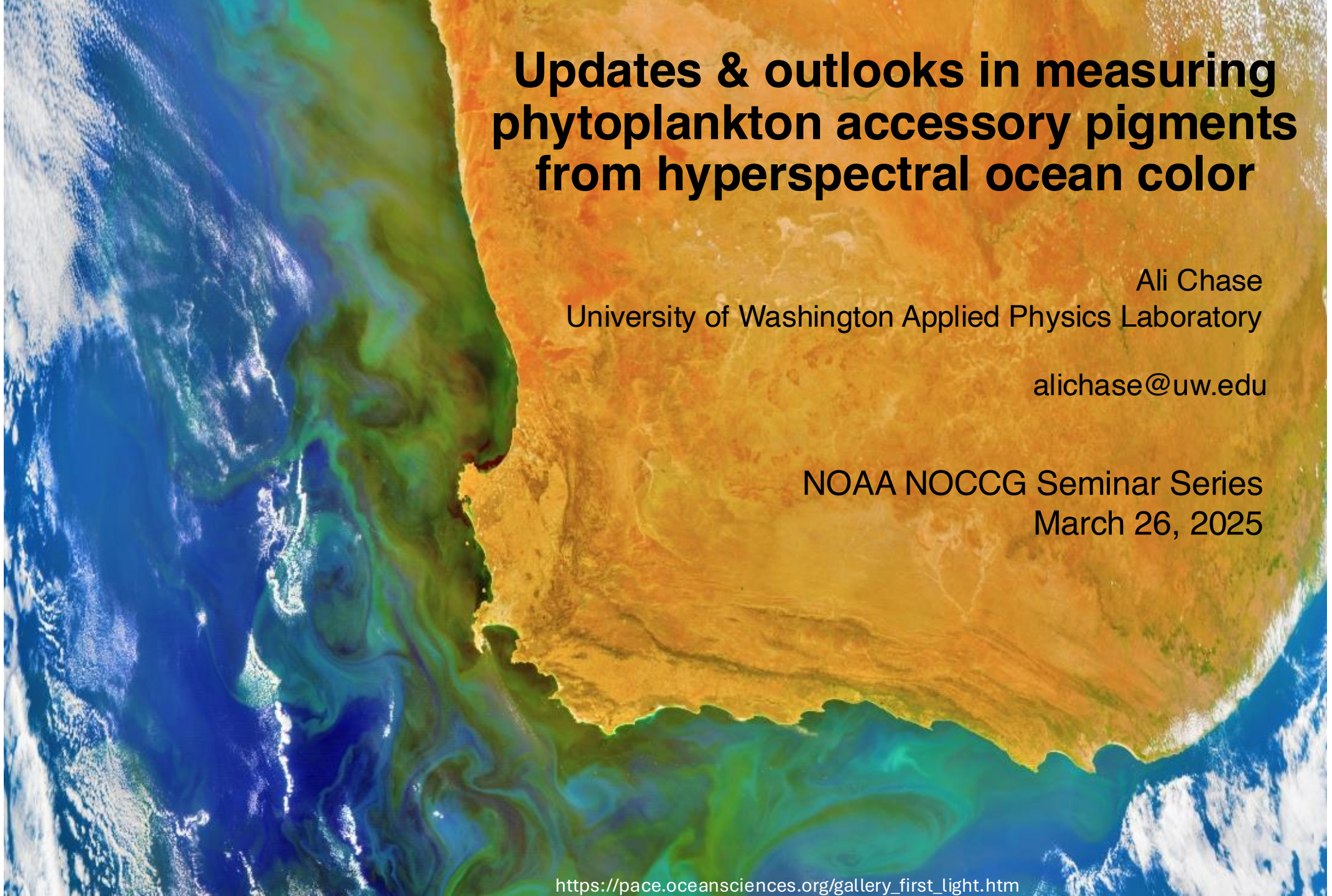


Updates & outlooks in measuring phytoplankton accessory pigments from hyperspectral ocean color

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NOAA NOCCG Seminar Series
March 26, 2025

https://pace.oceansciences.org/gallery_first_light.htm

Topics for this seminar

How do we estimate phytoplankton pigments from hyperspectral ocean color?

- Spectral residual method (SDP)
- Combined inversion & decomposition method (GPig)

Early applications to hyperspectral sensors

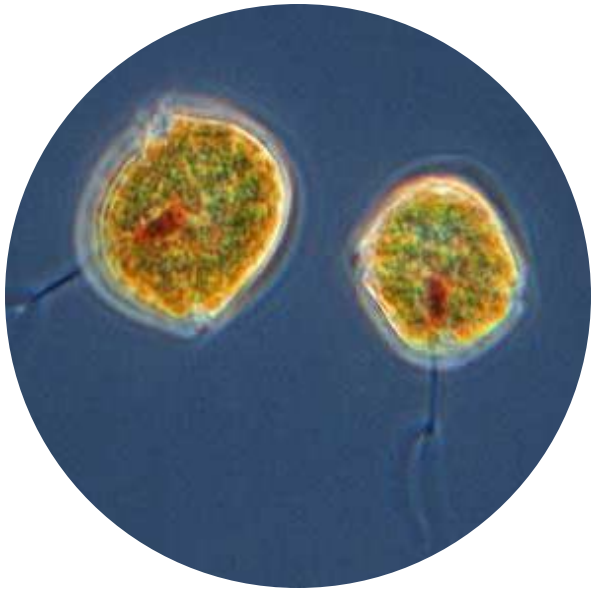
- PACE OCI
- EMIT

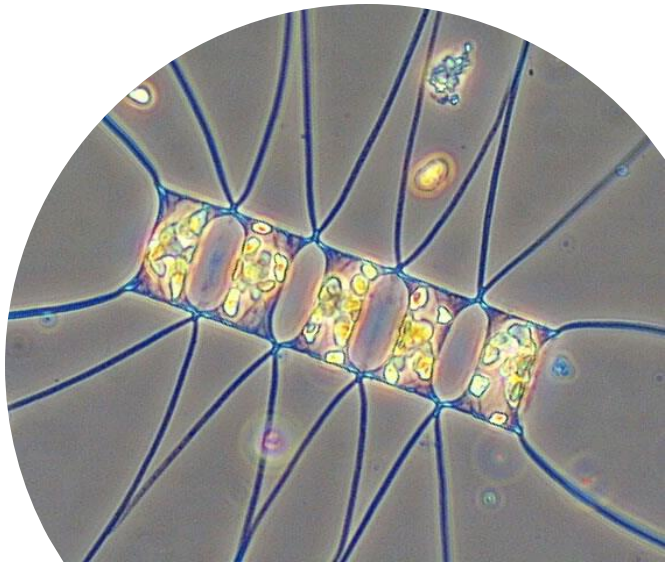
Pigments as inputs to estimate diatom carbon biomass from satellite

Phytoplankton taxonomic groups and their pigments

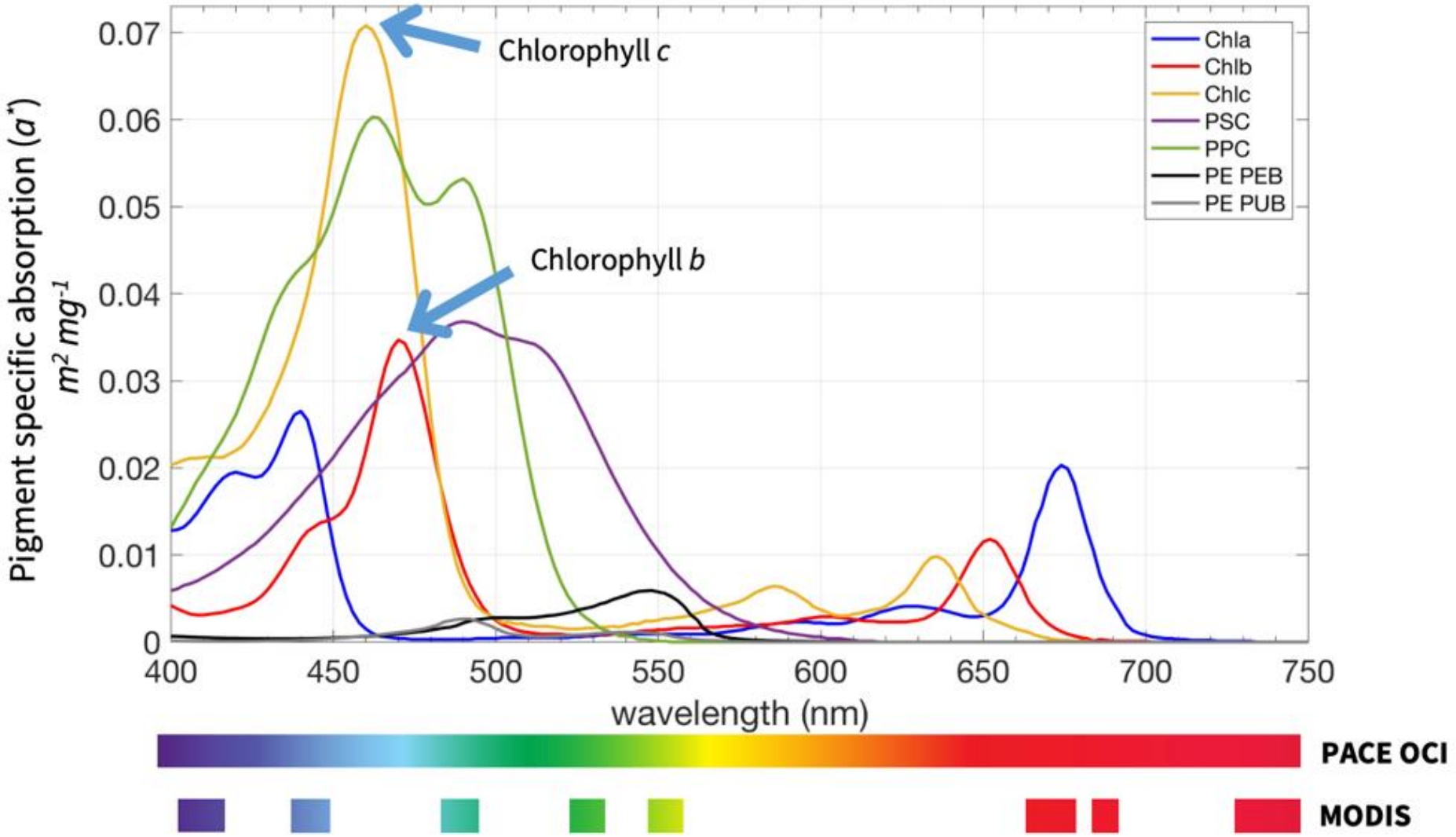
- Different phytoplankton taxonomic groups contain different pigments for absorbing visible light
- Phytoplankton community composition provides insights on ecosystem functioning that total biomass does not
- Hyperspectral ocean color information helps us tease apart different phytoplankton group signatures based on their absorption properties







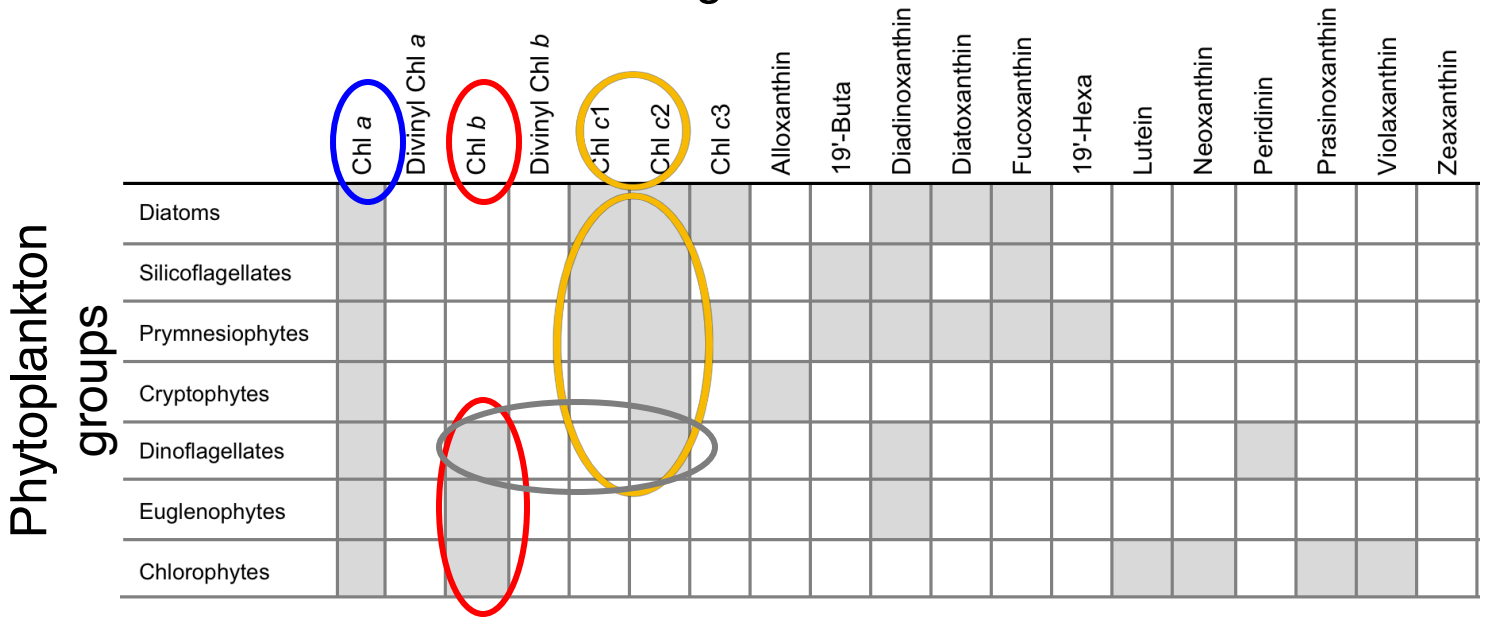
Phytoplankton pigments drive spectral absorption features

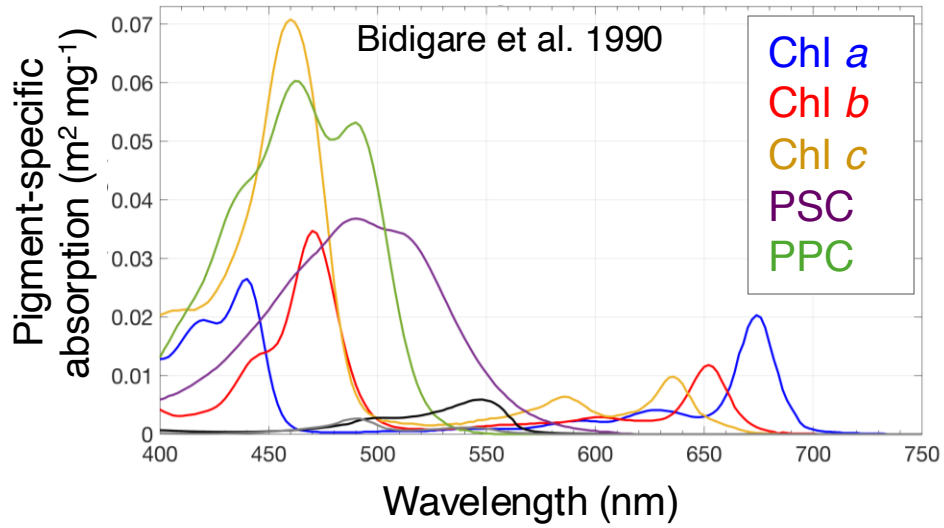


Absorption spectra: Bidigare et al. 1990

Phytoplankton groups and associated pigments

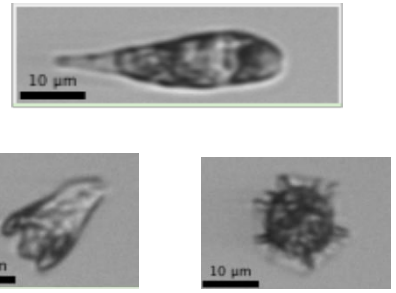
Pigments from HPLC





Chlorophyll *b*

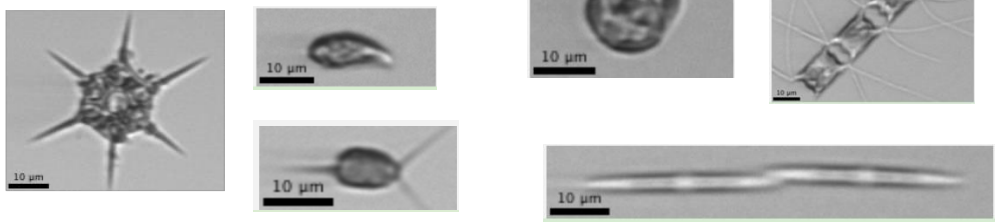
Chlorophytes, Euglenoids



Chlorophyll *c*

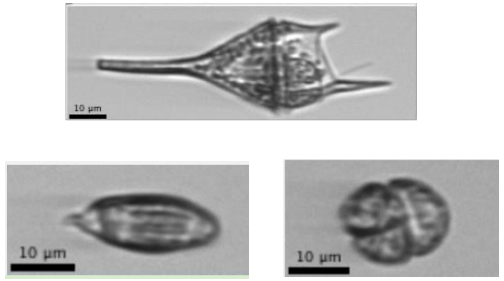
Silicoflagellates
Prymnesiophytes
Cryptophytes

