

ARSET

Applied Remote Sensing Training

<http://arset.gsfc.nasa.gov>

 @NASAARSET

Introduction to Remote Sensing of Harmful Algal Blooms

Week 1, September 5, 2017

Trainers:

Sherry Palacios

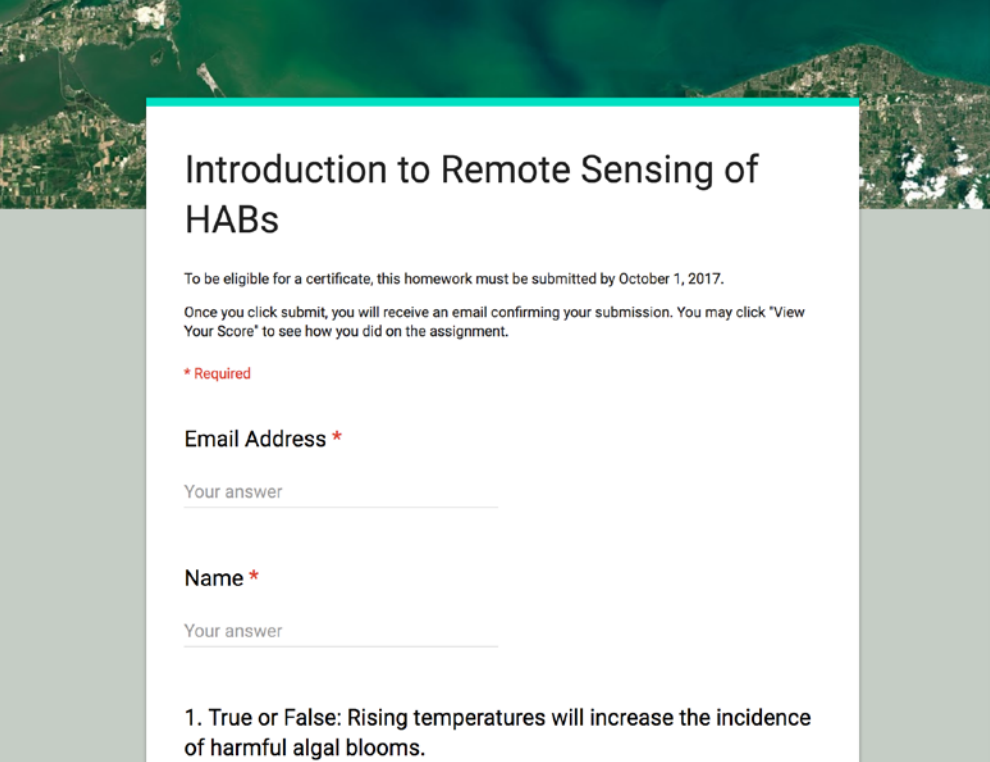
Amita Mehta

Course Structure

- Four, 1-hour sessions: Tuesdays in September (5, 12, 19, 26)
- Each session will be given twice:
 - Session A: 11:00 – 12:00 EDT (UTC-4)
 - Session B: 21:00 – 22:00 EDT (UTC-4)
- Presentations:
 - Overview of Harmful Algal Blooms (HABs)
 - Platforms and sensors, data access, and data processing
 - Understanding HABs in the coastal environment
 - Large scale monitoring and citizen science
- Two Homework Exercises: after weeks 2 and 4.
- Q&A after each session, and by email to instructors

Homework and Certificates

- Homework
 - **Answers must be submitted via Google Form**
- Certificate of Completion:
 - Attend all webinars
 - Complete homework assignments by the deadline (access from ARSET website)
 - **HW Deadlines: October 1st and 15th**
 - You will receive certificates approx. two months after the completion of the course from: marines.martins@ssaihq.com



The image shows a Google Form titled "Introduction to Remote Sensing of HABs". The form is set against a background of a satellite image of a coastal area. The text on the form includes:

Introduction to Remote Sensing of HABs

To be eligible for a certificate, this homework must be submitted by October 1, 2017.

Once you click submit, you will receive an email confirming your submission. You may click "View Your Score" to see how you did on the assignment.

*** Required**

Email Address *

Your answer

Name *

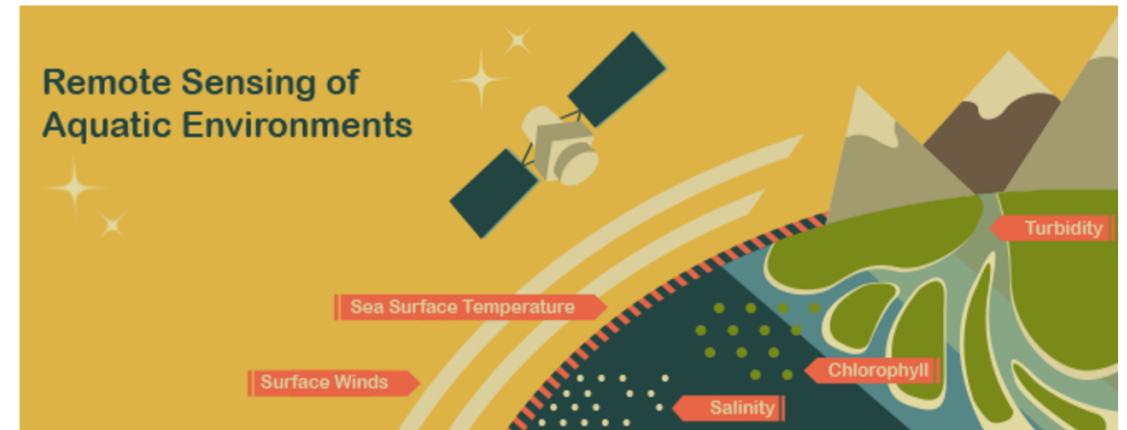
Your answer

1. True or False: Rising temperatures will increase the incidence of harmful algal blooms.

Prerequisites

- Fundamentals of Aquatic Remote Sensing
 - Session 2C
 - On demand webinar, available anytime
 - <http://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing>

Session 2C: Fundamentals of Aquatic Remote Sensing



Overview of relevant satellites and sensors, and data and tools for aquatic environmental management. [View the recording »](#)

- [Presentation Slides](#)
- [Presenter Script](#)

Application Area: Airquality, All, Disasters, Land, Water, Wildfires

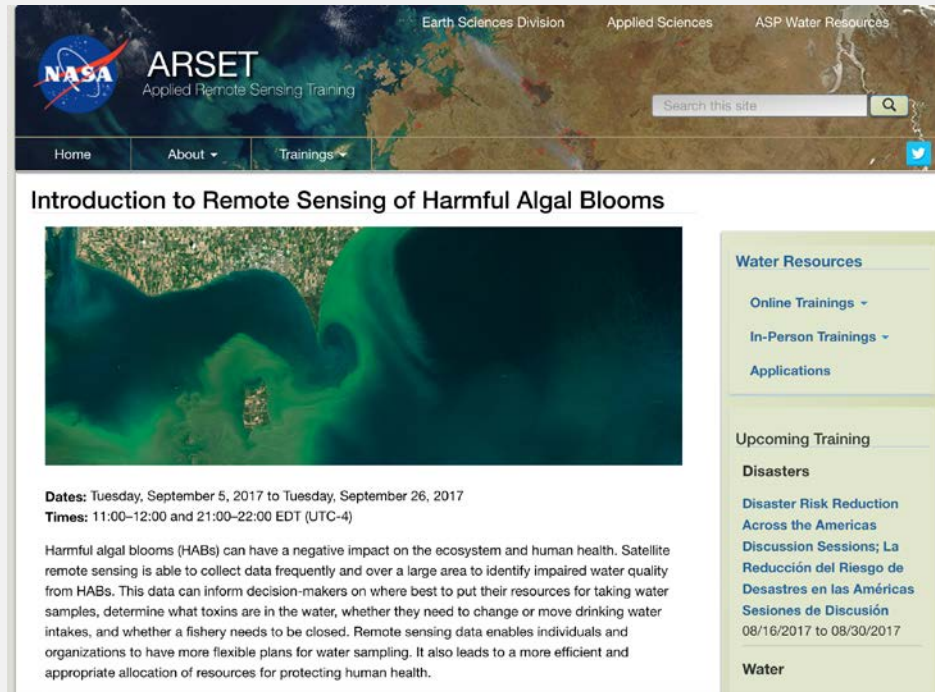
Available Languages: English

Keywords:

Conservation, Fires and Smoke, Flooding, Land-Cover and Land-Use Change (LCLUC), Satellite Imagery, Tools, Vegetation Indices, Water Quality

Course Material

Webinar recordings, presentations, and homework are available at:
<https://arset.gsfc.nasa.gov/water/webinars/HABs17>



The screenshot shows the ARSET (Applied Remote Sensing Training) website. The header includes the NASA logo, the text 'ARSET Applied Remote Sensing Training', and navigation links for 'Home', 'About', and 'Trainings'. A search bar is also present. The main content area features a satellite image of a coastal area with green algal blooms. Below the image, the course title 'Introduction to Remote Sensing of Harmful Algal Blooms' is displayed. The dates are 'Tuesday, September 5, 2017 to Tuesday, September 26, 2017' and the times are '11:00-12:00 and 21:00-22:00 EDT (UTC-4)'. A paragraph of text describes the impact of HABS and the role of satellite remote sensing. On the right side, there are navigation menus for 'Water Resources' (Online Trainings, In-Person Trainings, Applications), 'Upcoming Training' (Disasters, Disaster Risk Reduction Across the Americas Discussion Sessions; La Reducción del Riesgo de Desastres en las Américas Sesiones de Discusión 08/16/2017 to 08/30/2017), and 'Water'.

Learning Objectives:

By the end of the training, attendees will be able to:

- identify NASA's Earth Science remote sensing data products for the identification and monitoring of HABS
- describe how coupled remote sensing and modeling approaches are used in decision support tools
- use a selection of NASA Earth Science data tools to monitor HABS

Course Format:

- Four, one hour sessions
- Sessions will be held on Tuesdays in September: September 5, 12, 19, and 26 at 11:00 a.m.-12:00 p.m. or 21:00-22:00 p.m. EDT (UTC-4)
 - [Convert to your local time »](#)
- A certificate of completion will be provided to participants that attend all live webinars and complete all homework assignments

Prerequisites:

Complete [Session 2C: Fundamentals of Aquatic Remote Sensing](#) or have equivalent experience. Attendees that do not complete prerequisites may not be properly prepared for the pace during the training.

Audience:

Local, regional, state, federal, and international organizations interested in using satellite imagery for coastal and ocean applications. Governmental and non-governmental organizations in the public and private sectors engaged in environmental management and monitoring will be given preference over organizations focused primarily on research.

Registration Information:

There is no cost for the webinar, but you must register. Space is limited, and preference will be given to

Introduction to Remote Sensing of Harmful Algal Blooms

09/05/2017 to 09/26/2017

Land

Introduction to Remote Sensing for Scenario-Based Ecoforecasting

09/07/2017 to 09/28/2017

Course Outline



Week 1: Overview
of Harmful Algal
Blooms

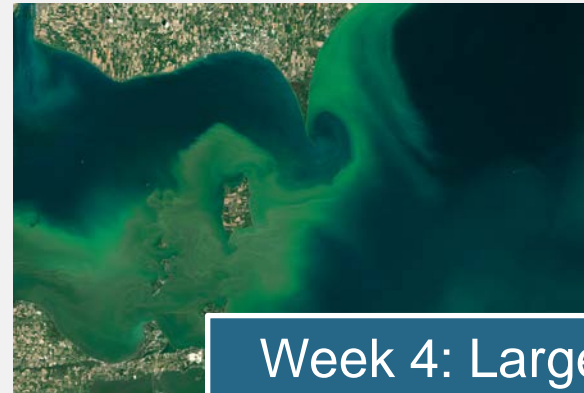


Week 2: Platforms &
Sensors, Data Access,
and Processing



Credit: Paul
Hillman/NOAA

Week 3: HABs in
the Coastal
Environment



Week 4: Large Scale
Monitoring

Outline - Session 1

- Course Structure and Objectives
- Overview of ARSET
- Overview of Marine and Freshwater HABs
- HABs, Ecosystems, and Human Health
- In Situ Monitoring Methods of HABs
- How Remote Sensing is Used for HAB Detection
- Advantages and Limitations of Remote Sensing in Aquatic Environments





ARSET
Applied Remote SEnsing Training Program

<http://arset.gsfc.nasa.gov>

NASA's Applied Remote Sensing Training Program (ARSET)

<http://arset.gsfc.nasa.gov/>

- Empowering the global community through remote sensing training
- Part of NASA's Applied Sciences Capacity Building Program
- Goal: increase the use of Earth Science in decision-making through training for:
 - policy makers
 - environmental managers
 - other professionals in the public and private sector
- Trainings offered focus on applications in:



Disasters



Land



Health & Air Quality



Water Resources

ARSET Training Formats

Online

- Offered through the internet
- Available live and recorded
- Typically 1 hr session, once per week, over 4-6 weeks
- Available at all training levels:
 - Fundamentals of Remote Sensing
 - Introductory
 - Advanced

In-Person

- 2-7 days in length
- Held in a computer lab
- Mixture of lectures and exercises
- Locally relevant case studies
- Available levels:
 - Introductory
 - Advanced

Train the Trainers

- Trainings and materials
- Offered online & in-person
- For organizers seeking to develop their own applied remote sensing training programs

ARSET Training Levels



Fundamentals

Level 0

- Online only
- Assumes no prior knowledge of remote sensing
- Examples:
 - *Fundamentals of Remote Sensing*
 - *Fundamentals of Aquatic Remote Sensing*



Basic Trainings

Level 1

- Online and in-person
- Requires level 0 training or equivalent knowledge
- Specific applications
- Example:
 - *Introduction to Remote Sensing of Ocean and Coastal Applications*



Advanced Trainings

Level 2

- Online and in-person
- Requires level 1 training or equivalent knowledge
- More in-depth or focused topics
- Example:
 - *Algal Bloom Monitoring in the Great Lakes*

ARSET ListServ

- For information on upcoming courses and program updates, please sign up for the listserv
- <https://lists.nasa.gov/mailman/listinfo/arset>



Overview of Marine and Freshwater HABs

What is a Harmful Algal Bloom?

