Simulating the Sea Ice Carbon Pump in the Beaufort Gyre

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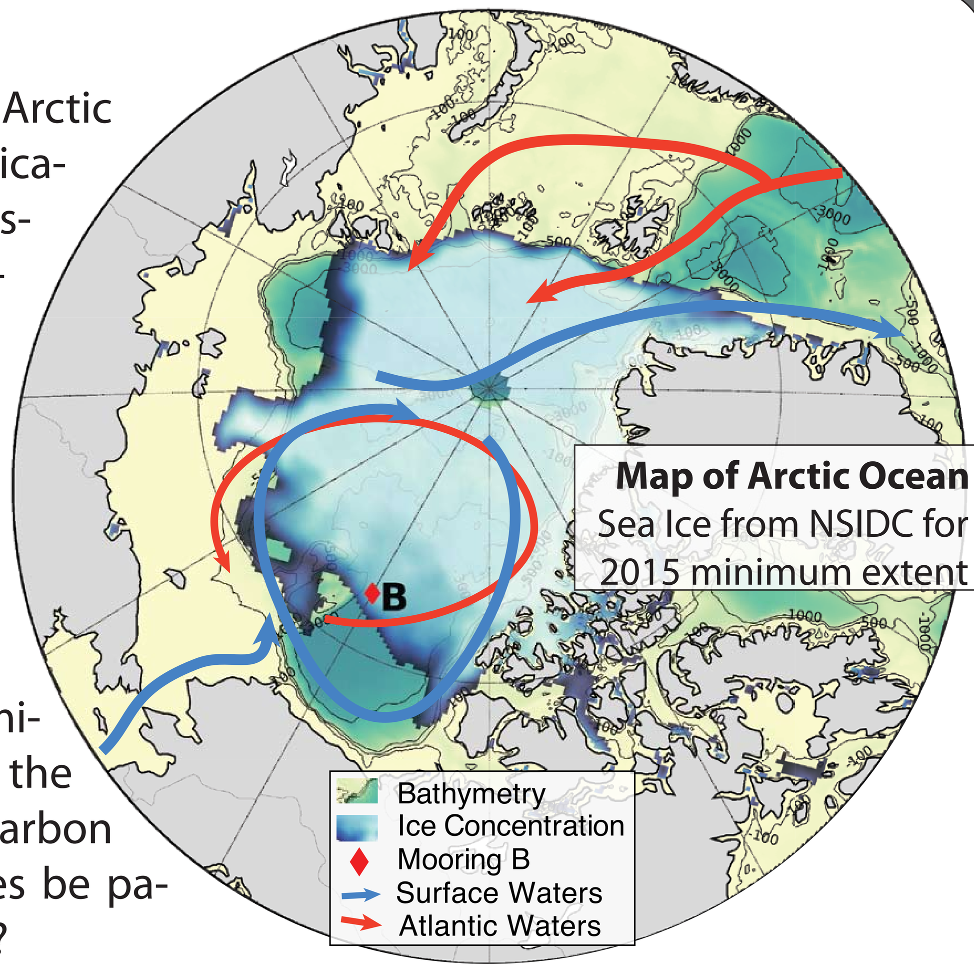
Motivation:

• Climate Change modifies Arctic Sea Ice conditions, with implications for hydrology, ecosystems, carbon chemistry, climate, communities and geopolitics.

• Seasonal cycle of freezing and melting of sea ice impacts processes that are regulating the concentration of carbon in seawater.

=> Which physical and chemical ice-related processes have the biggest impact on the carbon cycle? Should those processes be parametrized in climate models?



To investigate those questions, we use a 1D numerical model and mooring observations of physical and biogeochemical properties in the Beaufort Gyre.

How does Sea Ice Impact the Carbon Cycle?

The Sea Ice Carbon Pump refers to processes that are both:

• *Physical*: melting (freezing) dilutes (concentrates) DIC and Alkalinity, changing pCO_2, which controls air-sea CO_2 exchange. These processes also affect stratification, insulating deeper, carbon-rich waters from the atmosphere.