Diatoms

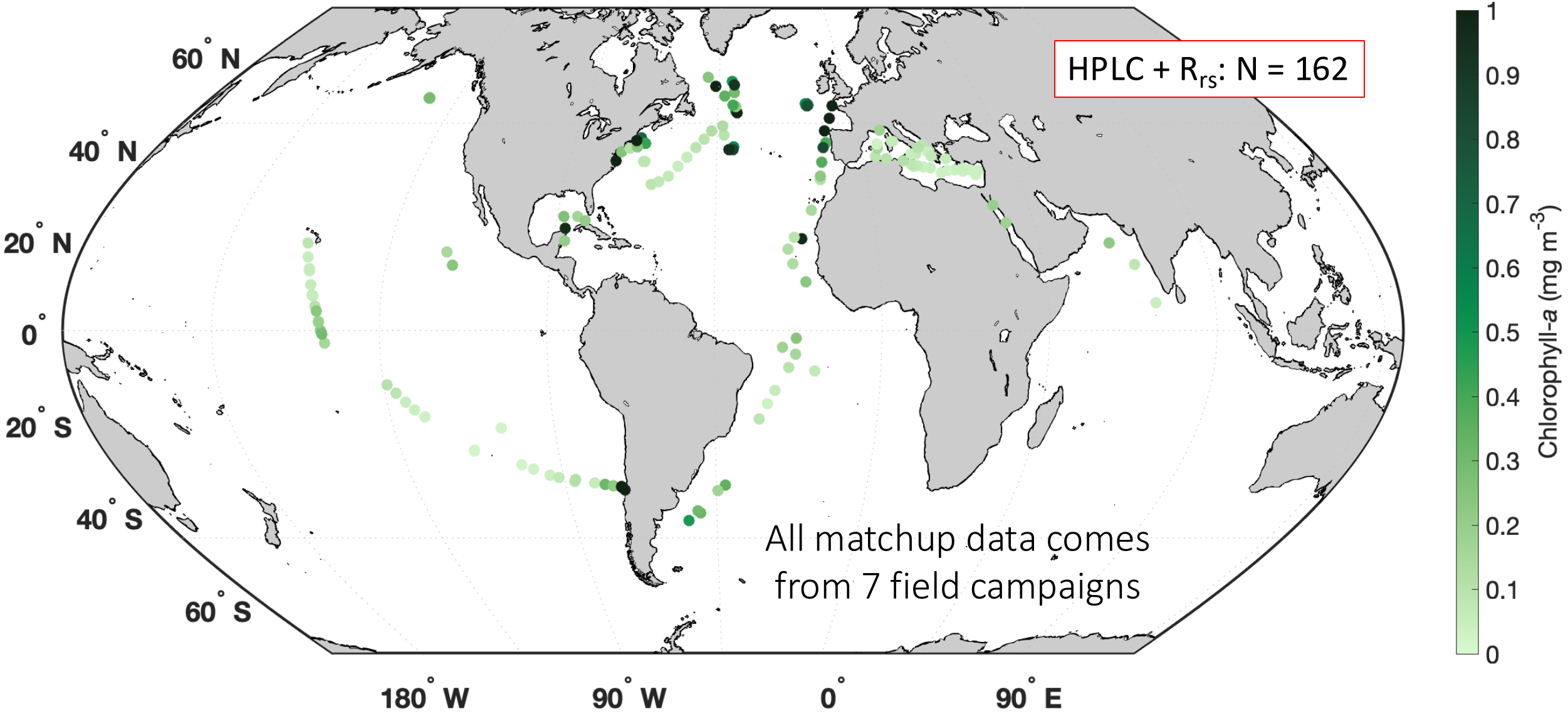


Chlorophylls *b* & *c*

Dinoflagellates



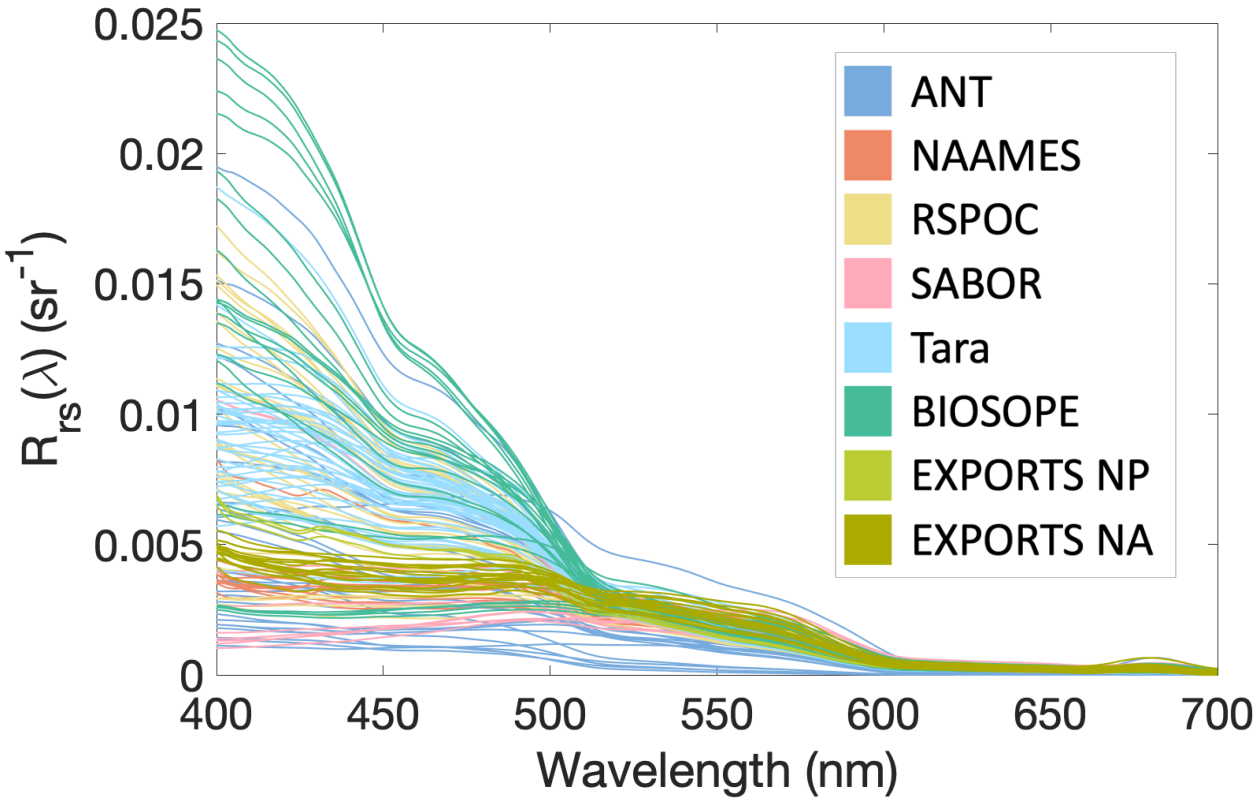
Spectral residual method



Adapted from Kramer et al., 2022 *Remote Sensing of Environment*

Spectral residual method

Measured spectra



Construct a generic hyperspectral model to reconstruct remote sensing reflectance:

$$R_{rs,mod}(\lambda) = f(a, b_b) \text{ where}$$

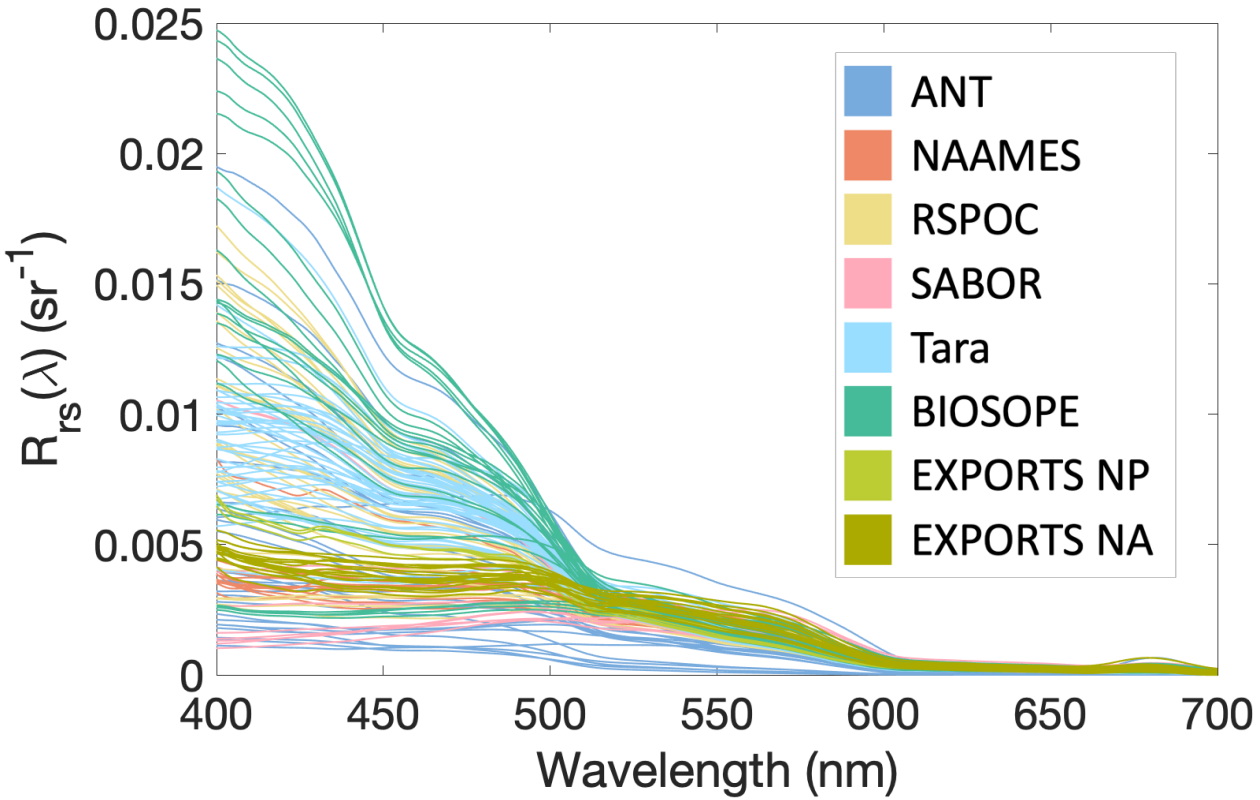
$$a = a_{ph} + a_{dg} + a_{water} \text{ and}$$

$$b = b_{bp} + b_{bwater}$$

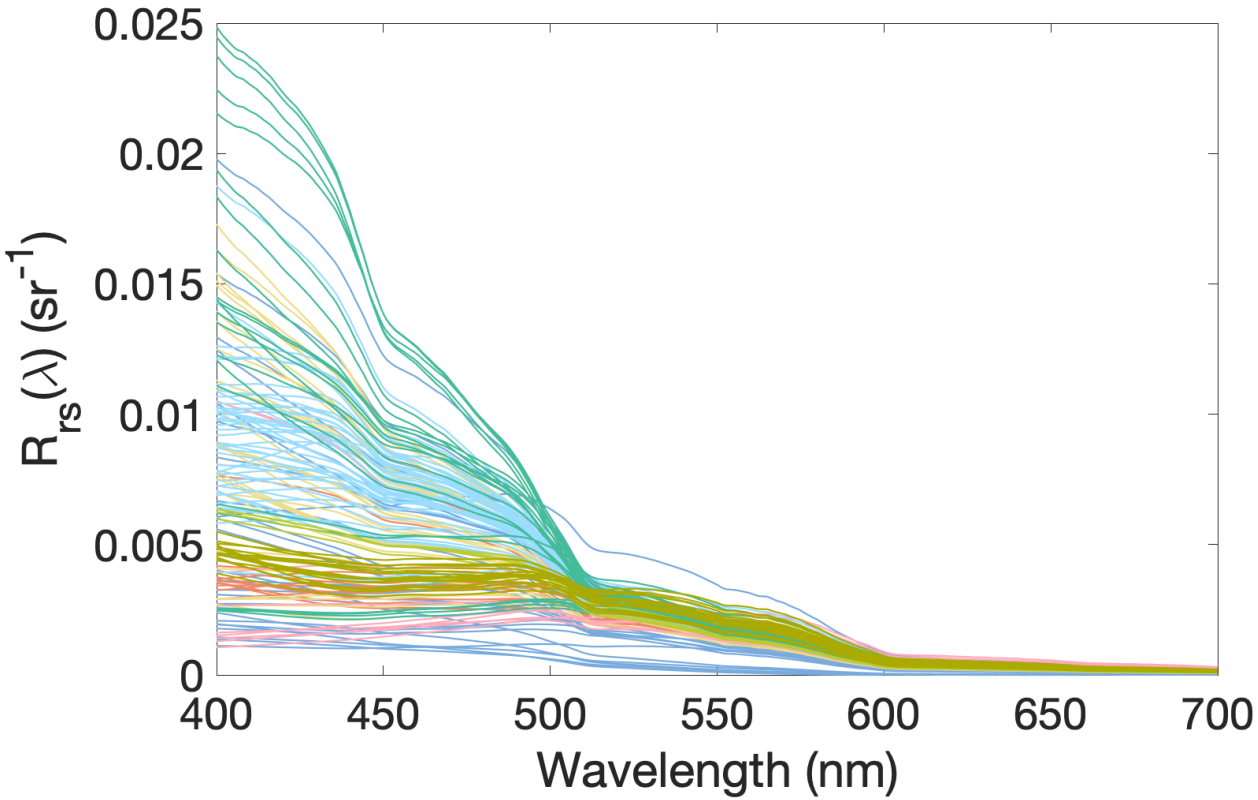
Adapted from Kramer et al., 2022 *Remote Sensing of Environment*

Spectral residual method

Measured spectra



Modeled spectra

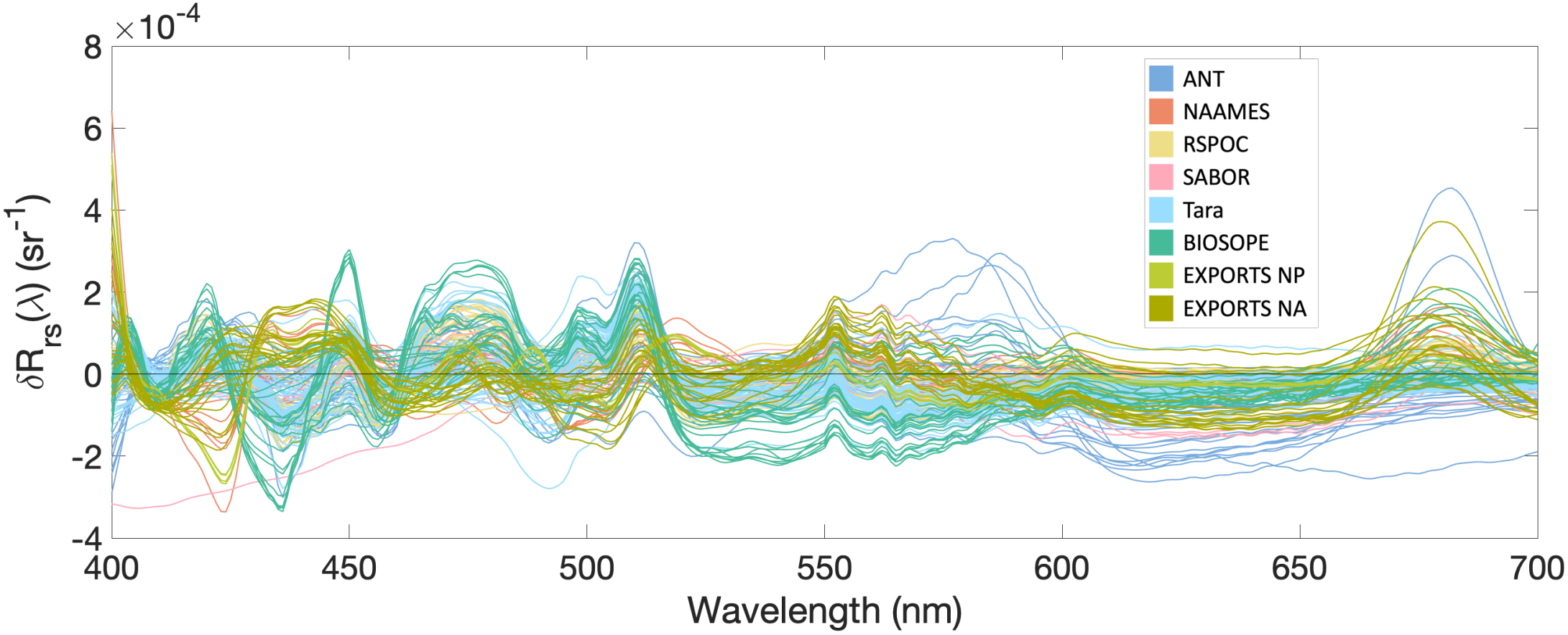


They would look identical if our assumptions were correct

Adapted from Kramer et al., 2022 *Remote Sensing of Environment*

Spectral residual method

R_{rs} residual (δR_{rs}) = $R_{rs,meas}(\lambda) - R_{rs,mod}(\lambda)$



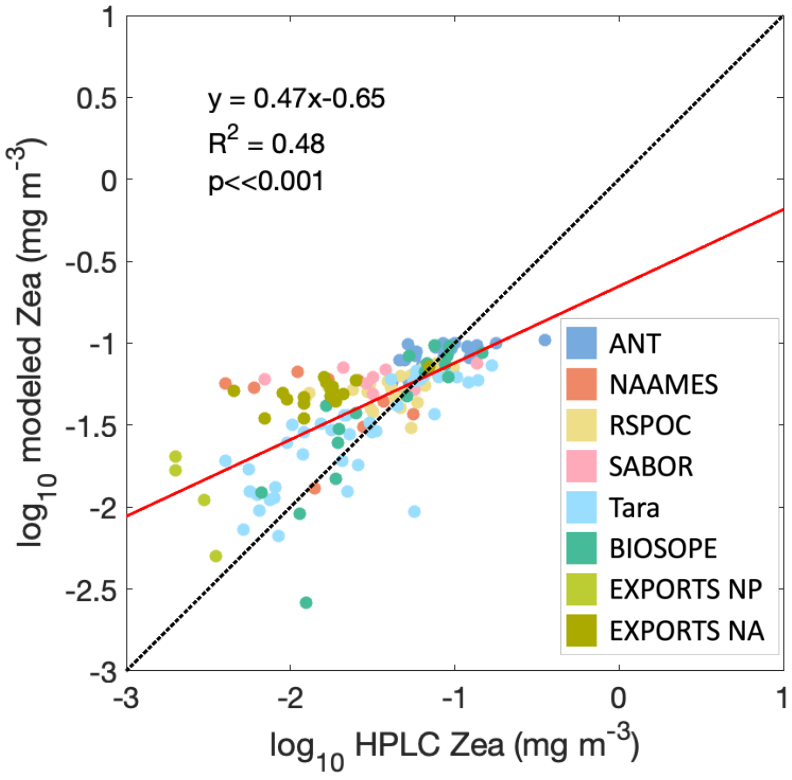
Use the reflectance residual (δR_{rs}) for further modeling…