“Harmful algal blooms, or HABs, occur when colonies of algae — simple plants that live in the sea and freshwater — grow out of control and produce toxic or harmful effects on people, fish, shellfish, marine mammals and birds. The human illnesses caused by HABs, though rare, can be debilitating or even fatal.”

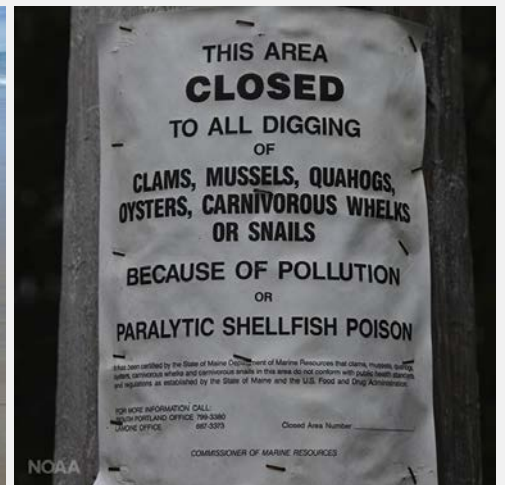
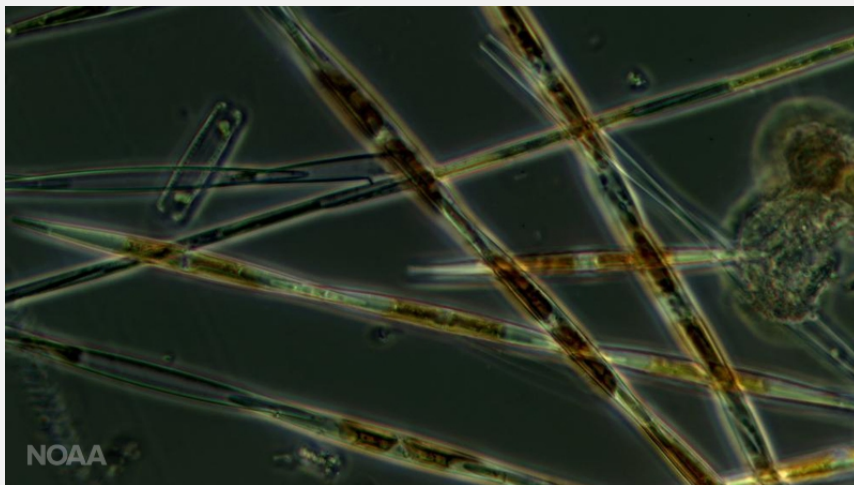


Image credit: <http://www.noaa.gov/what-is-harmful-algal-bloom>

How HABs Can Be Harmful

- Produce toxins
- Cause economic losses
- Contaminate drinking water
- Smother benthic organisms
- Deplete oxygen
- Impede visual predators
- Attenuate light to benthic submerged aquatic vegetation or corals

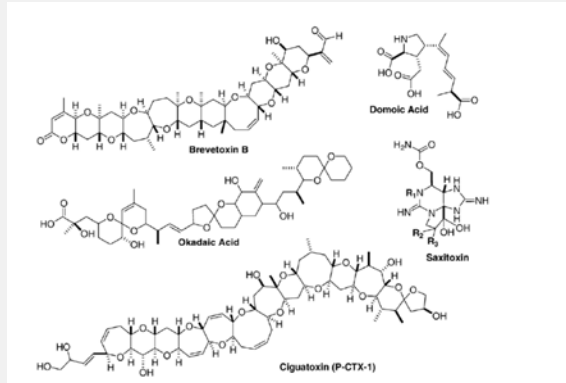


Photo Credits (clockwise from top left) Karina Cardozo (Cardozo et al., 2007); NASA Earth Observatory; NOAA Northwest Fisheries Science Center; Linda Preskitt

HAB Poisonings and Syndromes

A generalized view of the U.S. depicting the various HAB poisoning syndromes and other impacts that occur in specific areas. Colored dots or ovals indicate locations where the incidence of a particular syndrome has been reported, or where toxins have been detected in tissue extracts or plankton. Ovals are used to indicate regional phenomena that occur at multiple locations along a coastline. All 50 states are impacted by cyanobacteria HAB (cyanoHABs), typically in many different rivers, streams, reservoirs, etc. The same is true for 23 states impacted by golden algal blooms caused by *Prymnesium parvum*. It is not practical to indicate the location of each cyanoHAB or golden algal bloom, so each state experiencing these blooms is indicated using a single green and/or gold dot. Larger green ovals denote widespread cyanoHAB problems in those areas.

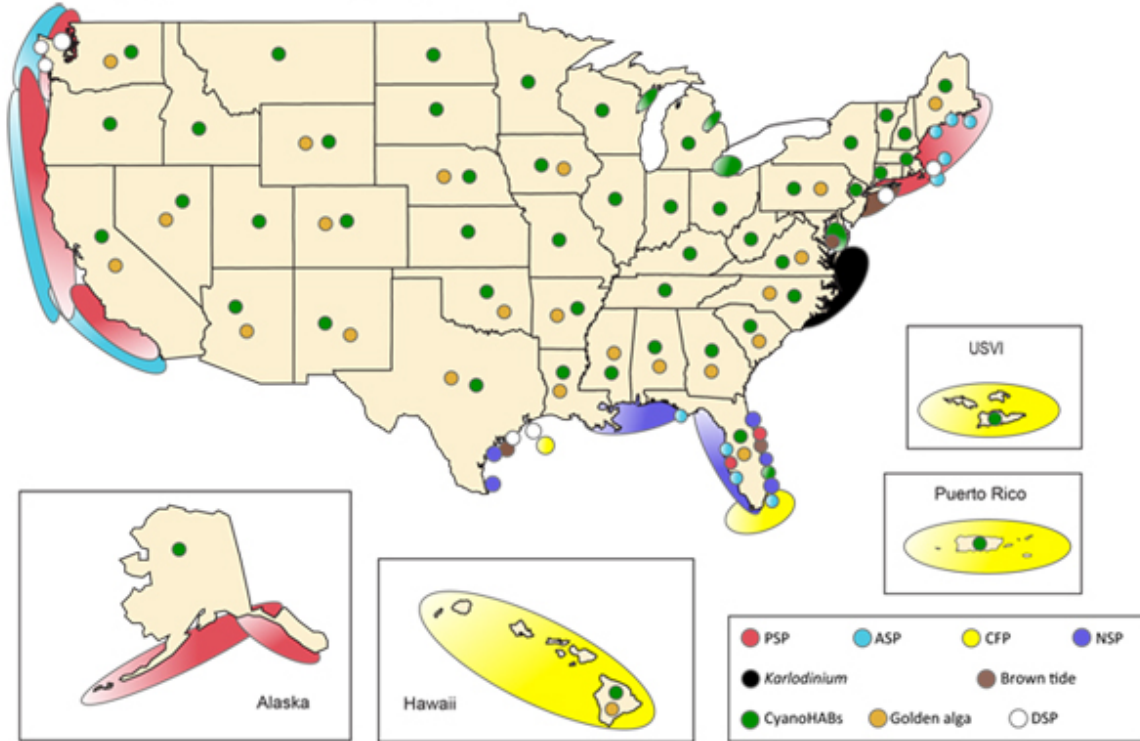
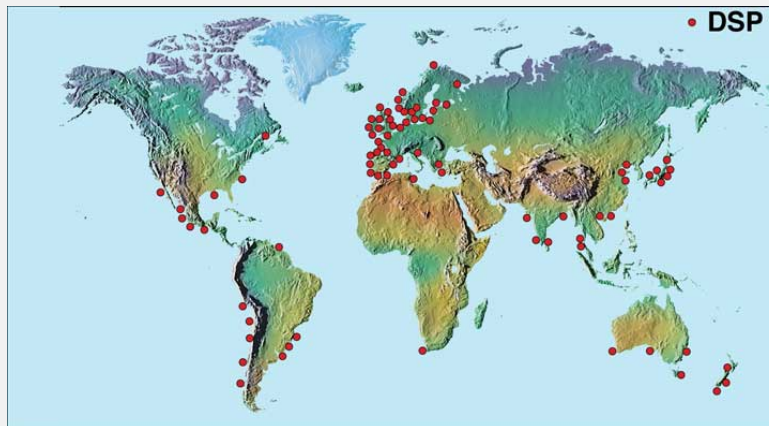
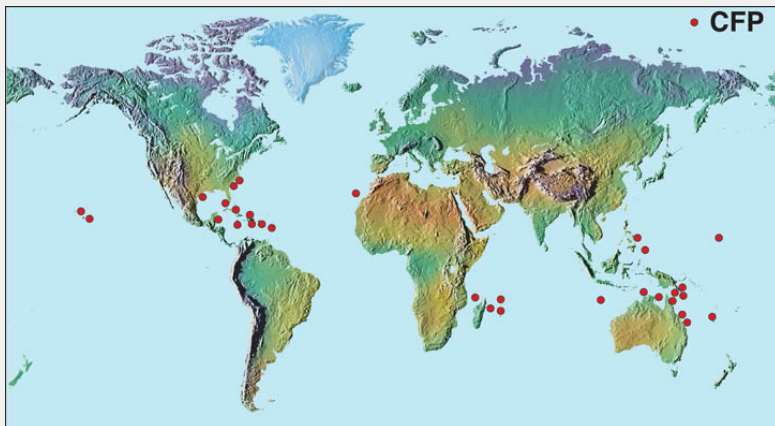
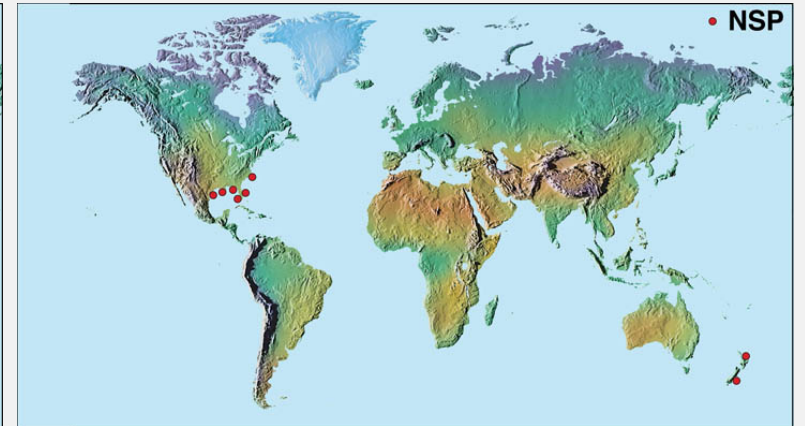
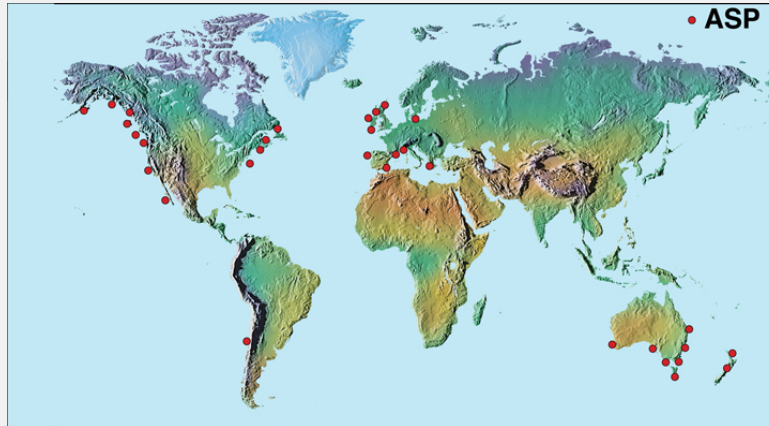
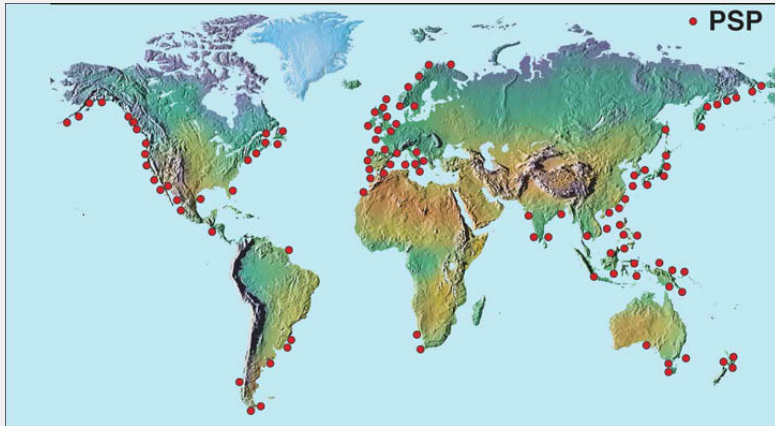