• *Chemical*: ice stores and releases Alkalinity and DIC, with a ratio that differs from seawater, therefore unbalancing the carbonate system (cf. Figure 3).

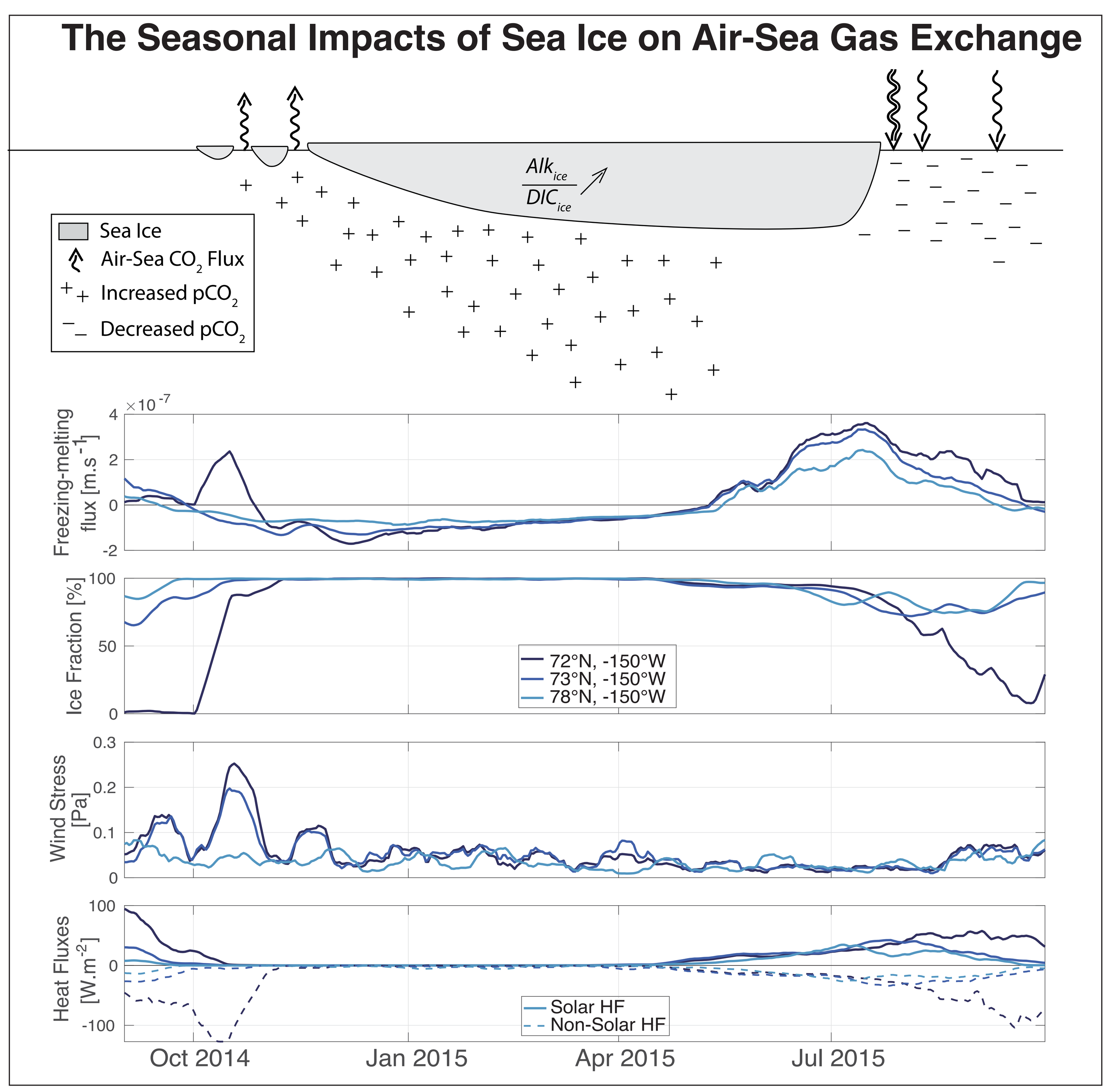


Figure 1: Top: schematic representing the impacts of sea ice on the air-sea gas exchange over the course of a seasonal cycle.
Bottom: Representative ice and atmospheric conditions in the Arctic Ocean. Atmospheric and ice properties are implemented to force the numerical model used in this study.

