Water quality monitoring using remote sensing

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Acknowledgments

Cedric Fichot
David Thompson
Michelle Gierach

Susan Ustin
Shruti Khanna

Sacramento

Brian Downing
Brian Bergamaschi

Menlo Park

Lisa Windham-Myers
M. Marvin-DiPasquale

Curtiss Davis
Nick Tufillaro

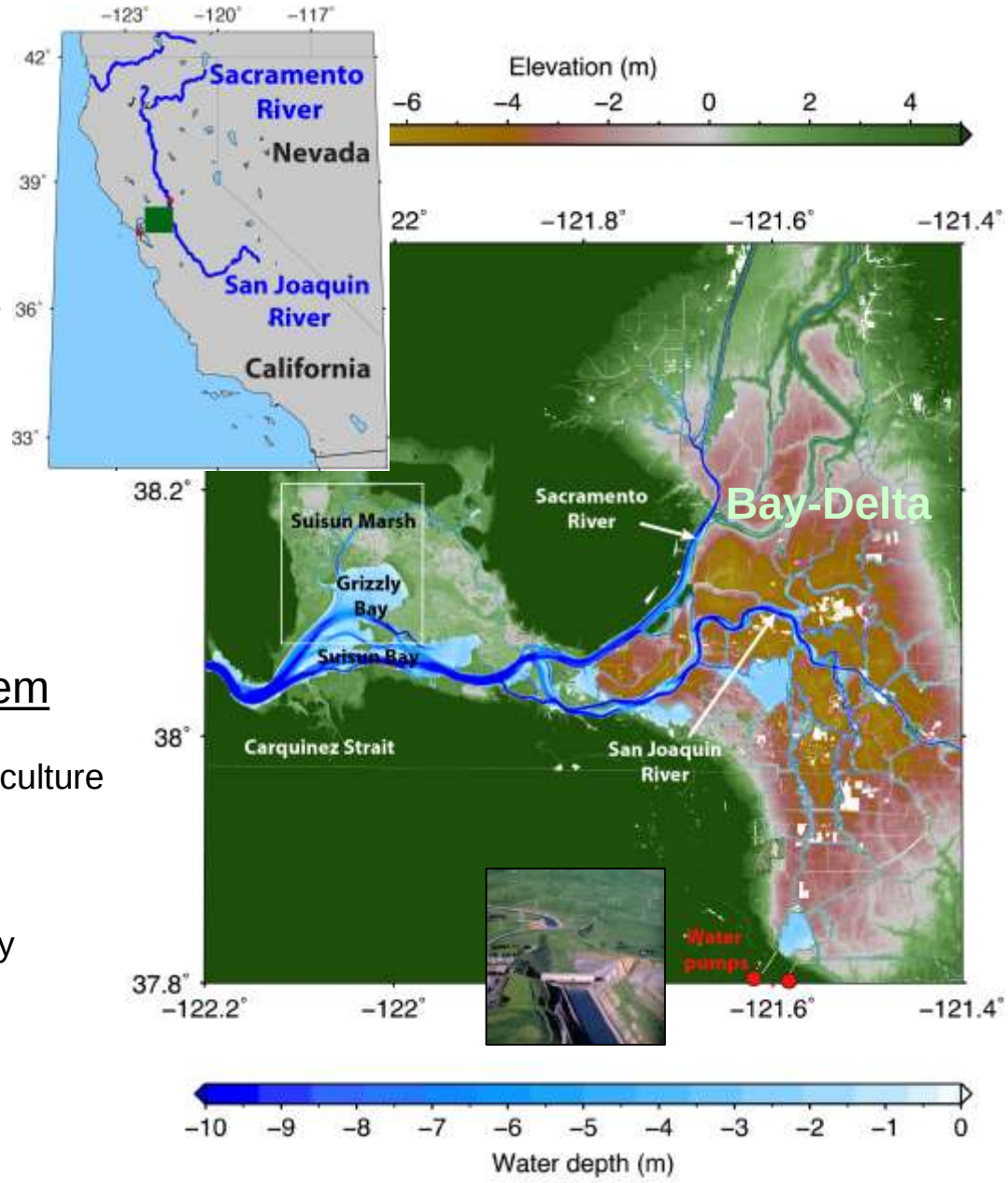
The Bay-Delta is a major water resource for California

Major freshwater resource for CA

- Confluence of Sacramento/San Joaquin rivers
- Supplies ~9 km^3 of water to CA each year
- Supplied 1M ha of farmland + 27M people

Altered, managed, and fragile ecosystem

- 120,000 ha of tidal marshes reclaimed for agriculture
- Subsidence on levied islands
- Alteration of habitats, biodiversity, water quality

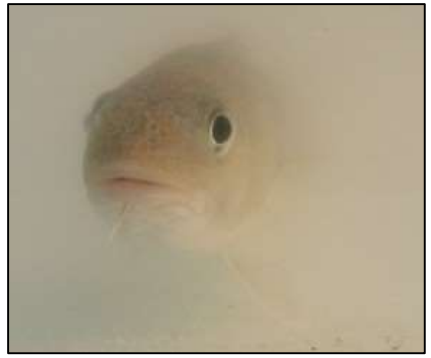


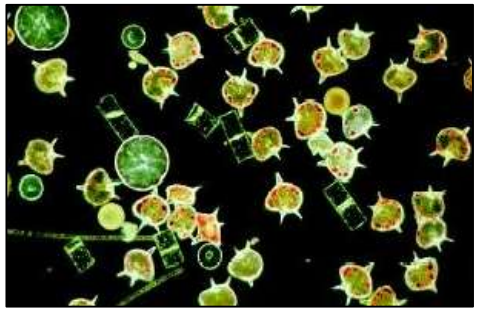
Water quality monitoring matters greatly in this system

Drinking water

Ecosystem health and productivity

- **Turbidity/Suspended sediments**
  - Light penetration
  - Habitat quality
  - Fish behavior
- **Dissolved Organic Carbon**
  - Disinfection by-products
  - Affects dissolved oxygen levels
  - Linked to contaminants (e.g., methylmercury)
- **Chlorophyll-a (Chl-a)**
  - Productivity of system
  - Nutrient and light availability
- **Submerged and Floating Aquatic Vegetation**
  - Often invasive species
  - Impact other ecology/habitat

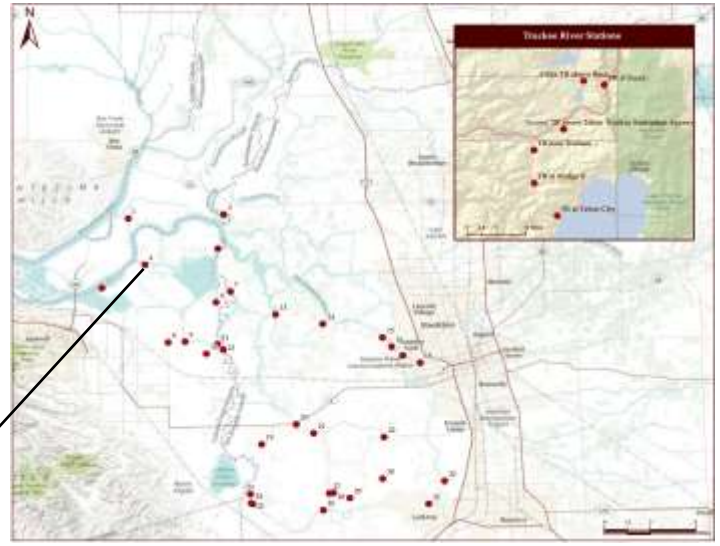


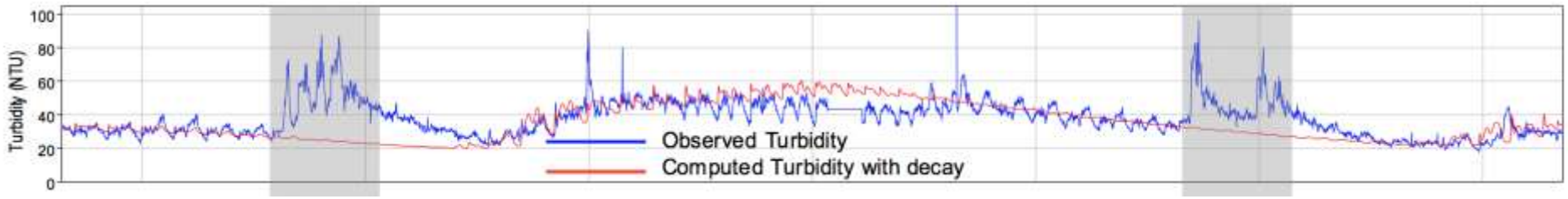


- **Temperature**
- **Salinity**

But water quality monitoring is a also challenge

- The Bay-Delta is a very heterogeneous and dynamic system (scales: meters, hours)
- Water quality monitoring network and field sampling not always spatially/temporally consistent
- Biofouling of instruments is very problematic in some areas

