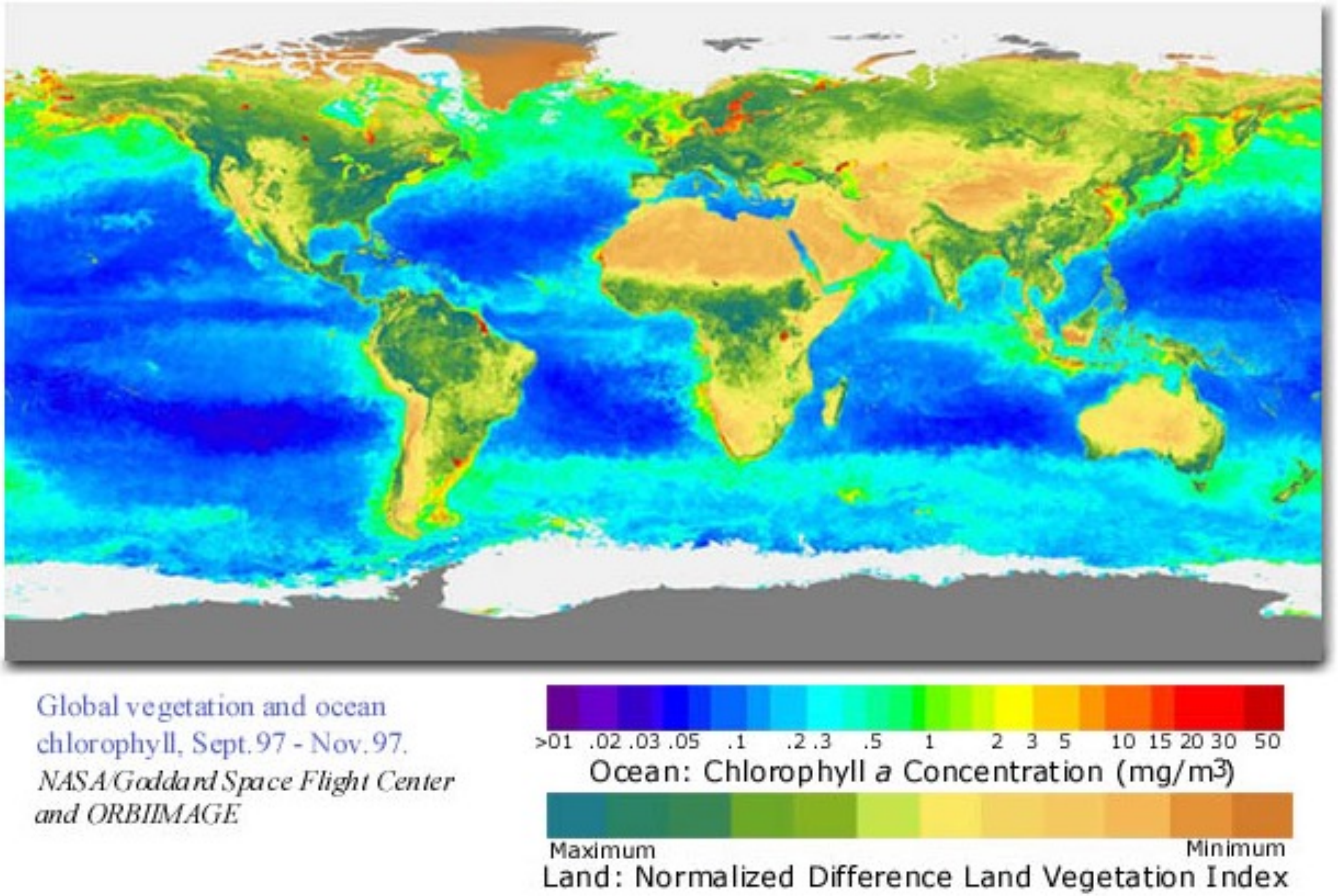
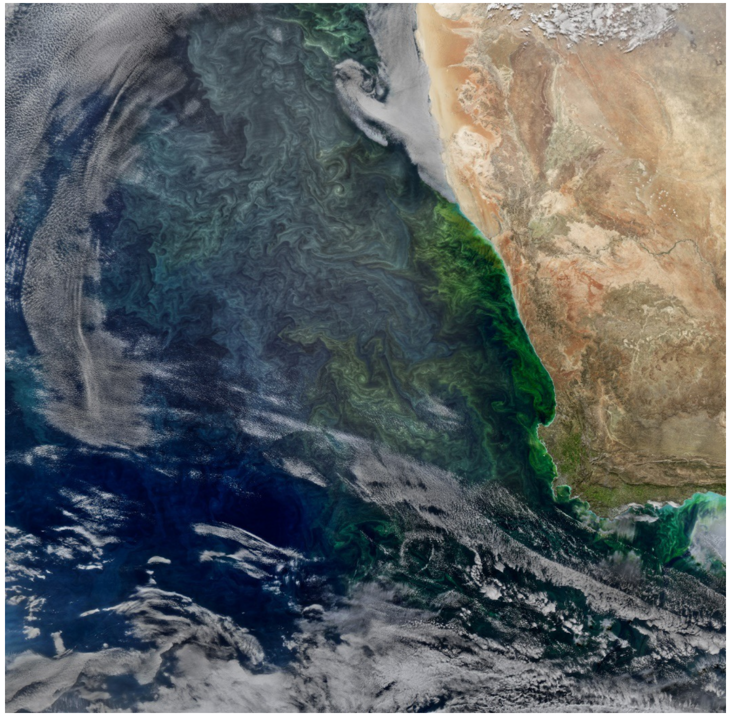
Lecture 1

Why measure IOPS? Broader perspective from space & connections to Biogeochemical parameters

Andrew Barnard, Oregon State University

An Ocean Color satellite ”view” of the Earth.



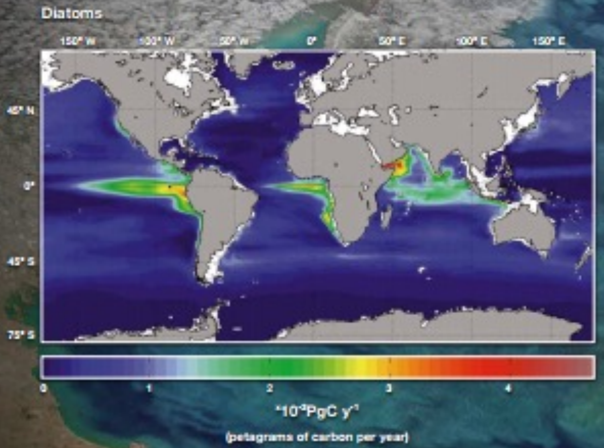


Aqua/MODIS Ocean Color Satellite image collected on September 2, 2017 of Africa's Benguela upwelling ecosystem

Modeling Phytoplankton

Coupled with ship-based measurements and computer models, satellite data allow scientists to observe and study different characteristics about the ocean and how they have changed over time, as well as predict how they might change in the future. This false-color image [right], generated using the NASA Ocean Biogeochemical Model, shows the primary production by diatoms, a group that tends to be large and contributes heavily to the global carbon cycle. Primary production reflects the amount of carbon that is converted using sunlight from carbon dioxide into organic carbon through a process called photosynthesis. The organic carbon represents the carbon that will be usable by higher trophic levels. These data help to improve our understanding of the global ocean carbon and biogeochemical cycles.

