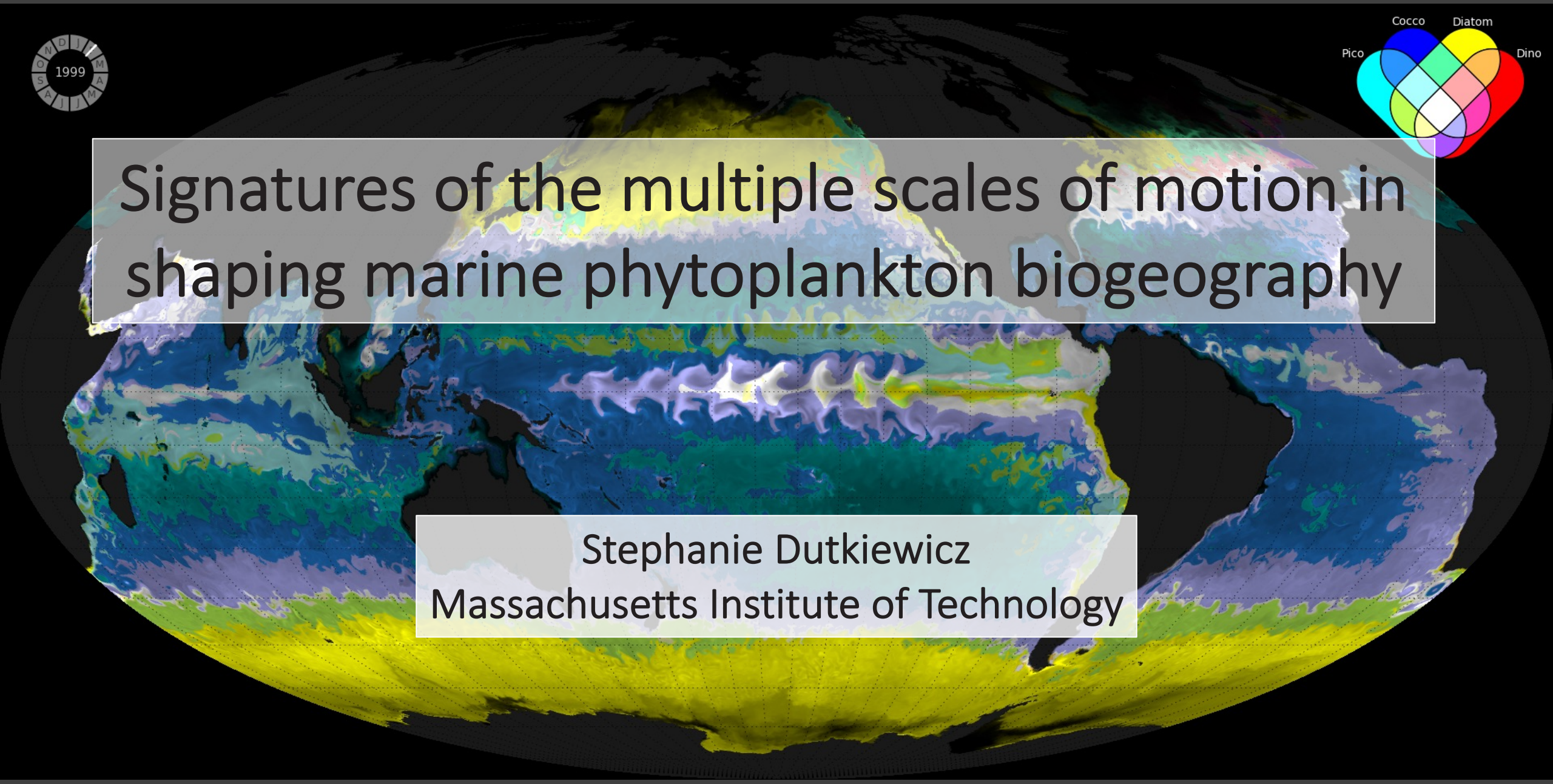
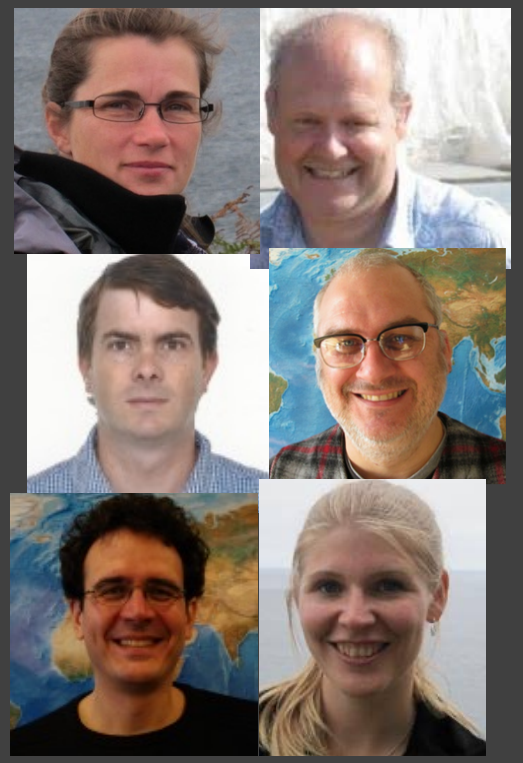


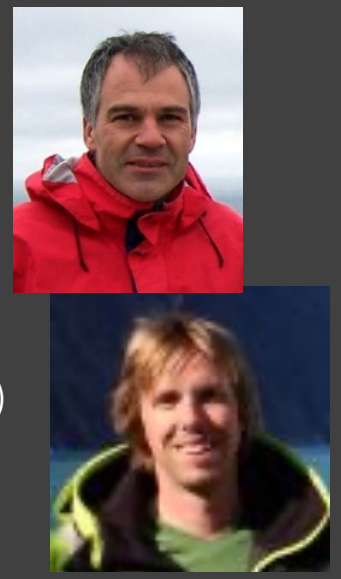
Signatures of the multiple scales of motion in shaping marine phytoplankton biogeography

Stephanie Dutkiewicz
Massachusetts Institute of Technology



Massachusetts Institute of Technology:

Stephanie Dutkiewicz
Chris Hill
Gael Forget
Mick Follows
Oliver Jahn
Maike Sonnewald
(now at GFDL, Princeton)

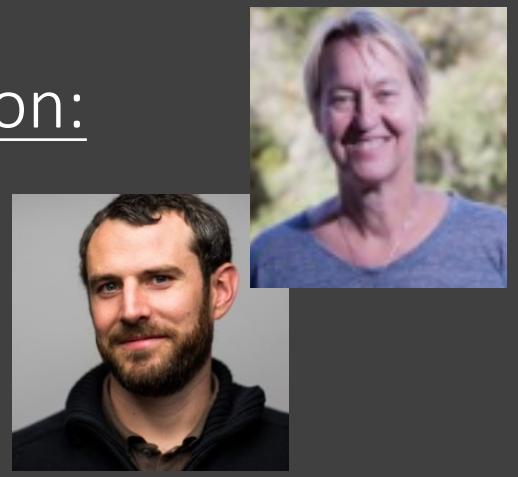


NASA Jet Propulsion Lab:

Dimitris Menemenlis
Dustin Carroll (now at Moss Landing)

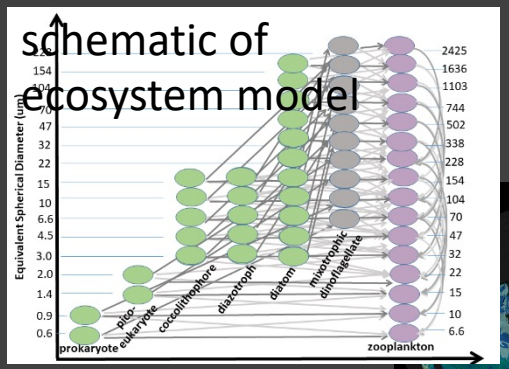
University of Washington:

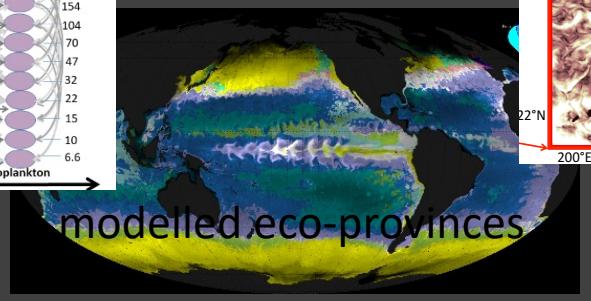
Ginger Armbrust
Francois Ribalet

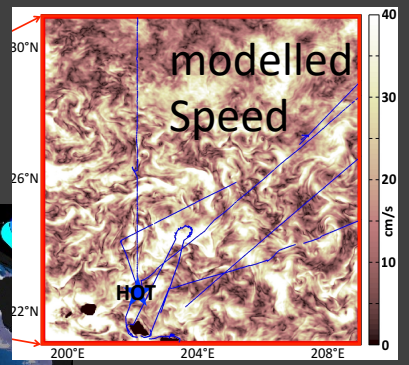


PROJECT GOALS

- Describing and understanding dynamic phytoplankton community biogeography from few kms to basin scales
- The observable signatures of these multiscale biogeographical patterns in satellite and in-situ data: how to monitor now and in future

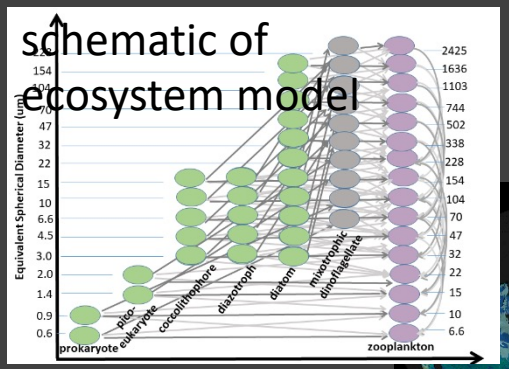


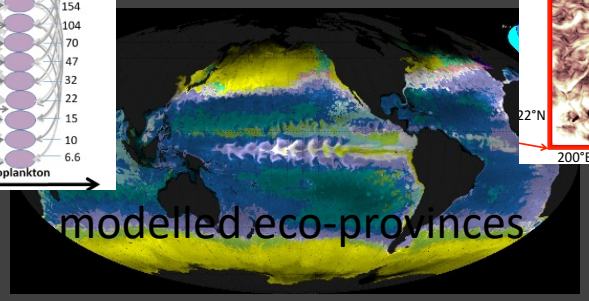


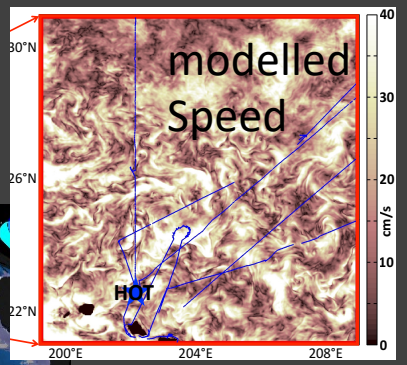


MODELS

- Data constrained ocean circulation models
- Complex marine ecosystem model





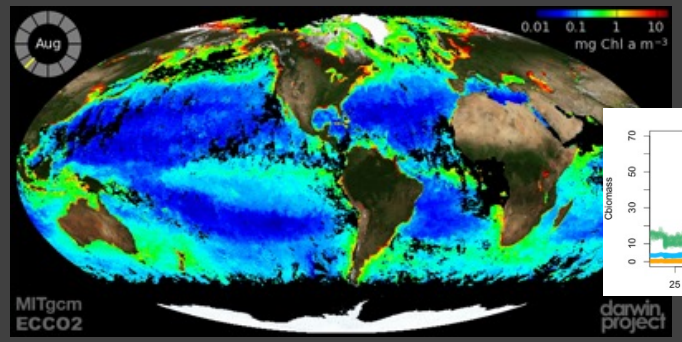


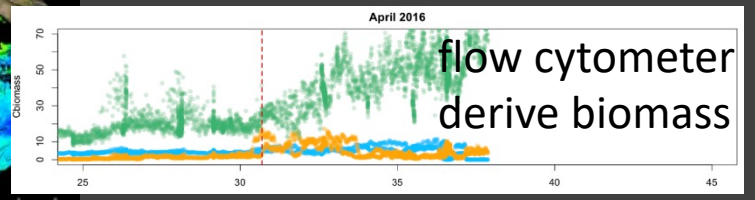
MODELS

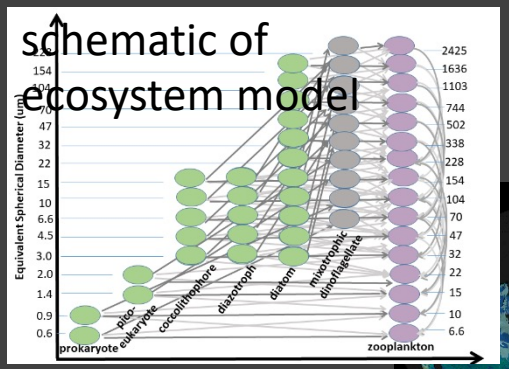
- Data constrained ocean circulation models
- Complex marine ecosystem model

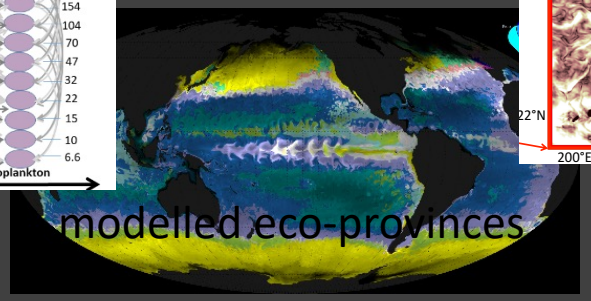
OBSEVATIONS

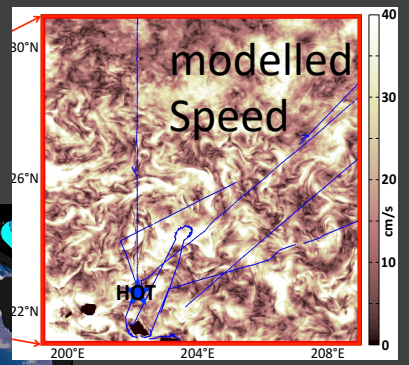
- Satellite data
- High resolution in situ data









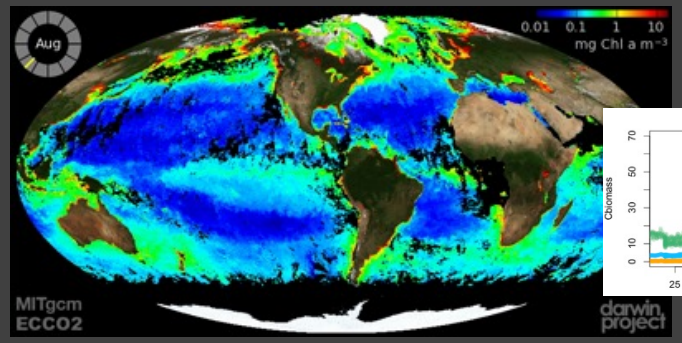


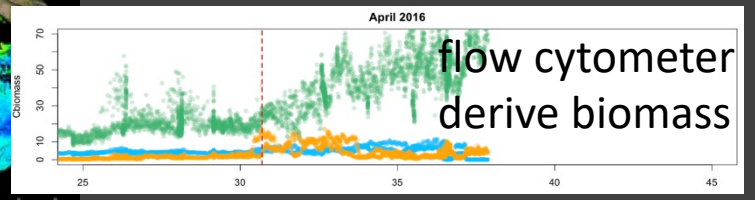
MODELS

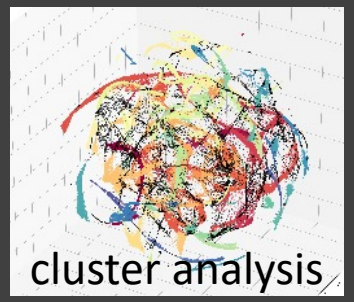
- Data constrained ocean circulation models
- Complex marine ecosystem model

