Acidification of the Arctic Ocean, the basis for *AMAP Arctic Ocean Acidification case studies*

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With contributions from
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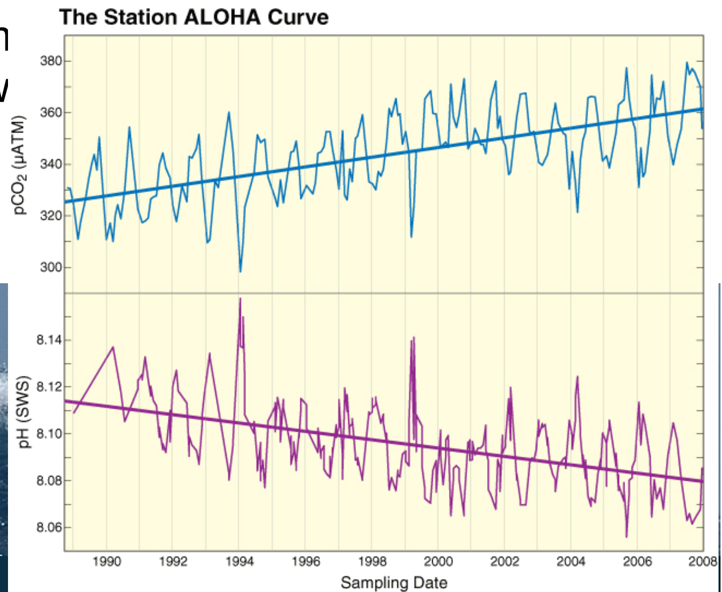
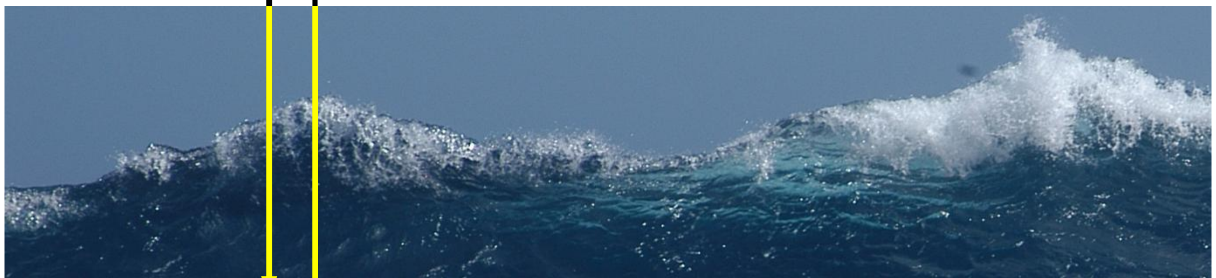


