first detected in early May, and by the end of the month researchers had detected some of the highest concentrations of domoic acid ever observed in Monterey Bay.

"It's a pretty massive bloom. The domoic acid levels are extremely high right now in Monterey Bay, and the event is occurring as far north as Washington state. So it appears this will be one of the most toxic and spatially



http://news.ucsc.edu/2015/05/algal-bloom.html

New domoic acid optical signature being developed

Updates: Things to know about the Santa Barbara oil spill

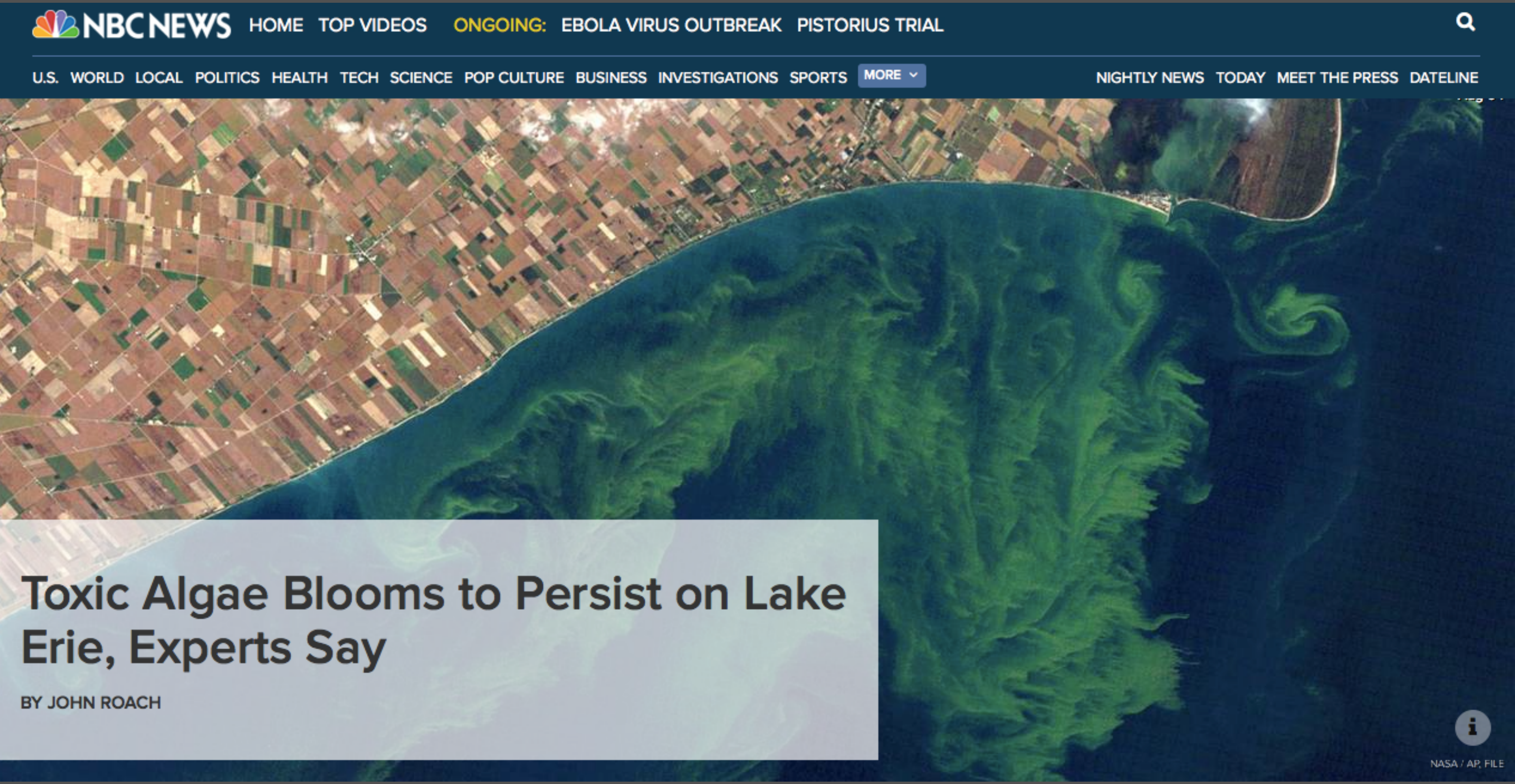
UPDATED 2:10 PM PDT Jun 01, 2015

KSBY

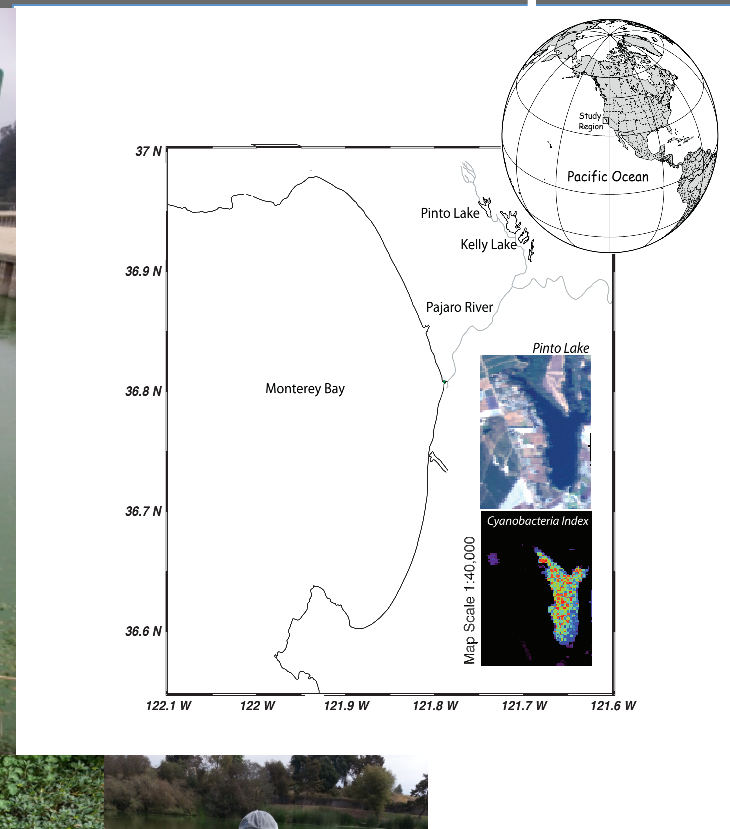
LOS ANGELES — Clea
Central Coast two weeks a
gallons of crude into the P

The May 19 spill occurred
oil platform blowout in 196

"Application of hyperspectral remote sensing to cyanobacterial blooms in inland waters"

