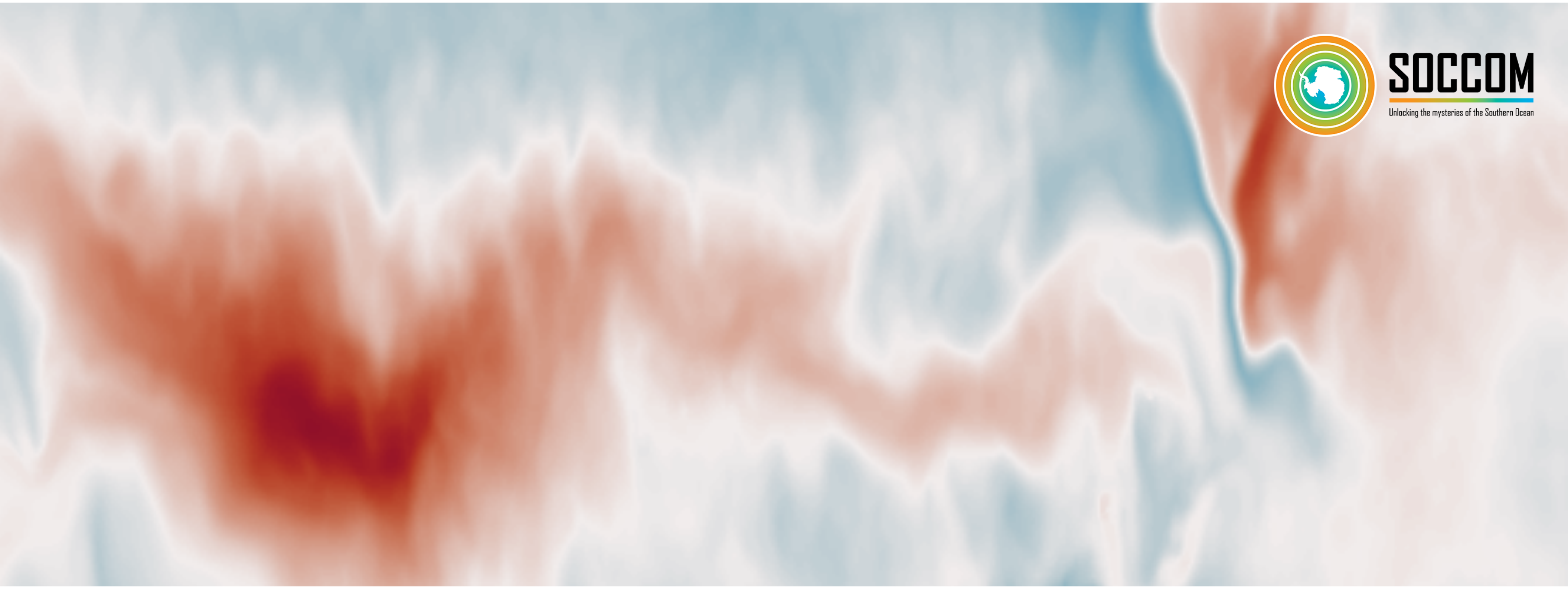
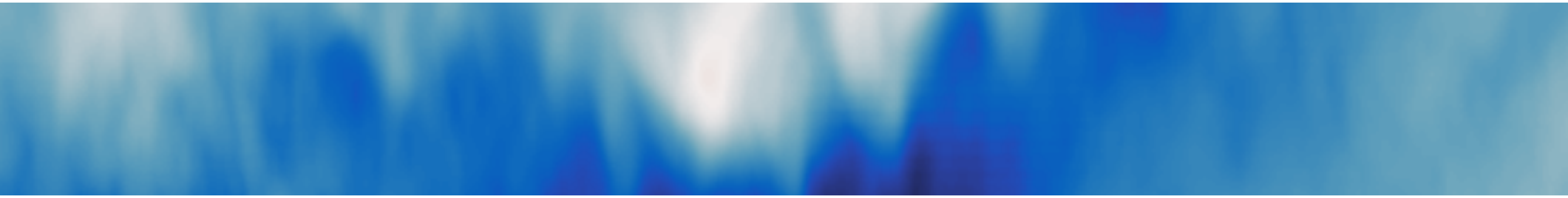
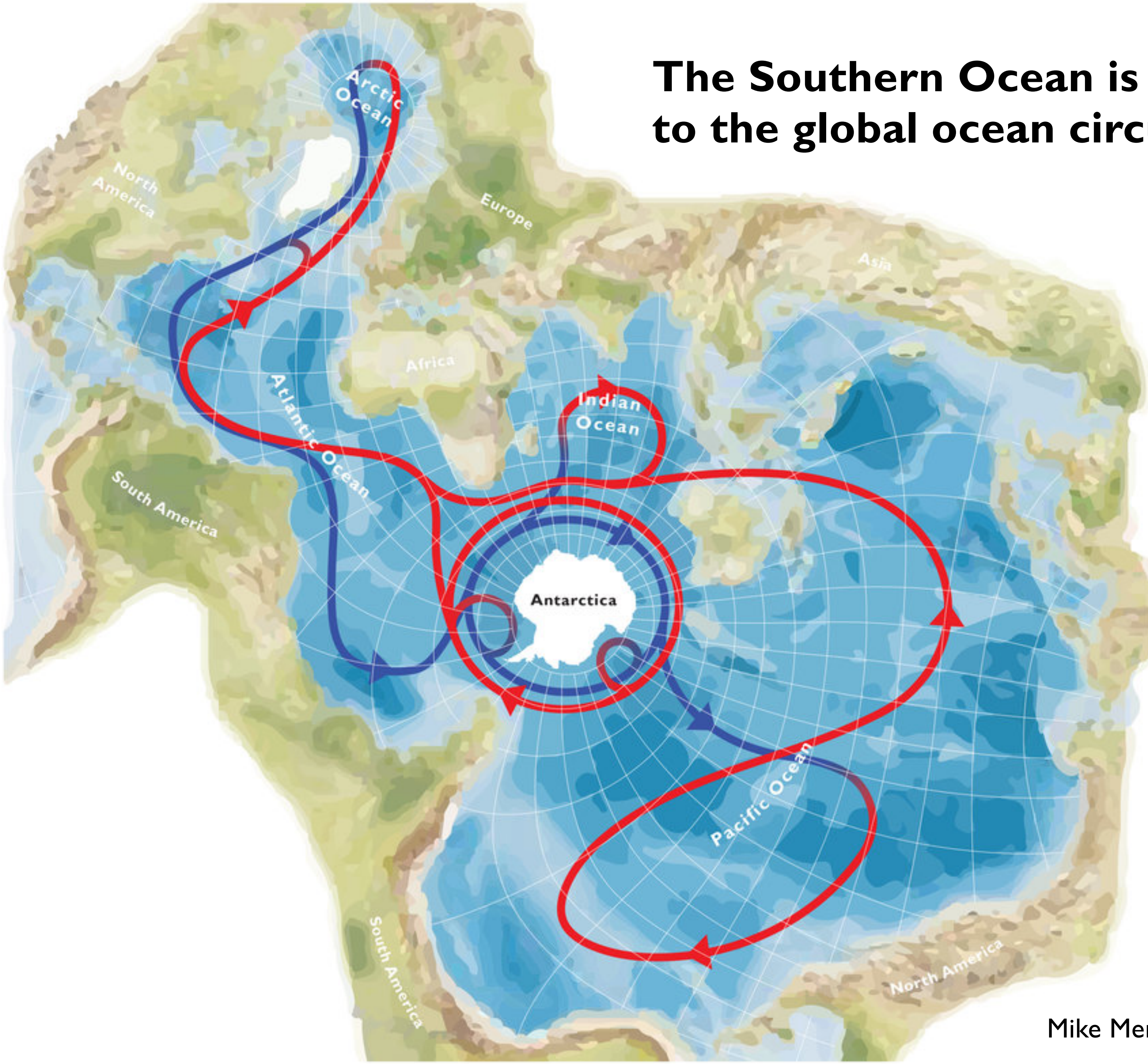


OBSERVING THE SOUTHERN OCEAN CARBON CYCLE WITH AUTONOMOUS FLOATS

C.J. Prend, A.R. Gray, L.D. Talley, S.T. Gille, F.A. Haumann, K.S. Johnson, S.C. Riser, I. Rosso, J. Sauvé & J.L. Sarmiento