CO_2



$CO_2(g) \leftrightarrow CO_2(aq)$

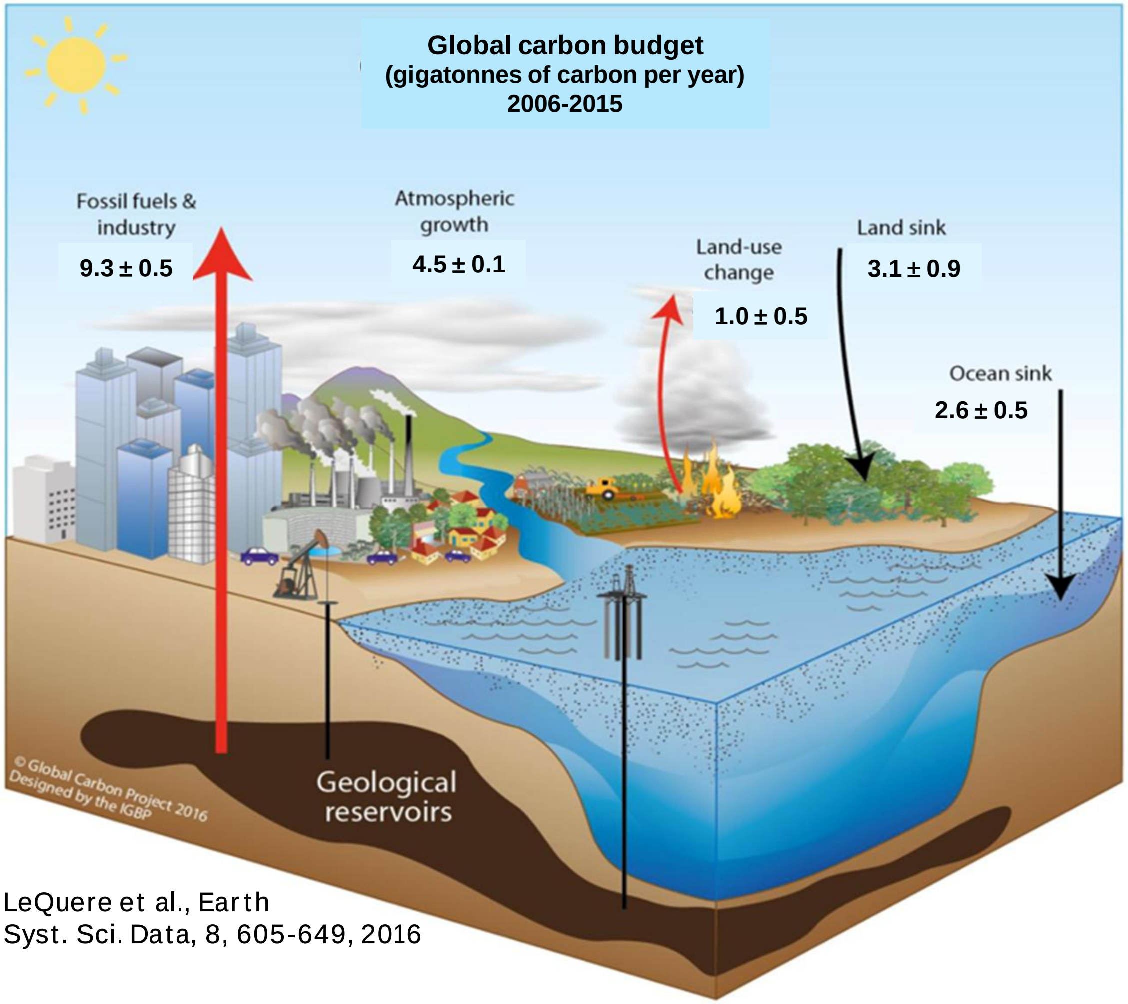
$CO_2(aq) + H_2O \leftrightarrow H_2CO_3$

$H_2CO_3 \leftrightarrow H^+ + HCO_3^-$

$HCO_3^- \leftrightarrow H^+ + CO_3^{2-}$

- CO_2 dissolves in seawater and reacts with water

Dominating form (HCO_3^-)



LeQuere et al., Earth Syst. Sci. Data, 8, 605-649, 2016

Approximately 26% of the CO_2 released from fossil-fuels is absorbed by the oceans, leading to ocean acidification.