Model Description and Validation

We use the 1D hydrodynamical model GOTM [1] coupled with the biological model PISCESv2 [2], slightly modified (cf. below). We force the 1D model with diagnostic outputs from a 3D regional setup of the NEMO-LIM-PISCES [3] numerical model. Comparison of the model outputs with in-situ observations from a mooring [4] is presented below.

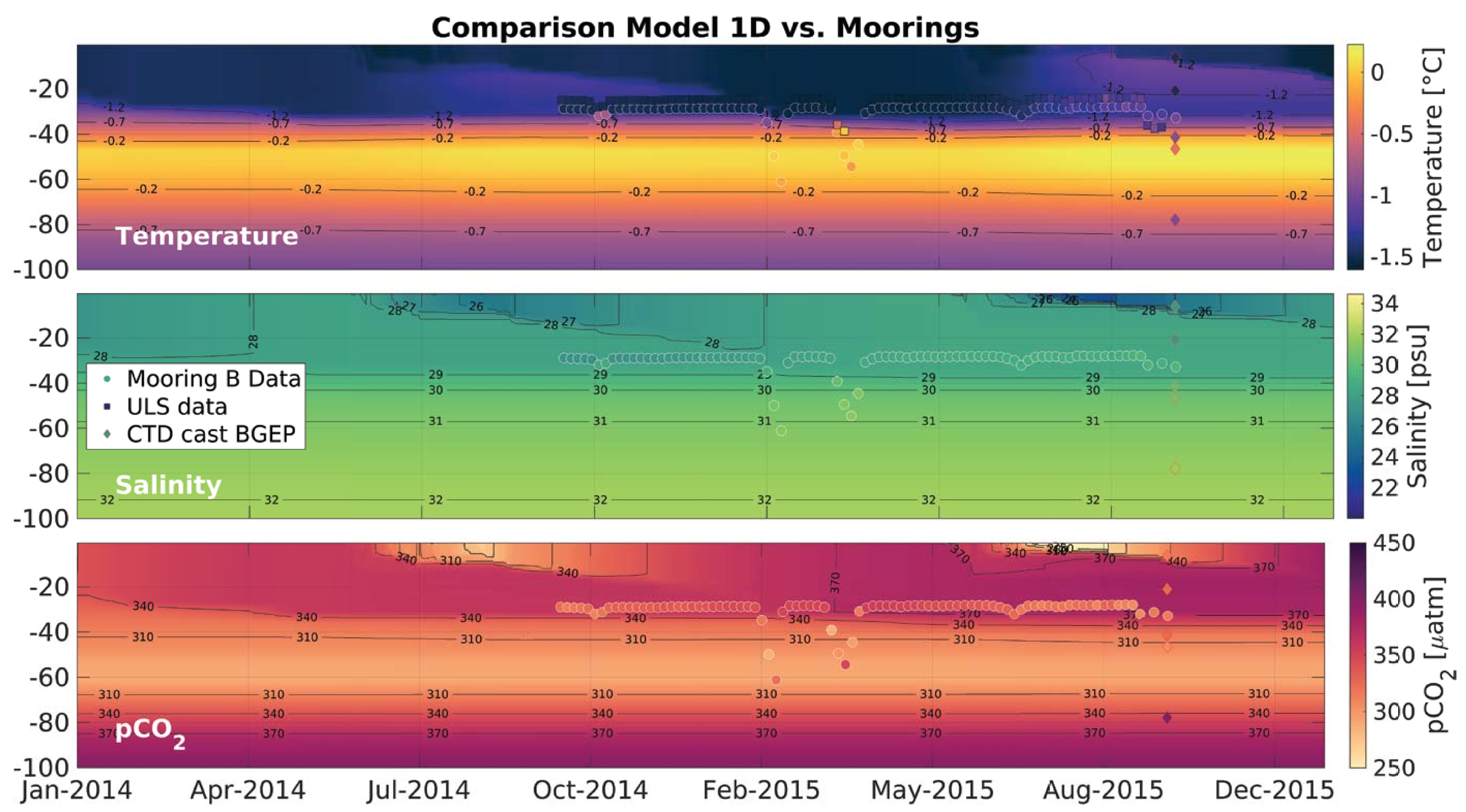


Figure 2: Model and Observations: Temperature (top), salinity (center) and pCO_2 (bottom) from the 1D simulation (background colors) and from Mooring B observations (superimposed dots, filled with observation values).

Carbon Storage in Ice

A simple parametrization for storage and release of carbon into ice is implemented. Alkalinity follows a similar equation. Biological processes are not taken into account in this study.

$$\partial_t DIC = \mathcal{F}^{AirSea}_{CO_2} + \mathcal{F}^{Surf}_{D\&C} + [DIC]_{ice}\mathcal{F}^{ice}_{fm}$$

- $\mathcal{F}^{AirSea}_{CO_2}$ in $[molC.m^{-2}.s^{-1}]$: air-sea CO_2 flux, as in PISCES [2]
- $\mathcal{F}^{Surf}_{D\&C}$ in $[molC.m^{-2}.s^{-1}]$: dilution-concentration effect
- $[DIC]_{ice}$ in $[molC.m^{-3}]$: DIC concentration in ice (constant parameter)
- $\mathcal{F}^{ice}_{fm}$ in $[m.s^{-1}]$: freezing-melting flux of ice

We can then assess the impact of each of those terms, as shown below.

