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Nutrients in melt ponds and snows on Arctic sea ice during 2014 sea ice camp

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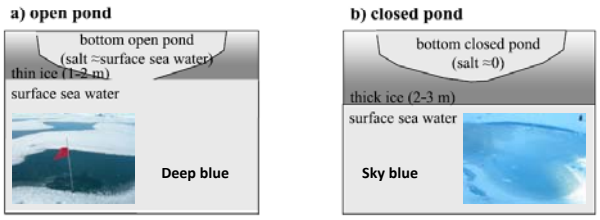
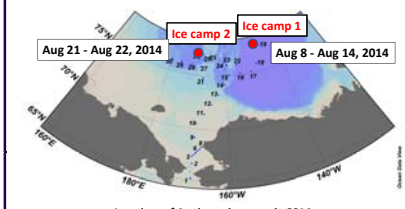
1. Introduction

- Melt ponds are the most distinctive summertime feature of Arctic sea ice, with estimated sea ice coverage ranging from 5 to 50% (Eicken et al., 1996).
- Melt ponds are pools of water that collect on the surface of sea ice due to surface melt driven by increased short-wave radiation absorption in summer, which is in contrast to Antarctic sea ice, where melt ponds are relatively rare.
- Melt ponds are largely classified into two types (Lee et al., 2012, JGR).

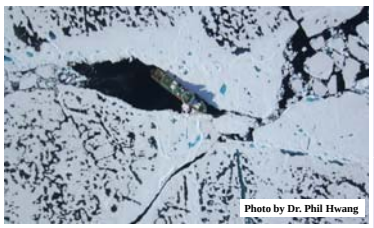


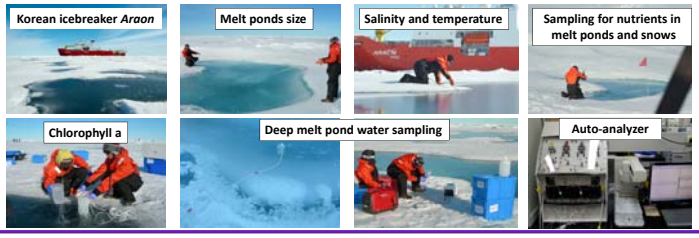
- Although considerable effort has been devoted to investigate physical processes (e.g., heat fluxes) and feedbacks of melt ponds (e.g., albedo), relatively little known about biogeochemical properties of melt ponds.
- Here, we report that distributions of nutrients (NH_4, NO_2+NO_3, PO_4 and SiO_2) in melt ponds and snows on Arctic sea ice.

2. Sampling and chemical analysis

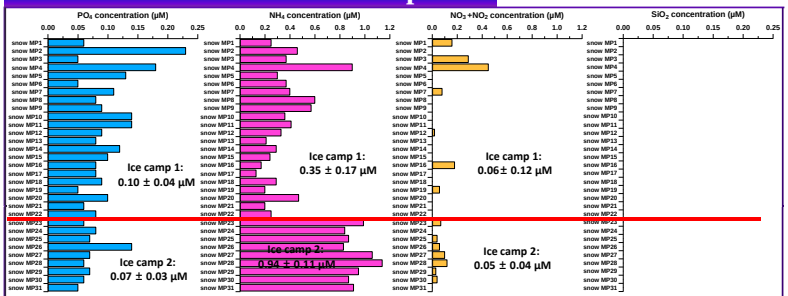


Locations of Arctic sea ice camp in 2014





3. Nutrients in snows near melt ponds



- PO_4 and NH_4 were dominant nutrient species in snows collected near melt ponds.
- However, SiO_2 was not detected in snows, suggesting that there is no atmospheric source of water-soluble SiO_2, and that SiO_2 could be a indicator to distinguish between atmospheric and seawater-derived nutrients.
- Compared to NH_4, NO_3+NO_2 concentration was one order of magnitude lower due to NO_3 and NO_2 losses in snows by photolysis.

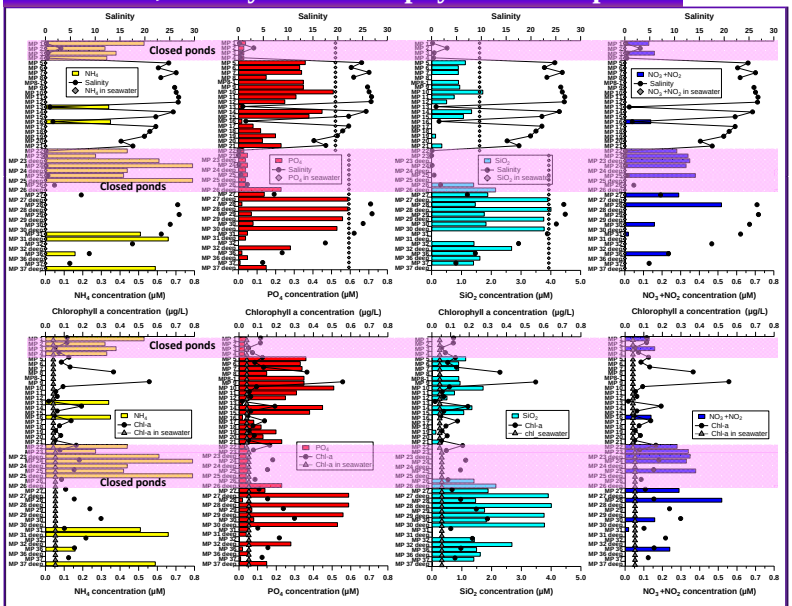
Why is NO_3 concentration in snow so low?

