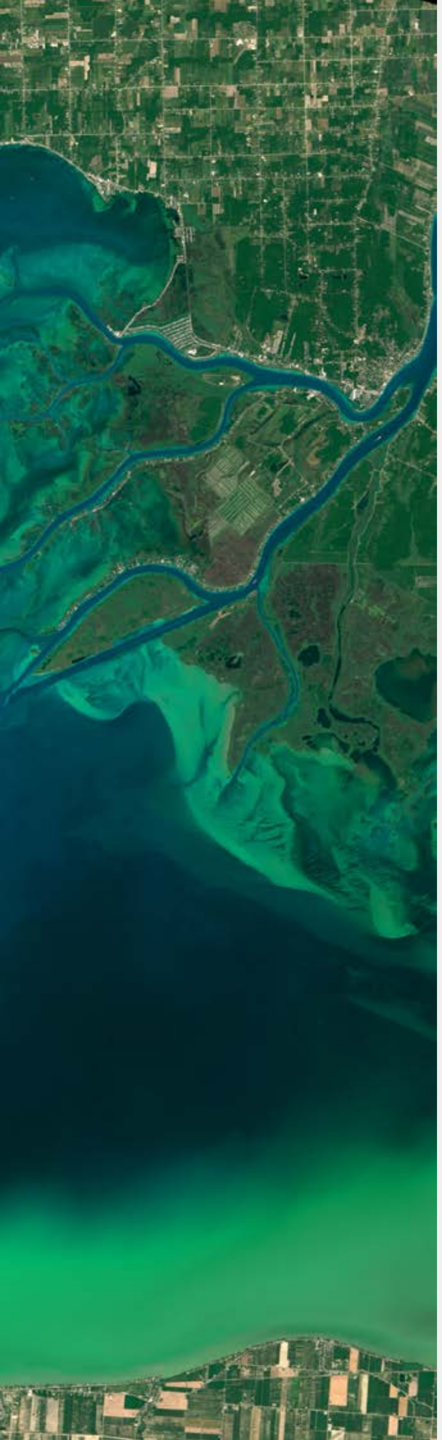


National Aeronautics and
Space Administration

ARSET
Applied Remote Sensing Training
http://arset.gsfc.nasa.gov
@NASAARSET

Introduction to Remote Sensing of Harmful Algal Blooms

Week 1, September 5, 2017

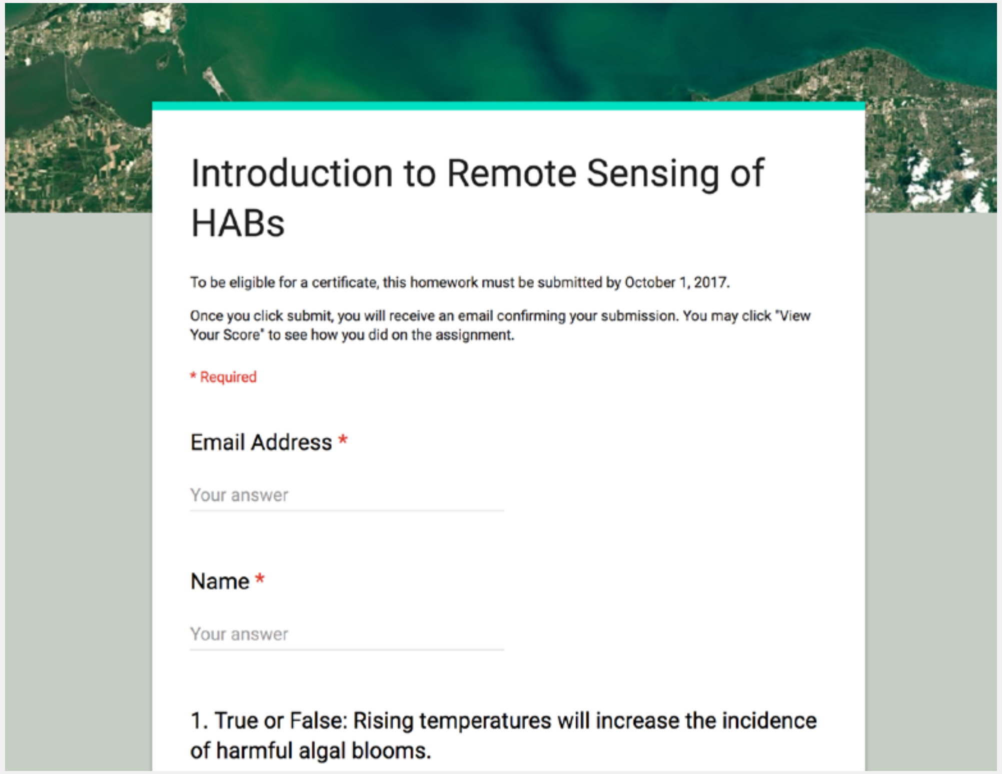
Trainers:
Sherry Palacios
Amita Mehta

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

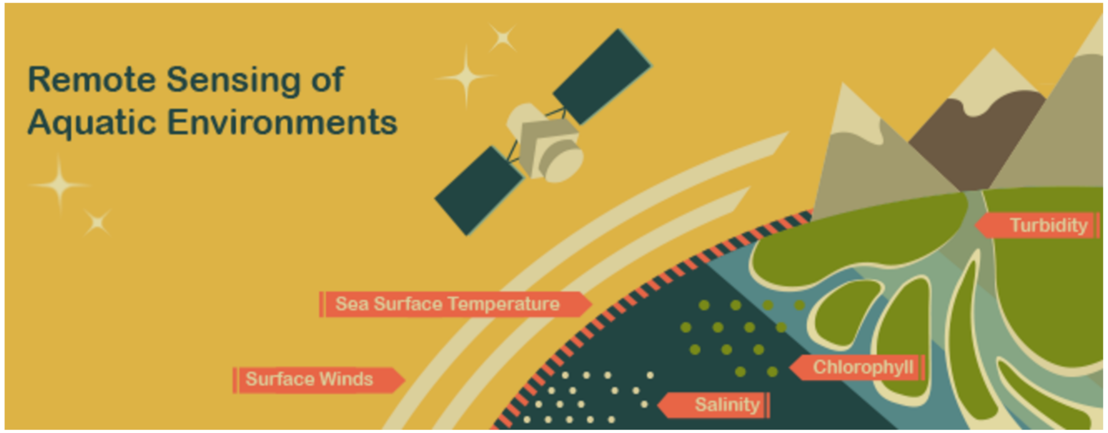
- Homework
  - **Answers must be submitted via Google Form**
- Certificate of Completion:
  - Attend all webinars
  - Complete homework assignments by the deadline (access from ARSET website)
    - **HW Deadlines: October 1st and 15th**
  - You will receive certificates approx. two months after the completion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



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



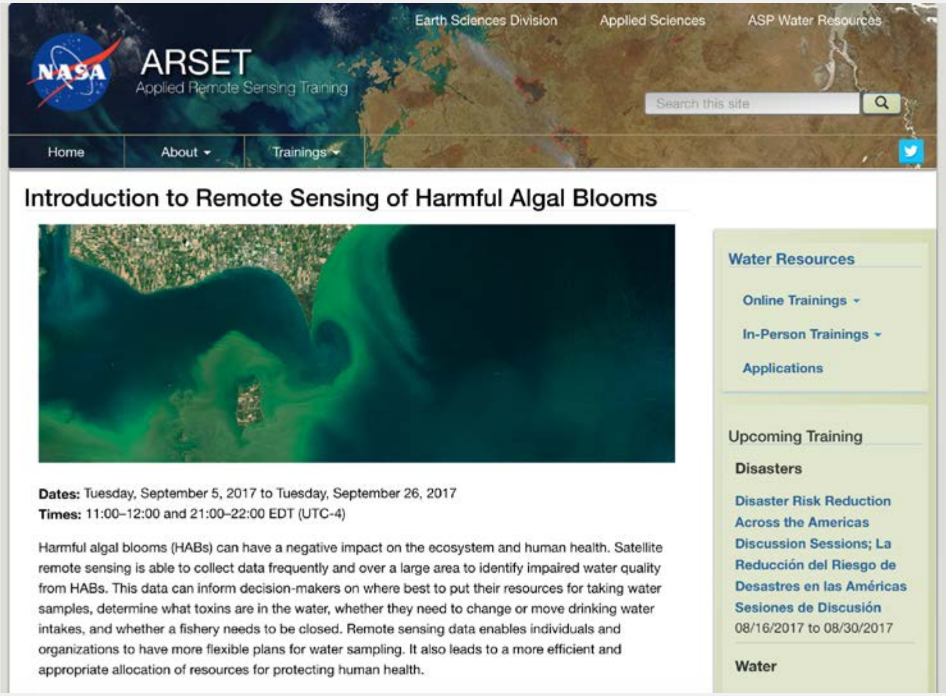
Overview of relevant satellites and sensors, and data and tools for aquatic environmental management. **View the recording »**

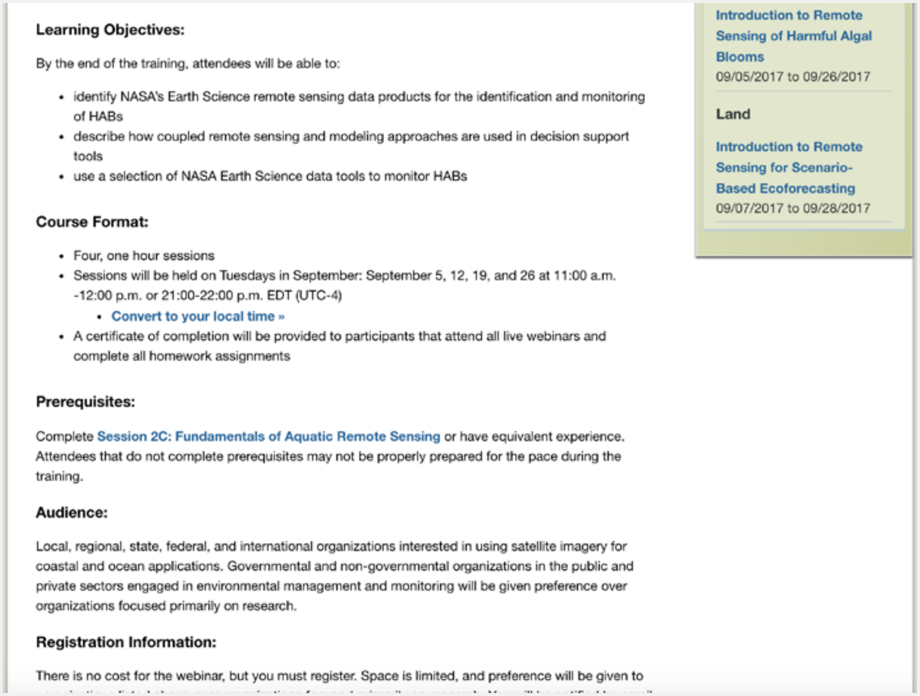
- **Presentation Slides**
- **Presenter Script**

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





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

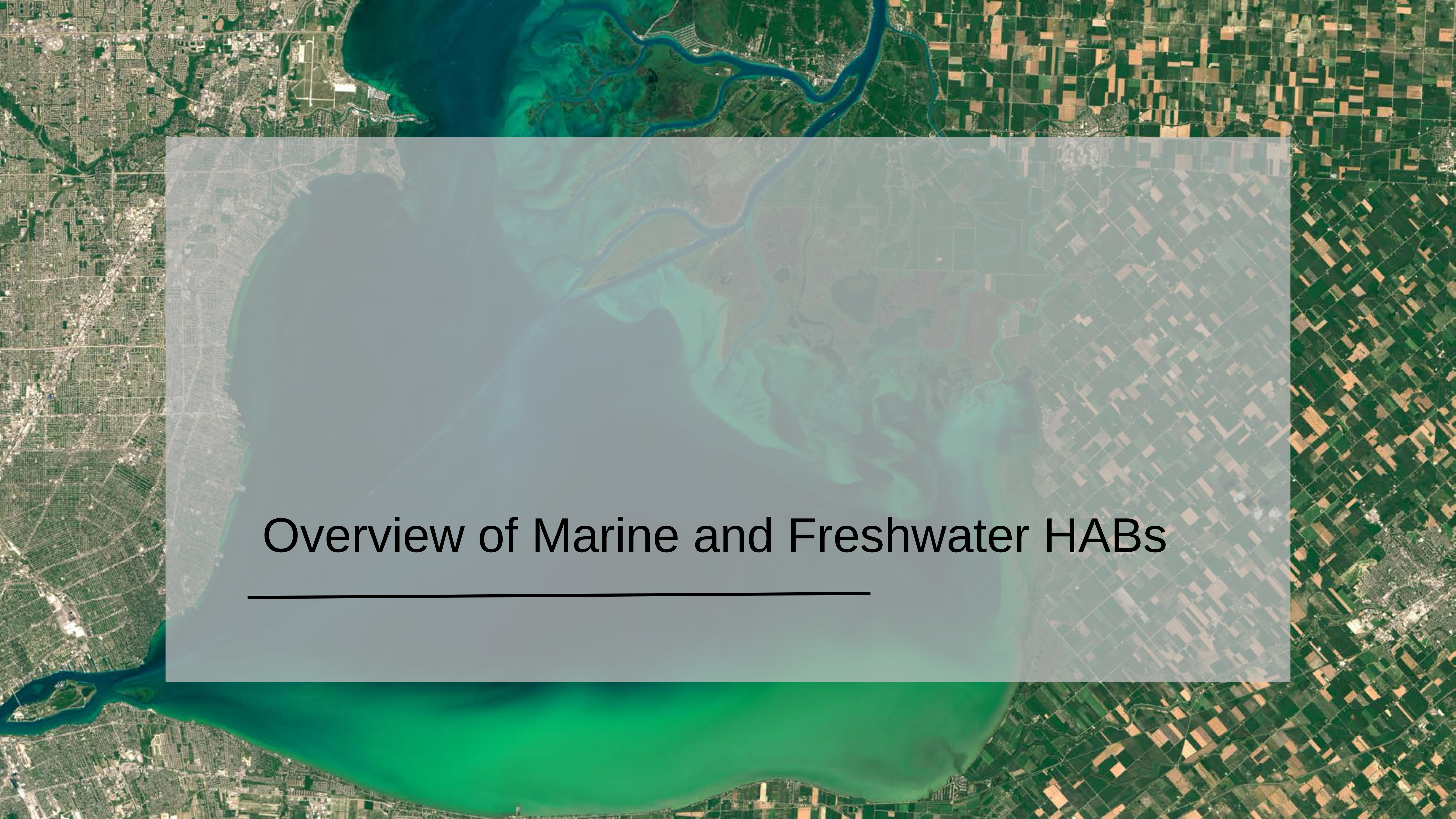
Level 2

- 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

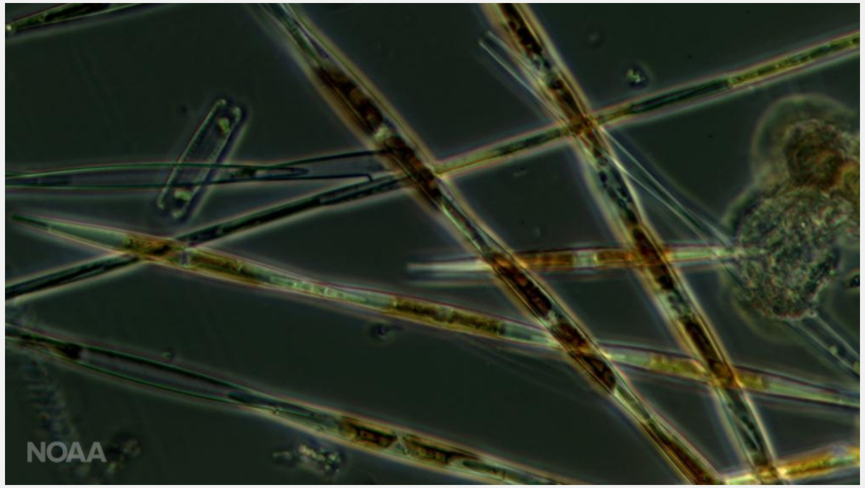
- For information on upcoming courses and program updates, please sign up for the listserv
- https://lists.nasa.gov/mailman/listinfo/arset

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.”