Adapted from Kramer et al., 2022 *Remote Sensing of Environment*

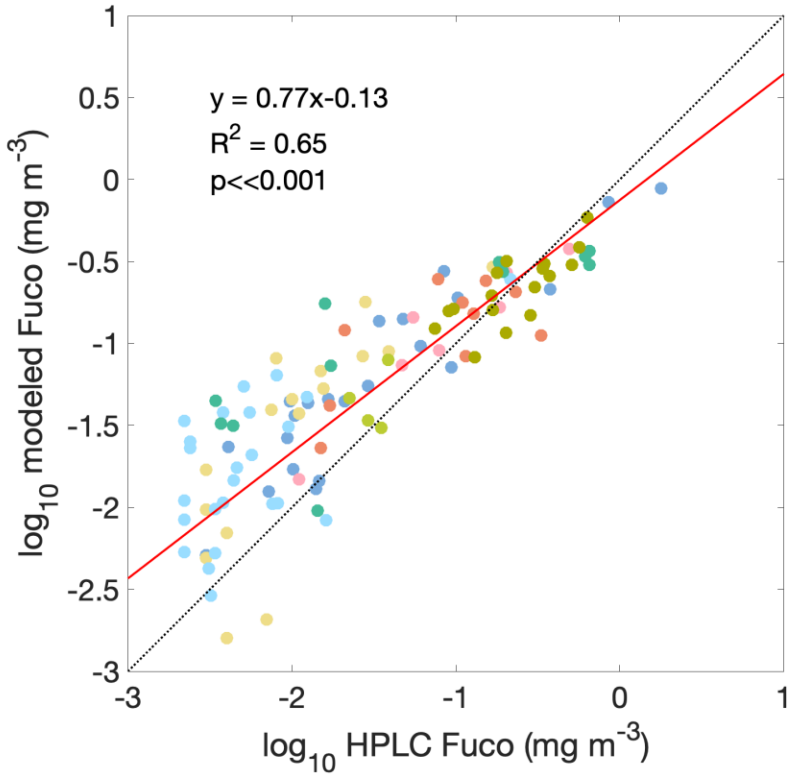
Spectral residual method

Modeled vs. measured pigments

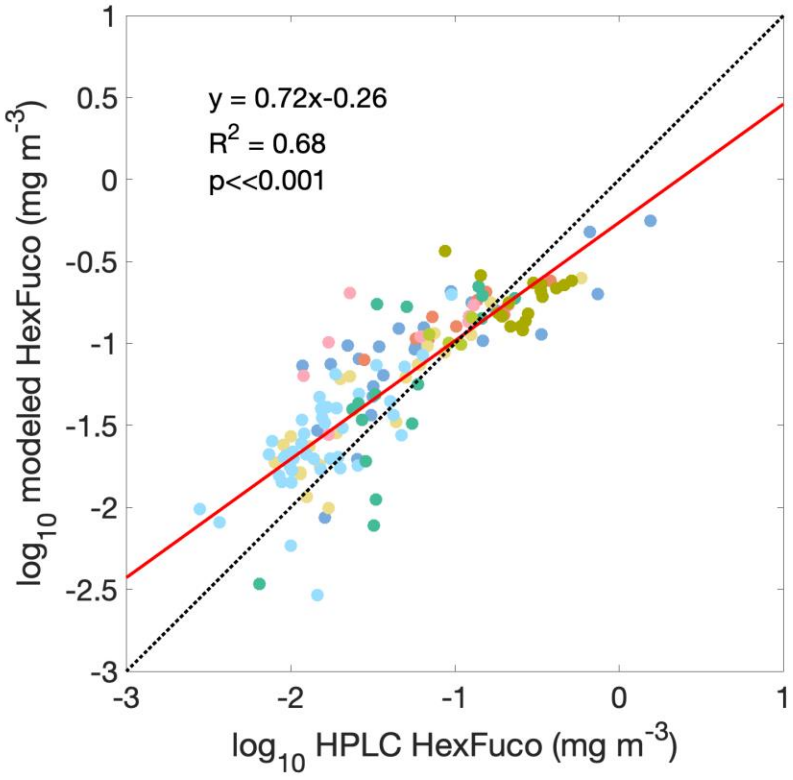
Zeaxanthin (cyanos)



Fucoxanthin (diatoms)



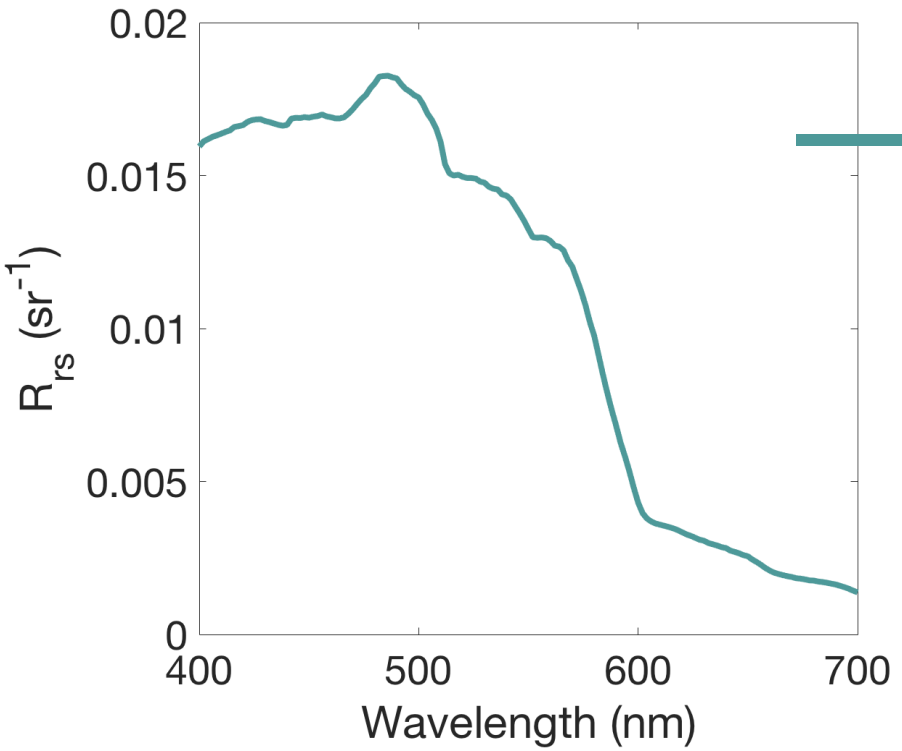
HexFuco (haptophytes)

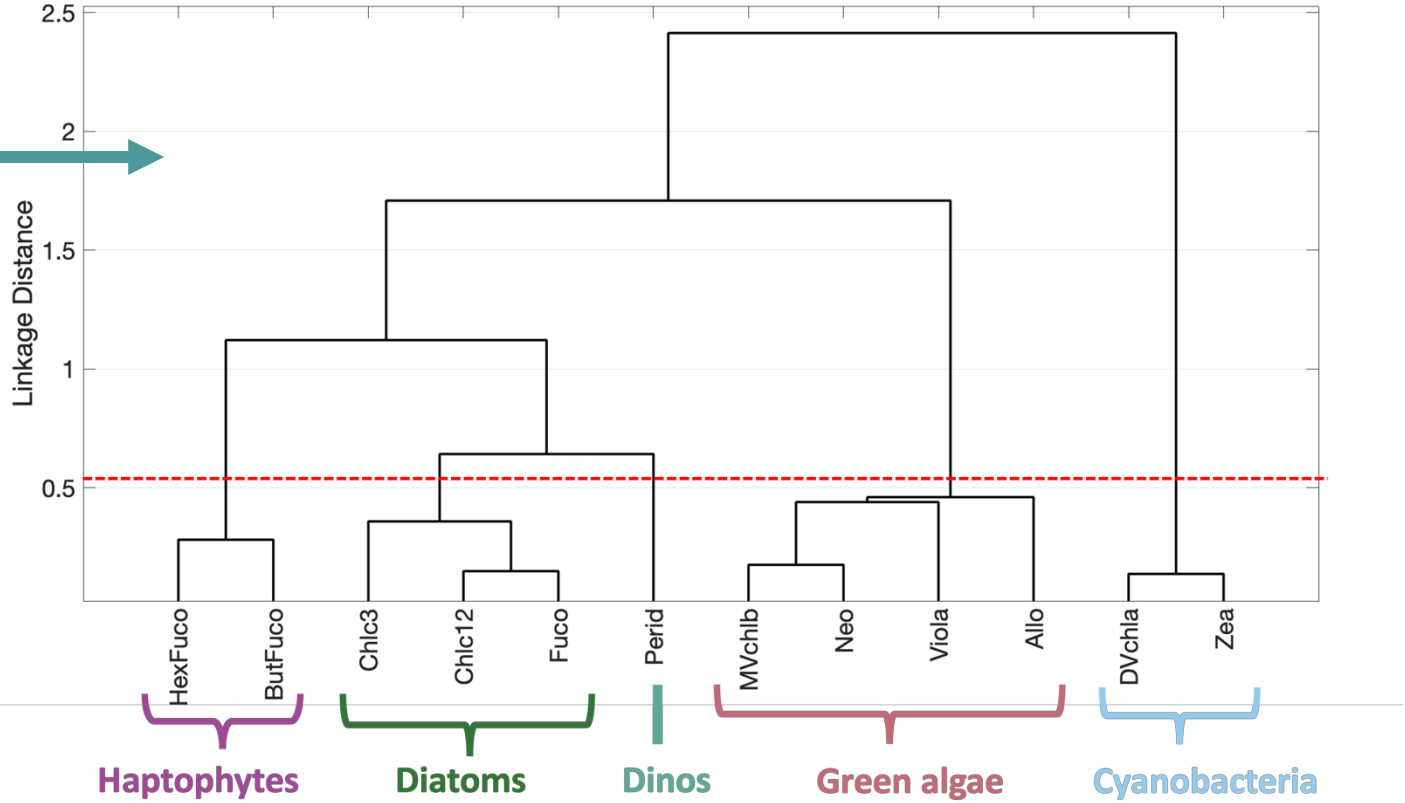


Adapted from Kramer et al., 2022 *Remote Sensing of Environment*
with new data included in Kramer et al., 2024 *Optics Express*

Going from ocean color to phytoplankton with PACE

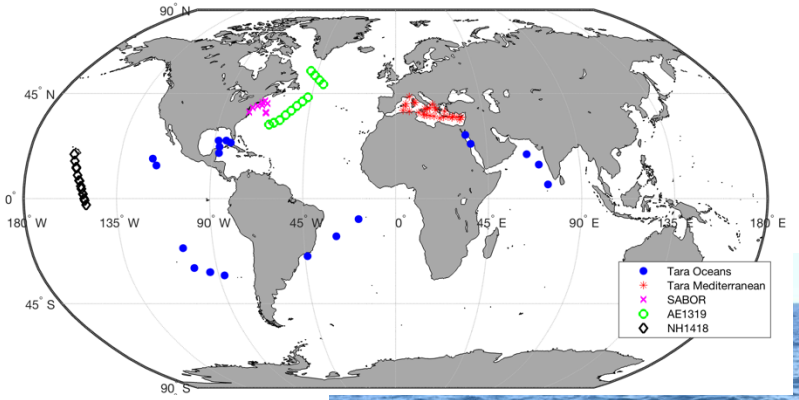
Using hyperspectral δR_{rs} data, we can model 13 phytoplankton pigment concentrations that represent 5 phytoplankton groups.

