Observing the carbon cycle in the Southern Ocean from biogeochemical floats with pH sensors

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OSU Oregon State University

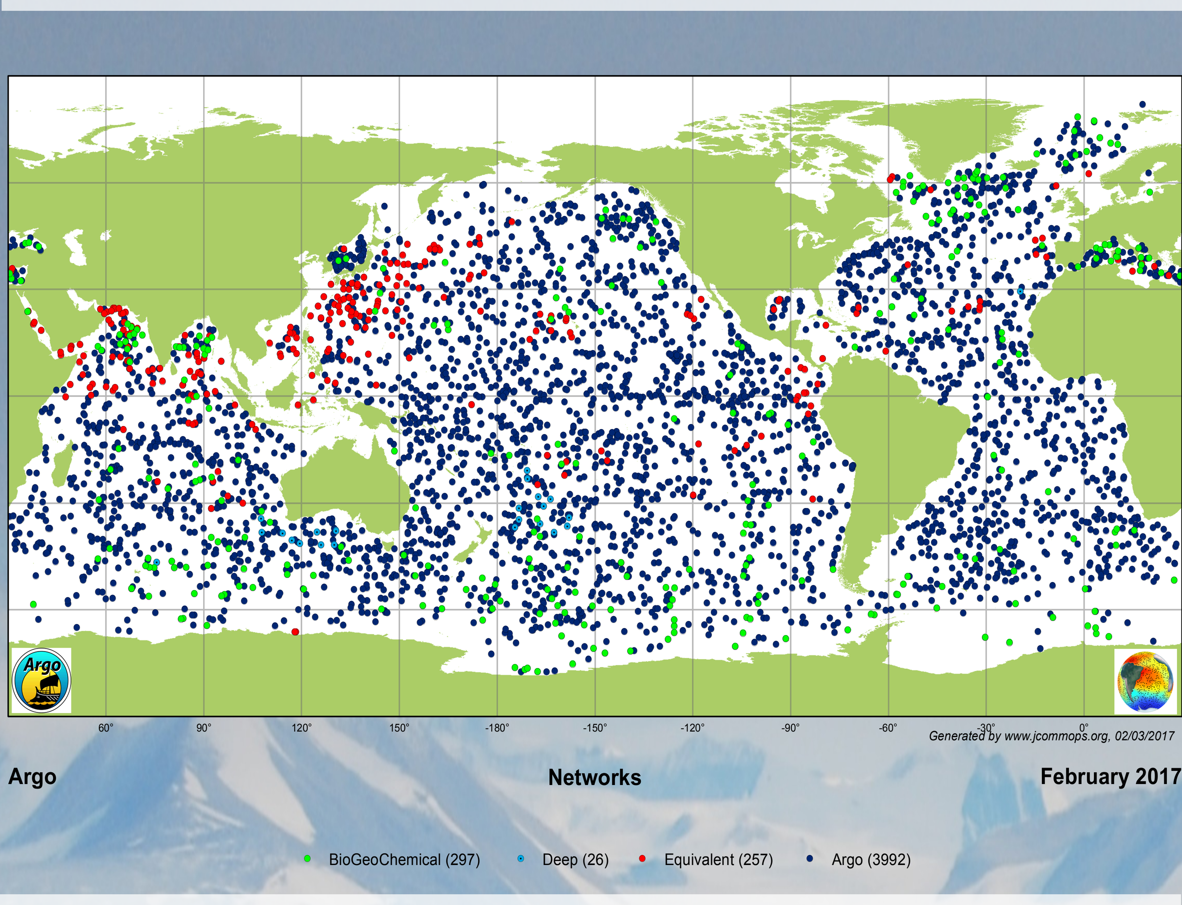
College of Earth, Ocean, and Atmospheric Sciences

ARCS Advancing Science in America

SOCCOM Southern Ocean Carbon and Climate Observations and Modeling

Overview of SOCCOM

The Southern Ocean plays a major role in the global carbon cycle by accounting for around half of the overall ocean carbon sink yet it is relatively undersampled and not well-represented in climate models. The Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) project aims to fill this observational gap by deploying 200 autonomous biogeochemical profiling floats in the Southern Ocean over 5 years. Now in year 3, there are over 80 floats in the water and reporting data back every 10 days (green dots in the Southern Ocean in the map to the left). These data are publicly available and are quality controlled in near-real time.