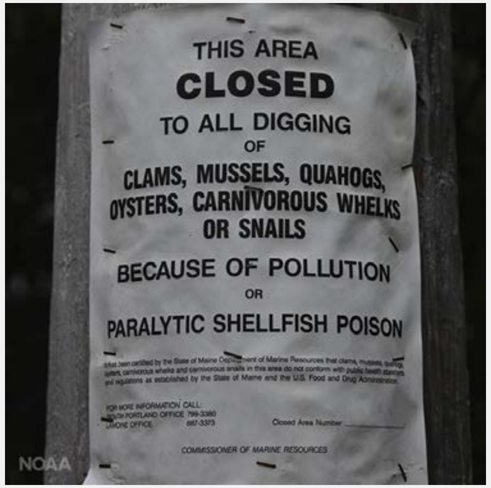


Image credit: http://www.noaa.gov/what-is-harmful-algal-bloom

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

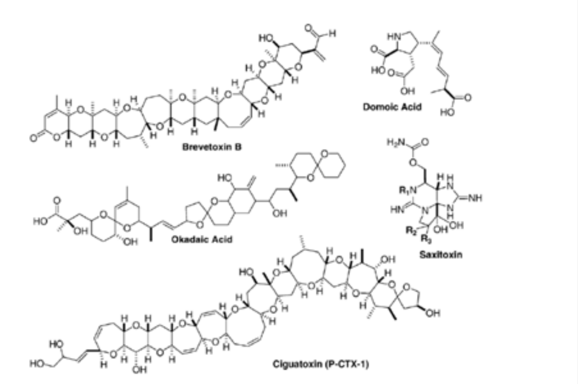


Photo Credits (clockwise from top left) Karina Cardozo (Cardozo et al., 2007); NASA Earth Observatory; NOAA Northwest Fisheries Science Center; Linda Preskitt

HAB Poisonings and Syndromes

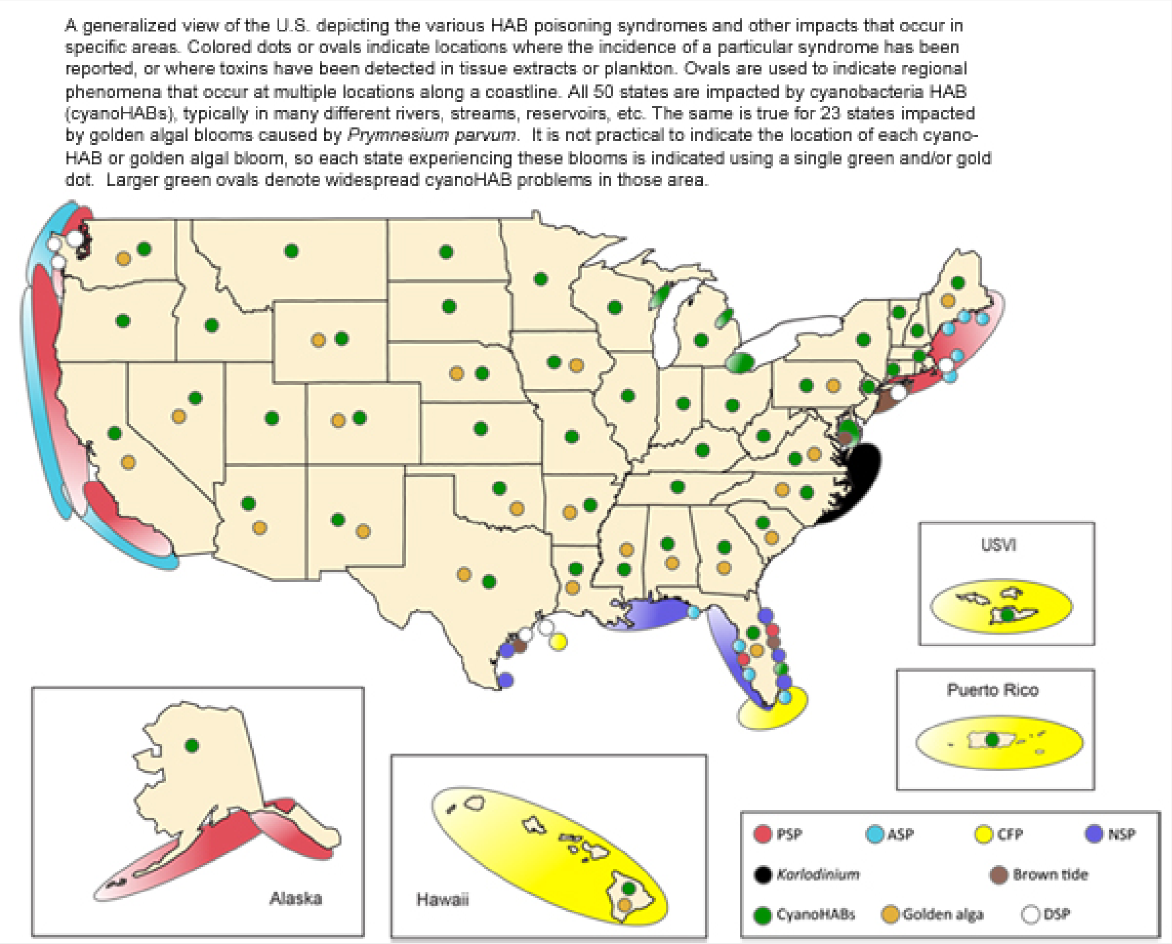
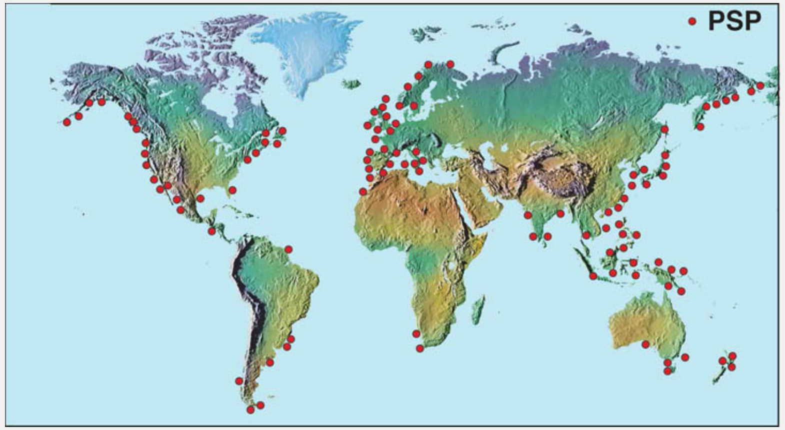


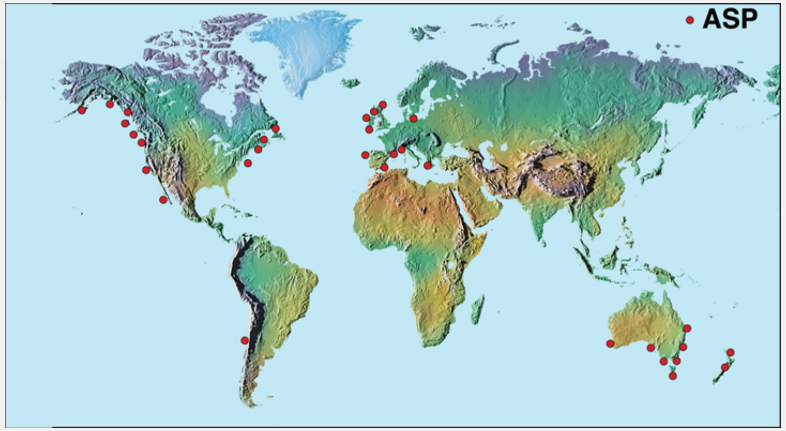
Image Credit: WHOI

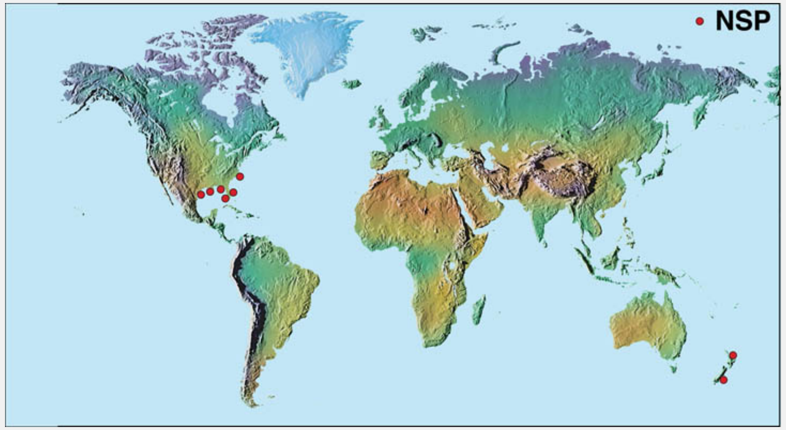
- Paralytic Shellfish Poisoning (PSP)
- Amnesic Shellfish Poisoning (ASP)
- Neurotoxic Shellfish Poisoning (NSP)
- Ciguatera Fish Poisoning (CFP)
- Brown Tide (BT)
- Cyanobacterial HABs (cyanoHAB)
- Diarrheic Shellfish Poisoning (DSP)

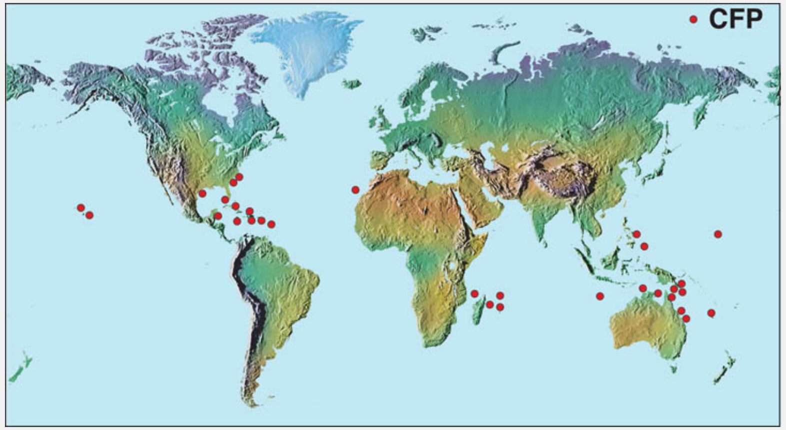
Global Distribution of HAB Toxins

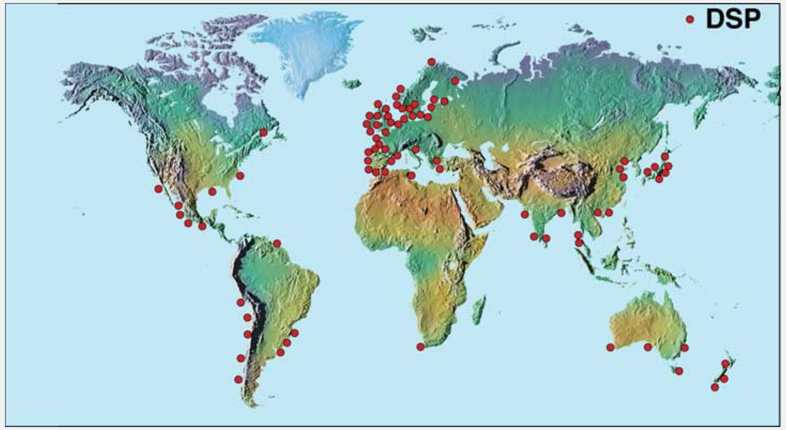
Recorded as of 2016









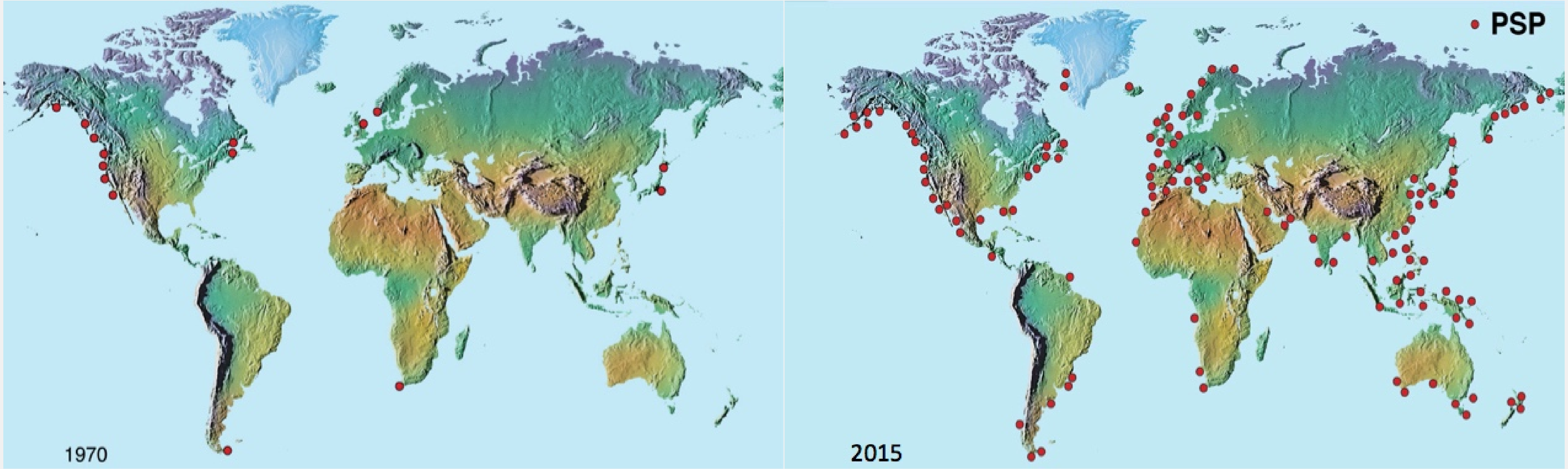


PSP - Paralytic Shellfish Poisoning
ASP - Amnesic Shellfish Poisoning
NSP - Neurotoxic Shellfish Poisoning
CFP - Ciguatera Fish Poisoning
DSP - Diarrheic Shellfish Poisoning

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

Why the Increasing Trend of HAB Events?

