Observations and Tools for Studying Ocean Biogeochemistry from the Surface to the Deep

Pathways Connecting Climate Changes to the Deep Ocean Workshop

Tracing physical, biogeochemical, and ecological signals from surface to deep sea

A joint US CLIVAR/OCB workshop
April 23-25, 2024, Lewes, DE and virtual

Andrea J. Fassbender

Interior Ocean Biogeochemistry Changes: Oxygen

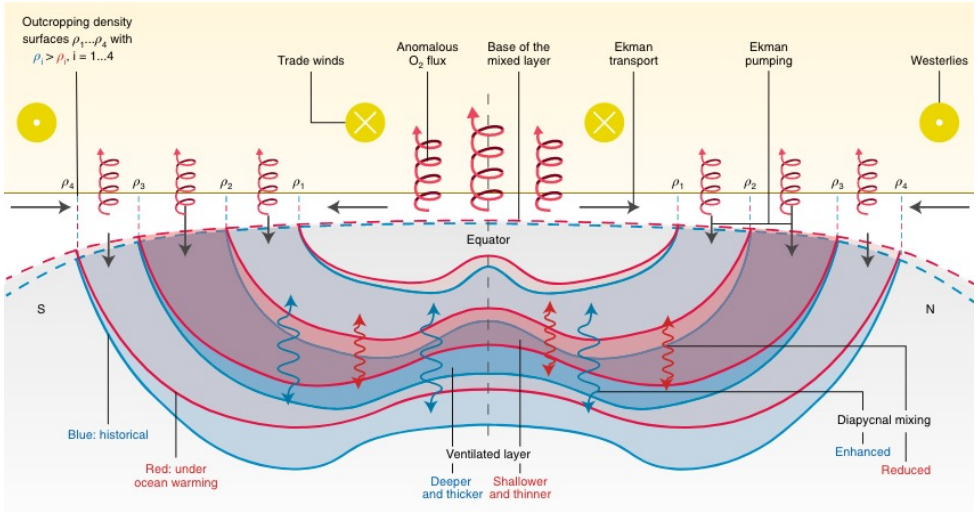
nature geoscience

REVIEW ARTICLE

https://doi.org/10.1038/s41561-018-0152-2

Drivers and mechanisms of ocean deoxygenation

Andreas Oschlies[1,2*], Peter Brandt[1,2], Lothar Stramma[1] and Sunke Schmidtko[1]

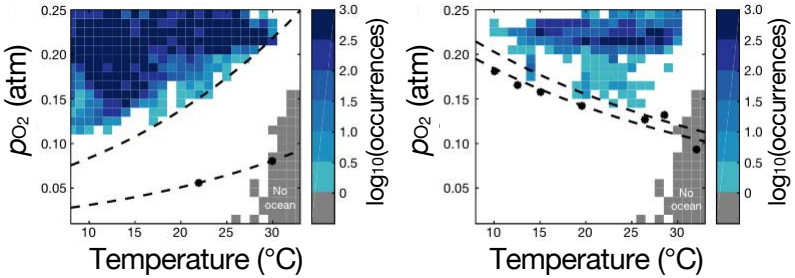


"Warming is considered a major driver: in part directly, via solubility effects, and in part indirectly, via changes in circulation, mixing and oxygen respiration."

Metabolic trait diversity shapes marine biogeography

nature

Curtis Deutsch[1,2]✉, Justin L. Penn[1] & Brad Seibel[3]



habitat of Summer flounder (subtropical eastern Atlantic)

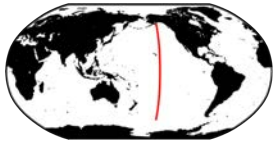
habitat of Sea squirt (cosmopolitan tunicate)

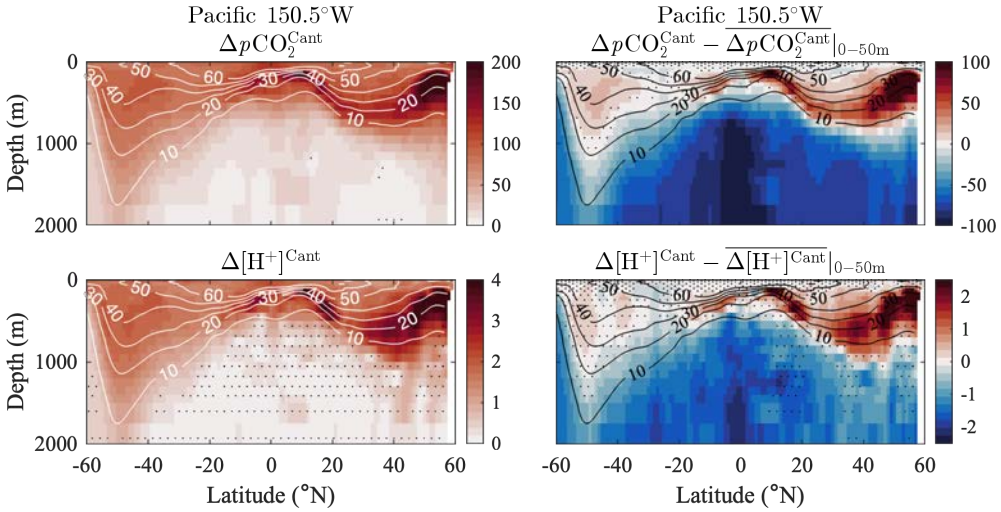
Interior Ocean Biogeochemistry Changes: Carbon

Global Biogeochemical Cycles

Amplified Subsurface Signals of Ocean Acidification

Andrea J. Fassbender[1], Brendan R. Carter[1,2], Jonathan D. Sharp[1,2], Yibin Huang[1,3,4], Mar C. Arroyo[1,4], and Hartmut Frenzel[1,2]

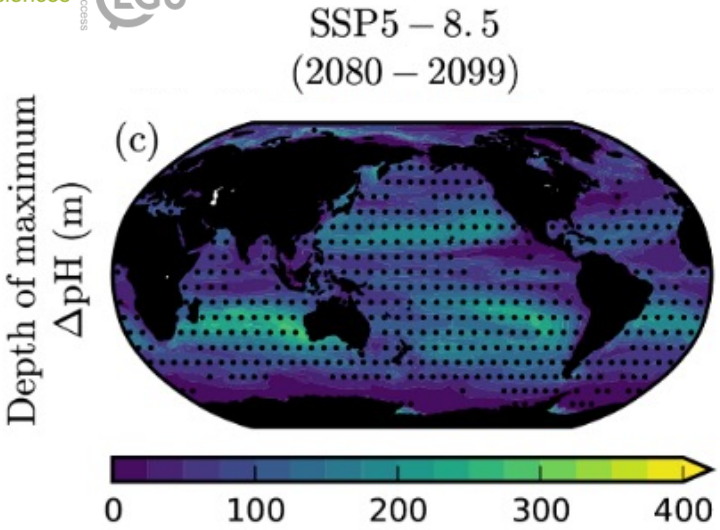




Twenty-first century ocean warming, acidification, deoxygenation, and upper-ocean nutrient and primary production decline from CMIP6 model projections

Lester Kwiatkowski[1], Olivier Torres[2], Laurent Bopp[2], Olivier Aumont[1], Matthew Chamberlain[3], James R. Christian[5], John P. Dunne[6], Marion Gehlen[7], Tatiana Ilyina[8], Jasmin G. John[6], Andrew Lenton[3,4], Hongmei Li[8], Nicole S. Lovenduski[9], James C. Orr[7], Julien Palmieri[10], Yeray Santana-Falcón[11], Jörg Schwinger[12], Roland Séférian[11], Charles A. Stock[6], Alessandro Tagliabue[13], Yohei Takano[8,14], Jerry Tjiputra[12], Katsuya Toyama[15], Hiroyuki Tsujino[15], Michio Watanabe[16], Akitomo Yamamoto[16], Andrew Yool[10], and Tilo Ziehn[3]

Biogeosciences Open Access EGU



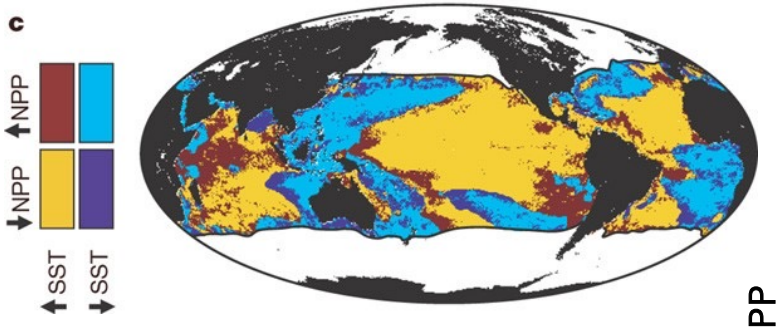
Interior Ocean Biogeochemistry Changes: Biological Productivity → Export

Climate-driven trends in contemporary ocean productivity

nature LETTERS

Michael J. Behrenfeld[1], Robert T. O'Malley[1], David A. Siegel[3], Charles R. McClain[4], Jorge L. Sarmiento[5], Gene C. Feldman[4], Allen J. Milligan[1], Paul G. Falkowski[6], Ricardo M. Letelier[2] & Emmanuel S. Boss[7]

relationships between annual mean SST and NPP from remote sensing for the period 1999 to 2004