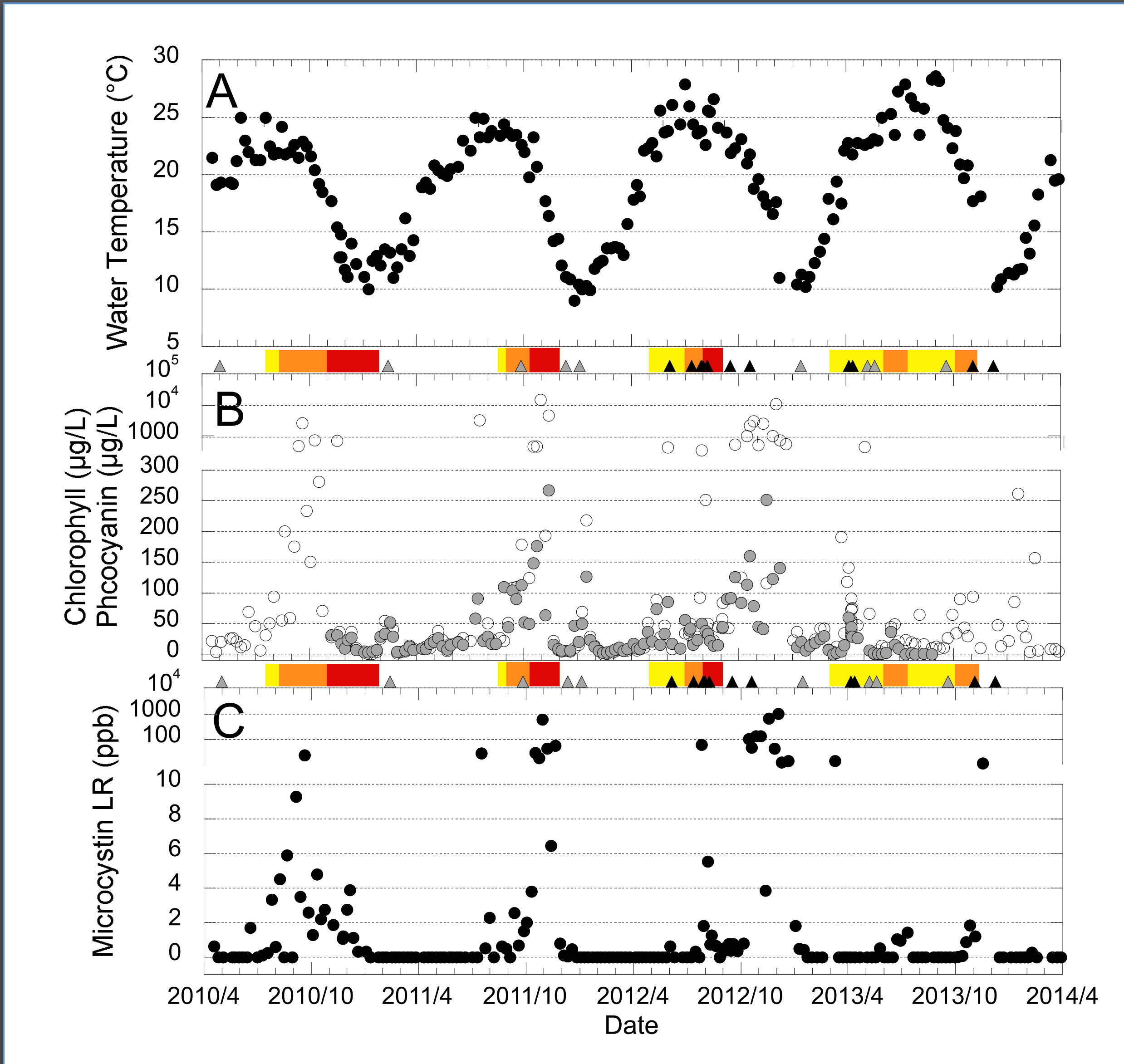


Pinto Lake, Our Favorite Toxic Cesspool



October 2, 2015!