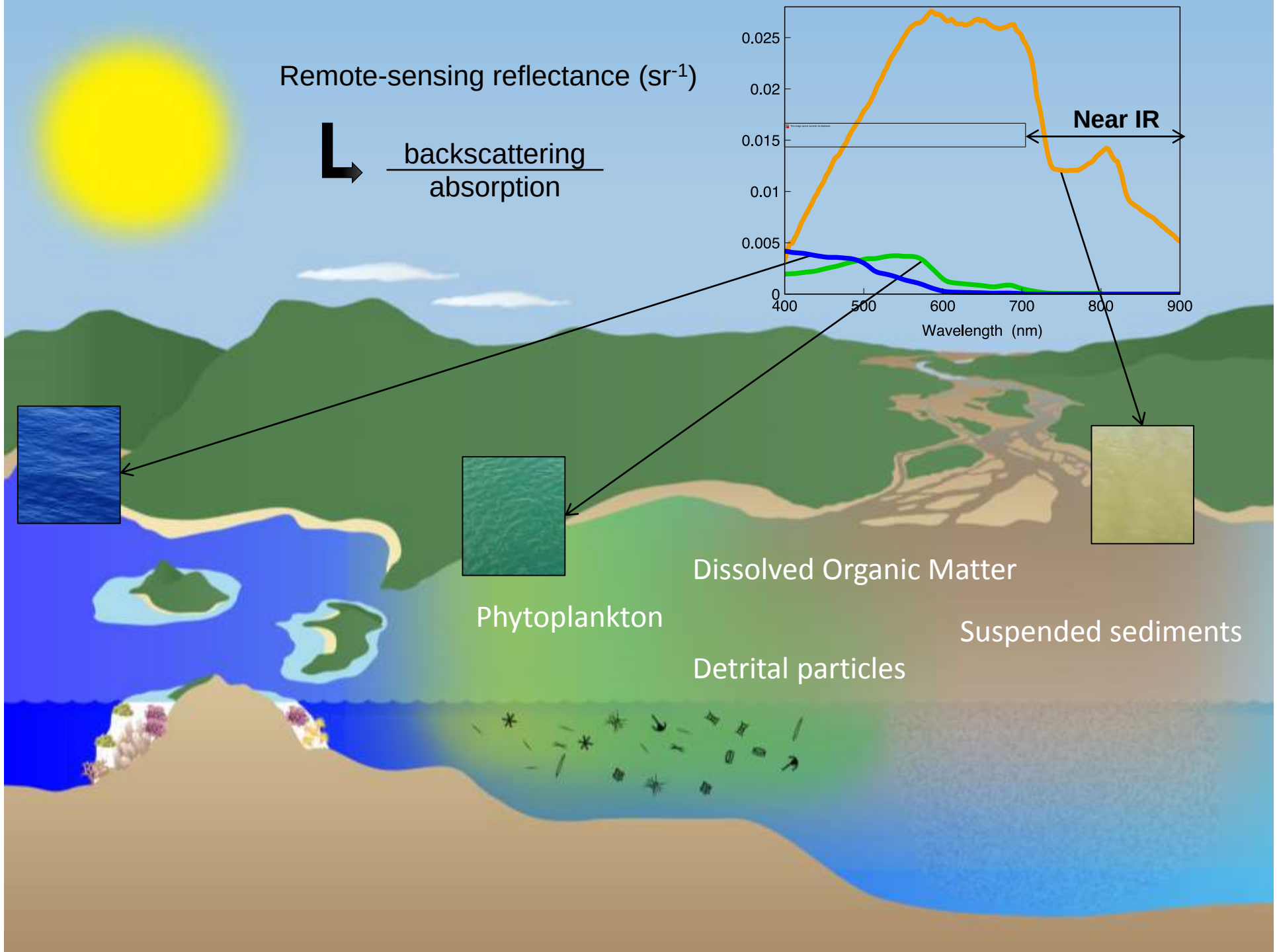




How remote sensing can help complement water quality monitoring approaches

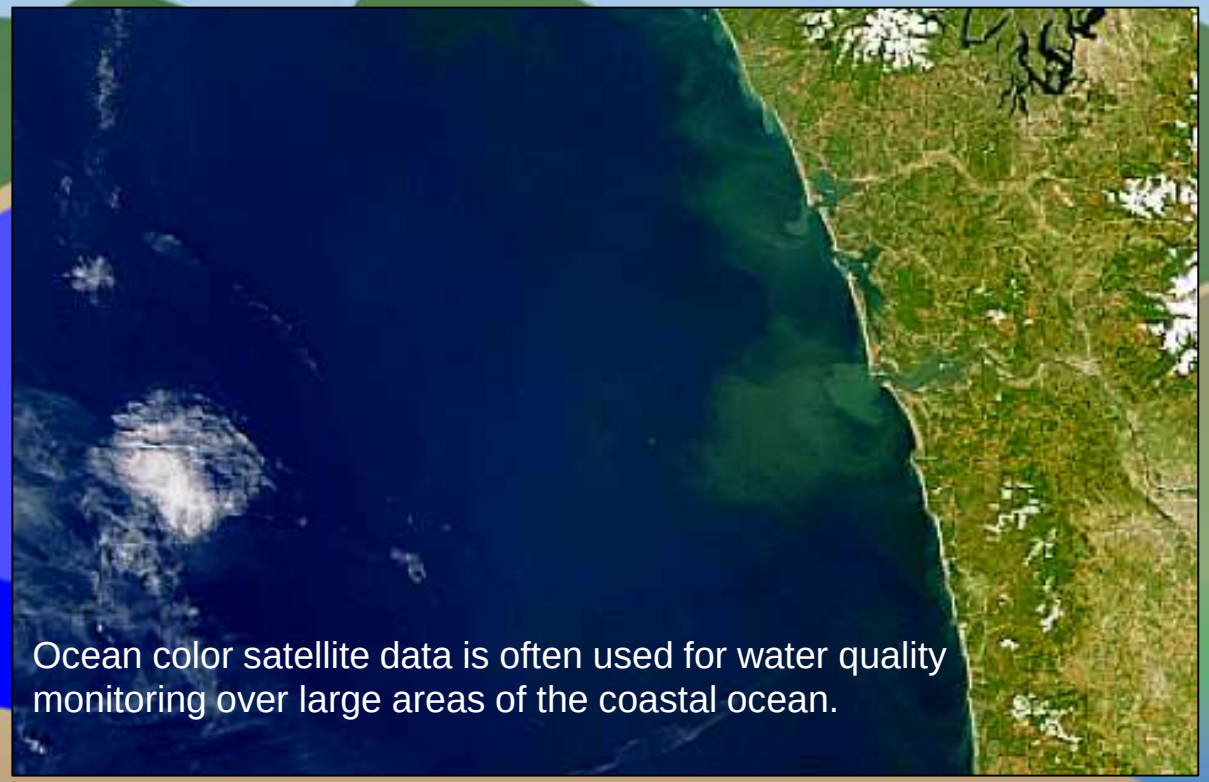
Touch on three efforts

- Turbidity and Chlorophyll-a w Satellite Capabilities
- Colored Dissolved Organic Matter, Chlorophyll-a, Turbidity, and Methyl-Mercury w Airborne Capabilities
- Submerged and Floating Aquatic Vegetation w Airborne Capabilities


Remote-sensing reflectance (sr-1)
backscattering
absorption
0.025
0.02
0.015
0.01
0.005
0
400
500
600
700
800
900
Wavelength (nm)
Near IR
Dissolved Organic Matter
Phytoplankton
Suspended sediments
Detrital particles

Current ocean-color satellite sensors:

e.g., MERIS, MODIS, VIIRS



Ocean color satellite data is often used for water quality monitoring over large areas of the coastal ocean.

Current ocean-color satellite sensors:

e.g., MERIS, MODIS, VIIRS

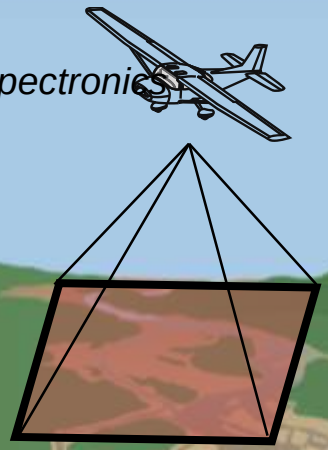
MODIS *Aqua*: 250 m resolution

Airborne imaging spectroscopy

***AVIRIS-ng*:** Airborne Visible Near-Infrared Imaging Spectrometer – next generation

***PRISM*:** Portable Remote Imaging SpectroMeter

HyMAP: *airborne hyperspectral sensor, Integrated Spectronics*



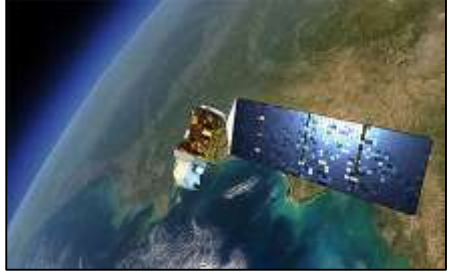
Airborne imaging spectroscopy
(hyperspectral)

↓

Detailed spatial distributions of
multiple water quality indicators in the Bay-Delta

- **Turbidity/Suspended sediments**
- **Dissolved Organic Carbon**
- **Chlorophyll-a (Chl-a)**

Landsat-8 Operational Land Imager (OLI)



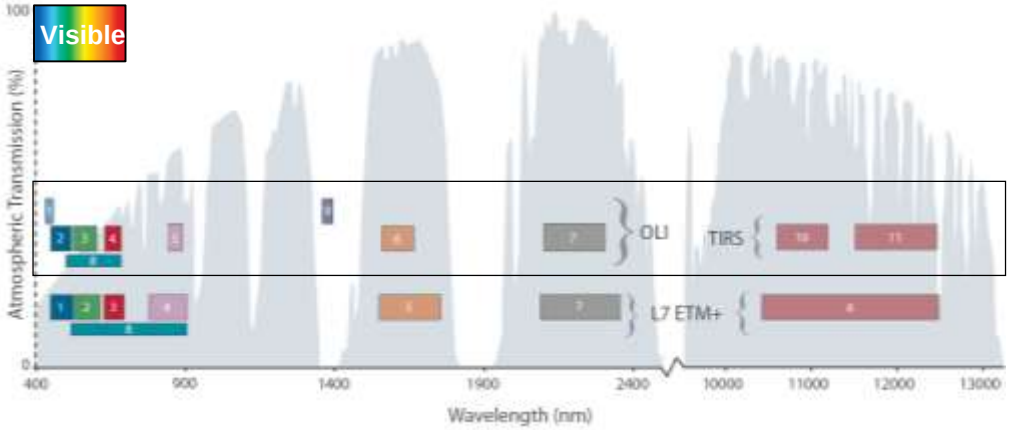
In operation since May 30, 2013

Resolutions

Spectral: 4 bands visible, 1 NIR, 2 SWIR

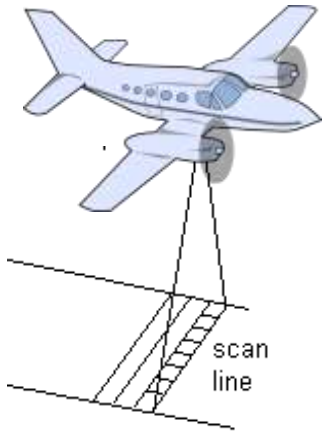
Spatial: 30 m

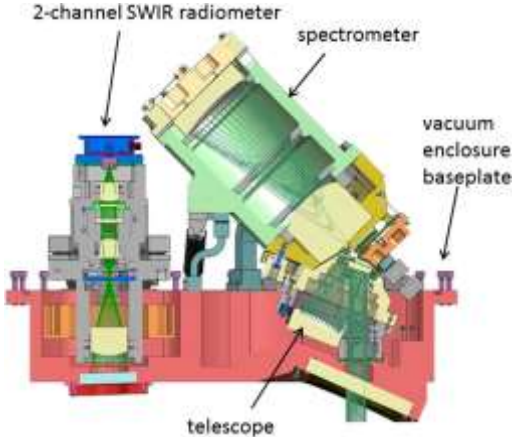
Temporal: 16-day revisit time



Freely available online (e.g., GLOVIS)
Processing for water with ACOLITE

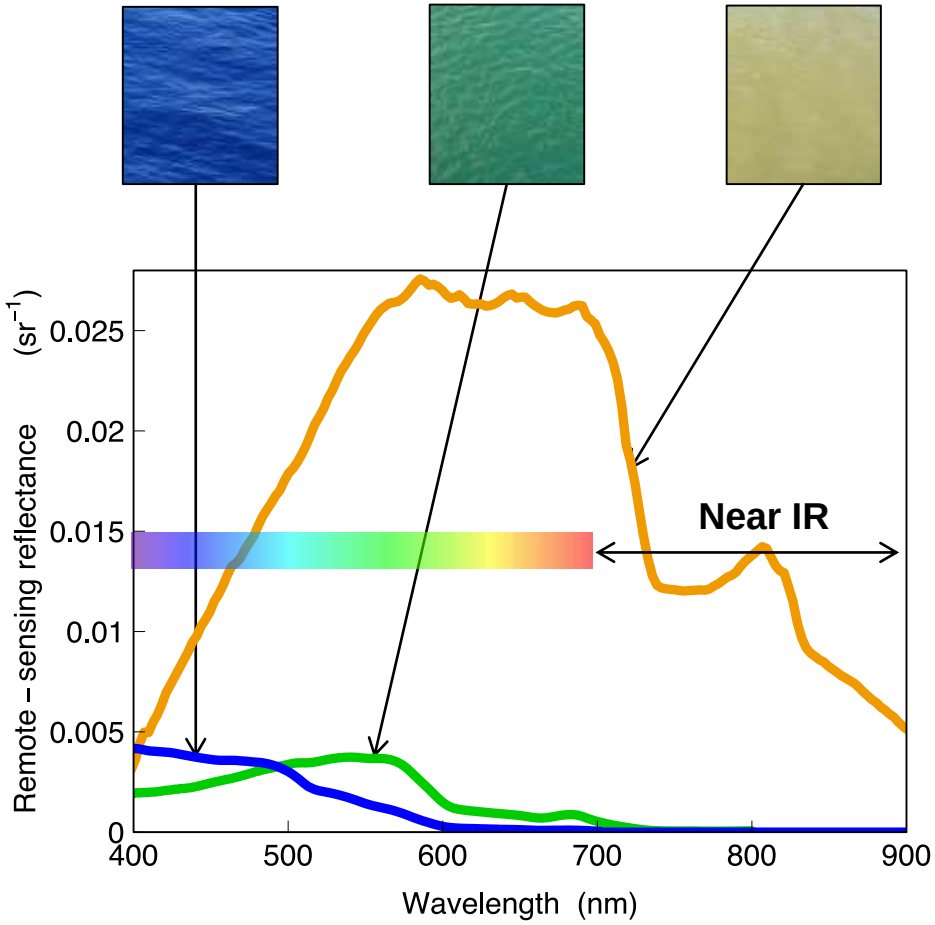
Portable Remote Imaging SpectroMeter





Mouroulis et al., *App. Opt.* (2014)

