Observation System Simulation Experiments: reconstructing surface ocean pCO_2 in the Atlantic Ocean

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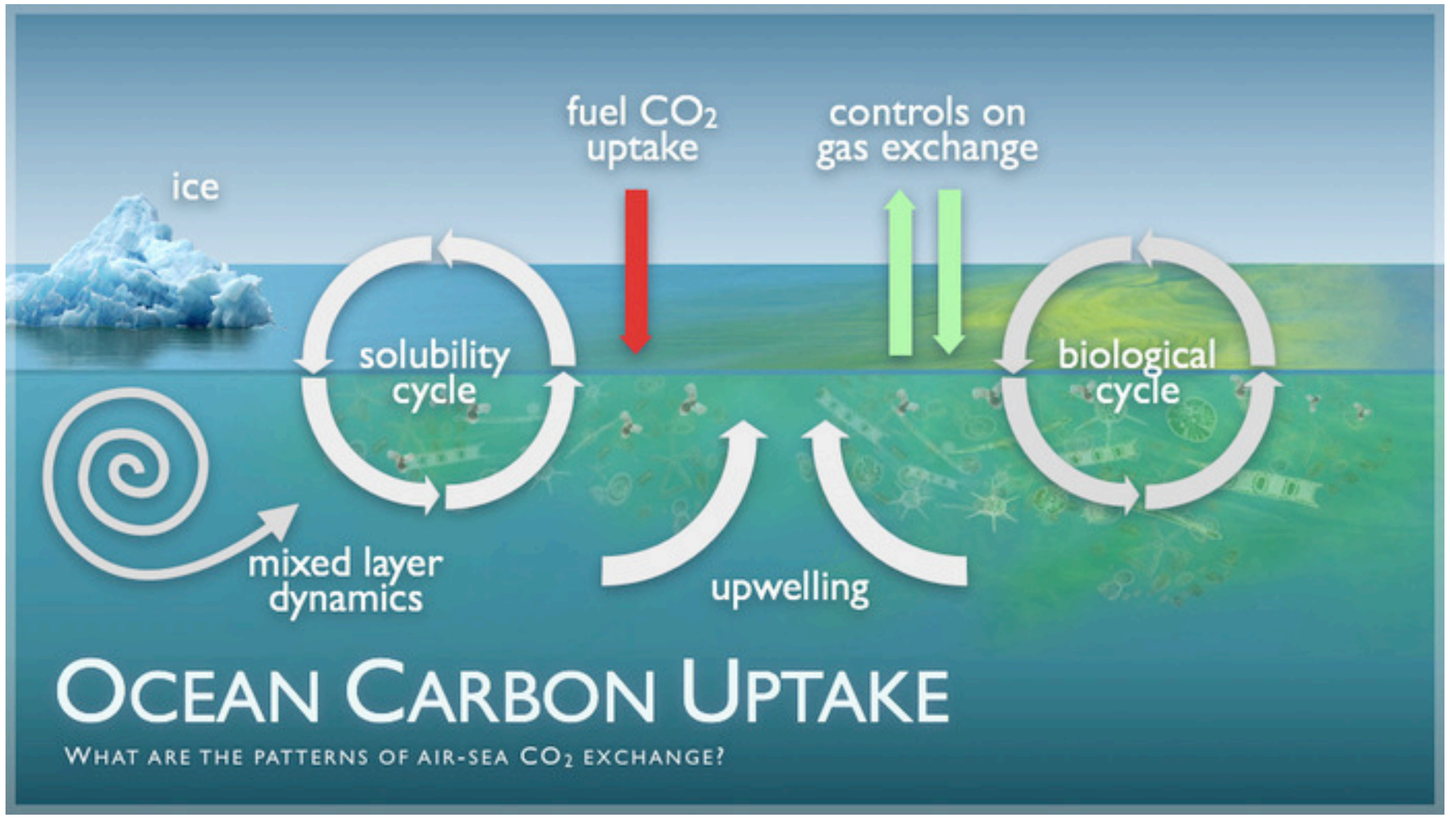
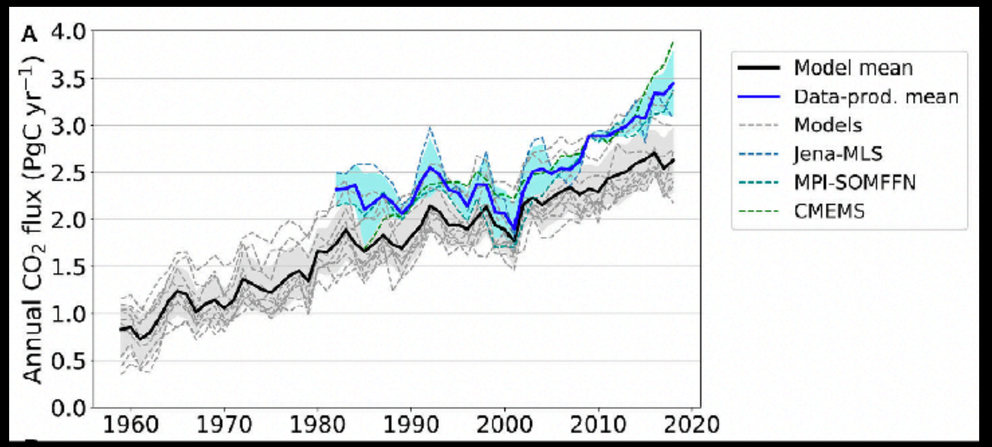
Observation System Simulation Experiments: reconstructing surface ocean pCO_2 in the Atlantic Ocean

Outline:

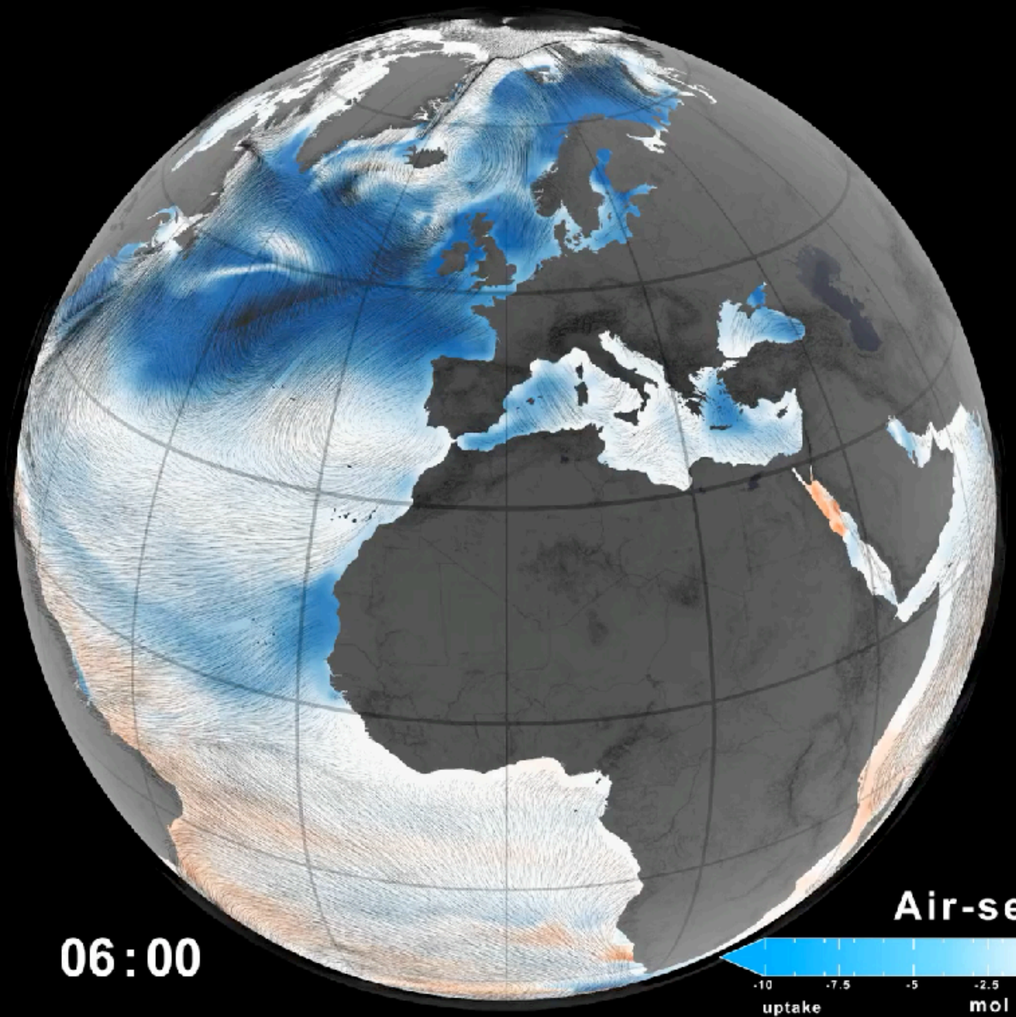
1. Short introduction to pCO2 observations
2. Getting ready
3. Exercise