Paralytic Shellfish Poisoning Case Study

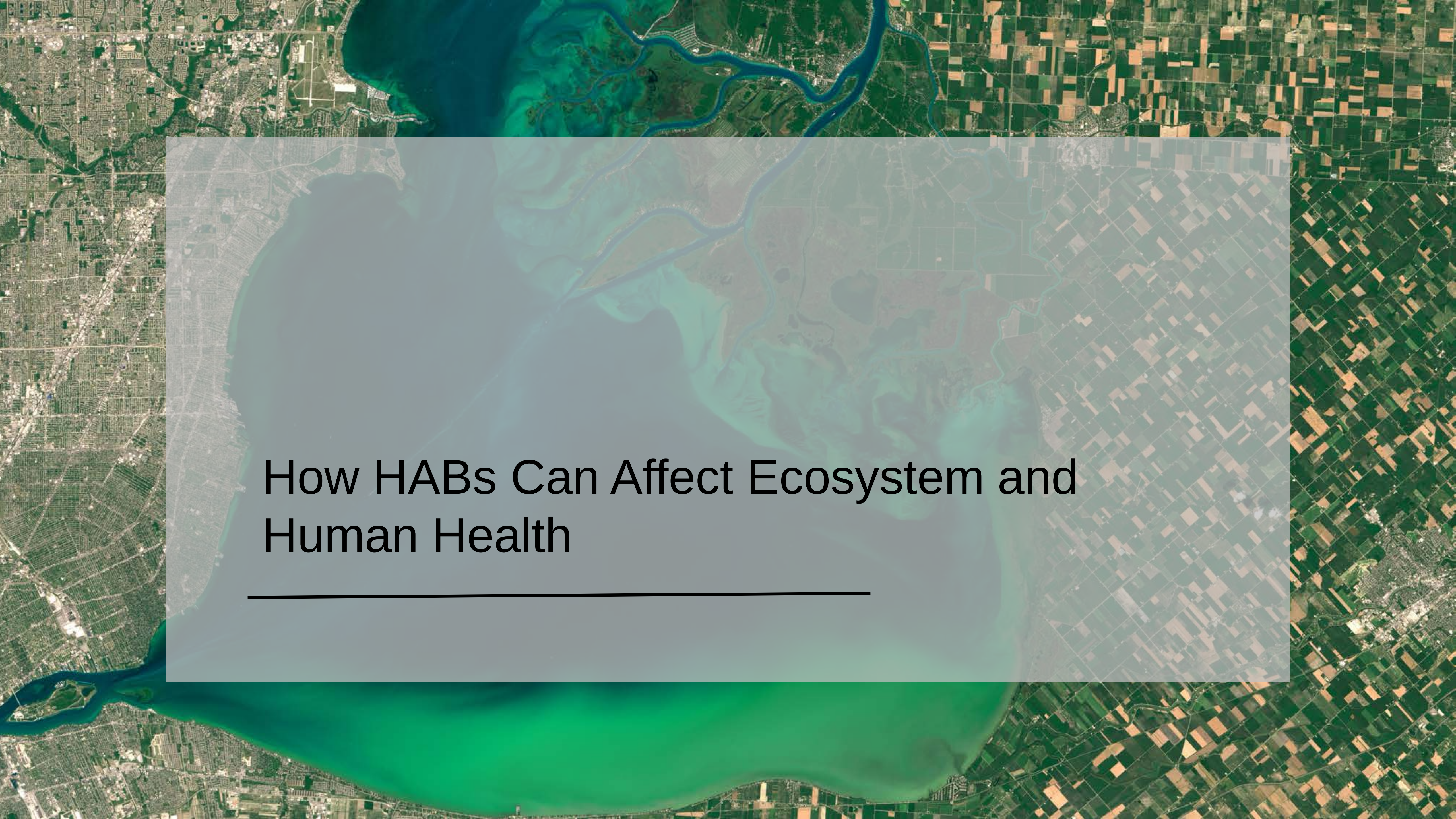


Credit: WHOI http://www.whoi.edu/redtide/regions/us/recent-trends

What Causes HABs?

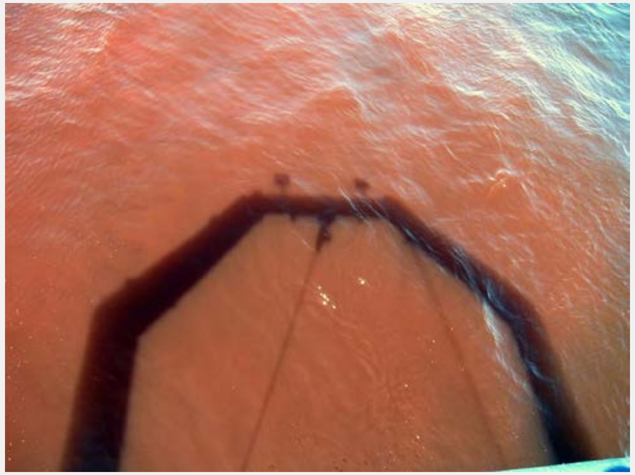
- Nutrient loading “eutrophication”
- Pollution
- Warm water
- Food web changes
- Introduced species
- Changes in water flow
  – e.g., after major events like hurricanes, drought, or floods
- Other, yet unknown, factors

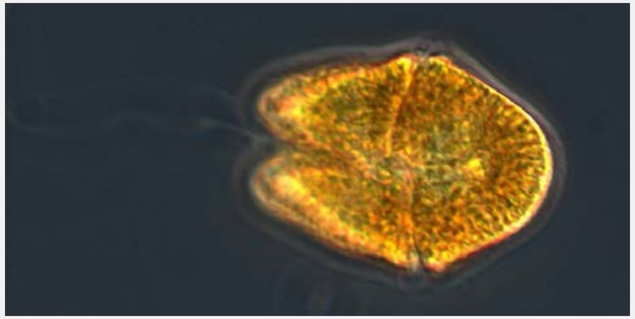
How HABs Can Affect Ecosystem and Human Health



Oxygen Depletion

Red tide – e.g., *Akashiwo sanguinea*





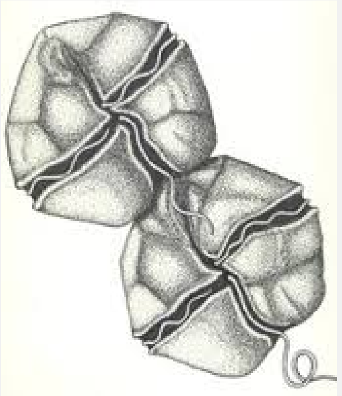

- Algae can proliferate to a high density so that photosynthesis does not offset biological oxygen demand
- Decay of algal blooms consumes oxygen in the environment resulting in ‘low oxygen’ or hypoxia (2 – 3 ppm)
- Hypoxia can cause die-offs of fish, corals, shellfish, and submerged aquatic vegetation

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



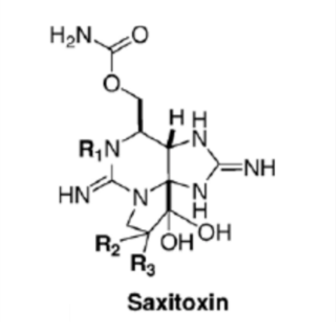


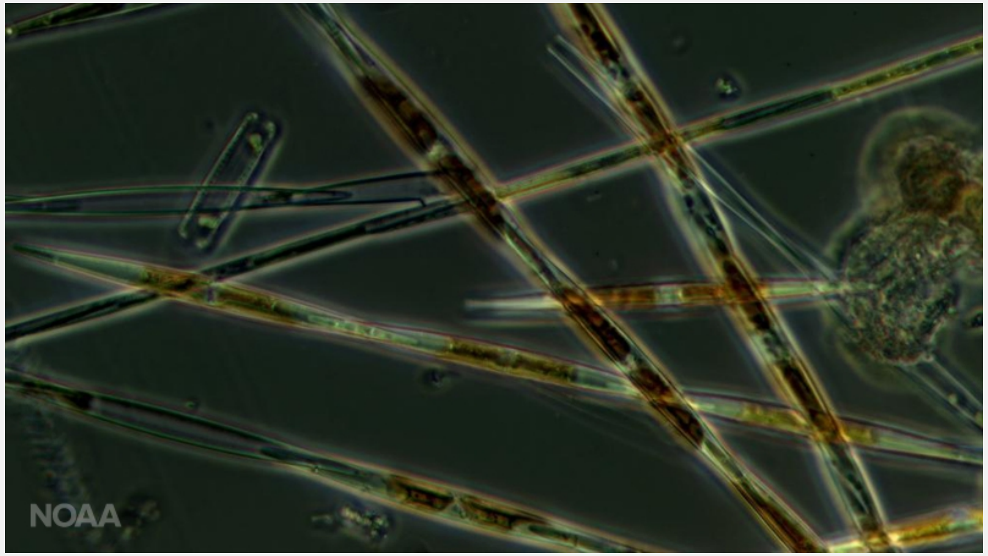
Image Credit: Left: Jan Rines (U. of Rhode Island) http://oceandatacenter.ucsc.edu; Right: Karina Cardozo (Cardozo et al., 2007)

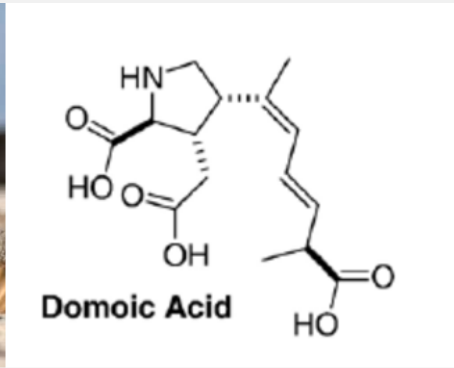
Credit: WHOI https://www.whoi.edu/redtide/human-health/paralytic-shellfish-poisoning

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





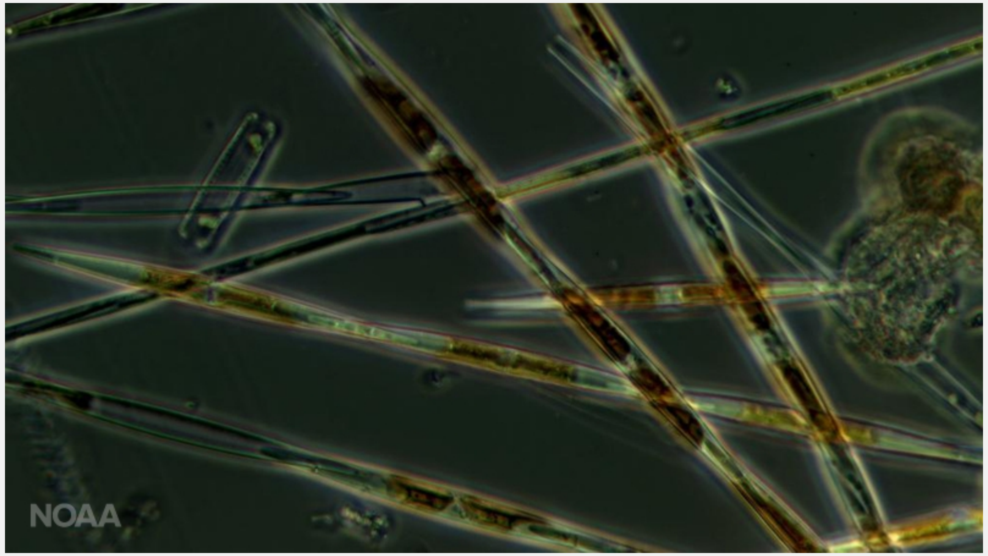
Credit: WHOI https://www.whoi.edu/redtide/human-health/amnesic-shellfish-poisoning

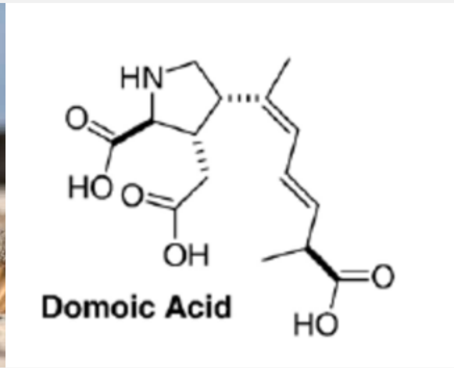
Image Credits: NOAA, Karina Cardozo (Cardozo et al., 2007) (DA molecule)

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 μg/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

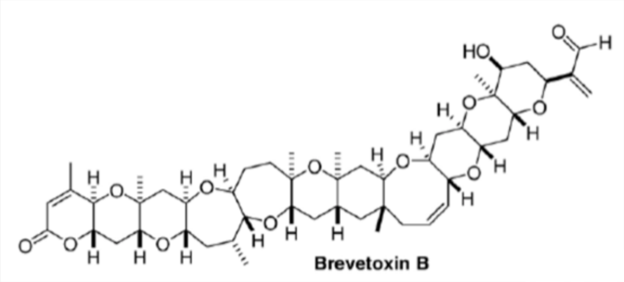
Coccolithophore Bloom – e.g., *Emiliania huxleyi*