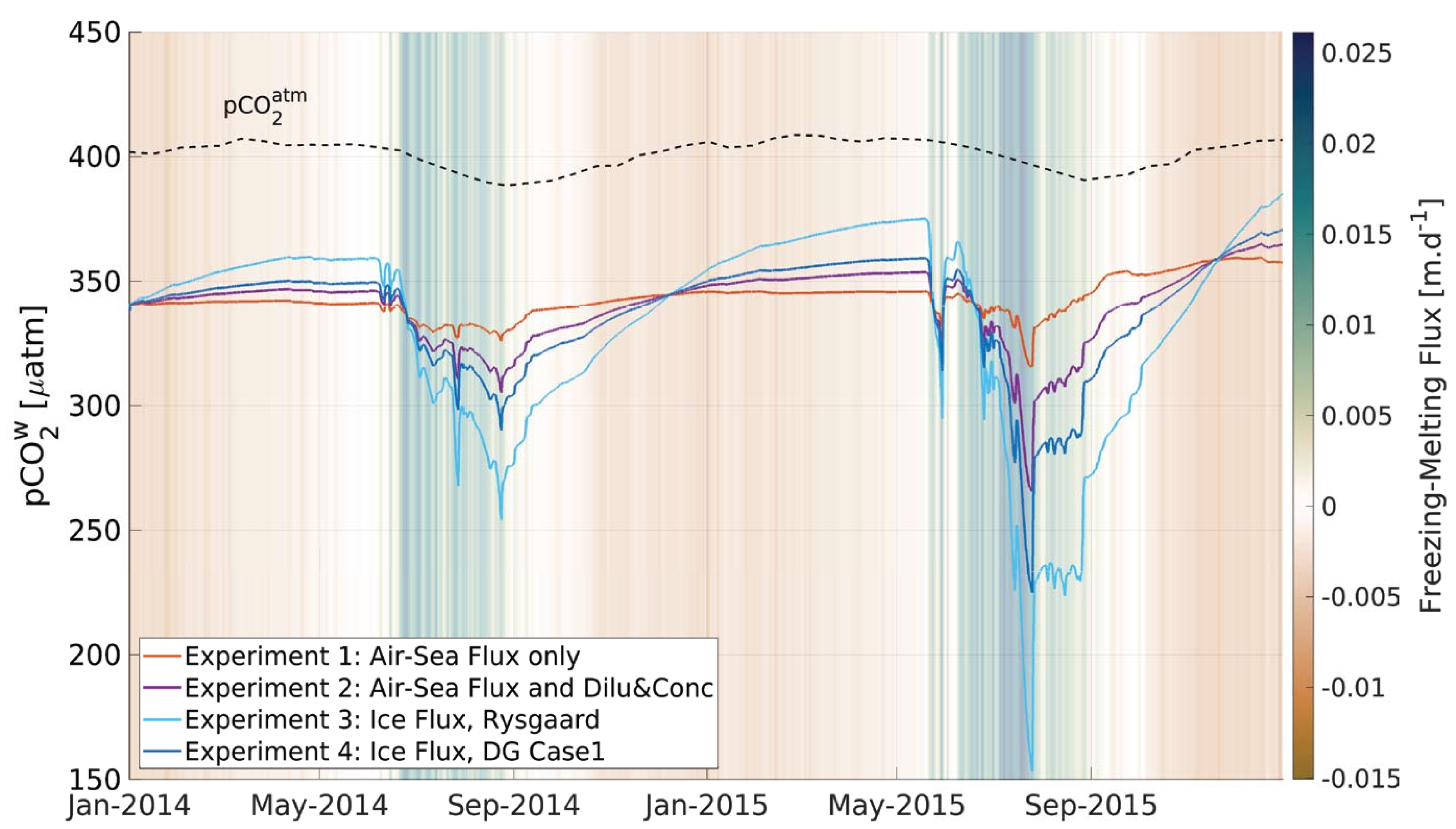


Figure 3: Sea surface pCO_2 seasonal cycle. Background colors represent freezing-melting flux; solid lines show surface pCO_2 in water, with no ice (red), when ice only impacts dilution and concentration of carbonate properties (purple), with carbon storage in ice with DIC_{ice}=300µmol.kg^{-1} and Alk_{ice}=540µmol.kg^{-1} [5] (light blue) and with DIC_{ice}=330 and Alk_{ice}=415 [4] (dark blue). Dashed black line is for atmospheric pCO_2.

Sensitivity to DIC and Alkalinity Concentrations in Ice

The ratio of Alkalinity to DIC controls the amplitude of the CO_2 uptake. This ratio is poorly constrained by observations, and its reported value can vary between 0.9 and 2.2. Over such a wide range, net CO_2 uptake can vary significantly (cf. below).