Observation System Simulation Experiments: reconstructing surface ocean pCO_2 in the Atlantic Ocean





Hauck et al., 2020



03 Jan 2012 06:00

Air-sea CO_2 Flux

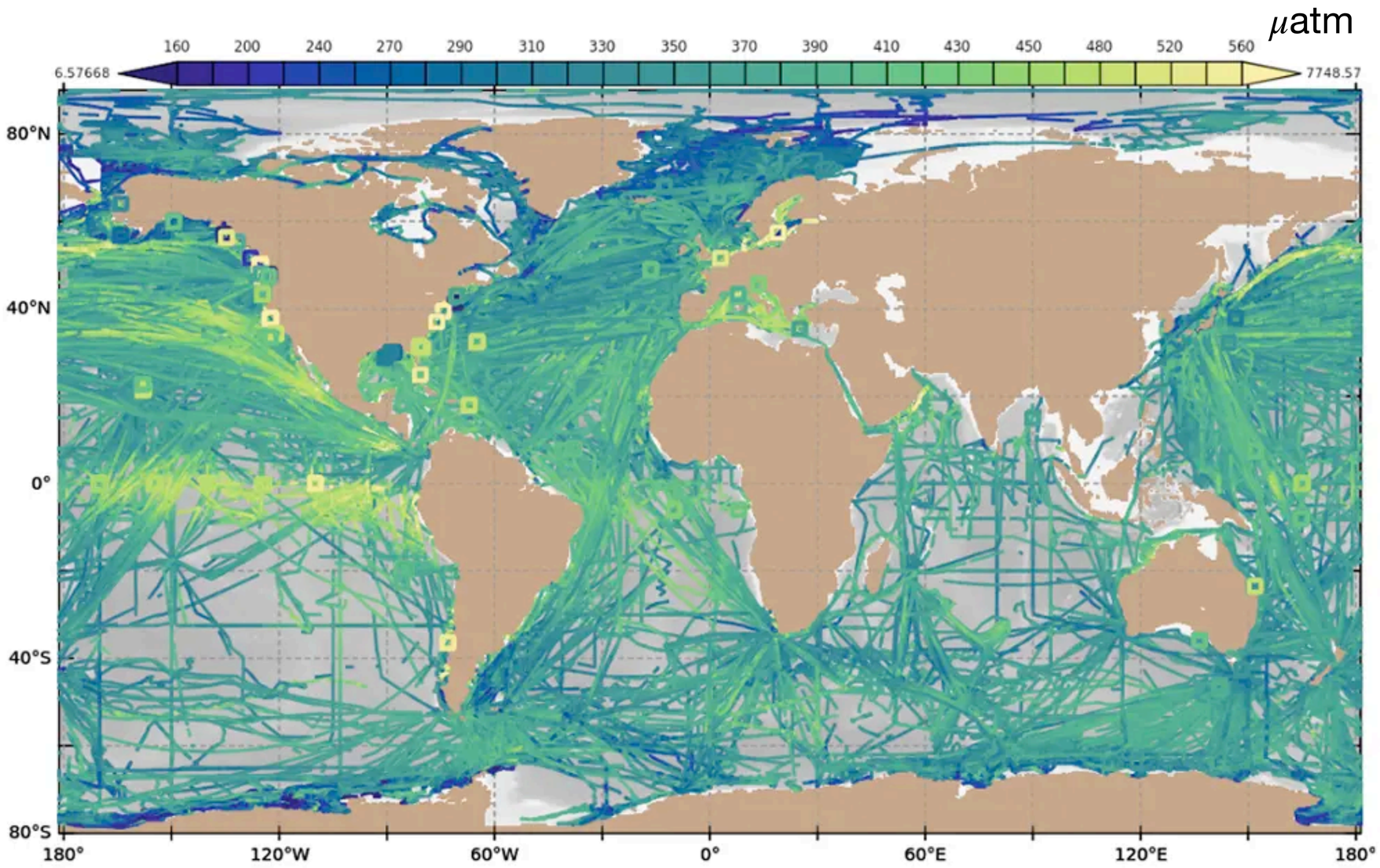
-10 -7.5 -5 -2.5 0 2.5 5 7.5 10

uptake

mol C / m^2 / year

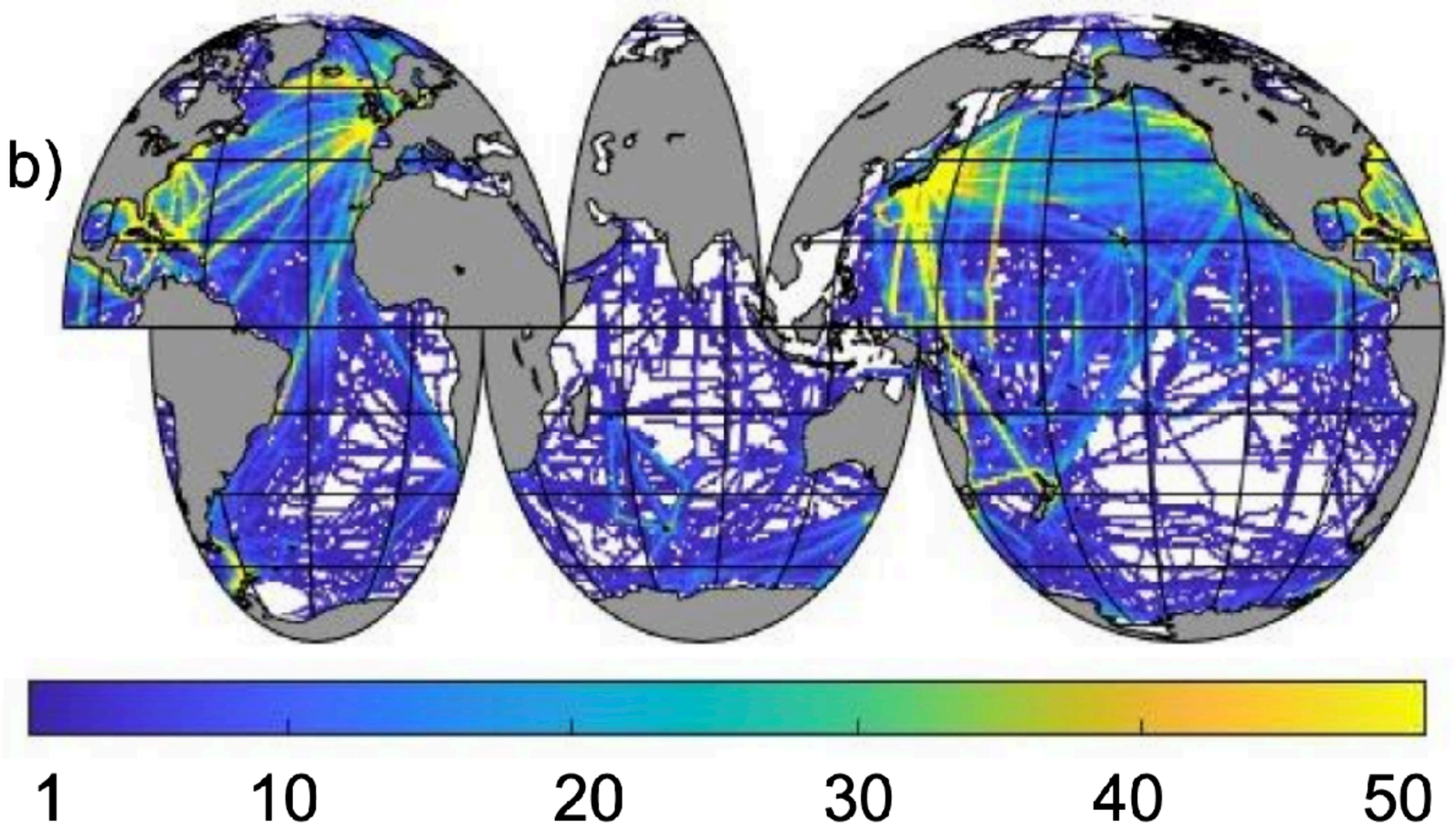
outgassing

Observation-based pCO_2 products: SOCAT



