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USING THE ARCTIC ENVIRONMENT TEST BASIN TO STUDY THE DYNAMICS OF DISSOLVED ORGANIC MATTER IN SEA ICE

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This is a report from the *INTERICE 5* project that used the Arctic Environment Test Basin at HSVA from 21 May to 19 June 2012. The overarching aim was to investigate the physical and biological controls of dissolved organic matter incorporation into growing sea ice and the effect of melting once the ice had consolidated. Measurements were also made on the CO_2 fluxes at the ice surface in relation to the chemical and biological changes taking place in the ice. The Interice 5 team was a multidisciplinary group of glaciologists, chemists and microbiologists from Belgium, Denmark, Finland, Germany and U.K. They were able to build on the experiences of previous *INTERICE 2, 3 & 4* projects to maximize the opportunities from the facility. The preliminary results from the experiment will be presented, in the context of what is known about these processes from field campaigns.

INTRODUCTION

During the INTERICE 4 campaign of 2009 we ran a short-term experiment to investigate the effects of freezing on the dissolved organic matter (DOM) in the parent water (Aslam et al. 2012; Müller et al. 2013; Eronen-Rasimus et al. 2014). These experiments used a artificially produced source of DOM, derived from highly concentrated algal suspensions. At the same time as measuring the chemical constituents we measured bacterial activity, and diversity. Surprisingly the bacteria, originally, from seawater collected in the North Sea (when collected the water was at 15°C), thrived in the ice and under-ice waters (temperatures <0°C). The "success" of the bacterial growth - measured in terms of increased biomass and activity - was clearly influenced by the nature of organic matter supplied. The unfortunate part of this work was that due to logistical constraints there was only one week of experimentation, and it was therefore pertinent to extend and develop these experiments further.

Naturally the growth of bacteria in sea ice & underlying waters, will result in considerable changes to the CO_2 dynamics within the system, and therefore to the atmosphere above. The interaction between the marine and atmospheric carbon cycle is a critical factor in understanding climate change. The polar oceans play an important role in mediating the

Earth's climate, for example, by providing an appreciable part of the global carbon sink in their surface waters and up to 80% of reflection of solar radiation by polar ice. The interplay between biology and climate change is a major focus of current studies, but there have been very few studies that have tried to directly link biological activity with gas fluxes in and out of sea ice and ultimately the effects that such activity may have on carbon cycling and sequestration.

DOM is a term that includes many types of chemical compounds that are operationally defined as those that pass through a 0.2 µm filter. This complex group of chemical is the matter on which aquatic bacteria break down for growth. Some of the compounds in the DOM pool is more easily assimilated by bacteria, and as such are more reactive than others. The pool of oceanic DOM is dynamic, with the more reactive components cycling rapidly (in terms of minutes to days), while more inert constituents have longer residence times resulting in their accumulation in the water column (some for thousands of years). The DOM pool can be added to by algal and bacterial exudation, viral lysis, grazing and excretion by-products, and removed by microbial heterotrophic activity. However, much of the DOM in marine waters, especially in coastal waters is derived from terrestrial sources and input via the rivers.

Concurrent with the addition and removal of DOM from the oceanic pool is the production and use of dissolved gases such as carbon dioxide and oxygen. DOM, depending on its nature, can act as the initial substrate that supports trophic flows through polar food webs, including those communities found within sea-ice (including bacteria, protozoa, microalgae and small metazoans). The supply of DOM has been argued as a more important factor in regulating rates of bacterial growth in polar waters than temperature *per se*. The results of INTERICE 4 clearly showed that the quality and nature of DOM is a key factor in regulating bacterial species diversity and activity in the population of bacteria incorporated into the ice. Therefore we designed an experiment for INTERICE 5 to test this hypothesis. In turn we wanted to investigate how bacterial growth in ice influences the biogeochemistry of CO_2 in the ice and in turn how this affects the flux of CO_2 and O_2 into, or out from, the ice matrix.