- Remote-sensing reflectance
- <u>Spectral range:</u> 350-1050 nm
- Hyperspectral (246 bands)
- High signal-to-noise
- Spatial resolution up to < 1 m



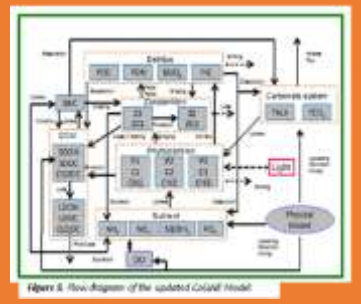
RIO-SFE Project

Remote/In situ Observing - San Francisco Bay and Estuary

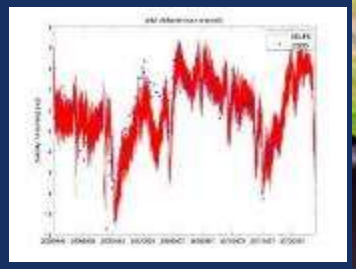
Results and discussions with SFE Stakeholders: **November 14, 2016**
Sacramento, CA

Field Observations
(RTC, NRL and OSU)

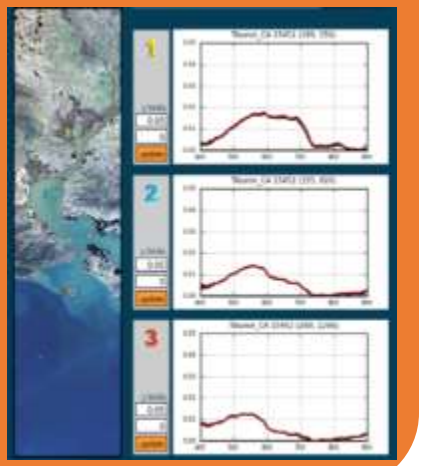
CoSiNE ecological model
(Fei Chai, U. Maine)



Results
merging data and models to understand SFE



Remote sensing
(Curt Davis, OSU)



SCHISM
Semi-implicit Cross-scale Hydroscience Integrated System Model
(Yi Chao, RSI)

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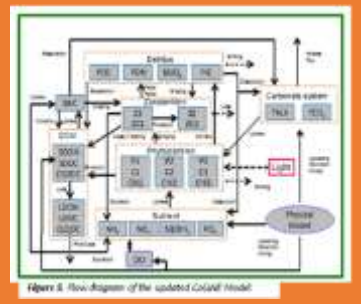

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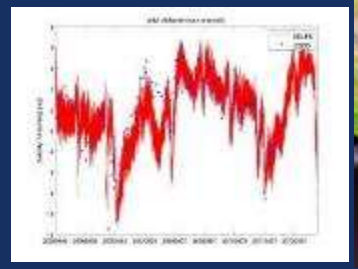

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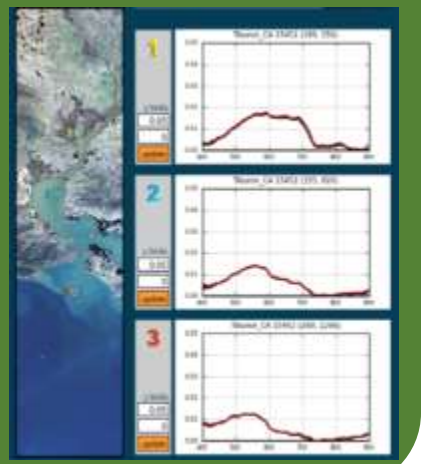
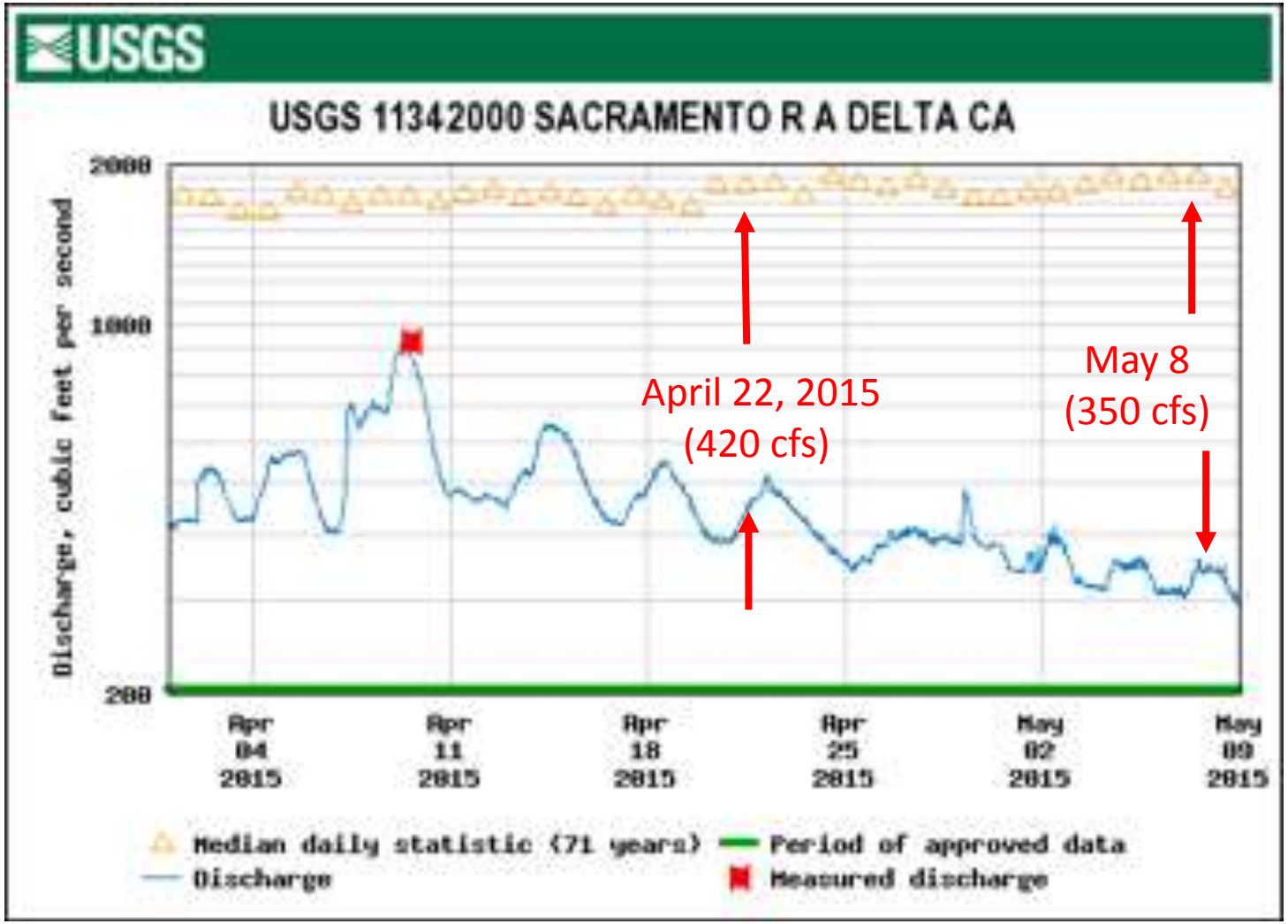


SCHISM

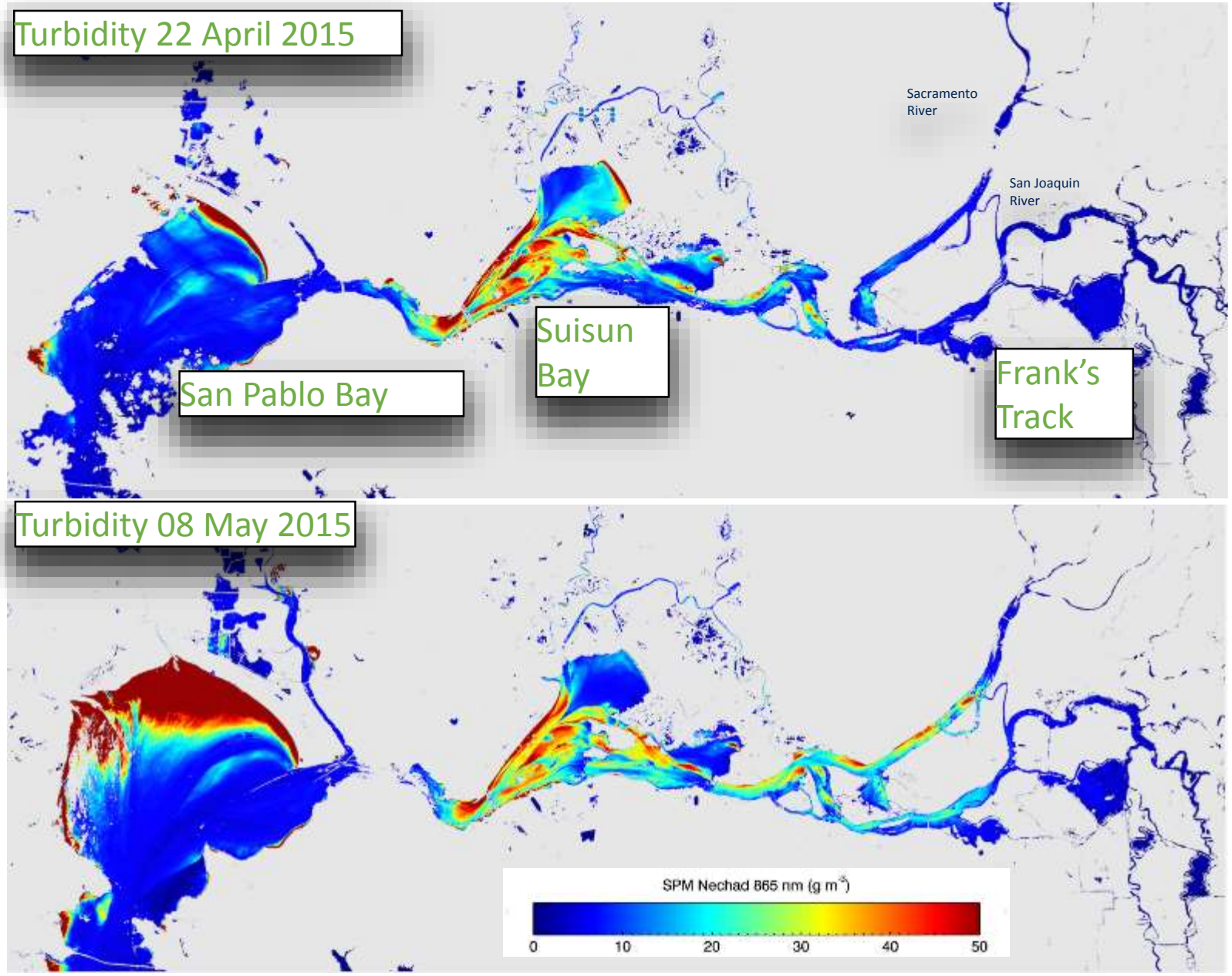
Semi-implicit Cross-scale Hydroscience Integrated System Model