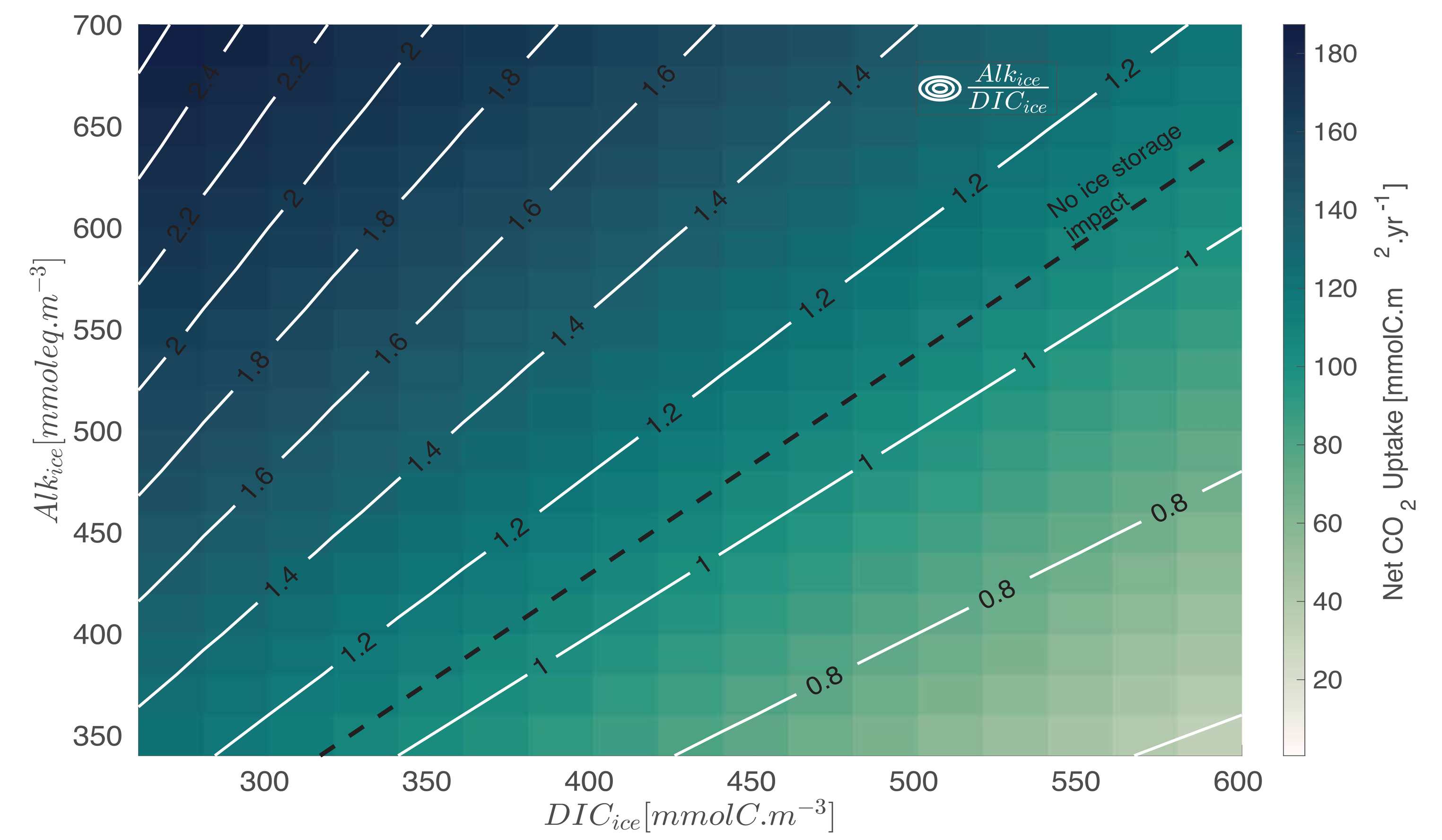


Figure 4: Net CO_2 uptake (colors) and Alk to DIC ratio in ice (white lines). Red line shows the net CO_2 uptake value without carbon storage in ice.

Spatial Variability

By using a set of forcing conditions along a meridian, we can simulate a wide variety of ice seasonal cycle, giving us spatial variability, , but also a potential preview of future conditions. The impact of ice conditions can then be investigated.