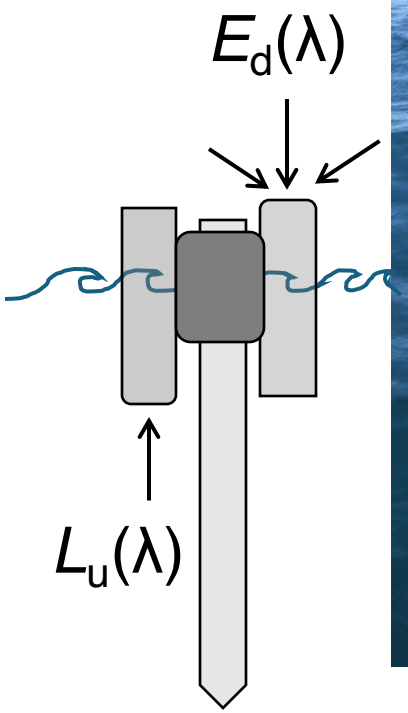


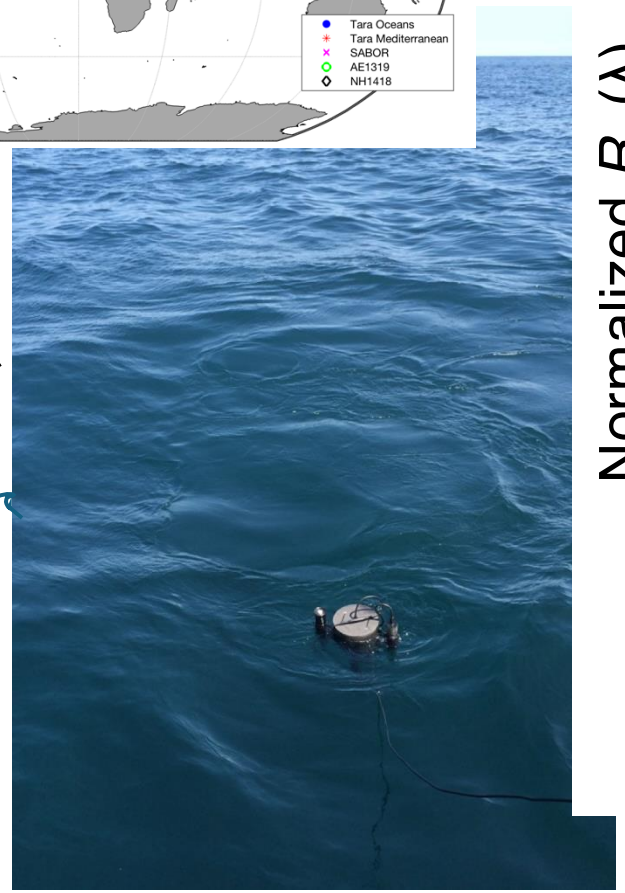


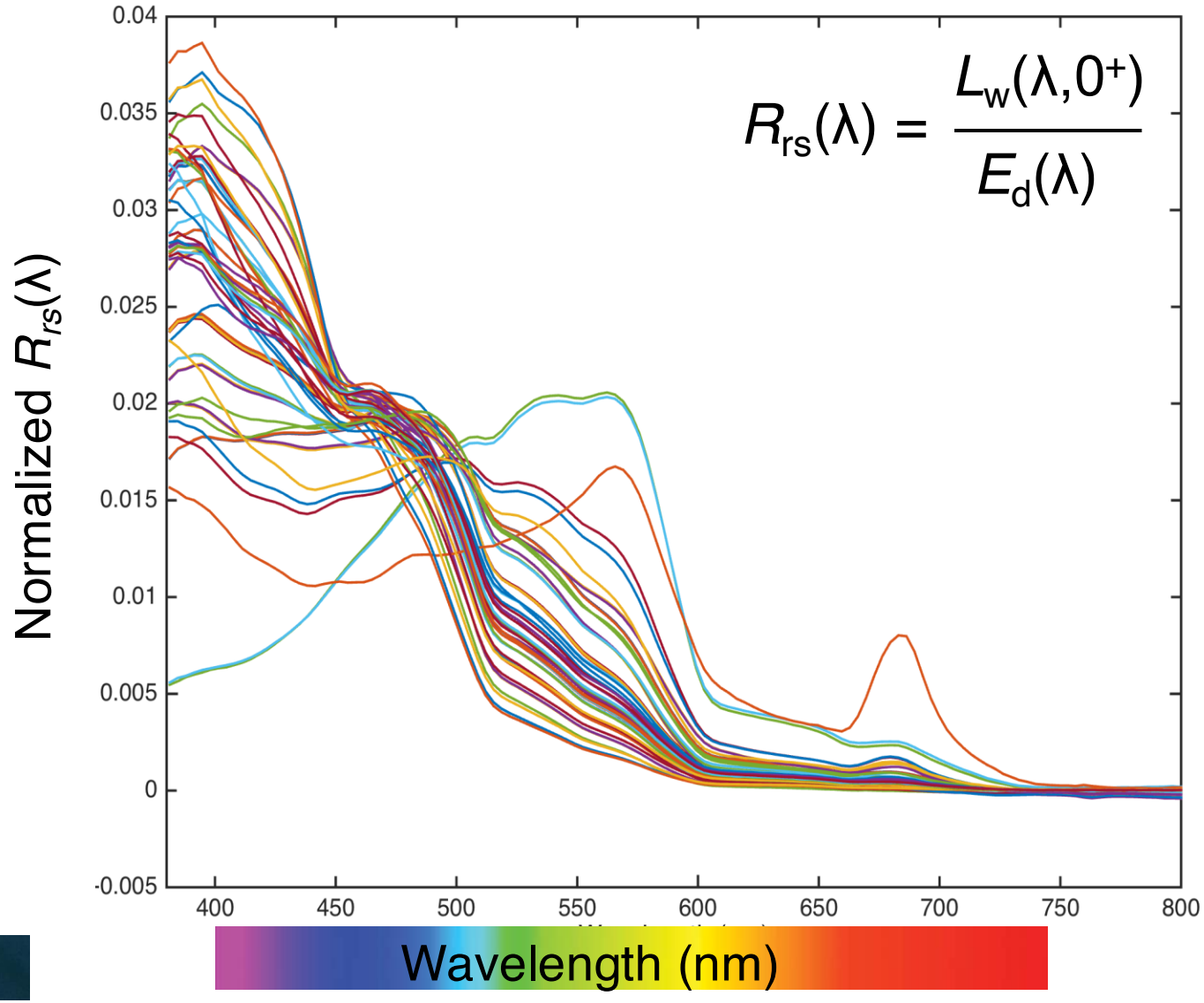
Kramer et al., 2022 *Remote Sensing of Environment*

Pigments estimated from $R_{rs}(\lambda)$ spectra measured *in situ*



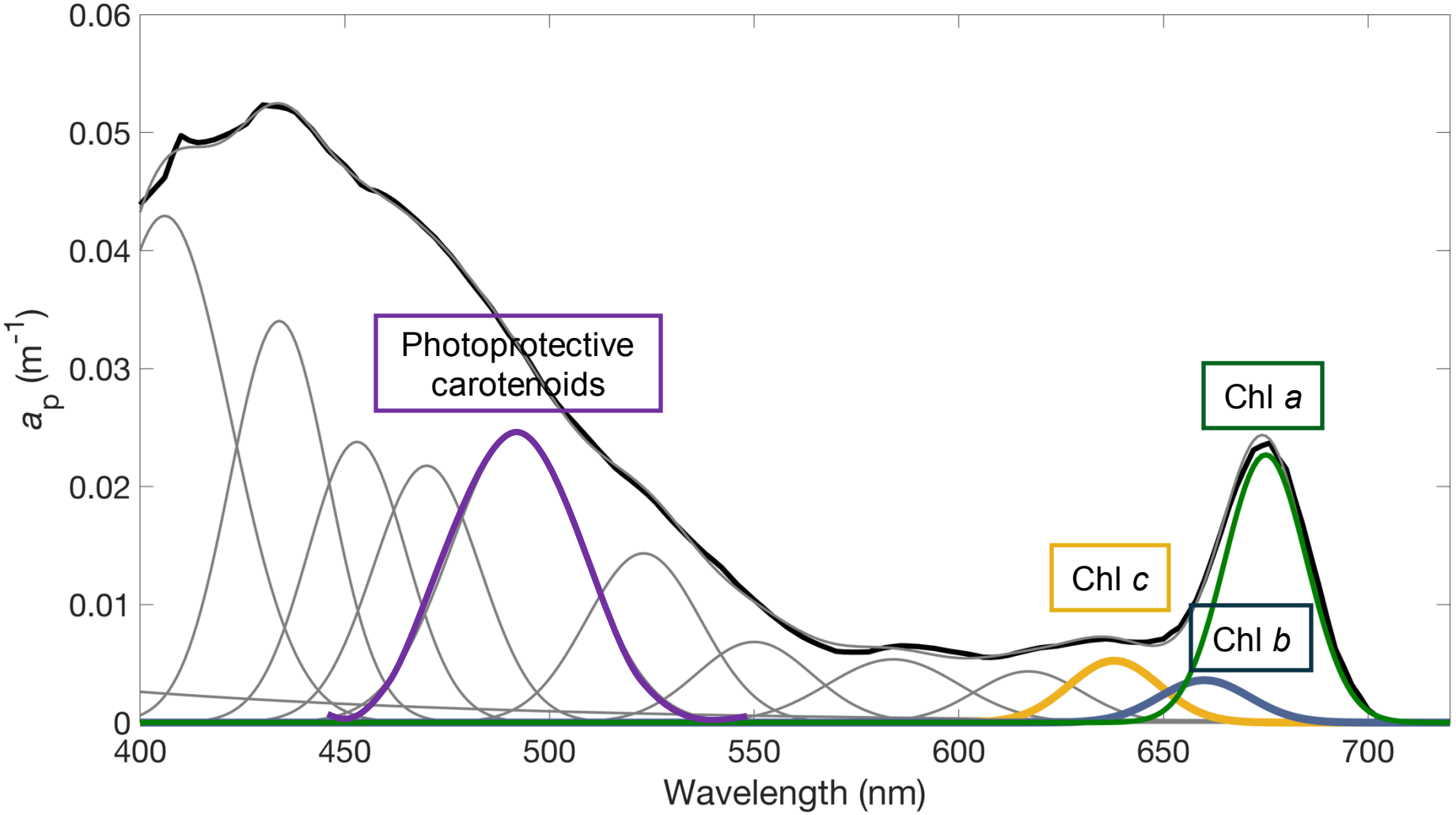






Chase et al. 2017, *JGR – Oceans*

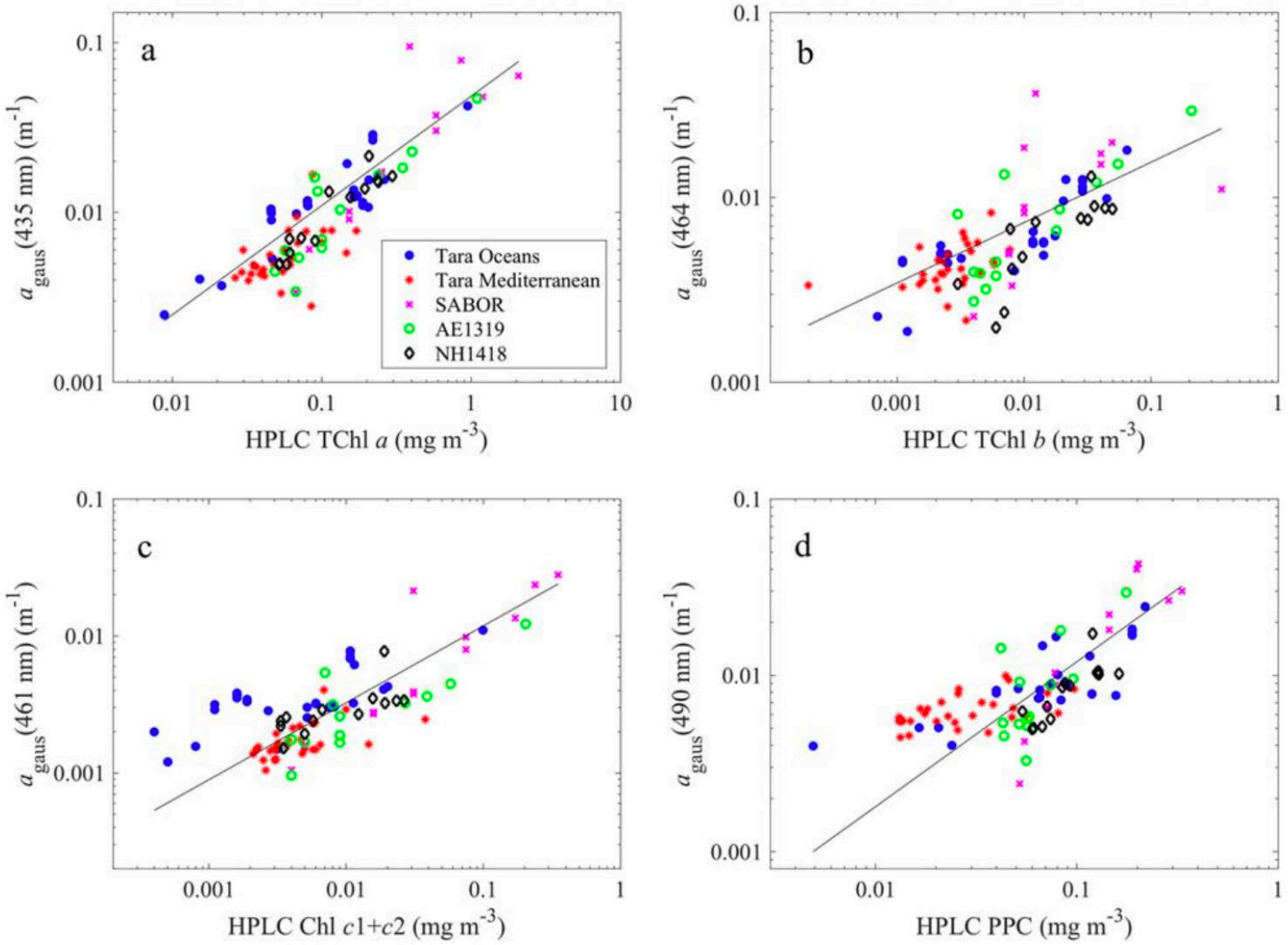
Gaussian functions representing phytoplankton pigment absorption



Chase et al. 2013

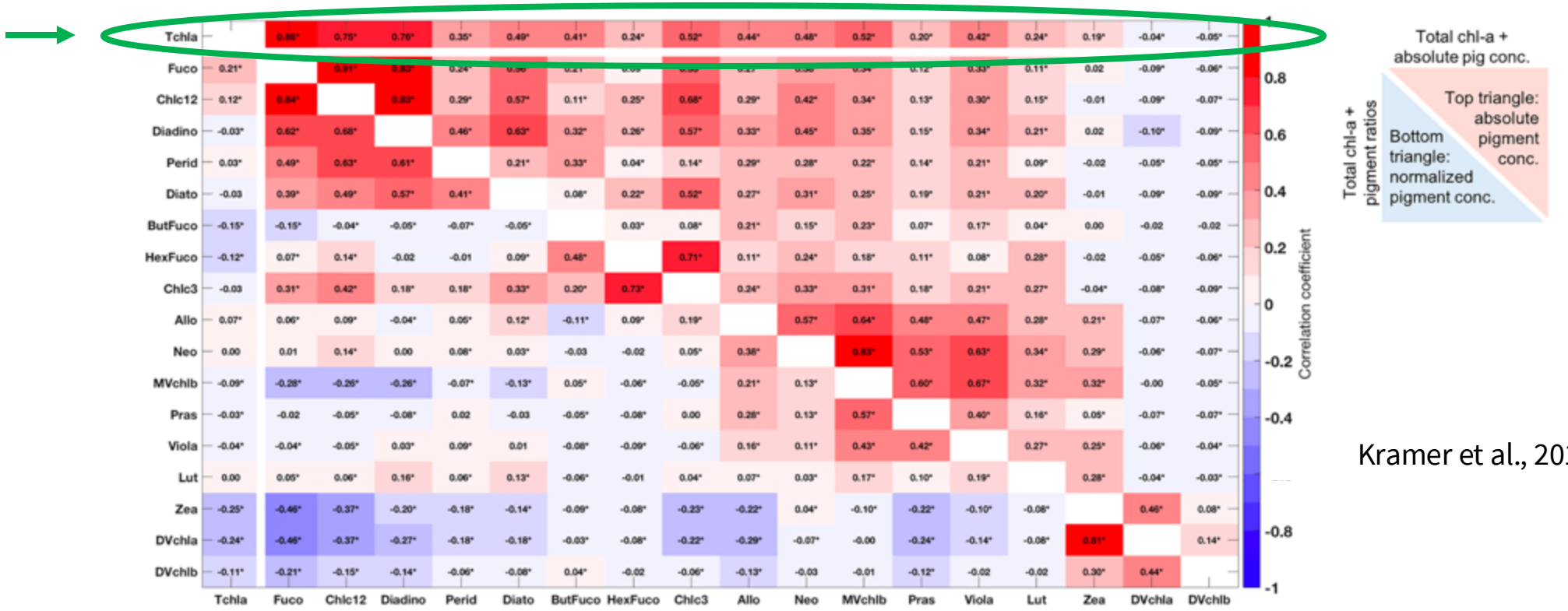
Combined inversion & decomposition method