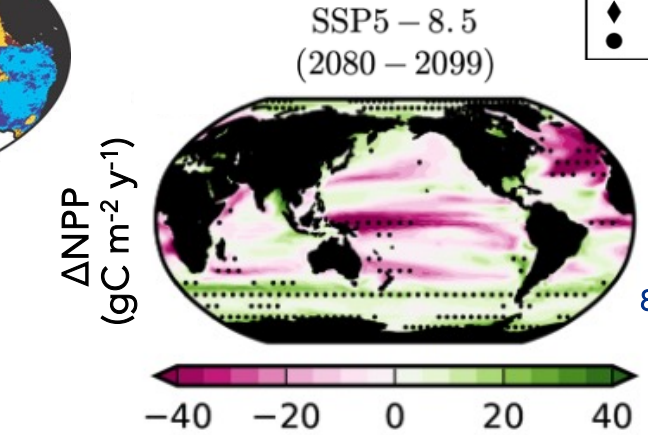


permanently stratified oceans

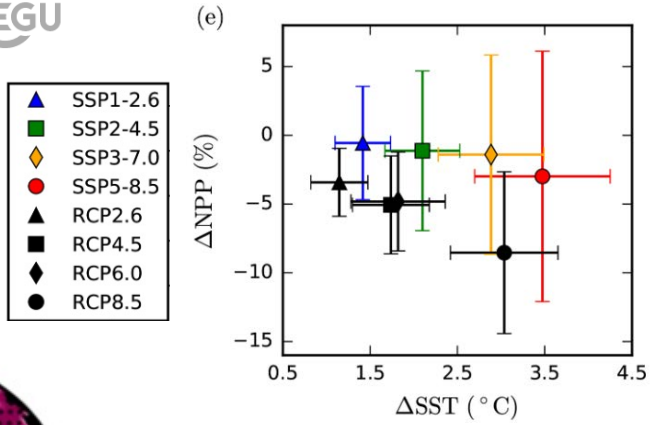
Twenty-first century ocean warming, acidification, deoxygenation, and upper-ocean nutrient and primary production decline from CMIP6 model projections

Lester Kwiatkowski[1], Olivier Torres[2], Laurent Bopp[2], Olivier Aumont[1], Matthew Chamberlain[3], ...

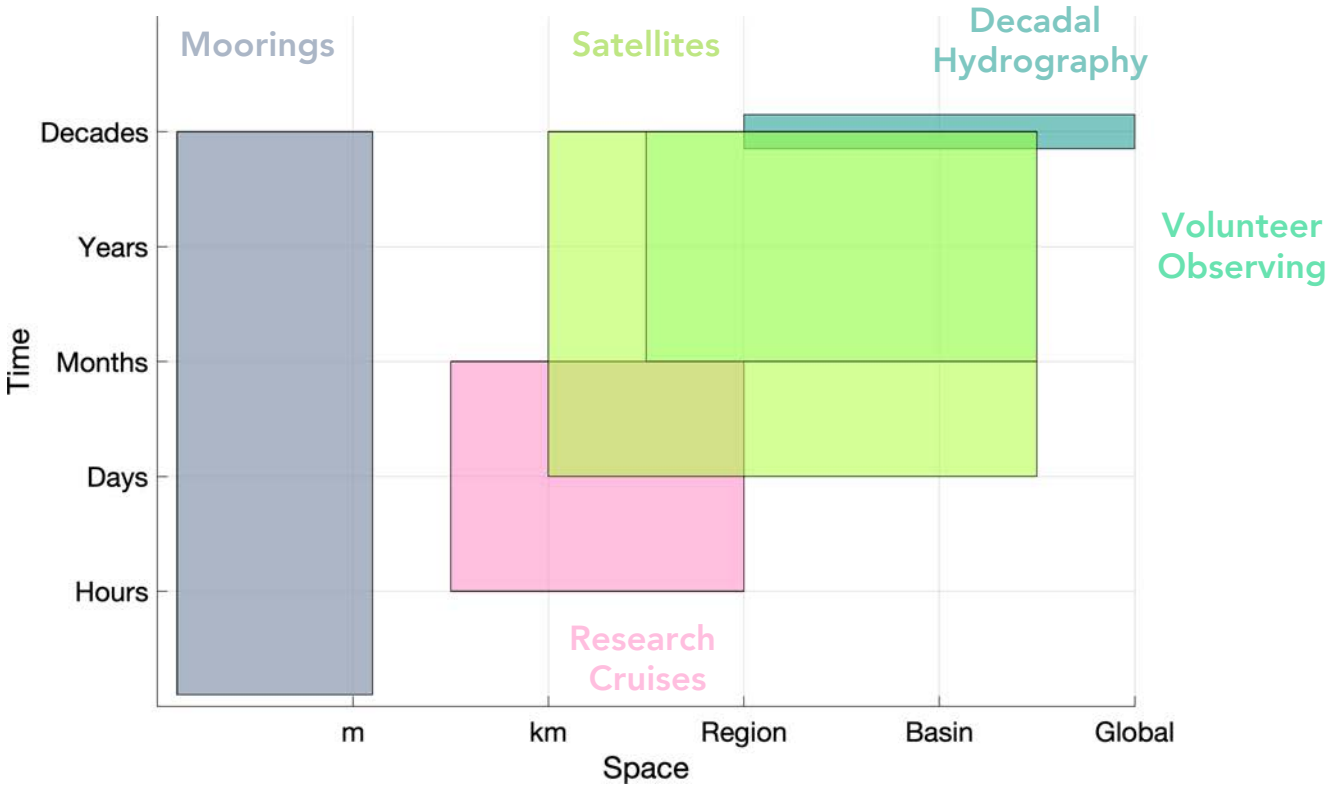
Biogeosciences EGU Open Access



stippling = 80% model sign agreement

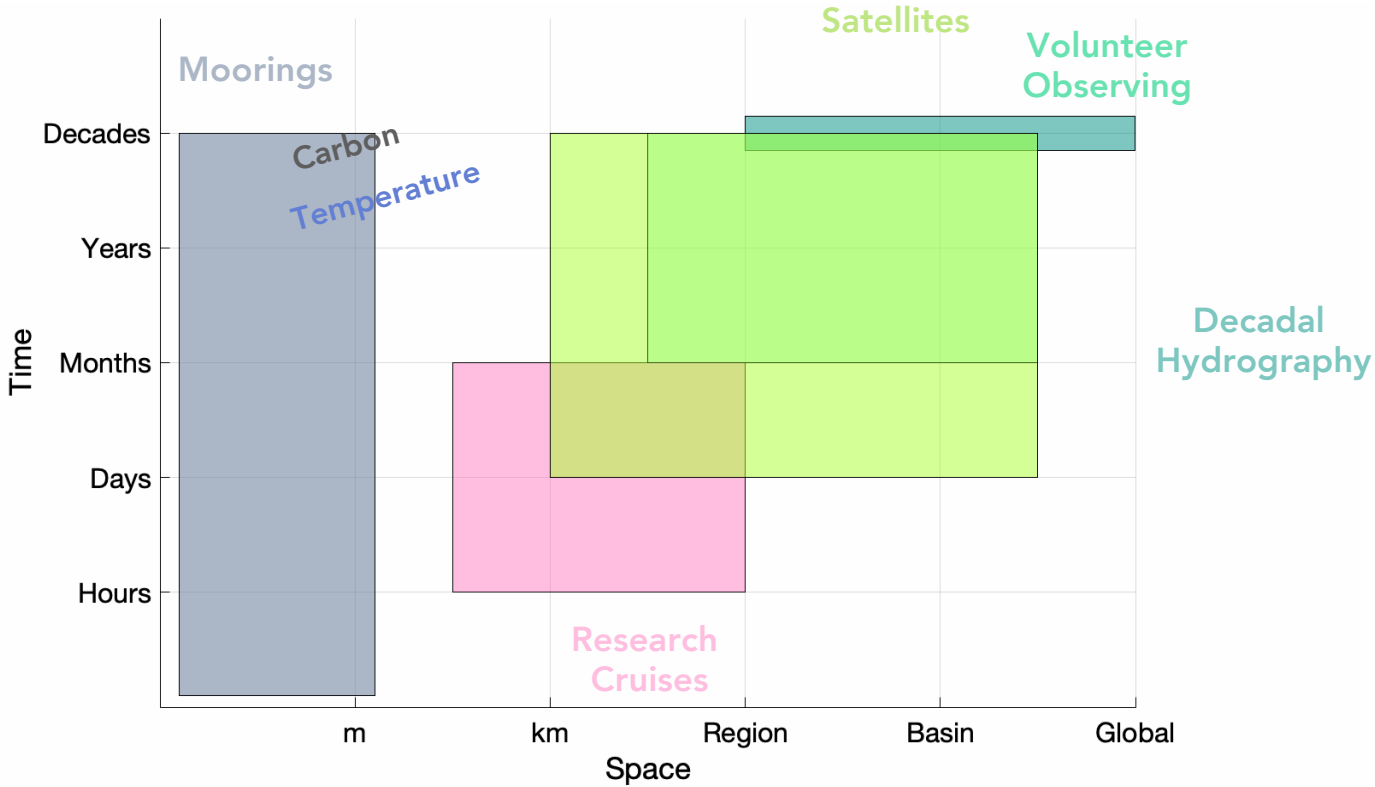


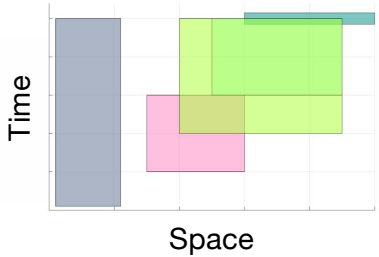
Conventional Observing Platforms for Ocean Carbon and Temperature