- Data: ship-based observations (lines) + moorings (squares) + drifters (lines)
- Latest SOCAT version (version 2025) has 41.4 million observations from 1957 to 2023

Observation-based pCO_2 products: SOCAT



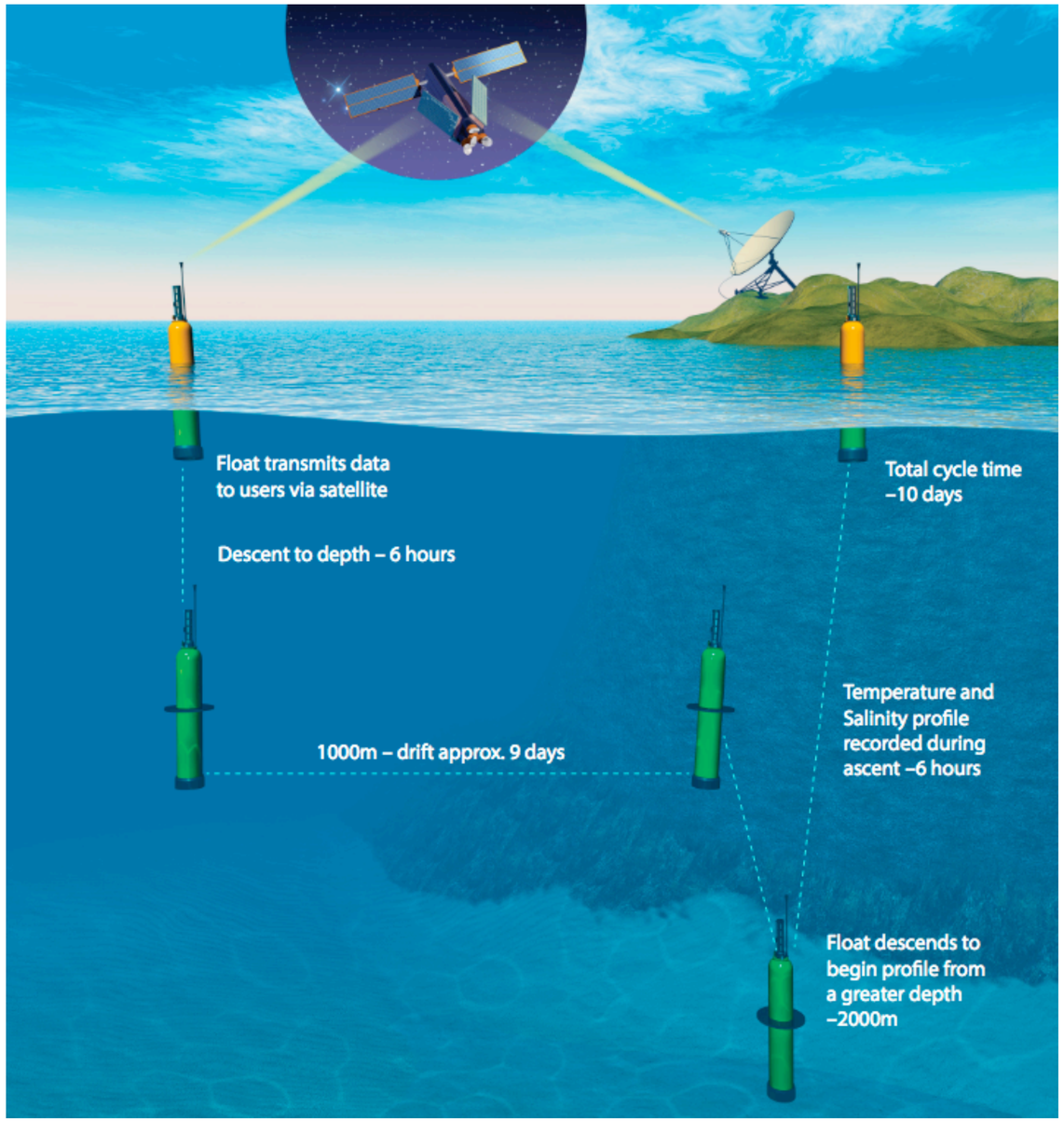
Bakkar et al., 2025

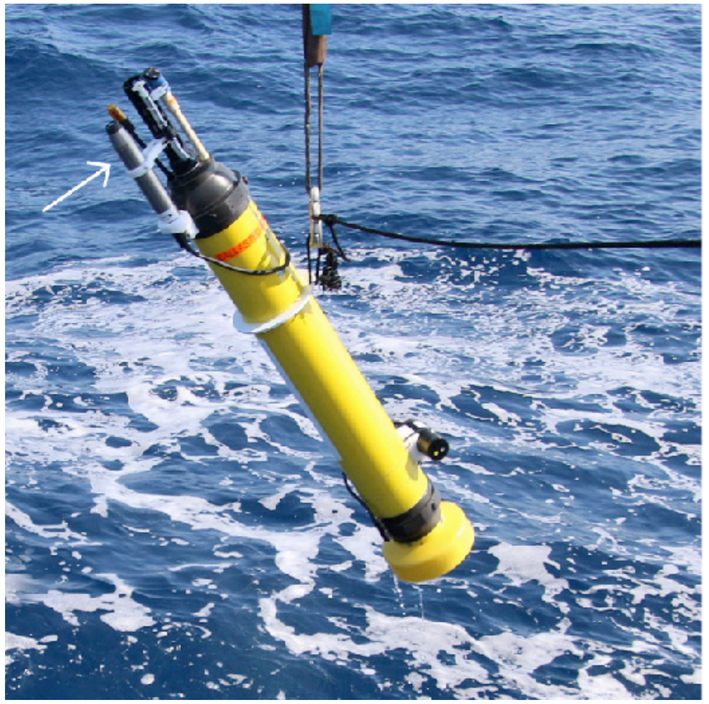
Number of individual months with 1° x 1° gridded fCO2 from 1970 to 2023

