BISICLO: Biogeochemical cycles, sea ice and climate in the Polar Oceans

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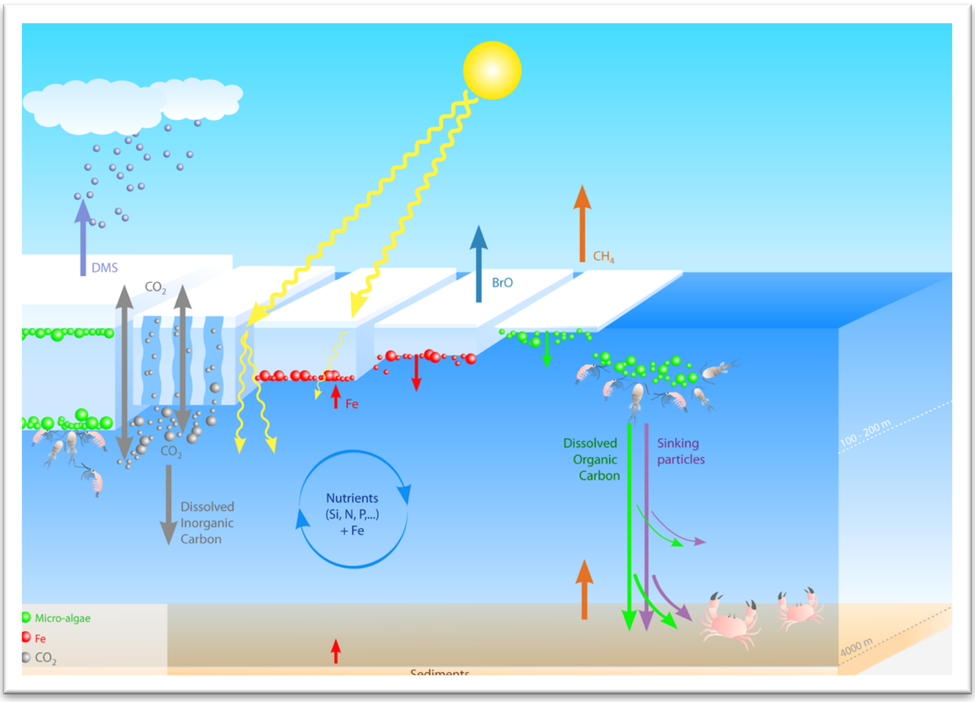

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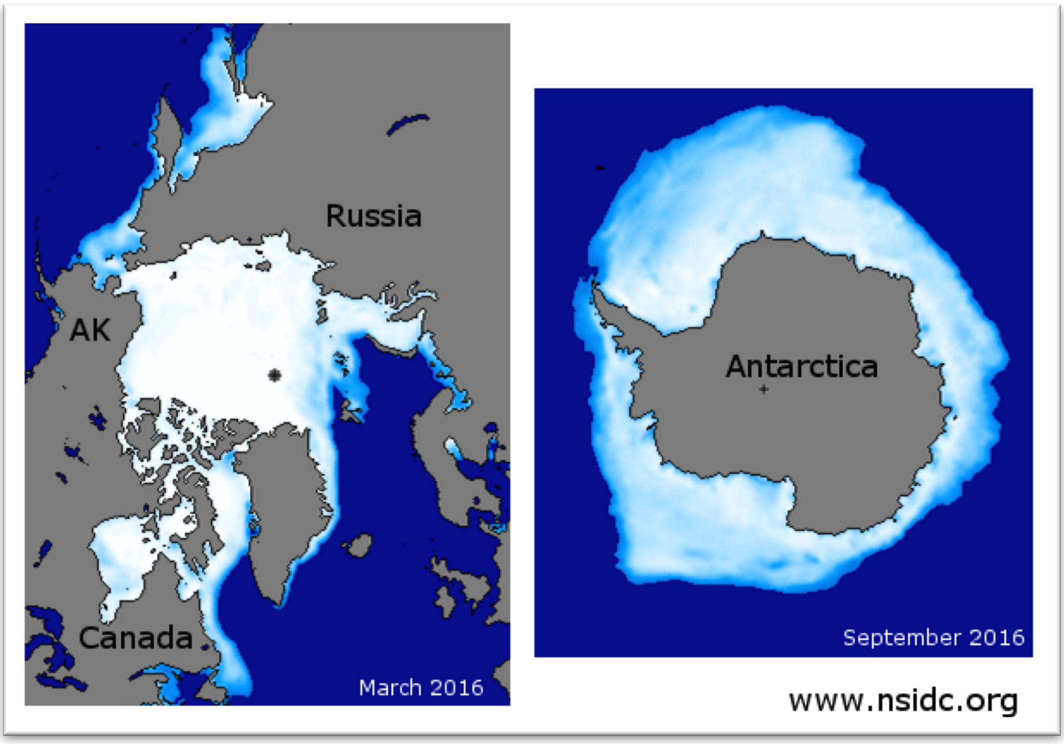
Goal