Credit: Cecile Rousseaux/USRA/NASA



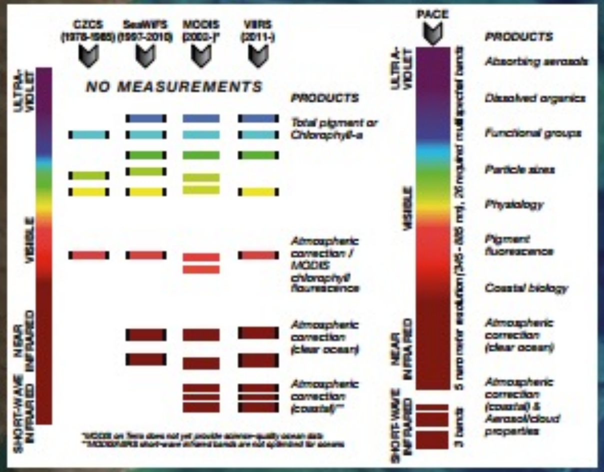
Spectral Coverage

Ocean Color Heritage Sensors compared with PACE

This graph compares the portions of the electromagnetic spectrum that the PACE Ocean Color Instrument will observe compared to previous NASA ocean color sensors. Human eyes are adapted to see a narrow band of this spectrum called visible light. Using satellite sensors to detect multiple spectral band combinations, scientists can study various aspects of ocean color in ways that they cannot from a photograph. Ocean color features, clouds, and aerosols each leave their signatures in the electromagnetic spectrum and scientists can observe and analyze these patterns to detect changes.

Find more information at *http://pace.gsfc.nasa.gov*.

Credit: NASA



Cover image:

This true color image of the North Atlantic Ocean was created using data from the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership satellite collected on April 12, 2015. Notice the swirling phytoplankton eddies and different color coastal waters associated with runoff from the eastern United States.

Credit: NASA

For more information, visit:
www.nasa.gov/earth

NASA Sets the PACE for Advanced Studies of Earth's Changing Climate
http://pace.gsfc.nasa.gov

The high spectral resolution of PACE will enable scientists to distinguish phytoplankton types, which will hopefully help to identify harmful algal blooms from space one day.

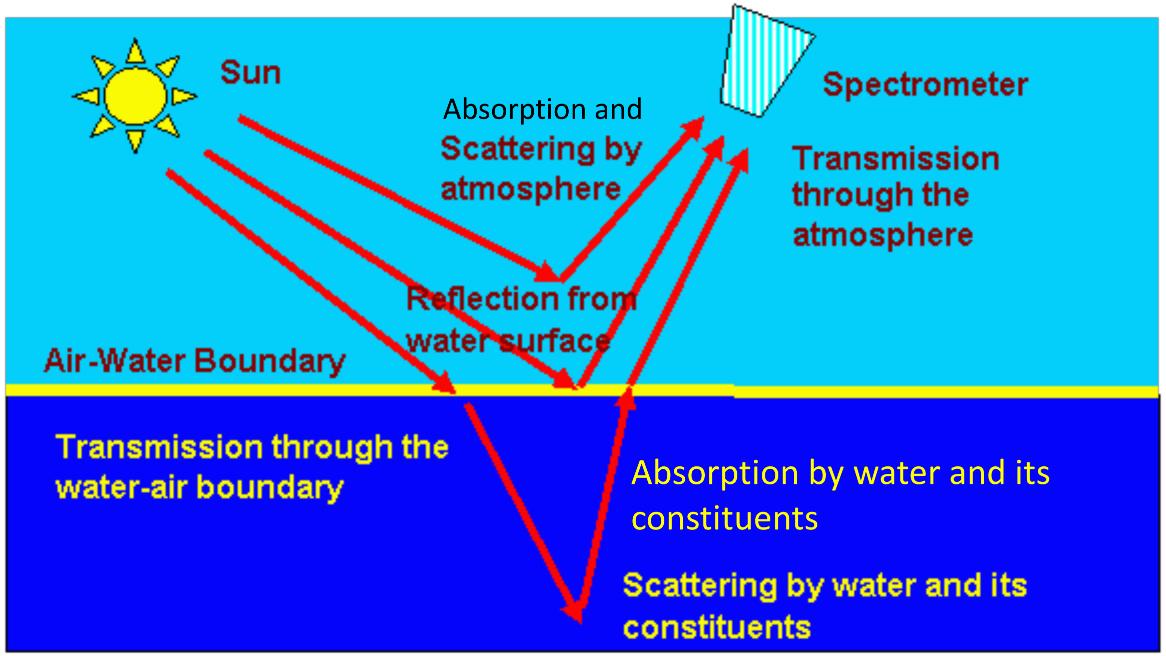
National Aeronautics and Space Administration

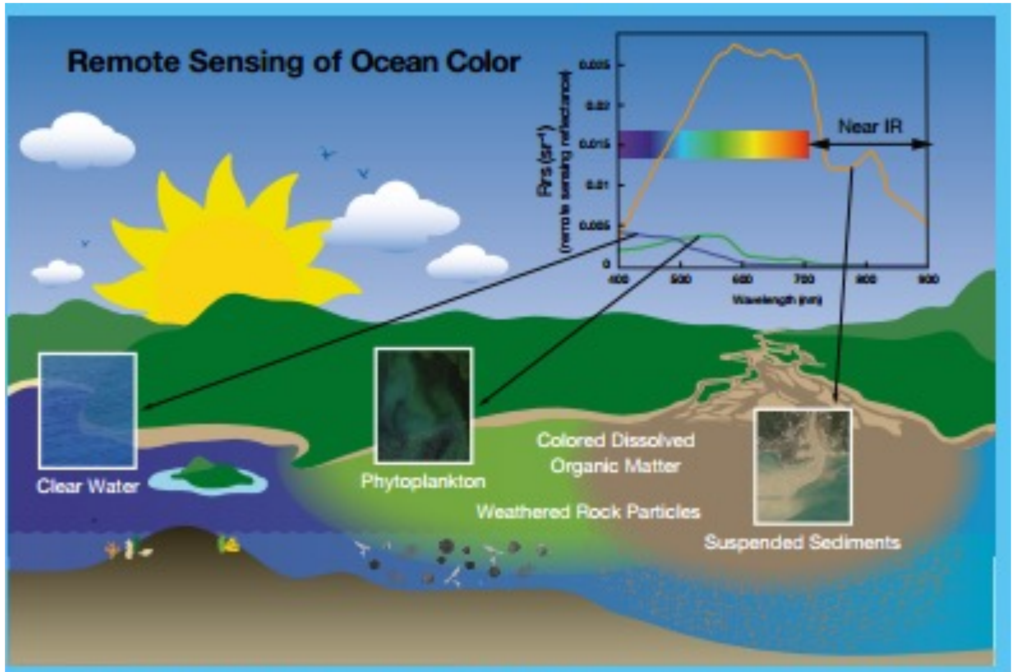
What Color is the Ocean?

Ocean Color

Some sunlight passes through the atmosphere, enters the ocean, gets scattered upwards, passes back up through the atmosphere and is detected by ocean color satellites.

By removing atmospheric effects and surface reflectance, you can isolate the light that interacted with the water column. The color of that light tells you about the constituents of within the water (e.g. plankton concentration, dissolved organics, sediments).