(Yi Chao, RSI)

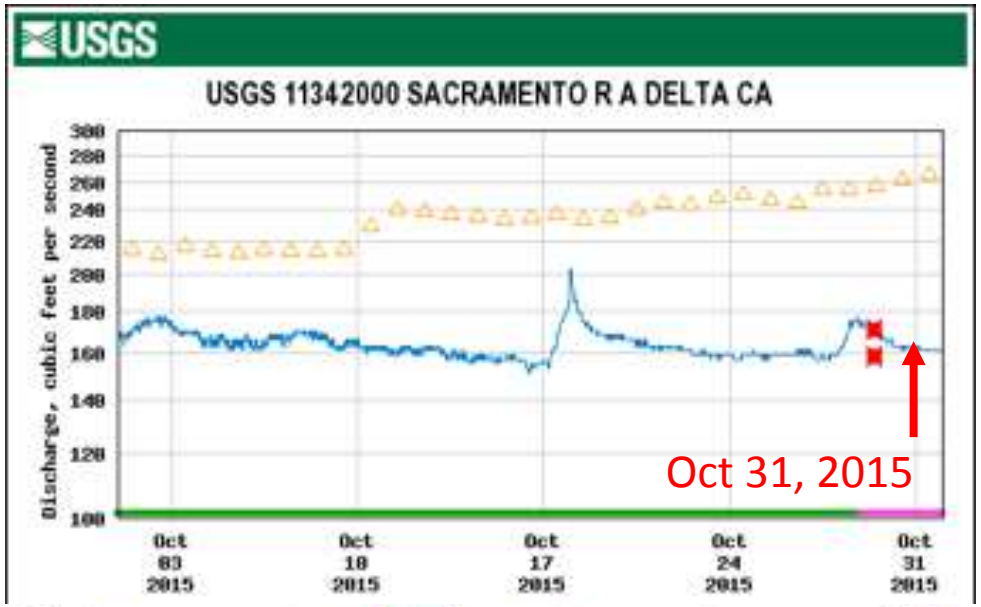
The Drought Sacramento River Flows



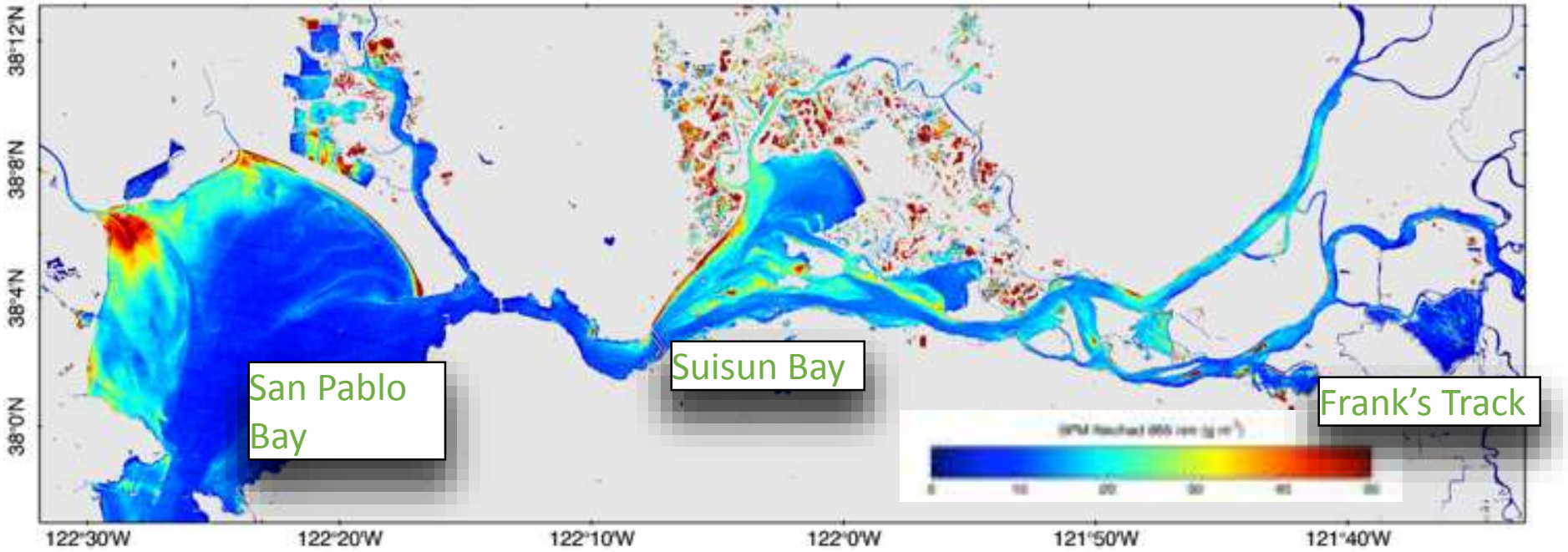
SPM Maps from L-8 OLI data



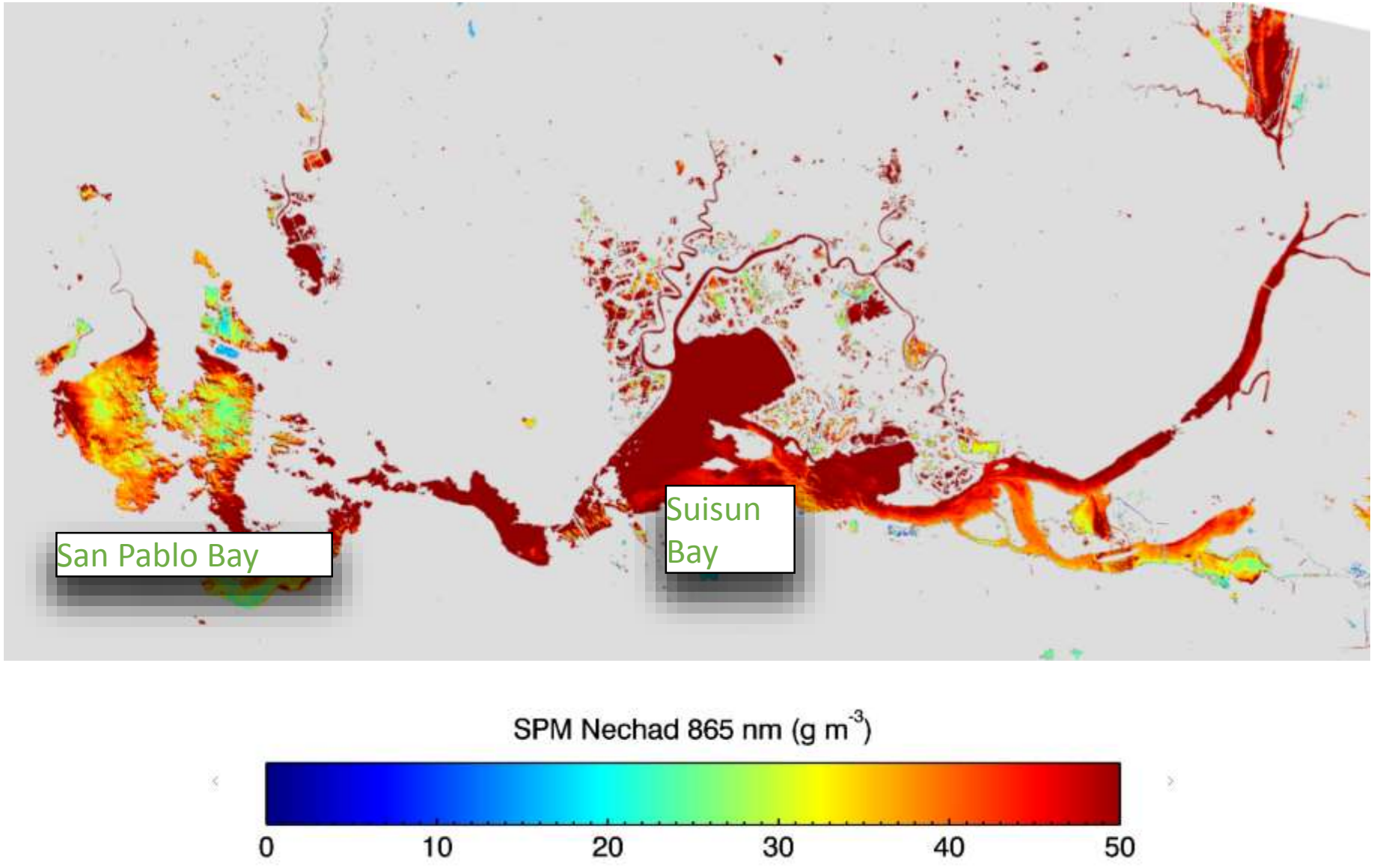
October 2015 Sacramento River Flows



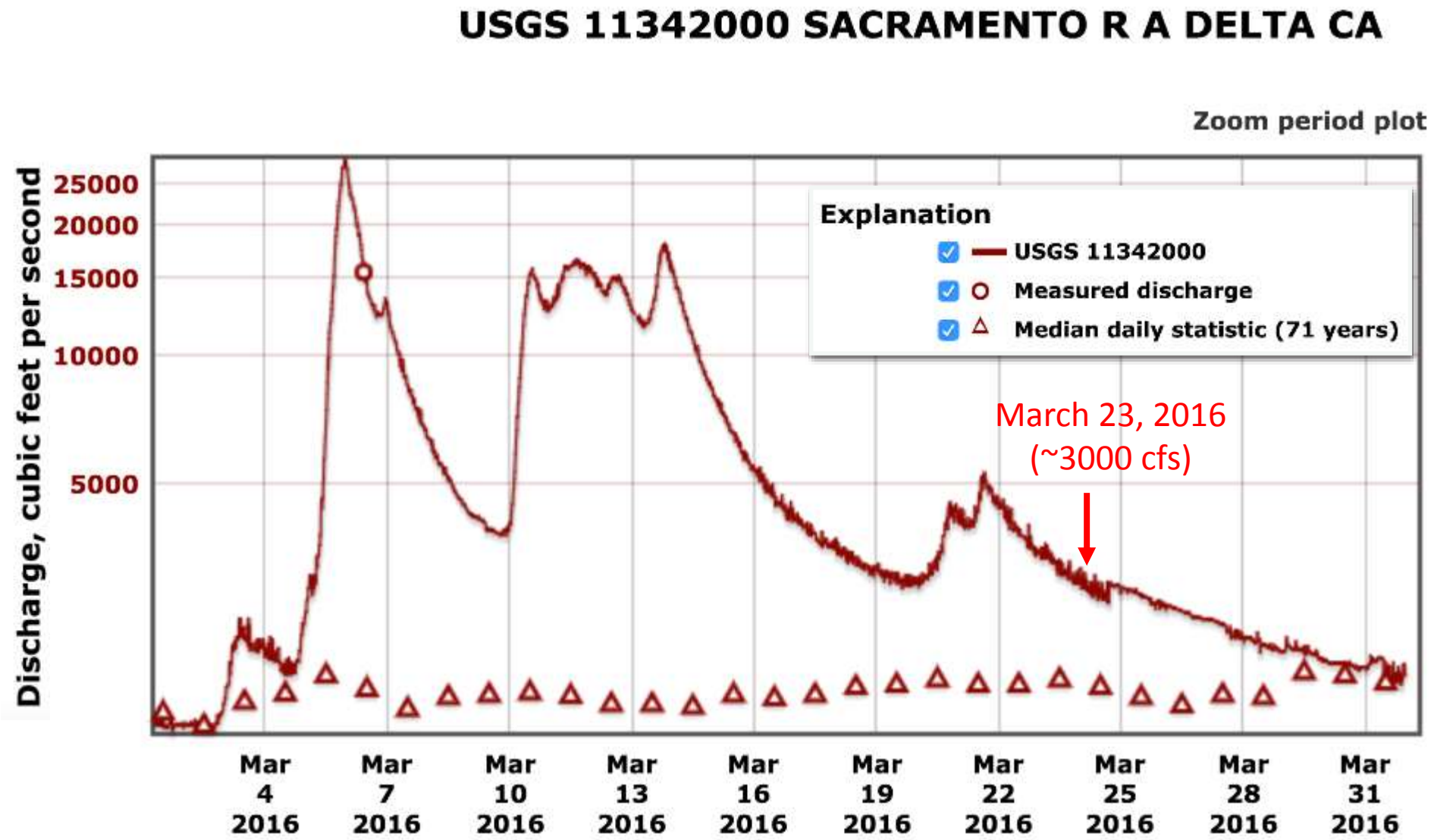
Very low River flow (160 cfs) and SPM from L-8 OLI data