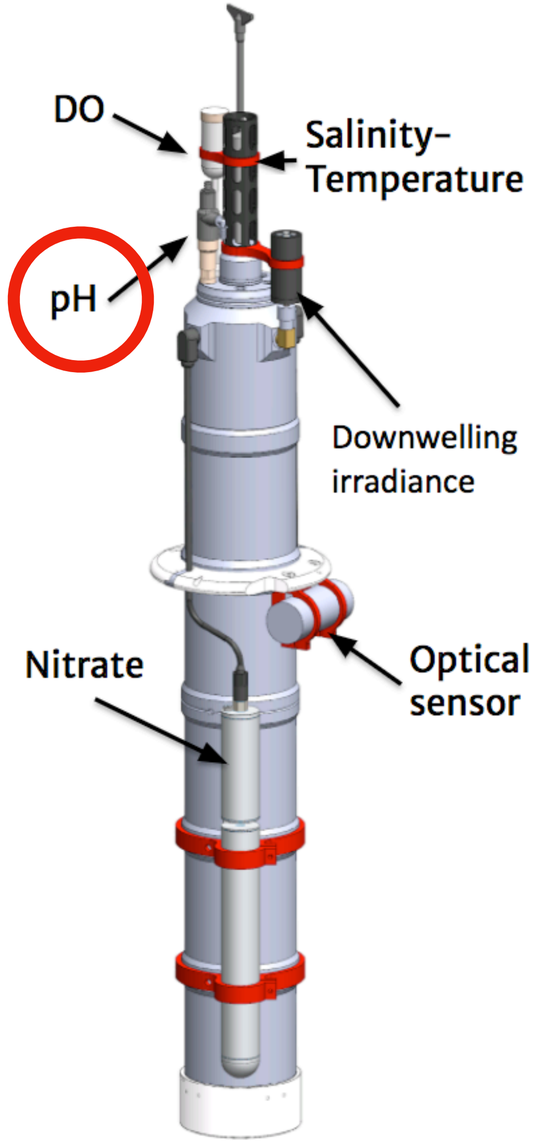
Data is sparse in space and time

ML methods are not good at extrapolating

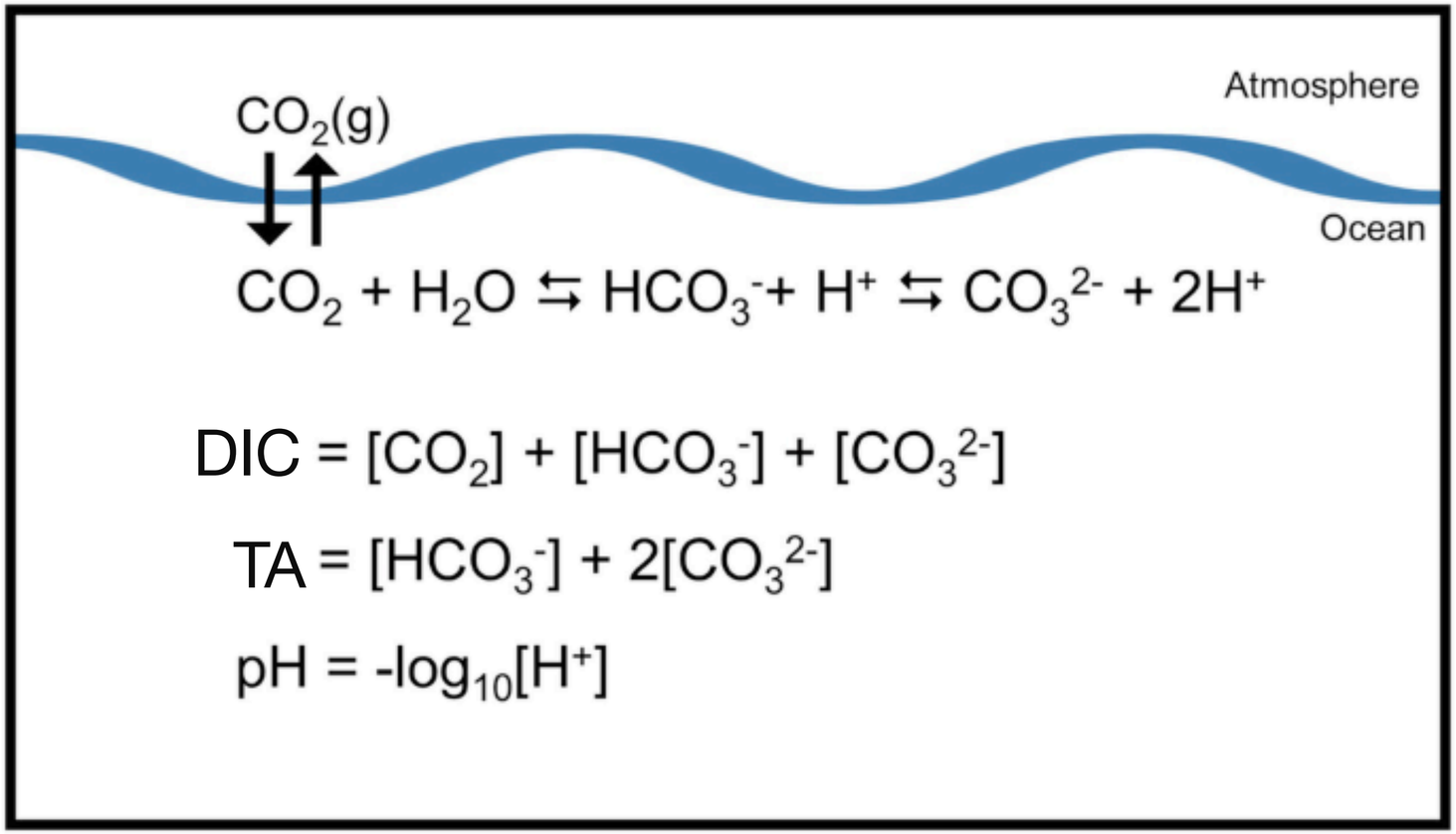
Observation-based pCO_2 products: autonomous BGC floats