Pinto Lake, Our Favorite Toxic Cesspool

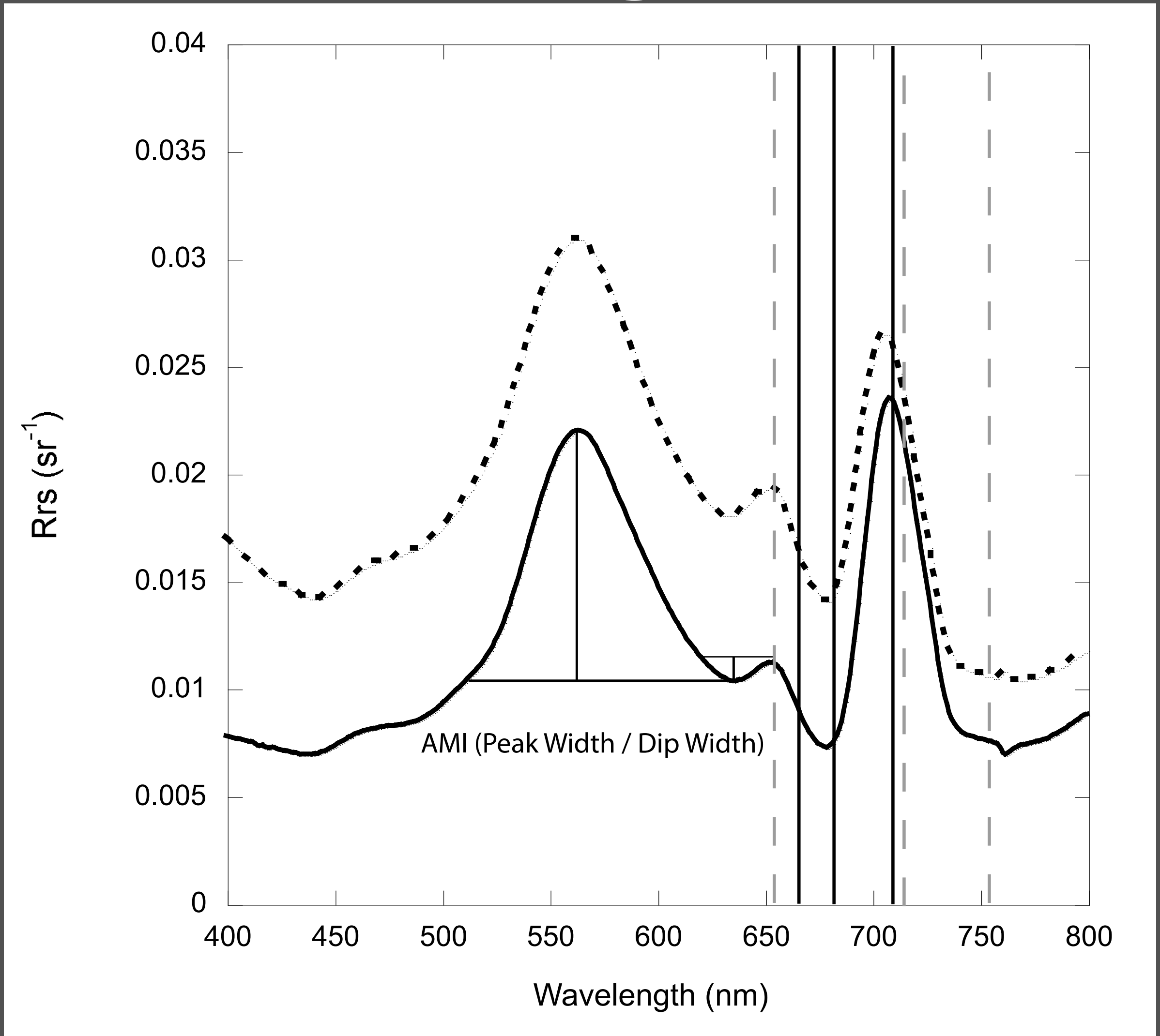


Aphanizomenon

Mixed

Microcystis

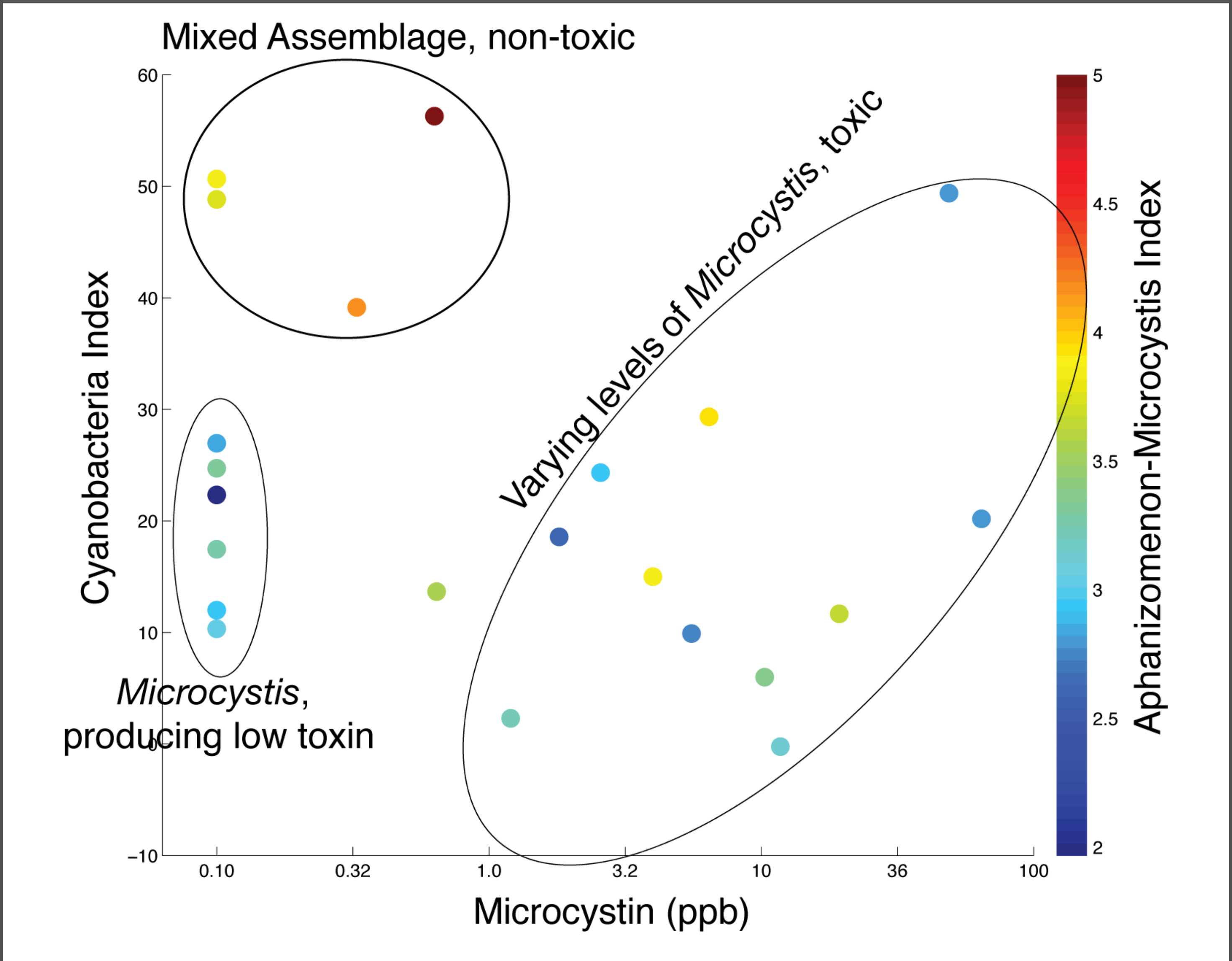
Detecting Blue-Green Algae



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

Predicting Toxic Blooms



Our Contribution to Coastal and Inland Science using the HyspIRI Airborne Campaign Dataset

Application of hyperspectral remote sensing to cyanobacterial blooms in inland waters

RM Kudela, SL Palacios, DC Austerberry, EK Accorsi, LS Guild, J Torres-Perez, *RSE Special Issue*

Remote sensing of phytoplankton functional types in the coastal ocean from the HyspIRI Preparatory Flight Campaign

SL Palacios, RM Kudela, LS Guild, KH Negrey, J Torres-Perez, J Broughton, *RSE Special Issue*

Lessons Learned

Hyperspectral remote sensing of coastal and inland waters has special needs with respect to

instrument calibration
signal-to-noise
atmospheric correction

Data Management

- Where will the *in situ* Monterey Bay data be available?

SeaBASS

SeaWiFS Bio-optical Archive and Storage System

Home | Data Users | Data Contributors | Data Search | NOMAD | Data Archive | Wiki | Lists | Contact Us

Welcome to SeaBASS, the publicly shared archive of in situ oceanographic and atmospheric data maintained by the NASA Ocean Biology Processing Group (OBPG). For information on how to search for data, please refer to the "Data Users" menu options. For information about preparing files for submission to SeaBASS, refer to "Data Contributors."