OBSEVATIONS

- Satellite data
- High resolution in situ data





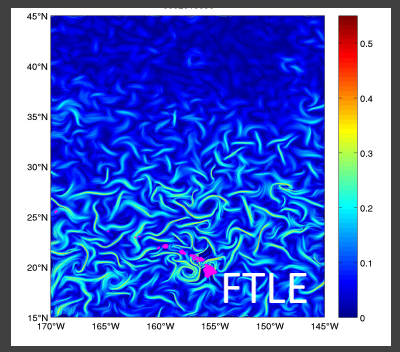


Tools to explore these:

- Machine learning
- Lagrangian tracking
- Ecological Theory

$$R^* = \frac{K_R}{\frac{\mu_m}{M} - 1}$$

$$S^*_{Fe} : S^*_N \geq R_P$$



Publications:

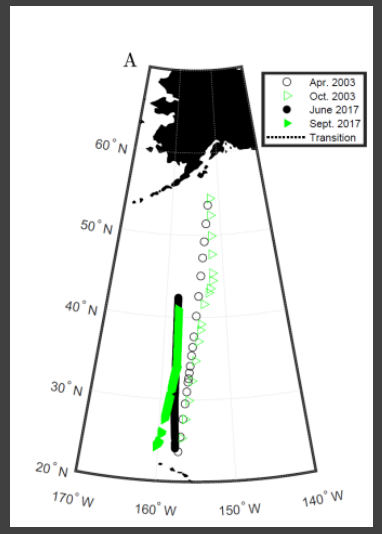
- Wilson, et al (2019) Kīlauea lava fuels phytoplankton bloom in the North Pacific Ocean. *Science.*
- Ribalet et al (2019) SeaFlow data 1.0: high-resolution abundance, size and biomass of small phytoplankton in the North Pacific. *Scientific Data*
- Kuhn et al Phytoplankton community temporal and spatial scales of decorrelation. *Journal of Geophysical Research*
- Dutkiewicz et al (2020). Dimensions of phytoplankton diversity. *Biogeosciences*
- Sonnewald et al (2020) Elucidating Ecological Complexity: Unsupervised Learning determines global marine eco-provinces. *Science Advances*
- Carroll et al (2020). The ECCO-Darwin Data-assimilative Global Ocean Biogeochemistry Model: Estimates of Seasonal to Multi-decadal Surface Ocean pCO2 and Air-sea CO2 Flux. *Journal of Advances in Modeling Earth Systems*
- Henderikx Freitas (2020). Diel variability of bulk optical properties associated with the growth and division of small phytoplankton in the North Pacific Subtropical Gyre. *Applied Optics*
- IOCCG (2020) Synergy between Ocean Colour and Biogeochemical/Ecosystem Models. (ed. Dutkiewicz, S.) Dartmouth, NS, Canada, International Ocean-Colour Coordinating Group (IOCCG), 184pp.
- Dutkiewicz et al (2021). Exploring biogeochemical and ecological redundancy in phytoplankton communities. *Global Change Biology*.
- Juranek et al (2021). The importance of the “middle class” to oceanic net community production. *Global Biogeochemical Cycles*.
- Follett et al (2021). Moving Ecological and Biogeochemical Transitions Across the North Pacific. *Limnology and Oceanography*
- Tréguer et al (2021). Reviews and syntheses: The biogeochemical cycle of silicon in the modern ocean. *Biogeosciences*
- Henson et al (2021). Future phytoplankton diversity in a changing climate. *Nature Communications.*
- Hyun et al (2021). Modeling Cell Populations Measured By Flow Cytometry With Covariates Using Sparse Mixture of Regressions. *Annals of Applied Statistics.*
- Cael, B.B (in press). Abrupt shifts in 21st century plankton communities. *Science Advances*.
- Anderson et al (in press). Marine phytoplankton functional types exhibit diverse responses to thermal change. *Nature Communications.*
- Follett et al (in revision). Collapse of *Prochlorococcus* population in the transition between subtropical and subpolar gyres. *Proceedings of the National Academy of Sciences*
- Magnolte et al (in review) . Plankton community response to fronts: Winners and losers. *Journal of Plankton Research*.

HIGHLIGHTED PROJECTS

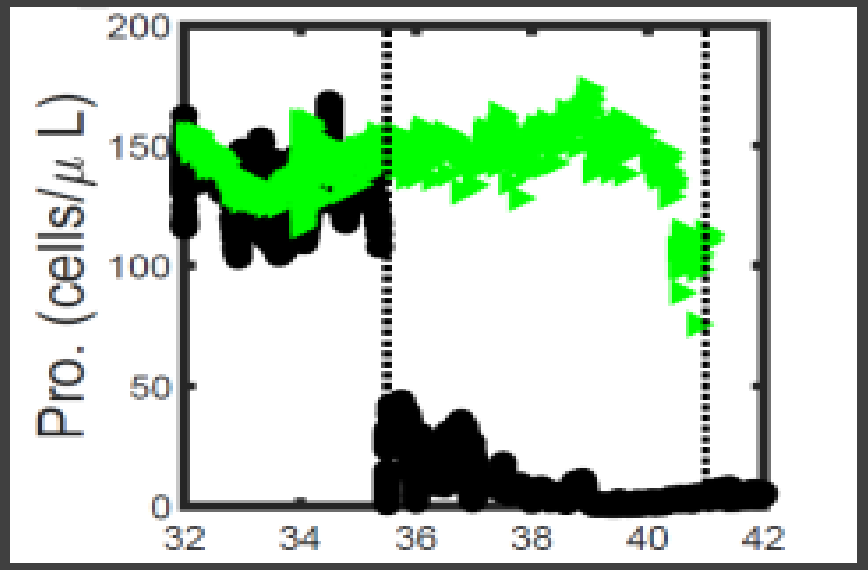
1) Understanding basin scale patterns of *Prochlorococcus* distribution