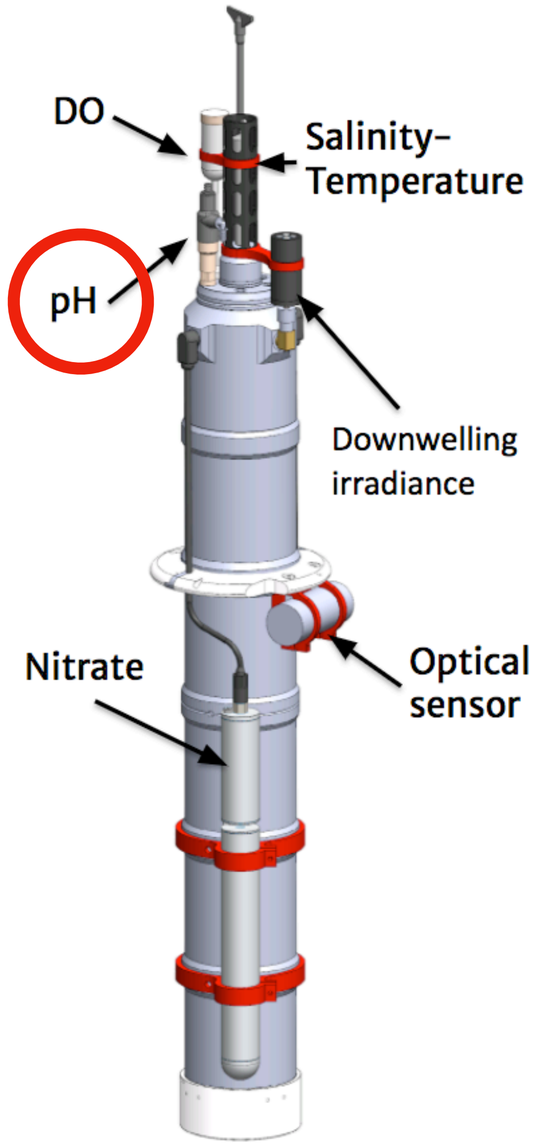






Observation-based pCO_2 products: autonomous BGC floats





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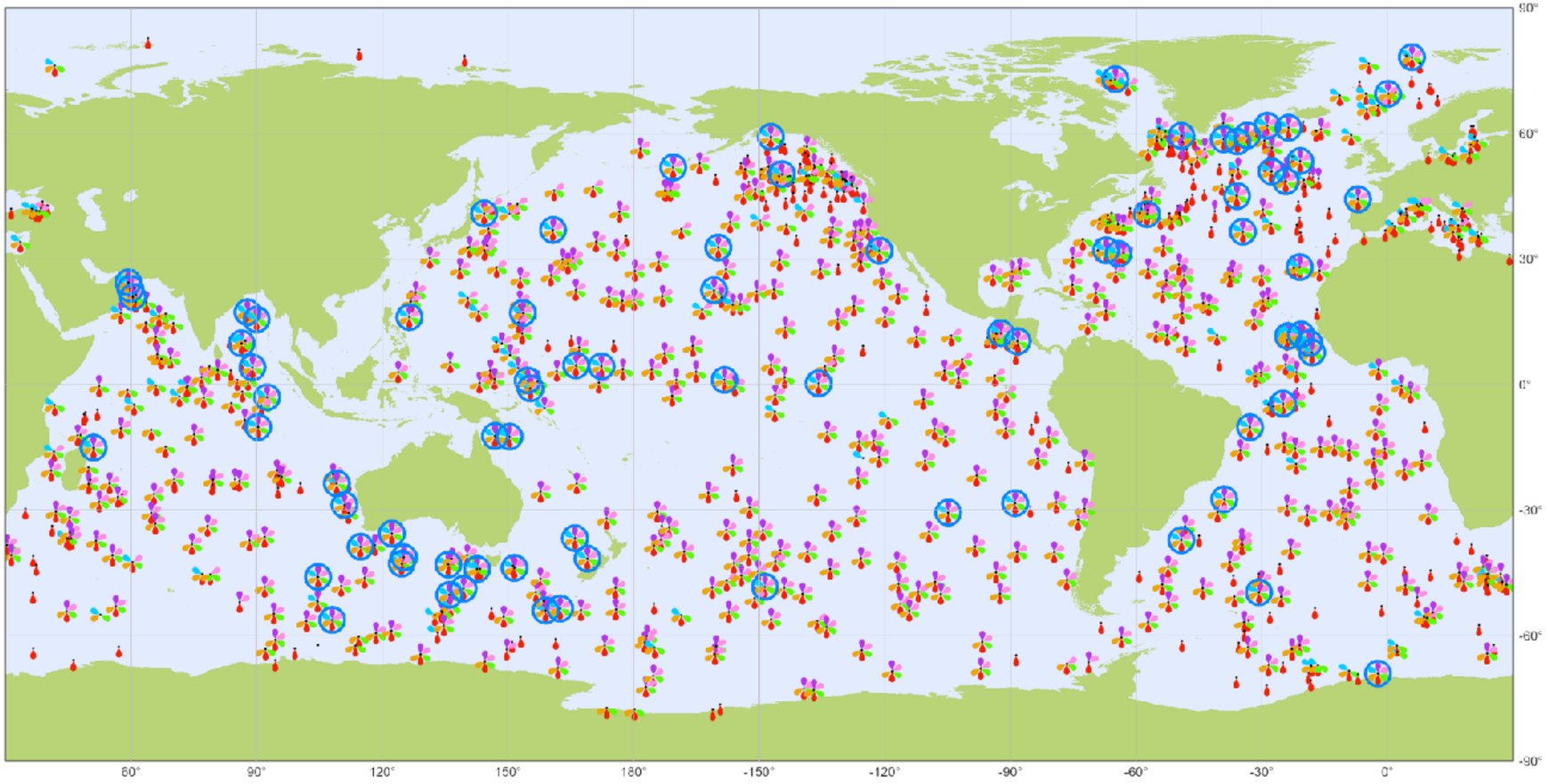


Biogeochemical Argo

Sensor Types

June 2025

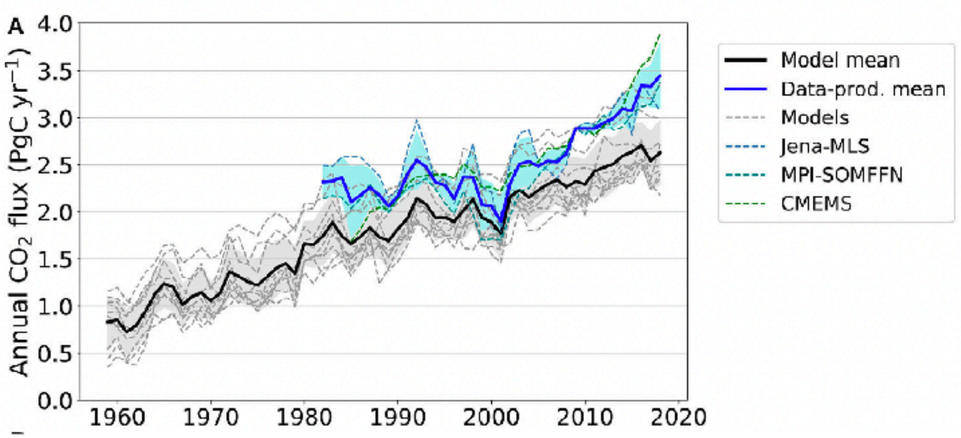
Latest location of operational floats (data distributed within the last 30 days)

Operational Floats (794)
Suspended particles (555)
Downwelling irradiance (170)
pH (459)
Nitrate (456)
Chlorophyll a (555)
Oxygen (783)
Full BGC Floats (79)

Generated by ocean-ops.org, 2025-07-04
Projection: Plate Carree (-150.0000)

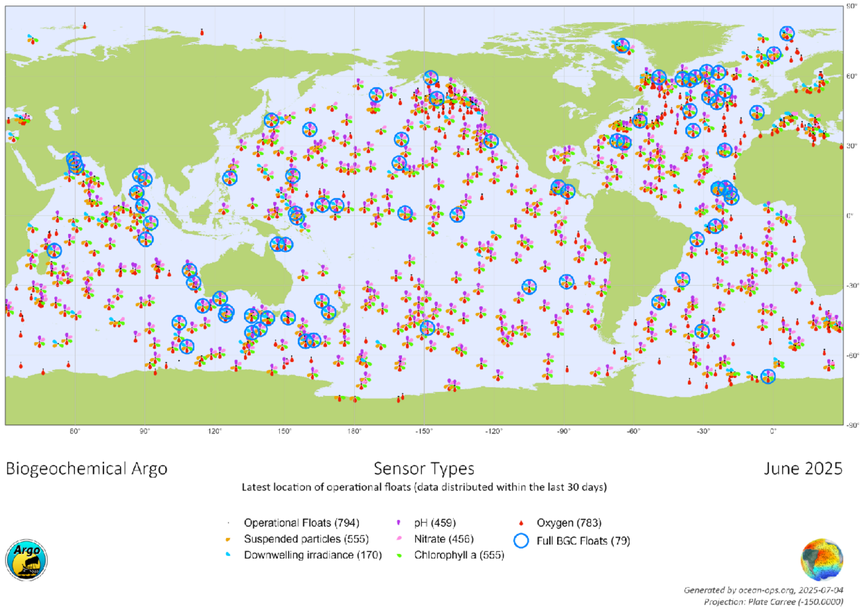
Observation System Simulation Experiment

The problem



Hauck et al., 2020

The solution



OSSE: How many floats should we deploy and where?