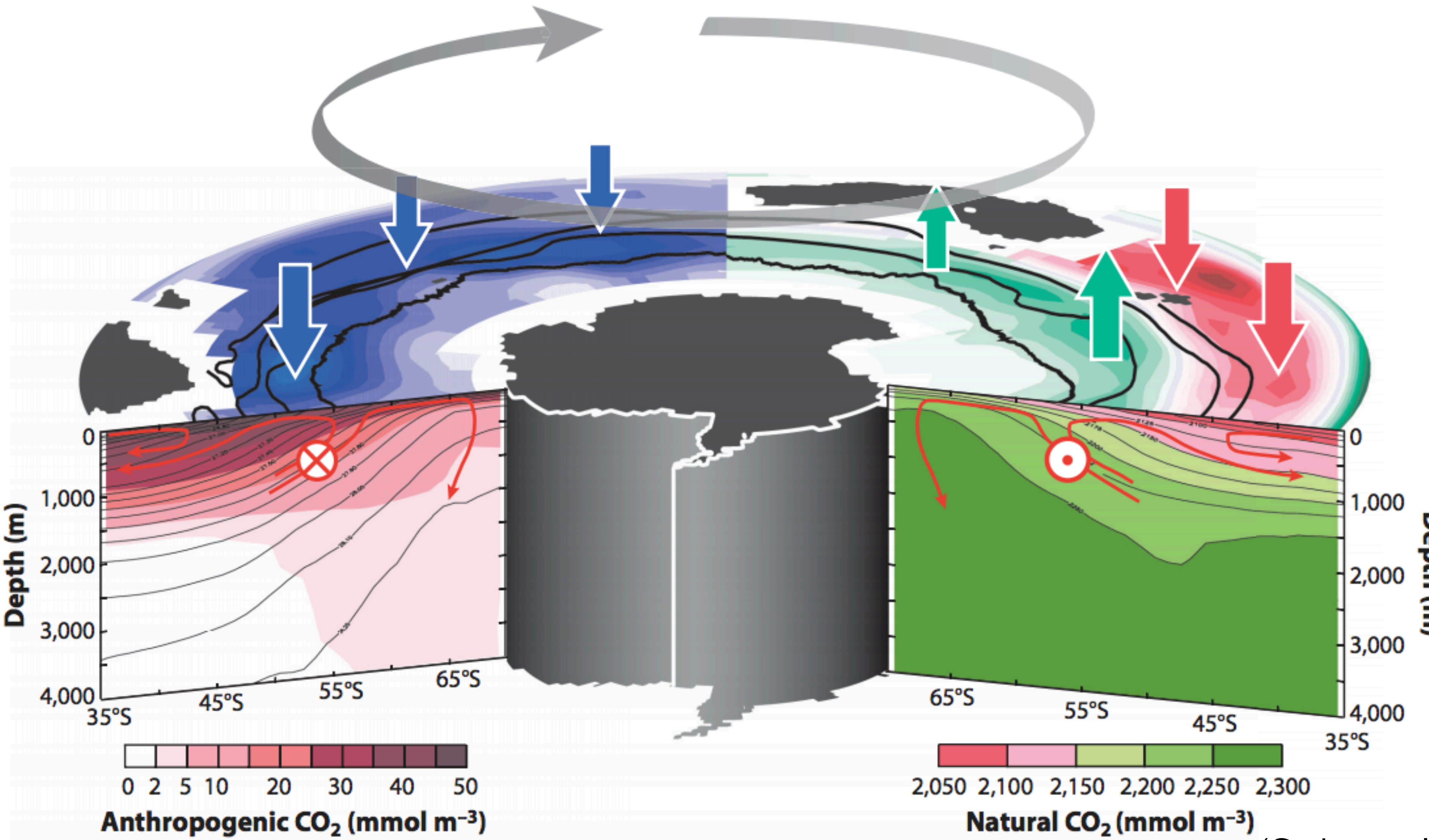
The Southern Ocean is central to the global ocean circulation!



Mike Meredith

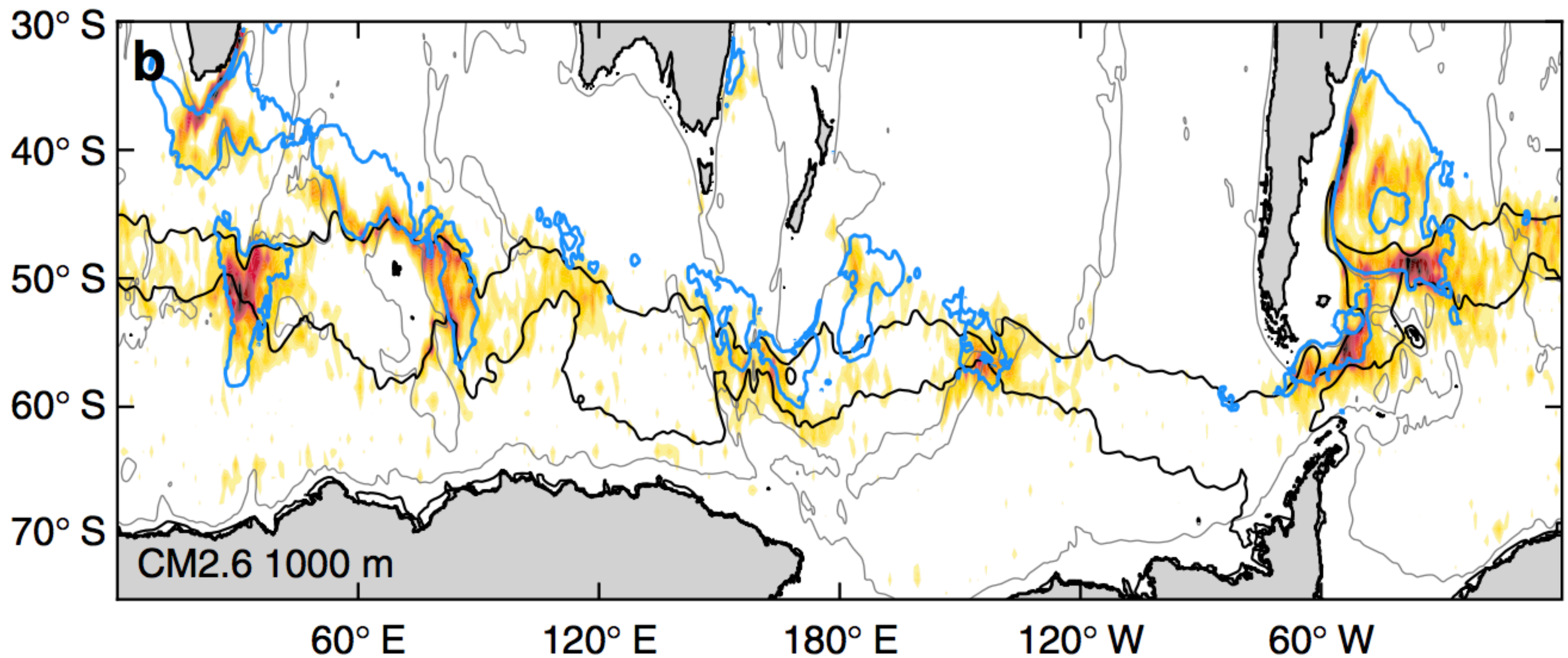
SOUTHERN OCEAN CARBON CYCLE

Net air-sea carbon exchange in the Southern Ocean is a balance between subduction of anthropogenic carbon and outgassing of natural carbon.



(Gruber et al., 2019)