Processing Version Labels

Apr 22 2015

The validation search results and stats download now include the actual processing version used to produce the extracts.

Minor UI Changes

Nov 19 2014

We've finally replaced the gaudy, Google Maps pins with a slightly less gaudy circle! The 'Download 'All' button in the bio-optical search results has also been moved above the results table (plotting/mapping buttons are still located at the bottom).

Multi- vs. Hyper-spectral Searching

Apr 22 2014

http://seabass.gsfc.nasa.gov/

Summary

- Data Collected
  - A robust *in situ* data set collected in Monterey Bay and Pinto Lake for all years and seasons: 2013, 2014, 2015
  - Currently, **two dates** of experimentally processed "scientific quality" AVIRIS images for Monterey Bay only (4/10/2013 & 10/31/2013)
  - Note: Matchups for Santa Barbara Channel Plumes & Blooms cruises on 4/16/14 & 10/21/14
- Lessons Learned
  - Hyperpsectral imagery has special needs with respect to instrument calibration, signal-to-noise, and atmospheric correction
  - It is possible to forecast blooms of the toxic cyanobacterium, *Microcystis*, using hyperspectral data
- Data Management
  - Preparing *in situ* data to target upload to SeaBASS in winter 2016
  - AVIRIS over water targets, needs further discussion with JPL