March 23, 2016 SPM



The Miracle in March



Installation of barrier to mitigate salinity intrusion into Delta at Frank’s Tract

Following the Franks Tract Salinity Barrier

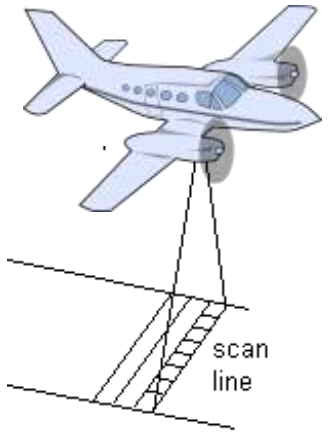
Suisun Bay to Frank's Track
Landsat 8 OLI 8 May 2015
SWIR Atmospheric Correction
for highly turbid waters
(Vanhellemont and Ruddick 2014) Pan Enhancement (15m)

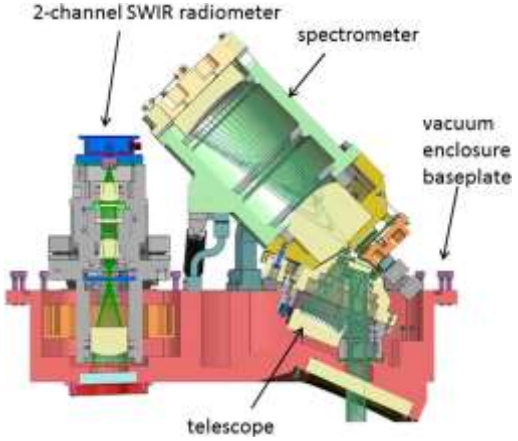
LS-8 OLI Franks Tract Aug 12, 2015

Presence of chlorophyll mats in Franks Tract

L-8 OLI Franks Tract March 23, 2016

Portable Remote Imaging SpectroMeter





Mouroulis et al., *App. Opt.* (2014)

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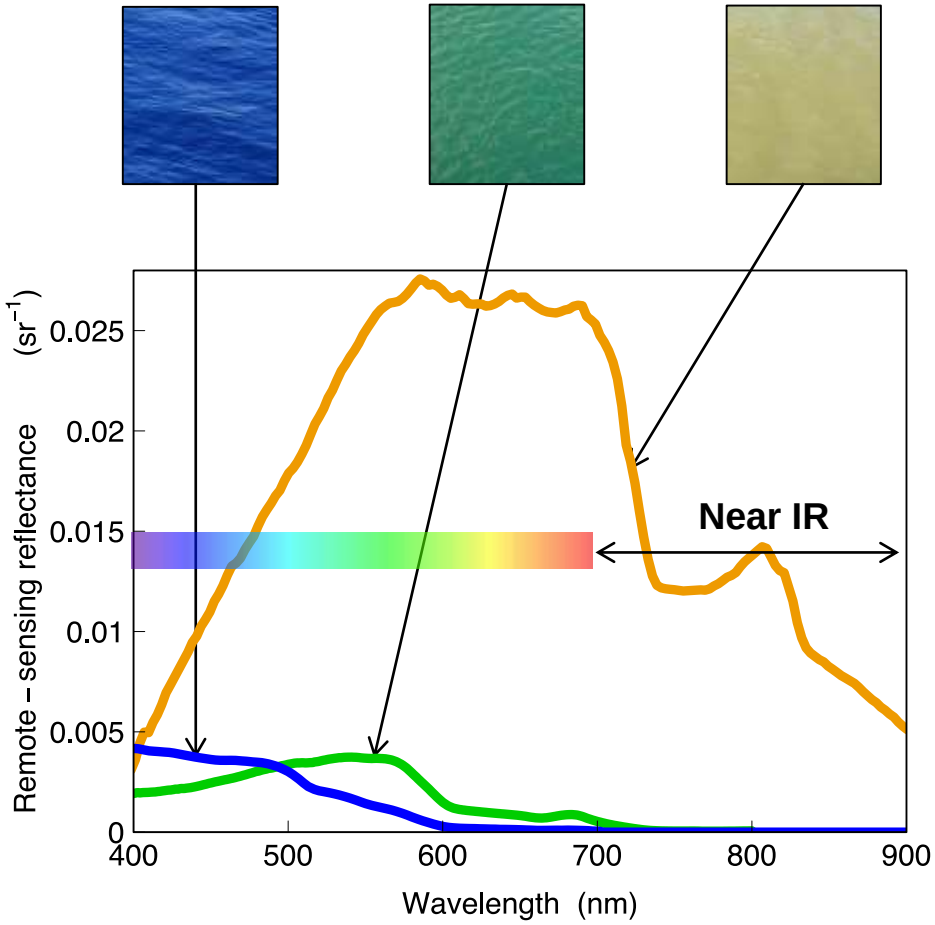
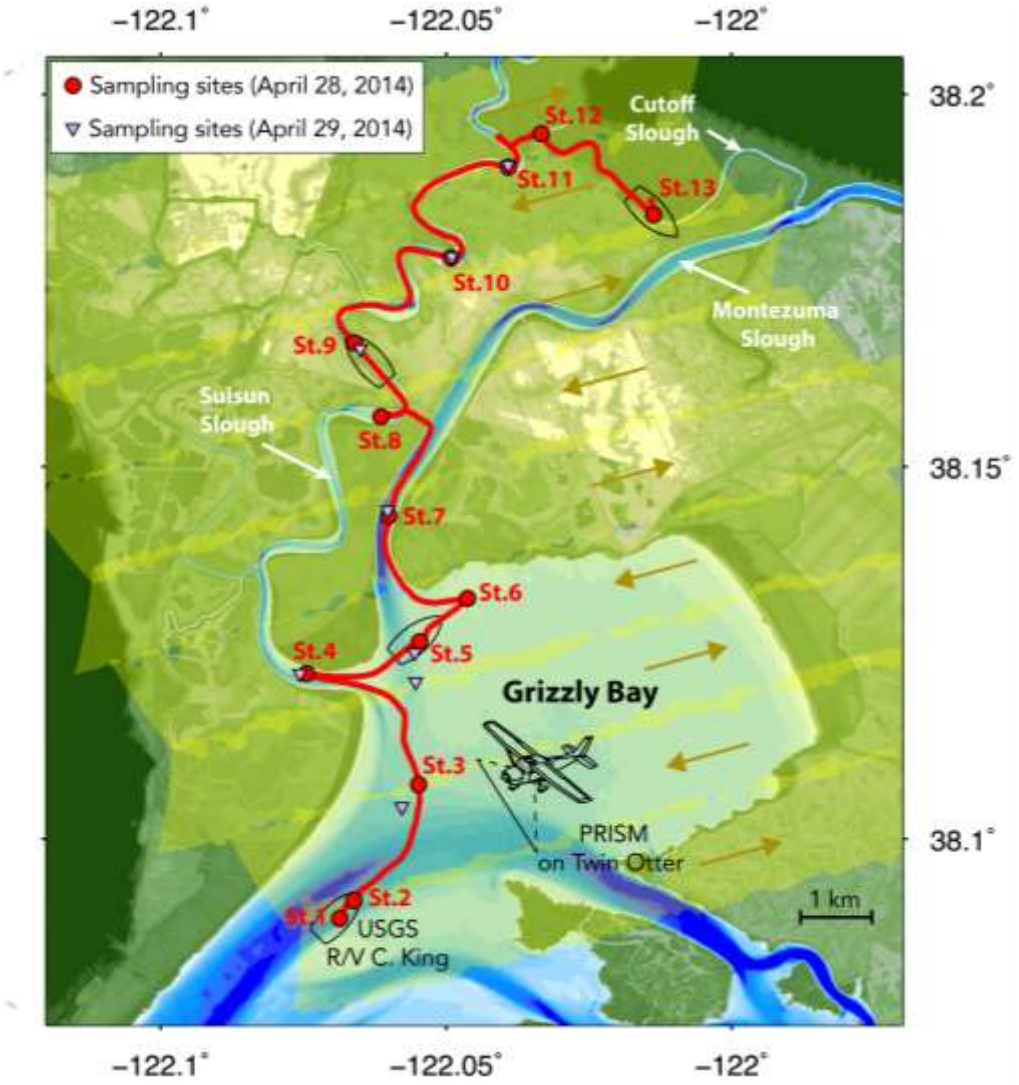


Data acquisition in Suisun Marsh and Grizzly Bay

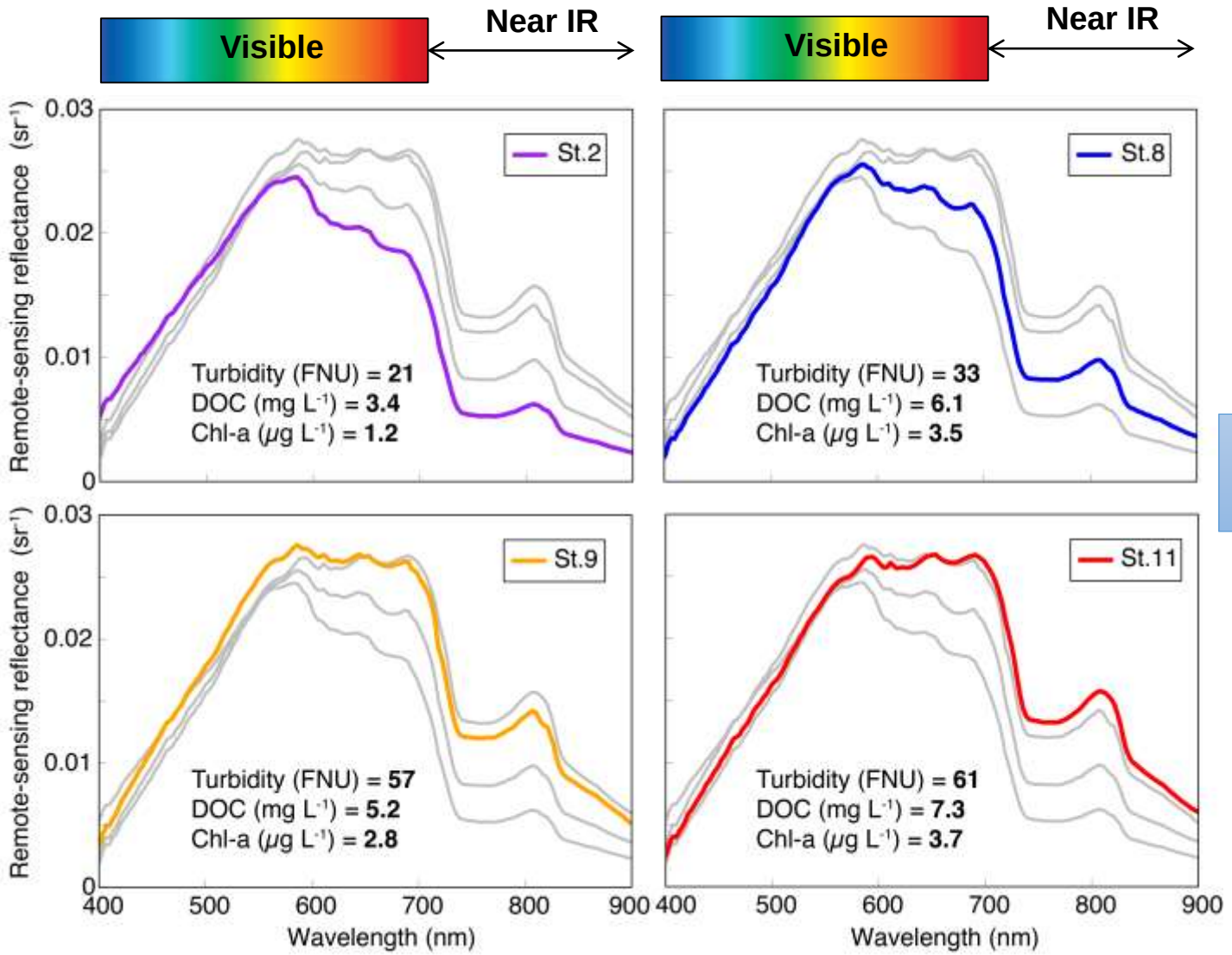
Airborne remote sensing
(PRISM)