BISICLO aims at better understanding the microbiology and chemistry of the sea ice zone, based on the analysis of observations and numerical models. The ultimate goal is to reliably envision the consequences of sea ice retreat on polar marine life and bio-chemistry.

Context & Rationale

Sea ice is natural ice formed by the freezing of seawater. A few meters thick, but thousands of kilometers wide, sea ice covers up to 2.5 times the size of Europe (about 25 million square kilometers) distributed over the two polar oceans.



Sea ice concentration maps at maximum extent in 2016, for Arctic (left) and Antarctic regions.

The *Arctic Ocean*, centered around the North Pole and located between Scandinavia, Russia, Alaska, Canada cannot be well perceived from the usual world maps. The Arctic Ocean used to be ice covered yearlong until the early 2000's, but recent years have seen a drastic decrease and models predict no more summer ice between 2040 and 2060, with environmental, commercial and geopolitical consequences.

Antarctica is a continent covered with *continental ice* centered around the South Pole. Around lies the *Southern Ocean*, which connects the three main oceans. The Southern Ocean is seasonally sea ice covered. Antarctic sea ice, currently stable, is expected to decrease in the course of the 21st century.

Beneath the sea ice, between sea ice chunks and also within the sea ice, there is **microbial life**, including micro-algae, adapted to the harsh sub-zero temperatures and low-light conditions. Micro-organisms live in small brine inclusions encased in the sea ice.

Ice algae are an important source of food for the winter survival of larger species, including zooplankton and krill, which in turn feed other marine species (fish, marine mammals, polar bear and penguin species). Microbial life and the environmental conditions (the ocean currents, sea ice and weather) shape the chemical composition of the polar oceans, which is key to the composition of the atmosphere as well.

A pancake sea ice floe colored by micro-organisms (Bellingshausen Sea, Antarctica, Spring 2007).

These biological and chemical processes taking place in the sea ice zone are not well understood [1]. Their impact on our planet is thus hard to quantify. Understanding sea ice processes is particularly important in the context of anthropogenic changes. Because of global warming, sea ice, a significant part of our heritage from the Earth, is threatened. At the very least, there is a need to document and understand sea ice processes to realistically envision the consequences of its retreat.

State-of-the-art

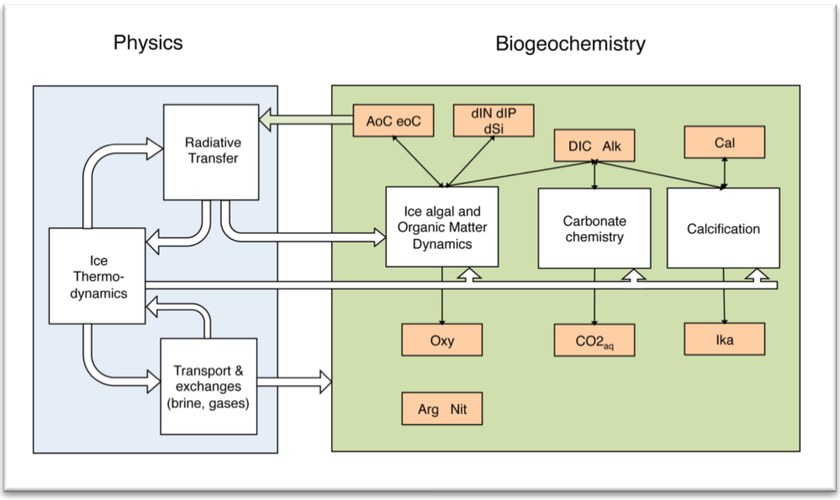
We started BISICLO from three initial premises:

1. There are just a few sea ice biogeochemical observations. In most cases, these can hardly be linked together or explained in simple terms.
2. The few observations available have not yet been synthesized, hence there is no large-scale vision of the system of interest.
3. Model representations of sea ice biogeochemistry are overly simple. Careful model representations, guided by model studies, have thus to be developed to progress.

Results

1. We are now able to estimate the budget of chemical elements in sea ice.

This is mainly enabled by a unique numerical tool: the first relatively complete sea ice biogeochemical process model with brine physics. This model, named LIM1D [2, 3] was enriched in the course of BISICLO.



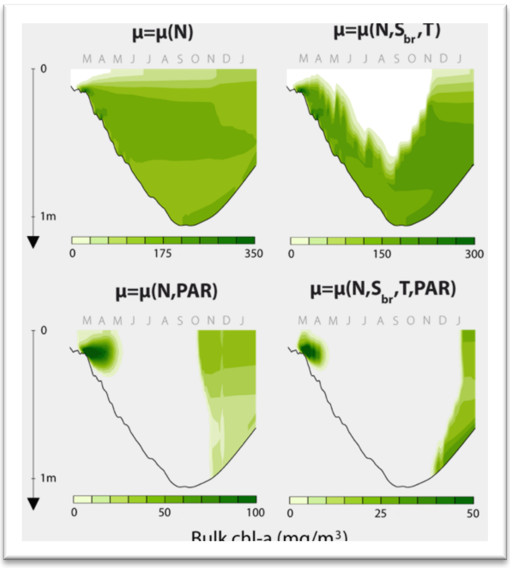
The conceptual representation of processes represented in the latest LIM1D version.

The model results are admittedly imperfect, but have proved very useful to scientific progresses on the dynamics of algae, carbon, oxygen, nutrients, and gases in sea ice. Let us mention our most important results.

- Fluid transport provides important limits to sea ice biogeochemical processes, by controlling the supply and release of chemical elements to / from sea ice [1-3].

- In this sense, ice algae are controlled by fluid transport processes, because they require nutrients, supplied by brine convection, but there are other important drivers. Our simulations illustrate how light, ice temperature and brine salinity shape the seasonality and vertical distribution of ice algae [3].

- LIM1D enabled the first estimate of carbon budget in sea ice [2]. Our simulations suggest a chiefly physically-driven carbon cycle in sea ice: carbon is supplied to the ice when ice forms and released to the ocean due by fluid transport and melt processes. Other processes (calcification, ice algae and ice-atmosphere exchanges) were found of lesser importance.