Image Credit: [WHOI](http://www.who.int)

- Paralytic Shellfish Poisoning (PSP)
- Amnesic Shellfish Poisoning (ASP)
- Neurotoxic Shellfish Poisoning (NSP)
- Ciguatera Fish Poisoning (CFP)
- Brown Tide (BT)
- Cyanobacterial HABs (cyanoHAB)
- Diarrhetic Shellfish Poisoning (DSP)

Global Distribution of HAB Toxins

Recorded as of 2016

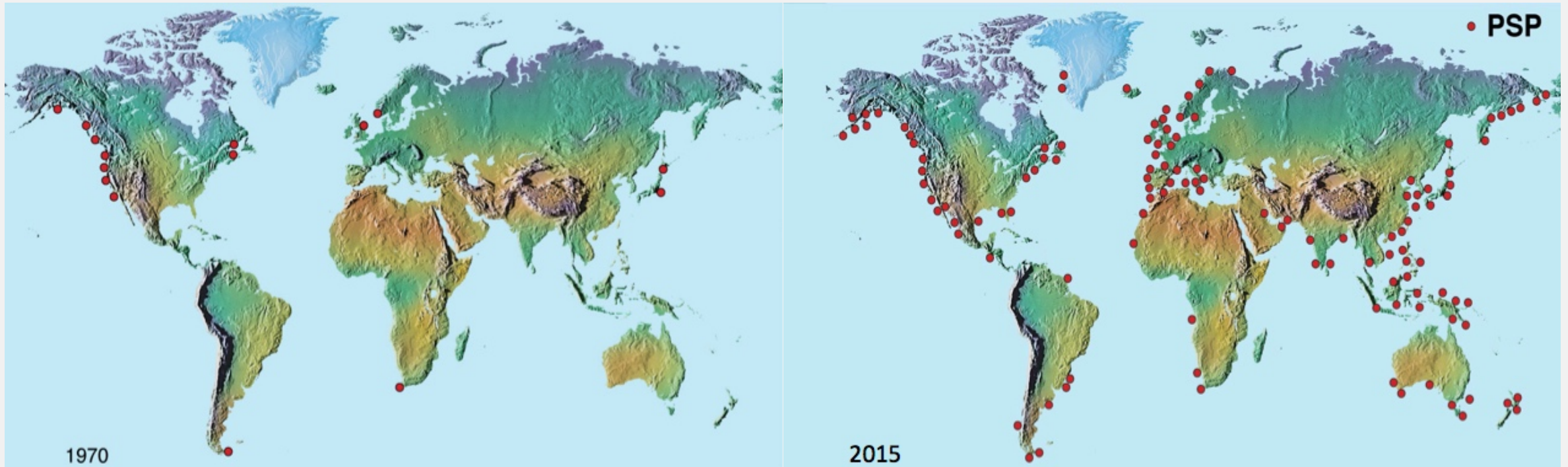


PSP - Paralytic Shellfish Poisoning
ASP - Amnesic Shellfish Poisoning
NSP - Neurotoxic Shellfish
Poisoning
CFP - Ciguatera Fish Poisoning
DSP - Diarrhetic Shellfish
Poisoning

Images: WHOI <http://www.whoi.edu/redtide/regions/world-distribution>

Why the Increasing Trend of HAB Events?

Paralytic Shellfish Poisoning Case Study



Credit: WHOI <http://www.whoi.edu/redtide/regions/us/recent-trends>

What Causes HABs?

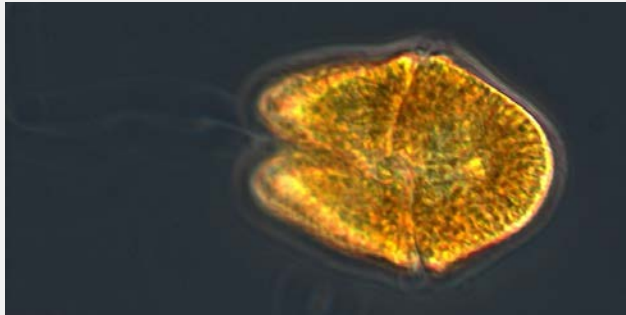
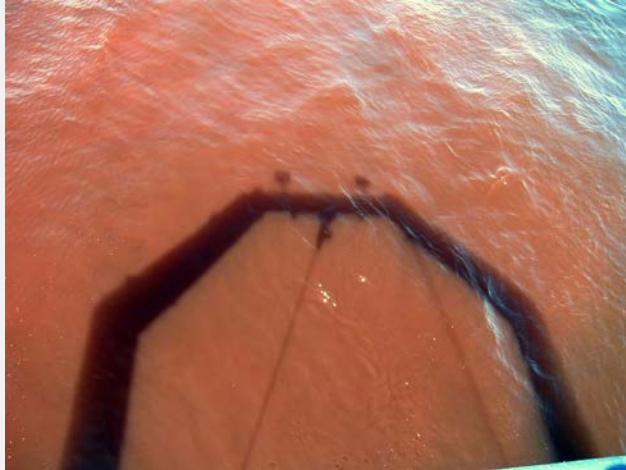
- Nutrient loading “eutrophication”
- Pollution
- Warm water
- Food web changes
- Introduced species
- Changes in water flow
 - e.g., after major events like hurricanes, drought, or floods
- Other, yet unknown, factors



How HABs Can Affect Ecosystem and Human Health

Oxygen Depletion

Red tide – e.g., *Akashiwo sanguinea*



- Algae can proliferate to a high density so that photosynthesis does not offset biological oxygen demand
- Decay of algal blooms consumes oxygen in the environment resulting in 'low oxygen' or hypoxia (2 – 3 ppm)
- Hypoxia can cause die-offs of fish, corals, shellfish, and submerged aquatic vegetation

Photo Credit: Sherry Palacios

Food Web Vectoring

Paralytic Shellfish Poisoning – e.g., *Alexandrium catanella*

- Caused by consuming shellfish containing toxins such as saxitoxin
- Onset of symptoms is within 24 hours
- A life threatening neurological syndrome
- Symptoms: tingling, numbness, burning in the abdomen, loss of bodily movements, giddiness, fever, and rash
- Large-scale monitoring in the U.S. with rapid response and regulation of fisheries
- Rapid response is key to protecting human health

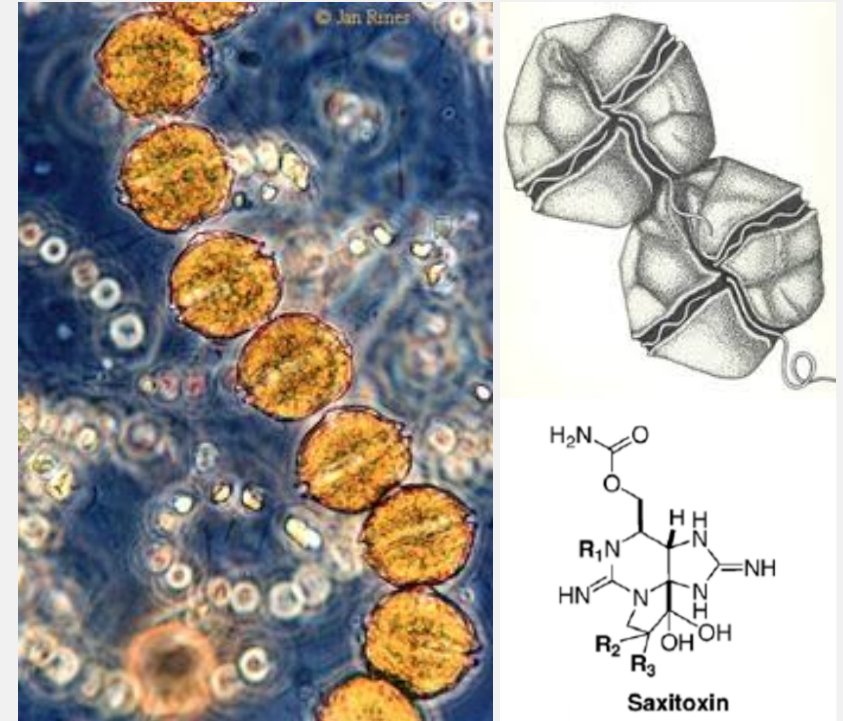


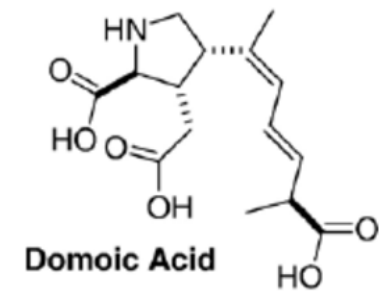
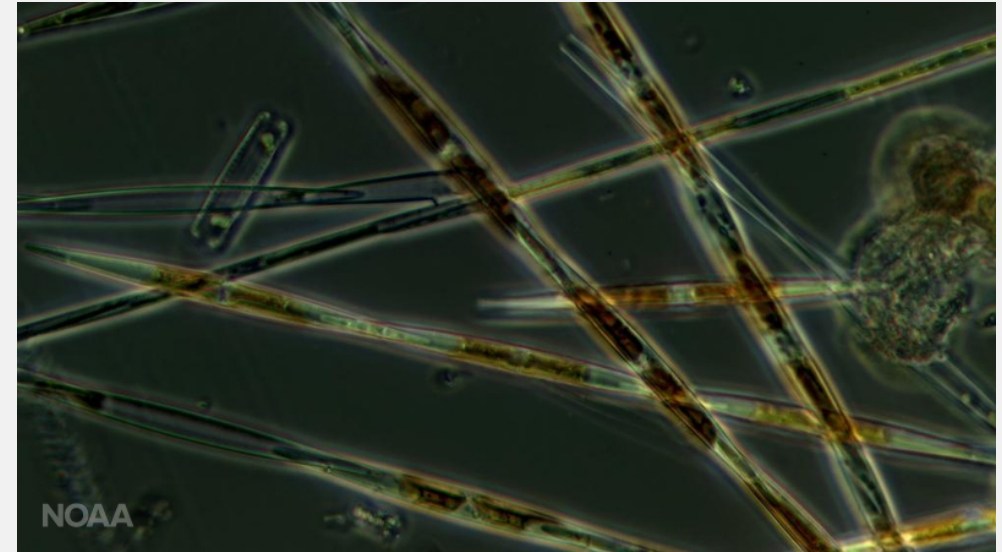
Image Credit: Left: Jan Rines (U. of Rhode Island) <http://oceandatacenter.ucsc.edu>; Right: Karina Cardozo (Cardozo et al., 2007)

Credit: WHOI <https://www.whoi.edu/redtide/human-health/paralytic-shellfish-poisoning>

Food Web Vectoring

Amnesic Shellfish Poisoning – e.g., *Pseudo-Nitzschia* sp.

- Caused by consuming shellfish containing toxins such as domoic acid (DA)
- Has gastrointestinal and neurologic effects with onset of symptoms within 24 - 48 hours
- Can be life threatening



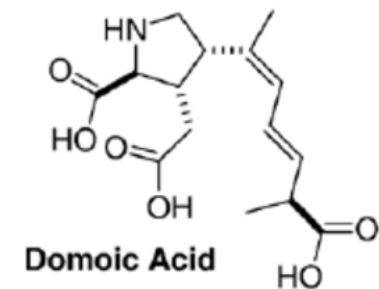
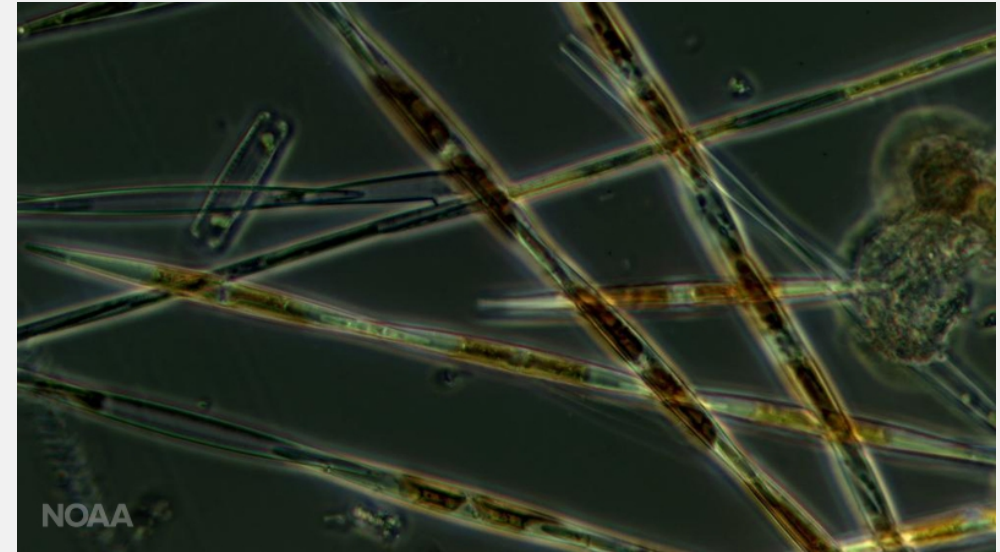
Credit: WHOI <https://www.whoi.edu/redtide/human-health/amnesic-shellfish-poisoning>

Image Credits: NOAA, Karina Cardozo (Cardozo et al., 2007) (DA molecule)

Food Web Vectoring

Amnesic Shellfish Poisoning – e.g., *Pseudo-Nitzschia* sp.