Underway water quality
from small boat (*in situ probes*)



Fichot et al. (2016)

Water quality algorithm



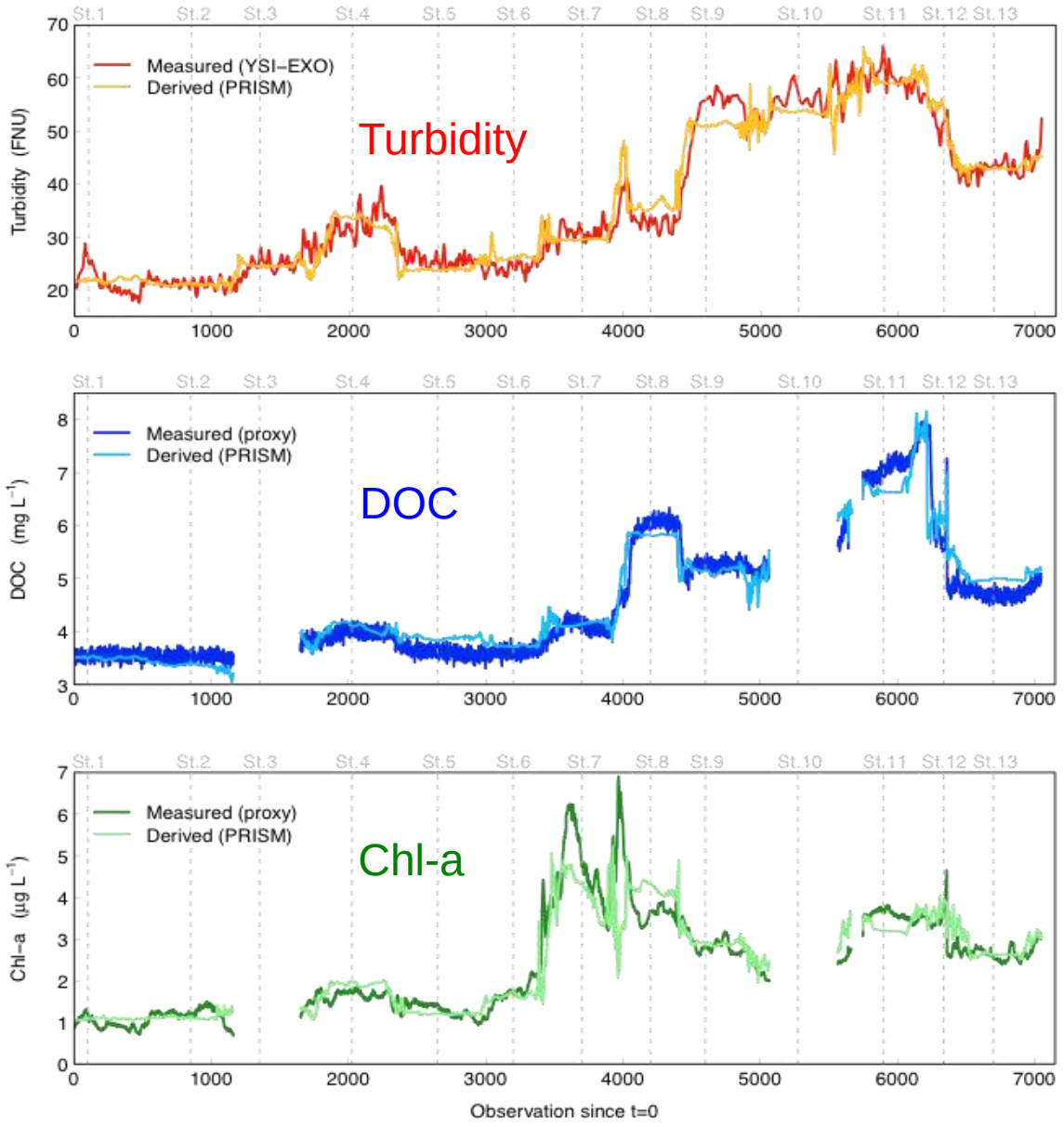
Remote-sensing reflectances

Partial-least-squares regressions

Water quality indicators

Fichot et al. (2016)

80-95% of the water quality variability was reproduced



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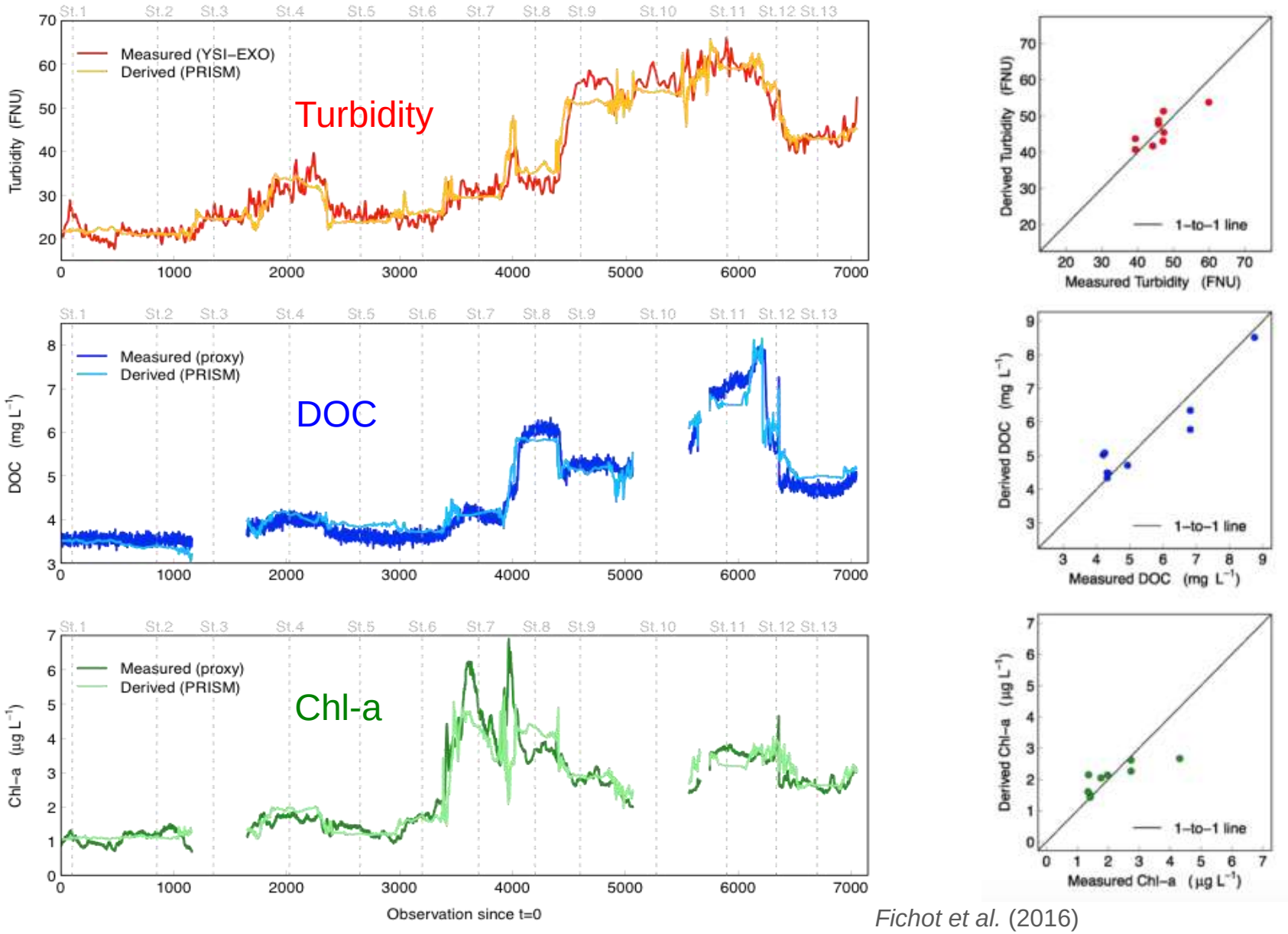

