The observing system and air-sea carbon flux

Amanda Fay
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Why do we care about the uptake of carbon?

- Ocean absorbs ~25% of CO₂ emissions
- Climate change is impacting both biological and physical processes that determine this ocean uptake
- The ocean uptake uncertainty/interannual/regional variability is more poorly constrained than previously known/acknowledged
Takahashi climatology update (in prep)

<table>
<thead>
<tr>
<th>Source</th>
<th>Time period</th>
<th>Flux estimate (contemporary) PgC yr(^{-1})</th>
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</thead>
<tbody>
<tr>
<td>Takahashi climatology</td>
<td>1980-2021</td>
<td>-1.79 ± 0.6</td>
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<td>Fay et al. 2023, in prep</td>
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<tr>
<td>Takahashi climatology</td>
<td>2000 (1970-2007)</td>
<td>-1.67 ± 0.9</td>
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<td>Takahashi et al. 2009</td>
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<td>GCB 2022*</td>
<td>2012-2021</td>
<td>-2.25 ± 0.4</td>
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<td>Friedlingstein et al. 2022</td>
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<tr>
<td>SeaFlux</td>
<td>1990-2019</td>
<td>-1.97 ± 0.45</td>
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<td>Fay &amp; Gregor et al. 2021</td>
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*When contemporary estimate is not reported, we utilize a riverine flux estimate of 0.65 PgC yr\(^{-1}\)
Current state of the air-sea CO$_2$ flux estimate

The Global Carbon Budget (GCB) shows a discrepancy between the different methods (models vs products) on the strength of the ocean sink over the last decade.

Uncertainties still to be researched…

- Riverine flux.
  - Needed for comparison of observation-based products and models.
  - Current estimates range from 0.21 to 0.78 PgC yr$^{-1}$

- Skin temperature effect.
  - It is understood that the SOCAT database has a warm bias due to intake collection depth

- Not all estimates are giving a global estimate

- Interaction of climate change with the different flux estimates: e.g., anthropogenic vs natural plus riverine, etc.

Fay & McKinley GRL 2021
SOCAT: there has been a decline in CO$_2$ observing efforts in the world’s ocean
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Fay et al. in prep
High quality measurements are absolutely imperative to our research.

Adapted from McKinley et al. 2020

\[ \Delta \approx 5 \mu \text{atm} \]
Assessments of data impact on poorly sampled regions

Automated Surface Vehicles (ASV’s) have great potential to fill spatiotemporal gaps in ocean carbon observations.

Climatological CO$_2$ air-sea flux differences with/without one individual ASV deployment in the South Pacific differ by about a tenth of a Pg yr$^{-1}$.
Assessments of data impact on poorly sampled regions

Current work (Heimdal et al. in prep) looking at idealized sampling patterns of the Saildrone in the Southern Ocean uses a model testbed approach and find a marked improvement in capturing the “true” carbon flux in the region.

Image courtesy of NOAA’s PMEL
Looking forward
My thoughts on what we need

There is a need for more observations and tools in under sampled regions specifically the South Pacific, Indian Ocean, Southern Ocean, and coastal regions. Utilize models/machine learning to educated where/when sampling could be most impactful.

High quality (low uncertainty) measurements are essential. While a variety of platforms can enhance the total observing network, they are not a replacement for the high-quality measurements of pCO₂ that are obtained on ships and sail drones. There is no replacement for this type of data.

Biases in our pCO₂ data cascade to flux calculations. With the average ocean disequilibrium around 6-8 μatm, even small biases or errors can quickly affect flux estimates.