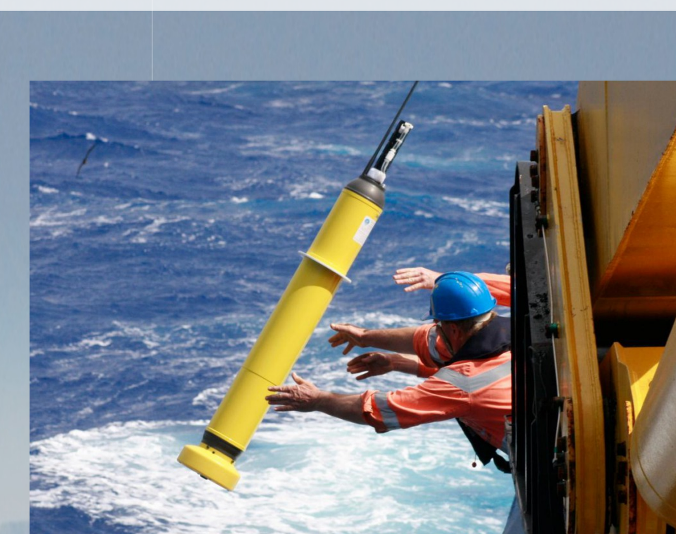


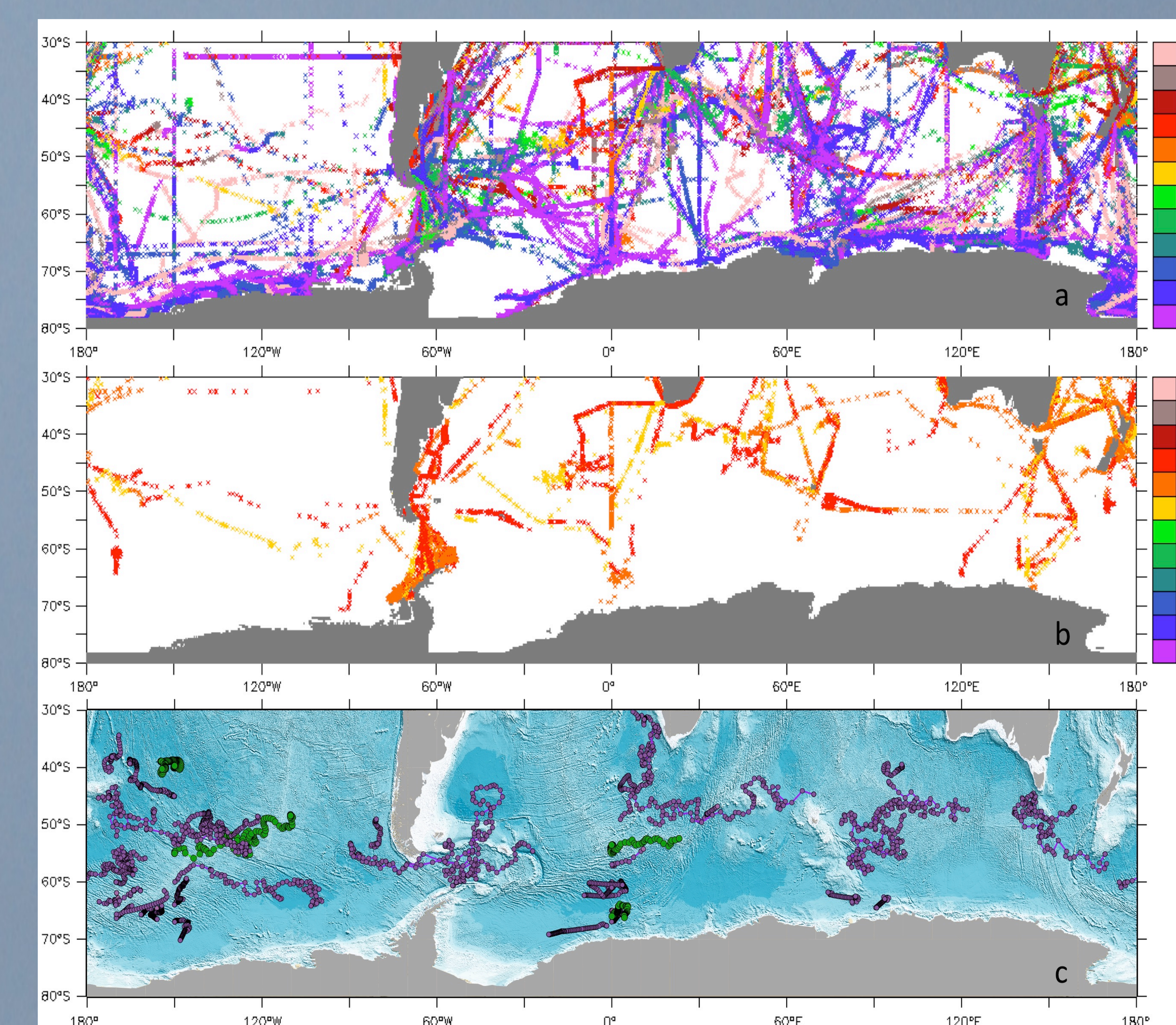
What is a SOCCOM float?