The Un-Sung Heroes

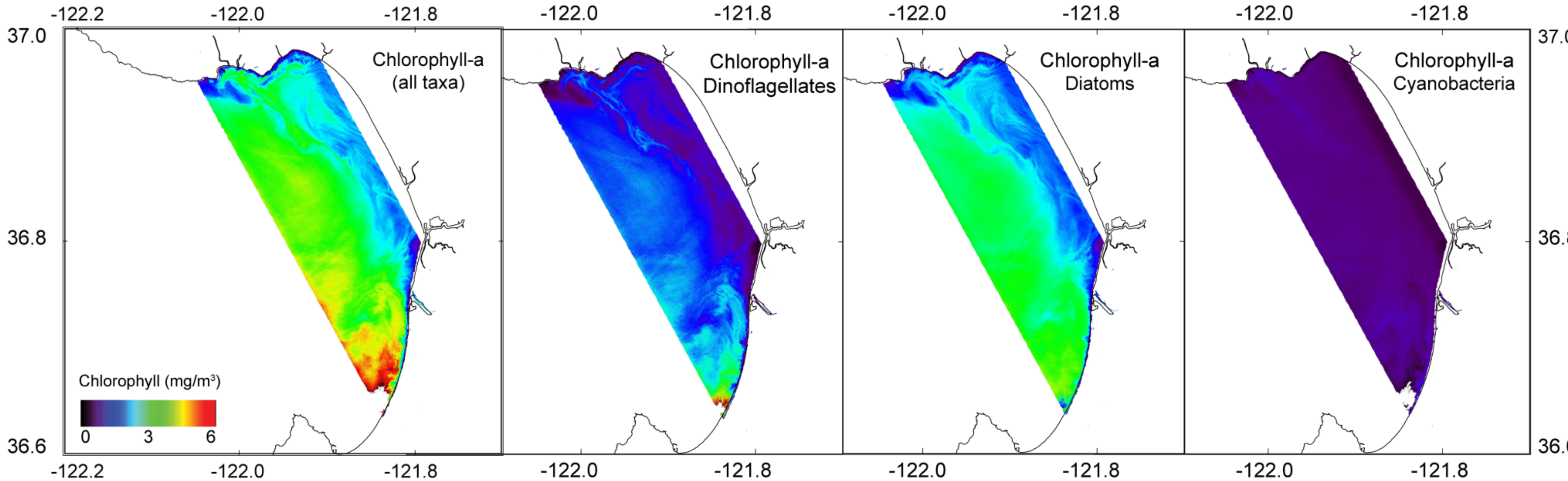
- Kendra Hayashi
- The Kudela Lab, mobilizing again, and again, and again (etc…) at very early hours
- The UC-Santa Barbara Plumes & Blooms Team
- Ian McCubbin
- David Thompson

Check out our posters!

Remote sensing of phytoplankton functional types (PFTs) in the coastal ocean from the HyspIRI Preparatory Flight Campaign

Sherry Palacios, Raphael Kudela, Liane Guild, Kendra Hayashi Negrey, Juan Torres-Perez, Jennifer Broughton

Remote Sensing of Environment, 2015, http://dx.doi.org/10.1016/j.rse.2015.05.014



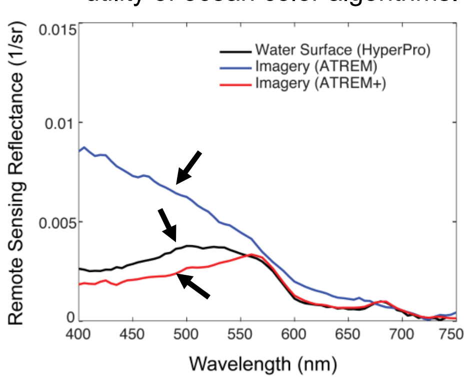
Context: Remote sensing of PFTs suggests that we can discriminate phytoplankton biodiversity for a better understanding of carbon uptake, energy flow through ecosystems, and detection of harmful algal blooms. High spectral resolution data enables algorithms a degree of taxon discrimination not possible with multispectral sensors. These algorithms are sensitive to variability in spectral shape and the need for accurate ocean color retrievals across the full spectrum is imperative.

Methods: (1) Computed chlorophyll (Chl-a) and taxon-specific biomass from corrected AVIRIS data of Monterey Bay, CA and compared to surface measurements, (2) Evaluated hyperspectral sensor specifications and image collection to improve ocean color retrievals.

Results: (1) Ocean color retrievals from AVIRIS (HyspIRI Airborne Flight Campaign) require additional correction to be useful to the coastal community, this work is ongoing with JPL, (2) It was not possible to discriminate among phytoplankton taxa using AVIRIS.

Implication: Remote sensing of coastal and inland waters has special needs with respect to instrument calibration, signal-to-noise, and atmospheric correction. Future hyperspectral ocean color sensors must address these challenges in order to obtain accurate ocean color retrievals. Until accurate retrievals are achieved, the promise of sophisticated spectral shape algorithms for ocean data products using hyperspectral data will not be possible.

Mismatch in spectral shape between image retrieval and surface measurement limits utility of ocean color algorithms.