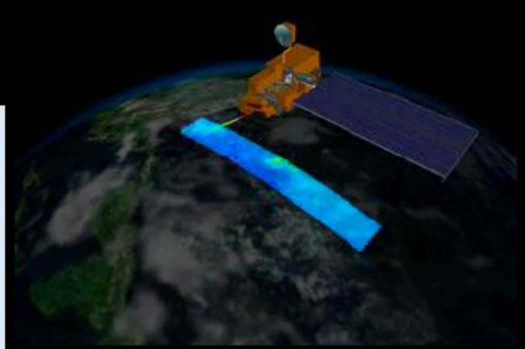


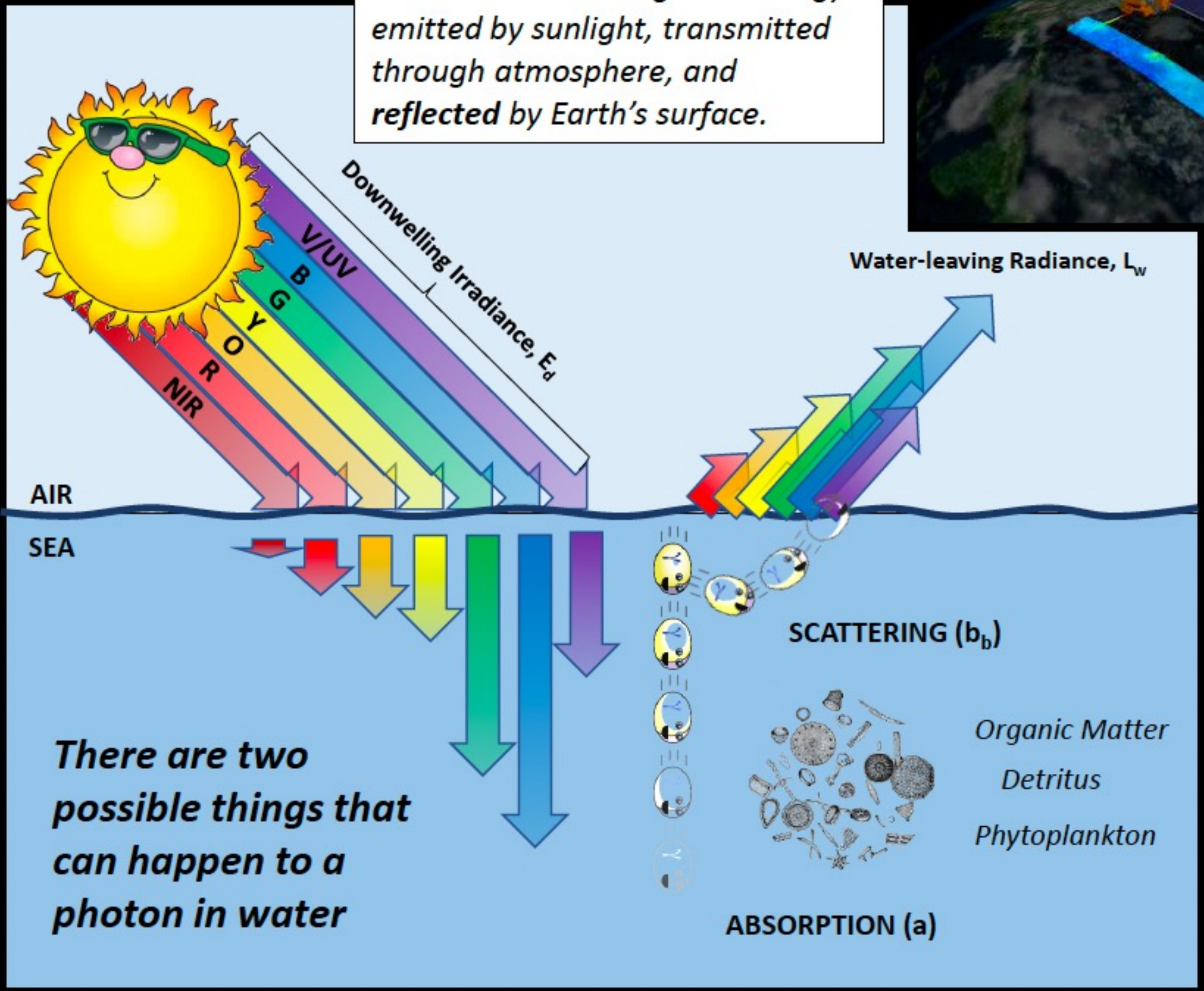


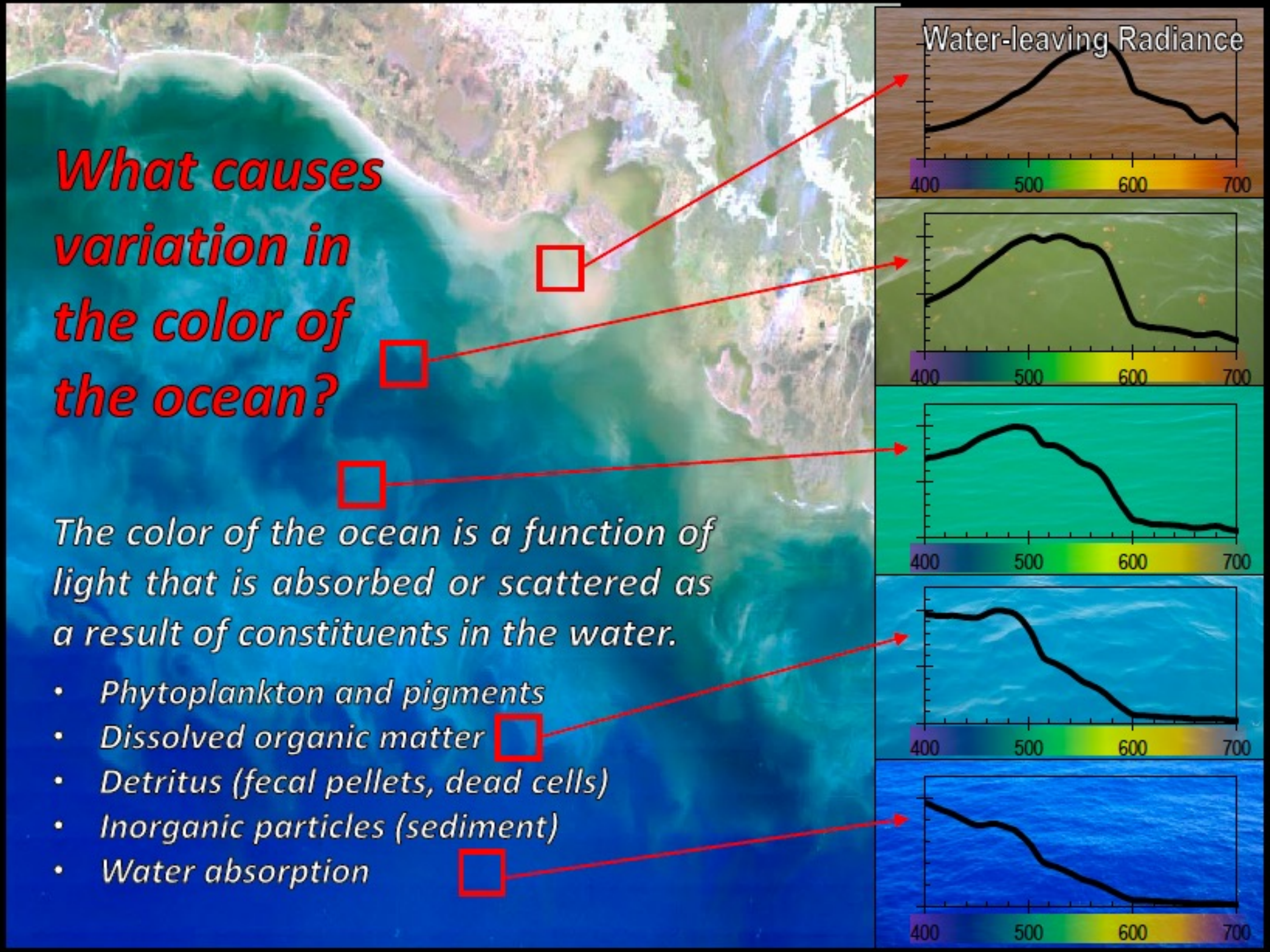
Scientists use a technique similar to spectrophotometry to quantify ocean color remotely. Satellite instruments (such as OCI) measure light reflected back to the satellite at different wavelengths and create emission spectra graphs [*inset, top right*]. Differences in the shape of the spectra can be used to determine what is in the water, such as sediments (orange line), chlorophyll (green line), or clear water (blue line). Brighter objects (e.g., sediments) reflect more light of all wavelengths while darker objects absorb more, thus the values are higher across the spectrum for sediment.