- Symptoms
 - Gastrointestinal: nausea, vomiting, abdominal cramps, diarrhea
 - Neurological: dizziness, headache, seizures, short term memory loss
- Large-scale monitoring in the U.S. with rapid response and regulation of fisheries
- Threshold of 20 $\mu\text{g/g}$ shellfish meat, but often viscera is even higher at this level-posing a risk



Credit: WHOI <https://www.whoi.edu/redtide/human-health/amnesic-shellfish-poisoning>

Image Credits: NOAA, Karina Cardozo (Cardozo et al., 2007) (DA molecule)

Disruption to Visual Predators

Coccolithophore Bloom – e.g., *Emiliana huxleyi*

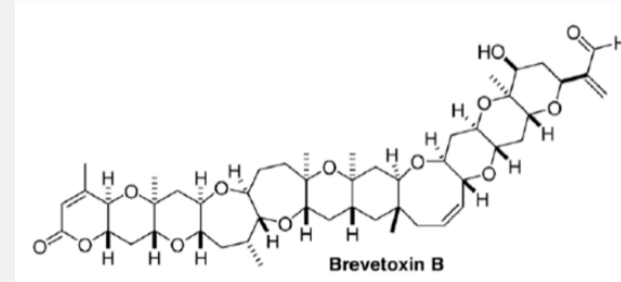


Photo Credit (Clockwise from Top): NASA Earth Observatory; Young et. al., 2003; Alison R. Taylor; Oregon Coast Aquarium

Food Web Vectoring & Airborne Toxic Events

Neurotoxic Shellfish Poisoning – e.g., *Karenia brevis*

- *Karenia brevis* forms intense blooms named 'Florida Red Tide' and releases a toxin known as brevetoxin
- Has gastrointestinal and neurologic effects that result from consumption of shellfish
- Cells and toxin can be lofted into the overlying atmosphere from wave action and cause respiratory problems in people downwind



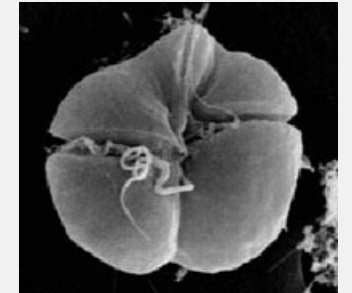
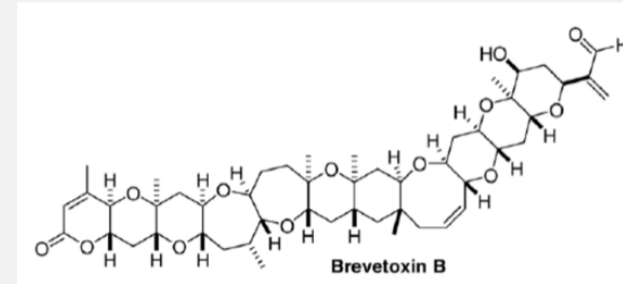
Credit: WHOI <https://www.whoi.edu/redtide/human-health/neurotoxic-shellfish-poisoning>

Photo Credit (Clockwise from Top): Karina Cardozo (Cardozo et al., 2007); John Dutton; P. Schmidt, Charlotte Sun Times

Food Web Vectoring & Airborne Toxic Events

Neurotoxic Shellfish Poisoning – e.g., *Karenia brevis*

- Typically not life threatening, hospitalization sometimes needed
- Symptoms
 - Gastrointestinal: nausea, vomiting
 - Neurological: prickling sensation in mouth, lips, and tongue, dizziness, slurred speech, partial paralysis, respiratory distress



Credit: WHOI <https://www.whoi.edu/redtide/human-health/neurotoxic-shellfish-poisoning>

Photo Credit (Clockwise from Top): Karina Cardozo (Cardozo et al., 2007); John Dutton; P. Schmidt, Charlotte Sun Times

Drinking Water Threat

CyanoHAB – e.g., *Microcystis aeruginosa*

- A number of fresh water cyanobacteria groups produce toxins that can be released into the environment
- When *Microcystis aeruginosa* blooms it forms distinctive surface scums, visible in remote sensing imagery
- Even at relatively low concentrations, its toxin microcystin can harm humans and animals if ingested



Credit: WHOI <https://www.whoi.edu/redtide/human-health/cyanobacteria>

Bulletin Credit: NOAA

Drinking Water Threat

CyanoHAB – e.g., *Microcystis aeruginosa*

- Microcystin is a hepatotoxin. Liver failure results from acute exposure and liver tumors under prolonged low-level exposure
- Symptoms – vomiting, diarrhea, abdominal pain, lethargy, and rash
- Forecasting cyanoHAB events is a high priority



Credit: WHOI <https://www.whoi.edu/redtide/human-health/cyanobacteria>

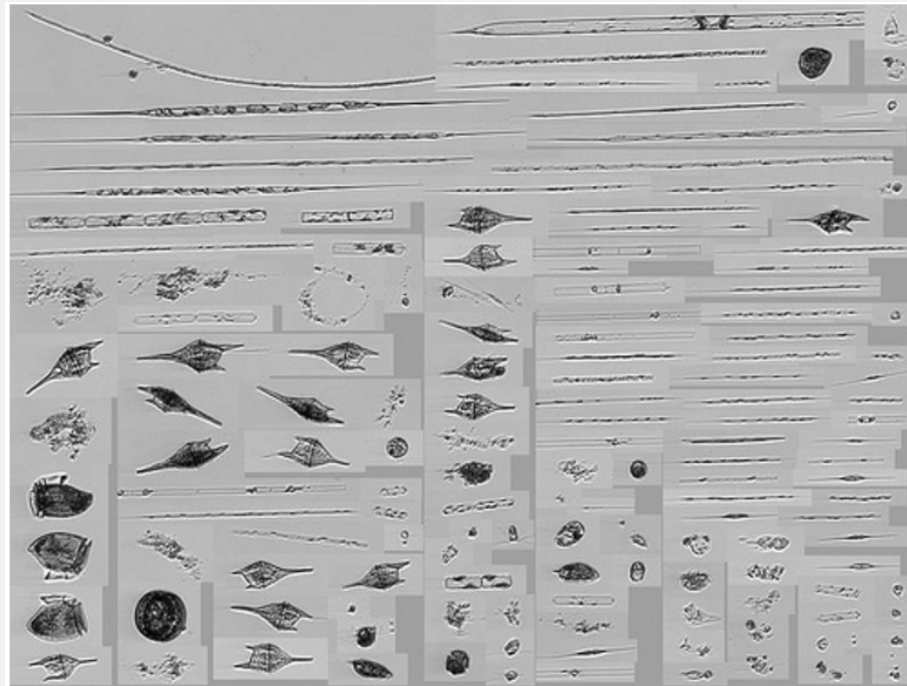
Bulletin Credit: NOAA



In Situ Monitoring Methods of HABs

Cell Enumeration

- Traditional microscopic measurements from whole water samples
- Automated imaging microscopy
- Automated imaging flow cytometry
- Example:
 - Imaging FlowCytobot



Credit: MBARI
Image Credits: Sosik & Olson (2007); Olson & Sosik (2007)

Optical Proxies

- Fluorometry
 - chlorophyll concentration
 - chlorophyll anomalies
 - taxon-specific accessory pigment fluorometry
- Inherent Optical Properties (IOPs)

Toxin Observations

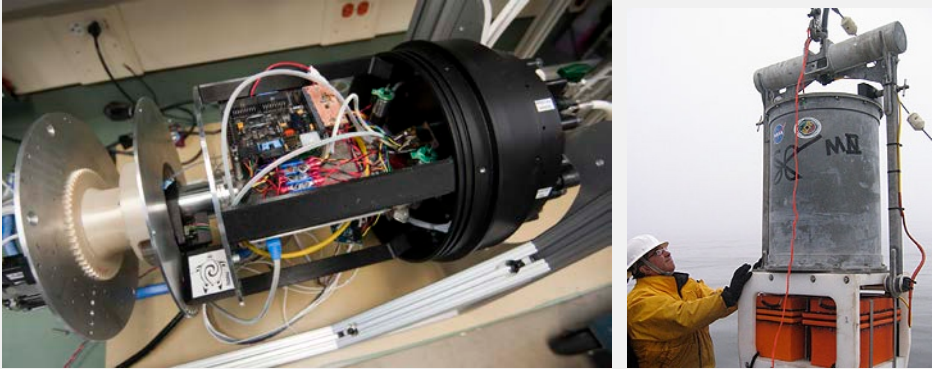
- Target organism loading: e.g., mouse bioassay, mussel
- Resin bead loading, i.e., SPATT
- Chromatographic – mass spectrometry measurements, i.e., LC-MS
- Molecular biological methods: e.g., ELISA



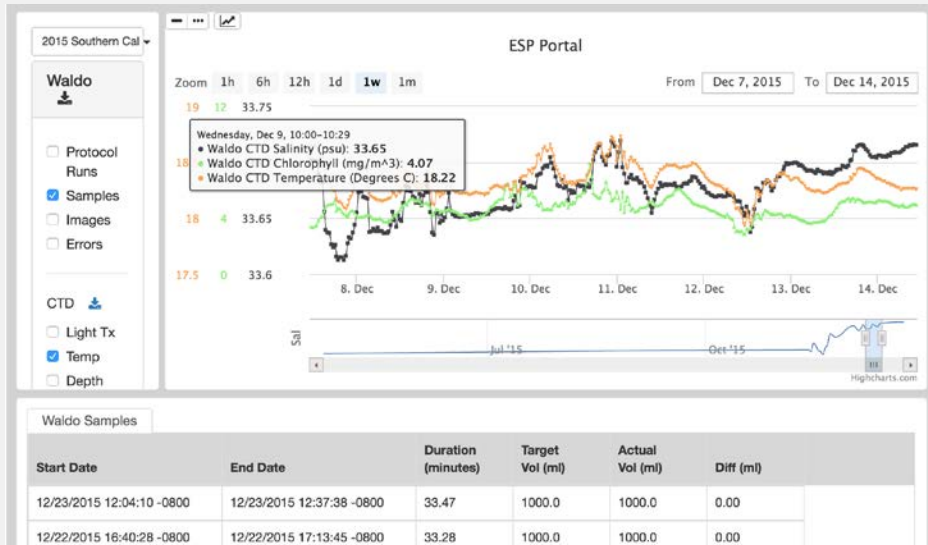
Image Credits: (L-R) Kylla Benes; Raphael Kudela; Borkman et al. (2012)

Ocean Observing Systems

Case Study – Environmental Sample Processor (ESP)



- Developed by the Monterey Bay Aquarium Research Institute (MBARI)
- Autonomous mooring deployed at sea, collects water samples, and identifies presence of organisms and/or biological toxins
- Onboard sampling and relaying of data to researchers or resource managers
- Can be configured for specific needs of region
- Samples can be preserved for later analysis



Credit: MBARI

An aerial photograph showing a large river system, likely the Mississippi River, winding through a landscape. The river is a deep blue color. The surrounding land is a mix of green fields and brown patches, indicating agricultural land. A semi-transparent grey rectangle is overlaid on the center of the image, containing the title text.

How Remote Sensing is Used for HAB Detection

Main Take-Away for the Webinar Series...