UPWELLING IS SPATIALLY VARIABLE

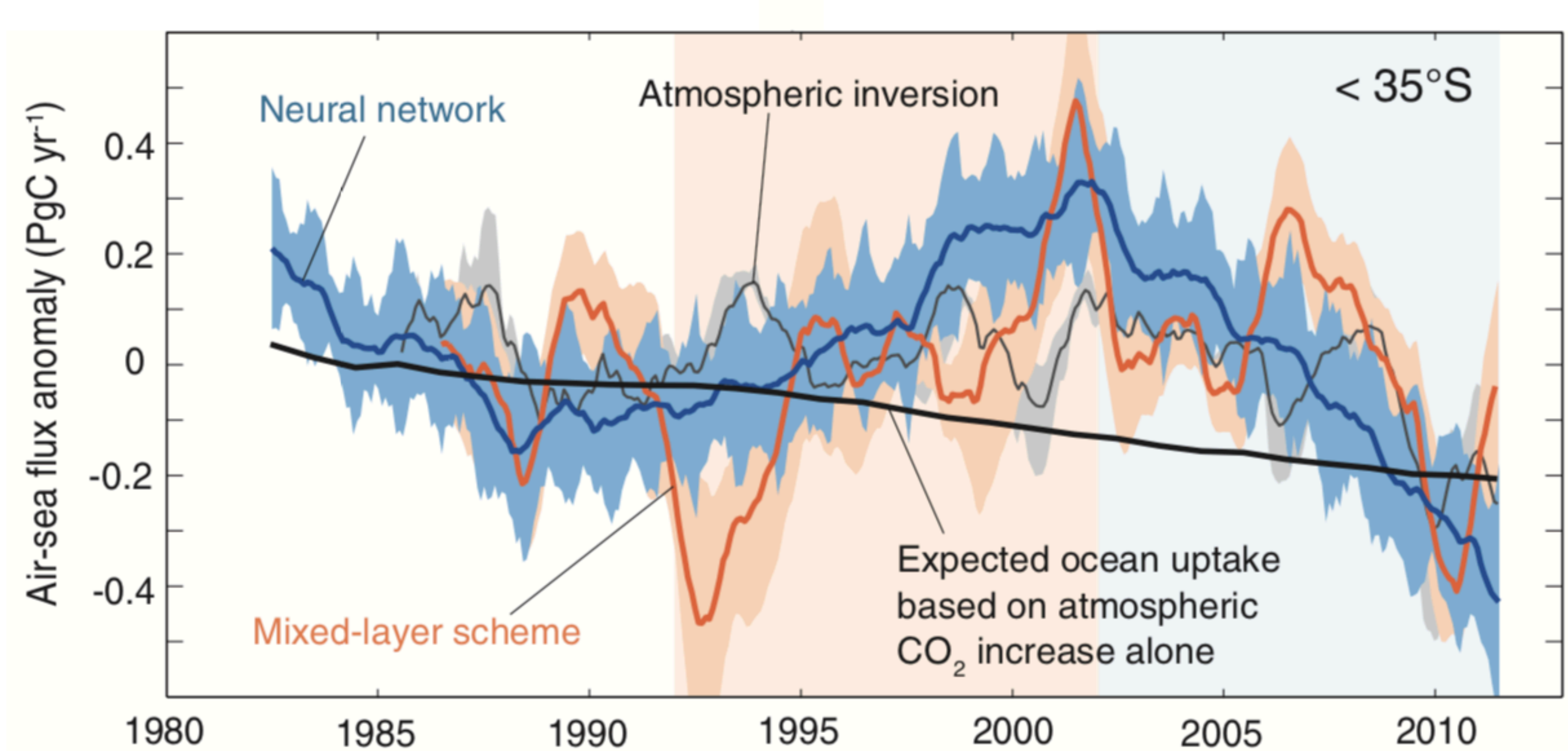


(Tamsitt et al., 2017)

Upwelling (vertical transport of particles across 1000 m) is concentrated at topographic features in the path of the ACC. But this is not necessarily synonymous with where particles cross into the mixed-layer!

SO CARBON SINK VARIABILITY

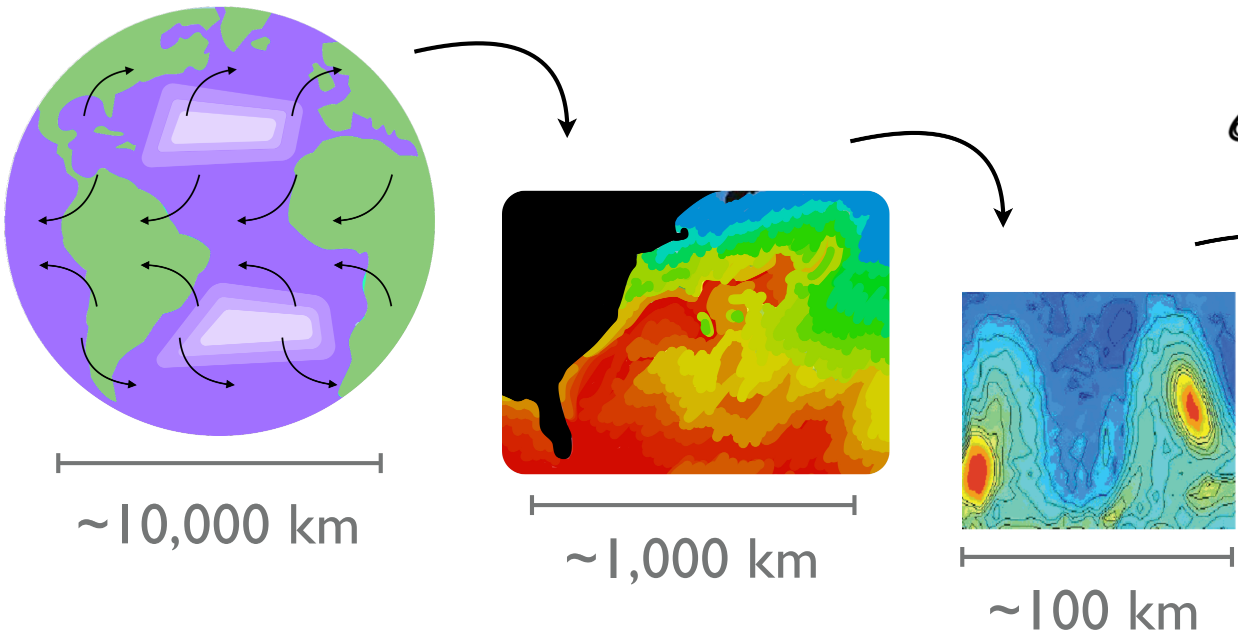
Southern Ocean air-sea carbon fluxes vary across a wide range of space and time scales. Much work focused on decadal variability inferred from sparse shipboard data. We need to better characterize variability at other scales in order to interpret these trends.

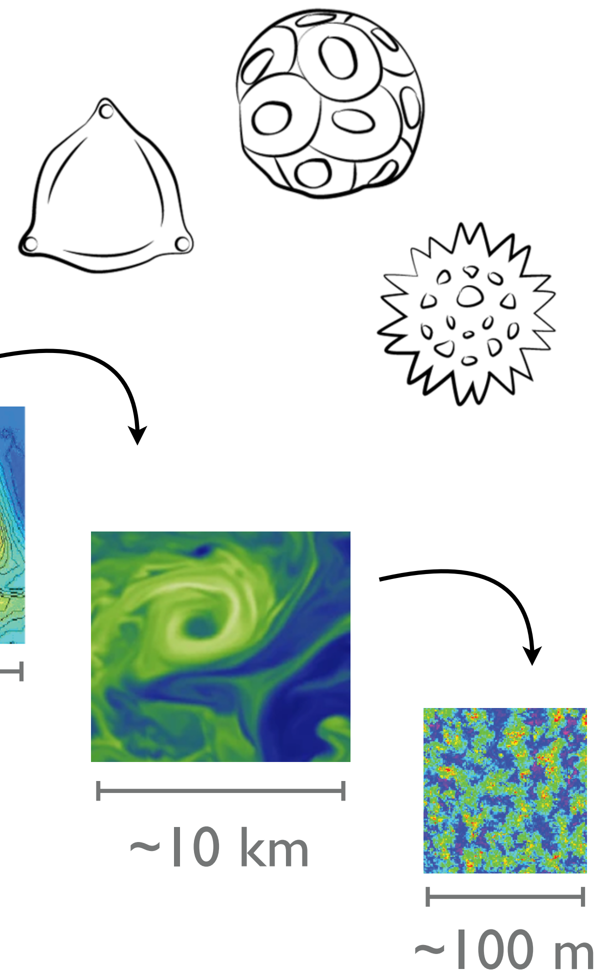


(Landschützer et al., 2015)

MOTIVATION

SCALES OF MOTION





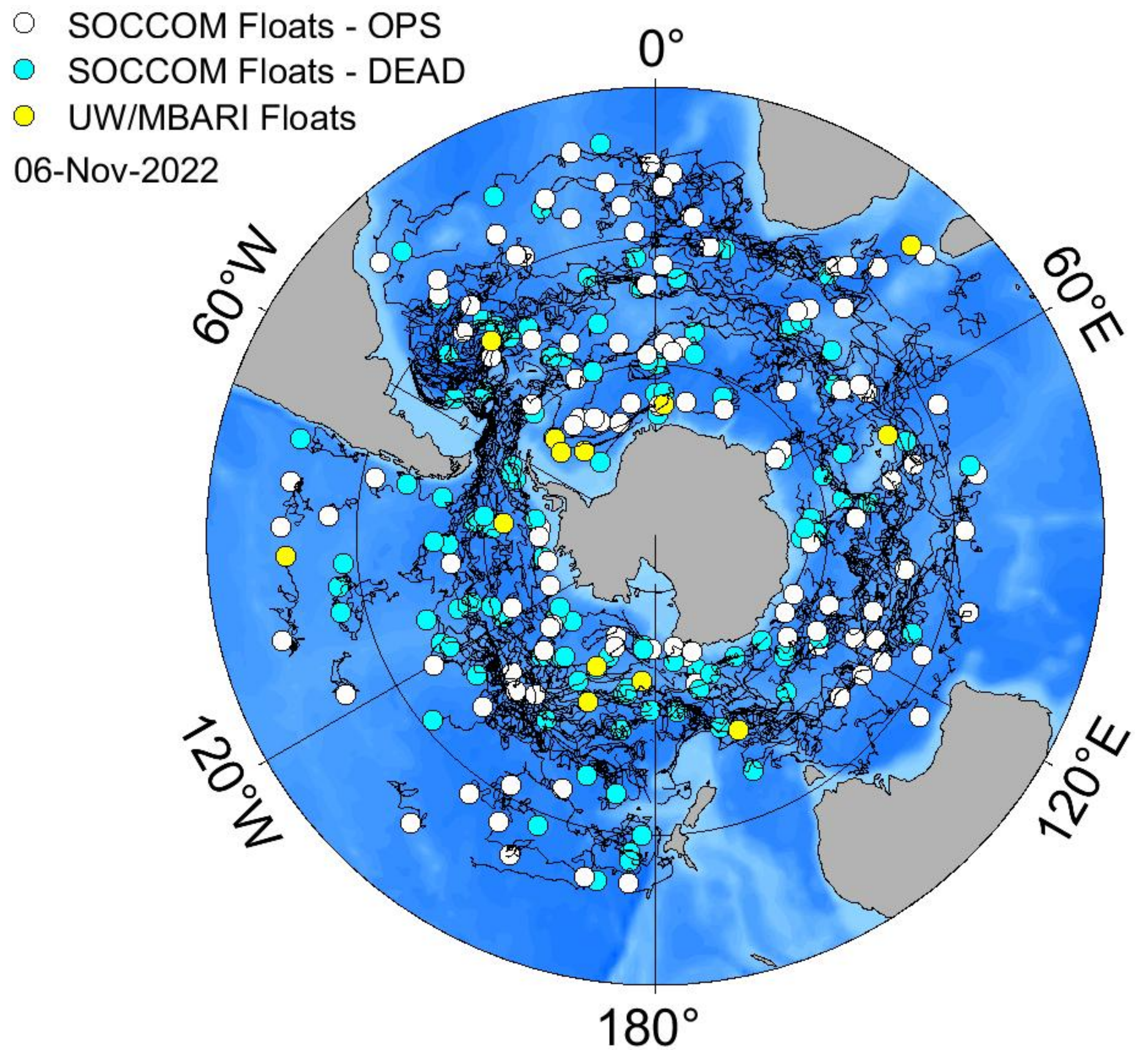
Observing the ocean is a challenge due to the multi-scale nature of ocean dynamics and biogeochemistry.

