Near-Surface Stratification Due to Ice Melt Biases Arctic Air-Sea CO_2 Flux Estimates

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Arctic Summertime Shallow Stratification

Bulk flux: CO_2 flux $\propto K\,(fCO_{2w} - fCO_{2a})$

- ***K*** : Gas transfer velocity
- **fCO_{2a}** : CO_2 fugacity at the atmosphere
- **fCO_{2w} :** CO_2 fugacity at the **sea surface**

- fCO_{2w} is typically measured at **~5 m depth**.
- Sea-ice melt leads to shallow stratification and results in different fCO_{2w} values between the **surface** and 5 m.
- Most of the Arctic Ocean CO_2 uptake estimates are based on the bulk method.

Affected by the shallow stratification

Eddy covariance air-sea CO_2 flux

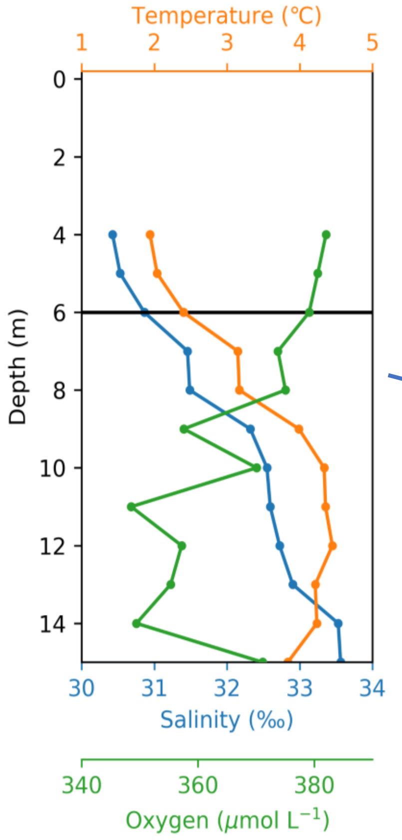
Direct flux measurements in the atmosphere

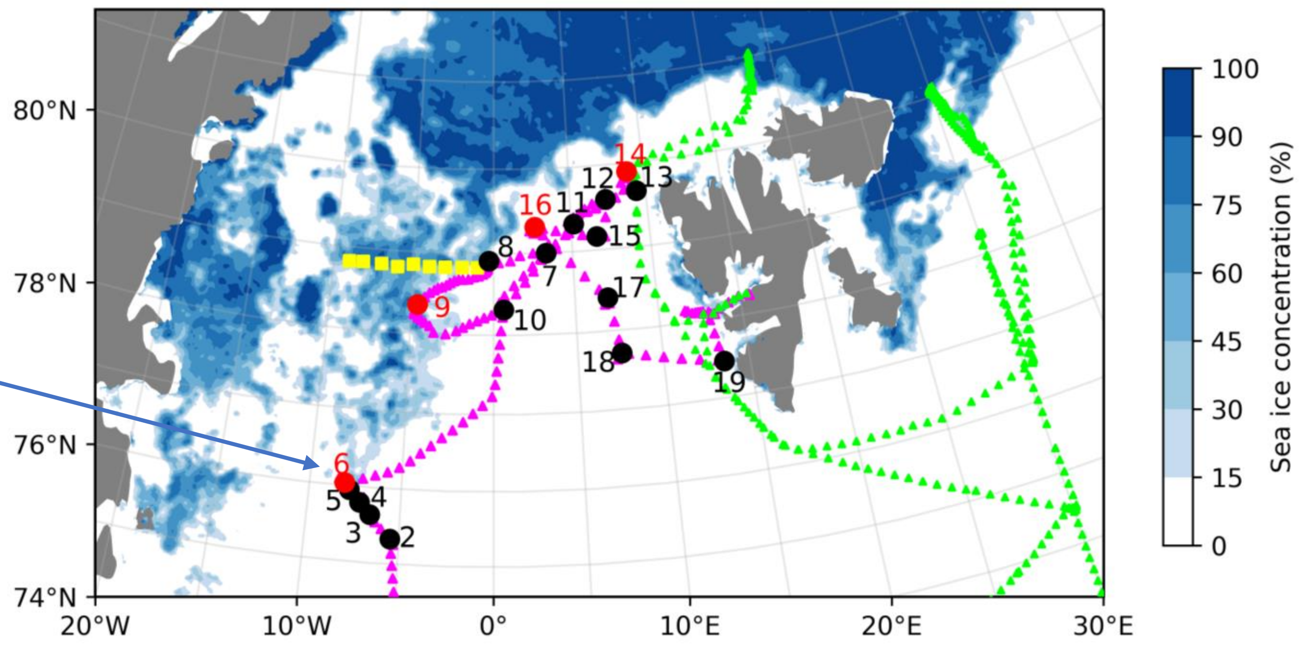
$$CO_2 \text{ flux} = \rho\overline{c'w'}$$