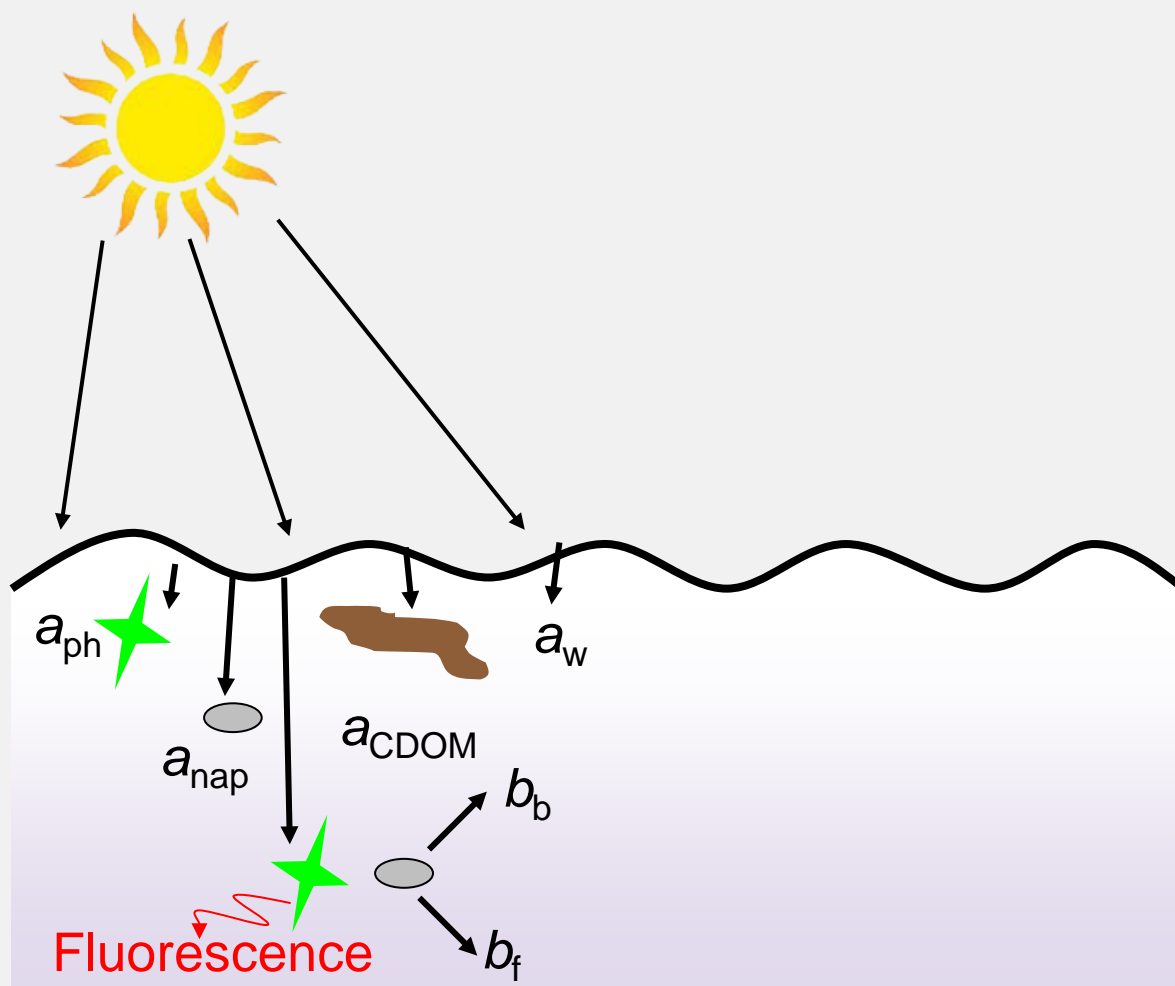
- Remote sensing imagery is a tool to aid in the monitoring and forecasting of HAB events to understand impacts to the ecosystem and/or human health
- Remote sensing imagery does not replace sampling on-the-ground
- Imagery, with associated algorithms and ecosystem models, informs adaptive sampling approaches used by resource managers

Remote Sensing Data Products Used in HAB Detection

- Chlorophyll
- Chlorophyll-a anomaly
- Algae discrimination based on inherent optical properties
- Coupled remote sensing observation and environmental condition modeling

How Light Interacts with Water

Defining Remote Sensing Reflectance (R_{rs}) – or ‘Ocean Color’



$$R_{rs}(\lambda, 0^+) \cong C \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}$$

Inherent Optical Properties

a = absorption by...

phytoplankton (ph)

non-algal particles (nap)

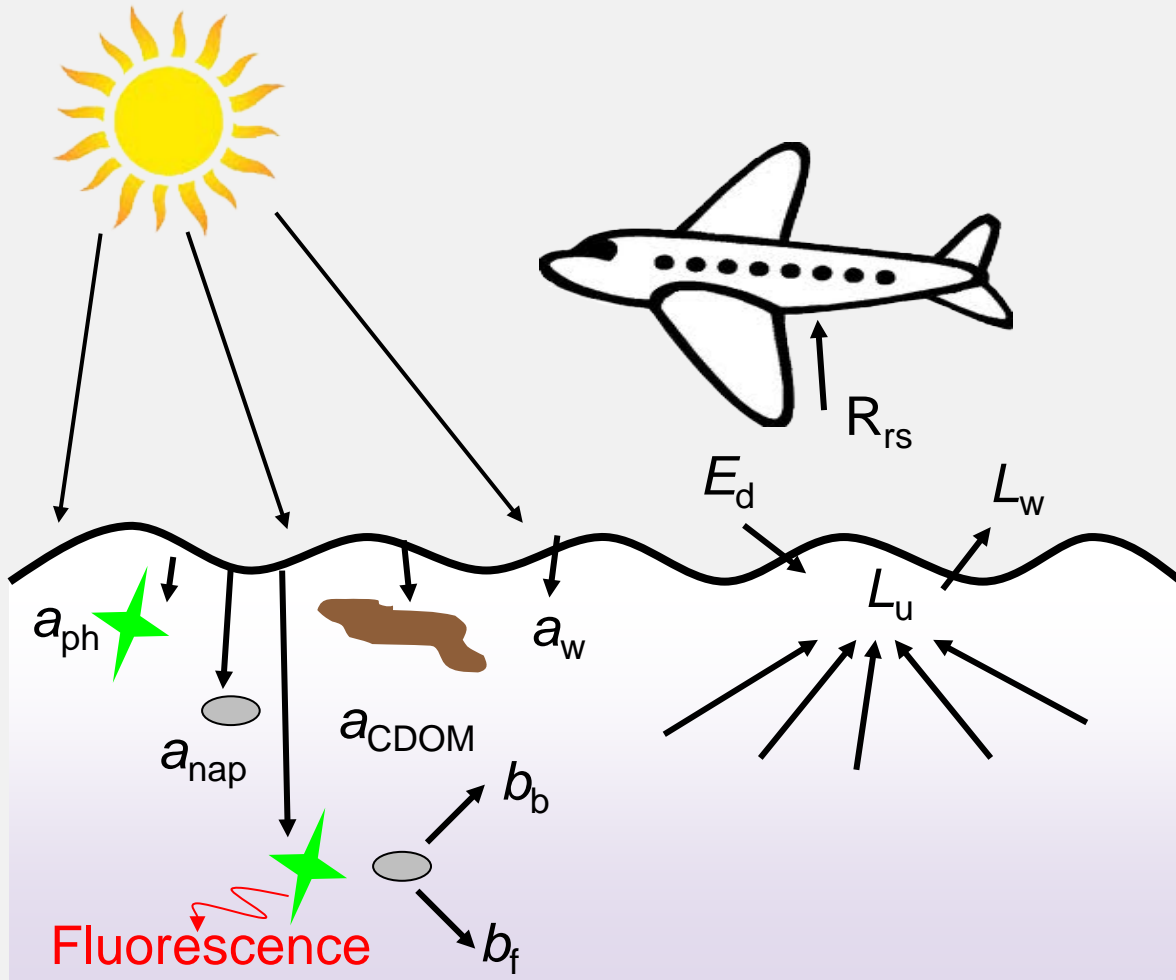
colored dissolved organic matter (CDOM)

water (w)

b = scattering in forward (f) and backward (b) directions

How Light Interacts with Water

Defining Remote Sensing Reflectance (R_{rs}) – or ‘Ocean Color’



$$R_{rs}(\lambda, 0^+) \cong C \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)} = \frac{L_w(\lambda)}{E_d(\lambda, 0^+)}$$

Inherent Optical Properties

a = absorption

b = scattering

Apparent Optical Properties

L_w = water leaving radiance

L_u = upwelling radiance

E_d = downwelling irradiance

R_{rs} = remote sensing (rs) reflectance

Inherent Optical Properties (IOPs) and the 'Color' of Water

$$R_{rs}(\lambda, 0^+) \cong C \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}$$

Light absorption (a) by phytoplankton (ph), non-algal particles (nap), water (w), and colored dissolved organic matter (CDOM)

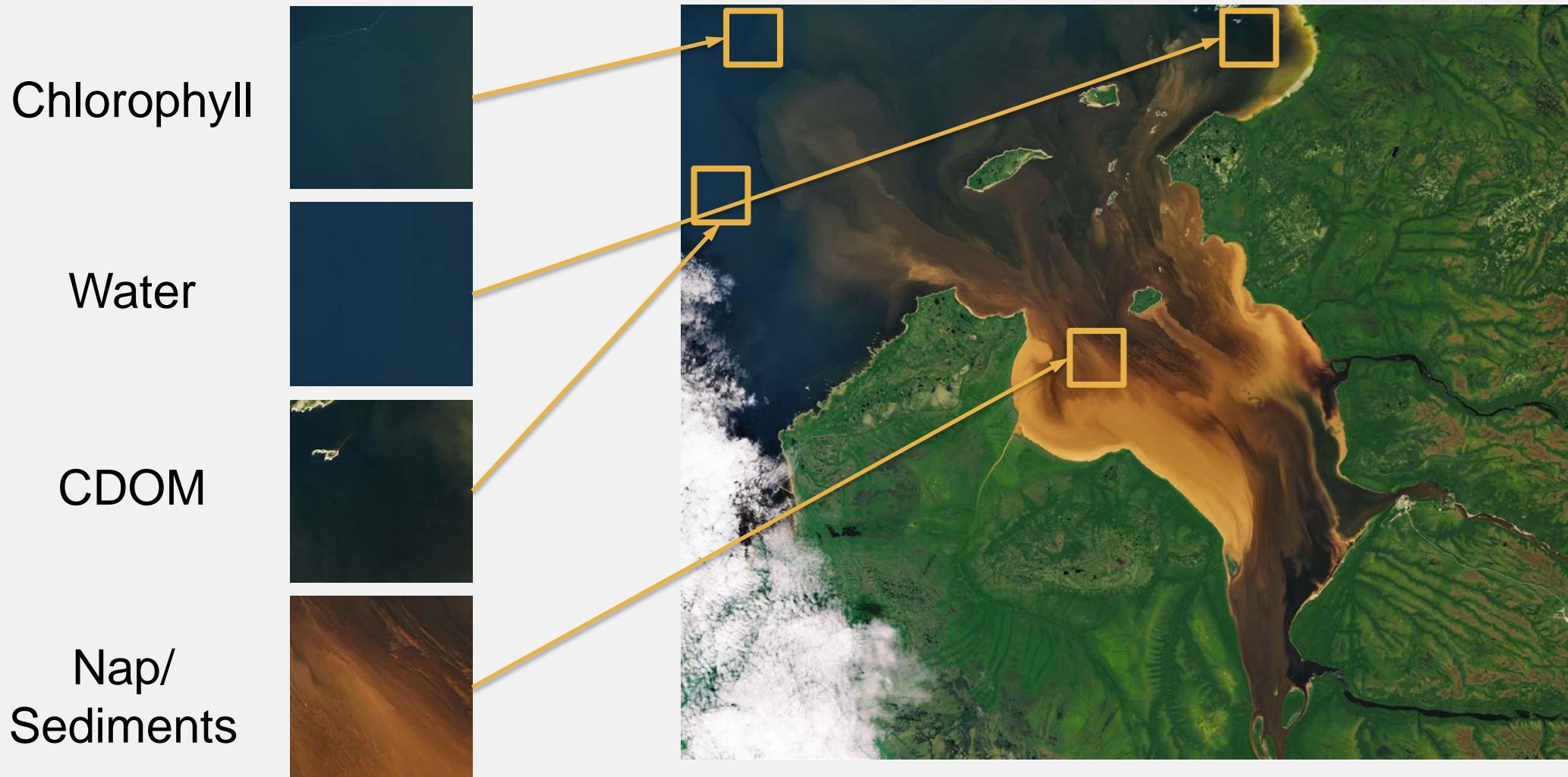
$$a = a_{ph} + a_{nap} + a_{CDOM} + a_w$$