2) Understanding role of sub-mesoscale in structuring plankton communities

Understanding basin scale patterns of *Prochlorococcus* distribution



SeaFlow high resolution data

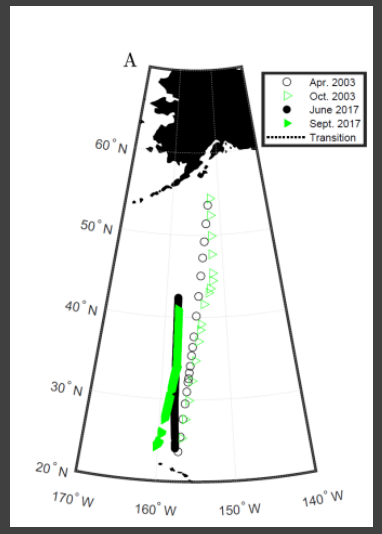


Prochlorococcus is smallest, most abundant phytoplankton

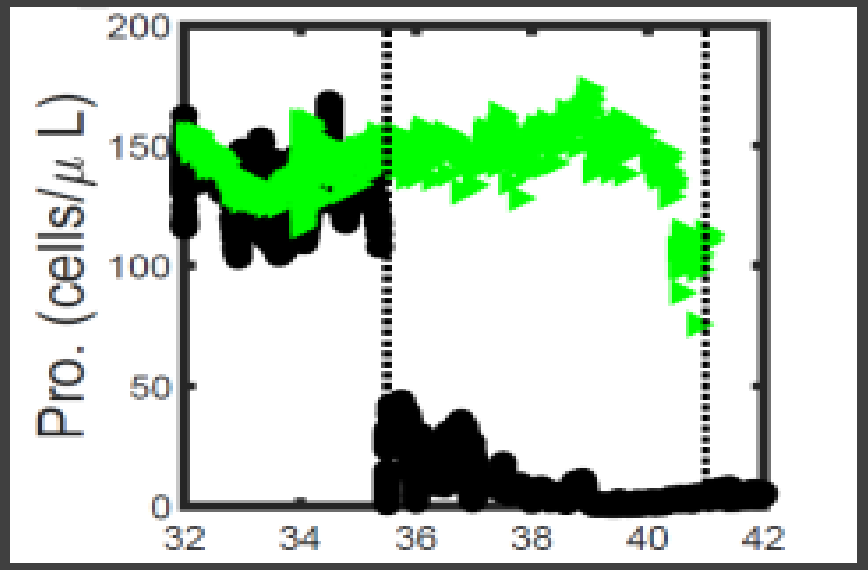
Known to not be found at high latitudes

Follett, C.L., S. **Dutkiewicz,** F, **Ribalet**, E. Zakem, D. Caron, V. **Armbrust**, and M.J. **Follows.** Trophic Interactions with Heterotrophic Bacteria Limit the Range of *Prochlorococcus. Proceedings of the National Academy of Sciences* (minor revisions)

Understanding basin scale patterns of *Prochlorococcus* distribution



SeaFlow high resolution data

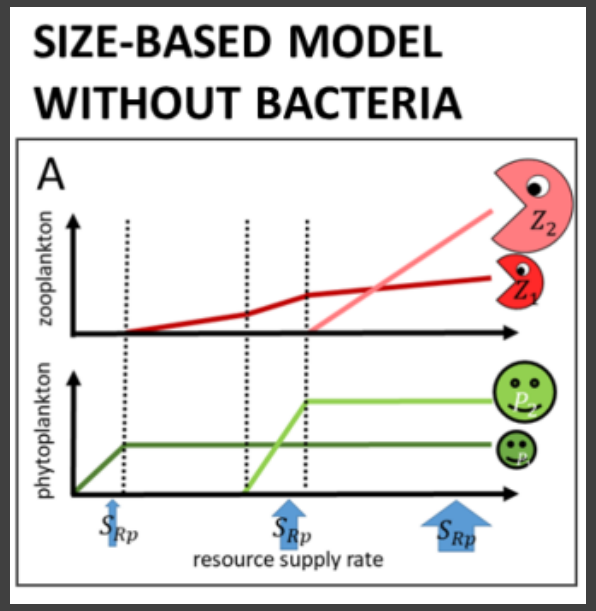


Explore with:

- Ecological theory
- Numerical model
- Observations

Follett, C.L., S. **Dutkiewicz,** F, **Ribalet**, E. Zakem, D. Caron, V. **Armbrust**, and M.J. **Follows.** Trophic Interactions with Heterotrophic Bacteria Limit the Range of *Prochlorococcus. Proceedings of the National Academy of Sciences* (minor revisions)

Understanding basin scale patterns of *Prochlorococcus* distribution: Theory



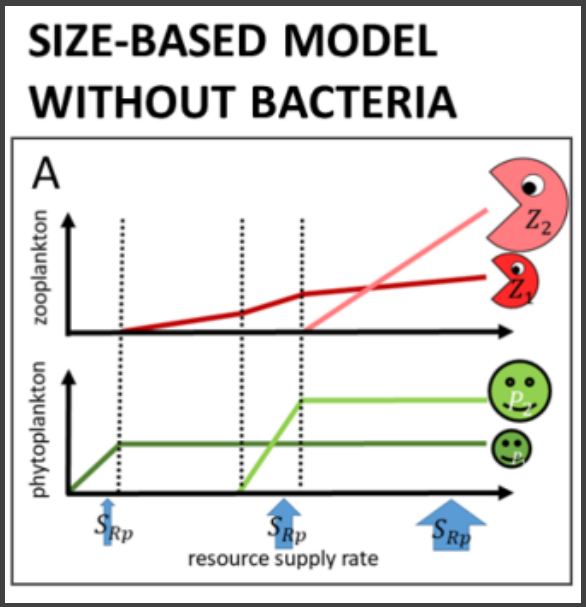
$$P_j^* = \frac{m_z}{\gamma g_j}$$

Previous ecological theory* does not predict this "collapse"

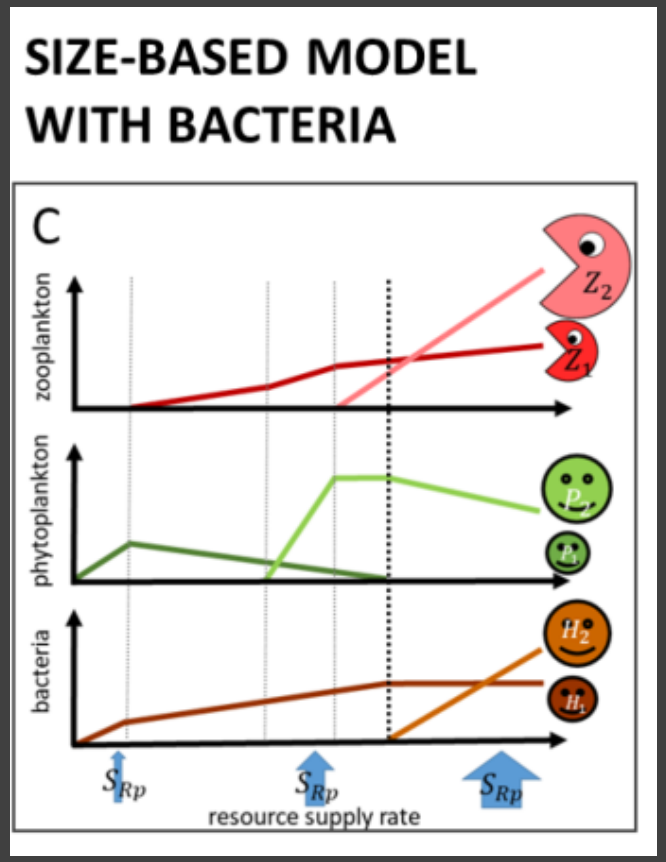
*Armstrong 1999, Poulin and Franks, 2014, Ward et al, 2014

Follett, C.L., S. **Dutkiewicz,** F, **Ribalet**, E. Zakem, D. Caron, V. **Armbrust**, and M.J. **Follows.** Trophic Interactions with Heterotrophic Bacteria Limit the Range of *Prochlorococcus. Proceedings of the National Academy of Sciences* (minor revisions)