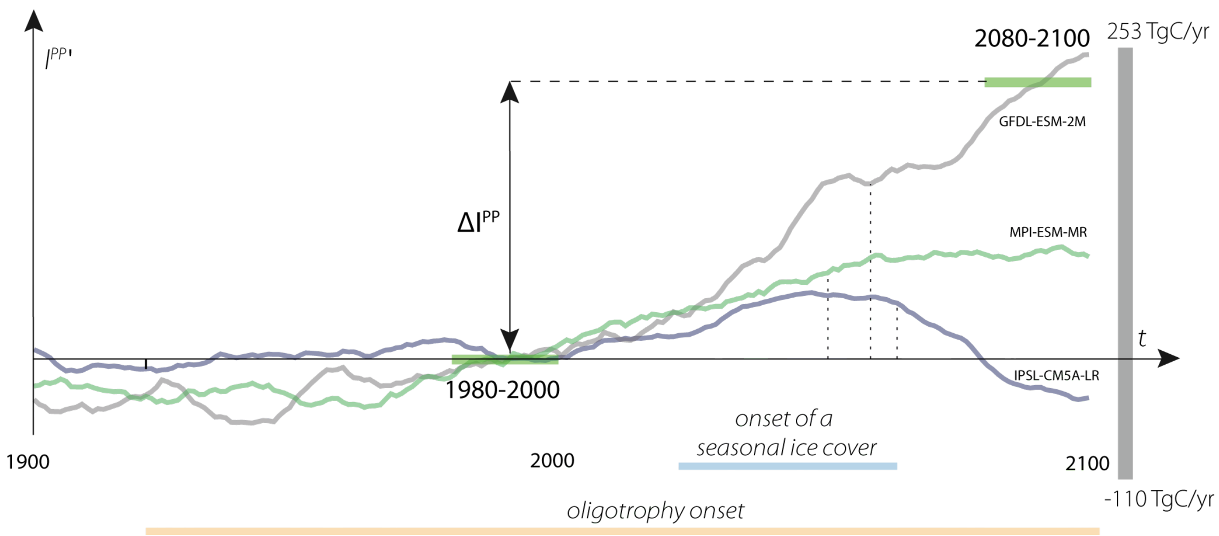
Idealized ice algal simulations ran with LIM1D [3] showing the role of the different drivers (nutrients-N, brine salinity-S_{br}, temperature- T and light- PAR) on ice algal chlorophyll-a.

2. Earth System Models suggest contrasted large scale impacts of sea ice on marine biogeochemistry.

To get a broader view on large-scale processes, we used Earth System models. Let us give two examples.

- Using a representation of the carbon cycle in sea ice reduced to physical processes in an Earth System Model [4], we questioned the ability of sea ice to favor deep ocean carbon sequestration, suggested as a powerful *sea ice carbon pump* for atmospheric CO_2. Our results suggest a most likely limited impact of the sea ice carbon pump on the carbon cycle, except in a few regions.

- We also questioned whether sea ice retreat will induce more or less Arctic phytoplankton, using the Earth System Models used for IPCC reports [5]. We found that all models predict an initial increase, but cannot yet give a reliable long-term answer, because of very large uncertainties in the nutrient stocks.



Increase or decrease of Arctic phytoplankton in 3 contrasted Earth System Models [5]

3. We have a large-scale observation view of most of the major biogeochemical elements in Antarctic sea ice.

Our second contribution was to promote the collection of historical sea ice biogeochemical observations, and the development of dedicated numerical analysis techniques. This was done in the framework of BEPSII, an international working group funded by the Scientific Committee for Oceanographic Research (see Special Feature of the Elementa Journal).

Based on these collections of typically >500 sea ice cores [6,7,8], we outperformed previous studies typically based on a few tenths of ice cores at most. We clearly showed that there are at least two periods of ice algal activity in Antarctic pack ice. That phosphates accumulate in sea ice. We also confirmed that Antarctic pack ice is very rich in iron. Observations also suggest that the nature of iron changes with the distance from the coast, in relation with continents and organic matter in sea ice. These basic findings & databases will be extremely useful for future Earth System Model studies. Analog studies will hopefully also be performed in the Arctic.

3. We suggest more efficient biogeochemical sampling methods in sea ice.

Current sea ice observations provide a limited view of sea ice biogeochemical processes. Optical methods can be calibrated on sea ice biogeochemical observations, which we are currently testing in the Storfjorden polynya in the Svalbard Archipelago. The ultimate goal is the development of automated and non-destructive sampling techniques, to retrieve chlorophyll from instrumented buoys or marine mammals.

Conclusions and Perspectives

Because sea ice observations are only a few, the sea ice environment must remain the focus of basic scientific investigations. Our favorite perspectives for sea ice biogeochemical studies are:

- the deployment of automated biogeochemical sensors in the sea ice zone;
- the continuation of combined observation-model process studies;
- the development of reasonable representations of sea ice biogeochemistry in Earth System Models
- the sound use of Earth System Model simulations;
- the start of observational and model biogeochemical sea ice studies at the regional scale.

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References (selected among 18 published contributions)

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