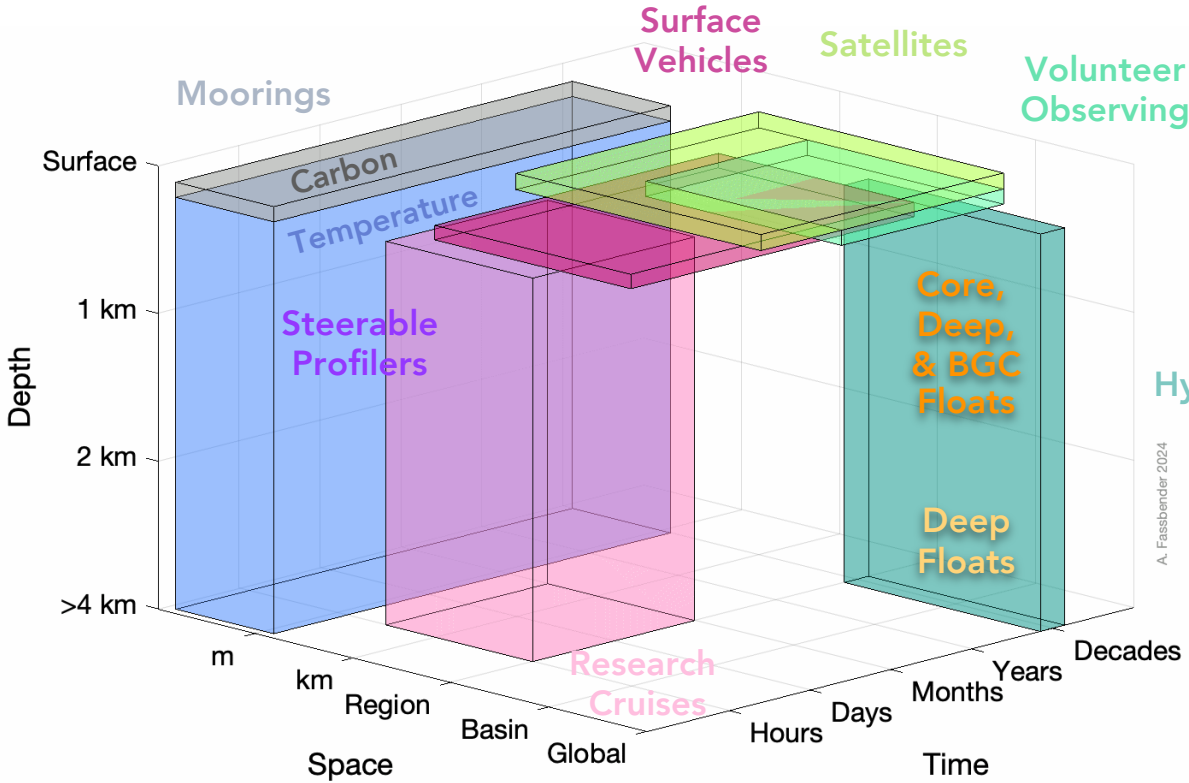
adapted from Bushinsky et al., 2019

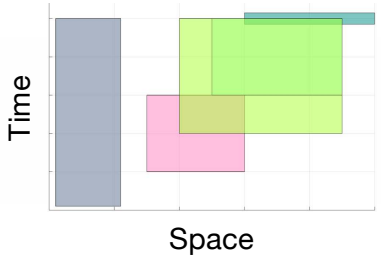
Conventional Observing Platforms for Ocean Carbon and Temperature





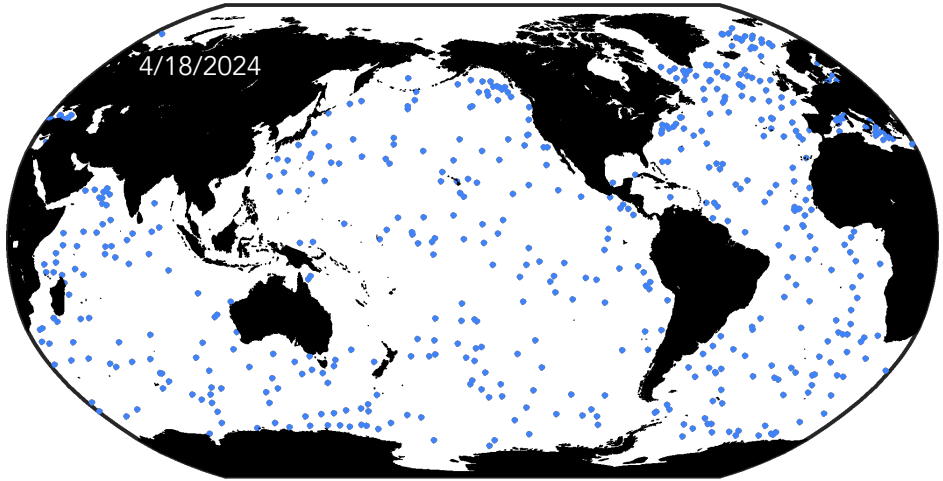
Autonomous Observing Platforms for Ocean Carbon and Temperature





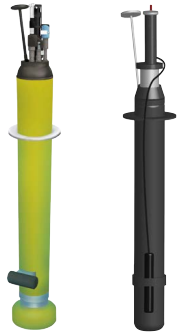
Biogeochemical (BGC) Argo Array Implementation Status

BGC Argo Status Map

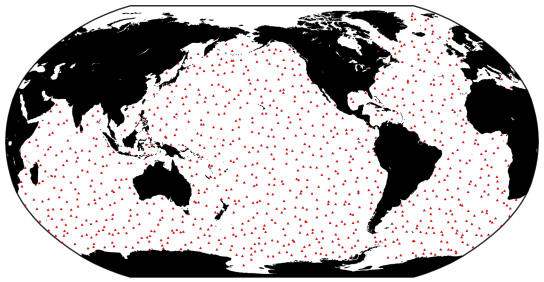


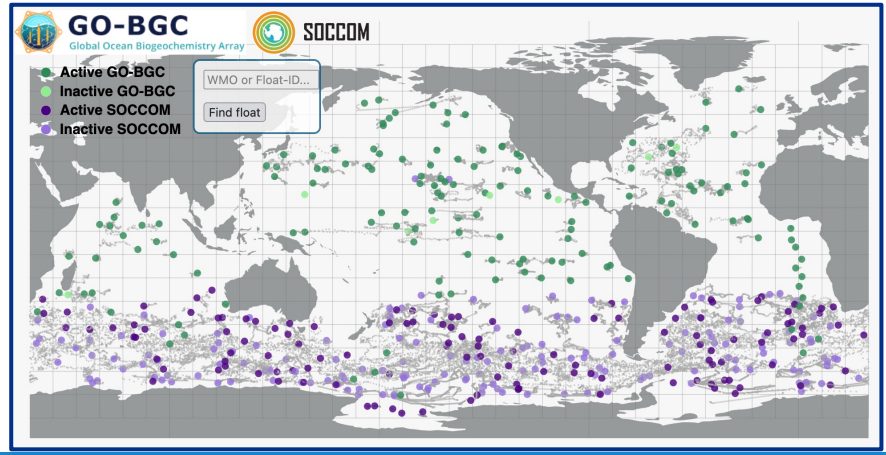
~54% implementation

2% carry all six parameters:
pH, oxygen, nitrate, backscatter, chlorophyll-f, irradiance



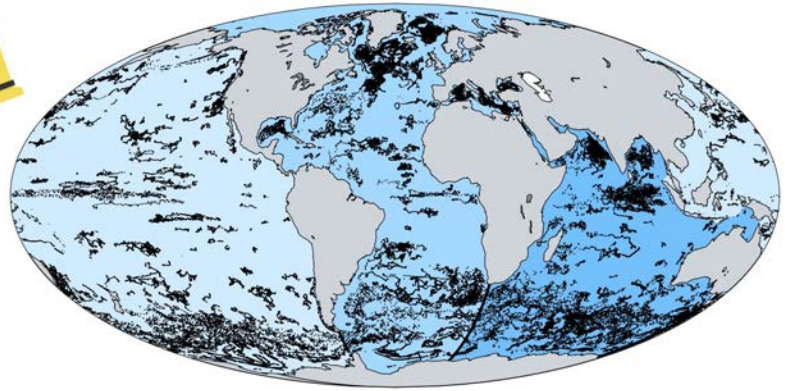
Goal Array: 1000 floats



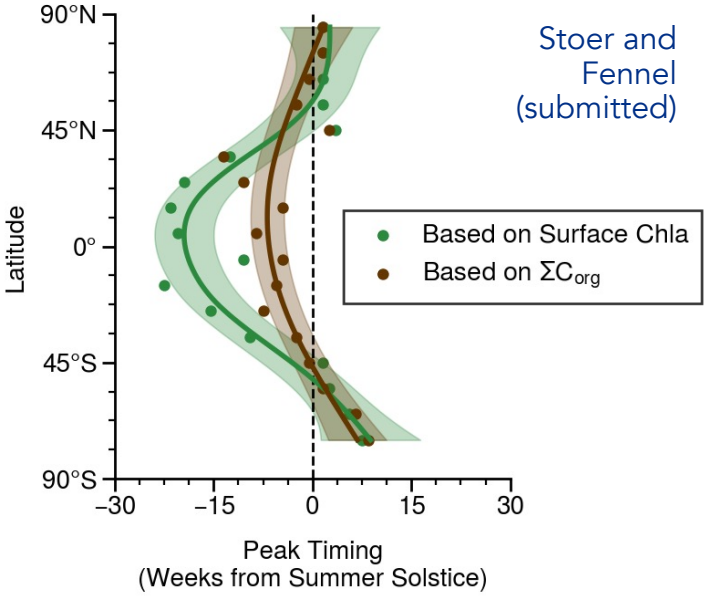


BGC Argo Capabilities: Bloom Timing & Carbon Stocks

We can now do global-scale carbon-centric phytoplankton dynamics from the >100,000 bio-optical profiles collected