BGC ARGO FLOATS

The SOCCOM project has deployed more than 200 BGC Argo floats in the Southern Ocean since 2014.

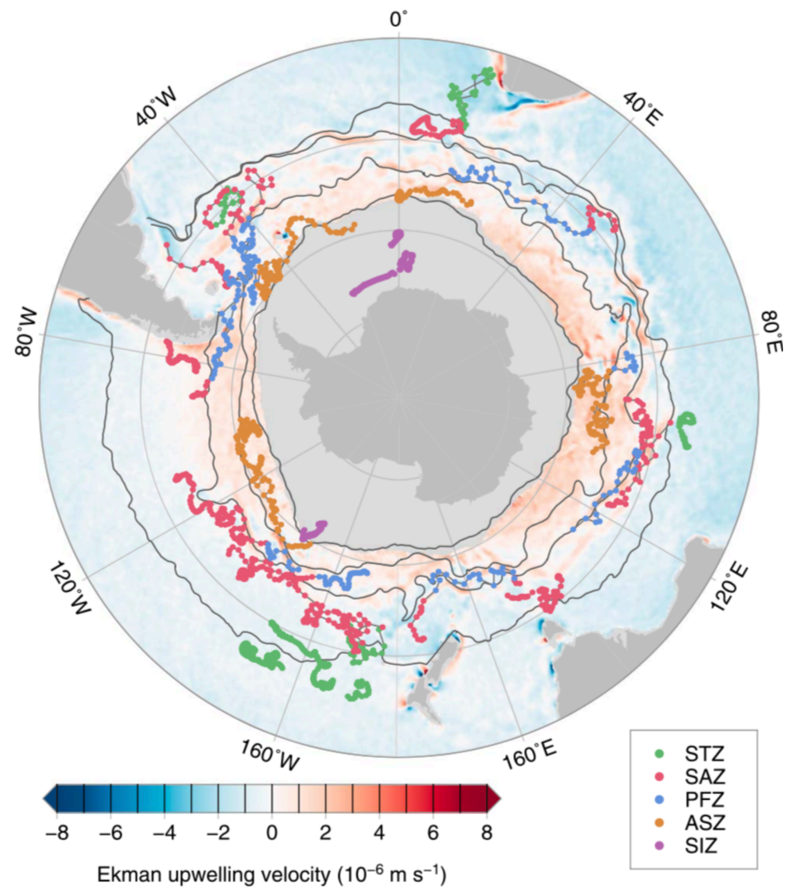
Temperature, Salinity, Pressure, Oxygen, Nitrate, pH, Fluorescence, and Backscatter.

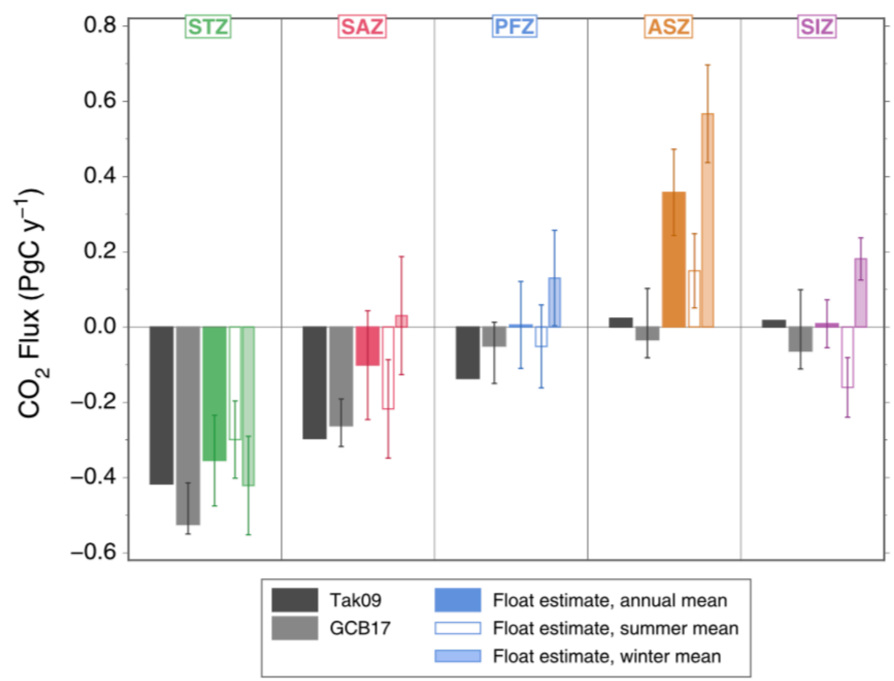
SOCCOM floats dramatically increased the coverage of subsurface biogeochemical data in the Southern Ocean.



FLOAT-BASED FLUX ESTIMATES

$$F_{CO_2} = kK_0(pCO_2^{ocn} - pCO_2^{atm})$$

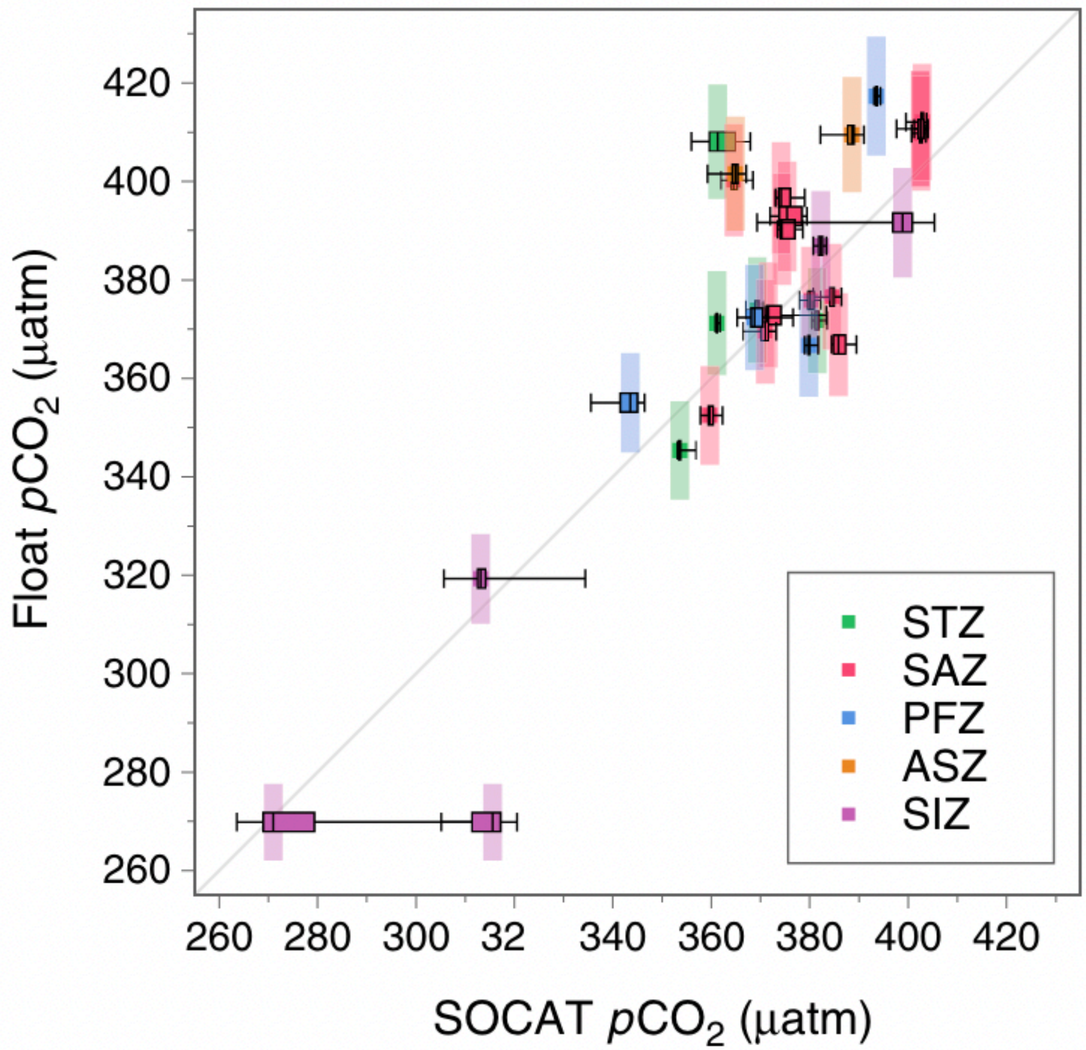




(Gray et al., 2018)

Float-based flux estimates suggest larger carbon outgassing than was previously thought due to the inclusion of wintertime measurements.