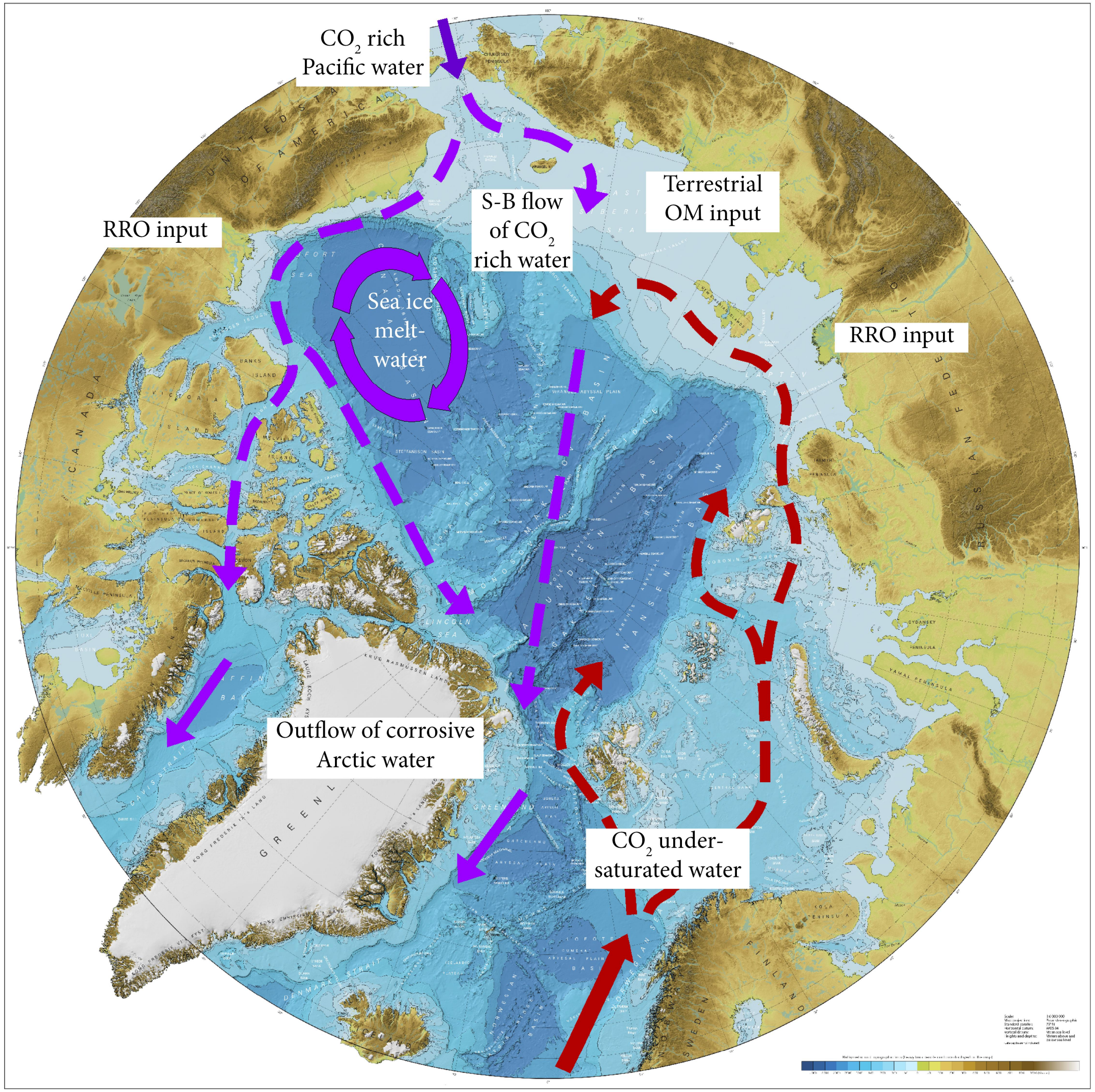
Also the ocean warming accounts for more than 90% of the total global energy change inventory from 1971 to 2010 (IPCC AR5).

The present AMAP Arctic Ocean Acidification assessment includes the case studies

1. Socioeconomic effects of ocean acidification on kelp and urchin harvest: A case study from North Norway
2. Ocean services of the Barents Sea
3. Greenland shrimp
4. Risk Assessment and Economic Impacts of Ocean Acidification on Alaska's Fishery Sector
5. Linking ocean acidification and other climate change effects on marine ecosystems to socio-economic impacts in the Canadian Arctic

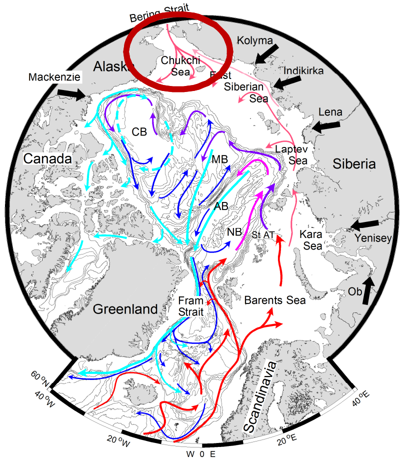
And they all rely on the marine climate of the region, which is determined by both climate and biogeochemical processes in the ocean

Summary



CO_2 rich Pacific water
S-B flow of CO_2 rich water
Terrestrial OM input
RRO input
Sea ice melt-water
RRO input
Outflow of corrosive Arctic water
CO_2 under-saturated water