Goals:
- have enough observations to reconstruct seasonal variability
- improve model skills to reconstruct oceanic carbon cycle

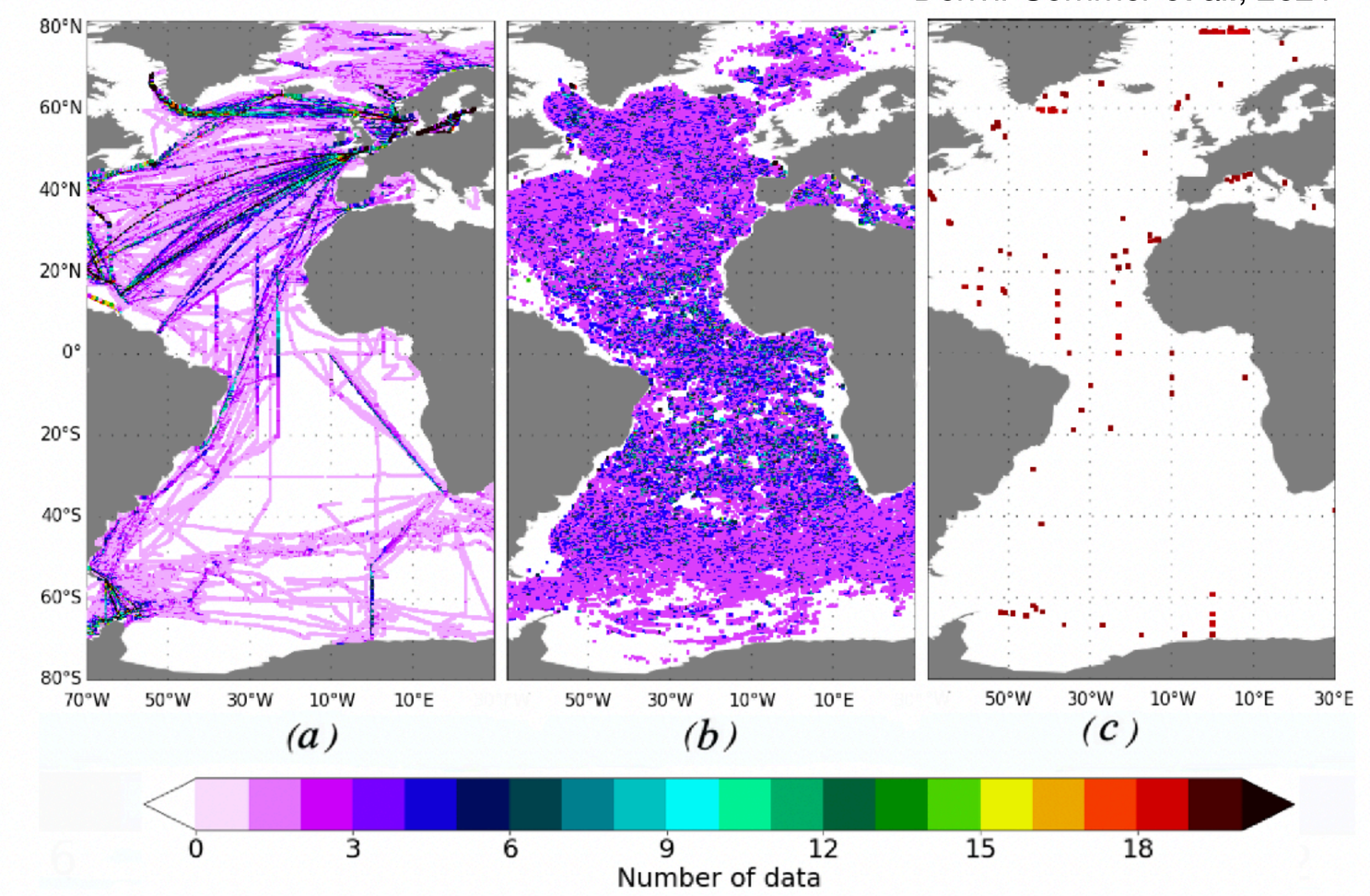
Note: 1 full BGC float costs ~$100k

OSSE: How many floats should we deploy and where?

- February (only), 2008-2010
- NEMO/PISCES ocean-BGC model: **truth**
- Synthetic data: subsample model where we have observations
- 3 tests:
  - SOCAT data only
  - SOCAT + 25% Argo (everywhere in Atlantic Ocean)
  - SOCAT + 25% Argo (only in South Atl)

Note: Argo float postion —> uses ALL Argo floats available, not just BGC. In other words, we assumes all floats deployed are BGC, which is not true

Denvil-Sommer et al., 2021



Spatial distribution of datasets used for training (number of measurements per grid point and 5 d time step): (a) SOCAT data forthe period 2001–2010, (b) synthetic Argo data for the period 2008–2010, and (c) mooring positions modelled for the period 2008–2010.

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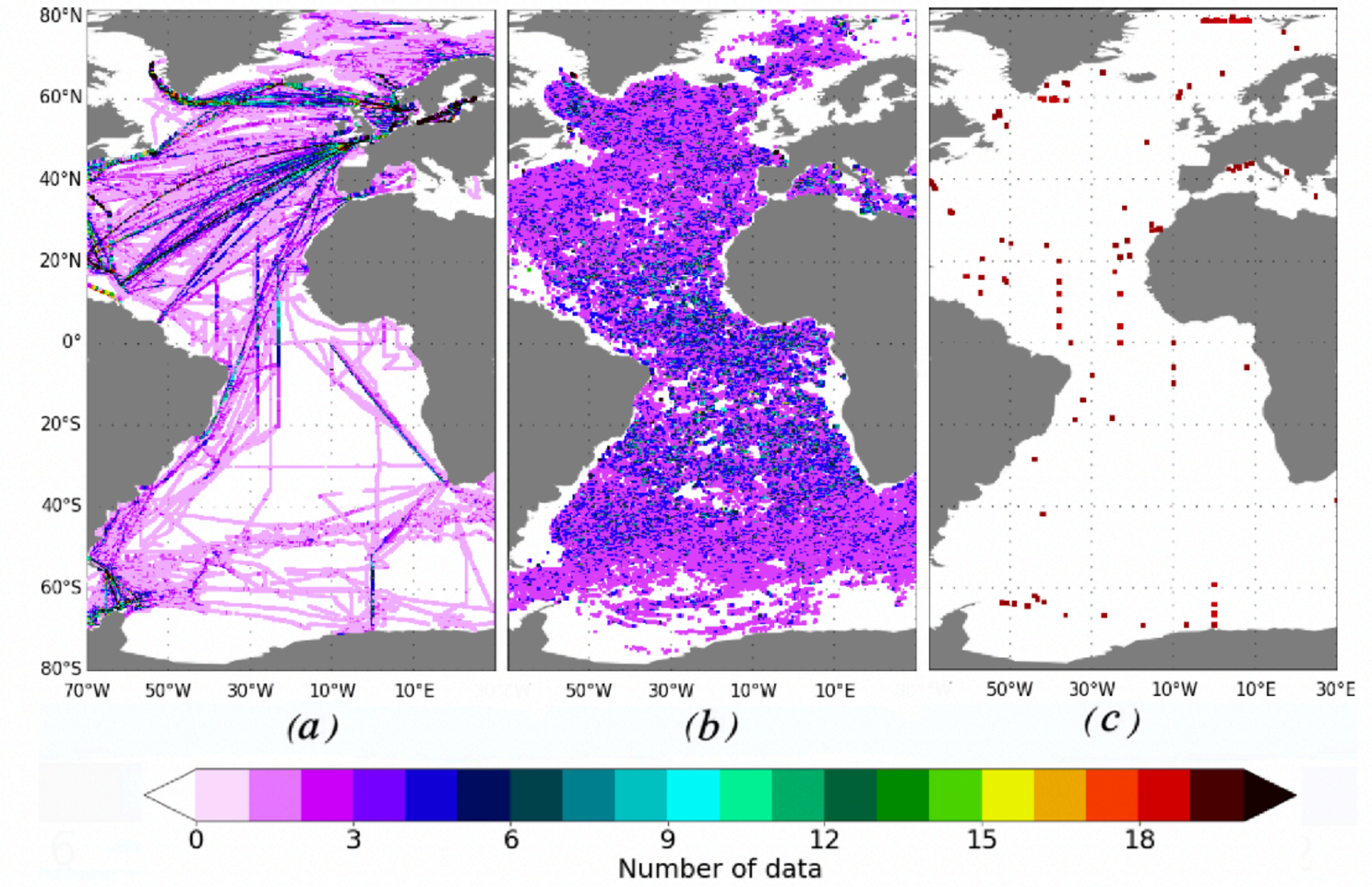
- Train a ML model based on the 3 tests mentioned above
- Use ML model to reconstruct surface ocean pCO2 in Atlantic Ocean from other observed features
- Verify which observational system (design) is best to reconstruct surface ocean pCO2