Absorption in the blue wavelengths and phytoplankton pigments

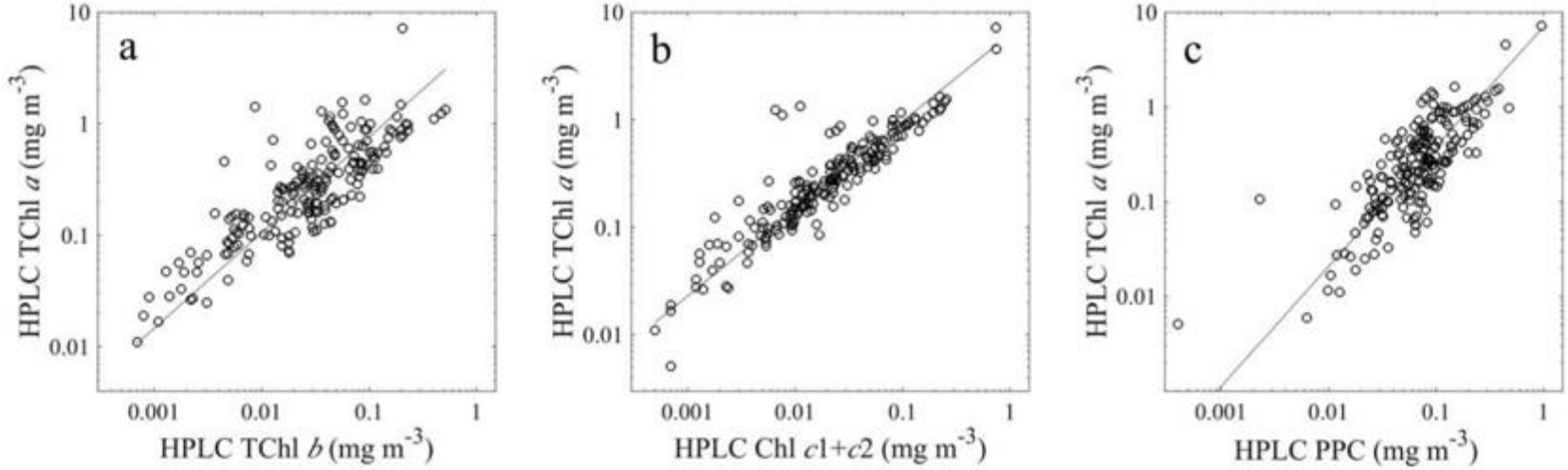


Chase et al., 2017. *JGR - Oceans*

But most pigments are correlated with Chl *a*…



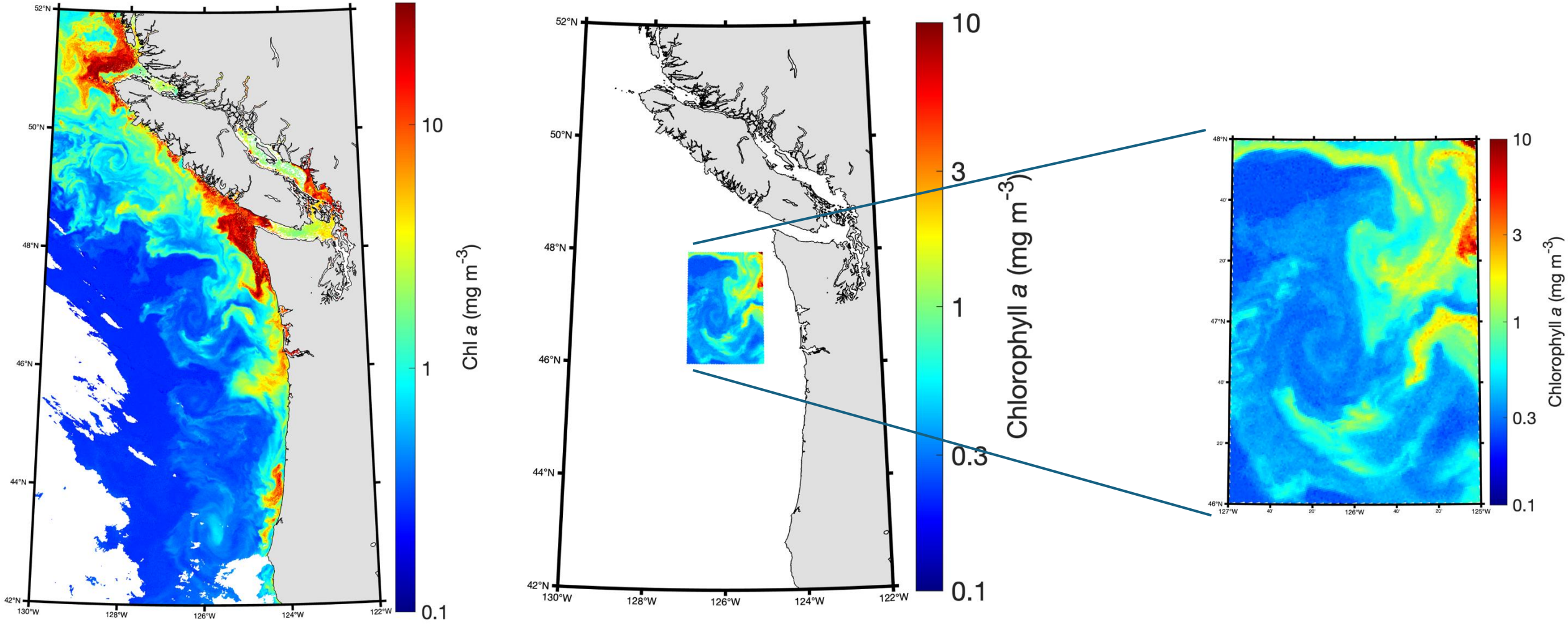
Kramer et al., 2019



Chase et al., 2017

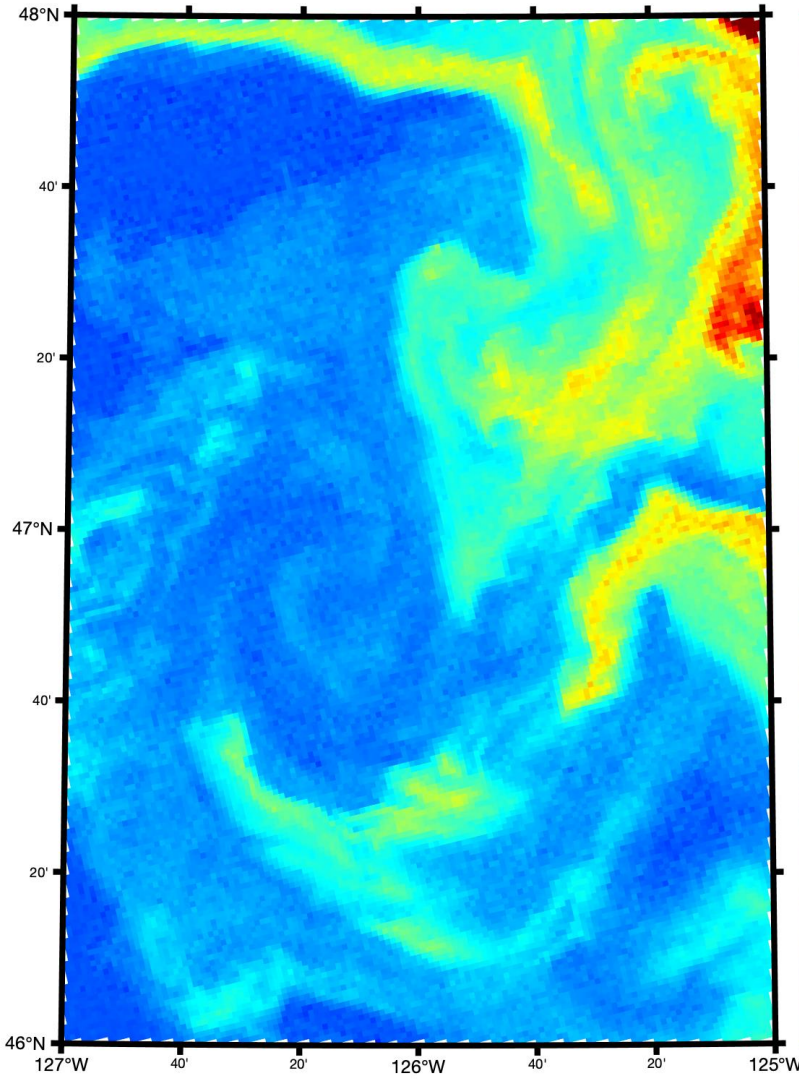
Application to PACE data

PACE OCI L2 Chlorophyll *a* – April 18, 2024

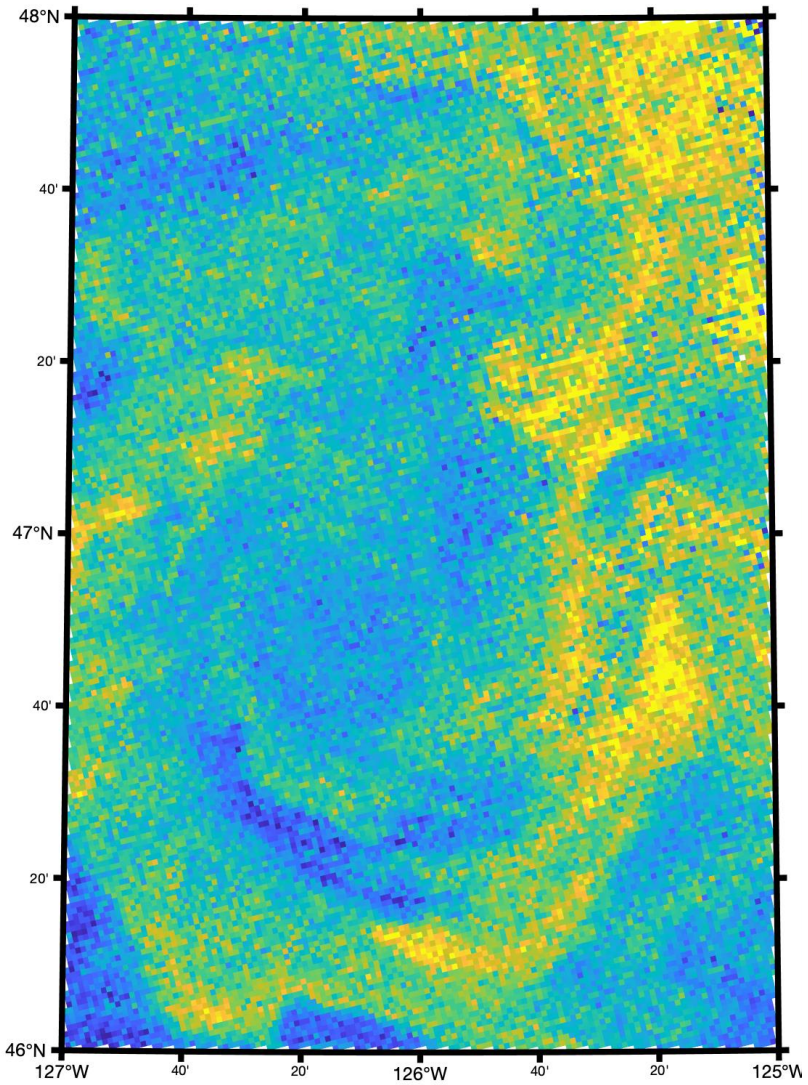


Application to PACE data

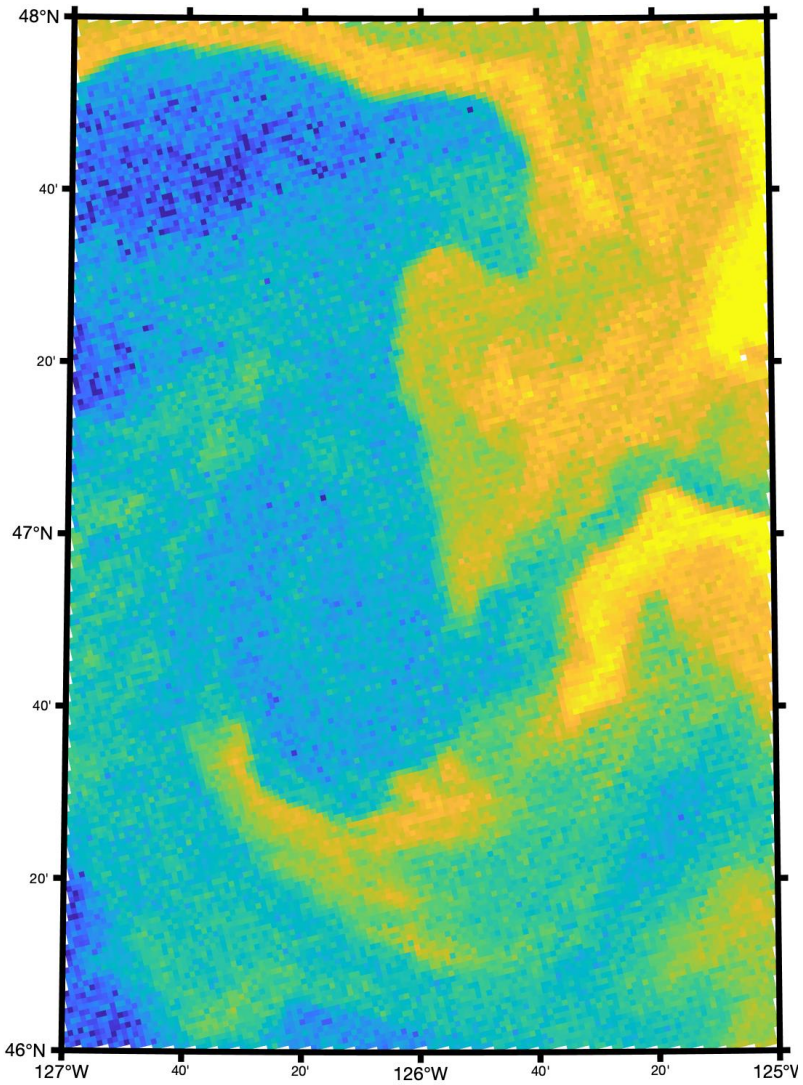
Pigments estimated from OCI L2 $R_{rs}(\lambda)$ spectra – April 18, 2024