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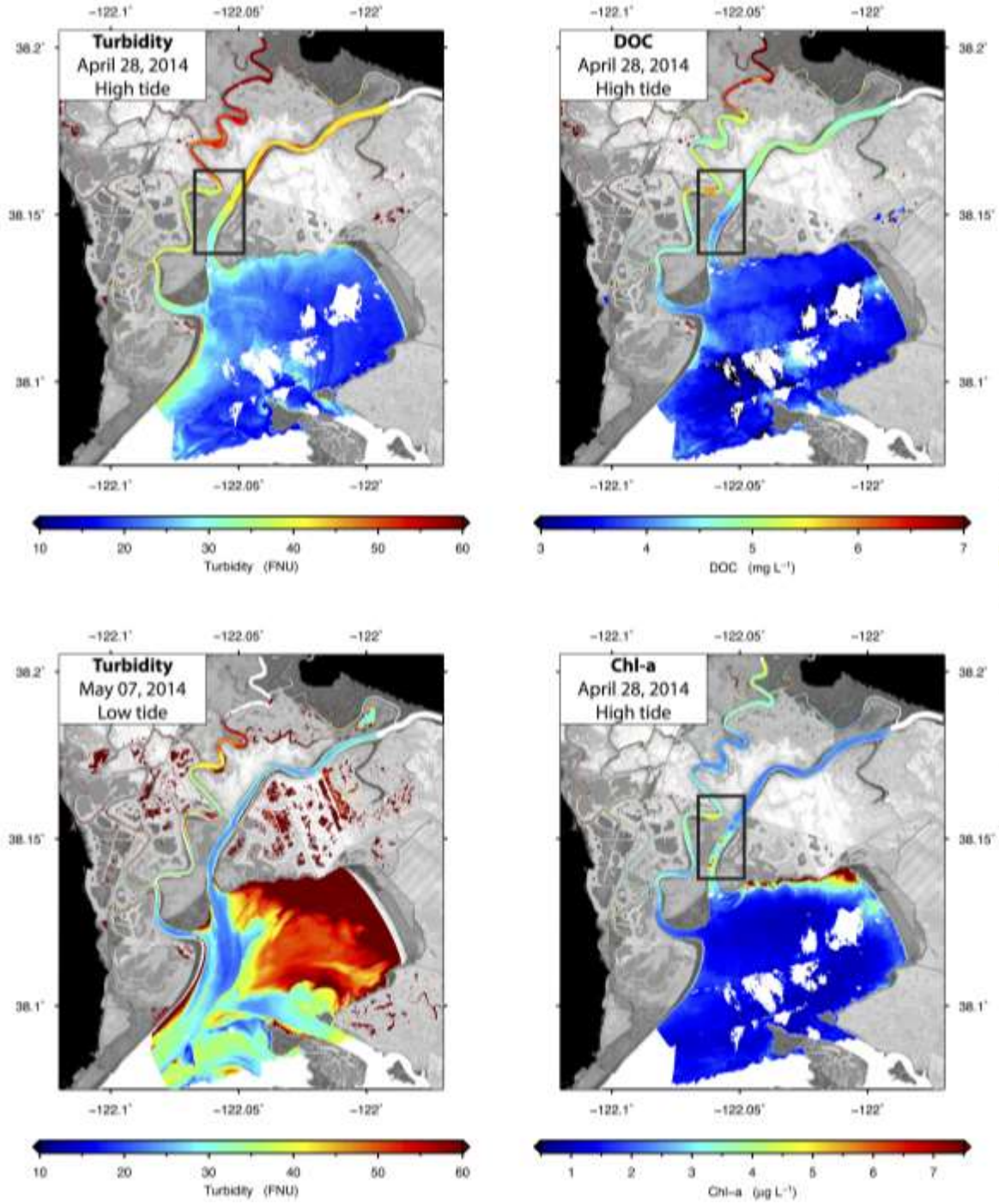
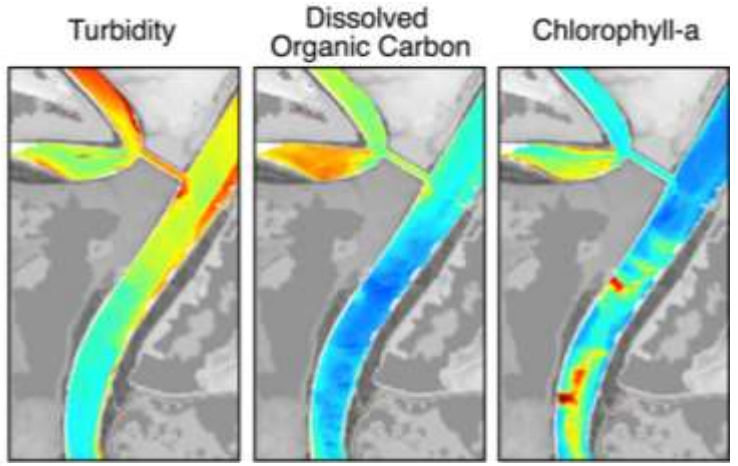


A single PRISM scene reveals the detailed, complex picture of water quality in the San Francisco Bay-Delta Estuary

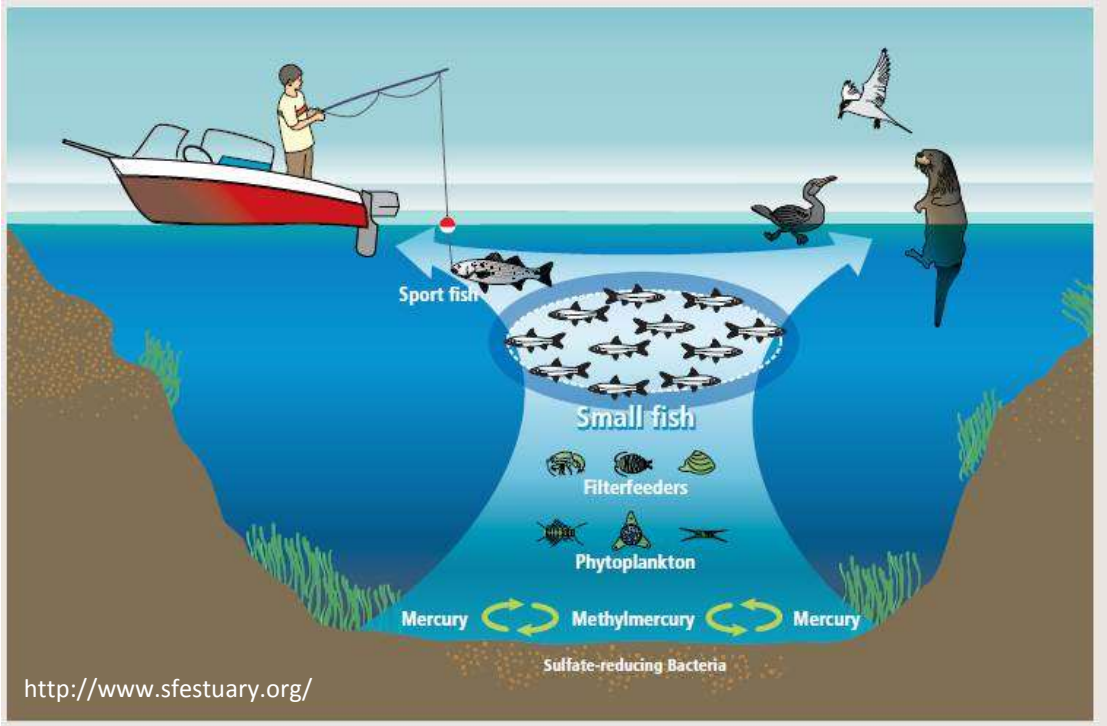


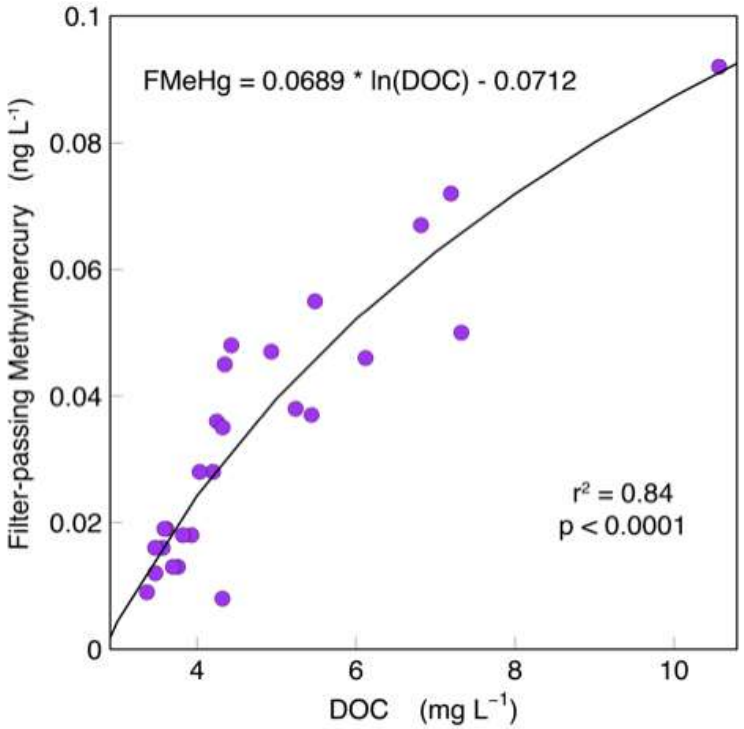
2.5 m x 2.5 m resolution

Fichot et al. (2016)

Remote sensing to identify hotspots of methylmercury?

- **Methylmercury is a potent toxin that bioaccumulates in the food chain**
- **Primarily produced in sediments by sulfate-reducing bacteria (e.g., salt marshes)**
- **Binds strongly to dissolved organic matter**





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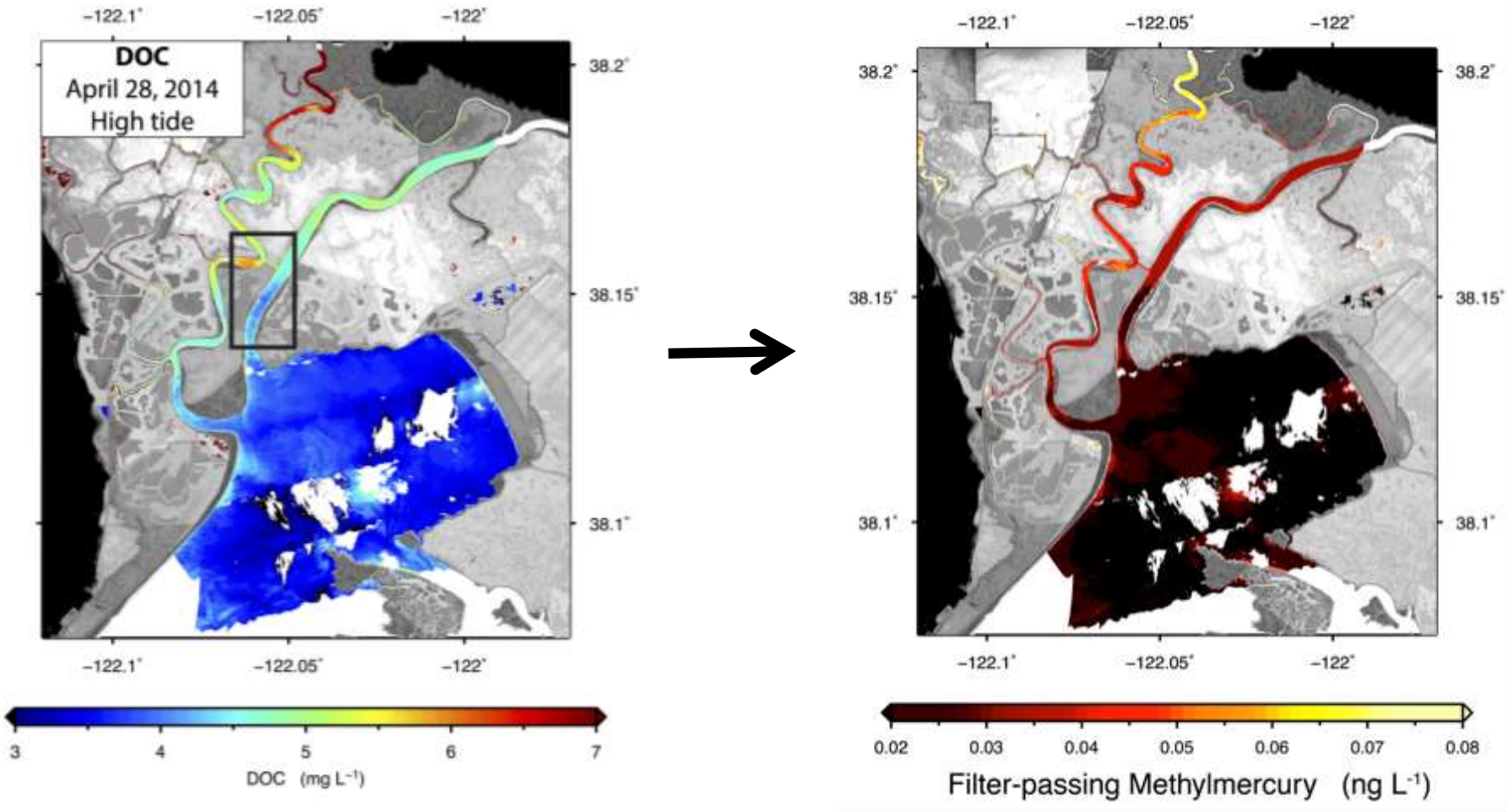
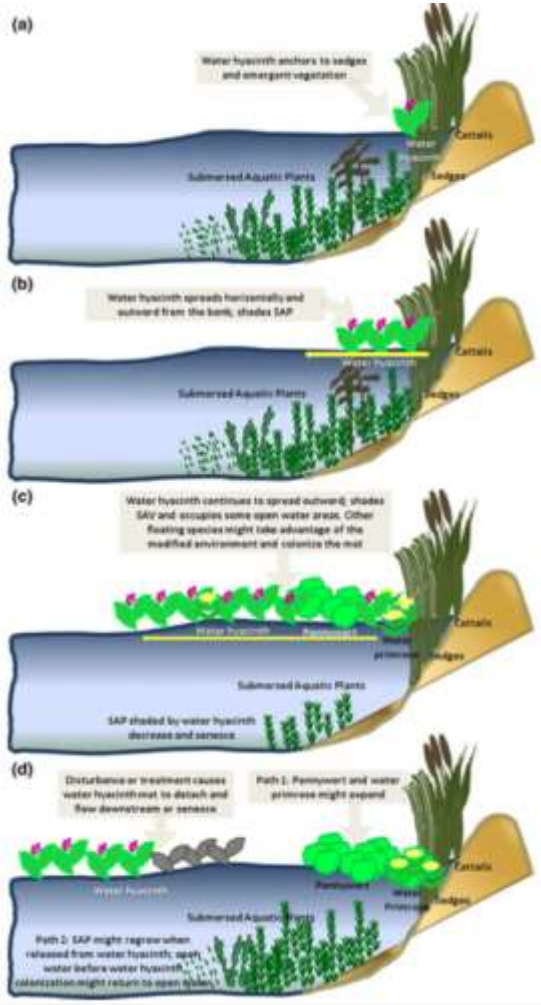