Light scattering (b) by particles in forward (b_f) and backward (b_b) direction

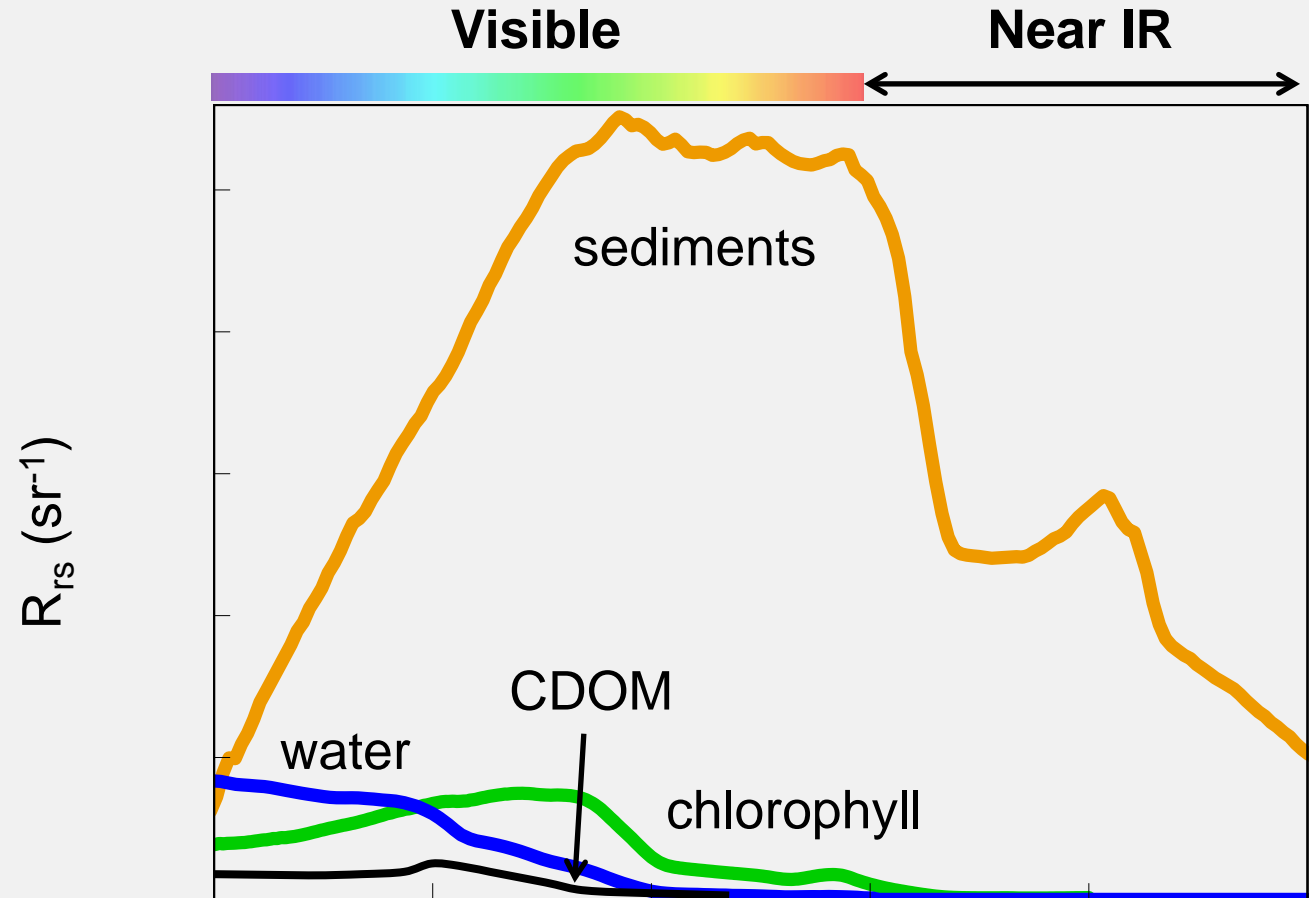
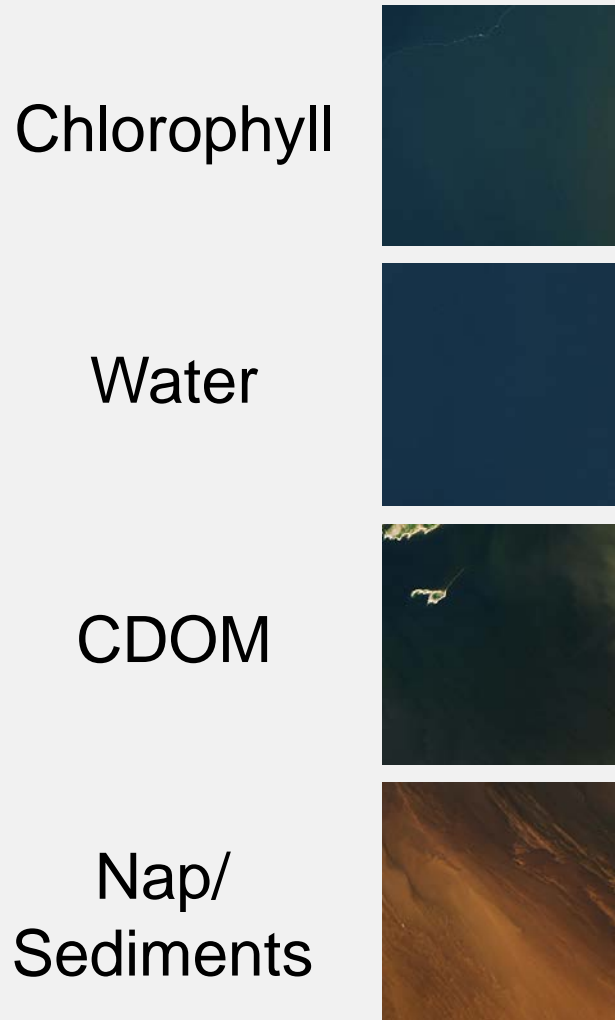
$$b = b_f + b_b$$