Understanding basin scale patterns of *Prochlorococcus* distribution: Theory



$$P_j^* = \frac{m_z}{\gamma g_j}$$



$$P_j^* = \frac{m_z}{\gamma g_j} - H_j^*$$

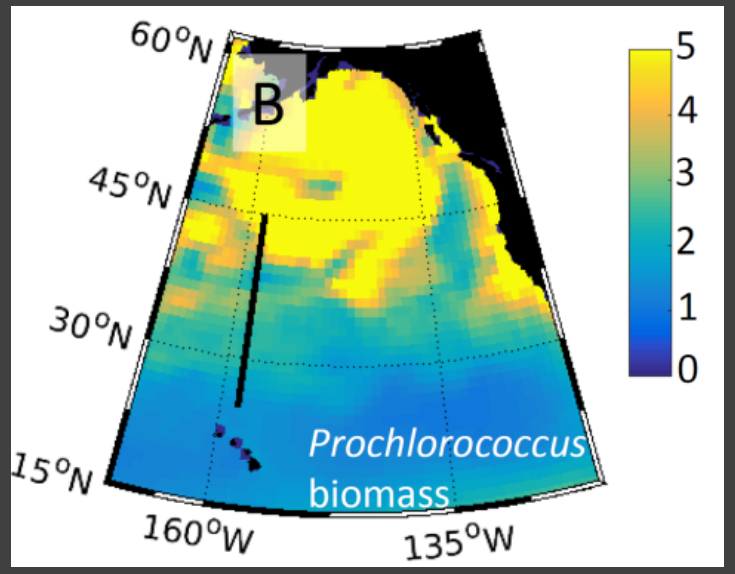
Previous ecological theory does not predict this "collapse"

But including shared predation with a similar sized heterotrophic bacteria does

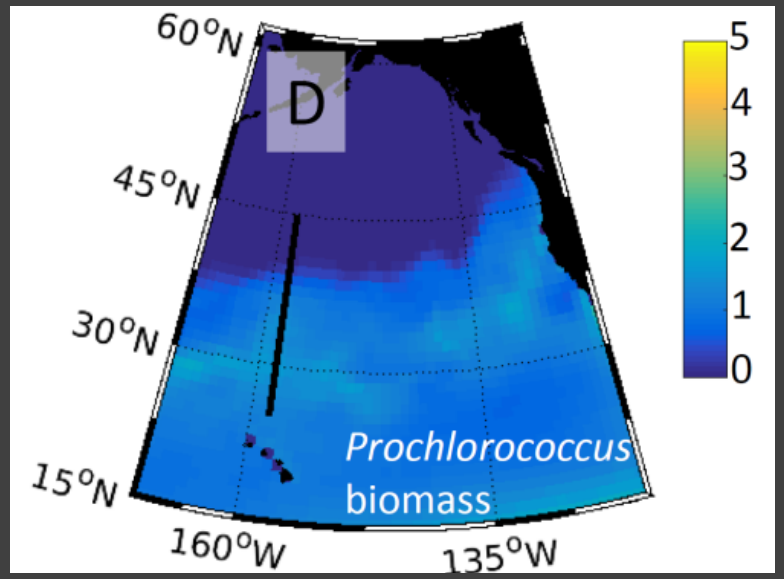
Follett, C.L., S. **Dutkiewicz,** F, **Ribalet**, E. Zakem, D. Caron, V. **Armbrust**, and M.J. **Follows.** Trophic Interactions with Heterotrophic Bacteria Limit the Range of *Prochlorococcus. Proceedings of the National Academy of Sciences* (minor revisions)

Understanding basin scale patterns of *Prochlorococcus* distribution: Model

Simulation without explicit heterotrophic bacteria



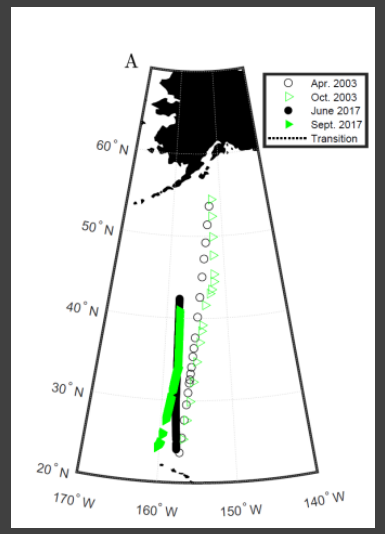
Simulation with explicit heterotrophic bacteria

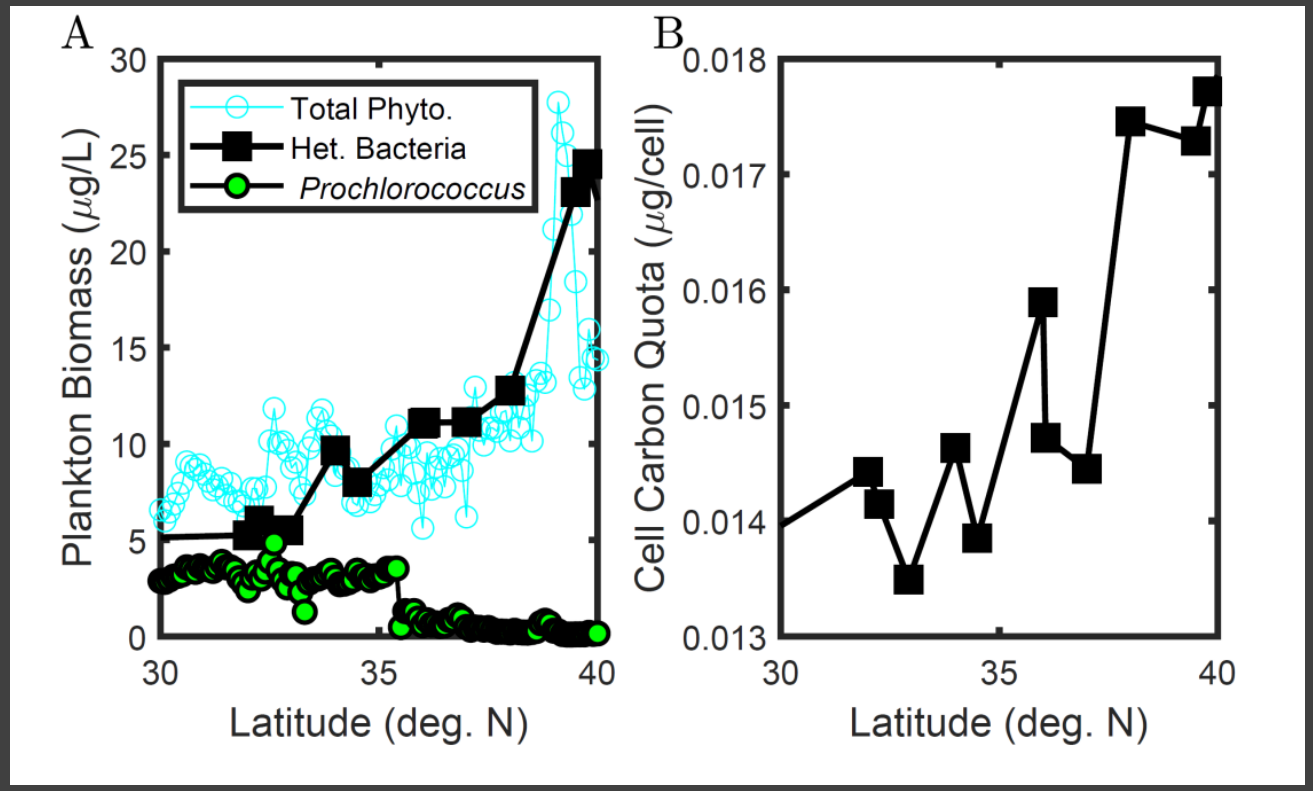


Explore using the MIT "Darwin" Ecosystem model

Follett, C.L., S. **Dutkiewicz,** F, **Ribalet**, E. Zakem, D. Caron, V. **Armbrust**, and M.J. **Follows.** Trophic Interactions with Heterotrophic Bacteria Limit the Range of *Prochlorococcus. Proceedings of the National Academy of Sciences* (minor revisions)

Understanding basin scale patterns of *Prochlorococcus* distribution: Observations