Fichot et al. (2016)

Monitoring of invasive submerged and floating aquatic vegetation

- Impacts sedimentation rates and reduces water flow velocity
- Associated with increased water surface temperature
- Reduces oxygen levels, can create anoxic conditions



Khanna et al 2012

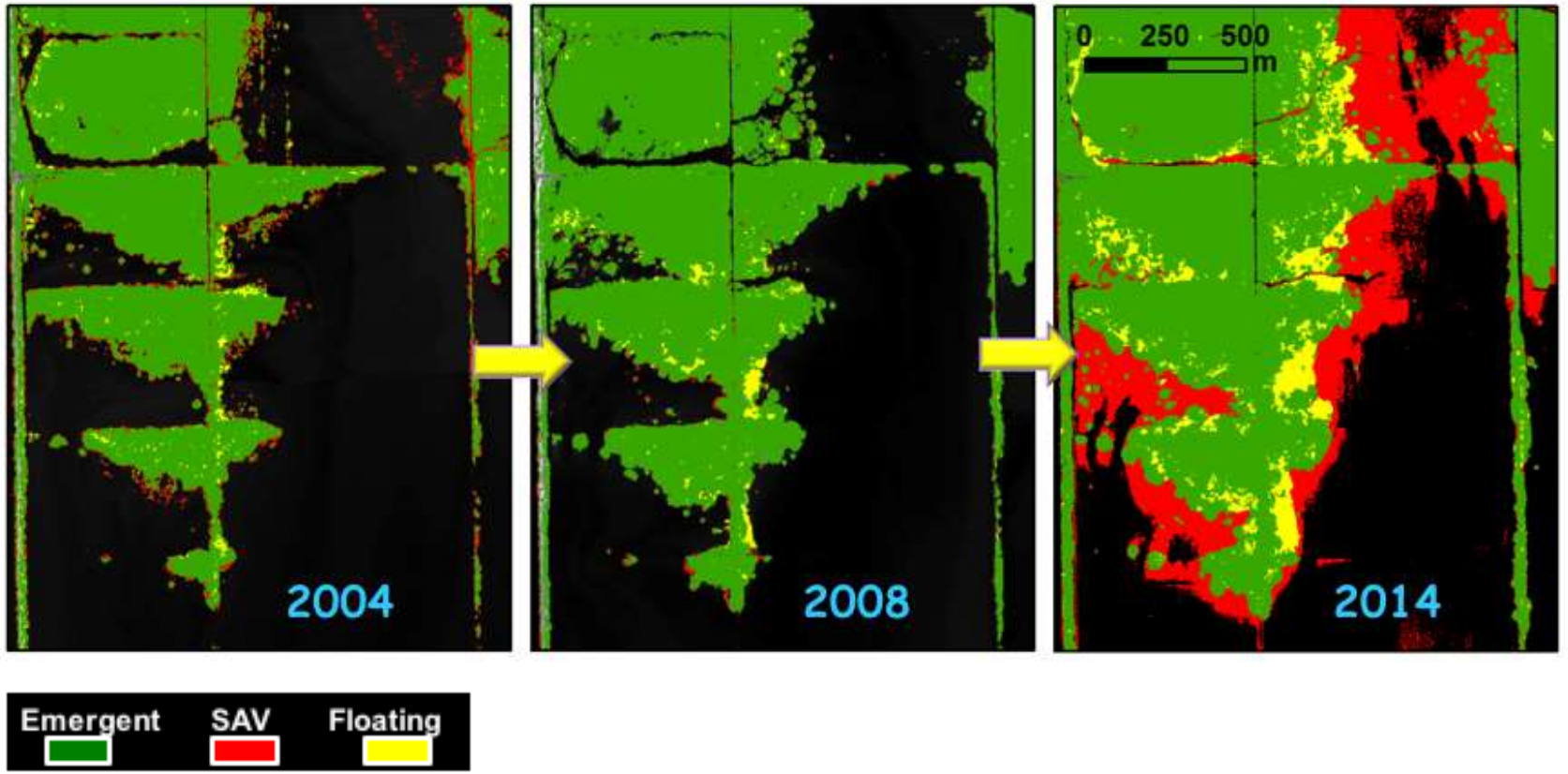
Mapping changes in invasive species distribution

Biol Invasions (2012) 14:717–733
DOI 10.1007/s10530-011-0112-x

ORIGINAL PAPER

Plant community dynamics relative to the changing distribution of a highly invasive species, *Eichhornia crassipes*: a remote sensing perspective

Shruti Khanna · Maria J. Santos ·
Erin L. Hestir · Susan L. Ustin



Khanna et al 2012

Summary

- Remote sensing can be used to develop consistently spatial and/or temporal maps of water column properties
- Water column properties most amenable to this approach are optically active or affect water color (turbidity, chlorophyll-a, CDOM, SAVs and FAVs)
- In some cases, models can be used to infer other WQ parameters (methylmercury)
- Airborne and satellite remote sensing complementary
- Remote sensing can be another tool to complement/supplement existing water quality monitoring

Acknowledgments

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Thank you! (contact for email list)

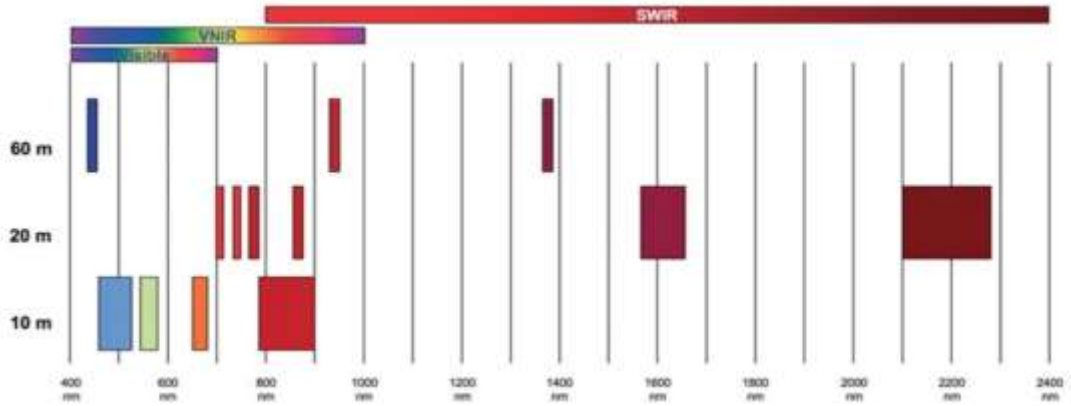
Christine M. Lee

christine.m.lee@jpl.nasa.gov

ESA Sentinel-2A and 2B

<u>Sentinel-2A:</u> launched June 23, 2015

<u>Sentinel-2B:</u> to launch end of 2016



<u>Resolutions</u>

<u>Spectral:</u> 3 bands visible

<u>Spatial:</u> 10 m - 20 m

<u>Temporal:</u> 10-day revisit time
5-day w the 2 satellites

Landsat 8 OLI Characteristics

Landsat 8 Operational Land Imager (OLI)

Launched February 11, 2013

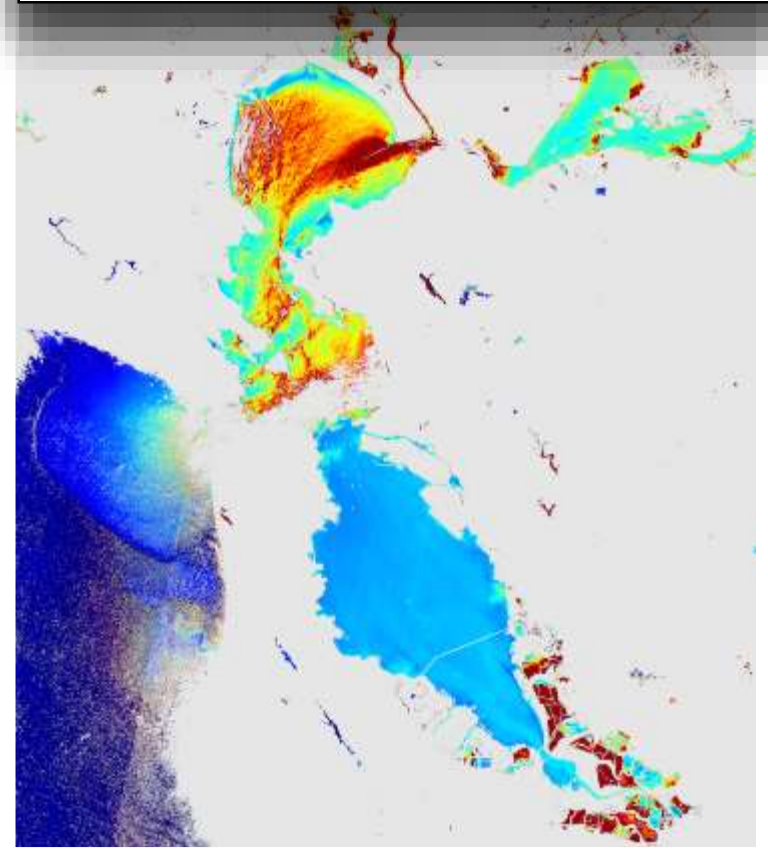
Bands	Wavelength (micrometers)	Resolution (meters)
Band 1 - Coastal aerosol	0.43 - 0.45	30
Band 2 - Blue	0.45 - 0.51	30
Band 3 - Green	0.53 - 0.59	30
Band 4 - Red	0.64 - 0.67	30
Band 5 - Near Infrared (NIR)	0.85 - 0.88	30
Band 6 - SWIR 1	1.57 - 1.65	30
Band 7 - SWIR 2	2.11 - 2.29	30
Band 8 - Panchromatic	0.50 - 0.68	15
Band 9 - Cirrus	1.36 - 1.38	30

Landsat bands are optimized for land products and here we adapt them for coastal ocean products.

Landsat-8 OLI San Francisco Bay 8 May 2015

RGB 8 May 2015

Chlorophyll-a by OC3 (turbid regions show anonymously high concentrations)



Atmospheric correction was done using an iterative SWIR method optimized for highly turbid waters (Vanhellmont & Ruddick, 2014). The standard open ocean OC3 chlorophyll algorithm produces anomalously high values in these turbid regions.