Inherent Optical Properties (IOPs) and the 'Color' of Water

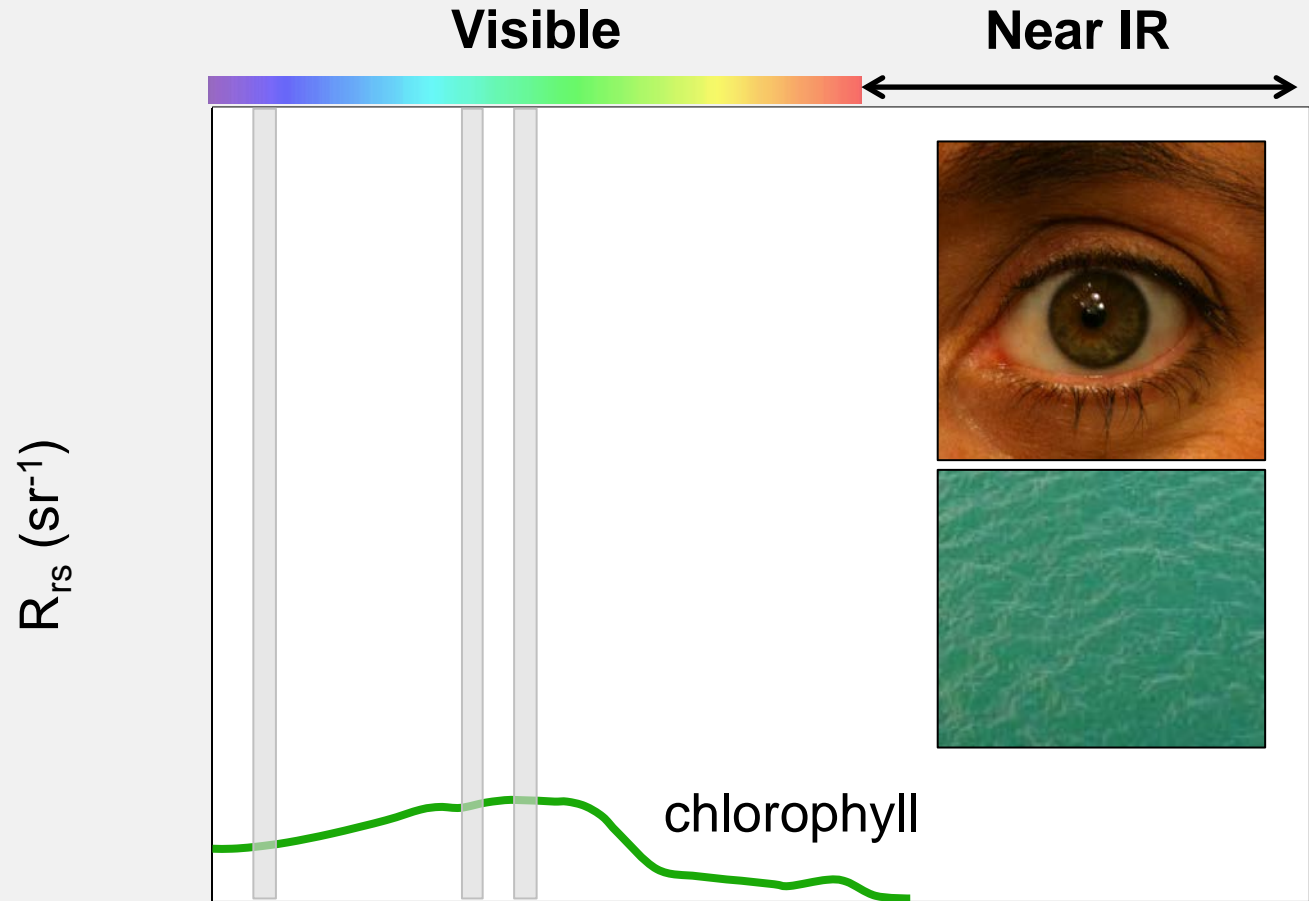


Inherent Optical Properties (IOPs) and the 'Color' of Water

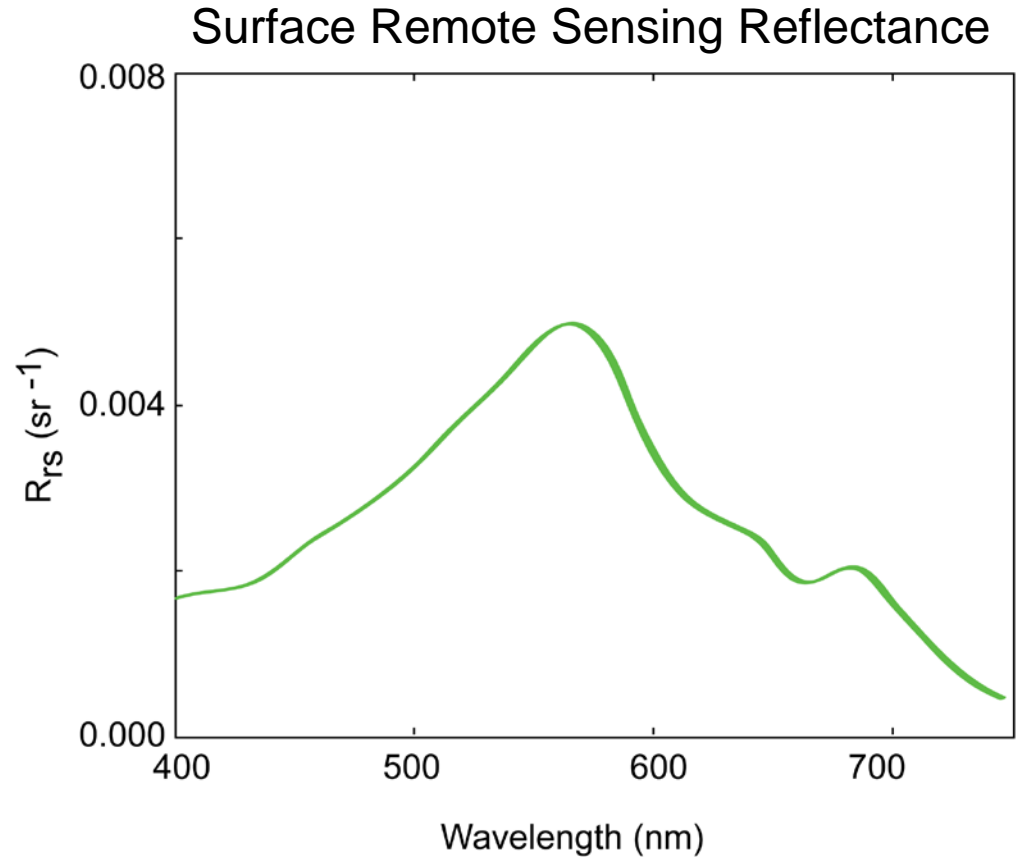


Inherent Optical Properties (IOPs) and the 'Color' of Water

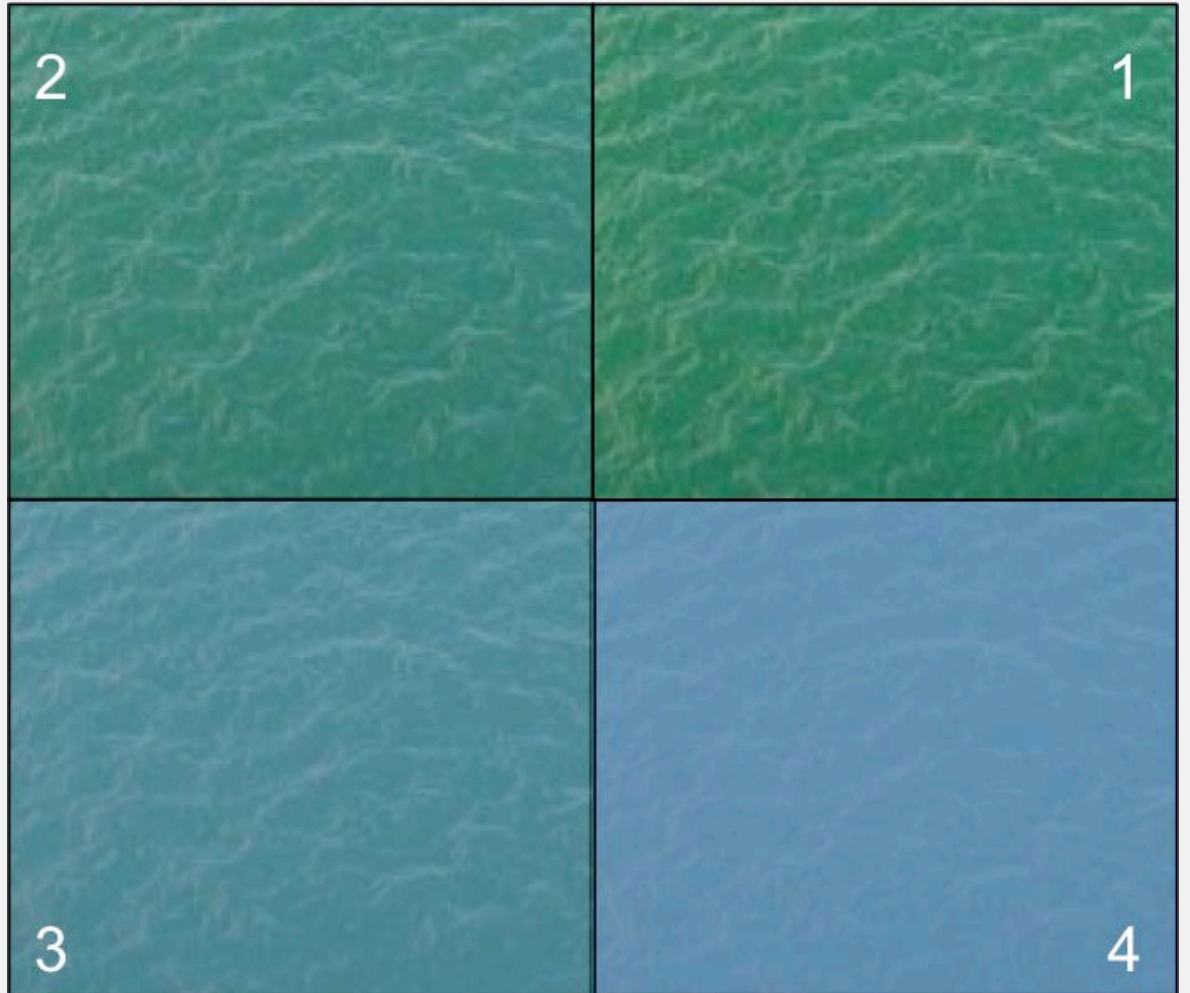
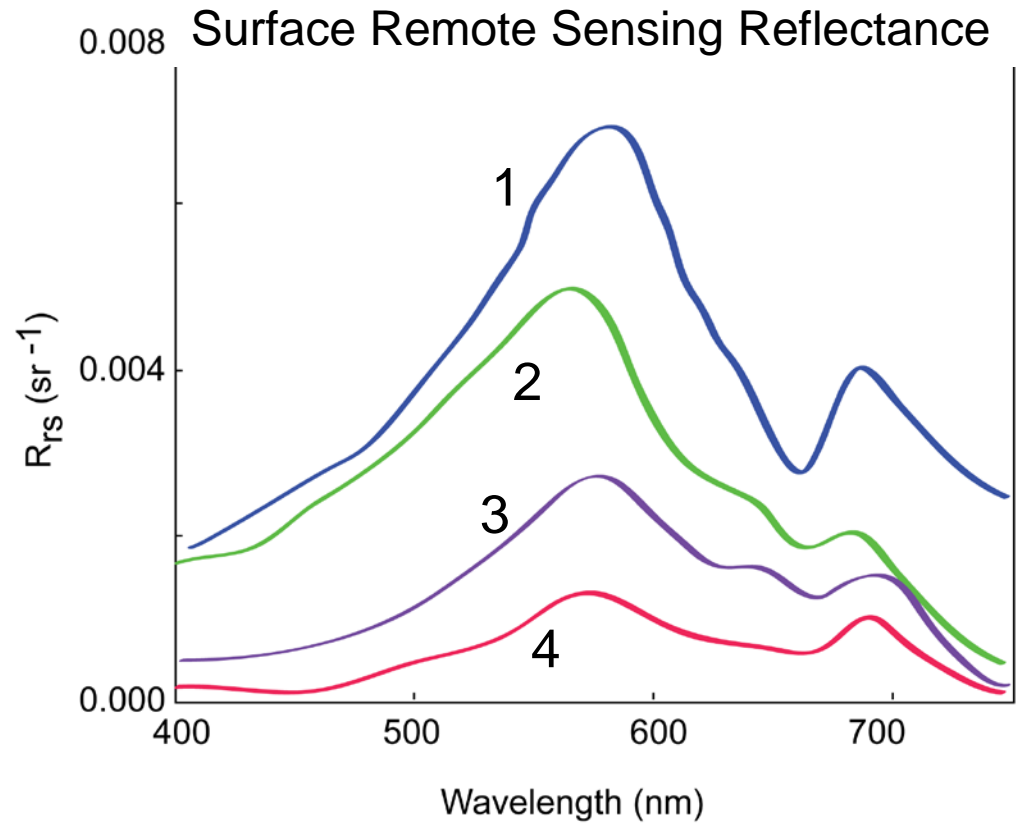
- The typical human eye has color-detecting receptors that sense light at:
 - 420-440 nm 'blue'
 - 534-555 nm 'green'
 - 564-580 nm 'red'
- Water with high chlorophyll content looks green because it reflects strongly in the green part of the spectrum



Chlorophyll-a From Remote Sensing Reflectance (R_{rs})

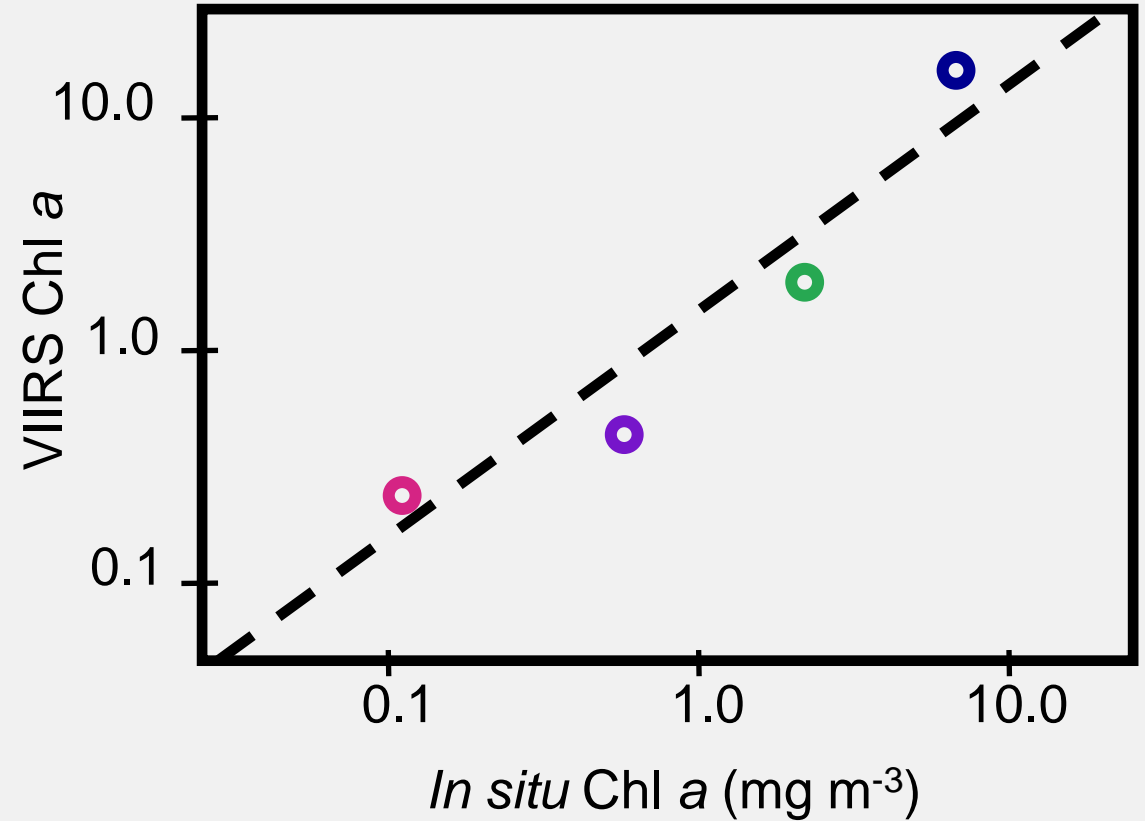
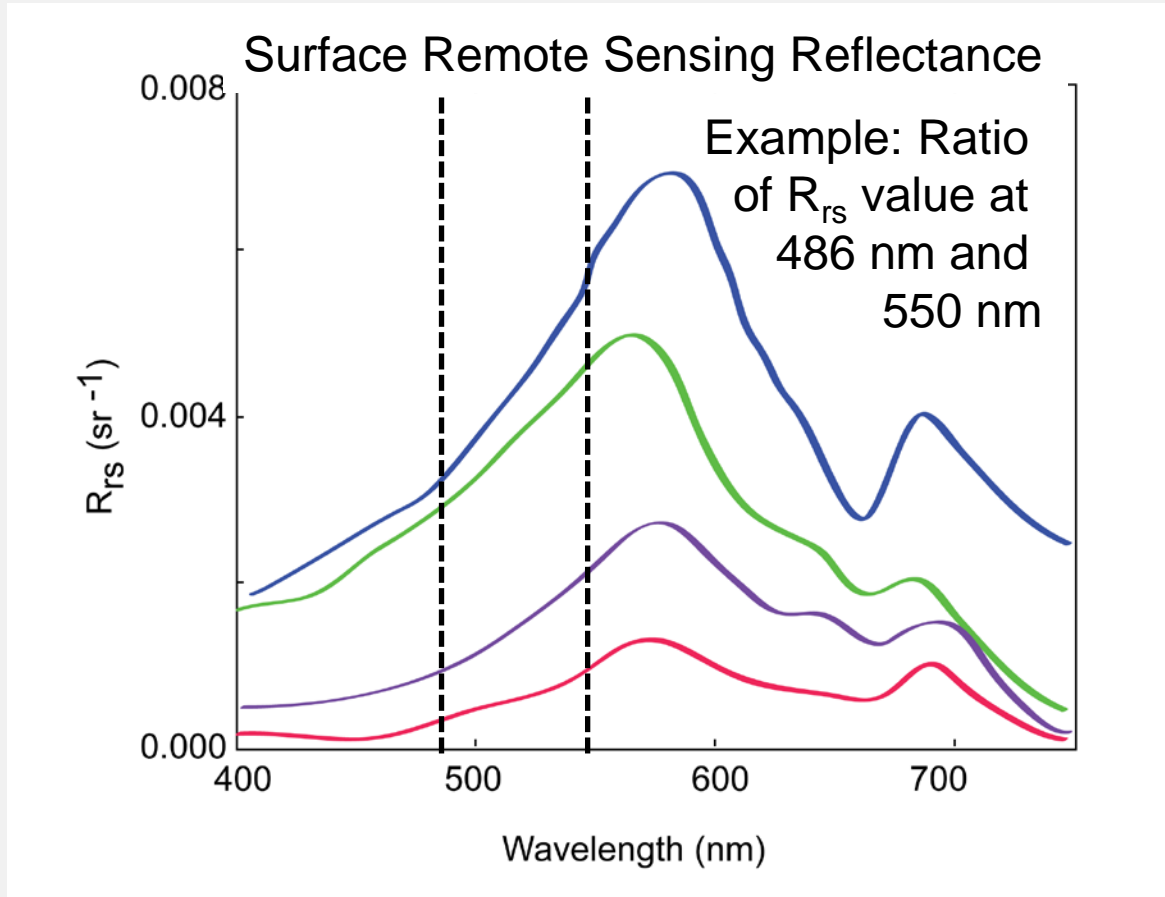


R_{rs} at Different Chlorophyll-a Concentrations



Chlorophyll-a Estimates

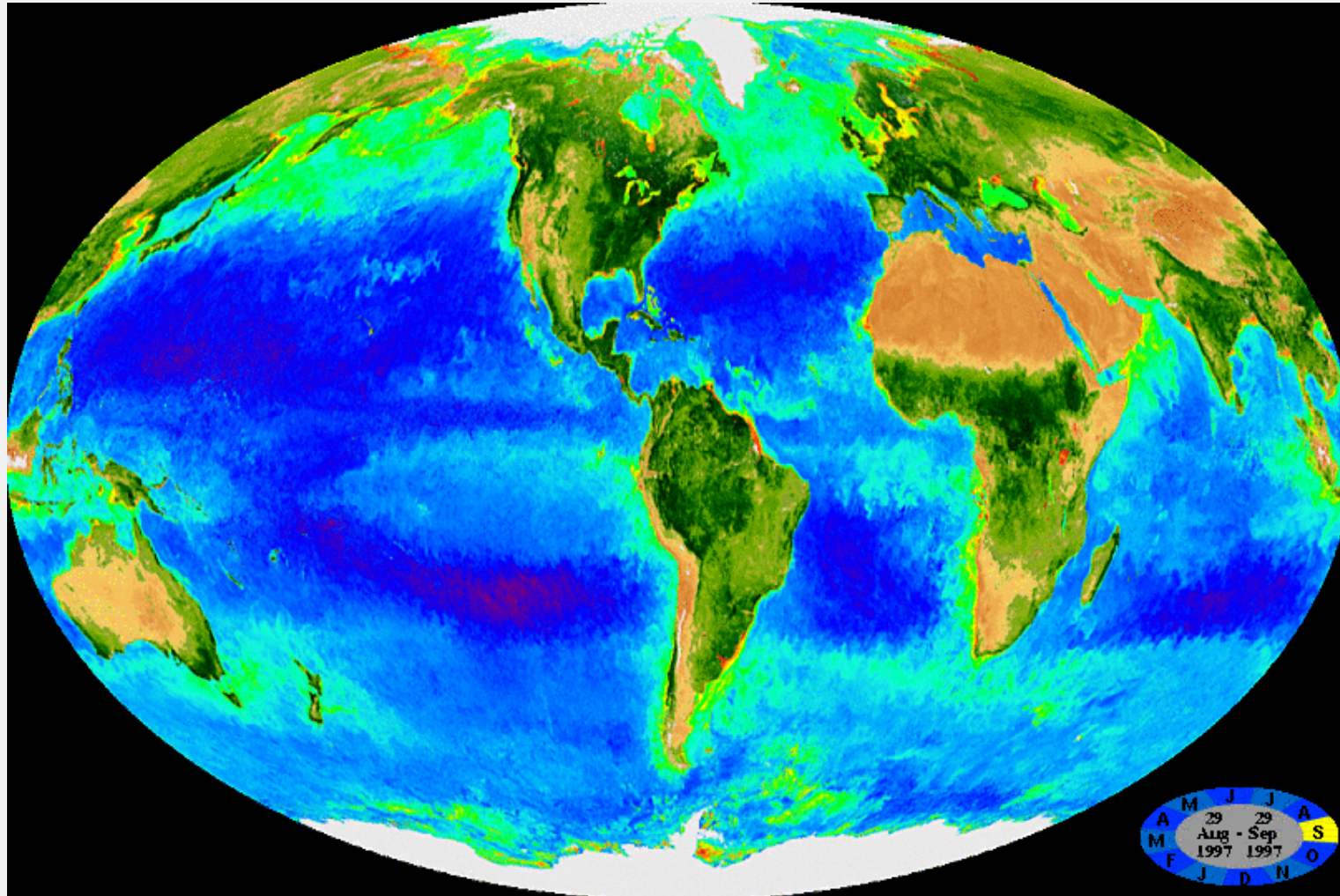
Estimations are a function of the ratios of R_{rs} values



