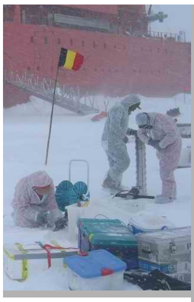
CO_2 transfer at the ice-sea and air-ice interfaces: a step towards the end of a long-lived dogma ?



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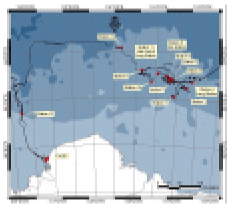
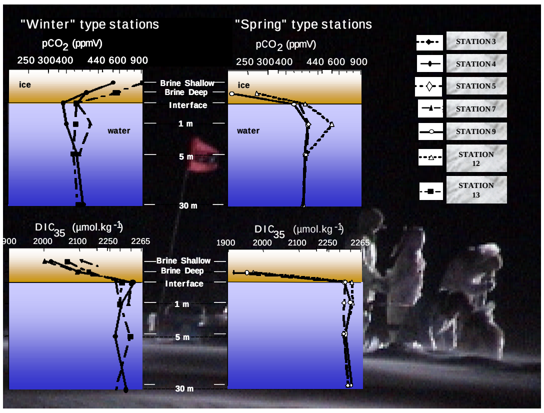


For decades, sea ice has been considered as an **inert and impermeable cover** which prohibits any exchange of gases between underlying water and the atmosphere.
In the framework of the Belgian project **SIBCLIM** (**Sea Ice Biogeochemistry in a Climate Change Perspective**) spring dynamics of partial pressure of CO_2 (pCO_2) within and below fast sea ice, and associated exchanges of CO_2 at the ice-sea and air-ice interfaces were investigated in conjunction with the measurement of an extended and comprehensive set of physical, biological, and biogeochemical variables.
Our preliminary results show that specific biogeochemical processes occur in sea-ice leading to **high CO_2 dynamics**. Furthermore, **CO_2 transfer** with both underlying water and the atmosphere above have been observed.

CO_2 dynamics



First direct measurements of pCO_2 within and below sea-ice have been measured using a new versatile pCO_2 measurement unit (SIES – Sea-Ice Equilibrator System) transportable on the field.

Preliminary results exhibit **strong CO_2 dynamics in sea-ice, mainly driven by internal physical and biogeochemical processes**. pCO_2 in brines ranged from marked undersaturation down to 210 ppmV to oversaturation up to 915 ppmV.

Amongst the physical properties of the sea ice cover, the **temperature profile appears to be the main controlling factor** on the CO_2 dynamics. Ice below the porosity **threshold of about -5°C** (winter type stations) displays the higher pCO_2 values, whilst the warmer, more porous, ice ("spring" type station) favours the set up of primary production and hence, shows the lowest pCO_2 values.

In "winter" type stations, negative correlation of pCO_2 and Dissolved Inorganic Carbon linearized against salinity (DIC_{35}) in the ice upper layer evidence **precipitation of calcium carbonate** within the coldest ice layer which increase pCO_2 towards the air-ice interface.

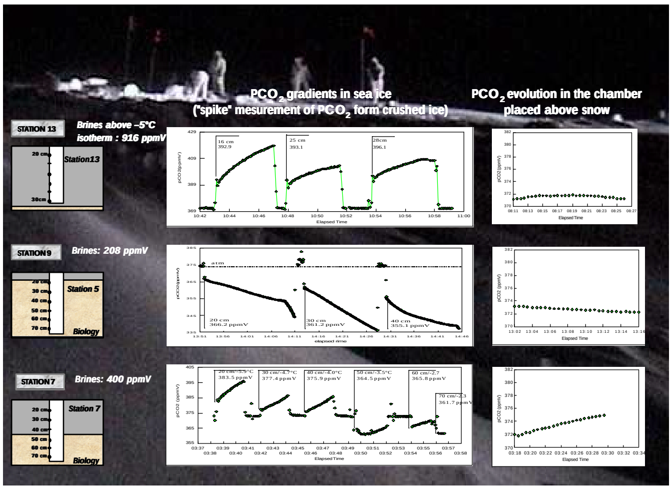
At the ice-sea interface, spring initial release of dense CO_2 rich brines tends to increase pCO_2 of the first meters of the water column while the following development of primary production lead to a decrease of pCO_2 at the ice-water interface

CO_2 transfer

In order to better assess vertical gradients of pCO_2 in the sea ice layer, we have measured PCO_2 in the air extracted from crushed ice at several depths. pCO_2 from crushed sea-ice evidenced **strong vertical gradient of PCO_2** with PCO_2 values ranging in some cases from **oversaturation at the air-ice interface** to **undersaturation at the ice-sea interface**.

Strong gradients of pCO_2 have been observed at the air-ice interface either positive or negative, depending primarily on the temperature profile. These gradients can drive exchanges of CO_2 (measured with the chamber technique) up to **2.0 mmol.m^{-2}.d^{-1}**, at the **air-ice interface** depending of the snow cover and the ice temperature.

Station	Type	CO_2 fluxes (mmol.m^{-2}.d^{-1})
13	Winter	0
7	Intermediate	1.97
9	Summer	-0.46



Conclusions and perspectives

In autumn and winter, temperature decrease and salinity increase in sea ice brines lead to **calcium carbonate precipitation**. This latter processes, and possible bacterial activity, are responsible of a strong increase in pCO_2 within sea ice. When theses processes occur, sea ice temperature is too low (below –5°) to allow brines exchange with the underlying water and gases exchange with the atmosphere (station 9).
In spring as the **sea ice temperature increases**, brines and gases can be exchanged with respectively underlying water and the atmosphere. Brine release in the underlying water lead to a small increase of the pCO_2 of the water column, while oversaturation of pCO_2 at the air-ice interface (station 7) drives **CO_2 release to the atmosphere** (under favourable temperature and snow conditions). However, at the same time, brine circulation initiates the onset of **high primary production** that is responsible of a dramatic decrease of pCO_2 and a **large undersaturation**. Consequently, sea ice begins to act as a **CO_2 sink**, firstly in the underlying water since generally phytoplankton starts to bloom at the ice-water interface, then for the atmosphere as the bloom reaches the sea ice upper layer.

Thereafter, it appears that spring Antarctic pack ice can either act as a source or as a sink of CO_2 for both the atmosphere and the underlying water, in close connection with its thermal and biogeochemical seasonal history. For decades, sea ice was seen as a simple inert stopper for air-sea exchange of CO_2; this long-lived paradigm should be revisited in some part.

SIBClim — Sea Ice Biogeochemistry in a Climate change perspective
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