Credit: NASA

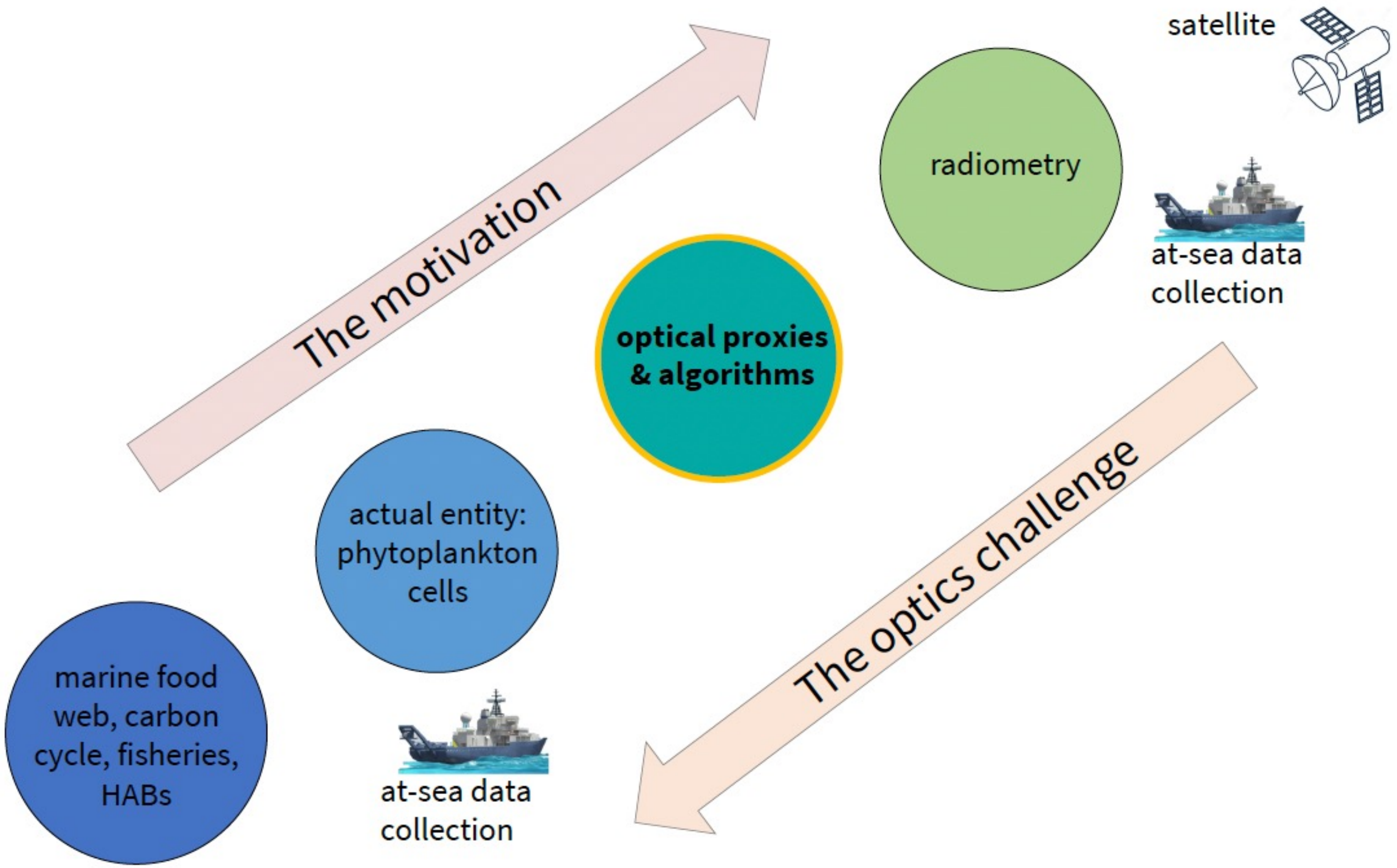
Measurements of ocean color are based on electromagnetic energy emitted by sunlight, transmitted through atmosphere, and ***reflected*** *by Earth's surface.*






What causes variation in the color of the ocean?
The color of the ocean is a function of light that is absorbed or scattered as a result of constituents in the water.
• Phytoplankton and pigments
• Dissolved organic matter
• Detritus (fecal pellets, dead cells)
• Inorganic particles (sediment)
• Water absorption
Water-leaving Radiance
400
500
600
700