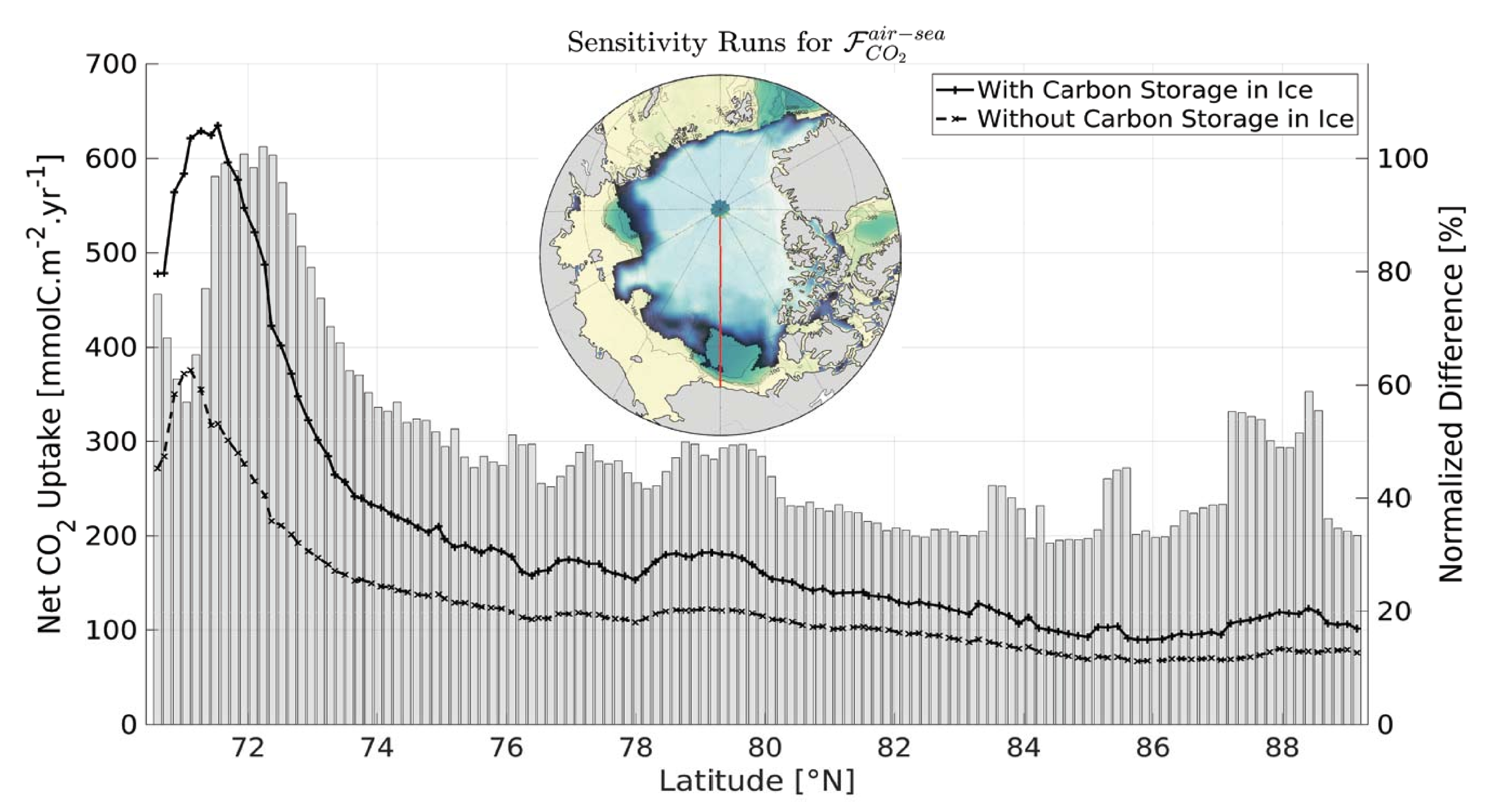


Figure 5: Net CO_2 Uptake with (solid) and without (dashed) carbon storage in ice. Bar graph shows the normalized error. Red line in the insert shows all latitudes represented here.

Conclusions and Next Steps:

The ratio of Alkalinity to DIC in ice controls the sea surface pCO_2 seasonal cycle. Therefore, the storage process has to be implemented in climate models to properly estimate air-sea gas fluxes. Under specific conditions, this process can double the net CO_2 uptake.

In the future, we will attempt to forecast the evolution of CO_2 gas exchange, by using idealized forcings to determine the main ice-related driver of CO_2 fluxes.

References

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