Chlorophyll *a*



Chlorophyll *c*

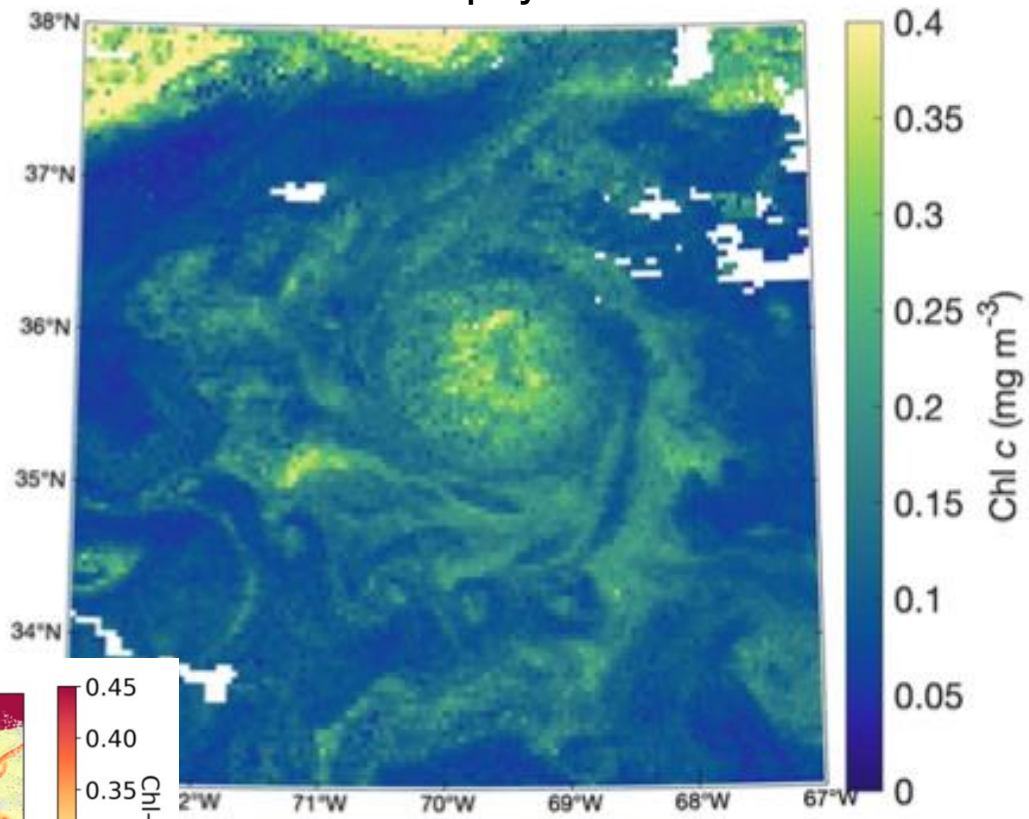


Chlorophyll *b*

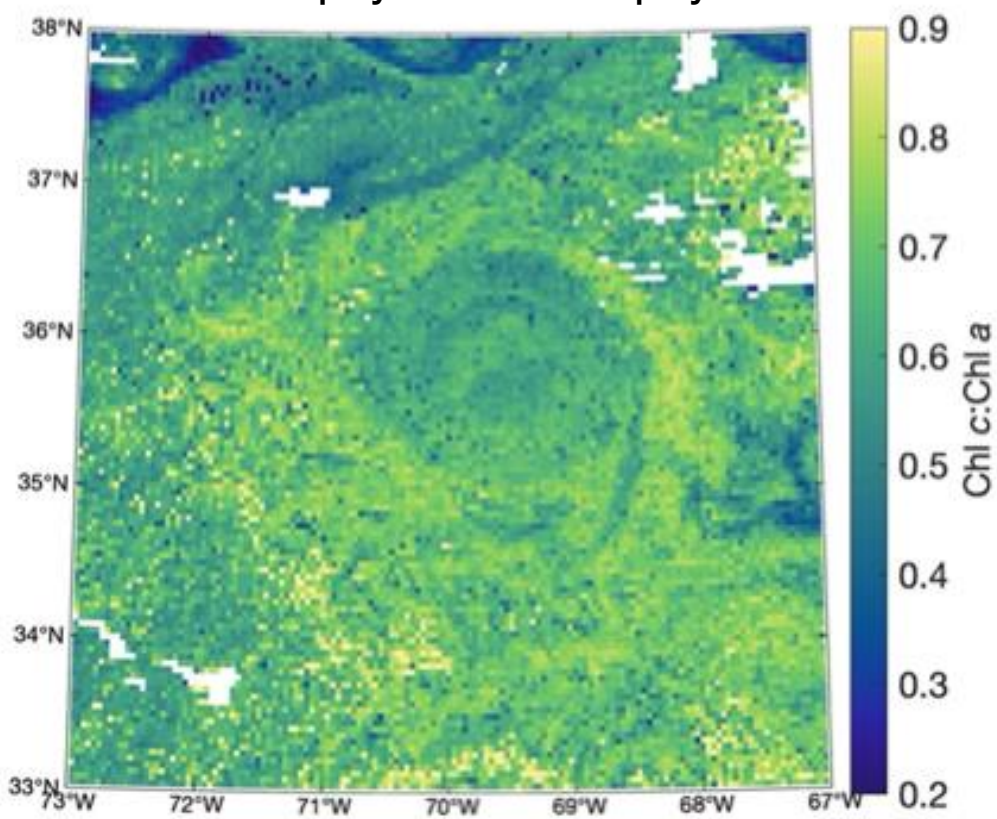
Application to PACE data

Pigments estimated from OCI L2 $R_{rs}(\lambda)$ spectra – April 14, 2024

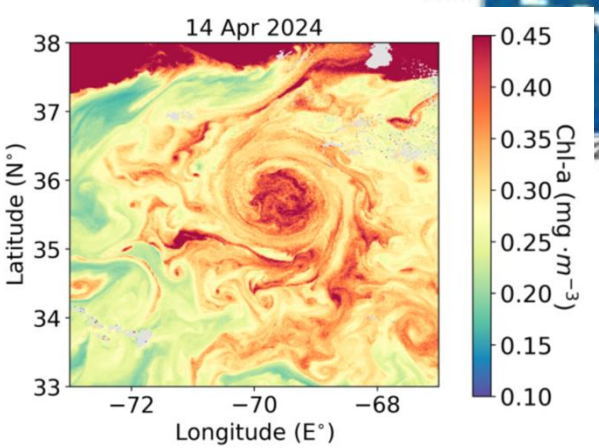
Chlorophyll *c*



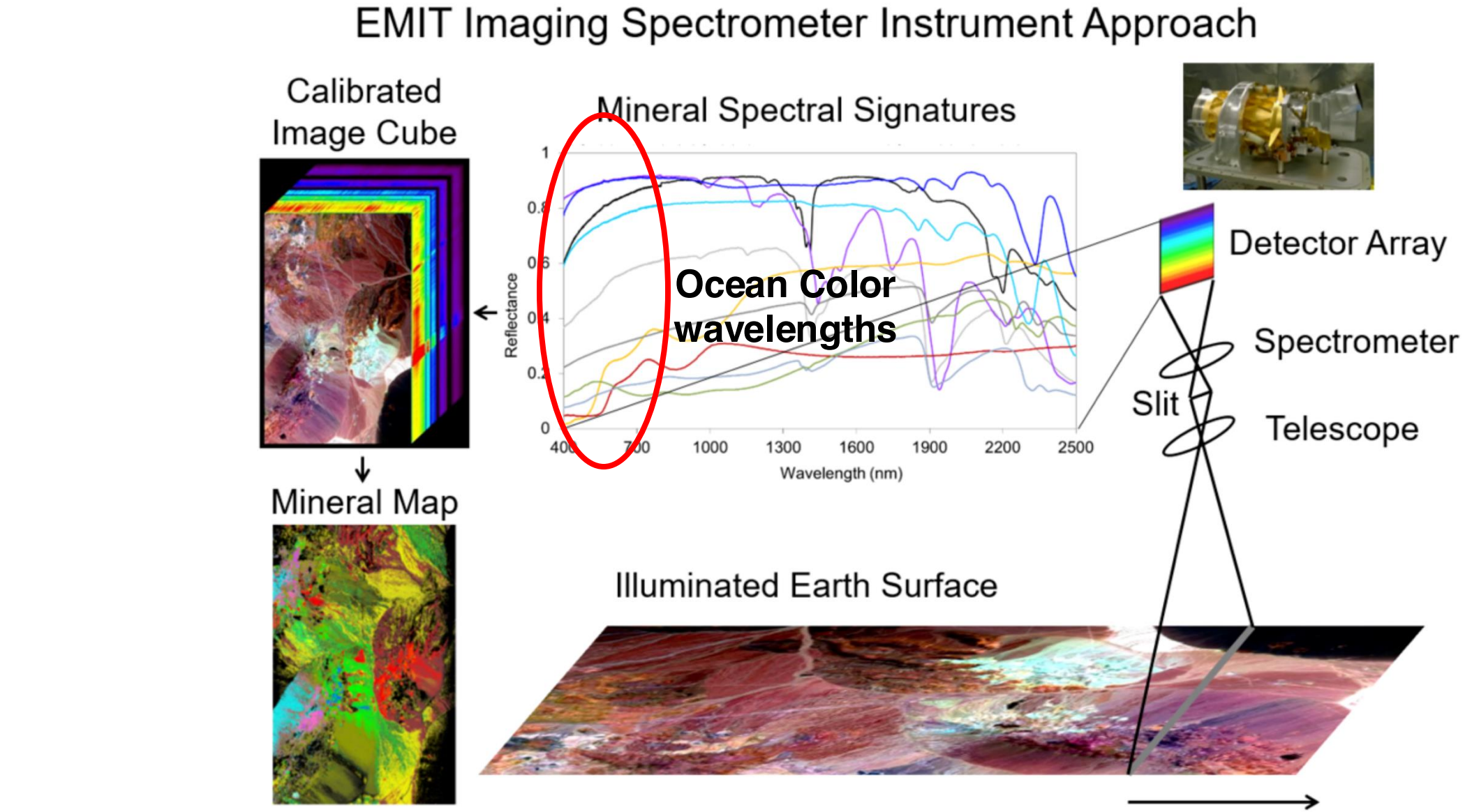
Chlorophyll *c* : Chlorophyll *a*



Chlorophyll *a*



Application to EMIT data

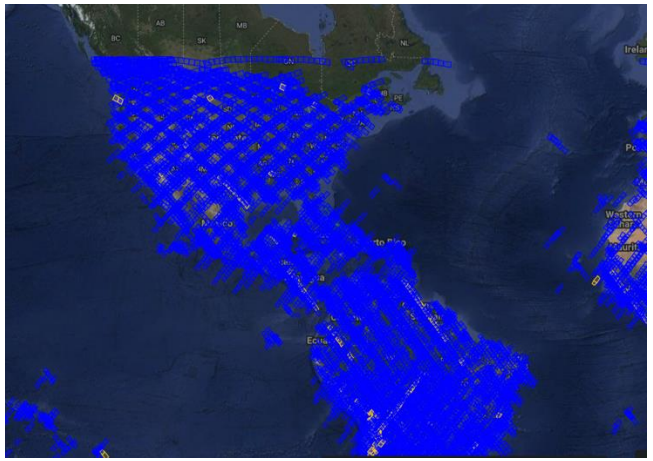


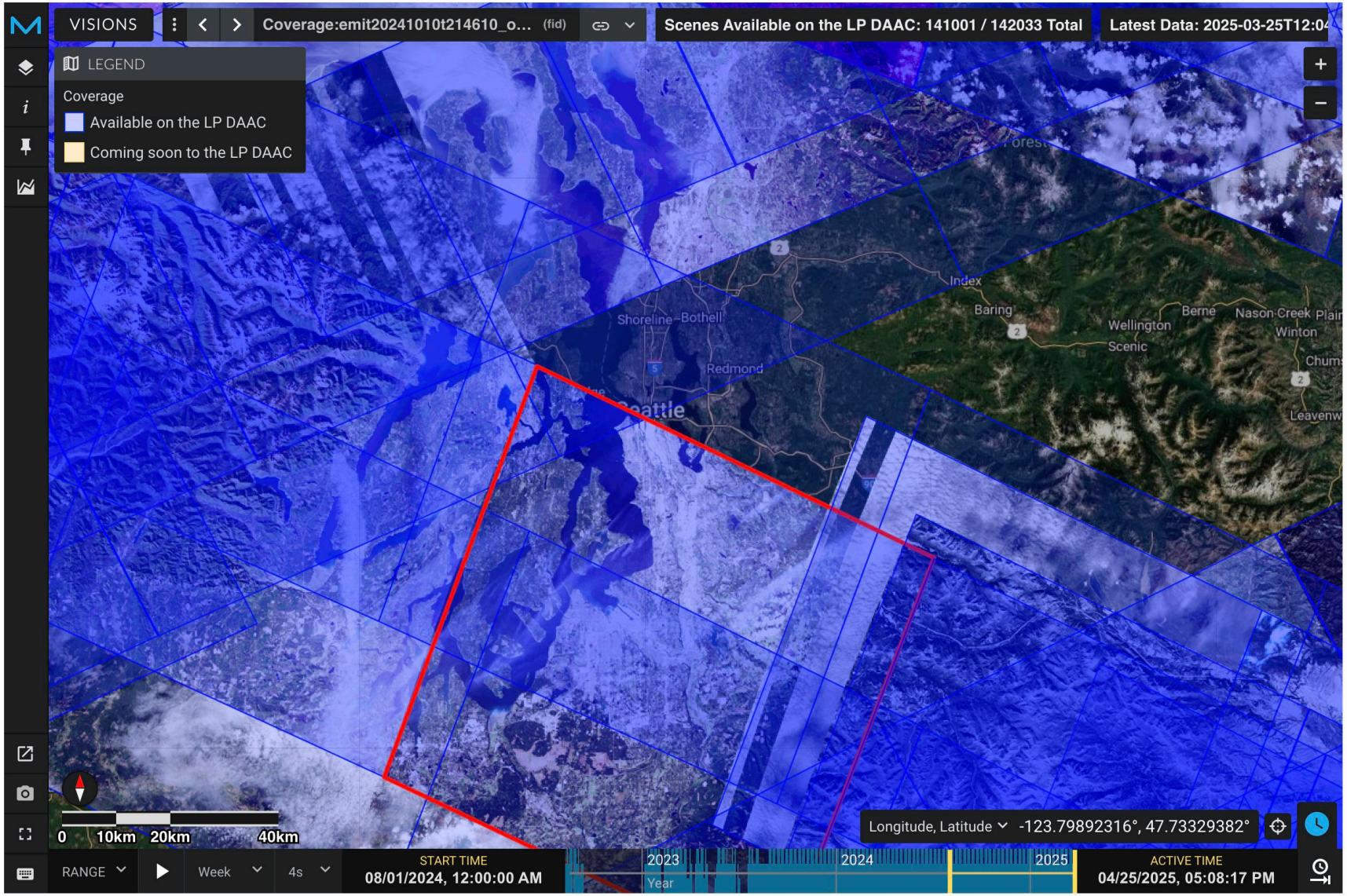
Jet Propulsion Laboratory
California Institute of Technology

https://earth.jpl.nasa.gov/emit/instrument/overview/

Application to EMIT data

EMIT data selection portal

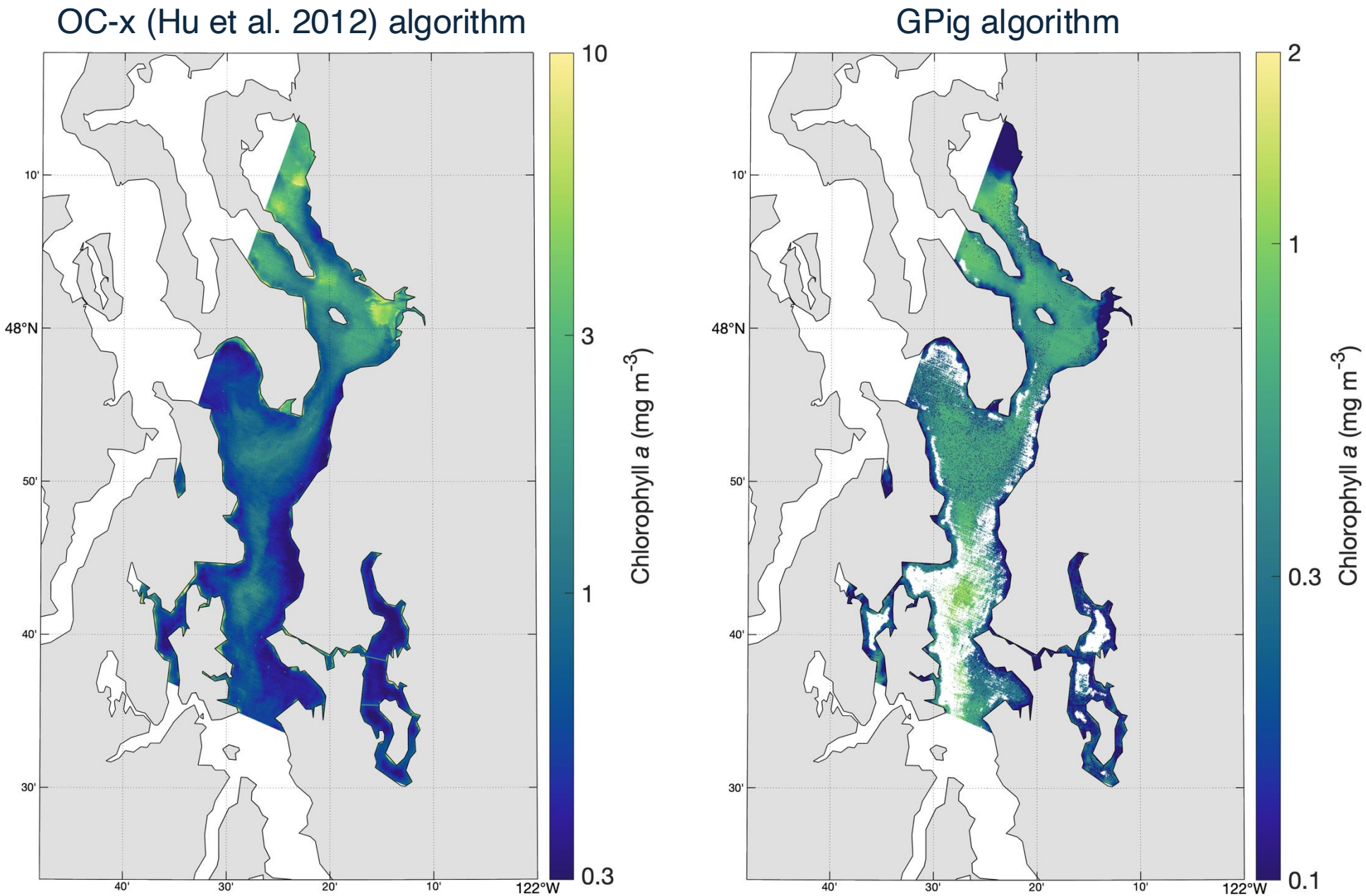




https://earth.jpl.nasa.gov/emit/data/data-portal/coverage-and-forecasts/

Application to EMIT data

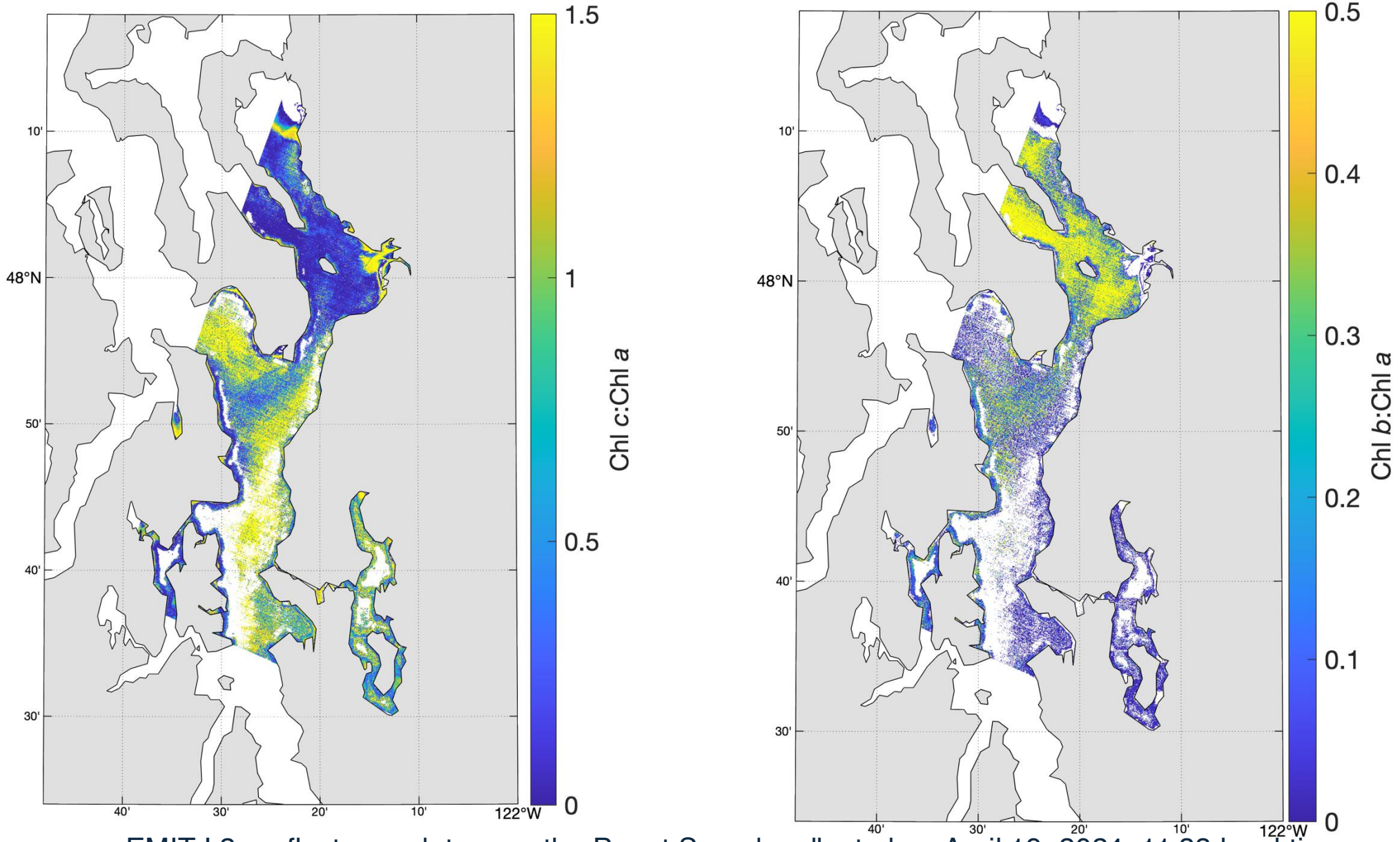
Chlorophyll a concentrations



EMIT L2a reflectance data over the Puget Sound, collected on April 19, 2024, 11:33 local time