A SOCCOM float is an autonomous profiling float that measures temperature (T) and salinity (S) and carries the following additional biogeochemical sensors:

- Deep Sea DuraFET (Johnson et al. 2016)
- ISUS UV Nitrate (Johnson et al. 2013)
- WETLabs FLBB backscattering and chlorophyll (Boss et al., 2008)
- Aanderaa or Seabird oxygen optode (Tengberg et al., 2006)

SOCCOM floats are set to "park" at 1000 m drifting with the currents until, every 10 days, it descends to 2000 m, turns on its sensors, and ascends to the surface taking measurements along the way. At the surface it transmits the profile data back to a data center via satellite before descending back to its park depth. Many of the floats can also operate under ice.





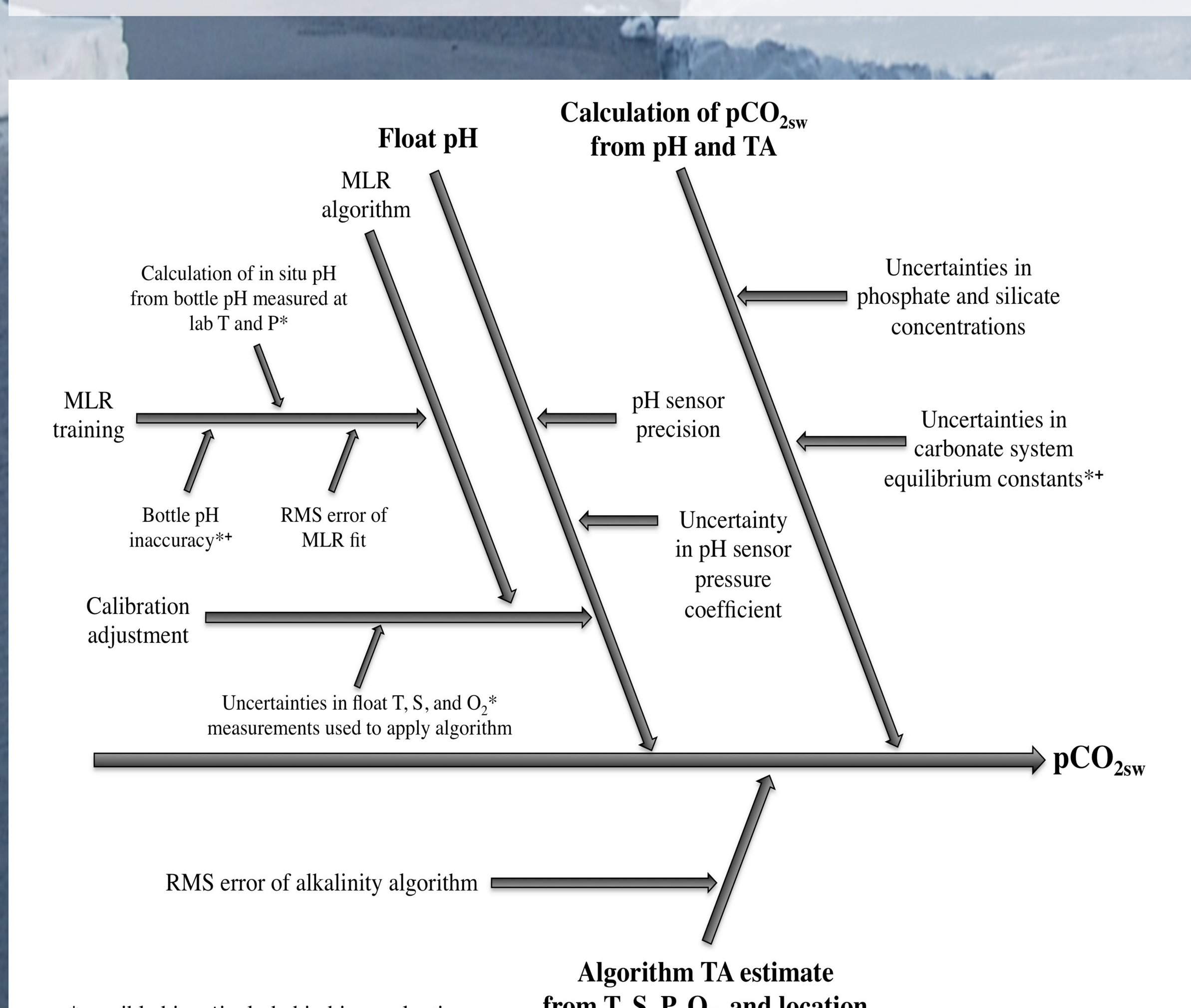
In the figure above, the top panel is ship-based underway $pCO_{2seawater}$ data included in the SOCATv4 (Surface Ocean CO_2 Atlas, Bakker et al., 2016) database south of 30°S from all years colored by month. The middle panel shows all SOCATv4 data south of 30°S from austral winter (July, August, September) and the bottom panel shows the locations of the SOCCOM floats as of January 2017.

How well can we calculate $pCO_{2seawater}$ from float pH?

To calculate the flux of carbon dioxide between the atmosphere and the ocean we need to calculate the ΔpCO_2:

$$\Delta pCO_2 = pCO_{2seawater} - pCO_{2atmosphere}$$

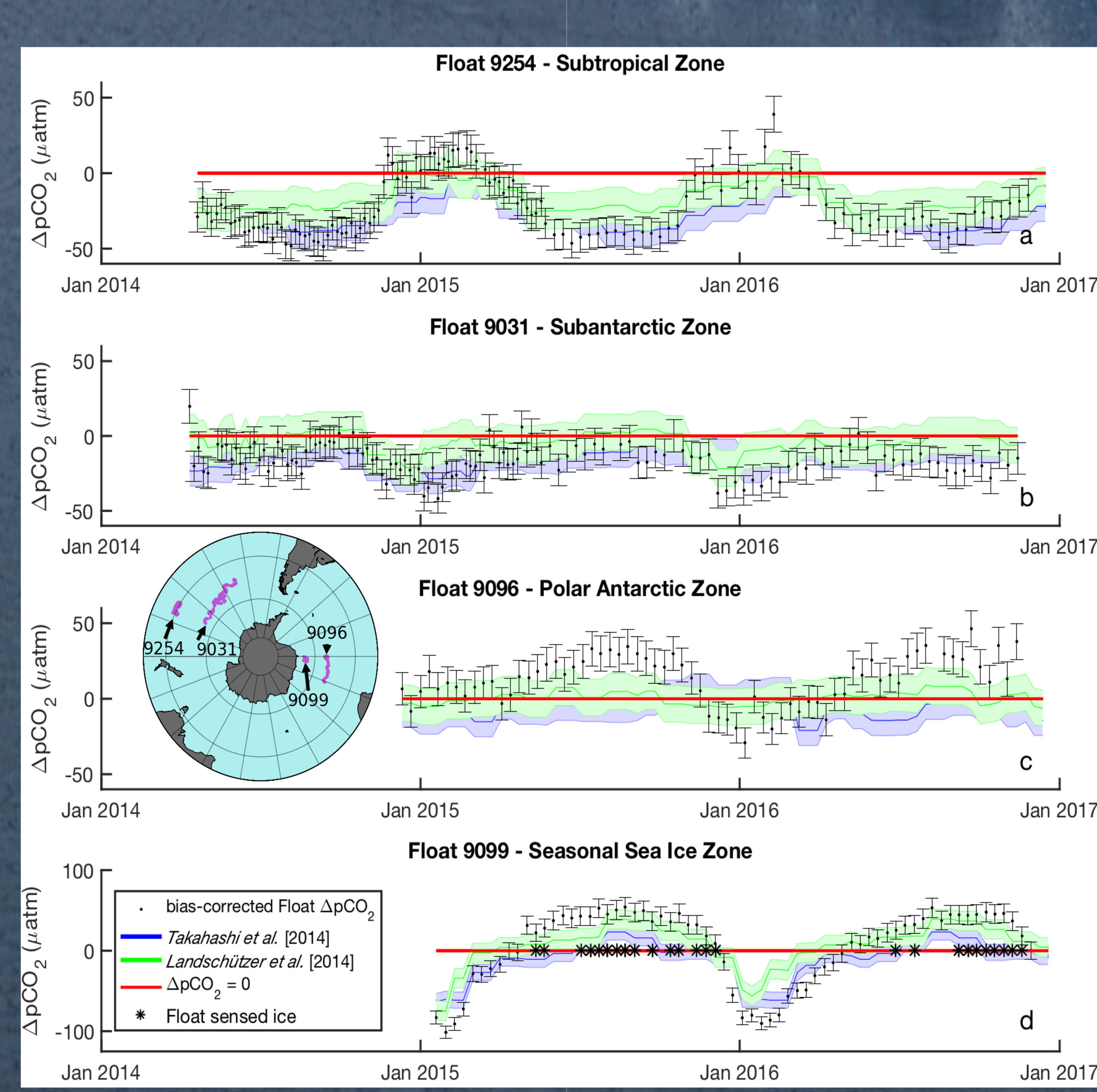
A positive ΔpCO_2 implies that the ocean will release carbon to the atmosphere. A float-based estimate of $pCO_{2seawater}$ can be calculated using the float pH measurements and an estimate for total alkalinity (Carter et al., 2016). **The uncertainty in float pCO_2 is 2.7% as compared to a 1% uncertainty in a traditional ship-based underway measurement.** This uncertainty was estimated using a careful analysis of uncertainties from three main sources: the float pH measurement, the alkalinity estimate, and the calculation of pCO_2 from pH and TA, as summarized in the fishbone diagram below.