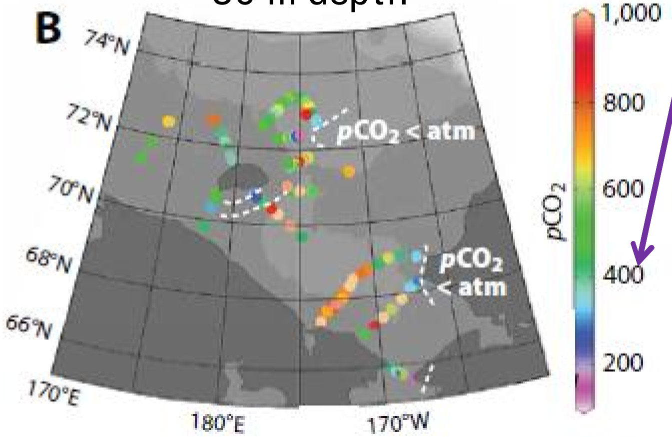
Inflow from the Pacific



Atmospheric level ~400 µatm

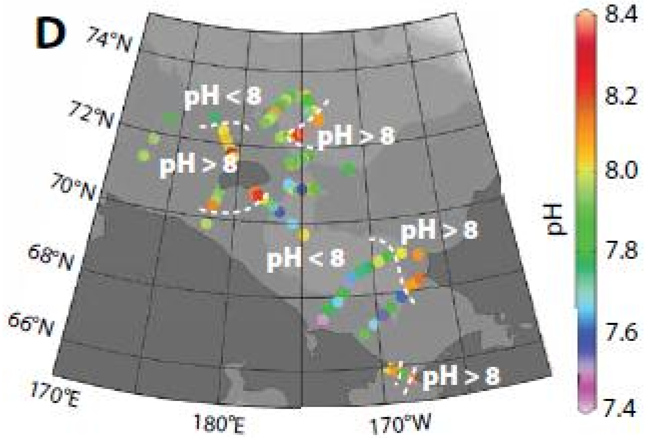
NEXT TO SEAFLOOR

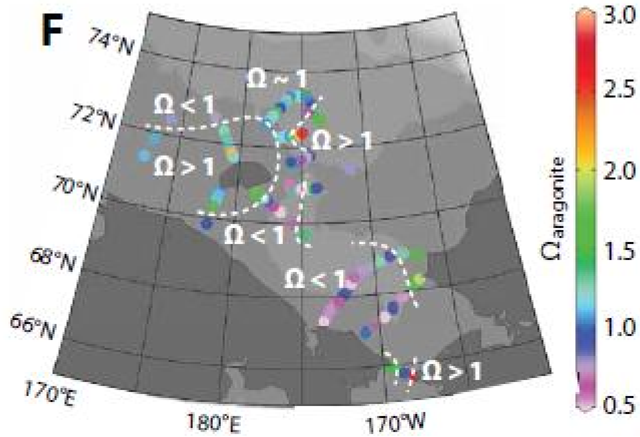
~50 m depth



The bottom water entering through the Chukchi Sea is largely supersaturated with respect to CO_2, a result of organic matter mineralization. One result being undersaturation with respect to calcium carbonate in the form of aragonite.

$\Omega^{aragonite} = ([Ca^{2+}]\ [CO_3^{2-}])\ /\ K_{sp}$, where K_{sp} is the chemical solubility product





Mostly $\Omega^{aragonite} < 1$,

$\Rightarrow$ $CaCO_3$ undersaturated waters

Bates, N.R. 2015. Assessing ocean acidification variability in the Pacific-Arctic region as part of the Russian-American Long-term Census of the Arctic. Oceanography 28(3):36–45, http://dx.doi.org/10.5670/oceanog.2015.56.

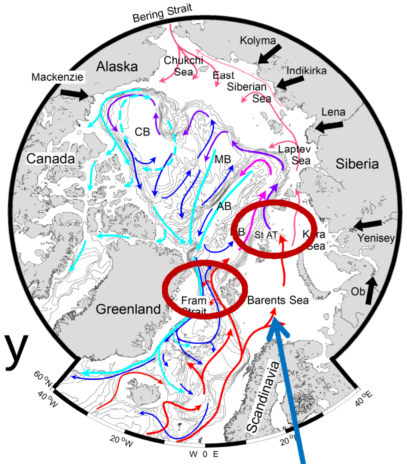
Inflow from the Atlantic

Is mainly undersaturated in CO_2 as it;