Ocean color remote sensing: the motivation & the challenge

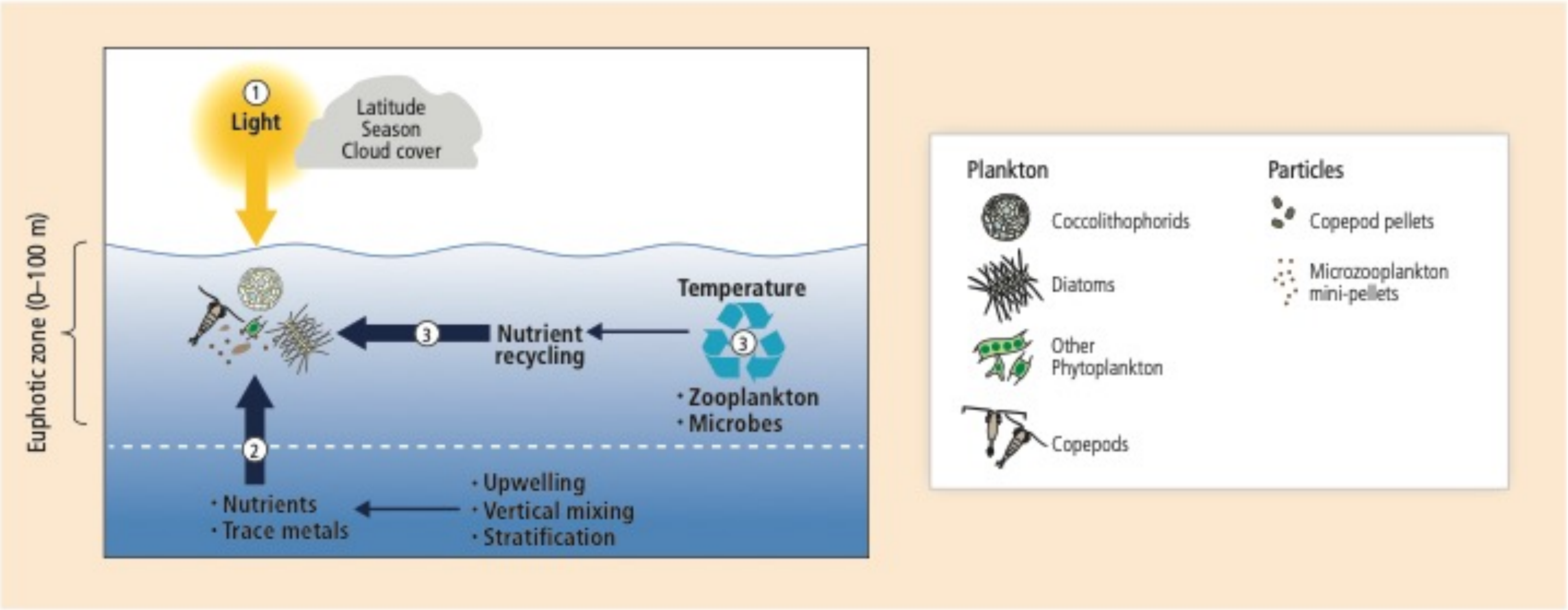


Adapted from M. J. Perry

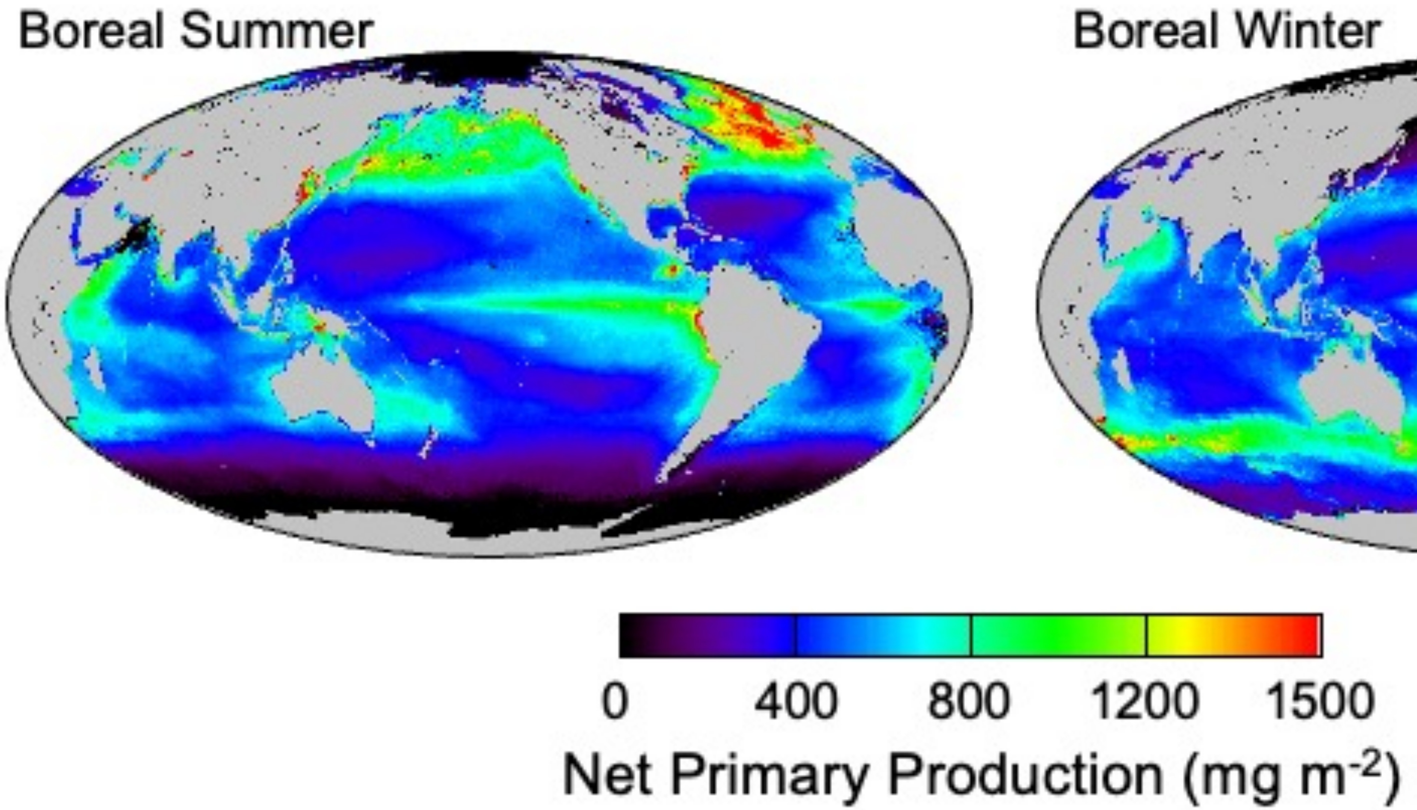
Perspectives on hyperspectral optics and remote sensing

Ali Chase, Applied Physics Laboratory – University of Washington, USA
IOCCG Summer Lecture Series, 26 July 2022, Villefranche-sur-Mer, France

(a)



Boyd, P.W., S. Sundby, and H.-O. Pörtner, 2014: *Cross-chapter box on net primary production in the ocean. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 133-136.


Boreal Summer
Boreal Winter
0
400
800
1200
1500
Net Primary Production (mg m-2)

Optically-based Biogeochemical (BGC) proxies

- Optical measurements (coefficients) that are related to (empirical or mechanistic) biogeochemical parameters
- The inherent optical properties (IOPs): absorption, scattering, beam attenuation provide a means to get at the BGC parameters

Some examples:

POC: beam attenuation, backscattering

CHL: chl fluorometers, absorption-based chl

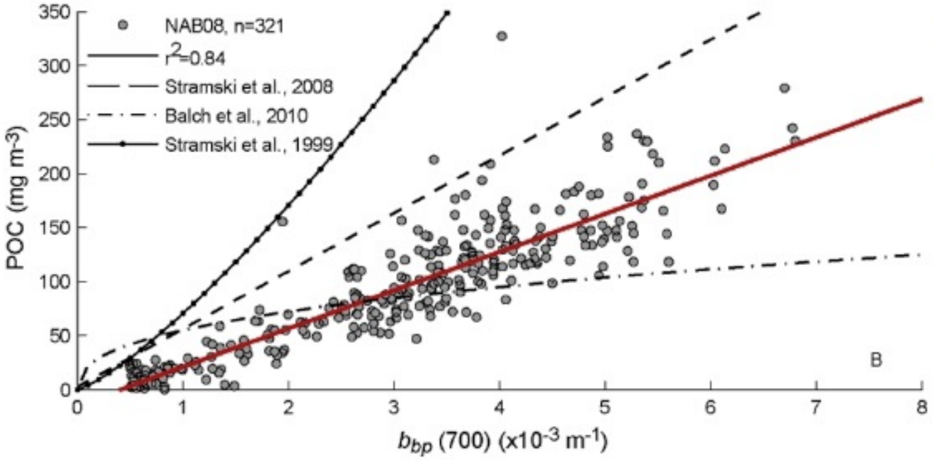
CDOM: dissolved absorption spectral shape

Phytoplankton functional groups: deconvolution of particulate absorption spectrum

Warning!!