Algorithm description: http://oceancolor.gsfc.nasa.gov/cms/atbd/chlor_a

Chlorophyll-a From Space

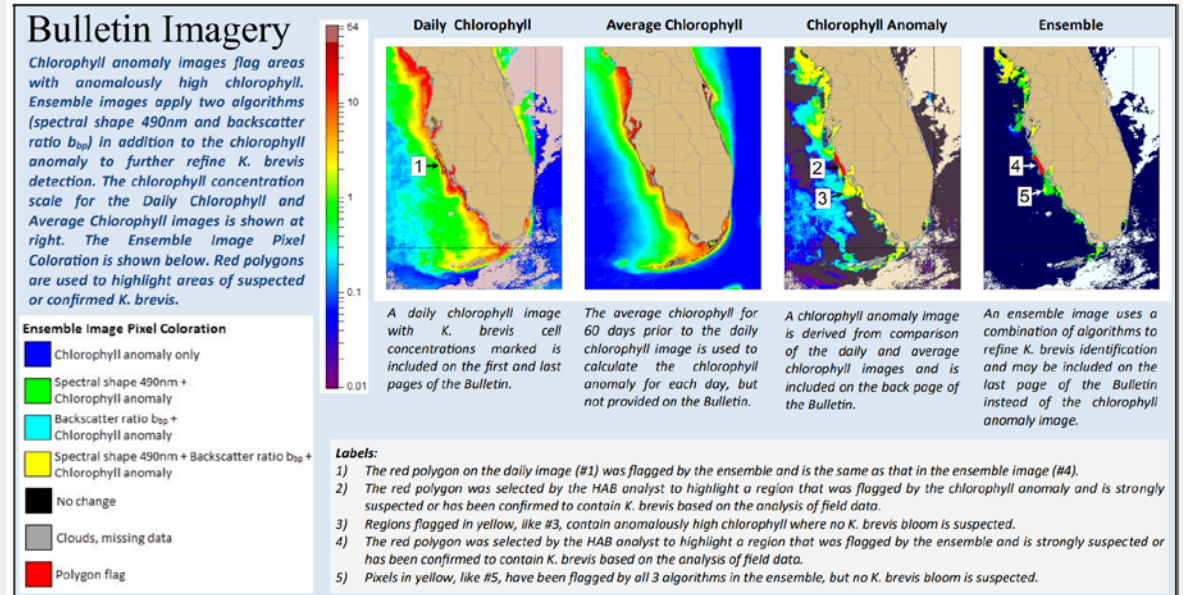
SeaWiFS Sensor - Animation



Chlorophyll-a Anomaly

Case Study – *Karenia brevis* on the West Florida Shelf

- Anomaly shows where the daily chlorophyll concentration differs from a mean computed over a 60-day period ending two weeks prior to the sample date
- Anomaly methods are not exclusive to this species and are an effective way to identify regions of rapid change in chlorophyll concentration
- *Karenia brevis* tends to be mono-specific



- An anomaly of 1 mg m^{-3} can indicate a *Karenia brevis* bloom in this region

Image Credit: https://tidesandcurrents.noaa.gov/hab/hab_publication/habfs_bulletin_guide.pdf

Chlorophyll-a Anomaly

Case Study – *Karenia brevis* on the West Florida Shelf

- *Karenia brevis* is a relatively large dinoflagellate resulting in low backscattering signal
- This signature backscattering signal gives mono-specific blooms a characteristic remote sensing reflectance spectrum
- This signature spectrum is used to differentiate this organism to monitor for HAB events

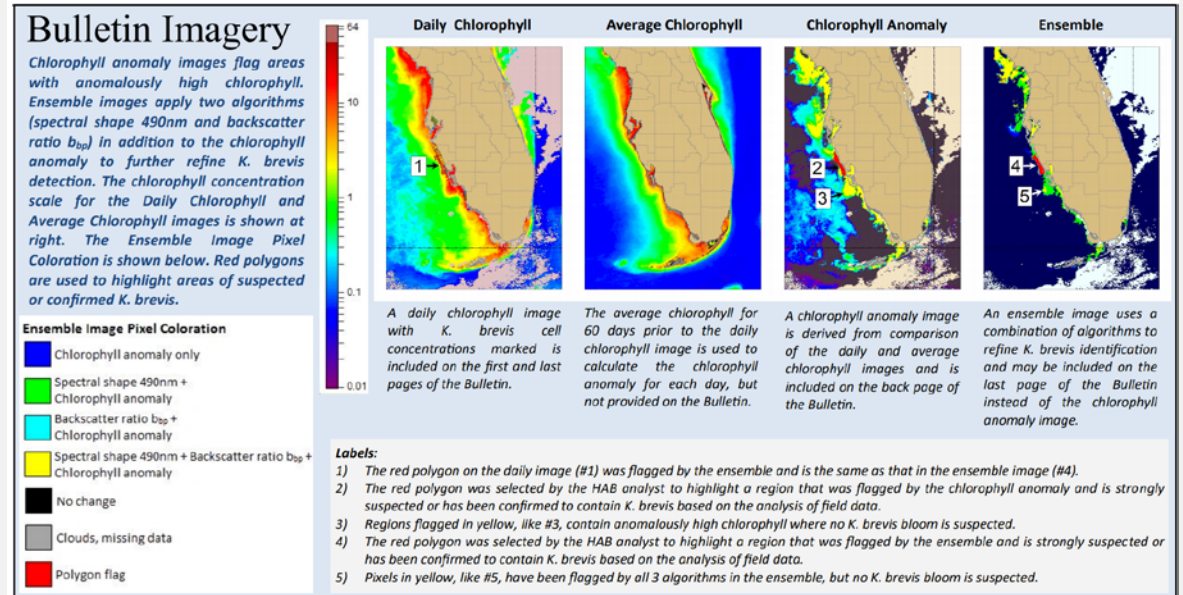
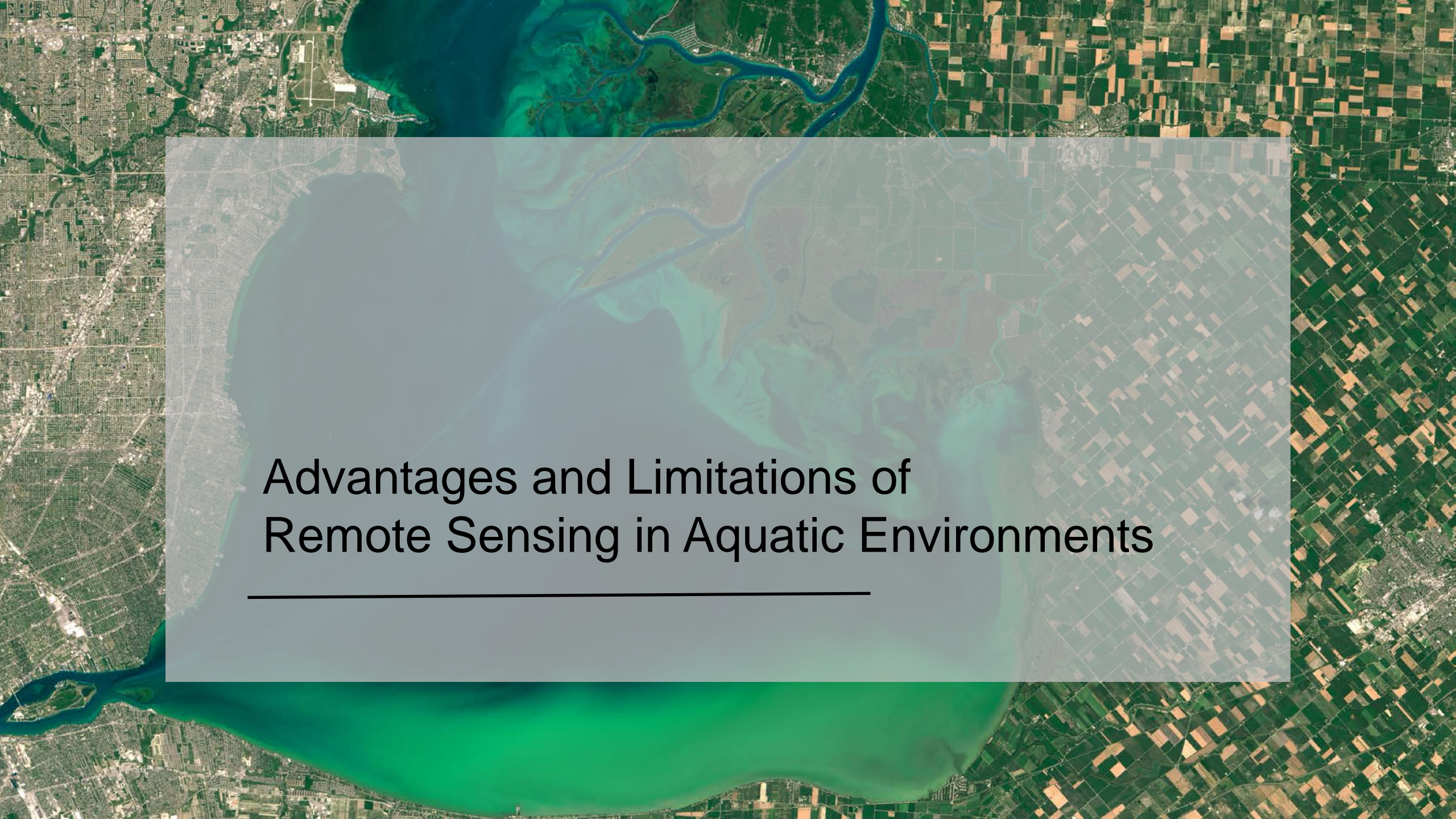


Image Credit: https://tidesandcurrents.noaa.gov/hab/hab_publication/habfs_bulletin_guide.pdf

An aerial photograph showing a wide river flowing through a landscape of agricultural fields and some urban areas. The river is a deep blue-green color. The surrounding land is a patchwork of green and brown rectangular plots. A semi-transparent grey rectangular box is overlaid on the center of the image, containing the title text.

Advantages and Limitations of Remote Sensing in Aquatic Environments

Limitations of Remote Sensing for HABs

- Indirect measure - not actually measuring toxins
- Cannot infer to species level
- Coarse spatial resolution over wide swaths - may not be appropriate for all locations
- All the same limitations of aquatic remote sensing:
 - atmospheric correction
 - glint
 - sun angle
 - clouds

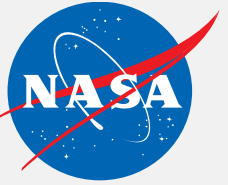
Advantages and Merits of Remote Sensing for HABs

- Remote sensing observations can inform water resource managers where to apply their sampling effort to verify the presence of a HAB (i.e., adaptive sampling)
- Sample measurements at spatial and temporal scale made possible with satellite imagery is not possible with in situ observations
- Remote sensing observations can be used as a data layer to integrate into models or forecasting systems

Summary

- Overview of Marine and Freshwater HABs
- HABs, Ecosystems, and Human Health
- In Situ Monitoring Methods of HABs
- How Remote Sensing is Used for HAB Detection
- Advantages and Limitations of Remote Sensing in Aquatic Environments





ARSET

Applied Remote Sensing Training

<http://arset.gsfc.nasa.gov>

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Thank you!

Next Week:

Platforms and Sensors, Data Access, and Data Processing