Denvil-Sommer et al., 2021



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Getting started

1. Clone this repository into a directory

```
git clone https://github.com/lcimoli/OSSE_pCO2.git
```

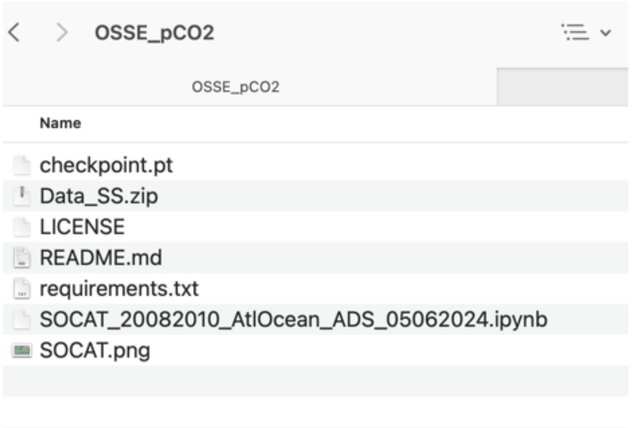
2. Download the data set from:

> Denvil-Sommer, A. (2024). Dataset for OSSE exercise at ICCS Summer School 2024 Cambridge [Data set]. Zenodo. https://doi.org/10.5281/zenodo.12567970

It is easiest to download `Data_SS.zip` and unzip it into the same directory as the code so that the .csv files are alongside the notebook file.

3. To setup the Notebook, we recommend running it in a virtual environment:

```
python3 -m venv venv
source .venv/bin/activate
pip install -r requirements.txt
```



Head to Jupyter notebook

Results

Table 1. Information on Observation System Simulation Experiments.

Denvil-Sommer et al., 2021

Data	OSSE number	Period for training	Averaged number of Argo floats per 5 d
SOCAT	OSSE 1	2001–2010	0
Argo (3° × 3°)	OSSE 2	2008–2010	404
SOCAT + Argo (3° × 3°)	OSSE 3	2001–2010 (SOCAT) + 2008–2010 (Argo)	403
SOCAT + Argo 25% (3° × 3°)	OSSE 4	2001–2010 (SOCAT) + 2008–2010 (Argo)	101
SOCAT + Argo 10 % (3° × 3°)	OSSE 5	2001–2010 (SOCAT) + 2008–2010 (Argo)	40
SOCAT + Argo south (3° × 3°)	OSSE 6	2001–2010 (SOCAT) + 2008–2010 (Argo south)	195
SOCAT + Argo 25 % south (3° × 3°)	OSSE 7	2001–2010 (SOCAT) + 2008–2010 (Argo south)	48
SOCAT + Argo 10 % south (3° × 3°)	OSSE 8	2001–2010 (SOCAT) + 2008–2010 (Argo south)	19
SOCAT + Argo south + moorings	OSSE 9	2001–2010 (SOCAT) + 2008–2010 (Argo south, moorings)	195
SOCAT + Argo south 25 % + moorings	OSSE 10	2001–2010 (SOCAT) + 2008–2010 (Argo south, moorings)	48
SOCAT + Argo south 10 % + moorings	OSSE 11	2001–2010 (SOCAT) + 2008–2010 (Argo south, moorings)	19

The successful OSSE 10 has a correlation coefficient of 0.85 and a standard deviation of 24.89 µatm. These results are close to the unrealistic benchmark case with total Argo float distribution over 2008–2010: 0.87 and 23.79 µatm. The total pCO2 over the whole region is also close to NEMO/PISCES, 370 and 371 µatm, respectively. The sea–air flux fgCO2 is -0:83 Pg yr-1 (OSSE 10) and -0:76 Pg yr-1 (NEMO). The bias in sea–air CO2 fluxes compared to NEMO/PISCES is reduced by 74% in OSSE 10 compared to OSSE 1 (fgCO2 is -1:03 Pg yr-1).