- ***ρ*** : Dry air density; ***c*** **:** Atmospheric CO_2 mixing ratio; ***w*** : vertical wind speed; ′: Fluctuation; ——: Average

Unaffected by the shallow stratification

Fluxes During Arctic Cruise JR18007





▲▲▲ Cruise track of JR18006

▲▲▲ Cruise track of JR18007

● — Stratified stations

● — Non-stratified stations

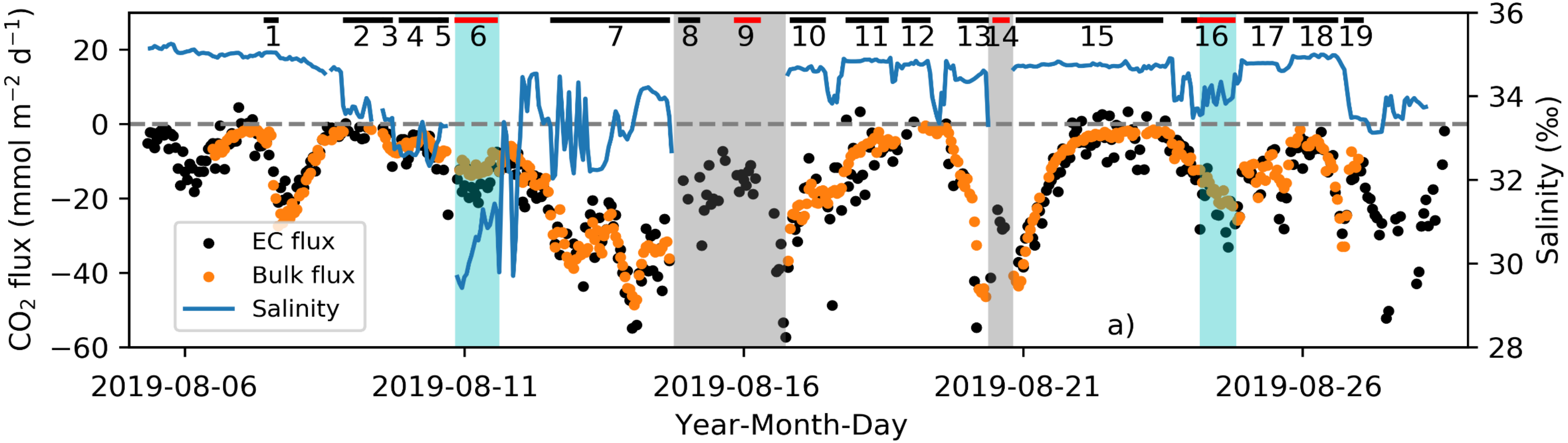
■ Dissolved inorganic carbon and alkalinity stations

● Bulk air-sea CO_2 flux

● Eddy covariance air-sea CO_2 flux

Stratified regions

Ice covered regions



Potential Impact on Arctic Ocean CO_2 Uptake Estimates

Conclusions:

- The **eddy covariance** (EC) air-sea CO_2 flux is **consistently higher** in magnitude than the **bulk flux** in sea-ice melt regions, which suggests an **underestimation of the bulk air-sea CO_2 flux**.

- Interpolating results from cruise JR18007 to the entire Arctic Ocean, we found: The summertime near-surface stratification due to **sea-ice melt** could lead to a **~10%** (with high uncertainty) **underestimation** of the annual Arctic Ocean CO_2 uptake.

- Detailed studies of **upper ocean (0–10 m) gradients** in CO_2 concentration, temperature, salinity, and biological rates along with **EC flux measurements**, are required to improve understanding of sea-ice melt impacts on air-sea exchange.

Look at our GRL paper for details: https://doi.org/10.1029/2021GL095266

Knowledge Gaps and Priorities for Next Steps

Knowledge gaps:

The difference of the CO_2, temperature, salinity, dissolved inorganic carbon (DIC), alkalinity (TA), and biological rates between the microlayer (~100 µm depth) and the bulk seawater (~5 m depth).

Priorities:

Timescales (years)	**1**	**5**	**10**
Priorities	Direct measure the upper ocean (0–10 m) variables (mentioned above) using CTD along with eddy covariance (EC) flux measurements in some Arctic sea-ice melt regions (case study).	Widely measure the upper ocean variable (e.g. CO_2) gradients in the Arctic ocean along with EC measurements (MOSAiC Expedition might help).	Make use of the *in-situ* measurements to calibrate the satellite data in the Arctic Ocean and estimate the impact of the shallow stratification due to sea-ice melt on the entire Arctic Ocean using these satellite data.