ESTIMATING CARBON PARAMETERS

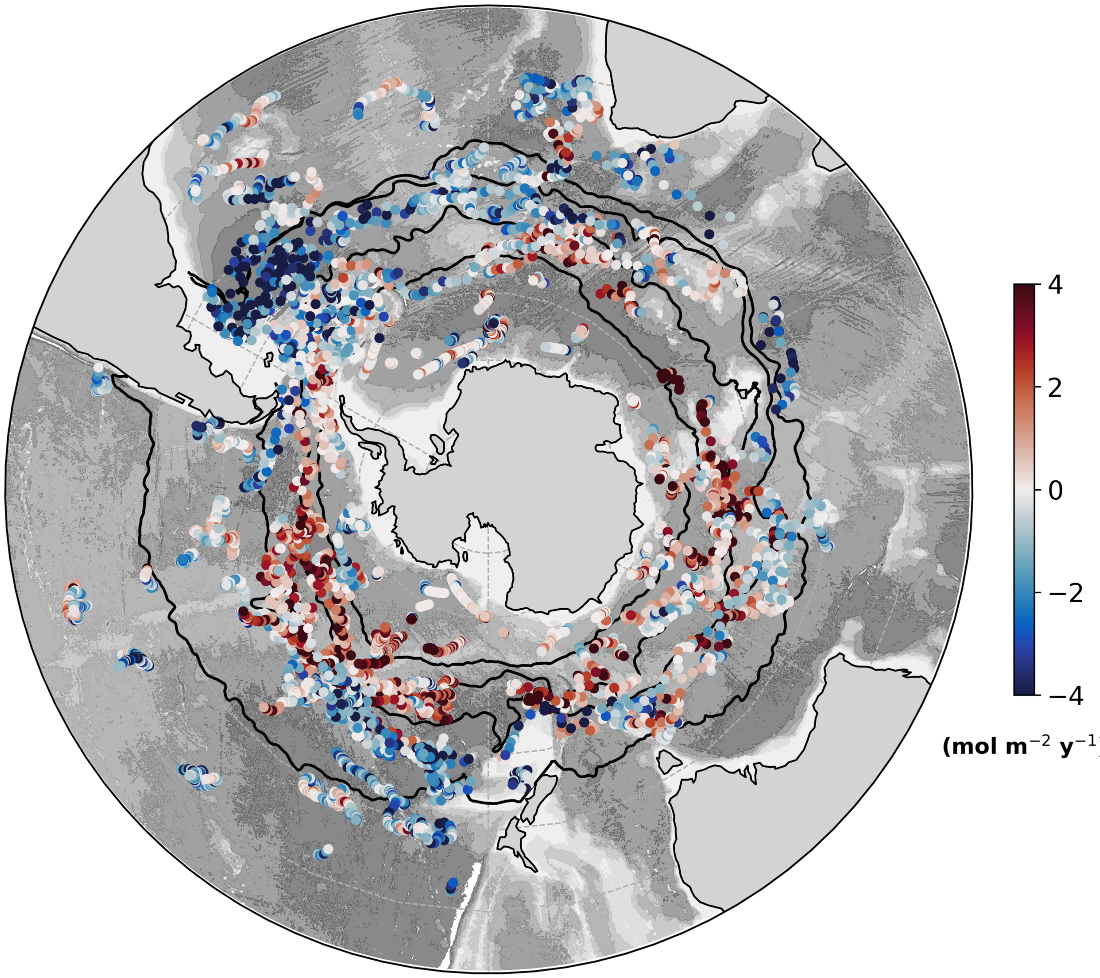


pH is the only carbon system parameter that is measured directly, so there are significant uncertainties and potential biases in float pCO_2 estimates.

Several more recent studies have suggested a weaker outgassing than presented in Gray et al. 2018 (e.g. Long et al., 2021; Mackay & Watson, 2021; Wu et al., 2022).

Gray et al. (2018)

UPDATED FLUX ESTIMATES

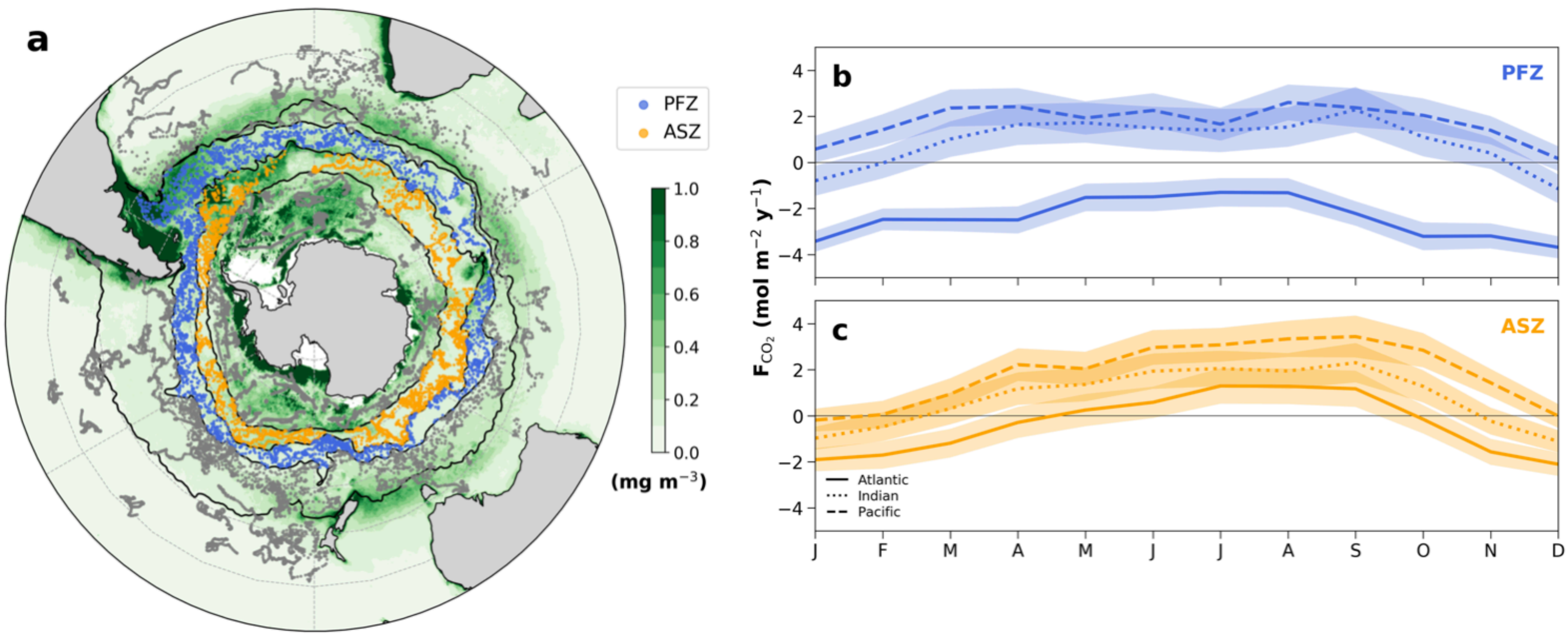


$$F_{CO_2} = kK_0(pCO_2^{ocn} - pCO_2^{atm})$$

Carbon outgassing in the ACC occurs preferentially in the Indo-Pacific sector during winter.