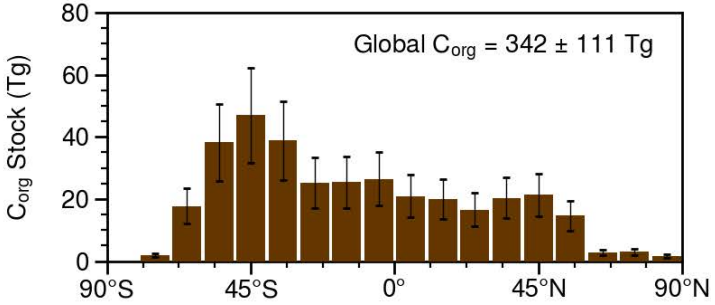


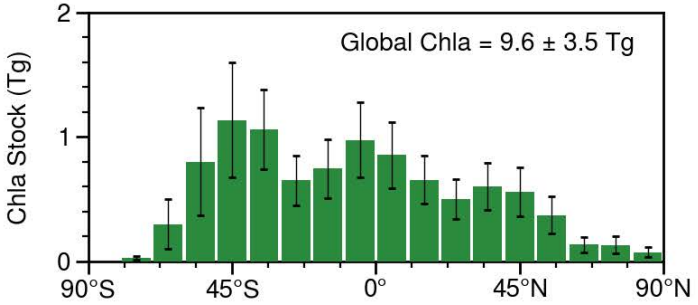
more accurate bloom timing



Stoer and Fennel (submitted)

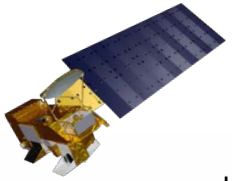
more accurate biogeography

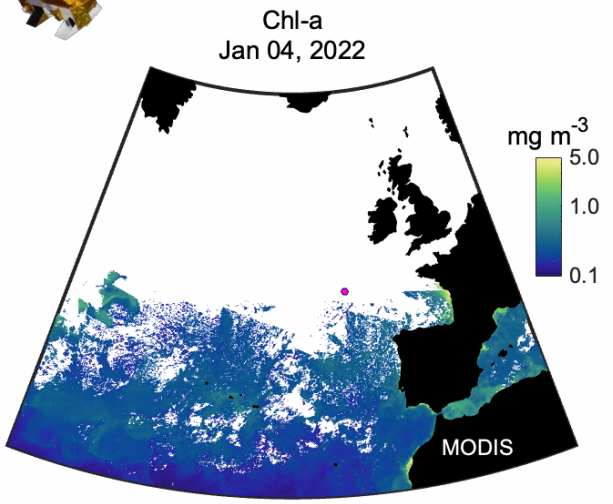




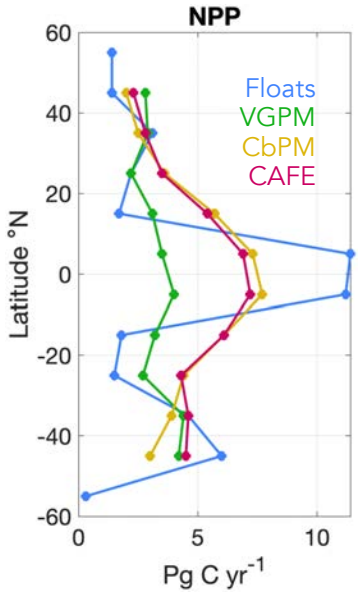
Adam Stoer
Graduate Student
Dalhousie University

BGC Argo Capabilities: Biological Productivity





NPP | NCP values from
Nina Buzby | Marin Cornec
Grad Student | Postdoc, UW



Johnson & Bif, 2021

GPP/NPP rates from composite diel cycles: Johnson & Bif, 2021; Stoer & Fennel, 2022

NPP from algorithms: Estapa et al., 2019; Long et al., 2021; Yang et al., 2021; Arteaga et al., 2022; Giddy et al., 2023

Seasonal/annual NCP (O_2, NO_3^-, C): Johnson et al., 2017; Yang et al., 2017, 2018; Bushinsky et al., 2018; Arteaga et al., 2019; Bif et al., 2019; Su et al., 2022; Sauvé et al., 2023

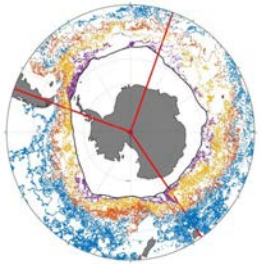
Productivity by carbon pool (DOC, POC, PIC): Williams et al., 2018, Haskell et al., 2020, Huang et al., 2022, 2023

BGC Argo Capabilities: Carbon Export Magnitudes & Mechanisms

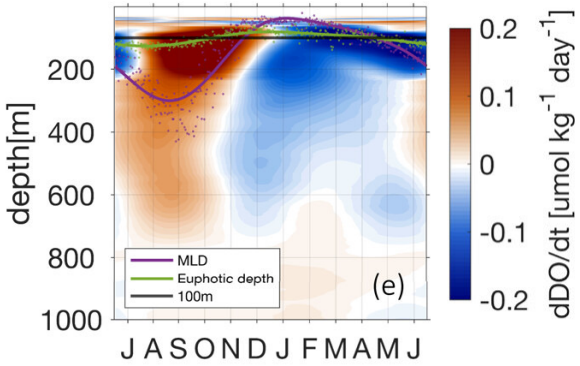
Geophysical Research Letters

New Estimates of Southern Ocean Annual Net Community Production Revealed by BGC-Argo Floats

Jiaoyang Su[1,2], Christina Schallenberg[1,3], Tyler Rohr[3], Peter G. Strutton[1,2], and Helen E. Phillips[1,3,4]



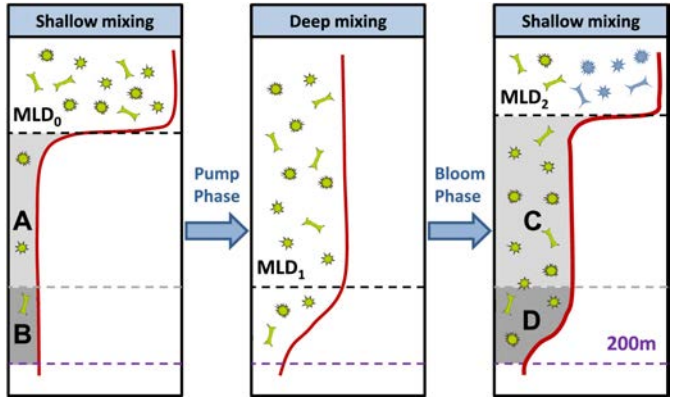
Subantarctic Zone (SAZ)

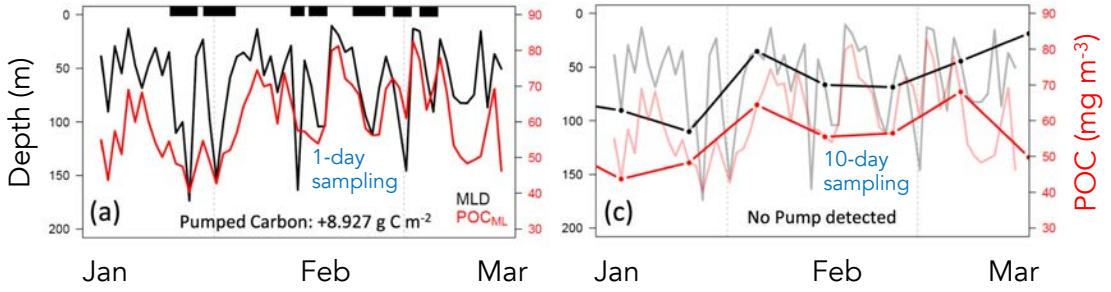


Geophysical Research Letters

Enhanced Winter Carbon Export Observed by BGC-Argo in the Northwest Pacific Ocean

Xiaogang Xing[1,2], Mark L. Wells[3,1], Shuangling Chen[1], Sheng Lin[1], and Fei Chai[1,3]





Oxygen utilization: Hennon et al., 2016; Arteaga et al., 2019

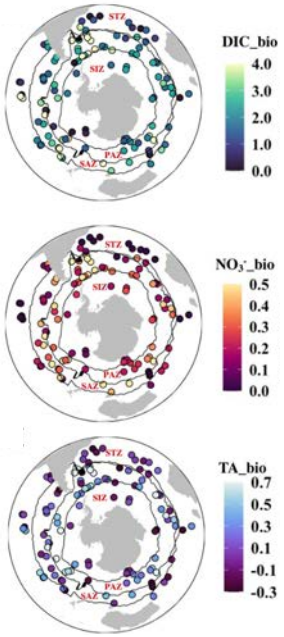
Particle export/pumps/fragmentation: Dall'Olmo and Mork 2014; Kheireddine et al., 2020; Briggs et al., 2020; Chen et al., 2021; Lacour et al., 2019, 2023; Wang & Fennel, 2022; Terrats et al., 2023; McClish & Bushinsky, 2023; Bif et al., 2024; Guo et al., 2024

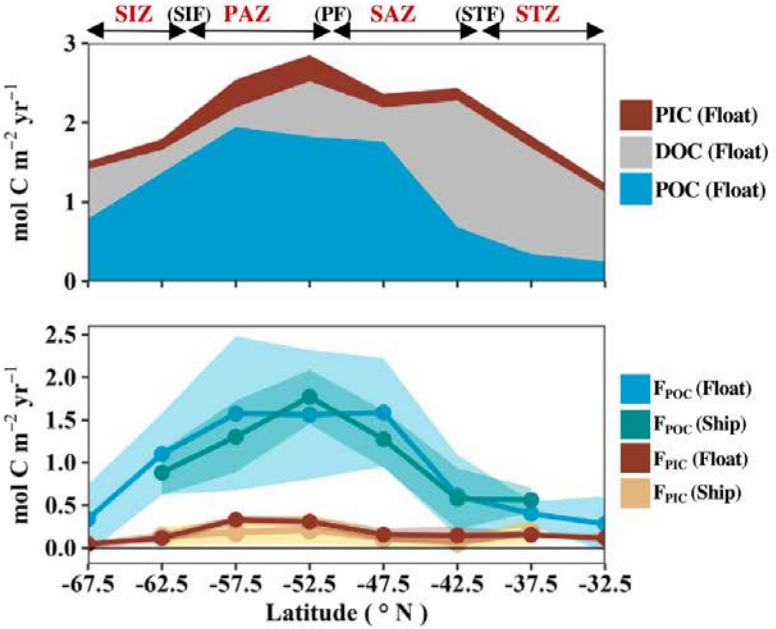
Inventory balance: Alkire et al,. 2012; Huang et al,. 2022, 2023