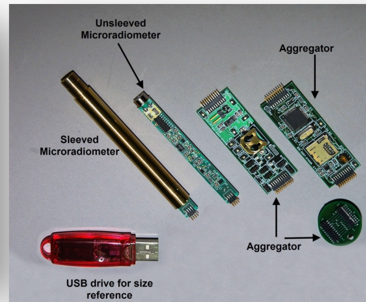


Airborne Missions Supporting Coastal Ocean Biology and Water Quality Research

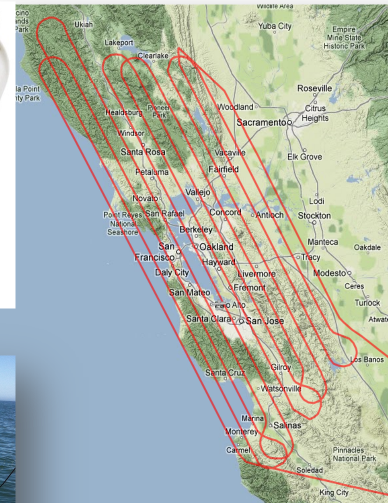
- Using HyspIRI at the Land/Sea Interface to Identify Phytoplankton Functional Types
- Ocean Color Ecosystems Assessment with Novel Instruments and Aircraft (OCEANIA)

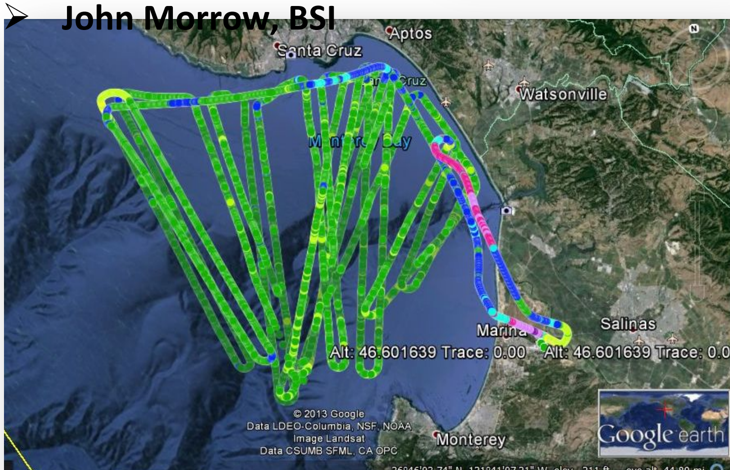
Liane Guild – ARC (PI-HQ2O, OCEANIA, Co-PI HyspIRI), Raphael Kudela – UCSC (PI-HyspIRI)

C-AIR, C-OPS Science
- Stanford Hooker, GSFC
- John Morrow, BSI



C-AIR Microradiometer Bundle

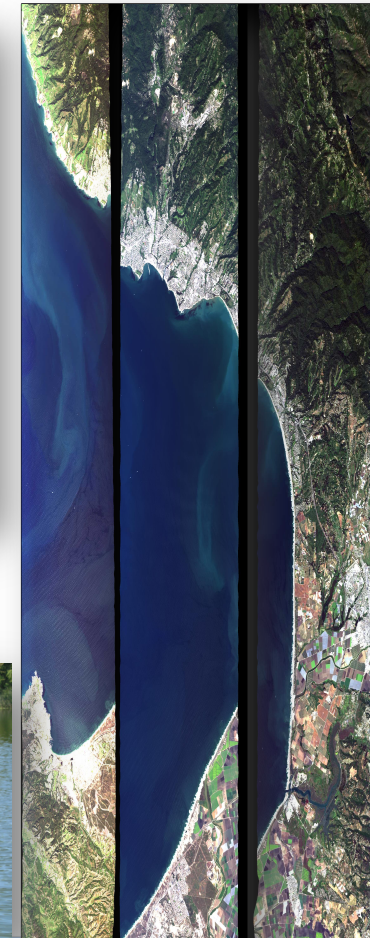




NASA ARC Engineering
- Steve Dunagan
- Michael Soulage

NASA ARC Science
- Steve Dunagan
- Sherry Palacios
- Juan Torres-Perez

UCSC Cruise Team
- Kendra Negray
- Jennifer Broughton



2013-2015 Missions → March/April → May/June → August → September/October

Ames Research Center

Coastal-Airborne In-situ Radiometers (C-AIR)

Liane Guild & Steve Dunagan (ARC), Stanford Hooker (GSFC), John Morrow (Biospherical Instr.)