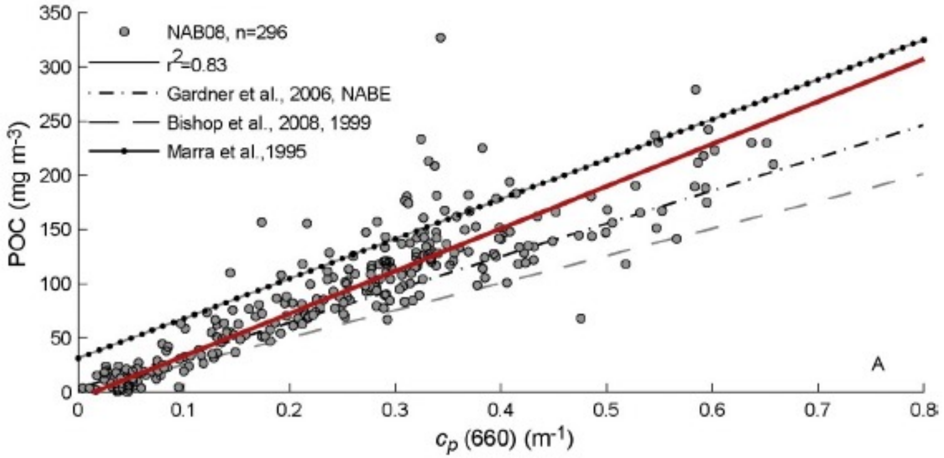
No optical proxy for BGC parameter is perfect, what uncertainty are you willing to live with

Particulate Organic Carbon



Particulate backscattering (b_{bp})

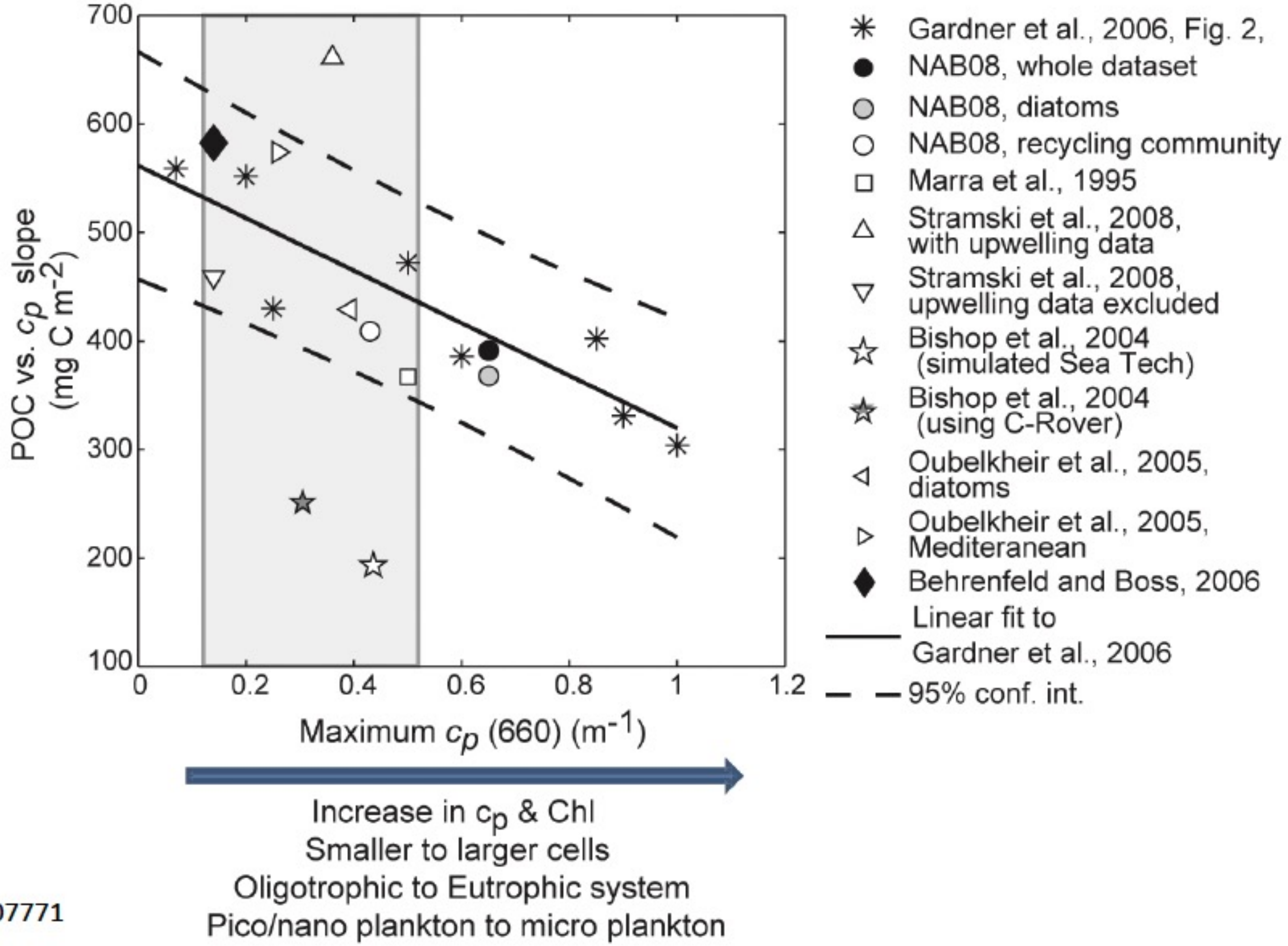
Beam attenuation (c_p)



Figures: Cetinić et al., 2012, JGR. 10.1029/2011JC007771
Slide from I. Cetinić

Credit: Meg Estapa, 2023, margaret.estapa@maine.edu

POC/c_p slope comparison (mg C m^{-2})



Figures: Cetinić et al., 2012, JGR. 10.1029/2011JC007771
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How many independent constituents can be extracted from an absorption spectrum? (Cael, Chase, and Boss, 2020. *Appl Opt*)

Absorption spectra have pretty similar shapes...

"we are looking for small differences in noisy measurements to parse between covarying pieces of information."