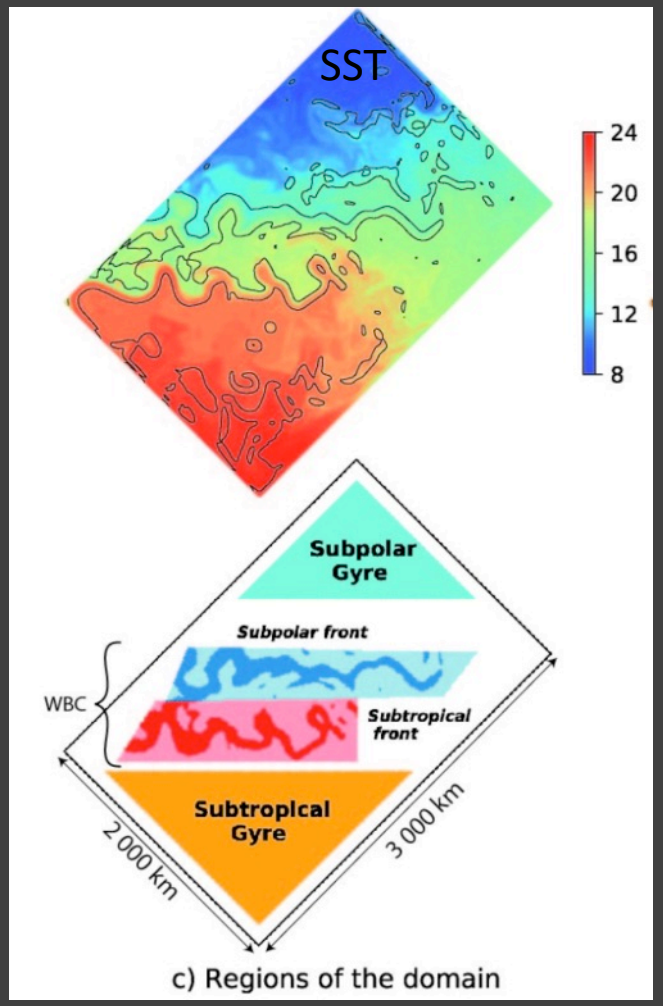
Follett, C.L., S. **Dutkiewicz,** F, **Ribalet**, E. Zakem, D. Caron, V. **Armbrust**, and M.J. **Follows.** Trophic Interactions with Heterotrophic Bacteria Limit the Range of *Prochlorococcus. Proceedings of the National Academy of Sciences* (minor revisions)

HIGHLIGHTED PROJECTS

1) Understanding basin scale patterns of *Prochlorococcus* distribution

2) Understanding role of sub-mesoscale in structuring plankton communities

Role of sub-mesoscale in structuring plankton communities



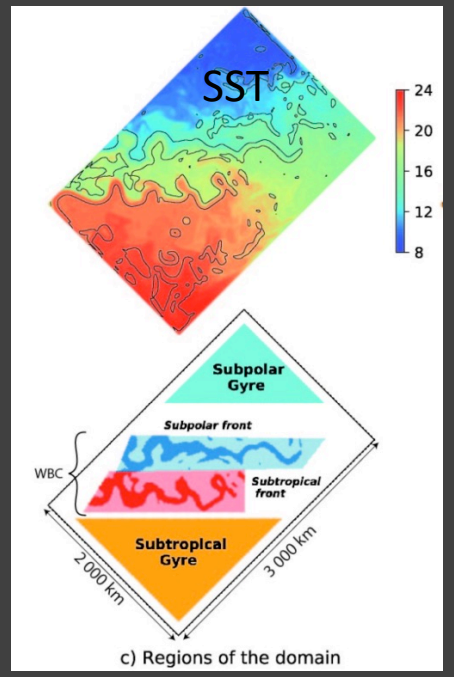
c) Regions of the domain

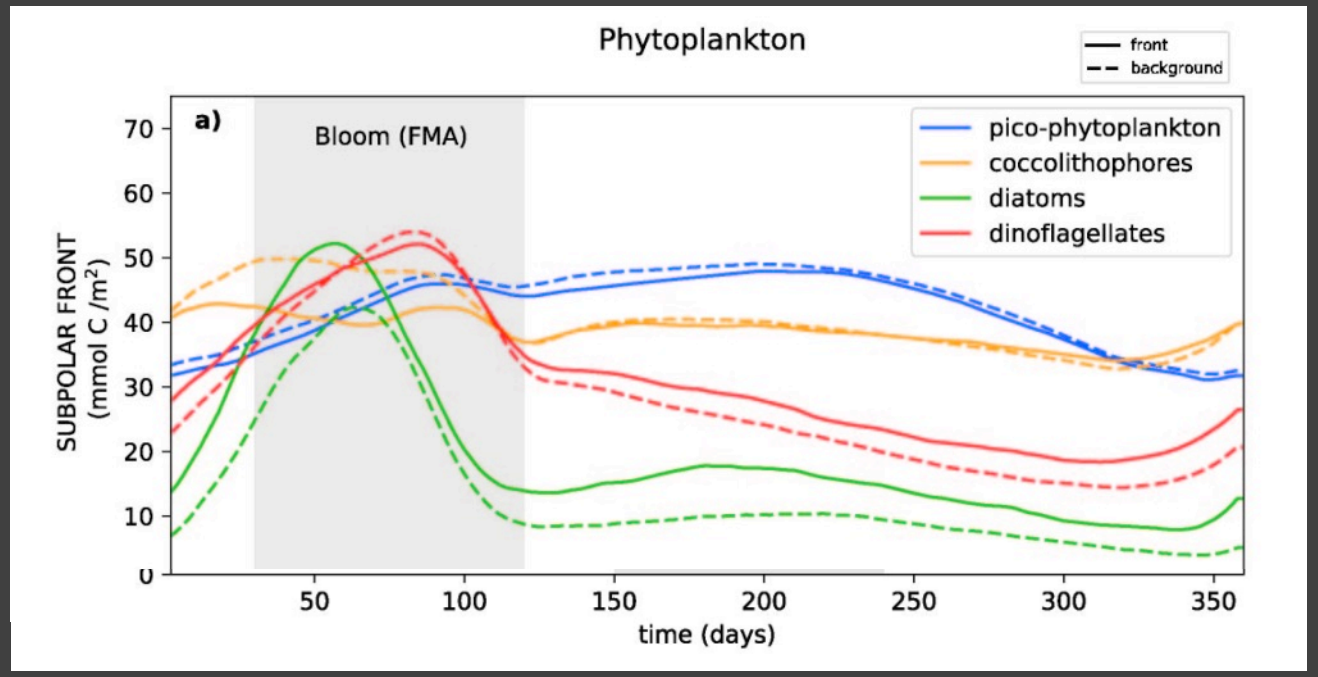
Regional high resolution model, with ecosystem including different size classes and functional groups of plankton

Focus on differences between front and backgrounds

Magnolte, I., Levy, M., S. **Dutkiewicz**, S. Clayton and O. **Jahn**. Plankton community response to fronts: Winners and losers. In review for *Journal of Plankton Research*.