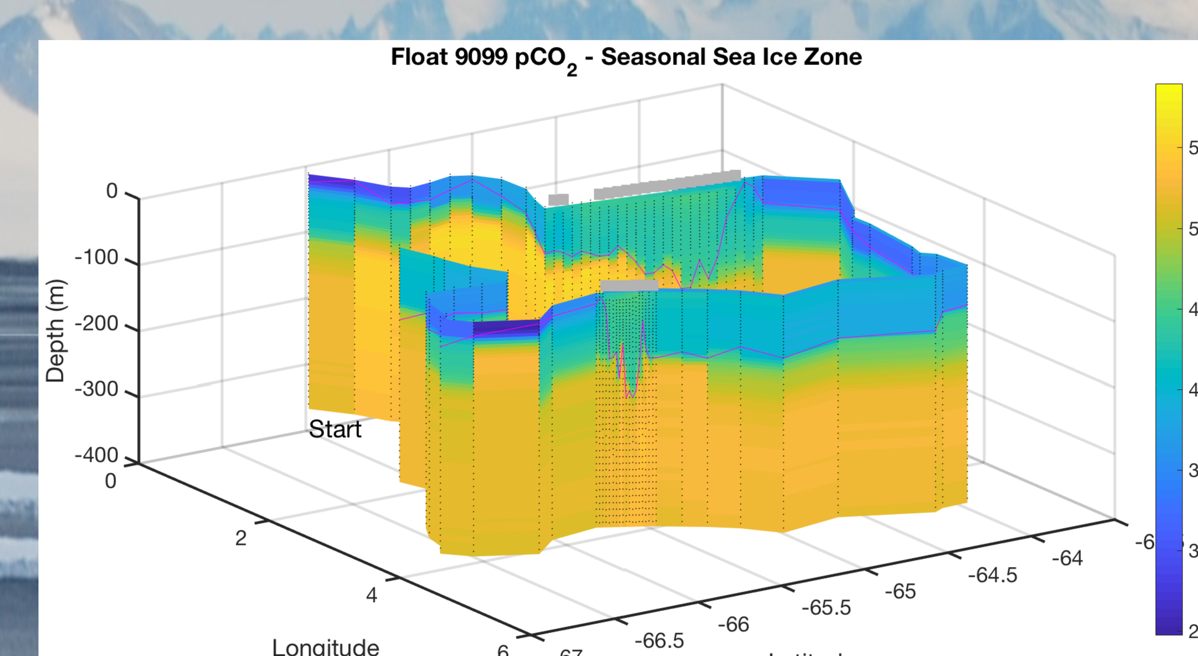


Results

While float-based calculated $pCO_{2seawater}$ is inherently more uncertain than most ship- or mooring-based $pCO_{2seawater}$ measurements, a well-calibrated array of biogeochemical floats can complement the existing global dataset by providing a seasonal context to regions where wintertime measurements are sparse. The figure below shows ΔpCO_2 from four floats each representing one of four major Southern Ocean frontal zones. In the Polar Antarctic Zone (panel c) and in the Seasonal Sea Ice Zone (panel c) the floats (black dots) see significantly higher ΔpCO_2 (leading to more carbon flux out of the ocean) than either the *Takahashi et al.* (2014) or the *Landschützer et al.* (2014) climatology (blue and green lines, respectively).

- The floats agree with the climatologies during the austral summer when there are significantly more underway $pCO_{2seawater}$ data to create the climatologies
- Large disagreements arise when there are no suitable data to constrain the climatology, such as austral winter and in ice-covered waters
- This disagreement is not surprising, considering (1) the limited availability of austral winter and under ice observations to compute the climatologies and (2) the $pCO_{2seawater}$ climatologies are based on climatological sea ice cover, which may differ from ice cover during float observations
- Differences between the floats and the climatologies cannot be explained by temperature differences.