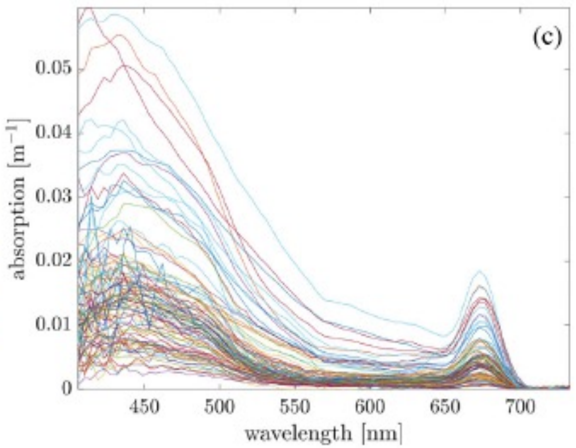
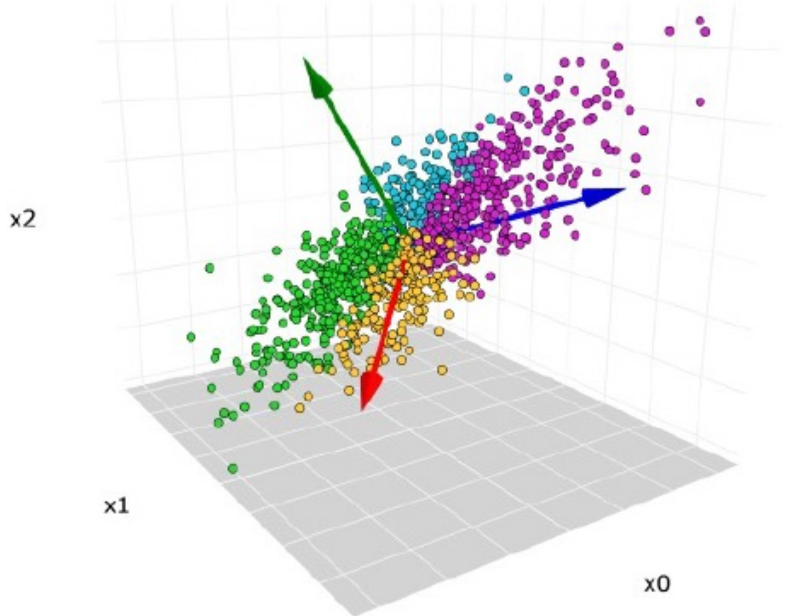
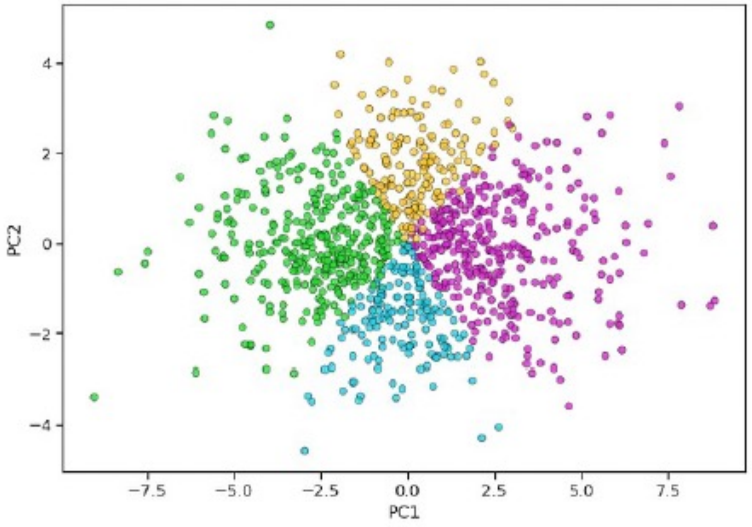


Figure: Cael et al. 2020, 10.1364/AO.389189

Principal component analysis (PCA): Linearly transform the data so that the greatest amount of variance lies along the first axis (first component), the next greatest amount along the second axis (second component), and so forth.





Figures: Cheng, C., 2022. https://towardsdatascience.com/principal-component-analysis-pca-explained-visually-with-zero-math-1cbf392b9e7d. Accessed 6/25/2023.

Credit: Meg Estapa, 2023, margaret.estapa@maine.edu

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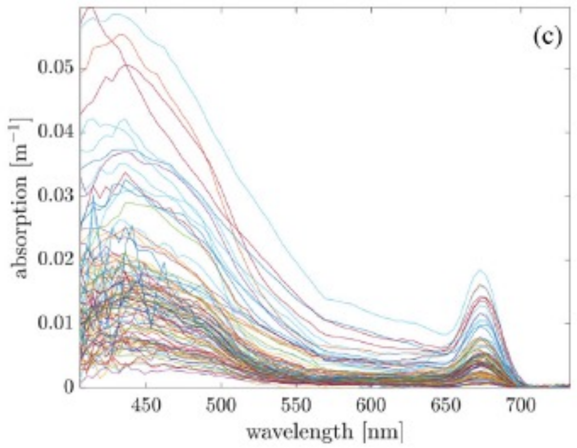
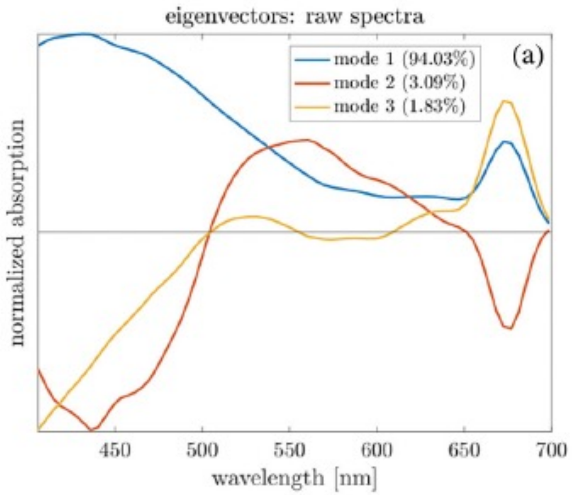
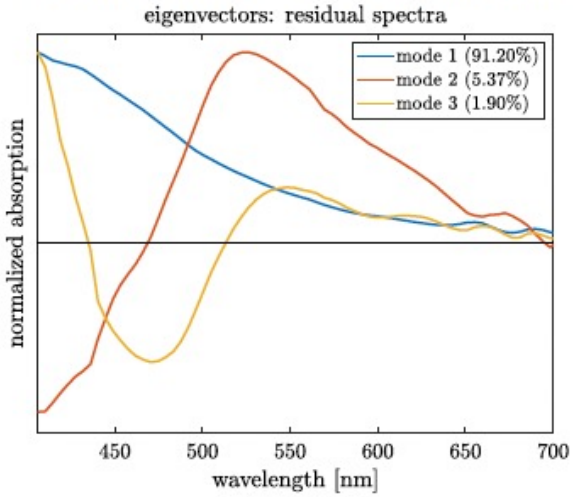


Principal component analysis (PCA): What are the basis vectors that sequentially describe the greatest amount of variance in the data?

PCA on $a_p(\lambda)$ from Tara Oceans…



Use a_{LH} to remove chl first, then PCA… now mode 1 looks like NAP



Take homes:

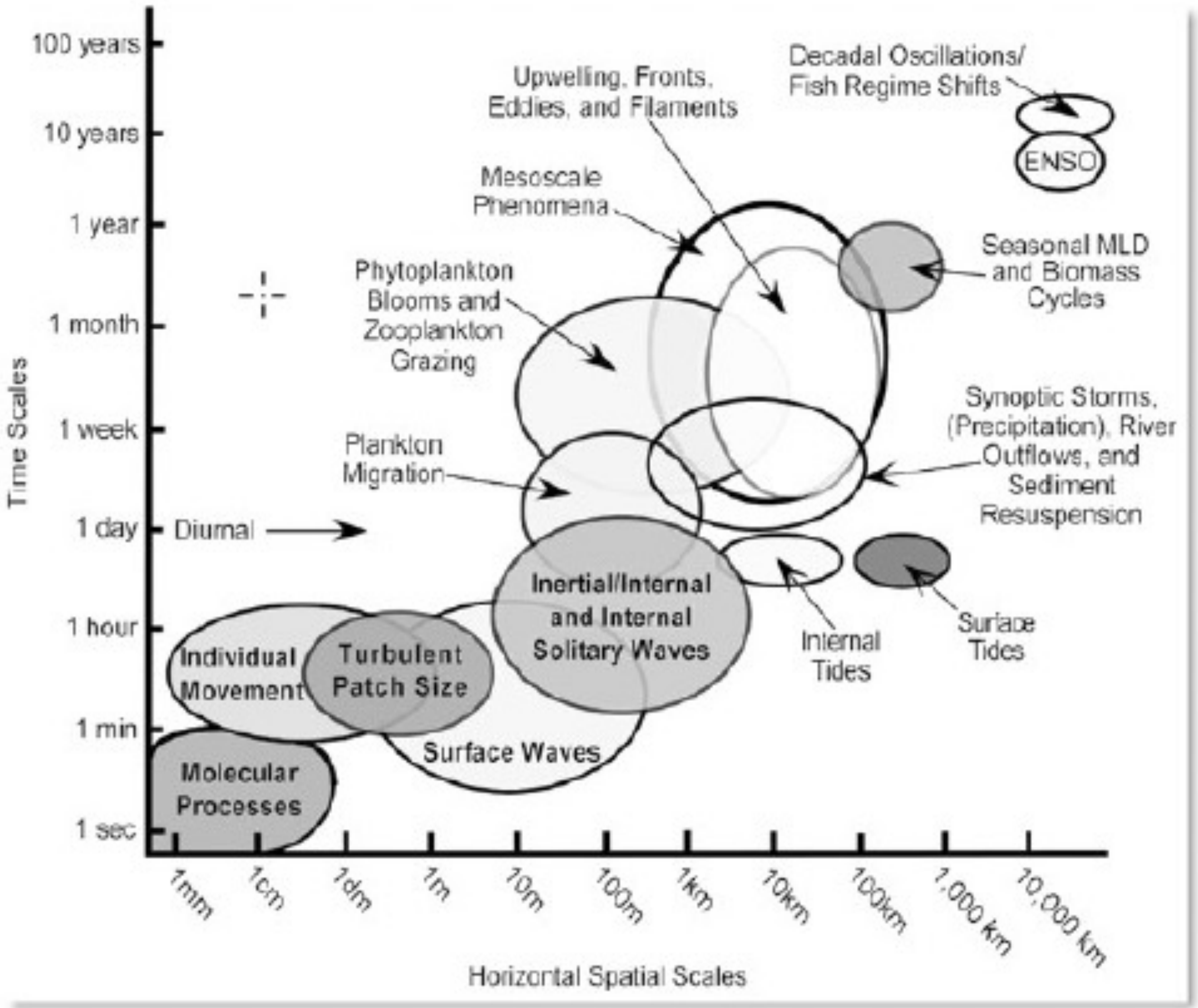
- There are 4-5 degrees of freedom (independently-covarying components) in hyperspectral $a_p(\lambda)$ observed *in situ*
- Overall amplitude/chlorophyll and NAP explain most of the variance
- To get more, you need really low uncertainty *or* **other sources of information**