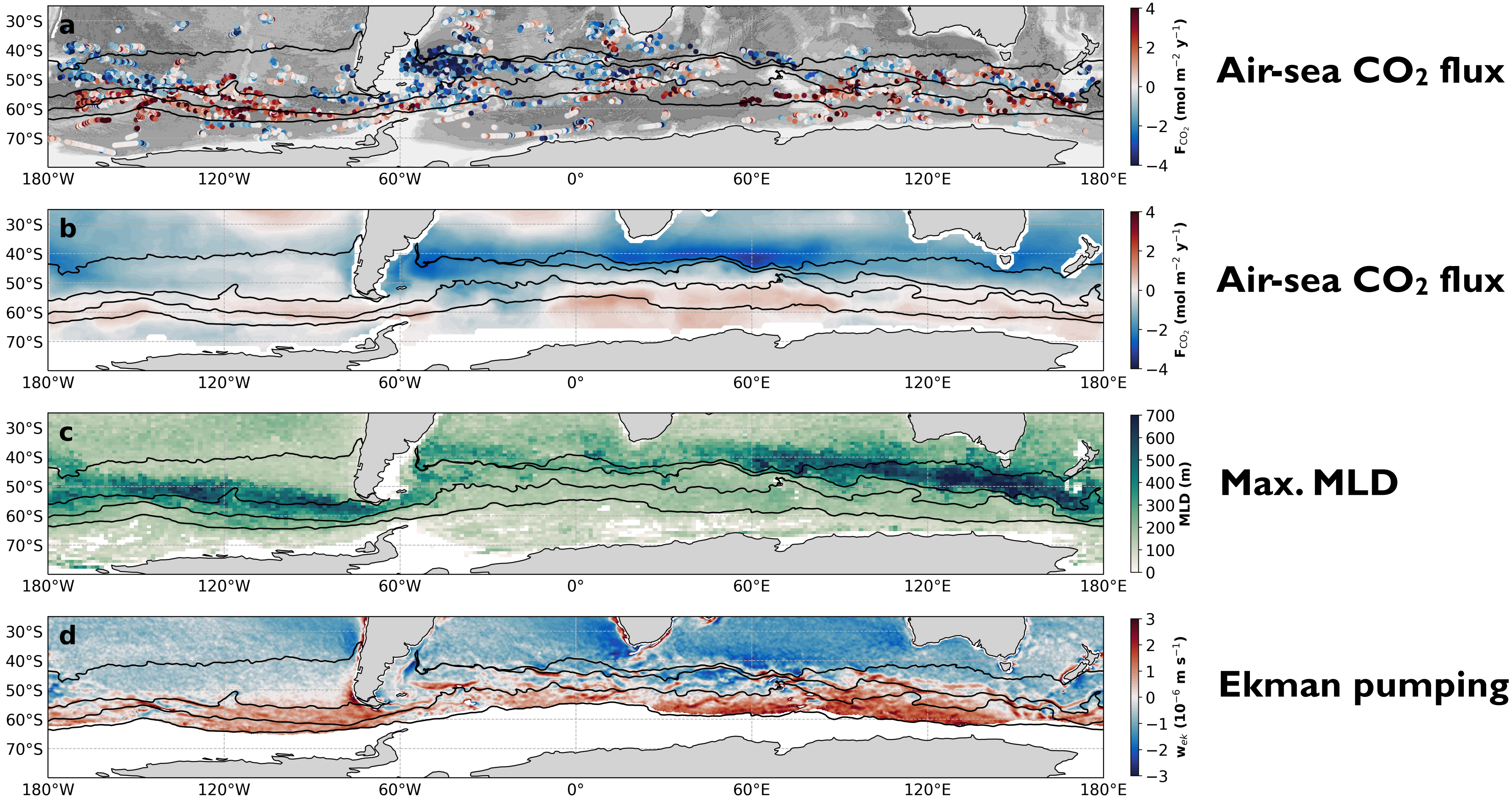
Float data are starting to resolve detailed spatial patterns in air-sea carbon exchange. **What controls these patterns?**

ZONAL ASYMMETRY OF OUTGASSING



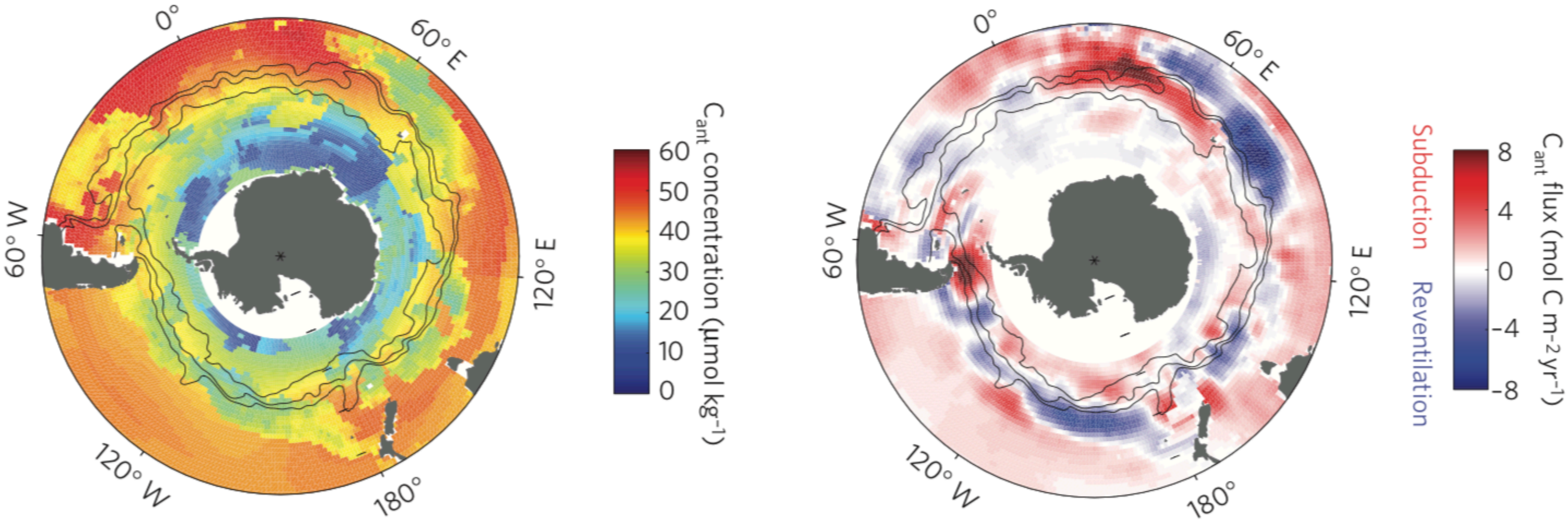
Carbon outgassing along the southern flank of the ACC occurs preferentially in the Indian and Pacific (during winter). Carbon uptake per unit area is highest in the Atlantic. This is consistent with other observation-based flux products (Landschützer, Takahashi, etc).

DRIVING MECHANISMS



Strong basin asymmetry in the mean latitude of ACC streamlines and depth of the maximum winter MLD.

CARBON SUBDUCTION IS LOCALIZED

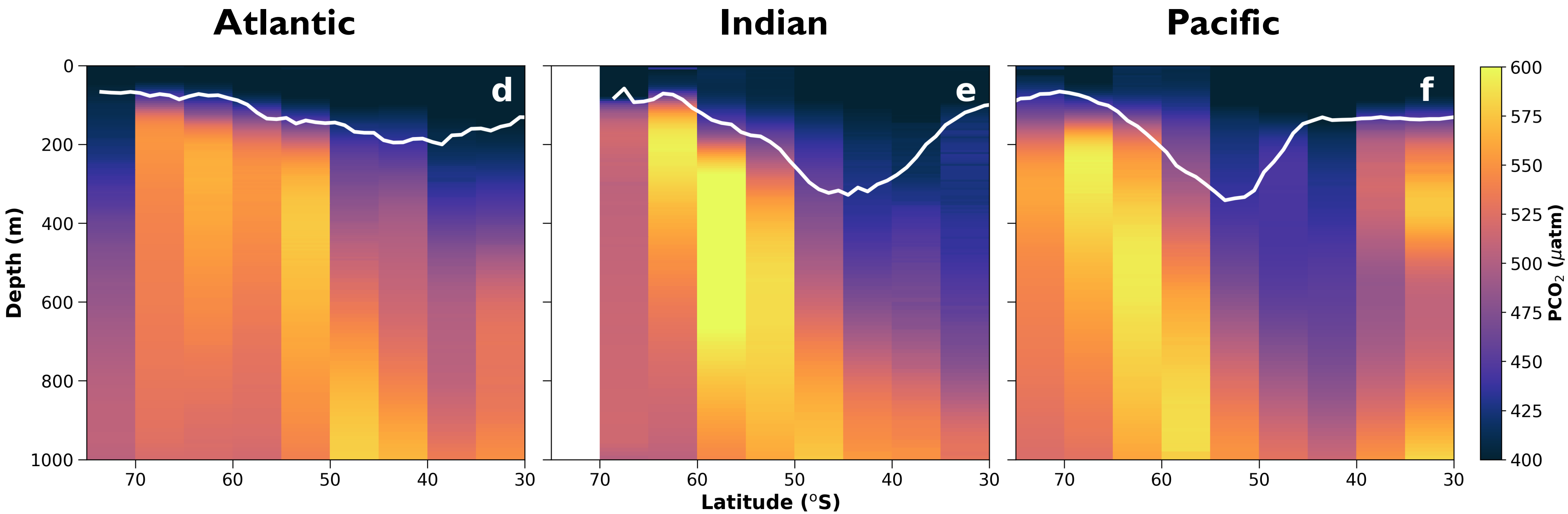


(Sallée et al., 2012)

Subduction of anthropogenic carbon is highly localized and strongly related to the spatiotemporal variability of the MLD itself.