Role of sub-mesoscale in structuring plankton communities

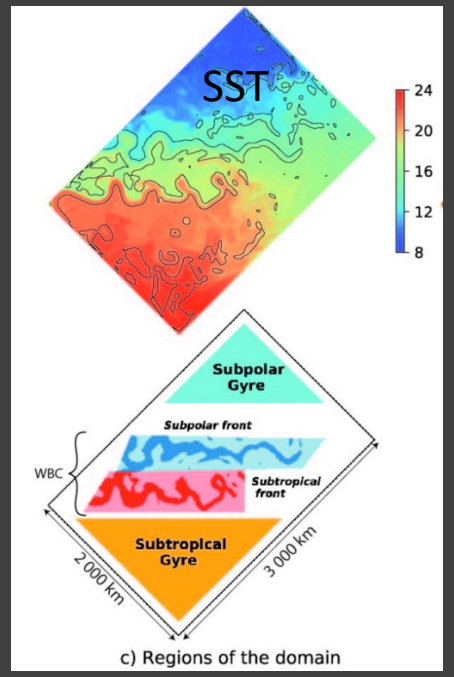


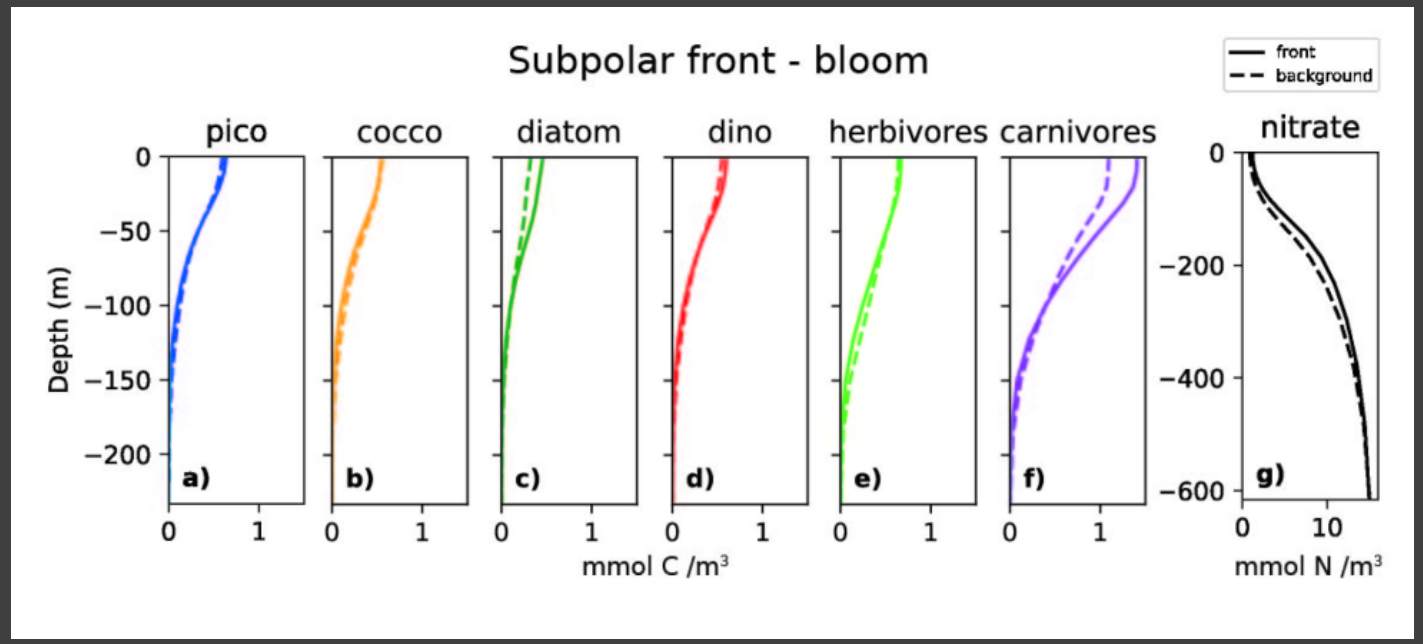


- not all groups of phytoplankton were enhanced at fronts

Magnolte, I., Levy, M., S. **Dutkiewicz**, S. Clayton and O. **Jahn**. Plankton community response to fronts: Winners and losers. In review for *Journal of Plankton Research*.

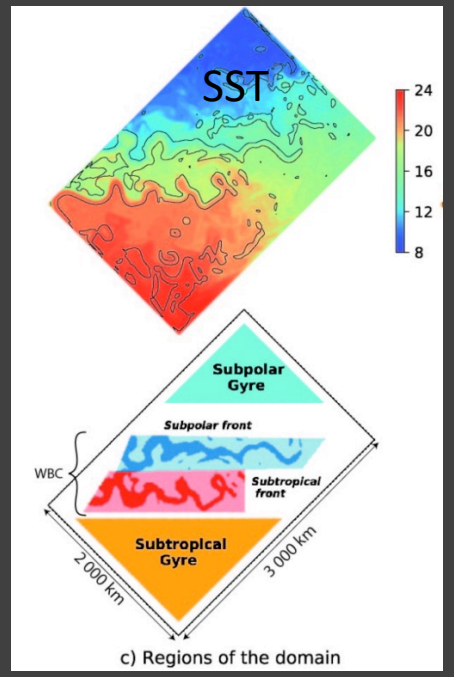
Role of sub-mesoscale in structuring plankton communities

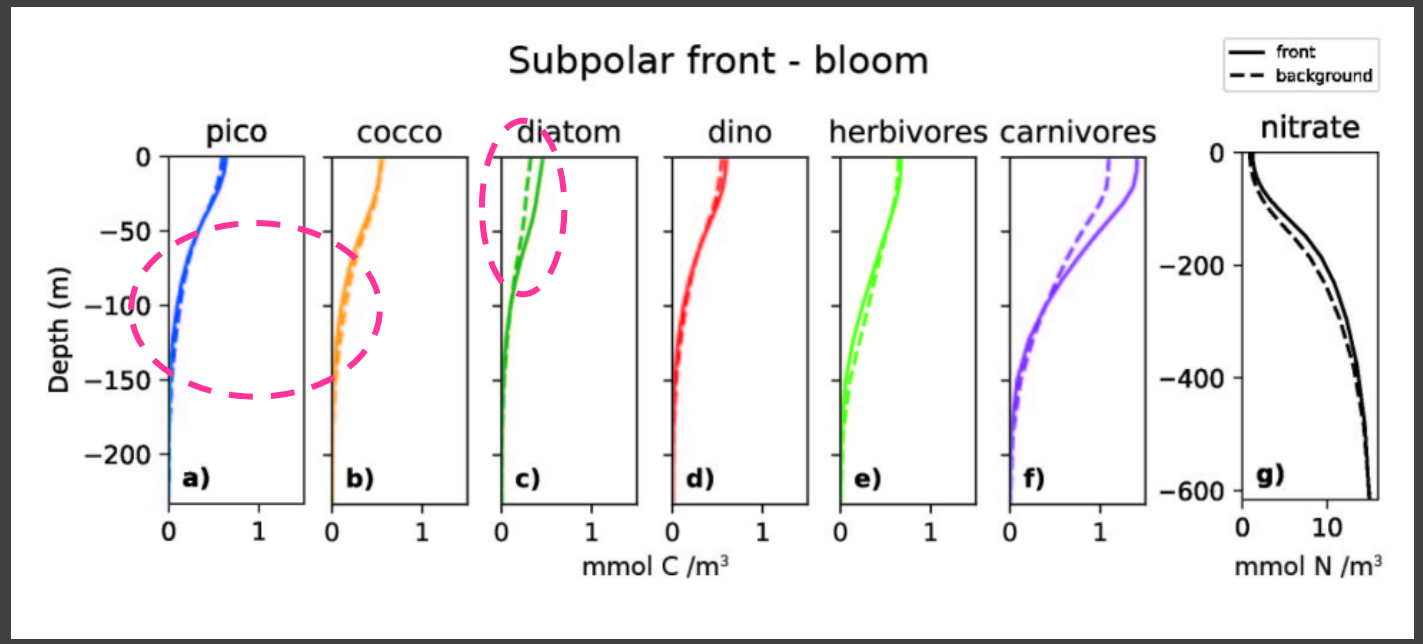




Magnolte, I., Levy, M., S. **Dutkiewicz**, S. Clayton and O. **Jahn**. Plankton community response to fronts: Winners and losers. In review for *Journal of Plankton Research*.