Figures: Cael et al. 2020, 10.1364/AO.389189

Credit: Meg Estapa, 2023, margaret.estapa@maine.edu

Why are *biogeochemical proxies* important

- Typically
  - We can measure optical properties on highly resolved, yet long-term time and broad space scales
  - Desired biogeochemical properties involve time consuming, expensive, and/or sample-dependent analyses which limit the temporal and spatial resolution and expanse
  - Optically-based proxies provide estimates of BGC properties on time and space scales that are relevant to their inherent processes, not afforded by discrete sampling



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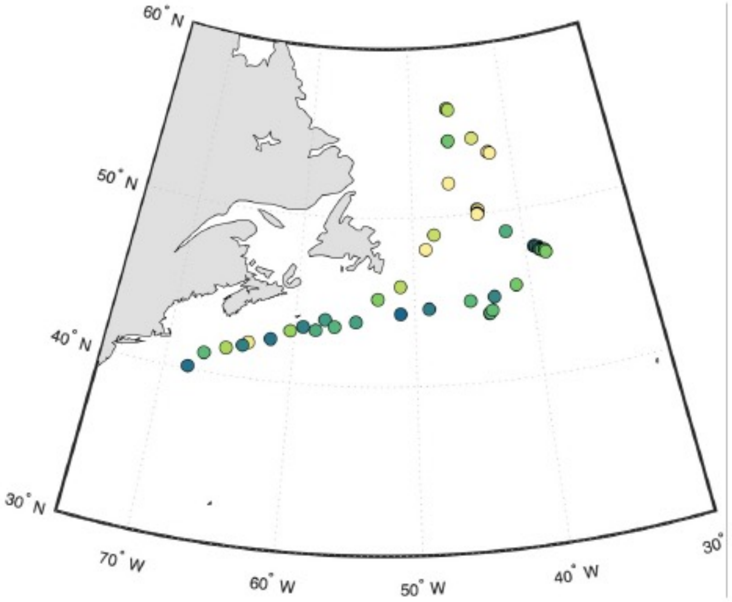
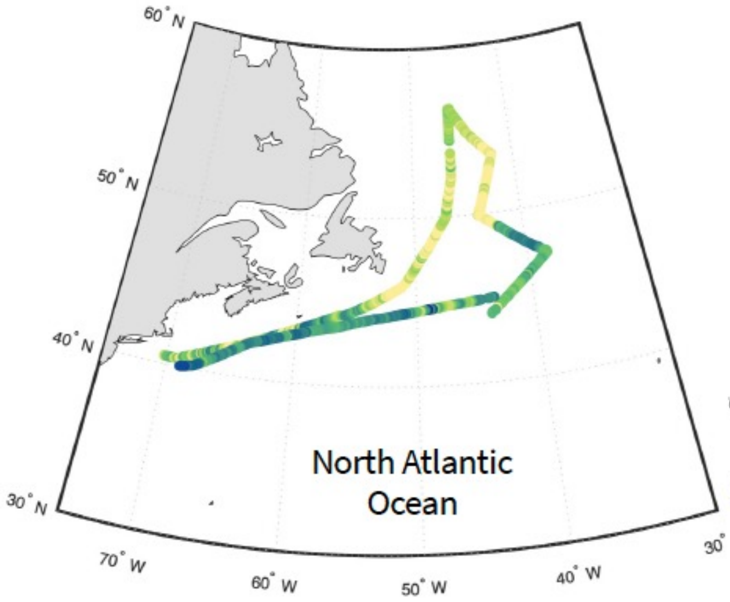
Trade-offs for spatial and temporal resolution – how can we scale up to regional and global views?

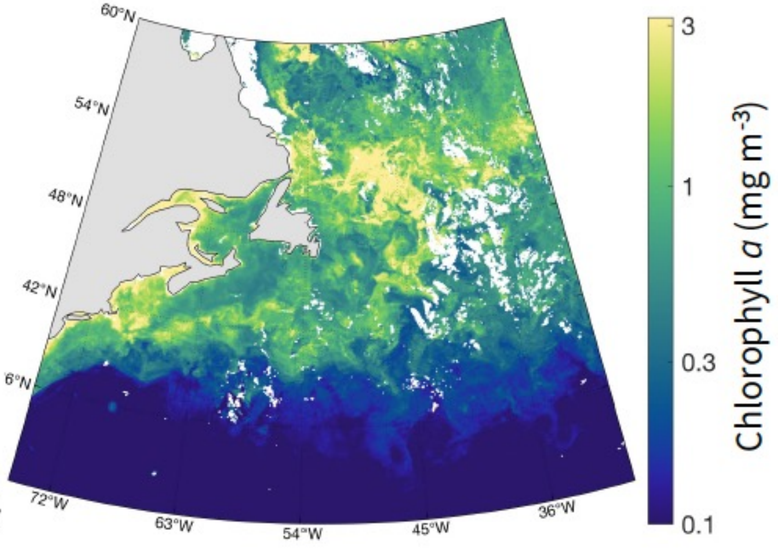
Discrete samples



Ship-board continuous measurements



Satellite remote sensing



Direct measurement of cells & processes ⟷ Spatial & temporal resolution

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The OOI array

The OOI array – AC-S

Measurements of the spectral

Beam attenuation (c),
Absorption (a), and
Scattering (b)

$$c = a + b$$

Sea Bird's AC-S in-situ spectrophotometer provides simultaneous beam attenuation and absorption coefficients at four nanometer resolution across the visible spectrum. (Photo Courtesy of Sea Bird Scientific.)

Welcome to the course!!

Questions?