Application to EMIT data

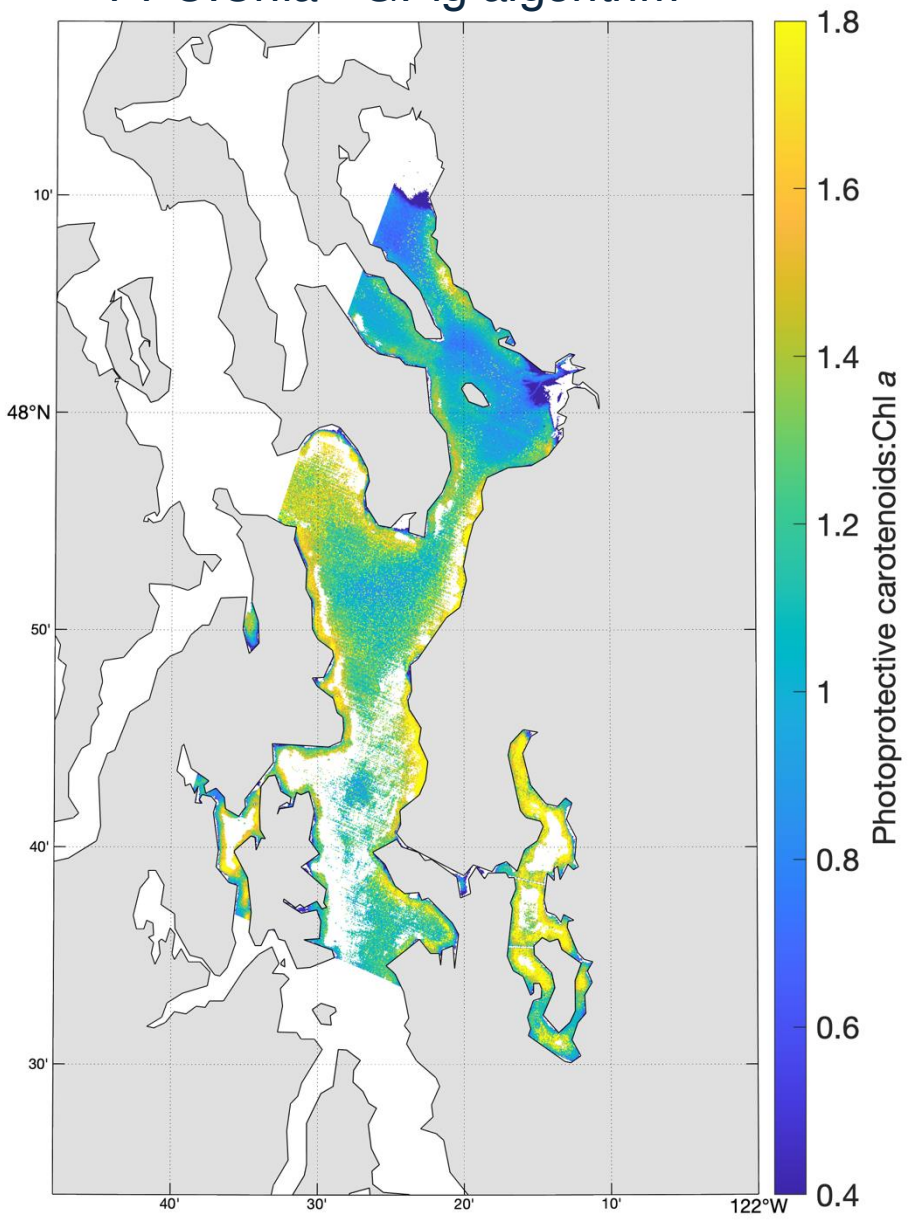
GPig-based calculations of Chl b and Chl c, shown relative to Chl a



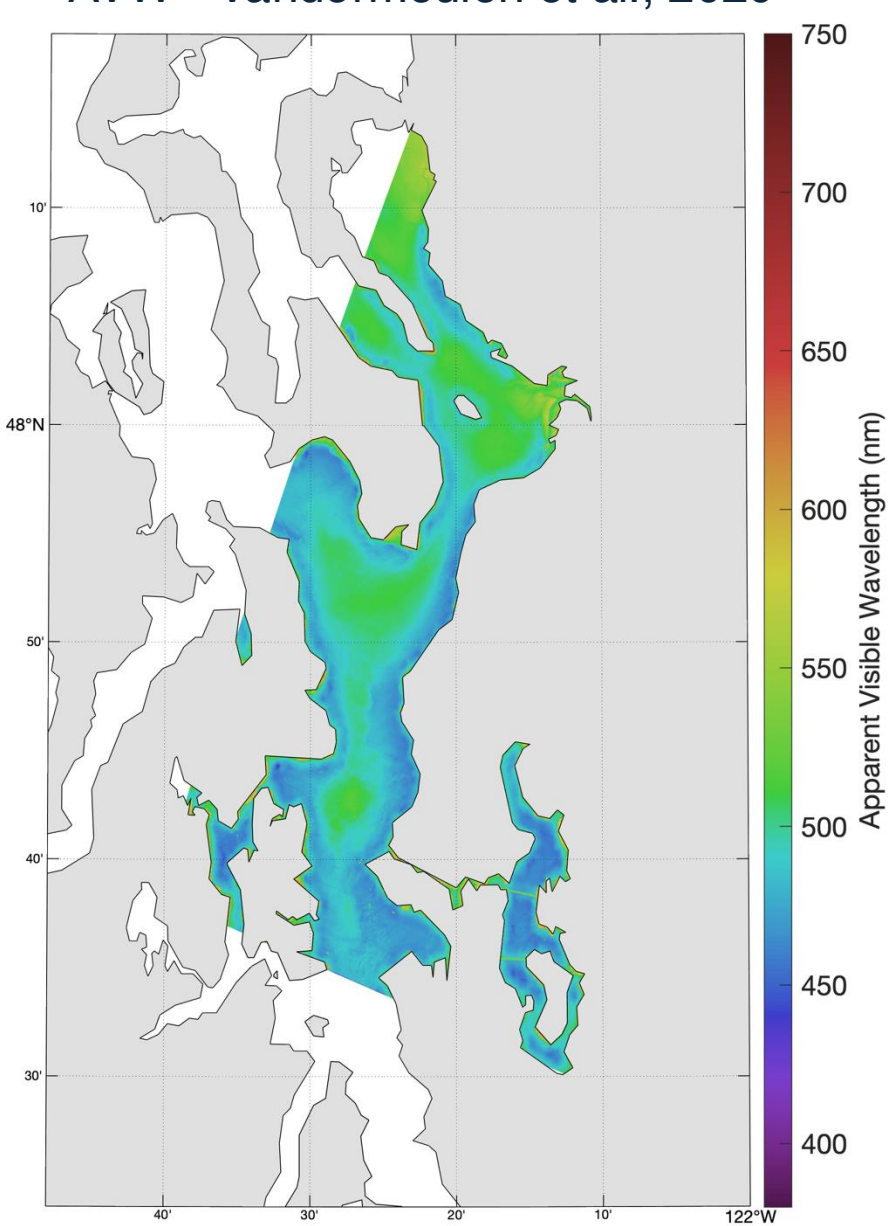
EMIT L2a reflectance data over the Puget Sound, collected on April 19, 2024, 11:33 local time

Application to EMIT data

PPC:Chla - GPig algorithm

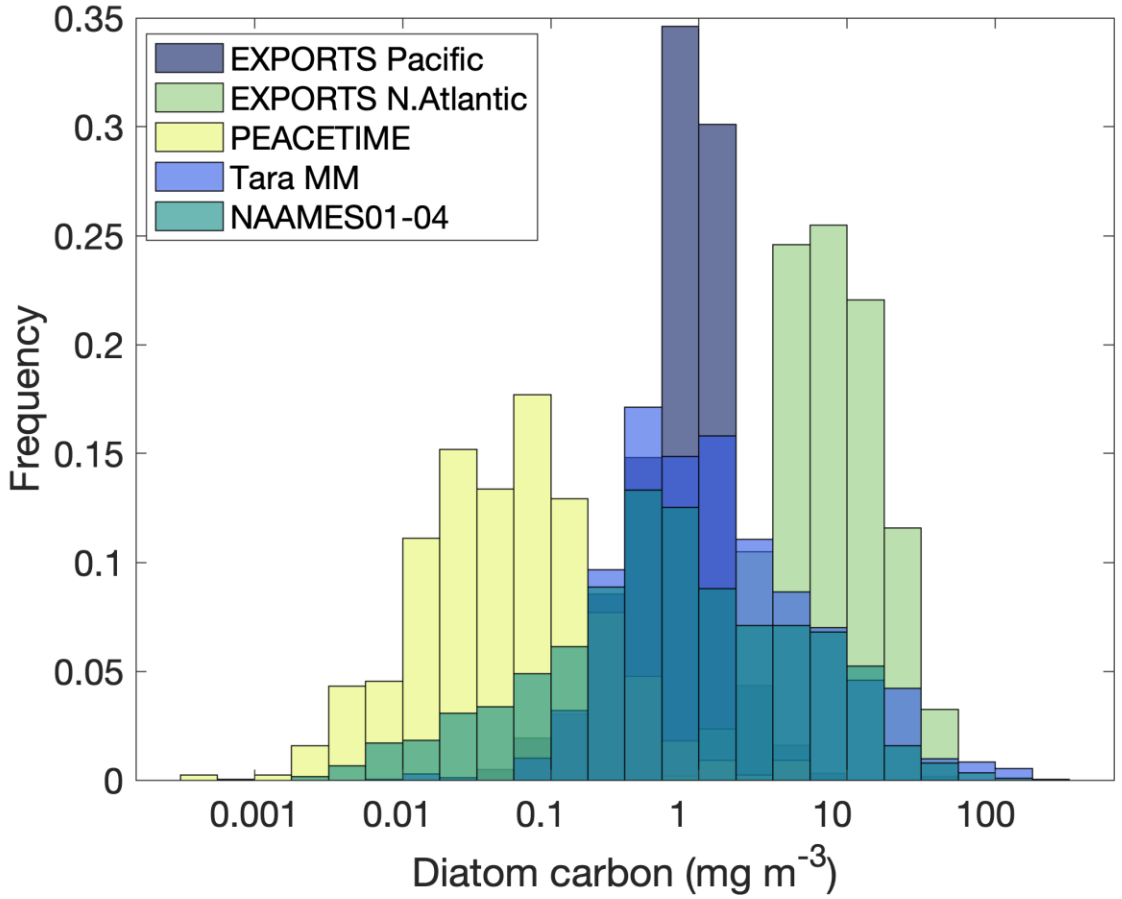


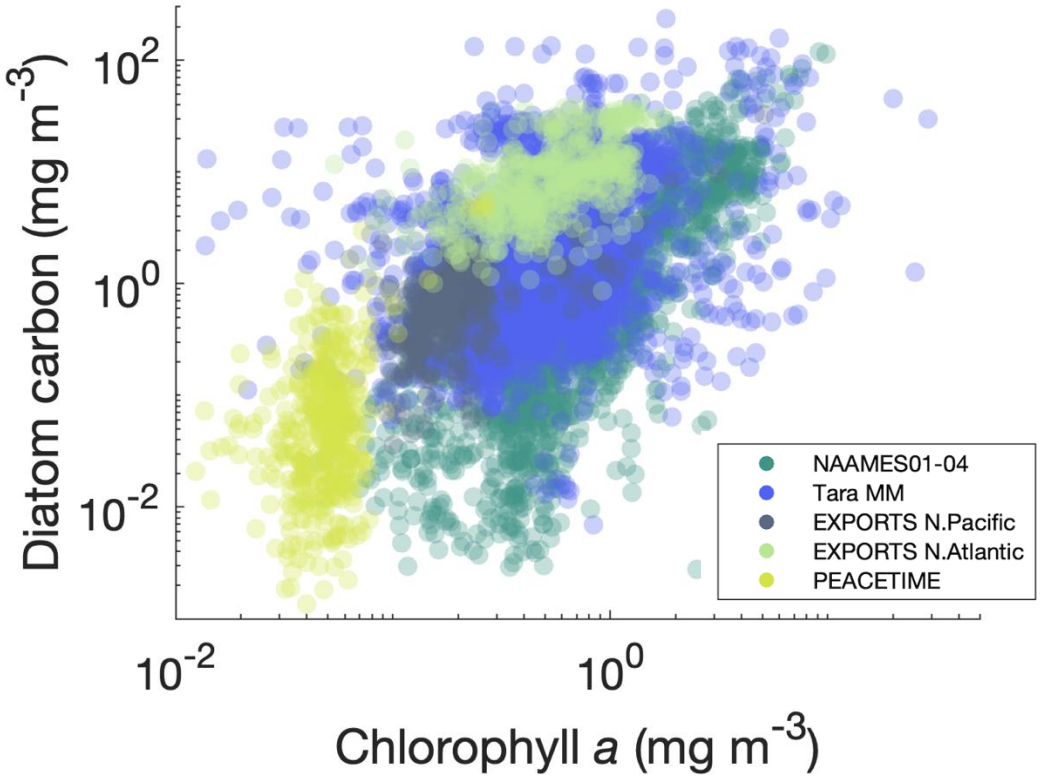
AVW - Vandermeulen et al., 2020



EMIT L2a reflectance data over the Puget Sound, collected on April 19, 2024, 11:33 local time

Diatom carbon derived from imaging-in-flow cytometry reveals relationships between diatoms and model input variables



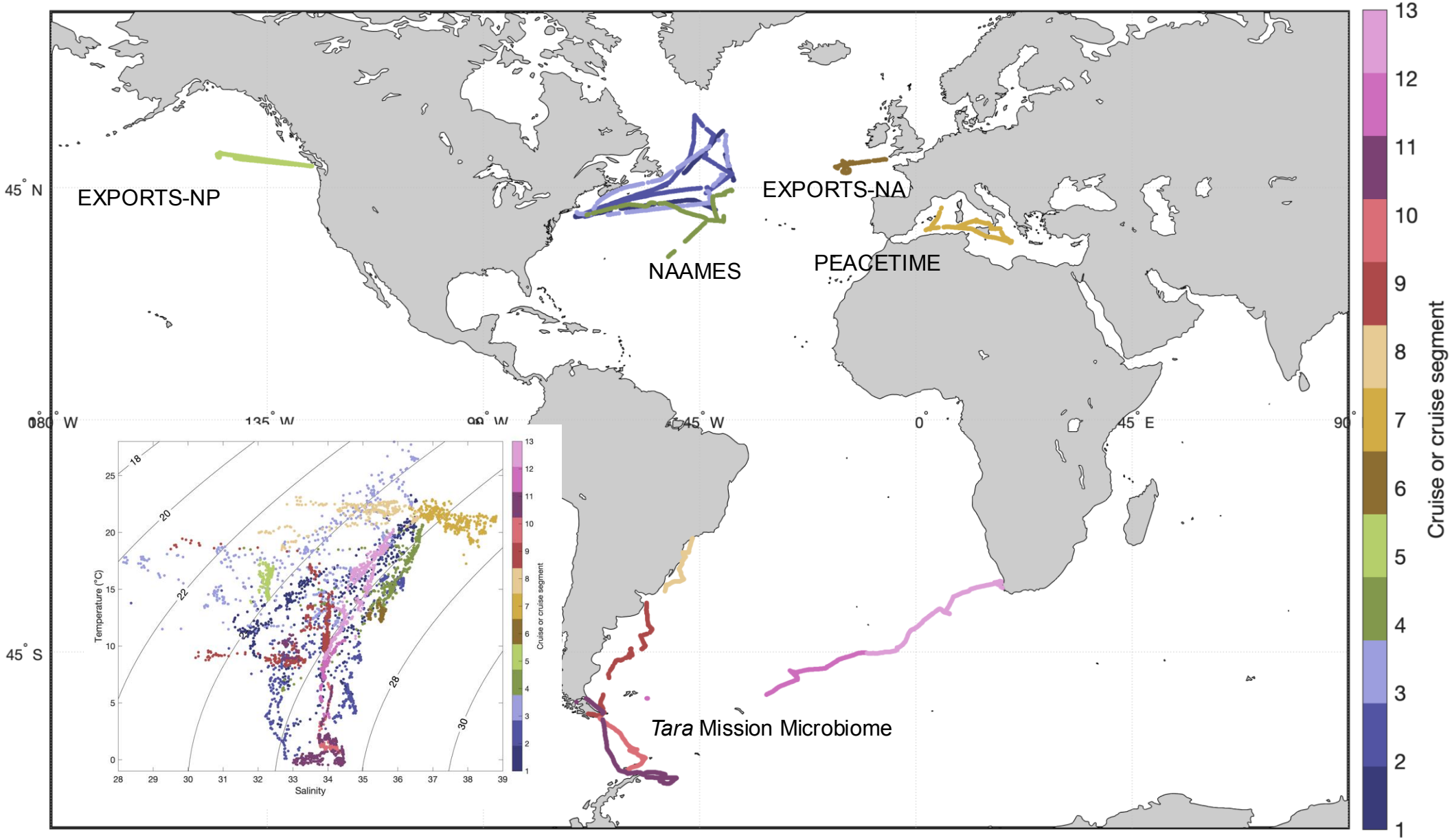




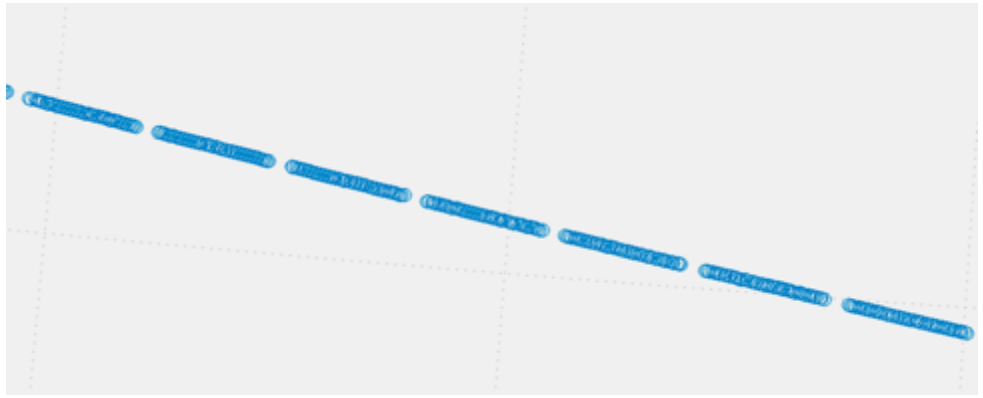
Diatom images from the IFCB

Chase et al. *in prep*

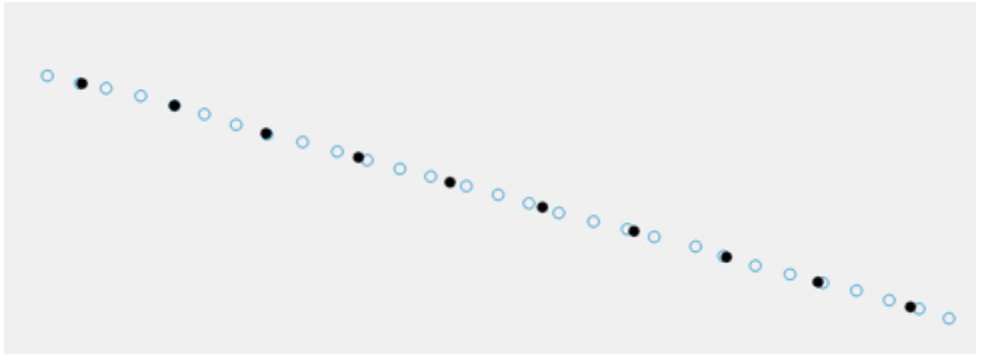
Continuous underway measurements provide in situ data across diverse regimes