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



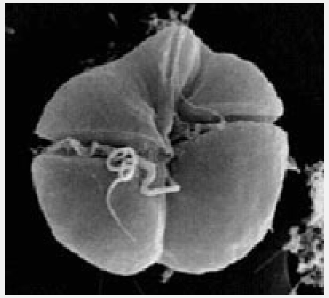


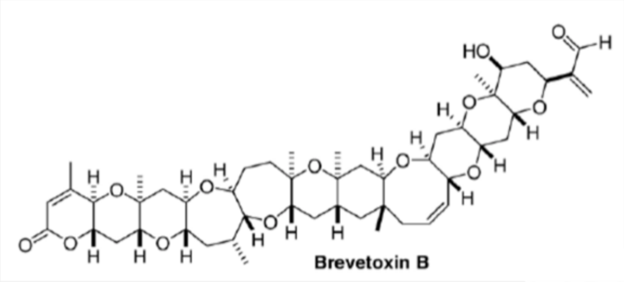
Photo Credit (Clockwise from Top): Karina Cardozo (Cardozo et al., 2007); John Dutton; P. Schmidt, Charlotte Sun Times

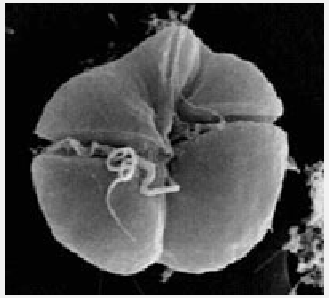
Credit: WHOI https://www.whoi.edu/redtide/human-health/neurotoxic-shellfish-poisoning

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

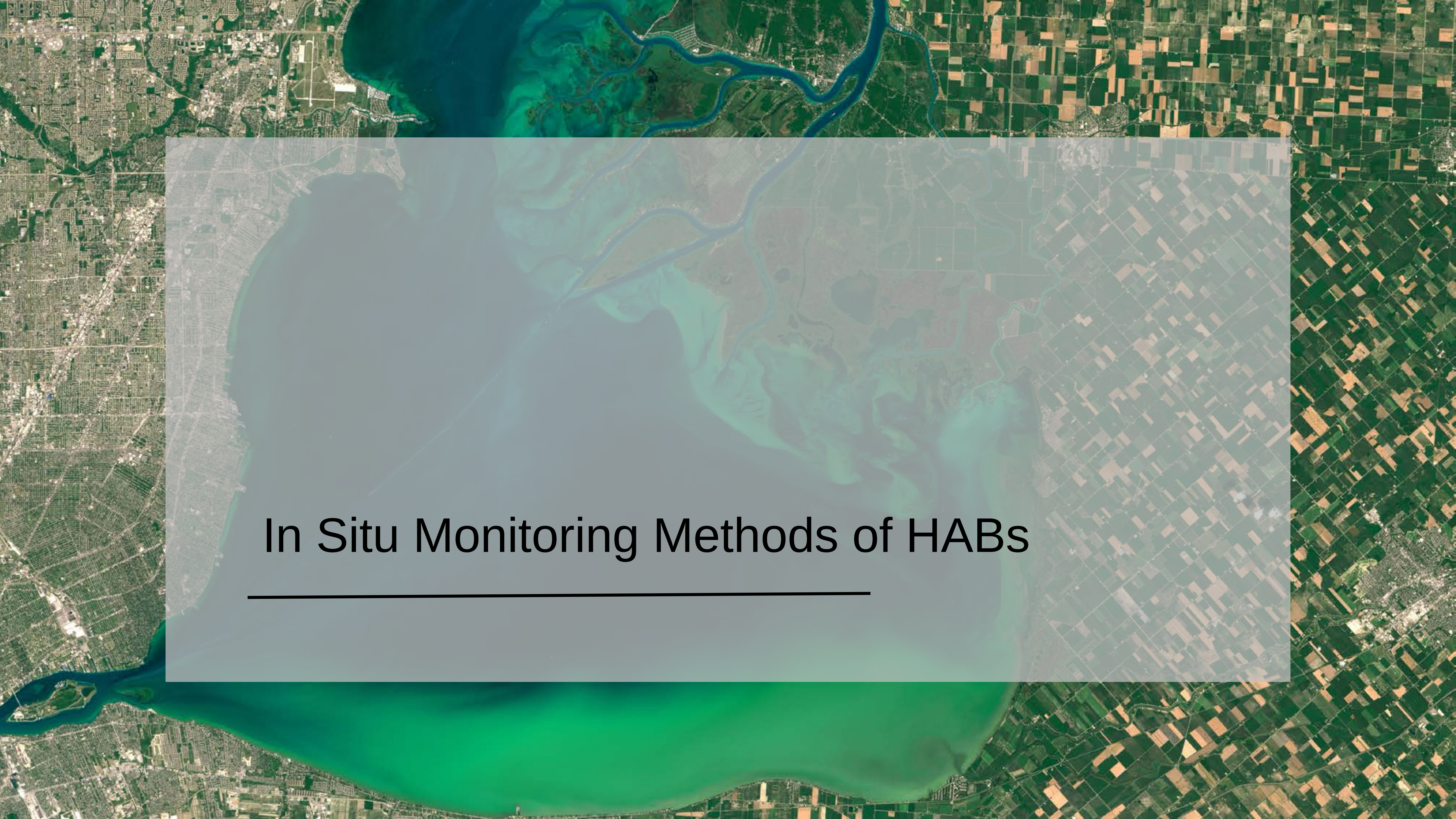
CyanoHAB – e.g., *Microcystis aeruginosa*

- 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

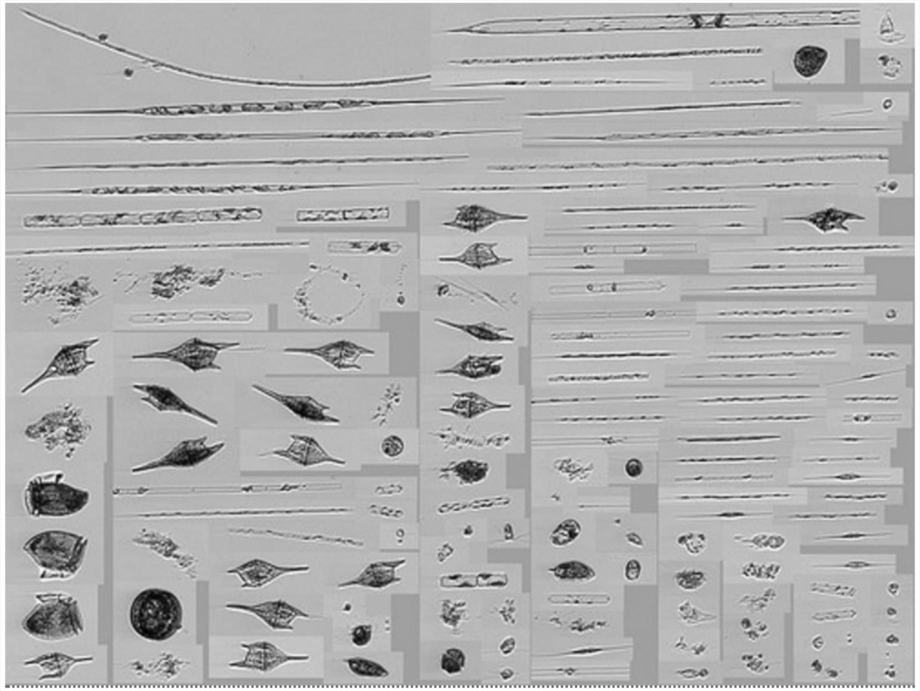
Bulletin Credit: NOAA

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

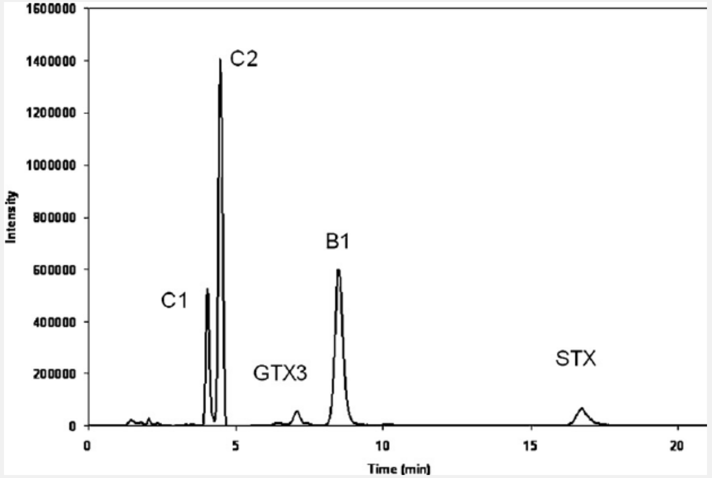
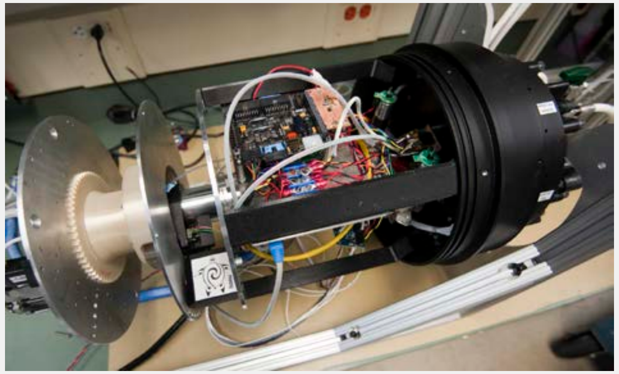
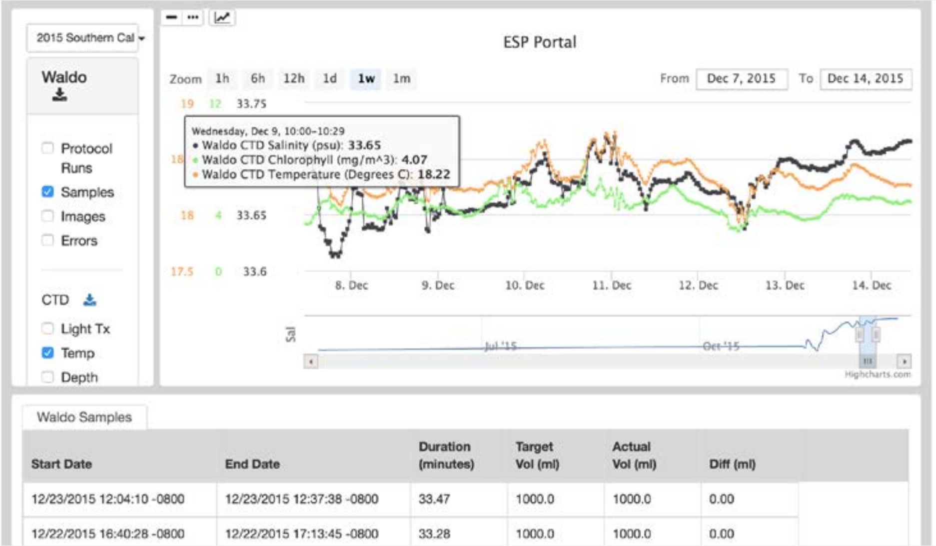


Image Credits: (L-R) Kylla Benes; Raphael Kudela; Borkman et al. (2012)

Ocean Observing Systems

Case Study – Environmental Sample Processor (ESP)