The figure above shows a 3-D section plot of the upper water column pCO_2 for float 9099 along its 2.5-year lifetime from January 2015 through September 2017. This float is located in the South Atlantic in the Seasonal Sea Ice Zone. Float 9099 experiences ice coverage for up to half of the year (marked by gray boxes) and during this time the float location is interpolated between the last and first ice-free profiles. Each float pH measurement is plotted as a small black dot.

- In winter, ice traps the CO_2 from respiration and upwelled high-DIC waters
- The springtime ice-edge bloom draws down pCO_2

Conclusions

Ongoing shipboard and moored observation programs show that the $pCO_{2seawater}$ is increasing globally as a result of anthropogenic emissions. Nonetheless, our current understanding of the seasonal cycle and interannual variability, and thus the mechanisms controlling $pCO_{2seawater}$ and air-sea CO_2 flux, is lacking over many parts of the world ocean. Despite the estimated 2.7% relative standard uncertainty in current biogeochemical float-based $pCO_{2seawater}$ (pH, TA) estimates, it is clear from the differences between existing climatologies and new float pH-based $pCO_{2seawater}$ (pH, TA) estimates that incorporating information from these novel carbon observational platforms can improve climatologies, climate models, and future projections. While true space/time cross- overs between biogeochemical floats and shipboard pCO_2 systems are rare, and spatial and temporal heterogeneity make direct comparisons difficult, we have shown that a well-calibrated biogeochemical float provides meaningful data that strengthen the current body of $pCO_{2seawater}$ observations.

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