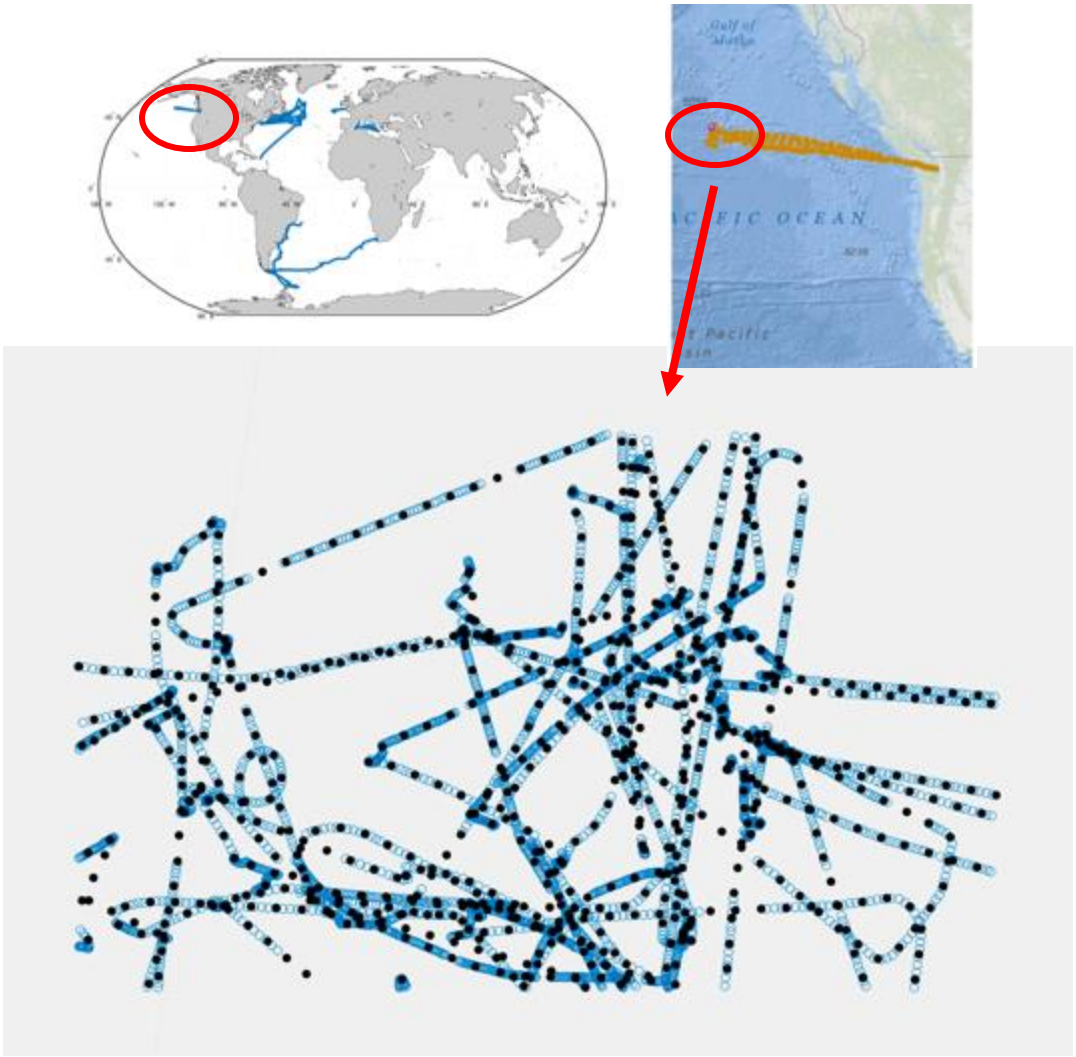
Averaging & merging all input data to a 1-km along-track “grid”



Above: example underway data 1-min binned data
Below: 1-min binned (open blue) & 1-km grid (black)



- Mean and standard deviation are stored during averaging for subsequent error propagation and uncertainty analysis
- Various types of datasets can be easily compared based on grid indices



Example when the ship is focusing on one location or feature in the ocean

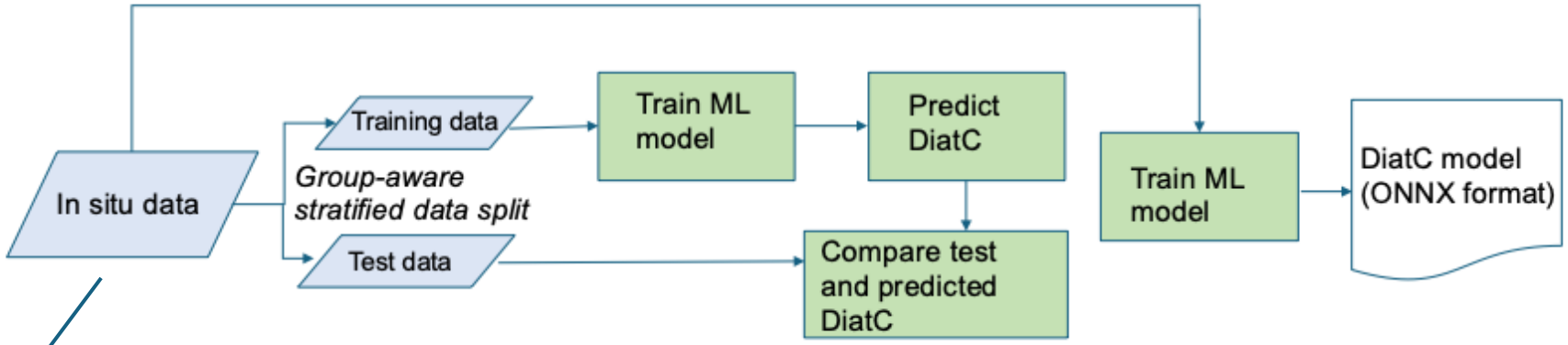
Workflow for Random Forest model training and testing

Inputs

- Temperature
- Chl *a*
- Accessory pigment absorption
- Particulate backscattering

Target

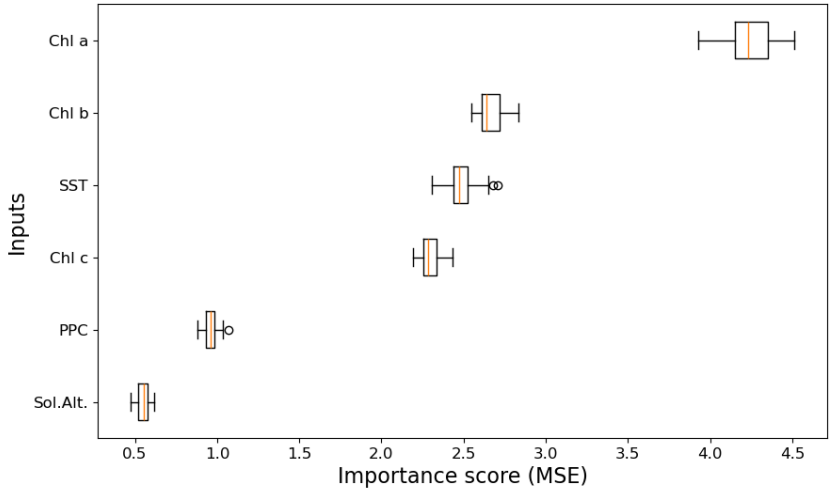
- Quantitative plankton imagery (IFCB)



DiatC model metrics based on test data

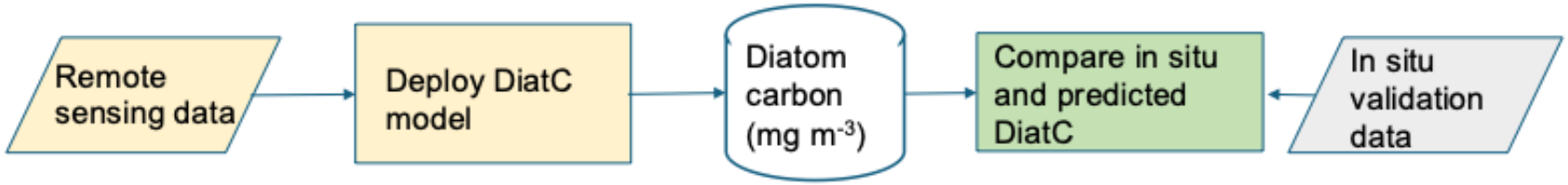
Median Abs. Error	1.59 mg m^{-3}
Mean Bias Error	-3.21 mg m^{-3}

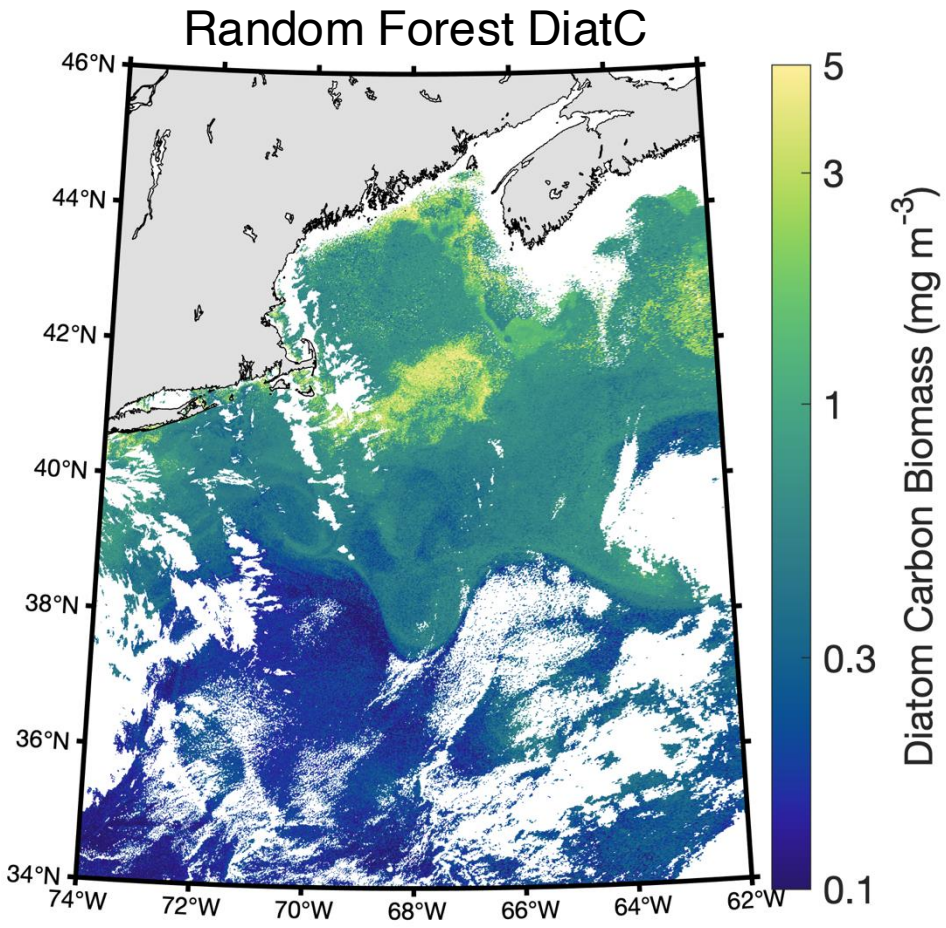
63% of Error Abs. Val are ≦ 3 mg m^{-3}

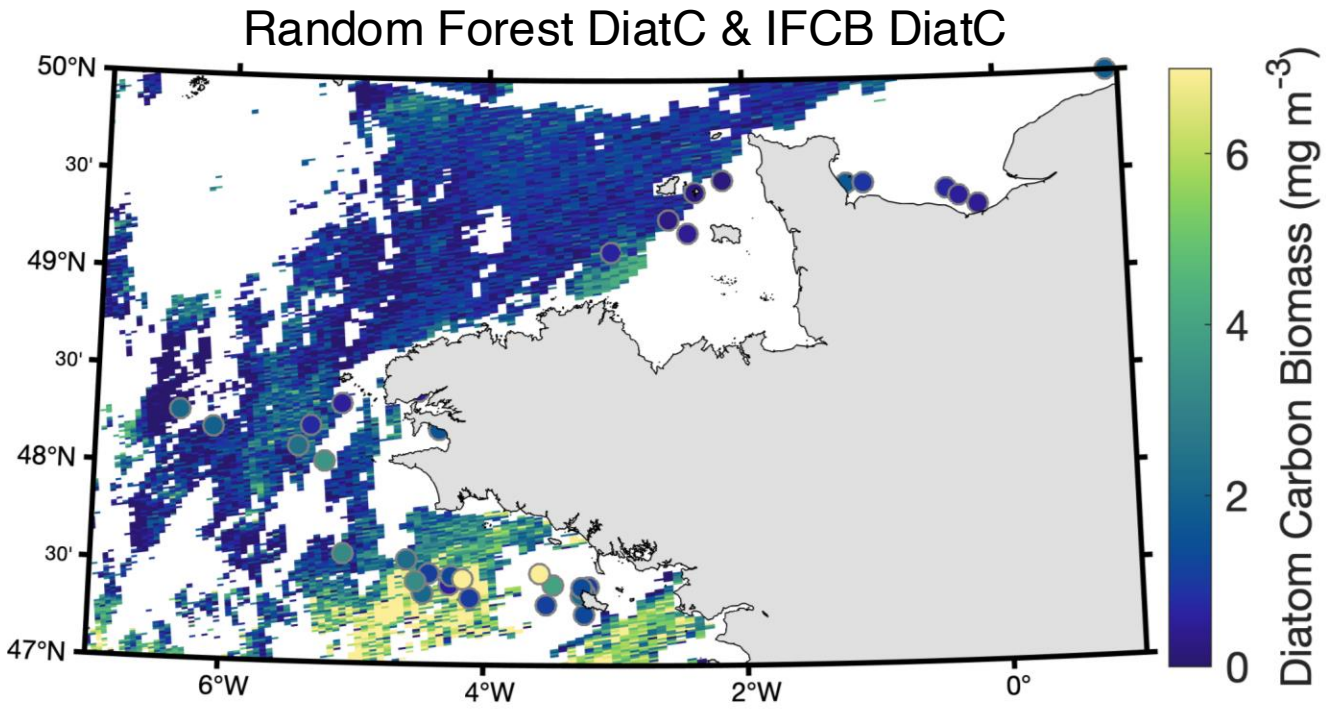


Using pigments to estimate diatom biomass

Workflow for model deployment and evaluation







Diatom biomass estimated from the RF model using pigments derived from PACE OCI, with IFCB-derived diatom biomass (Biotherm IMOCA) overlain (filled dots), April 28, 2024

Ongoing work

→ Efforts together with NASA GSFC colleagues to implement pigment algorithms as PACE products

→ Fieldwork campaigns to collect in situ data as part of PACE mission validation

→ Evaluation of pigment and diatom carbon biomass algorithms to refine algorithms and characterize uncertainties

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Code and Resources

GitHub alisonpchase

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Code repositories and workflow documentation for image classification available at:

https://github.com/ifcb-utopia