Role of sub-mesoscale in structuring plankton communities

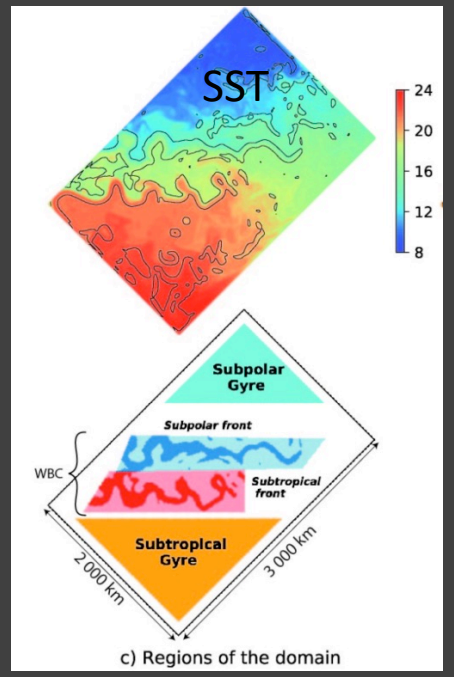


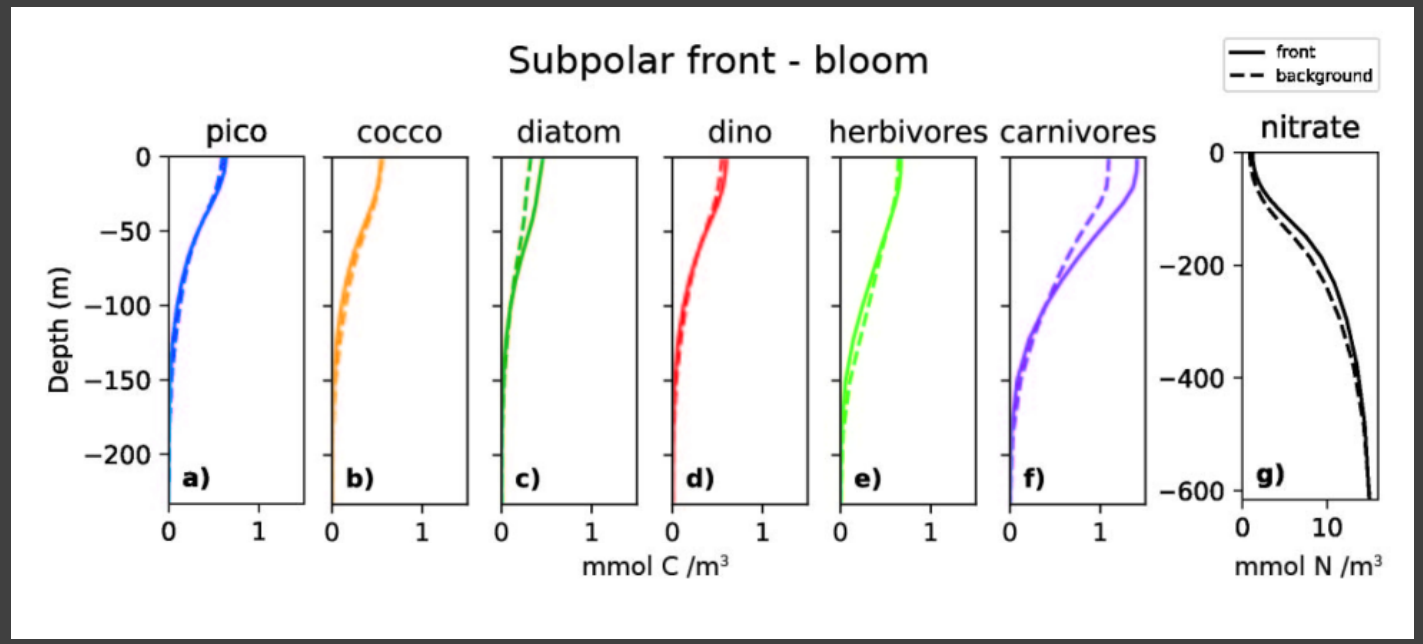


- Shading by enhanced blooms of diatoms at surface depleted some groups at depth

Magnolte, I., Levy, M., S. **Dutkiewicz**, S. Clayton and O. **Jahn**. Plankton community response to fronts: Winners and losers. In review for *Journal of Plankton Research*.

Role of sub-mesoscale in structuring plankton communities

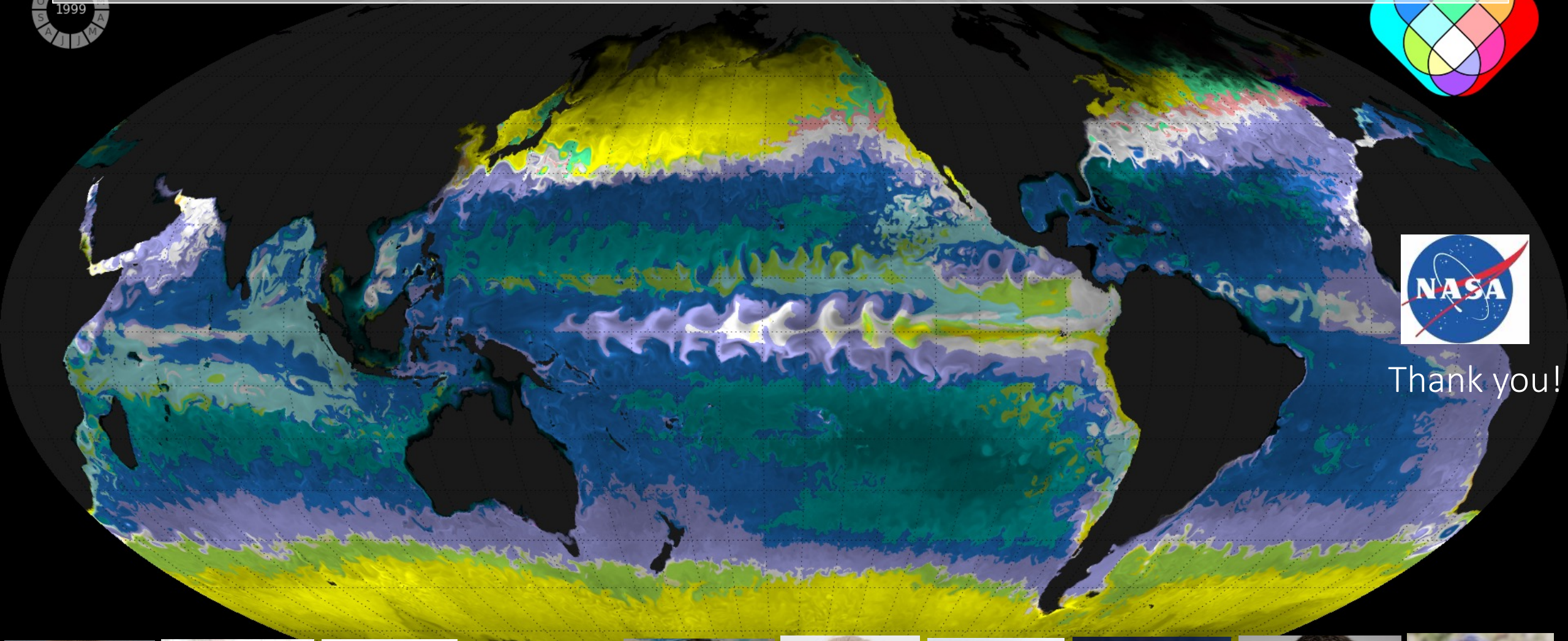




- Shading by enhanced blooms of diatoms at surface depleted some groups at depth
- Increase grazers lead to higher grazing on less fast growing species

Magnolte, I., Levy, M., S. **Dutkiewicz**, S. Clayton and O. **Jahn**. Plankton community response to fronts: Winners and losers. In review for *Journal of Plankton Research*.

Signatures of the multiple scales of motion in shaping marine phytoplankton biogeography



Thank you!

ECOSYSTEM MODEL