Biogenic carbon pool production maintains the Southern Ocean carbon sink

PNAS

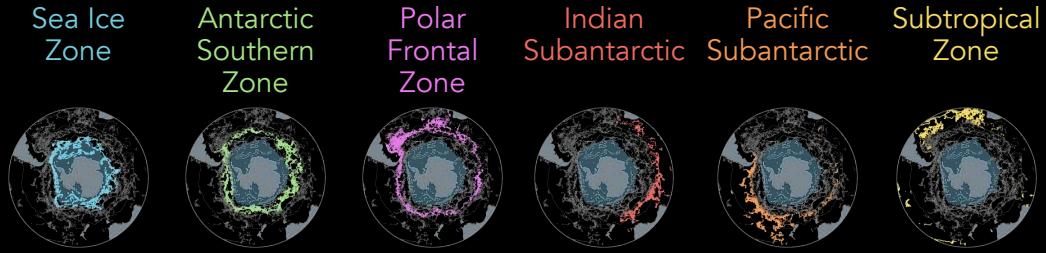
Yibin Huang[a,b], Andrea J. Fassbender[a,b,1], and Seth M. Bushinsky[c]



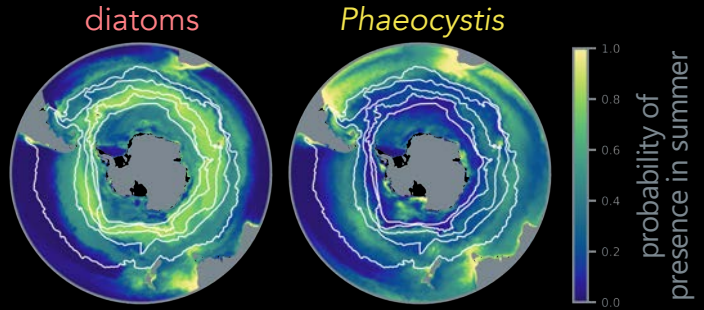


BGC Argo Capabilities: Phytoplankton Distributions & the Environment

BGC-Argo floats clustered into biophysically similar regions

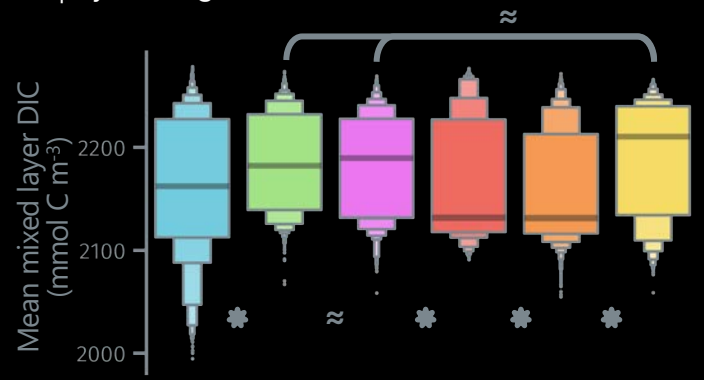


Phytoplankton distributions modeled from microscopy observations

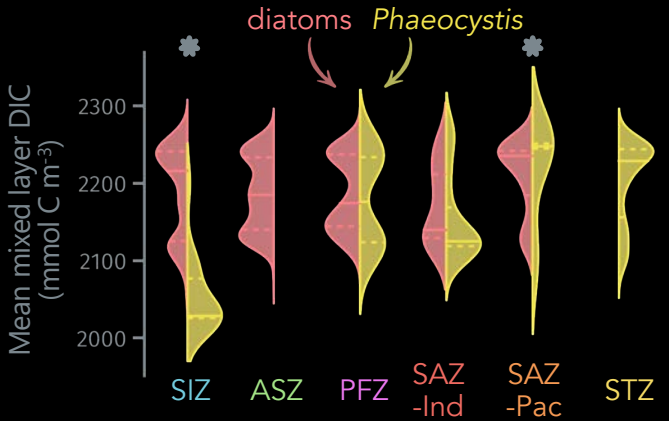


Hannah Joy-Warren
Postdoc, UW-APL

Biophysical regions have different DIC concentrations



Regional differences in DIC-taxa overlaps

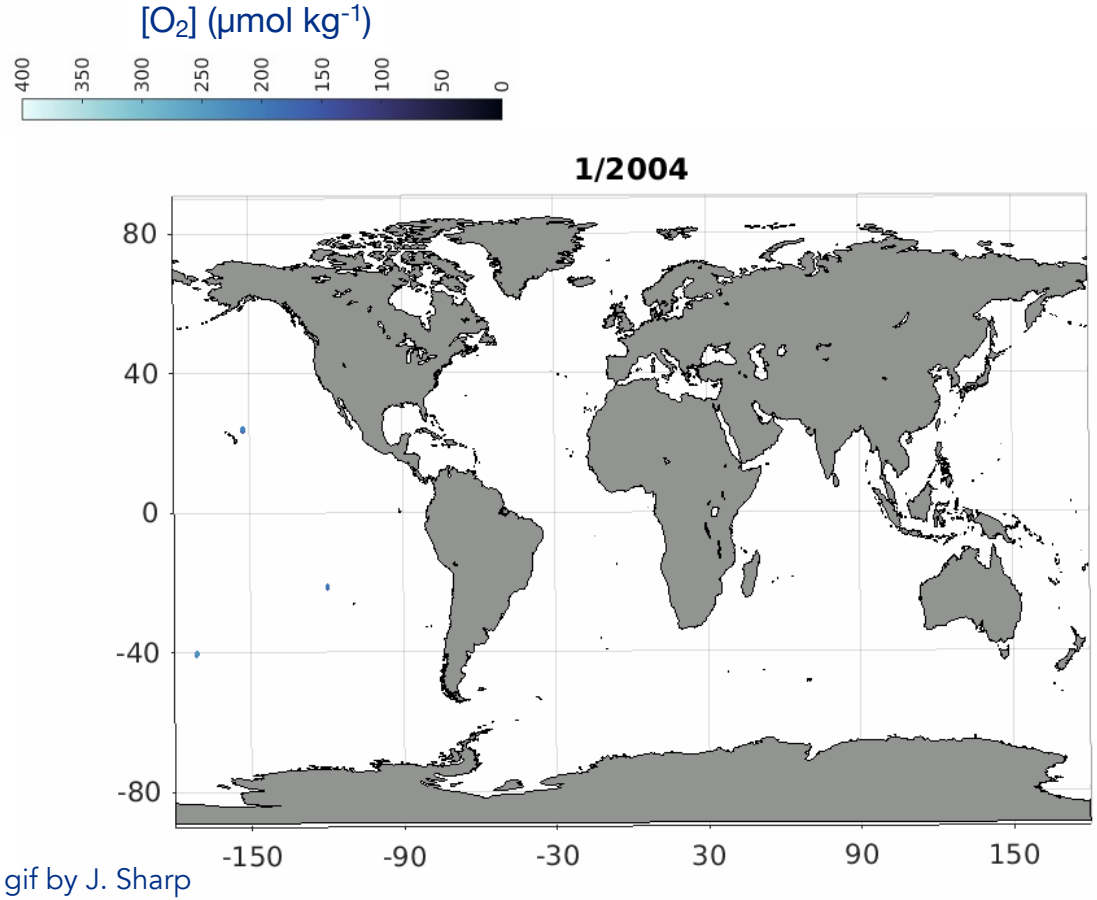


Phytoplankton groups: Rembauville et al., 2017; Terrats et al., 2020

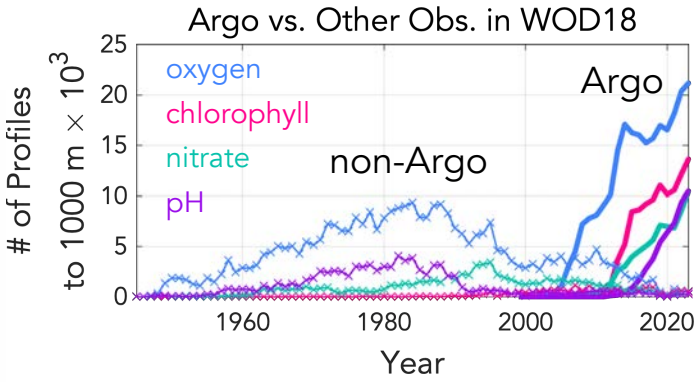
O_2 & CO_2 fluxes: Bushinsky et al., 2017, 2018; Gray et al., 2018; Bushinsky et al., 2019; Prend et al., 2022; Sauvé et al., 2023; Huang et al., 2023

Extreme events: Yang et al., 2018; Bif et al., 2019; Long et al., 2021; Tang et al., 2021; Weis et al., 2022; Zhang et al., 2023

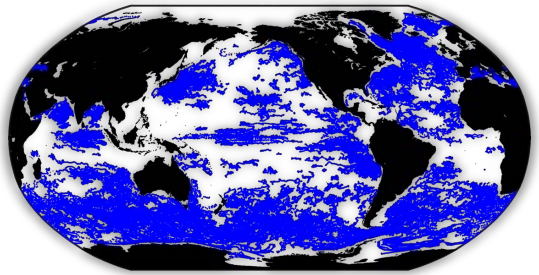
BGC Argo Global Data Accumulation



gif by J. Sharp



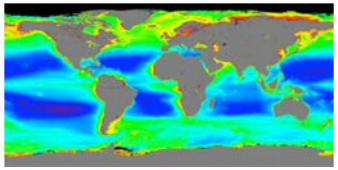
D-Mode O_2 Profiles



BGC Argo Data Synthesis: Backscatter, Particulate Organic Carbon, Chlorophyll, Light