Readiness level:
- ☐ TRL 1-3: Concept
- ☐ TRL 4-6: Prototype
- ☑ TRL 7-9: Demonstrated

NASA Ames Airborne Instrument - Liane Guild, PI

Technology / Application

Description

C-AIR microradiometer instruments are COTS systems (Biospherical Instruments, Inc.) designed to help retrieve aquatic normalized exact water-leaving radiance for satellite-based ocean color research.

A **microradiometer** consists of a microprocessor, photodetector, preamplifier with controllable gain, 24-bit analog-to-digital converter, and a serial port, all on one small circuit board assembly. The brass sleeve provides support and isolation from electronic noise. **Aggregators** are used to bundle clusters of microradiometers and auxiliary sensors as would typically exist in individual instrument heads. They have on-board power control, and additional sensors including tilt angles, input voltage and current, internal humidity and temperature. C-AIR sensors feature:

- **Spectral range: 320-875 nm with 10 nm FWHM bandwidth; 15 Hz data rate;**
- **Very wide dynamic range (10 decades), will not saturate with Sun glint**
- **Radiance (2.5° FAFOV) and irradiance configurations**
- **NIST traceable calibrations**.

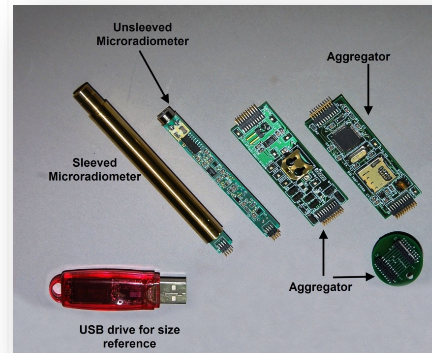
Fight requirements: Flight track within the solar principal plane

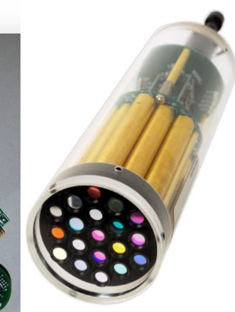
Needed: Application specific GUI software development

References:

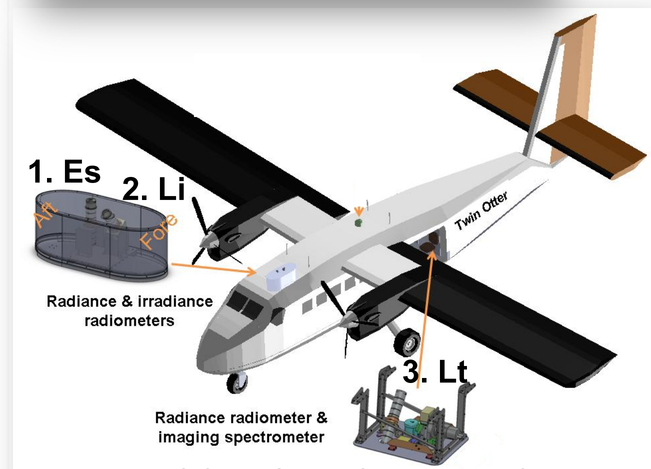
Morrow, J.H., S.B. Hooker, C.R. Booth, G. Bernhard, R.N. Lind, and J.W. Brown, 2010: Advances in Measuring the Apparent Optical Properties (AOPs) of Optically Complex Waters. *NASA Tech. Memo. 2010–215856*, NASA GSFC, Greenbelt, Maryland, 80 pp.

Guild L., J. Dungan, M. Edwards, P. Russell, S. Hooker, J. Myers, J. Morrow, S. Dunagan, P. Zell, R. Berthold, and C. Smith, 2011, *NASA's Coastal and Ocean Airborne Science Testbed (COAST)*, Proceedings, 34th International Remote Sensing of Environment, April 10-15, 2011, Sydney, Australia.





Microradiometer radiance bundle



NPS CIRPAS Twin Otter, Marina, CA

Funding / Timeline

Based on SBIR microradiometer package for in-water bio-optical measurements
- **2010-1011** Integrated with airborne suite and 1st airborne flight (HOPE-COAST)
- **2013** 2nd airborne mission (SIF OCEANIA)
  - supported cal/val of HyspIRI CA Airborne Mission (Monterey Bay)

POC

- **POC:** Liane Guild, Code SGE
- **Email:** liane.s.guild@nasa.gov
- **Phone:** 650-604-3915