Inter-hemispheric comparison of partial pressure of CO_2 (pCO_2) in sea ice has revealed that there is higher pCO_2 in the Arctic Ocean compared to the Southern Ocean. It has been suggested that such difference could be due to enhanced respiration in Arctic sea ice, as a consequence of higher loading of riverine-derived particulate and dissolved organic carbon (POC and DOC). Higher pCO_2 can potentially result in enhanced air-ice CO_2 fluxes (Geilfus et al. 2012; Zhou et al. 2013). Therefore we continuously monitored the air-ice CO_2 fluxes over both treatments to assess if the DOM enrichment does promotes CO_2 release to the atmosphere from the growing sea ice. The pCO_2 in sea ice depends on the following parameters or processes:

1) The initial CO_2 content in the water, as sea ice formed from the freezing of DOC-poor and DOC-rich seawater can have different CO_2 content.
2) The incorporation of CO_2 into the ice and its rejection during ice-growth, due to physical processes
3) After the incorporation into the ice, other processes can change the CO_2 content within the ice over its growth and decay
    a. Biological production and consumption of CO_2 through respiration and photosynthesis respect
    b. Carbonate precipitation and dilution
    c. CO_2 concentration and dilution

d. Ice permeability and CO_2 exchanges with the atmosphere and underlying water. This will result in CO_2 fluxes that can be measured.

INTERICE 5 EXPERIMENT

We designed the INTERICE 5 experiment to grow sea ice in two series of mesocosms (Figure 1; 1.2 m^3 experimental bags suspended in the main test basin): 1) Filled with seawater and 2) a mixture of seawater and river water collected from a northern Finnish river known to contain high amounts of DOM. We hypothesised that the ice formed in the tanks with DOC-rich seawater would have higher CO_2 content than that formed from natural seawater. At the same time as measuring the CO_2 dynamics in the system we also made detailed investigations of the bacterial growth and activity in the mesocosms as well as the chemical modifications to the DOM as it was incorporated into the ice. Because the experiments were performed in low light conditions, we effectively removed the primary producers and so no photosynthesis took place within the experiment. This meant that the only relevant biological activity in the ice and waters was due to bacteria.

The CO_2 fluxes into or out of the ice were measured using Licor Li8100 automated chambers (Figure 1) which are more commonly employed for soil respiration measurements. In parallel, we set up a chamber above the surface prior to seawater freezing. This allowed, for the first time, to capture air-ice CO_2 fluxes during the onset sea ice formation and all through the growing phase. Such measurements can hardly be carried out in the field.

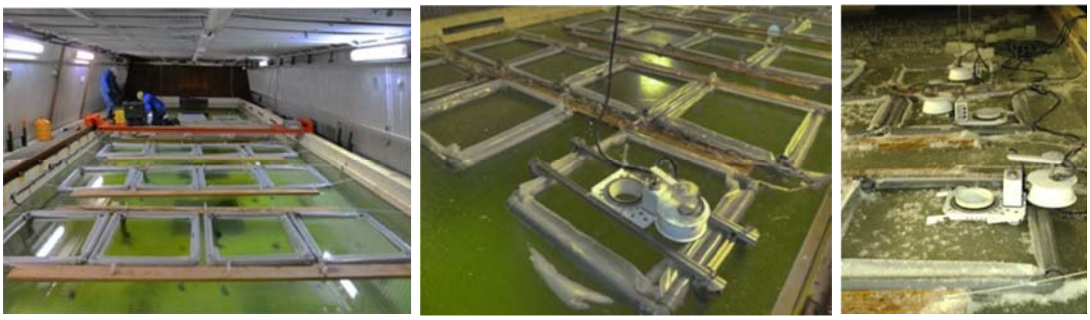

Figure 1. Experimental mesocosms prior to freezing (left). Air-ice CO_2 fluxes measurements over freezing seawater carried out with an automated chamber during freezing (middle) and after the ice had formed to provide solid platform for the chambers (right).

We maintained the air temperatures at -14 °C from day 0 to 14, and then the air temperature was increased to -1 °C to trigger a decay phase. This resulted in three distinct phases of the experiment: (1) An initial ice growth stage, from Day 1 to Day 5, where ice temperature decreased from the top (about -4.5 °C) to the bottom (about -1.8 °C, the freezing point of sea water). (2) An intermediate ice growth stage, from Day 5 to Day 15 where ice temperature still decreased from the top to the bottom, but surface temperature decreased to -6 °C. (3) During the ice melt stage, from Day 15 to Day 19, the temperature profiles became more homogeneous; the whole ice cover reached -1.8 °C. The ice thickness increased until day 16, reaching a maximum ice thickness of 24 cm, and then stabilized or slightly decreased towards the end of the experiment. The consequences of these physical developments on the chemical composition of the ice, gas fluxes, bacterial dynamics will be presented.

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