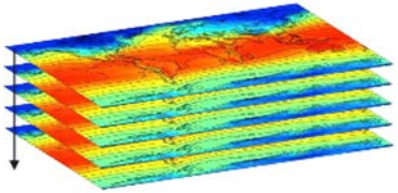
Satellite Ocean Color & Argo (SOCA) data used to map vertical distributions of bio-optical properties

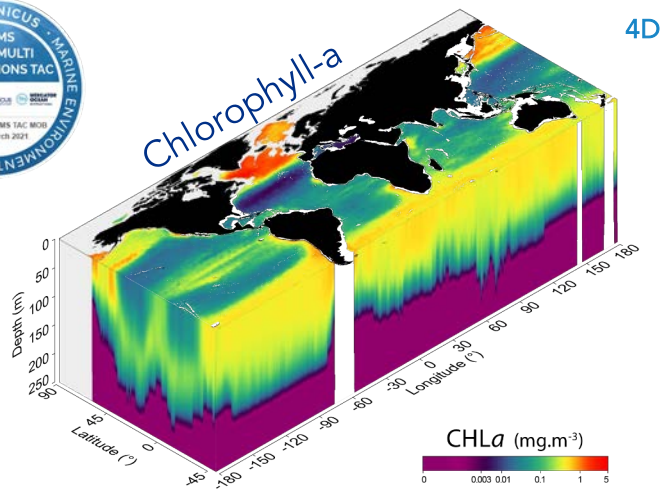
GlobColour Satellite Fields



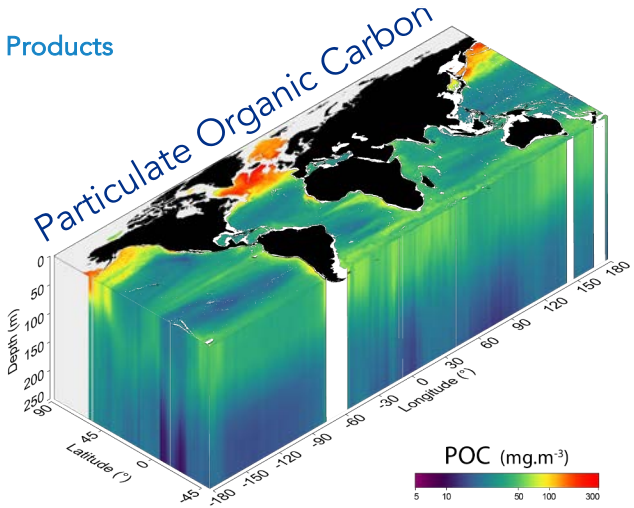
+

ARMOR3D Fields (T/S + MLD)





4D BGC Products



SOCA-derived global 4D gridded POC ($+b_{bp}$) and Chl from the European Copernicus Marine Service:

- **Horizontal resolution:** ¼ (⅛ after Nov. 2024)
- **Vertical resolution:** 36 depth levels from surface to 1000 m
- **Temporal resolution:** weekly from 1998 to 2022 & monthly climatology

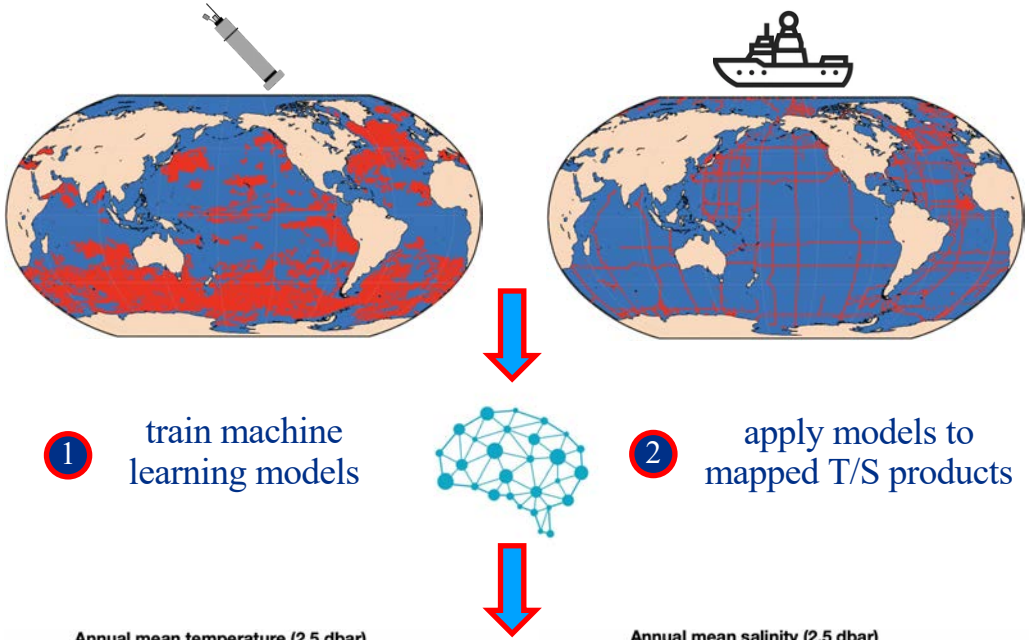
Coming soon: SOCA-light (PAR + Ed(490, 443, 555)) - Renosh et al. (2023)

SCAN ME

Raphaëlle Sauzède
LOV IMEV

BGC Argo Data Synthesis: Oxygen

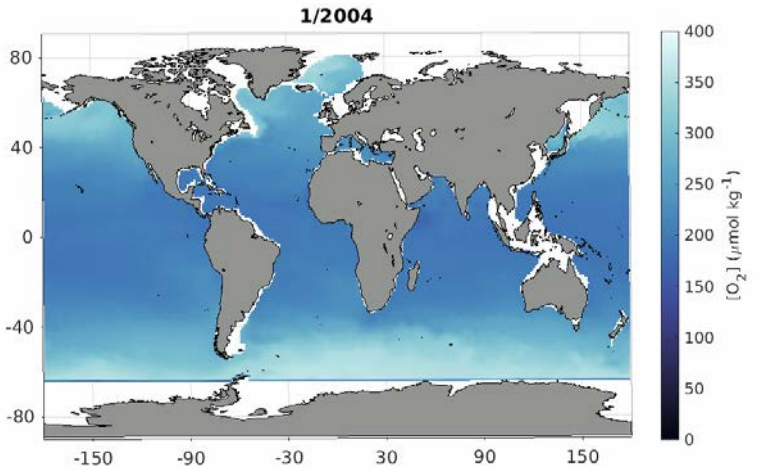
Jon Sharp
PMEL/CICOES

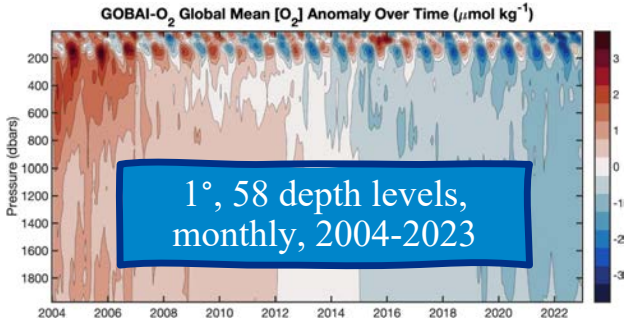


1 train machine learning models

2 apply models to mapped T/S products

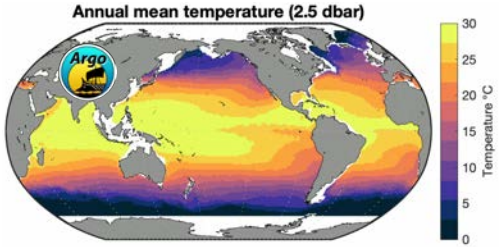
3 map ocean oxygen

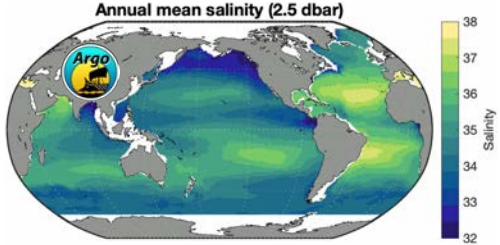




GOBAI-O2

scan me!



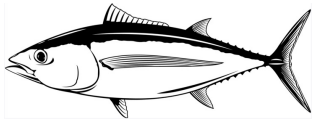


Roemmich & Gilson, SIO

Applications: Species Distribution Modeling

Mary Margaret Stoll
UW Grad Student

Albacore tuna
(*Thunnus alalunga*)