Conclusions and future work

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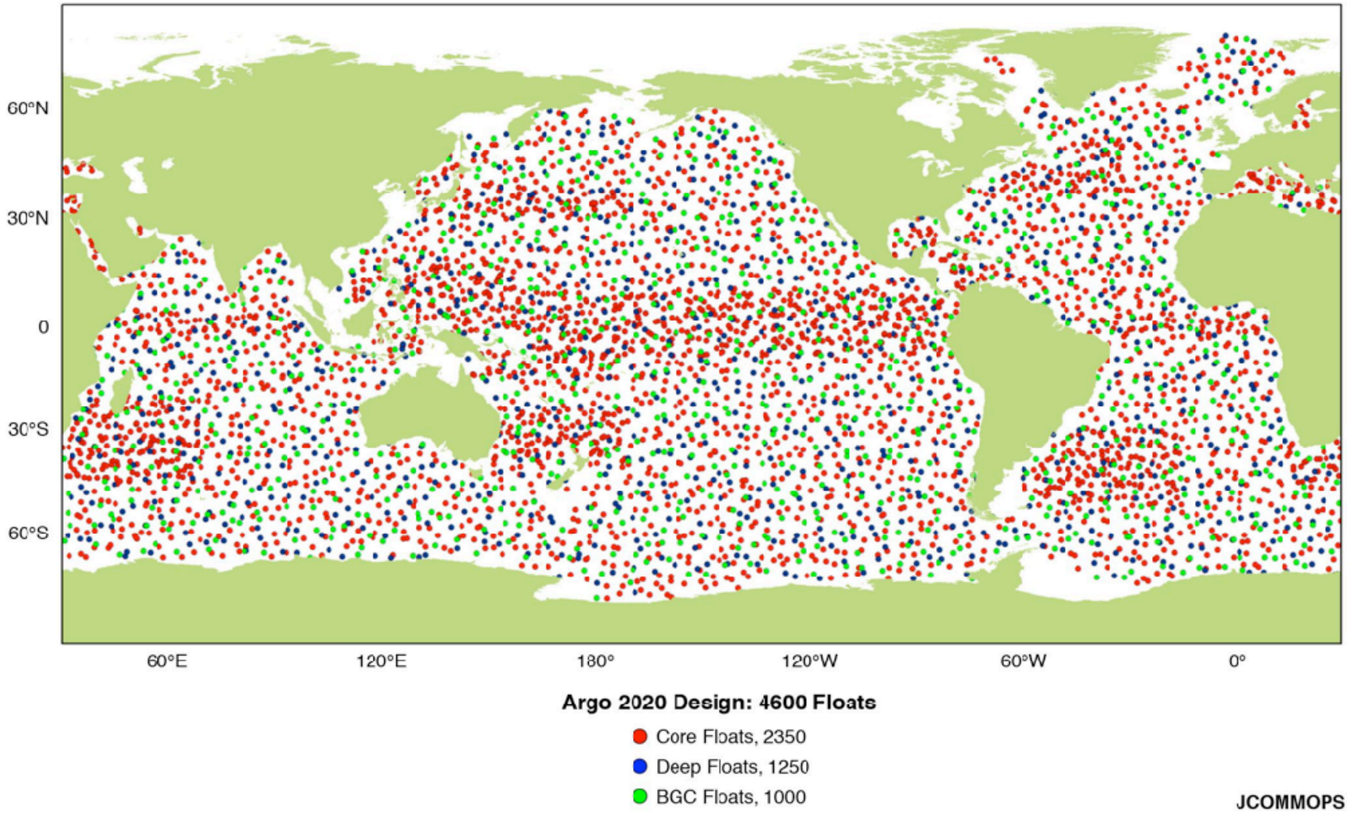
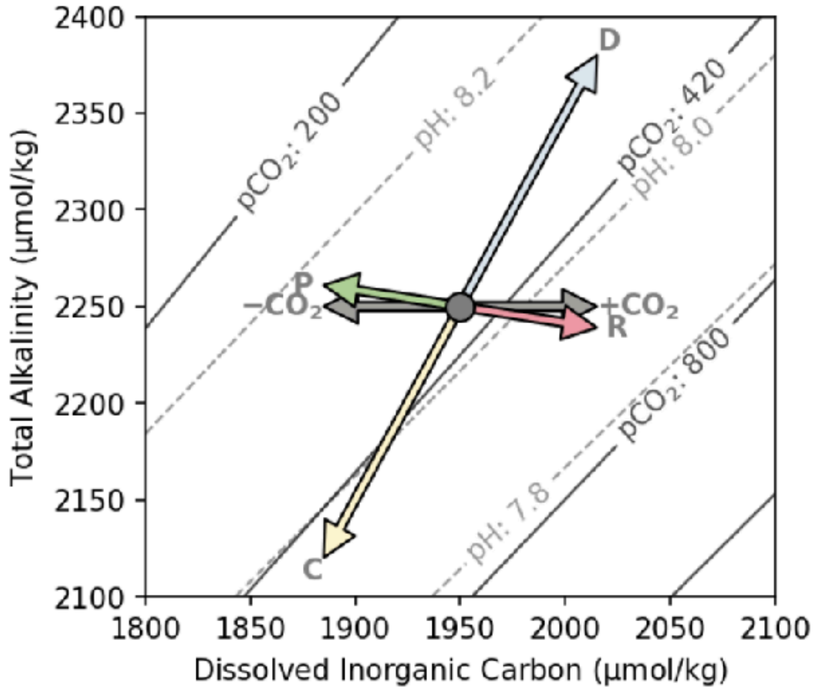
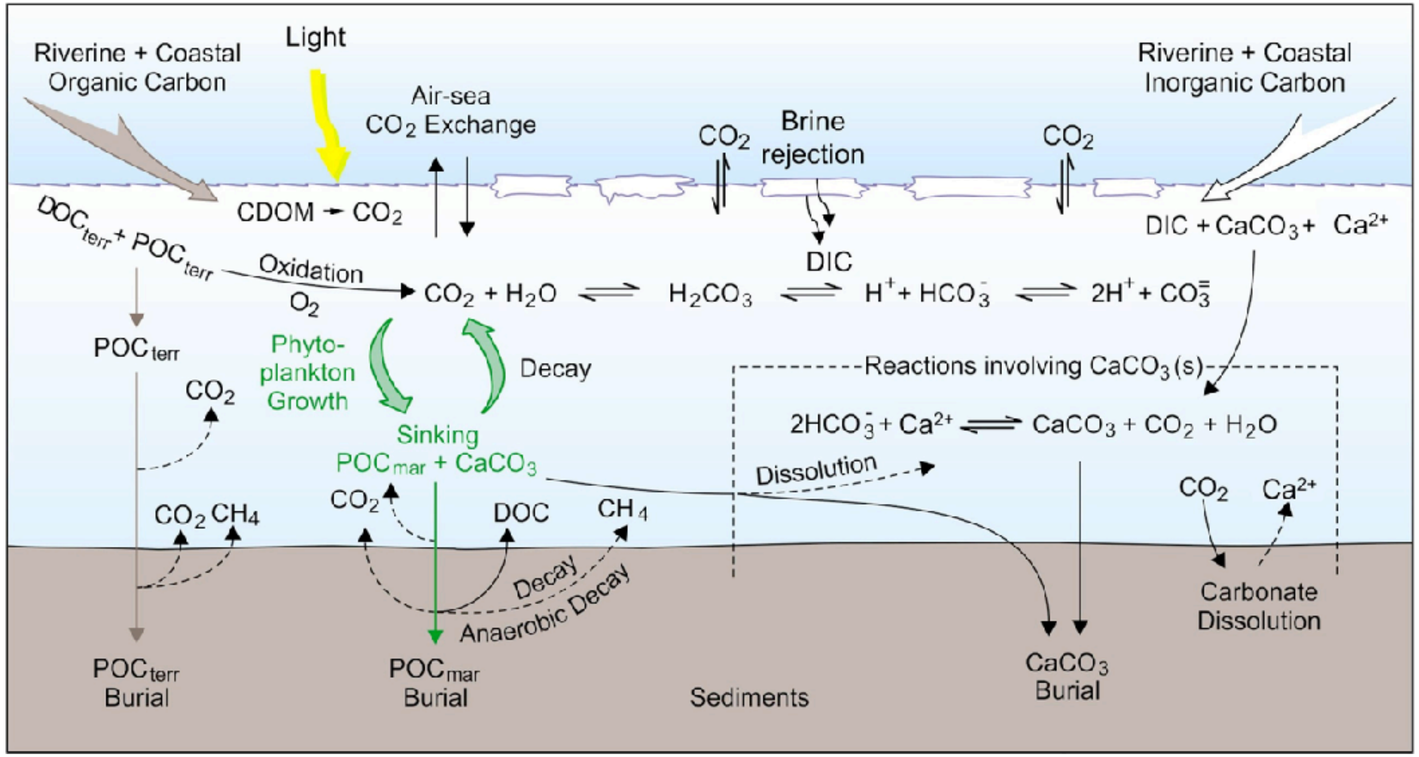
One Argo design



Conclusions and future work

Monitoring ocean carbon: why pCO2 is not enough





References

Denvil-Sommer, A., Gehlen, M., and Vrac, M.: Observation system simulation experiments in the Atlantic Ocean for enhanced surface ocean pCO2 reconstructions, Ocean Sci., 17, 1011–1030, https://doi.org/10.5194/os-17-1011-2021, 2021.

Hauck J, Zeising M, Le Quéré C, Gruber N, Bakker DCE, Bopp L, Chau TTT, Gürses Ö, Ilyina T, Landschützer P, Lenton A, Resplandy L, Rödenbeck C, Schwinger J and Séférian R (2020). Consistency and Challenges in the Ocean Carbon Sink Estimate for the Global Carbon Budget. Front. Mar. Sci. 7:571720. doi: 10.3389/fmars.2020.571720