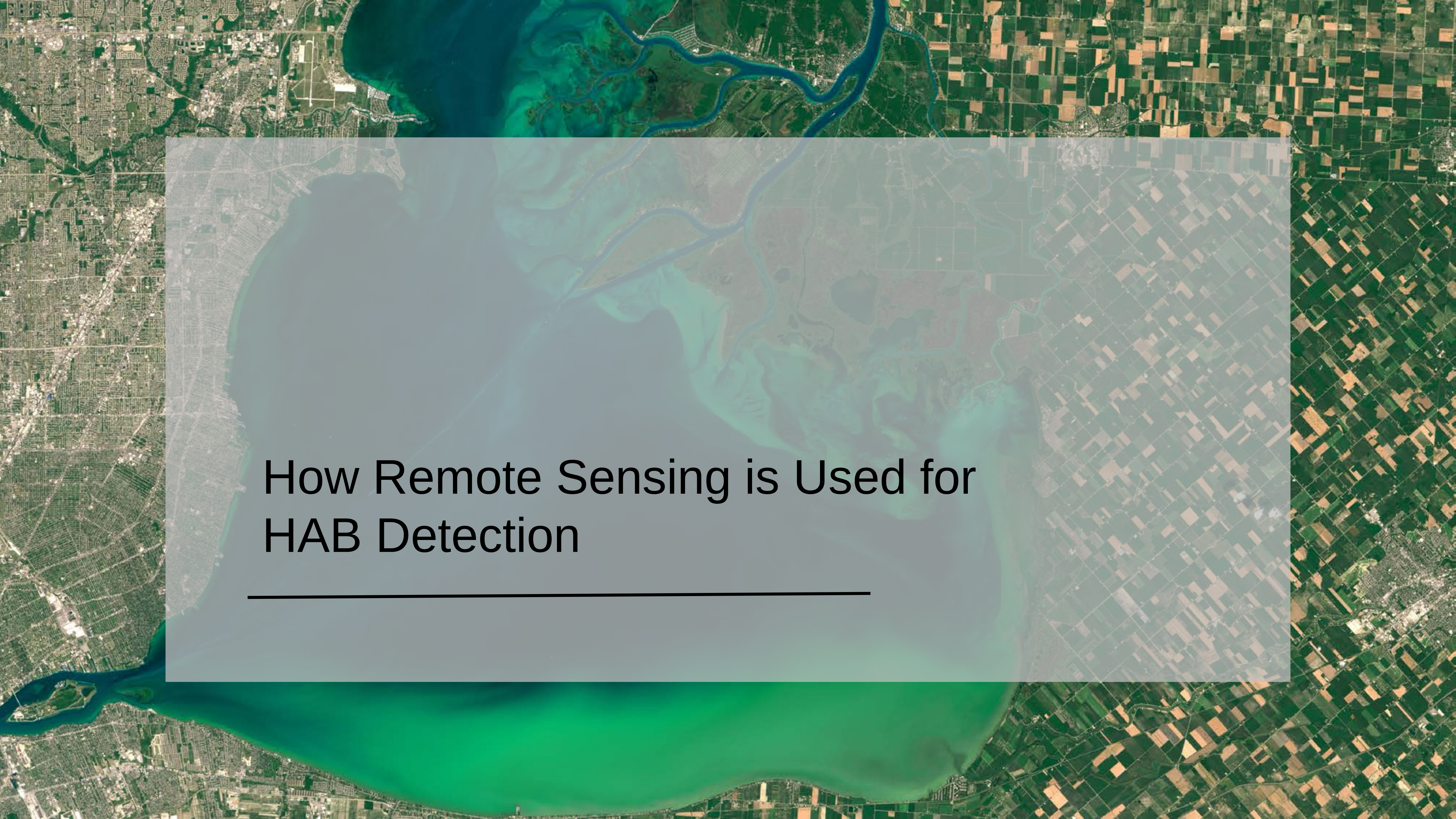




Credit: MBARI

- 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

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

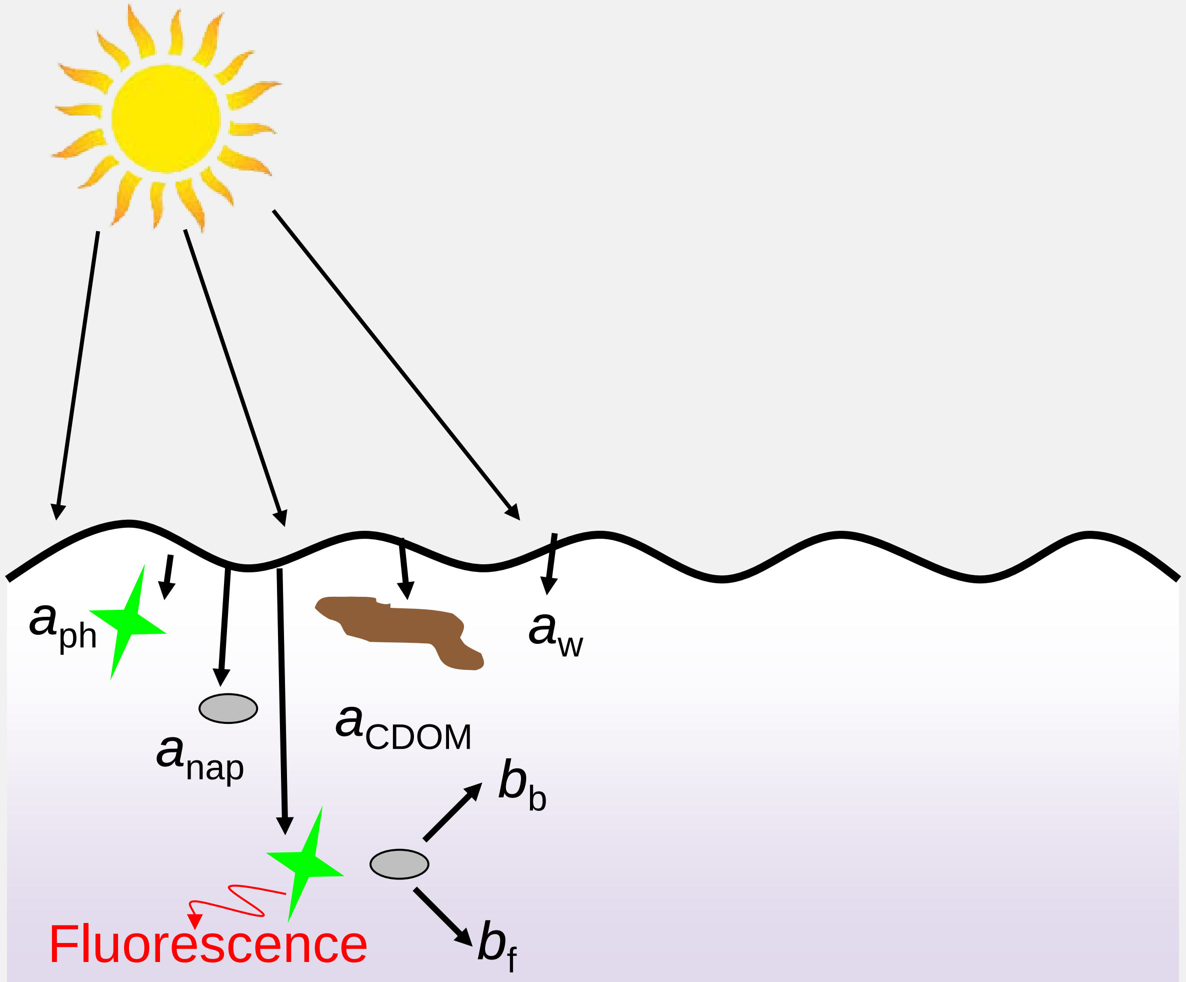
- Imagery, with associated algorithms and ecosystem models, informs adaptive sampling approaches used by resource managers

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

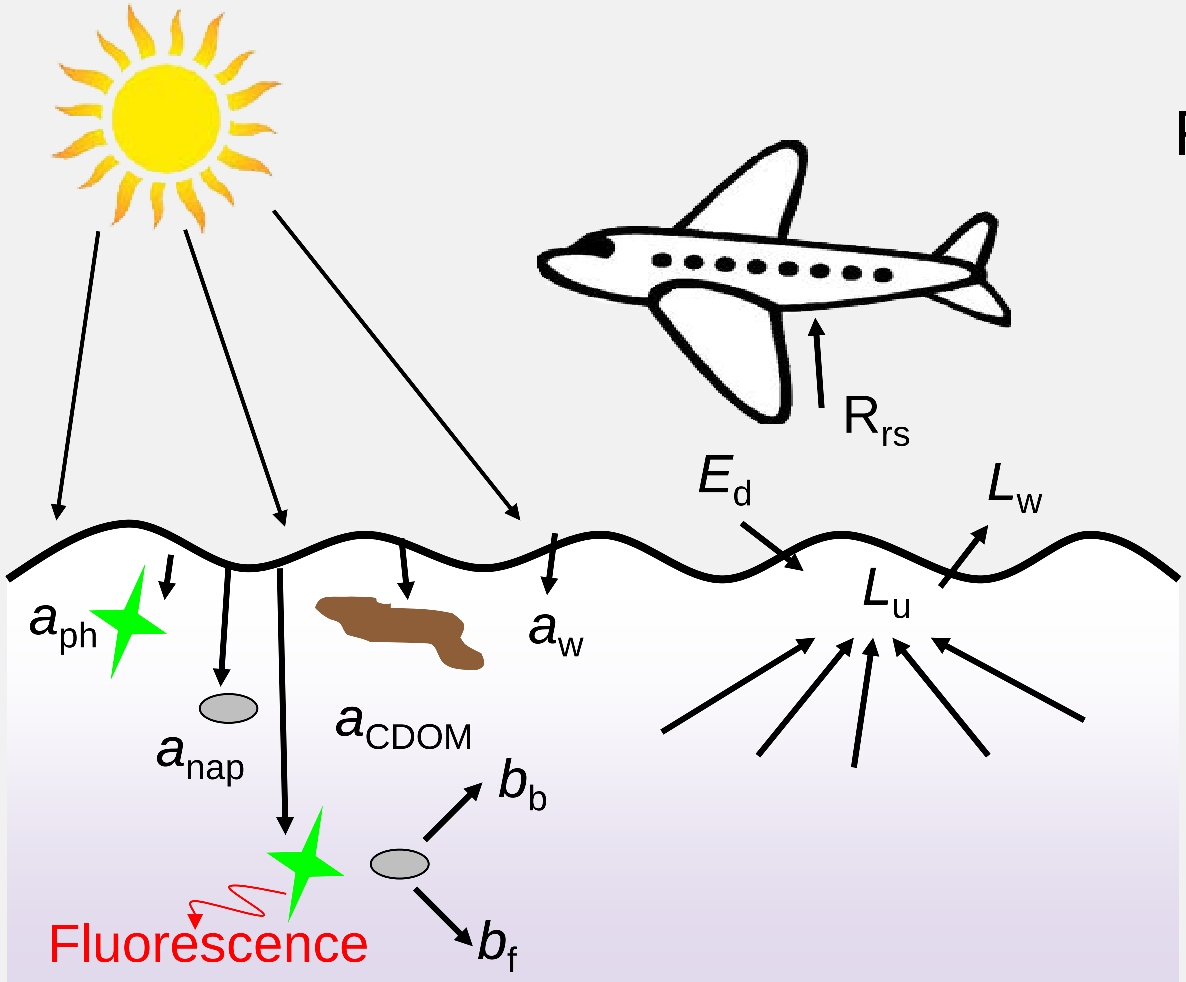
a = absorption by…

- 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

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

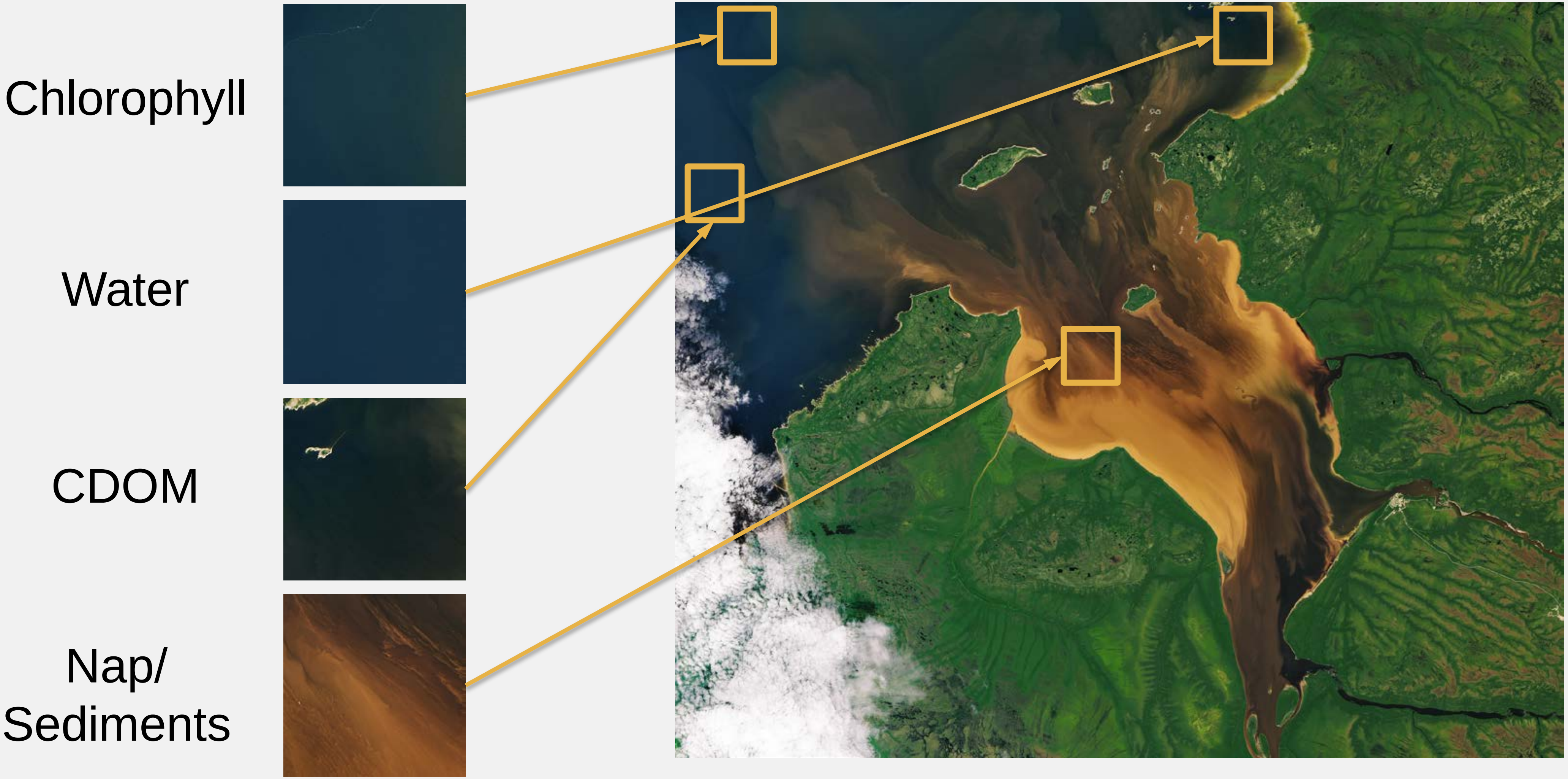
Light absorption (a) by photoplankton (ph), non-algal particles (nap), water (w), and colored dissolved organic matter (CDOM)

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

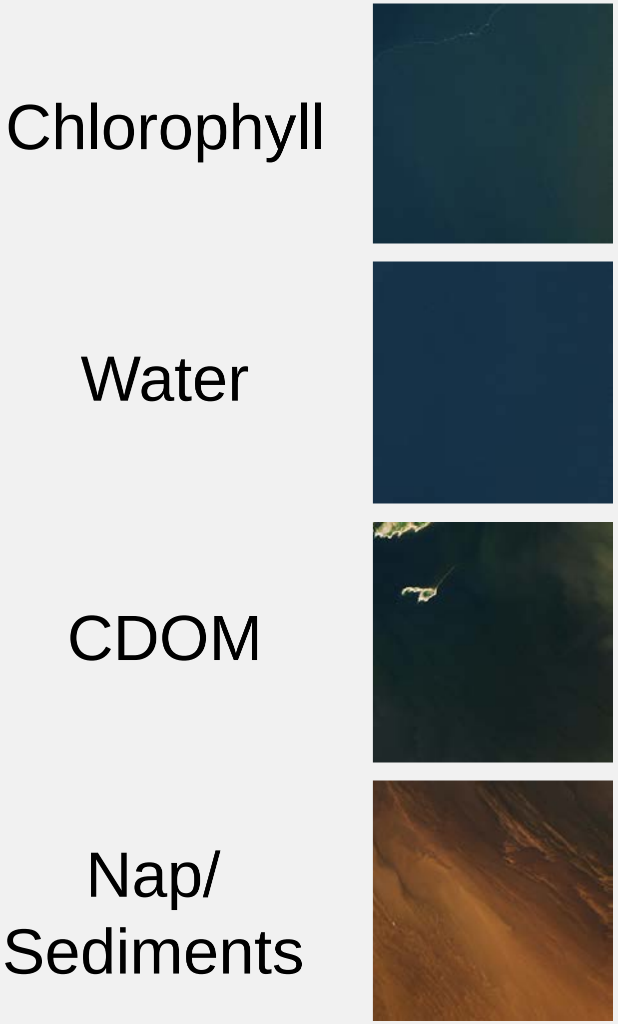
Light scattering (b) by particles in forward (b_f) and backward (b_b) direction