Nitrate photolysis

- $NO_3^- + hv \rightarrow NO_{2(g)} + O^-$
- $NO_2^- + hv \rightarrow NO_{(g)} + O^-$

(Domine and Shepson, 2002)

4. Nutrients, salinity and chlorophyll a in melt ponds



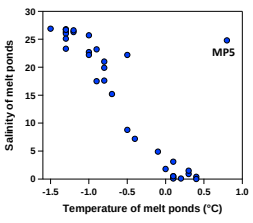
- In the closed melt ponds (salinity ≈ zero), NH_4 and NO_3+NO_2 showed high concentrations, whereas PO_4 concentrations were low and SiO_2 was not detected.
- In contrast, in the opened ponds (salinity ≈ surface seawater), both nitrogen species were depleted as those in surface seawater, while PO_4 and SiO_2 concentrations were as high as those in surface seawater.
- Likewise SiO_2 in snows, SiO_2 in the closed ponds was not detected. From these results, it was suggested that not only salinity, but also nitrogen species, especially NH_4 and SiO_2 can be used as an indicator to distinguish between the closed and opened ponds, and that high NH_4 concentrations in the closed ponds were derived from snows.
- In addition, all nutrients species concentrations in surface and deep waters of the opened ponds showed large differences, suggesting that the melt pond waters were strongly stratified.
- Although no statistically significant relationships were found between chlorophyll a and nutrients variation trends, chlorophyll a concentrations in both types of melt ponds were higher than those in surface seawater, implying that additional nutrients supplied to the melt ponds from snows might contribute to more high biological activities in the melt ponds.

5. Statistics of melt ponds and snows

Pearson correlations

	PO_4	NO_3	NH_4	SiO_2	Temp	Salinity	Chl-a	Snow PO_4	Snow NO_3	Snow NH_4
PO_4	1									
NO_3	-.419	1								
NH_4	-.500	.426	1							
SiO_2	.316	-.004	-.591	1						
Temp	-.449	.269	.564	-.430	1					
Salinity	.655	-.391	-.695	.426	-.834	1				
Chl-a	.096	.027	-.154	.264	-.326	.306	1			
Snow PO_4	.188	-.375	-.079	.059	.190	-.066	-.077	1		
Snow NO_3	-.372	.178	.278	-.159	.374	-.445	-.217	.088	1	
Snow NH_4	-.379	.544	.128	.315	-.051	-.108	.266	-.071	.218	1

	PO_4 (μM)	$NO2+NO_3$ (μM)	NH_4 (μM)	SiO_2 (μM)	Temp (°C)	Salinity	Chl-a (μg/L)
All MP	0.15±0.15	0.09±0.14	0.14±0.22	0.66±0.70	-0.54±0.66	14.6±11.0	0.14±0.11
Opened MP	0.20±0.15	0.05±0.13	0.03±0.11	0.92±0.67	-0.88±0.51	21.2±6.53	0.15±0.12
Closed MP	0.04±0.01	0.16±0.15	0.38±0.19	0.13±0.43	0.19±0.14	0.83±0.95	0.10±0.05
Snow near closed MP	0.10±0.06	0.11±0.15	0.56±0.33				
All snow	0.09±0.04	0.06±0.09	0.52±0.31				



- A strong inverse relationship was observed between salinity and temperature of melt ponds, showing that temperatures of the closed ponds are higher than those of opened ponds.
- PO_4 and SiO_2 concentrations showed significant positive relationships with salinity, suggesting that seawater is a major source of these two species.
- Considering that NO_2+NO_3 and NH_4 concentrations in seawater were totally depleted, negative relationships between N species and salinity indicated that most N species were derived from snows.

6. Summary

- To examine chemical components of nutrients (NH_4, NO_2+NO_3, PO_4 and SiO_2) in different types of melt ponds (i.e., closed and opened ponds) and differences of nutrients in between melt ponds and snows near melt ponds, a total of 36 melt ponds and snow samples were collected at two different sea ice stations located in northern part of the Chukchi Sea during the ARA05B cruise aboard Korean icebreaker *Araon*.
- Our results suggest that NH_4 and SiO_2 can be used as an indicator to distinguish between the closed and opened ponds, and that high NH_4 concentrations in the closed ponds were derived from snows.
- During 2nd ice camp, it was clearly observed by the differences of nutrients concentrations between surface and deep waters that melt pond waters were strongly stratified.
- Considering that the Arctic Ocean is currently experiencing rapid environmental change, such as warming and decreases in sea ice concentration and thickness, the role of melt ponds could be important.