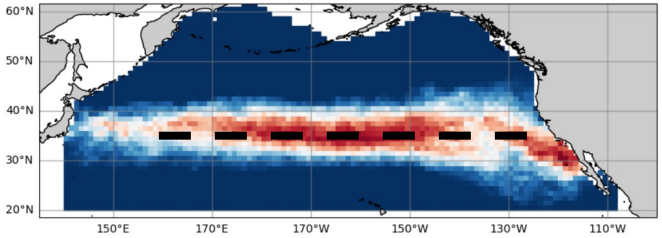


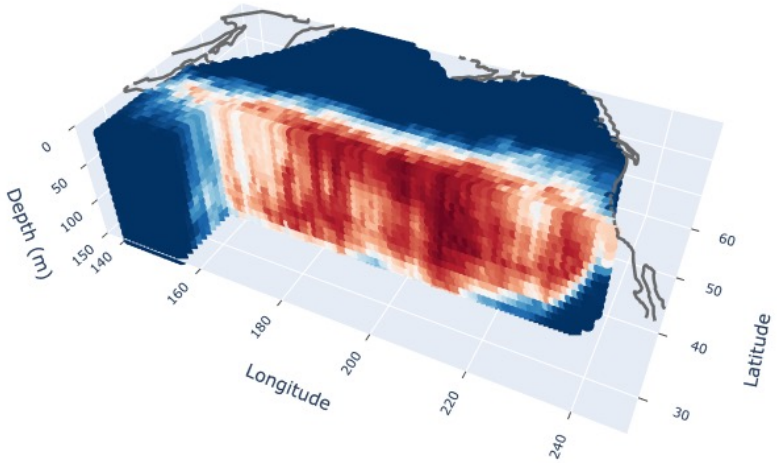
Mean Probability of Occurrence

>50%

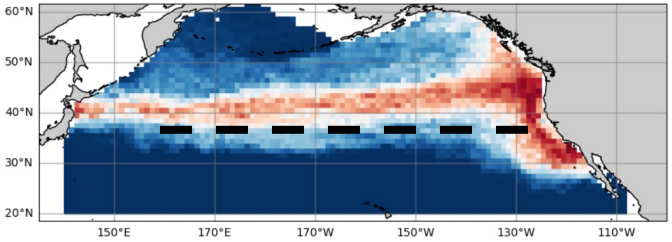
<50%

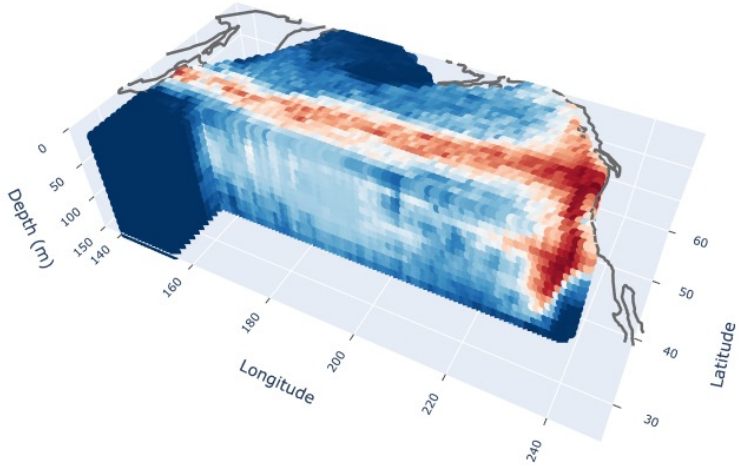
Winter





Summer

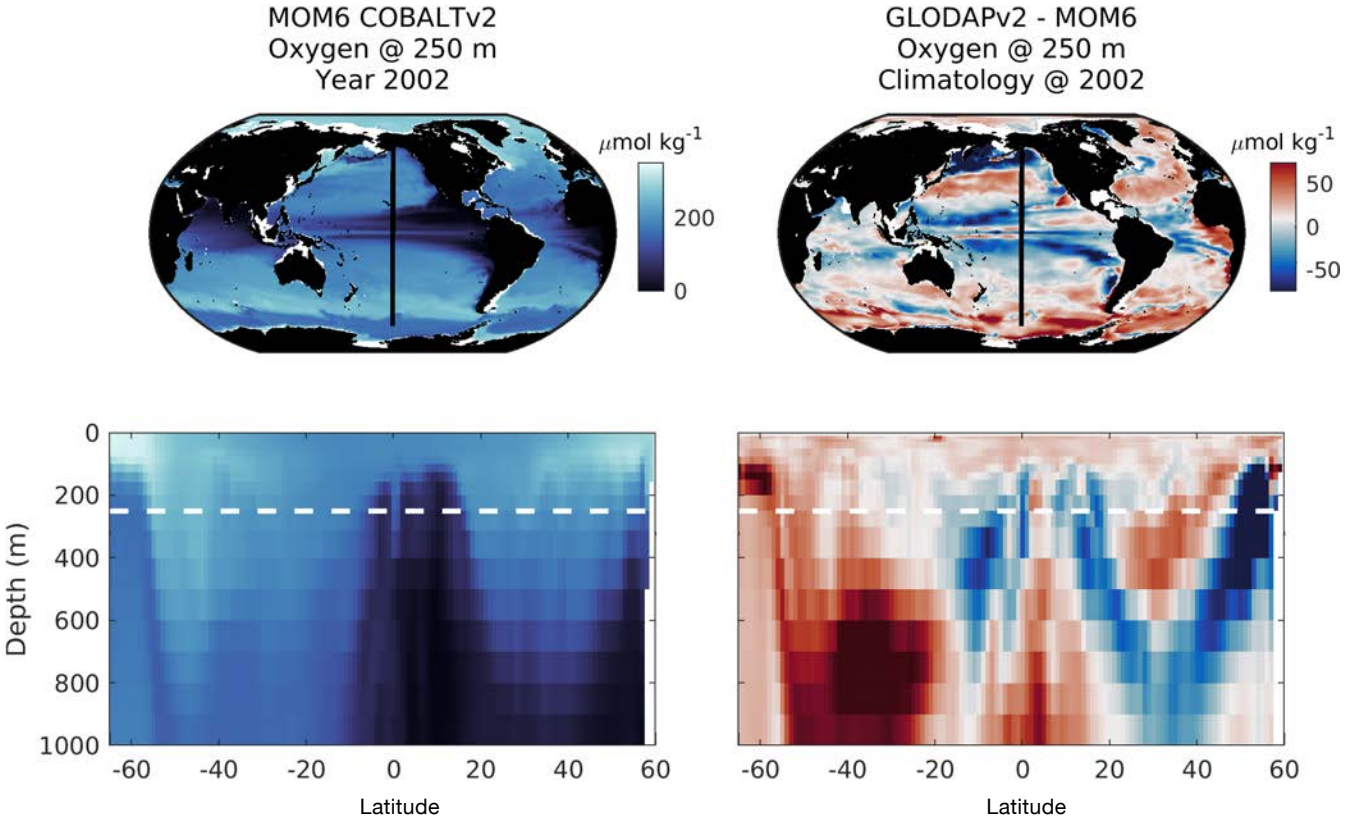




Applications: Biogeochemical Model Benchmarking

Earth System Model (ESM)

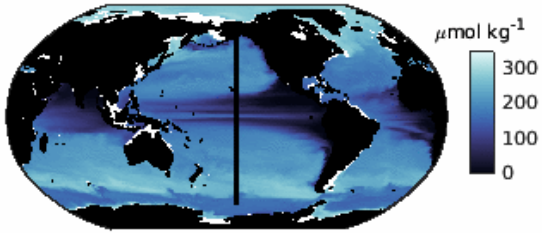
glodap - ESM



Applications: Biogeochemical Model Benchmarking

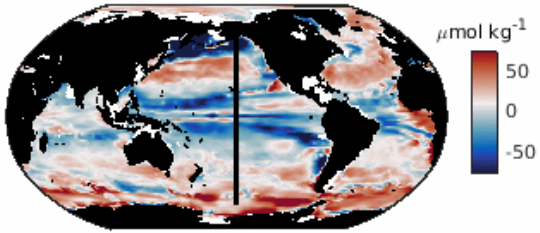
Earth System Model (ESM)

MOM6 COBALTv2
Oxygen @ 250 m
Year 2004



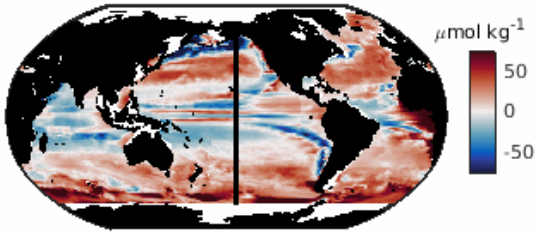
glodap - ESM

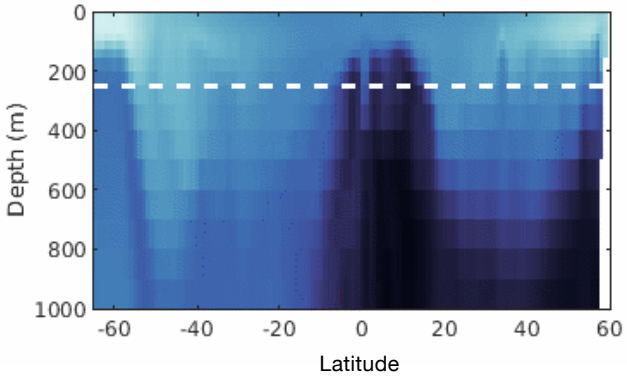
GLODAPv2 - MOM6
Oxygen @ 250 m
Climatology @ 2002