What about obduction of remineralized carbon from upwelled deep water?

UPWELLING CARBON-RICH DEEP WATER

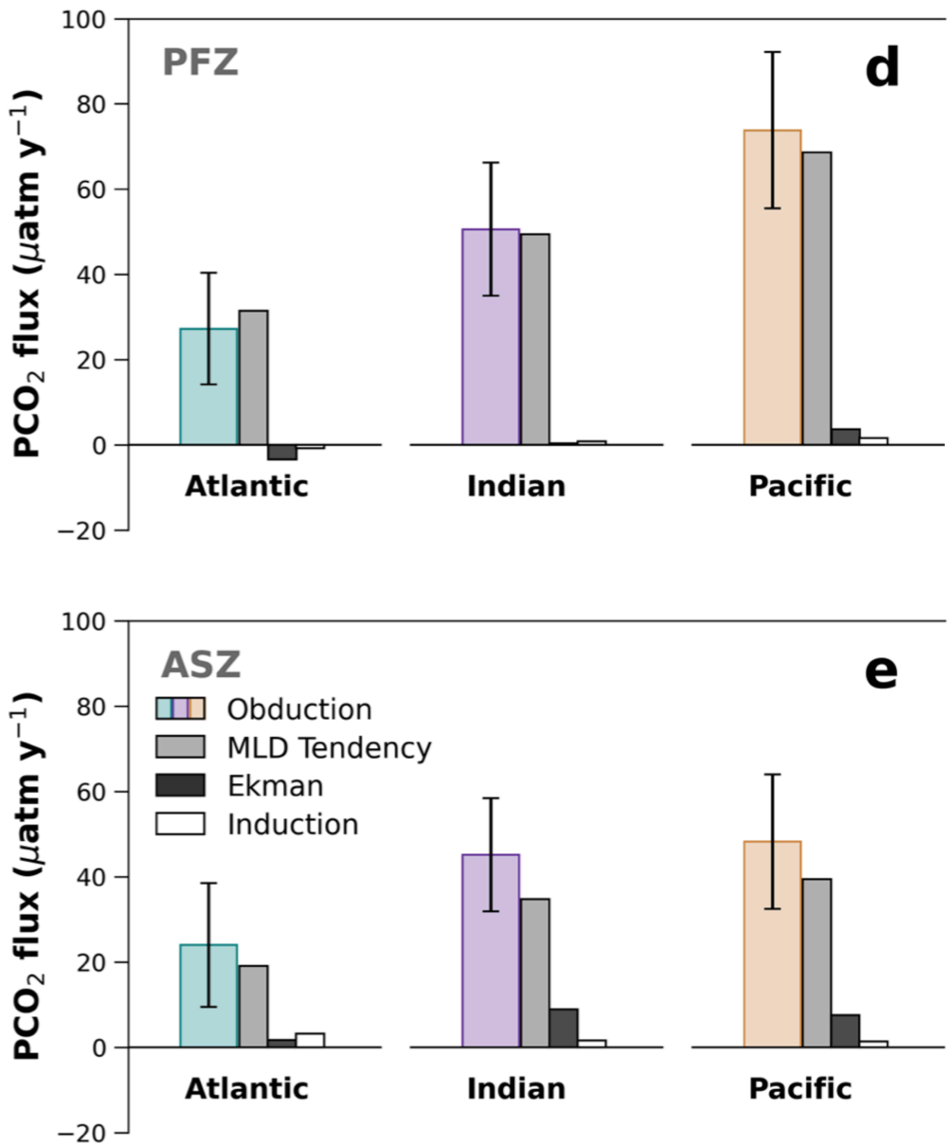


How does carbon-rich upwelled deep water actual get into the mixed-layer where air-sea exchange occurs?

$$\frac{\partial C_m}{\partial t} = \ldots + \frac{(C_h - C_m)}{h}\underbrace{\left(\frac{\partial h}{\partial t} + \mathbf{u}_h \cdot \nabla_H h + w_h\right)}_{E} + \ldots$$

Quantify the change in surface pCO_2 associated with each component of obduction.

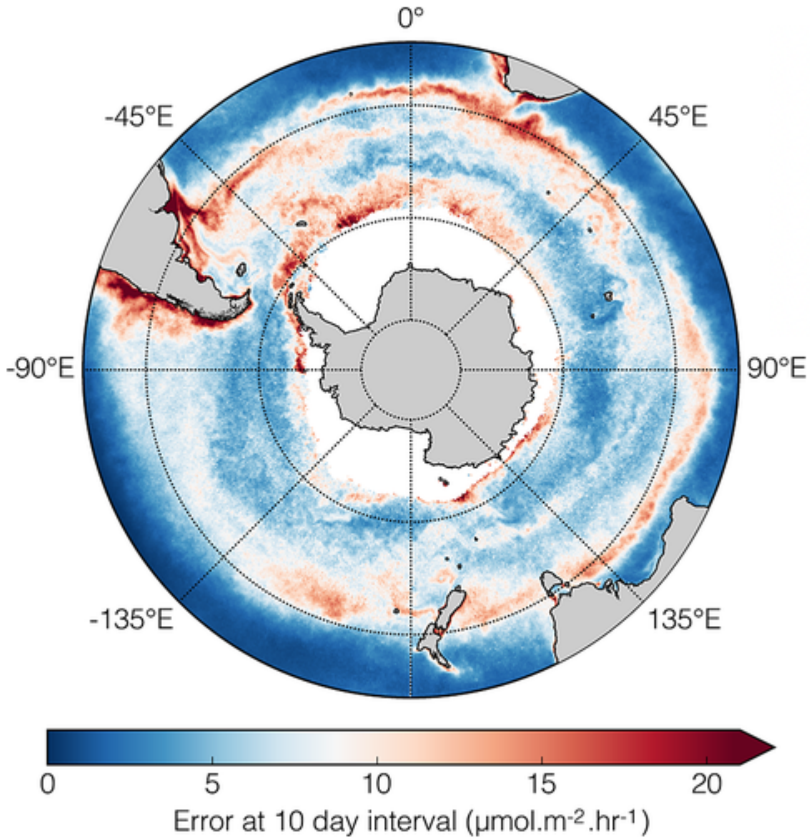
OBDUCTION FLUXES OF CARBON



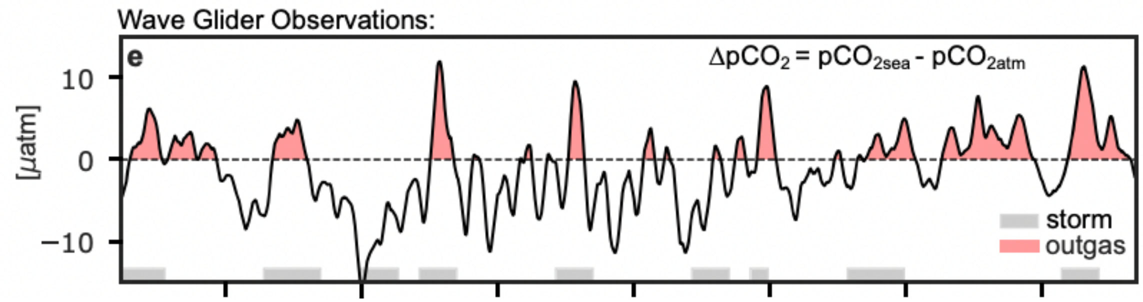
Obduction fluxes of PCO_2 are highest in the Pacific sector in both the PFZ and ASZ due to the larger amplitude of MLD seasonal cycle and higher values of PCO_2 at the mixed layer base.