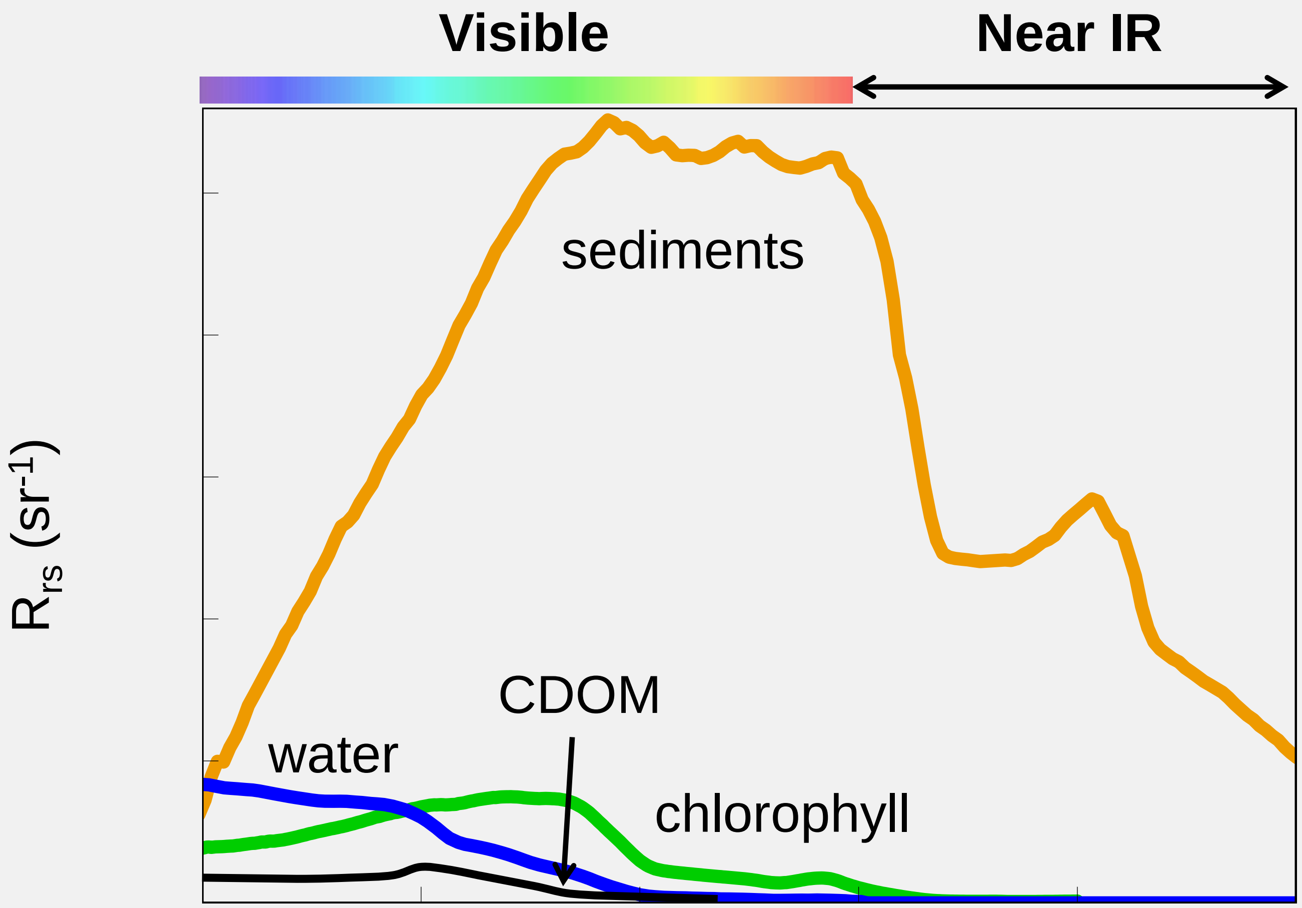
$$b = b_f + b_b$$

Inherent Optical Properties (IOPs) and the ‘Color’ of Water



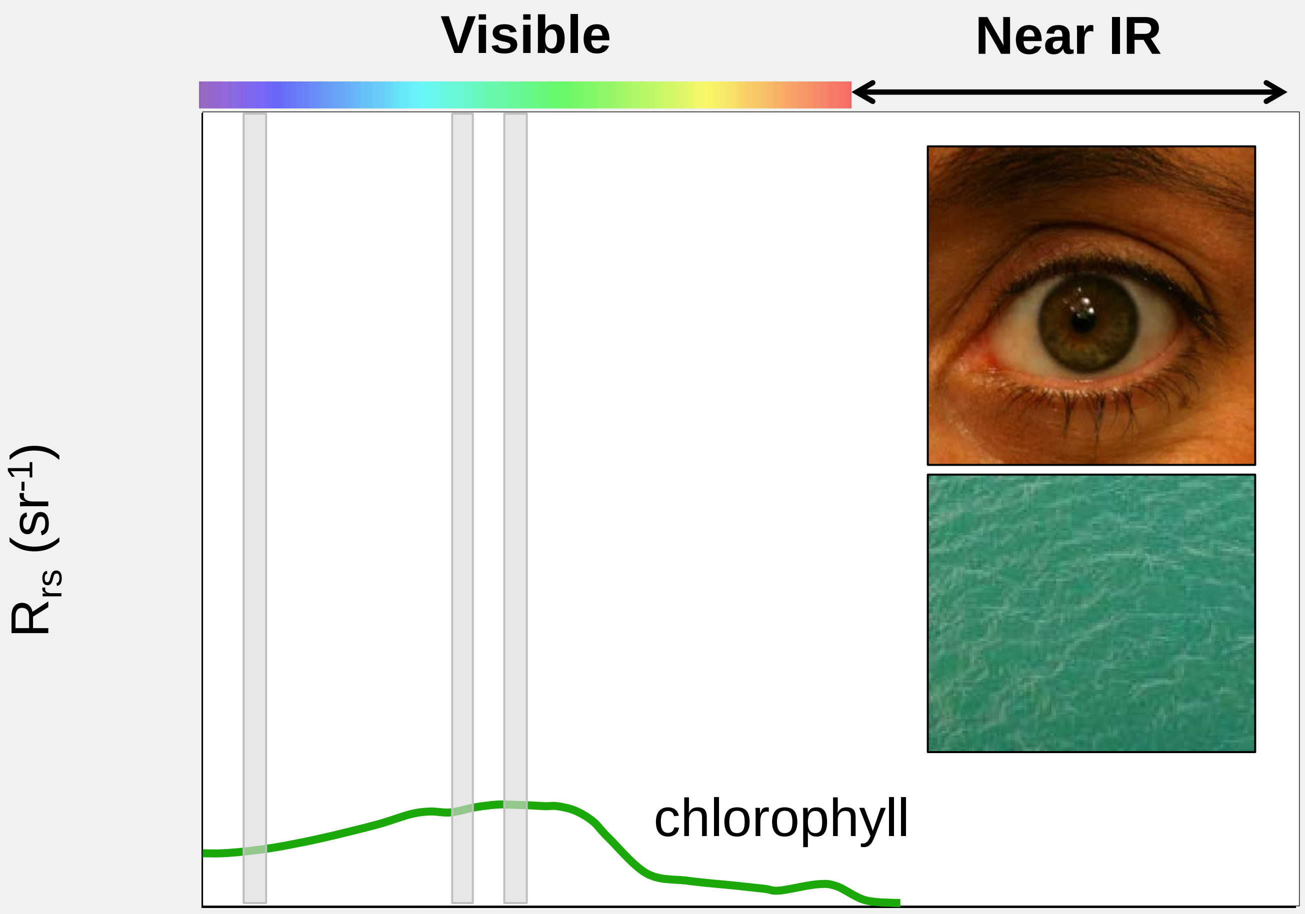
Inherent Optical Properties (IOPs) and the 'Color' of Water



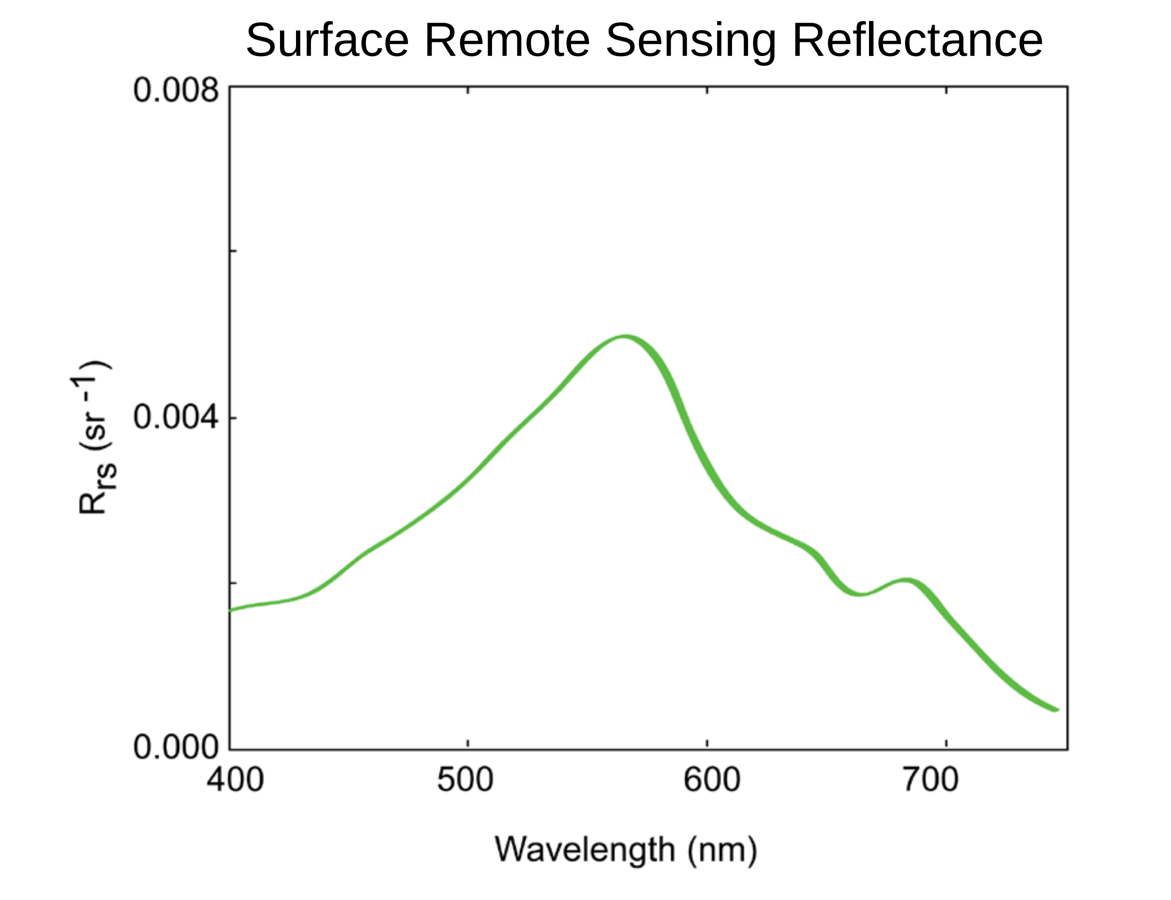


Inherent Optical Properties (IOPs) and the ‘Color’ of Water

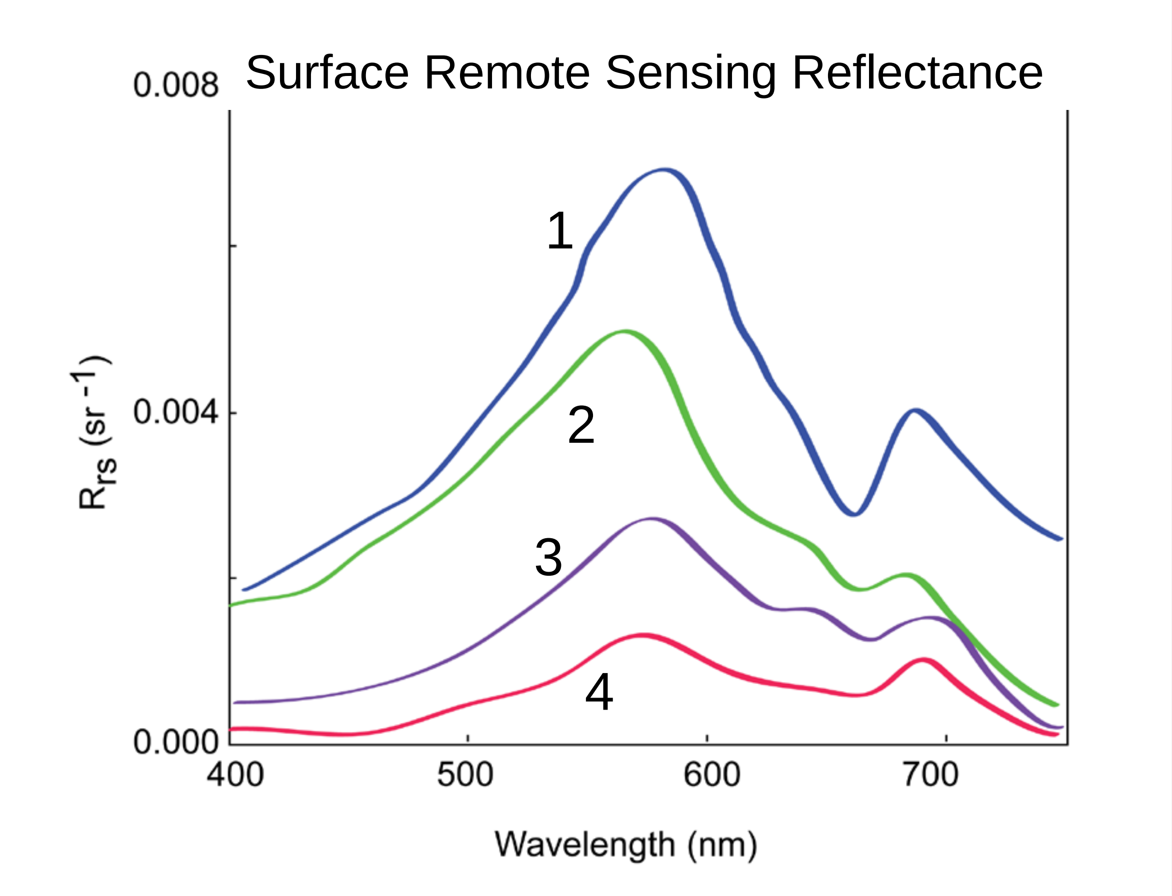
- The typical human eye has color-detecting receptors that sense light at:
  - 420-440 nm ‘blue’
  - 534-555 nm ‘green’
  - 564-580 nm ‘red’
- Water with high chlorophyll content looks green because it reflects strongly in the green part of the spectrum