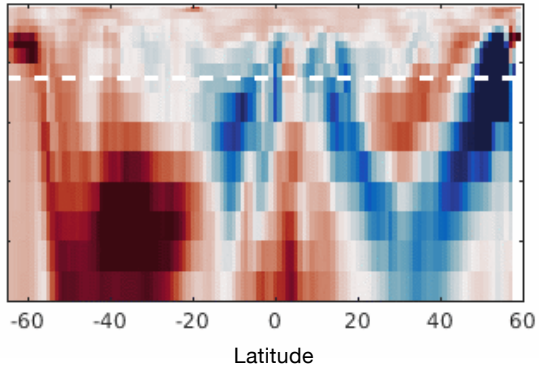


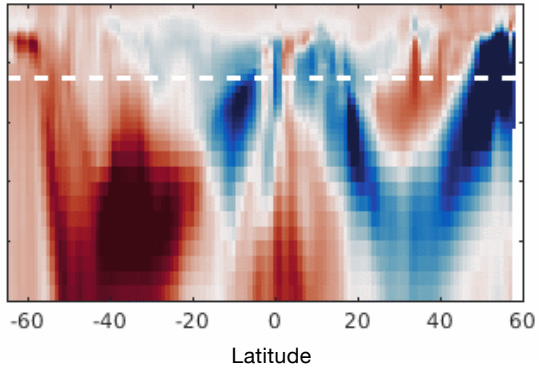
GOBAI-O_2 - ESM

GOBAI-O_2 v2.1 - MOM6
Oxygen @ 250 m
Year 2004

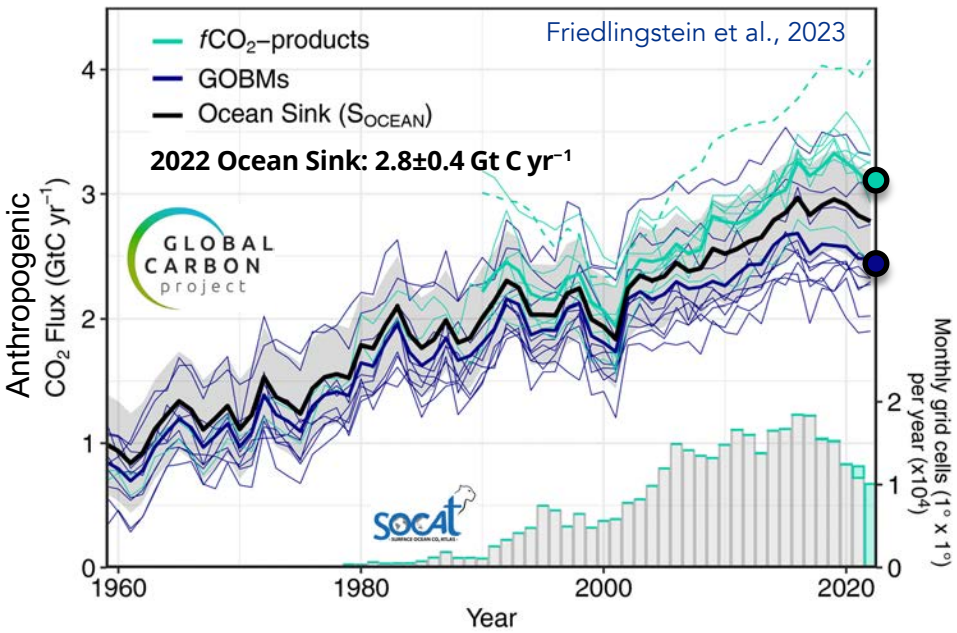








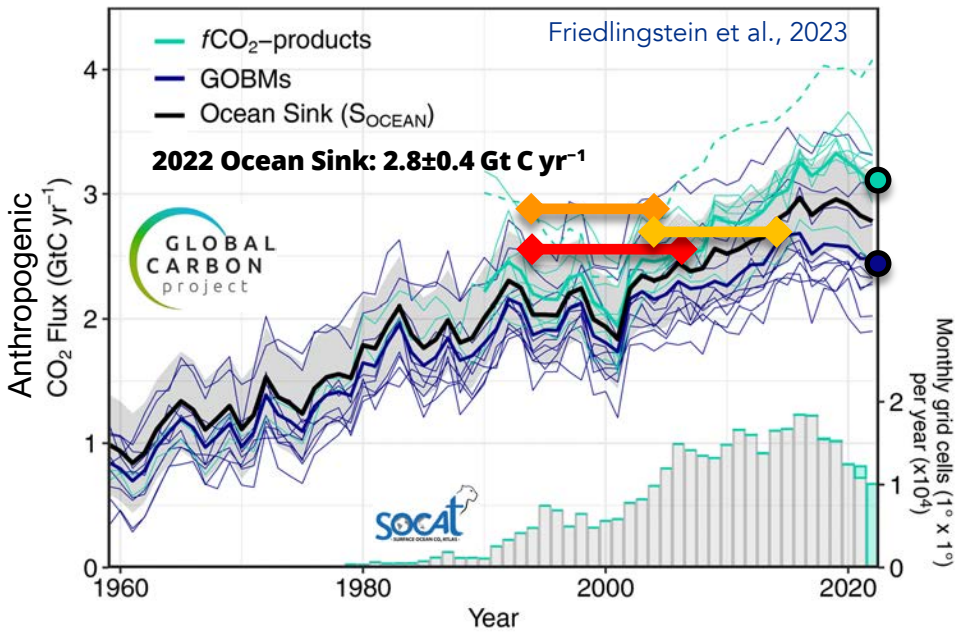
Applications: Ocean Carbon Budget

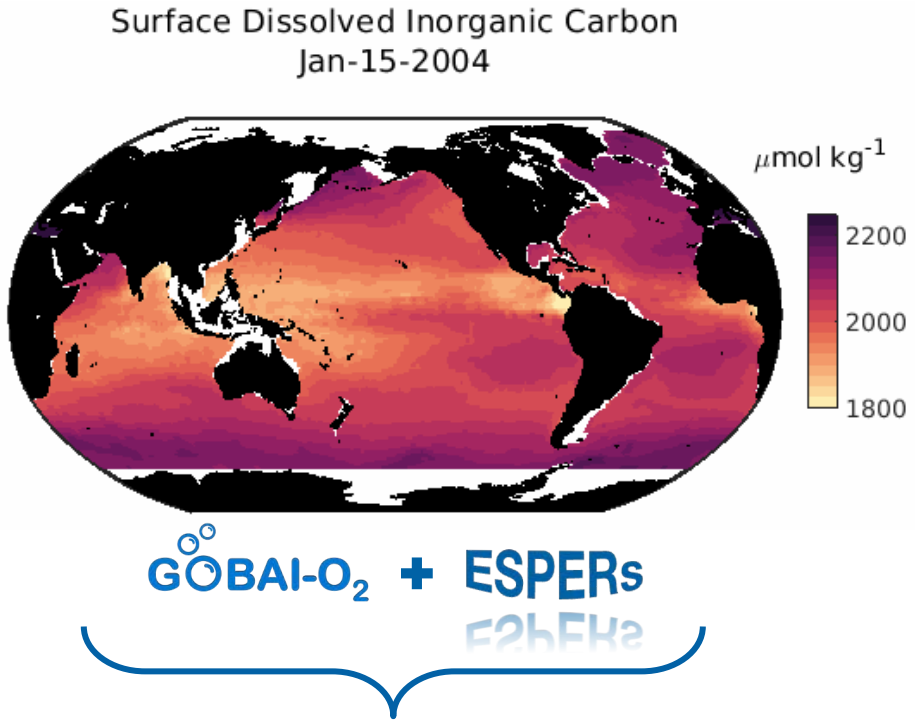


<u>Quantifying the Ocean Carbon Sink:</u>

1. Global Ocean Biogeochemistry Models
2. CO_2 Data Products

Applications: Ocean Carbon Budget



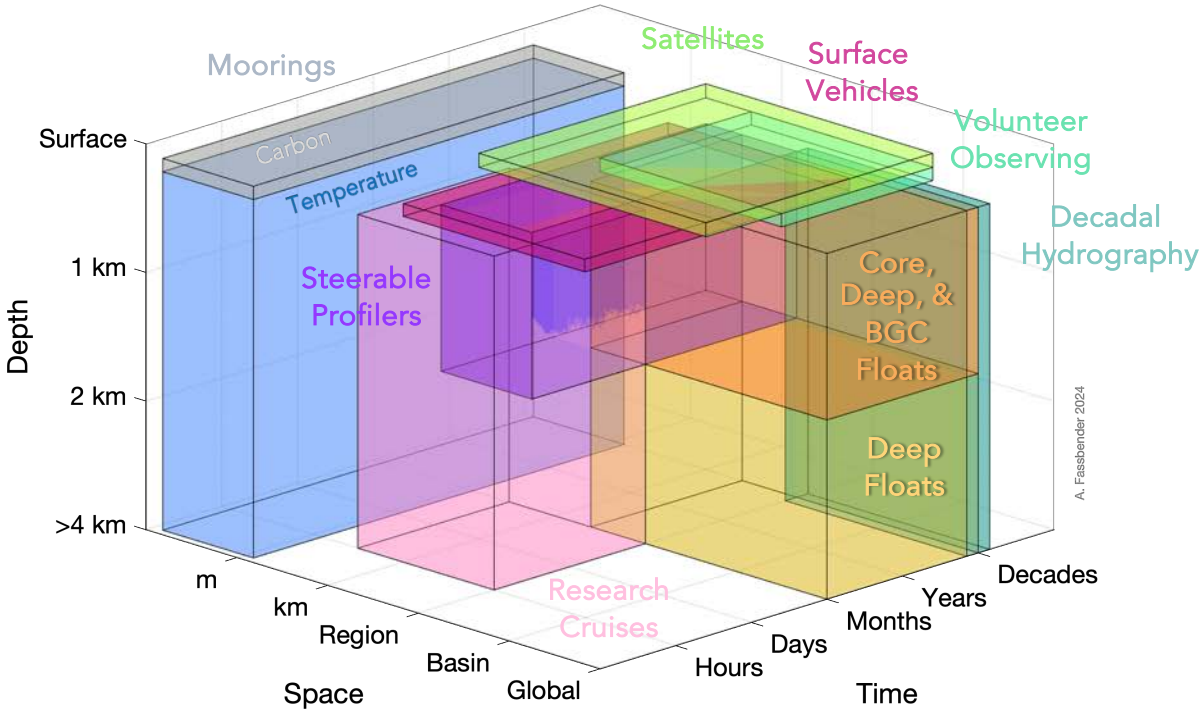


Quantifying the Ocean Carbon Sink:

1. Global Ocean Biogeochemistry Models
2. CO_2 Data Products
3. Repeat Hydrography (Gruber$_{2019}$;Müller$_{2023}$)

Sharp et al., 2023
Carter et al., 2021

Pathways Connecting Climate Change to the Deep Ocean Occur at a Range of Space & Time Scales Requiring a Comprehensive BGC Observing System



Sustained funding for U.S. BGC Argo does not exist beyond a few pilot arrays. The NSF GO-BGC project will conclude in 2026 and it is not clear that SOCCOM will be renewed.

If you think these platforms could be valuable for your research, **please consider writing proposals to NSF to use the data and/or deploy more floats.** Partner with one of the US float-deploying institutions for assistance.