The difference in obduction flux of PCO_2 between basins is similar to the observed zonal asymmetry in surface ocean pCO_2. **Differences in obduction of carbon-rich deep water could account for the basin asymmetry in outgassing.**

SAMPLING ALIAS



Monteiro et al. (2015)



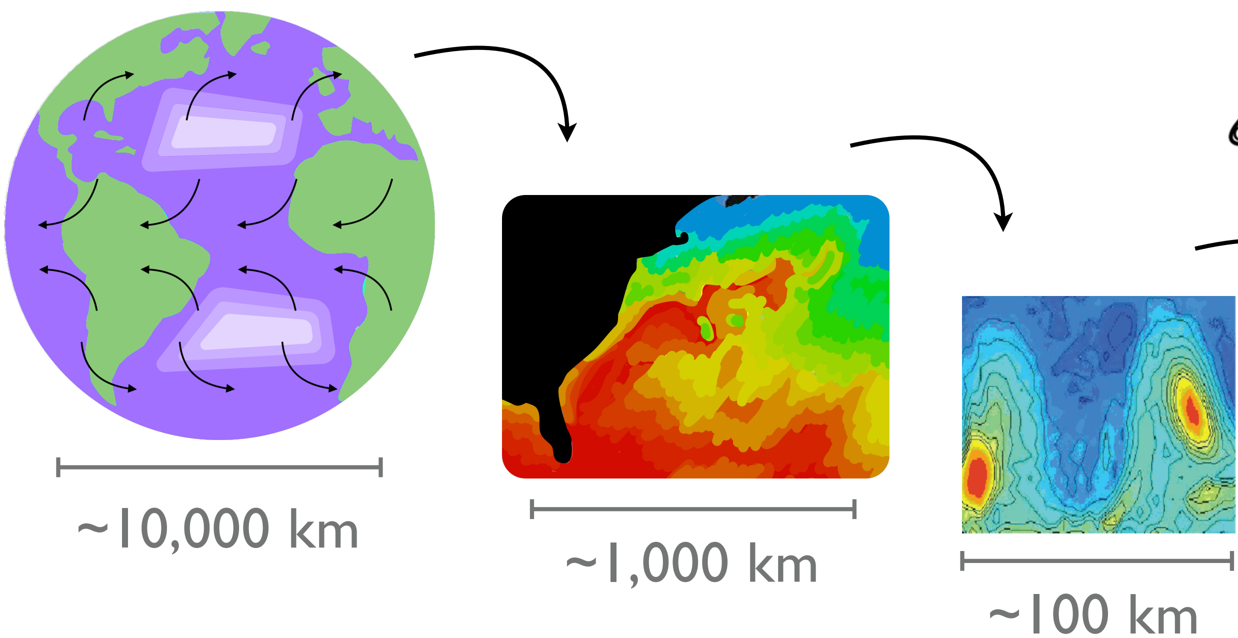
Nicholson et al. (2022)

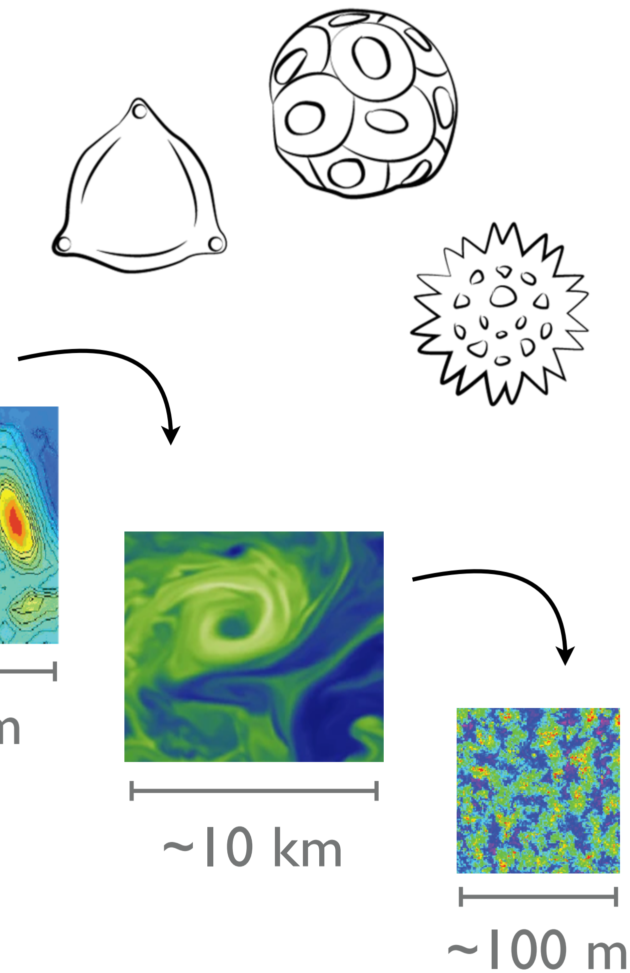
Storm-driven entrainment can modulate air-sea carbon fluxes. High-frequency variability imprints on the annual mean.

Many locations in the Southern Ocean require sampling at higher frequencies than the 10-day float cycle time in order to accurately capture the annual mean air-sea carbon flux.

MOTIVATION

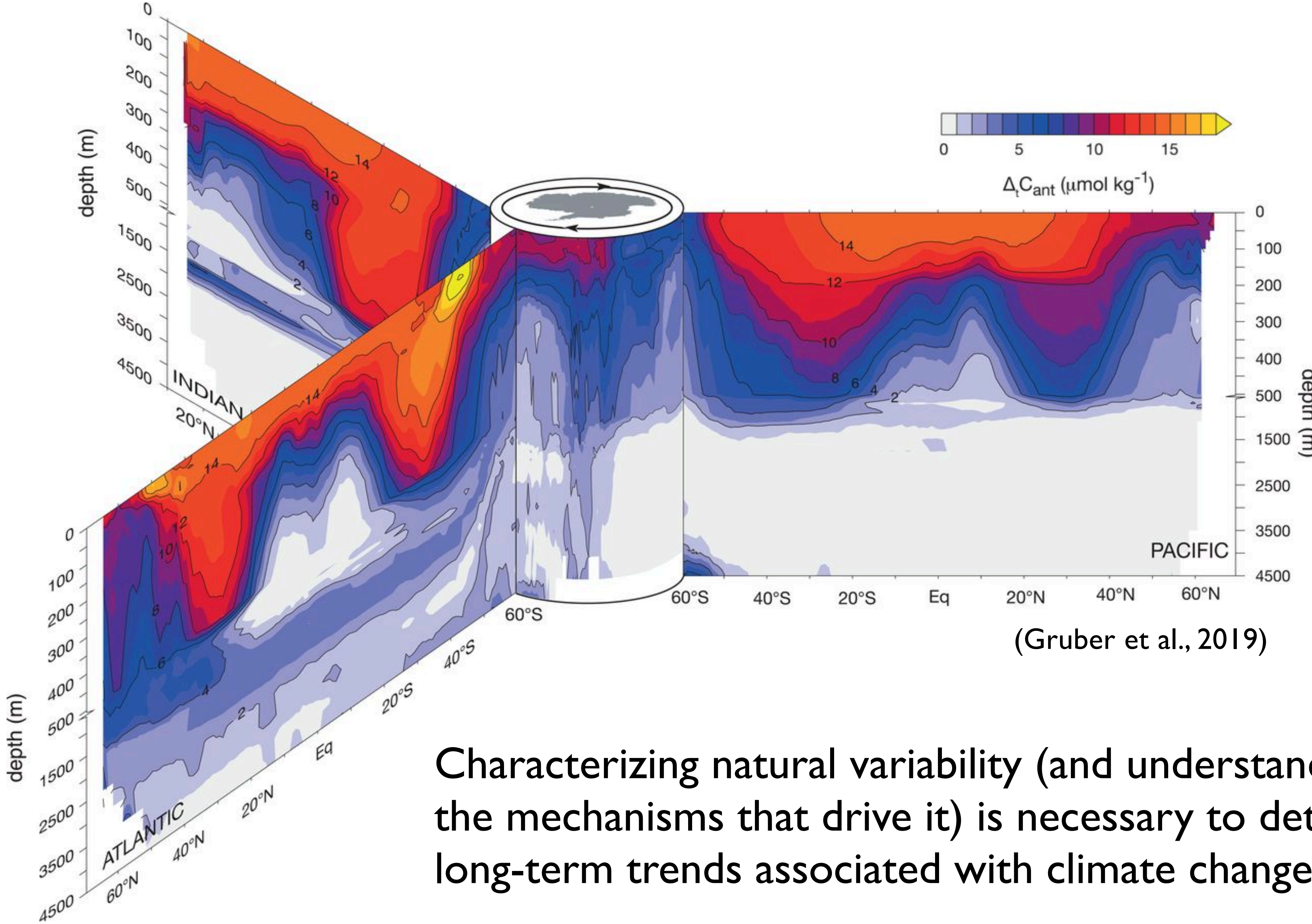
SCALES OF MOTION





Observing the ocean is a challenge due to the multi-scale nature of ocean dynamics and biogeochemistry.

DETECTING LONG-TERM CHANGES



(Gruber et al., 2019)

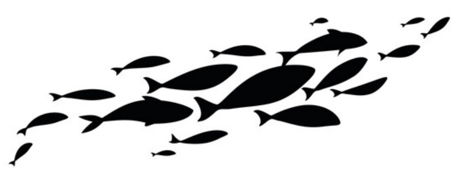
Characterizing natural variability (and understanding the mechanisms that drive it) is necessary to detect long-term trends associated with climate change.

CONCLUSIONS

• Float data can be used to investigate the subsurface carbon content and transport processes that drive air-sea flux variability, in contrast to past studies based on surface pCO_2 measurements alone.

• Carbon outgassing occurs preferentially in the Indo-Pacific sector of the ACC due to a higher annual mean surface ocean pCO_2, which is driven by systematic differences between basins in the fraction of upwelled carbon-rich water that enters the surface mixed-layer.

• It is crucial to consider sampling alias in the context of investigating variability and trends of the Southern Ocean carbon sink.



Email: cprend@uw.edu