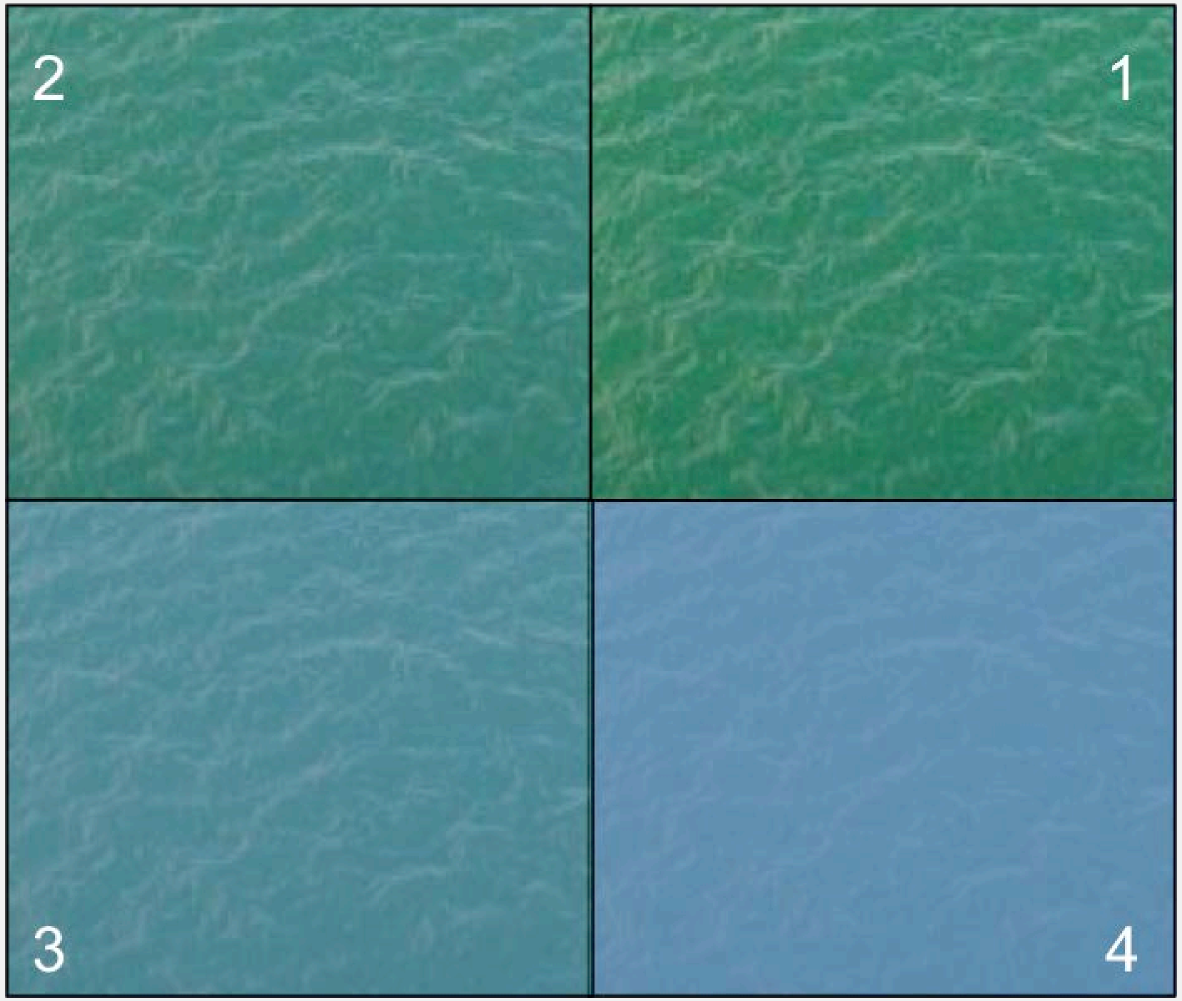


Chlorophyll-a From Remote Sensing Reflectance (R_{rs})



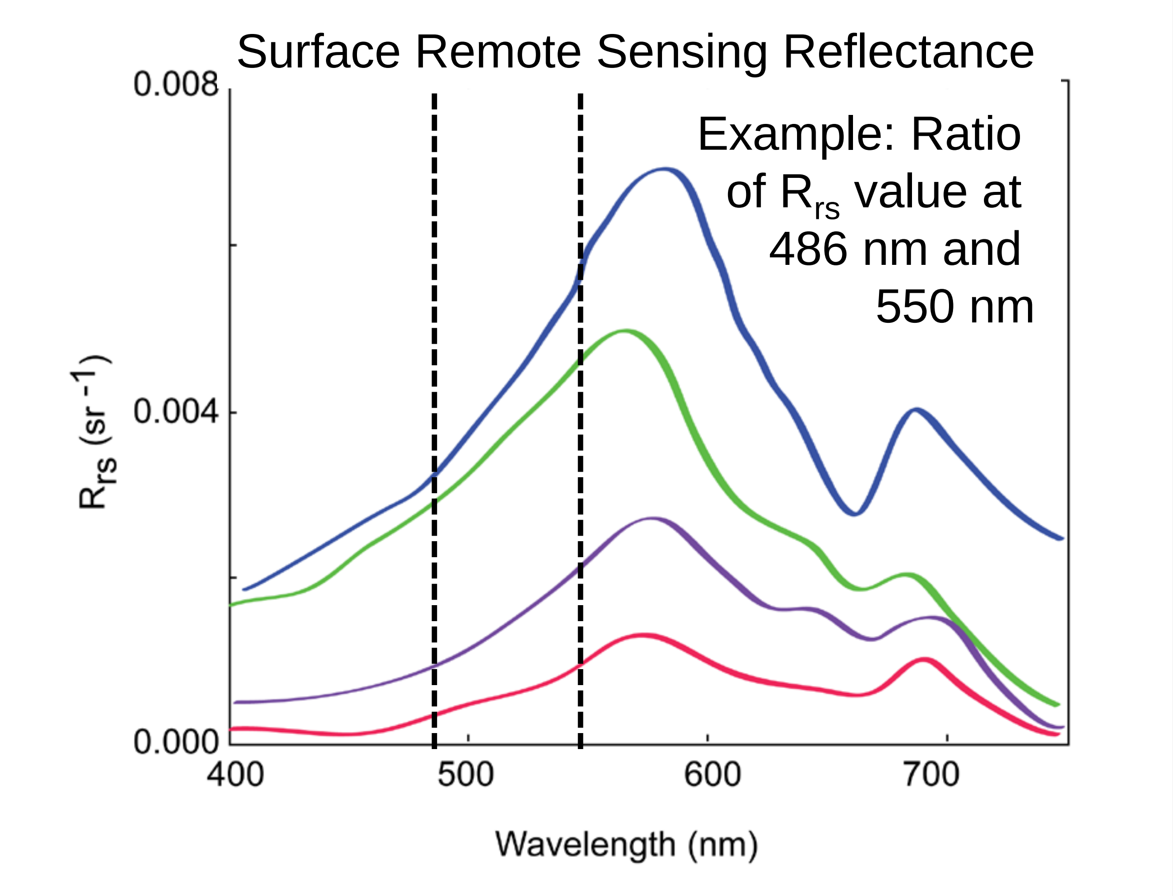
R_{rs} at Different Chlorophyll-a Concentrations

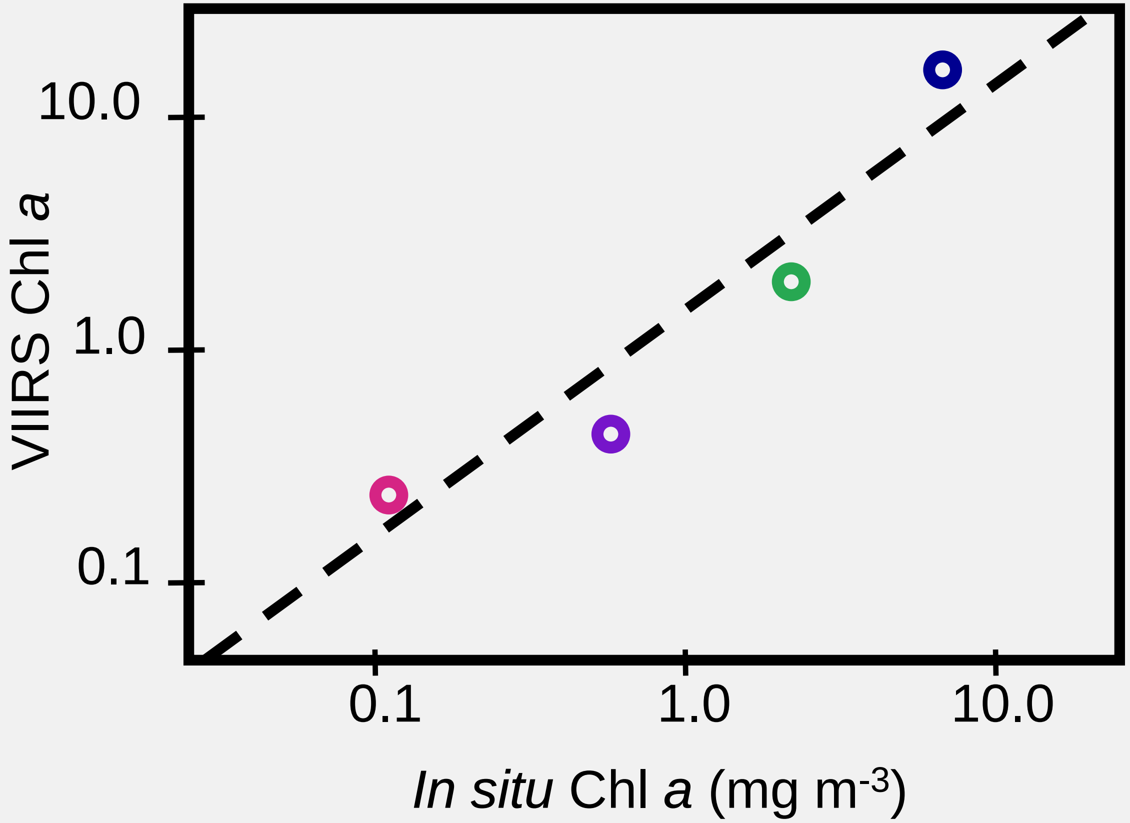




Chlorophyll-a Estimates

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

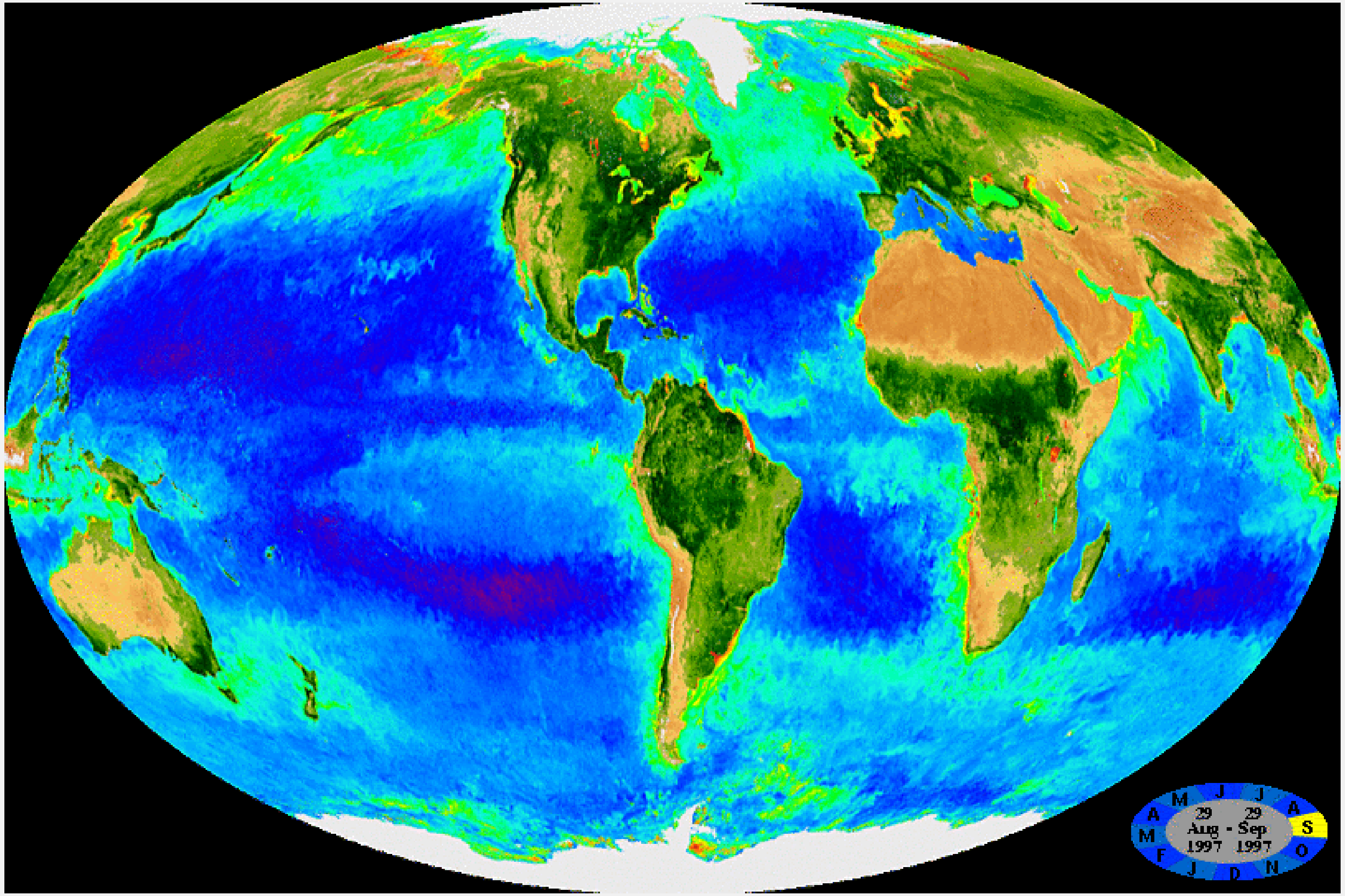




Algorithm description: http://oceancolor.gsfc.nasa.gov/cms/atbd/chlor_a

Chlorophyll-a From Space

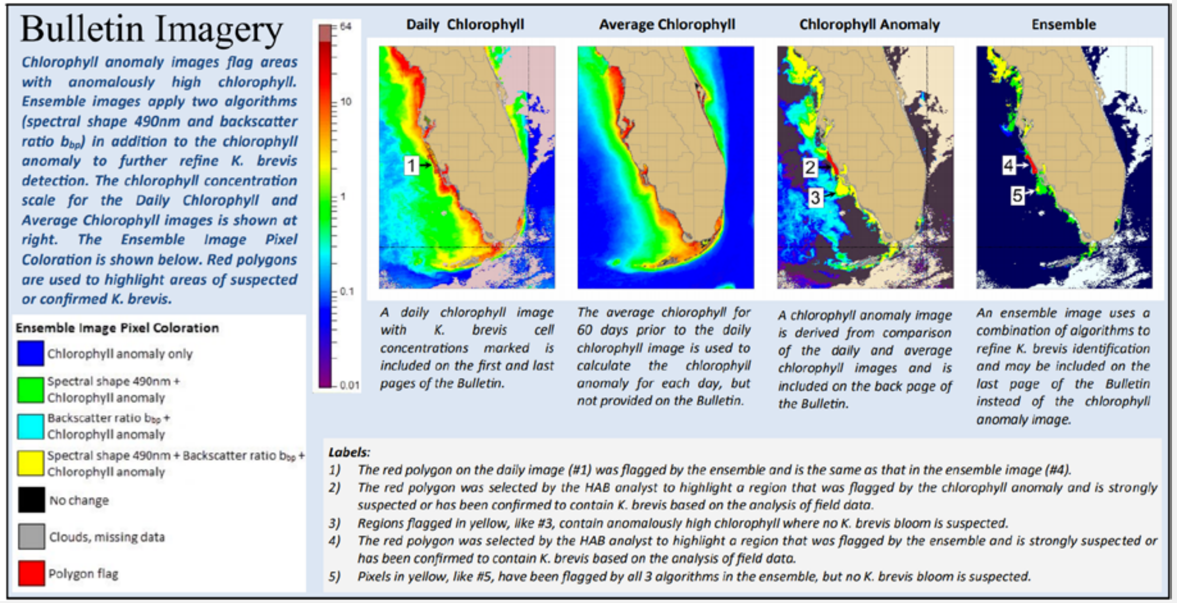
SeaWiFS Sensor - Animation



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

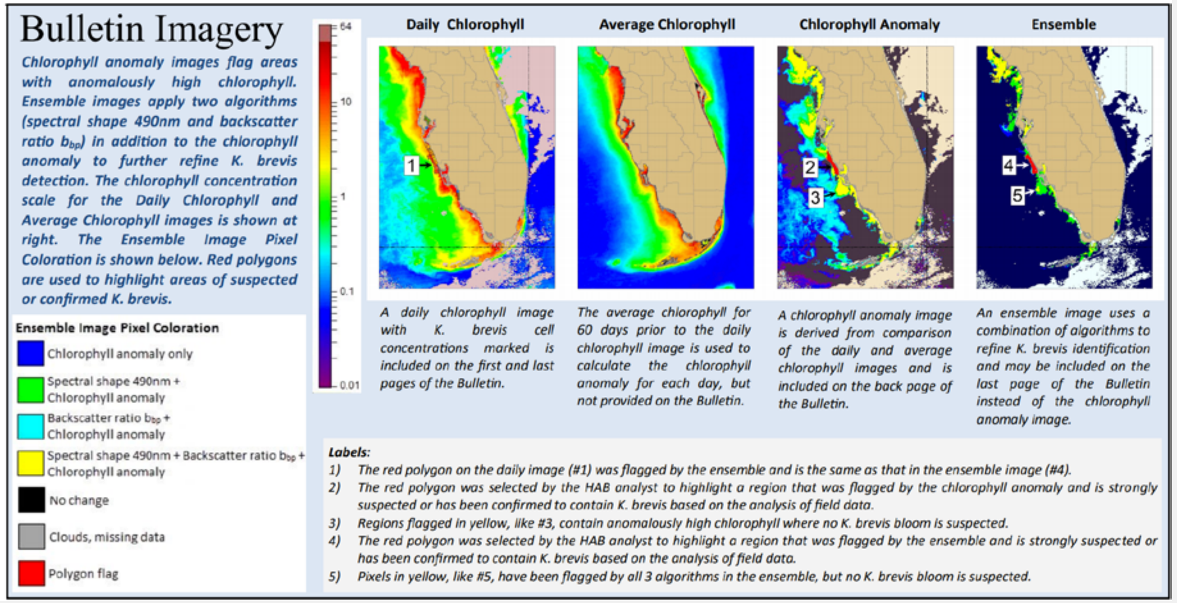
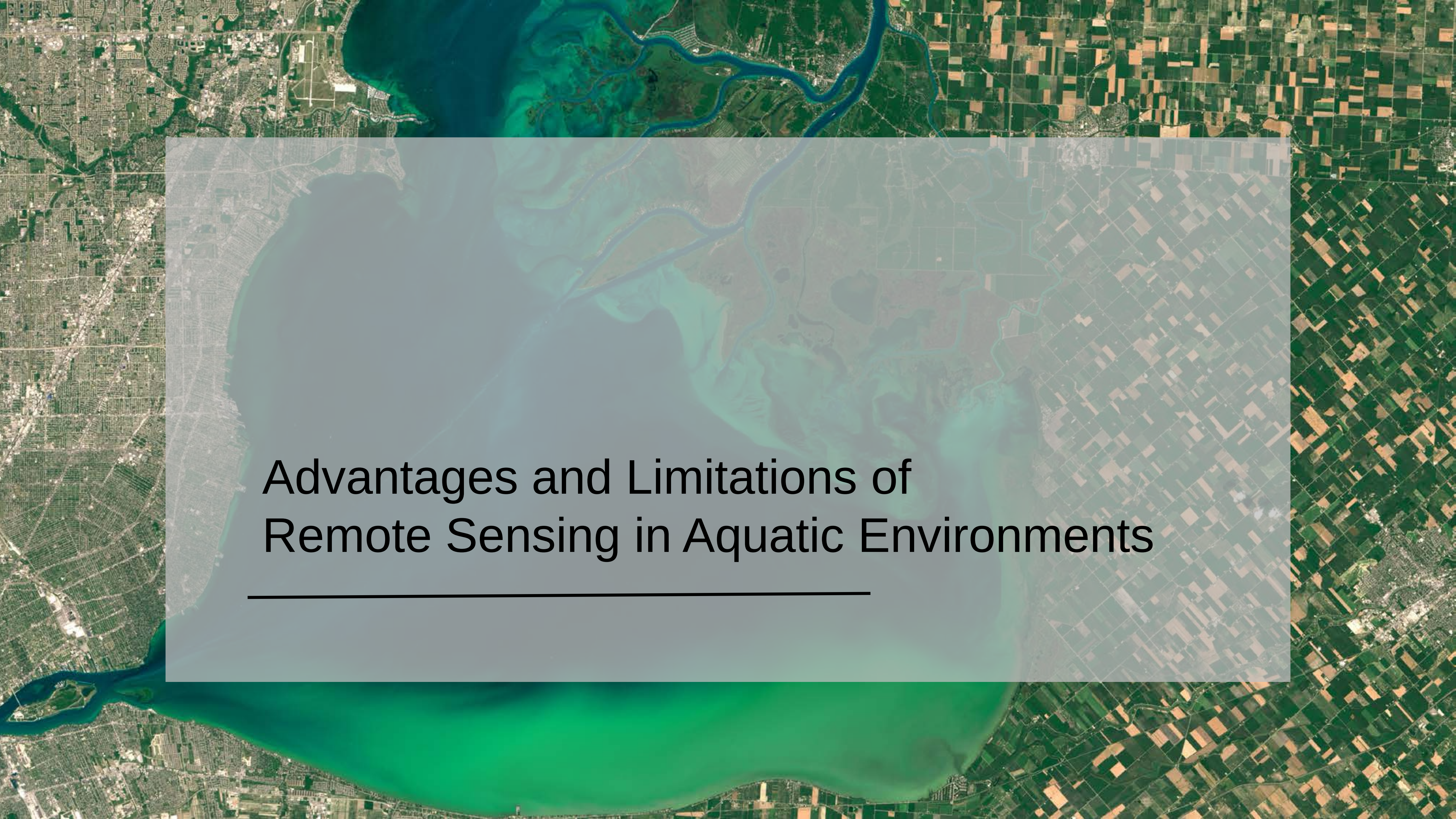


Image Credit: https://tidesandcurrents.noaa.gov/hab/hab_publication/habfs_bulletin_guide.pdf

Advantages and Limitations of Remote Sensing in Aquatic Environments



Limitations of Remote Sensing for HABs

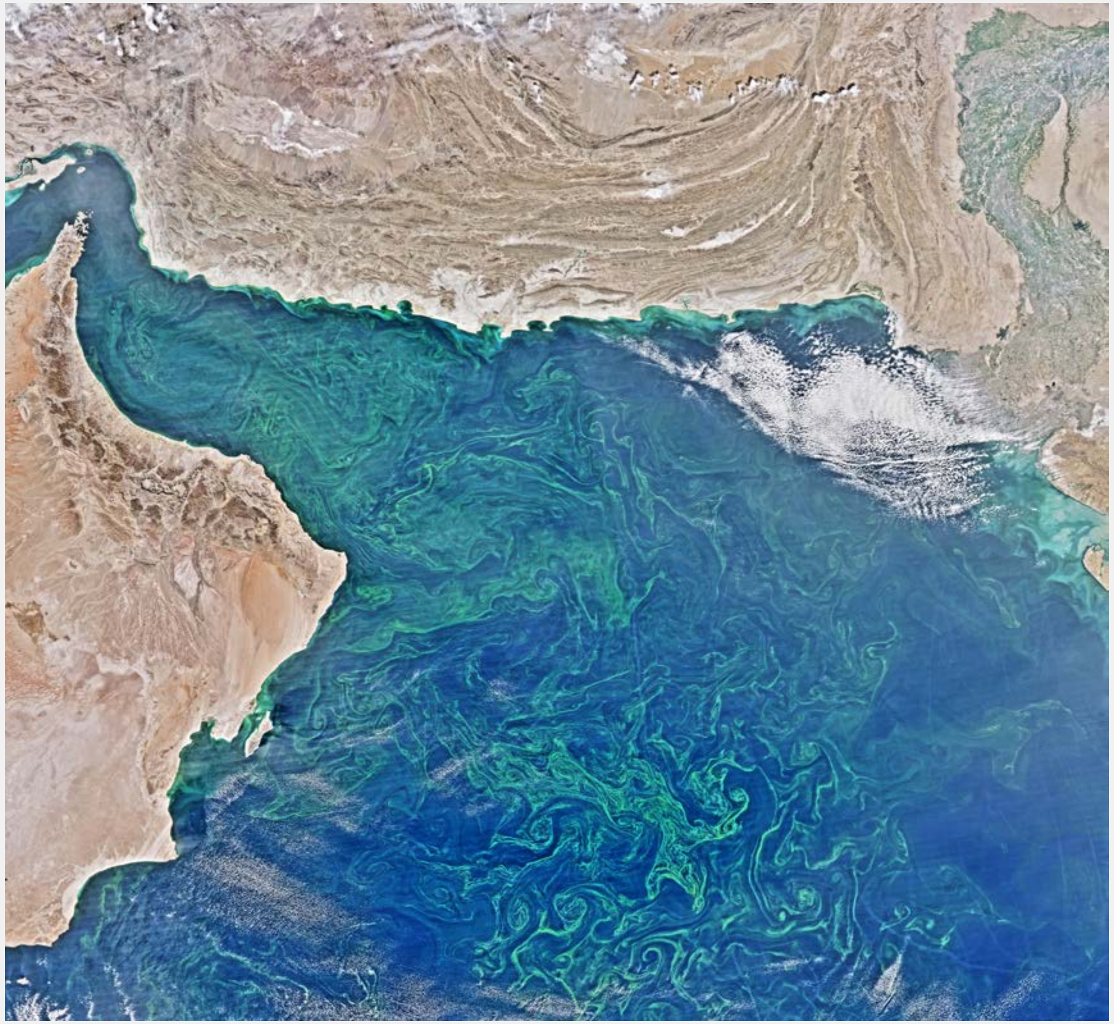
- Indirect measure - not actually measuring toxins
- Cannot infer to species level
- Coarse spatial resolution over wide swaths - may not be appropriate for all locations
- All the same limitations of aquatic remote sensing:
  – atmospheric correction
  – glint
  – sun angle
  – clouds

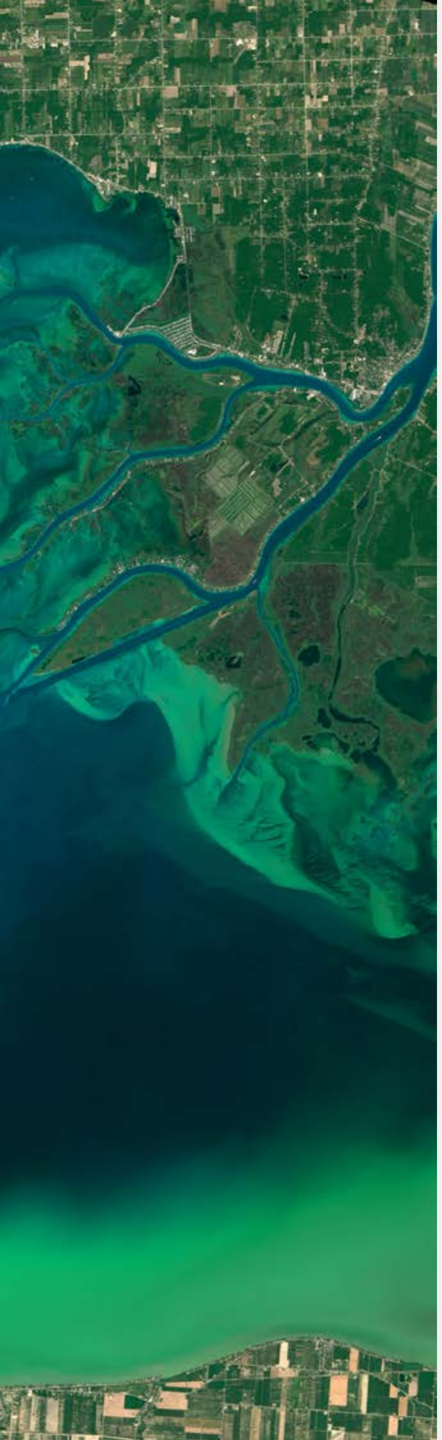
Advantages and Merits of Remote Sensing for HABs

- 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





National Aeronautics and
Space Administration

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