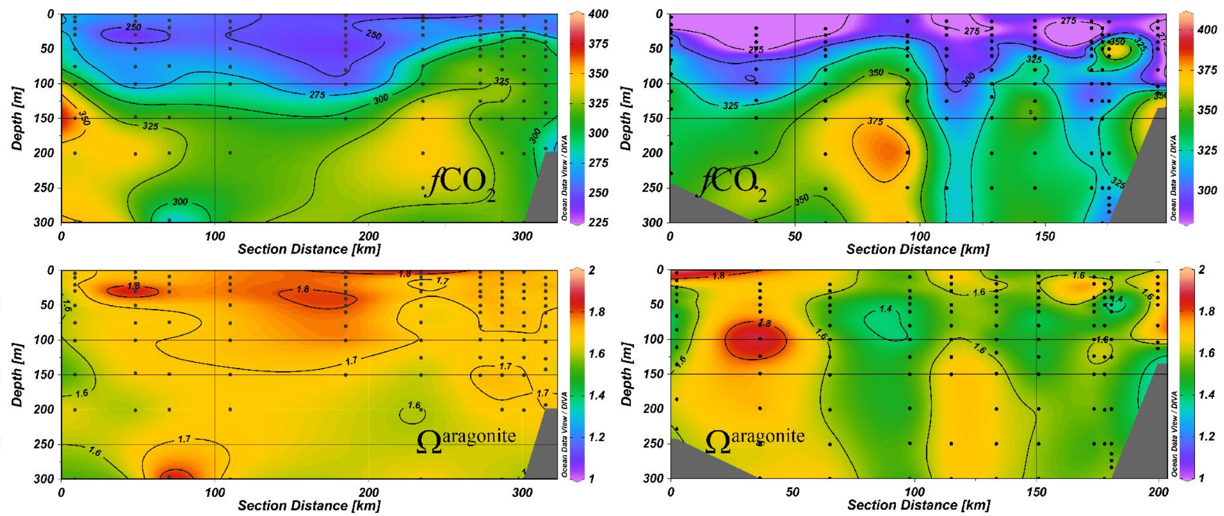
i) has been in contact with the atmosphere for a long time,

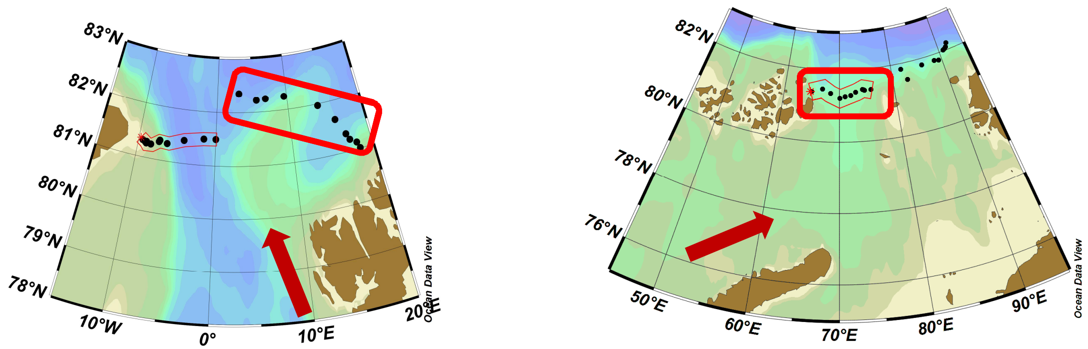
ii) cooled by the atmosphere and thus increased its solubility

iii) exposed to primary production that consume CO_2



Barents Sea bottom depth typically several 100 meters





Consequently $\Omega^{aragonite}$ is > 1, and the water is supersaturated with respect to aragonite

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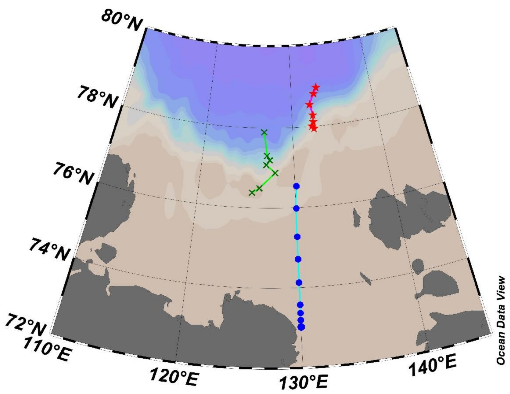
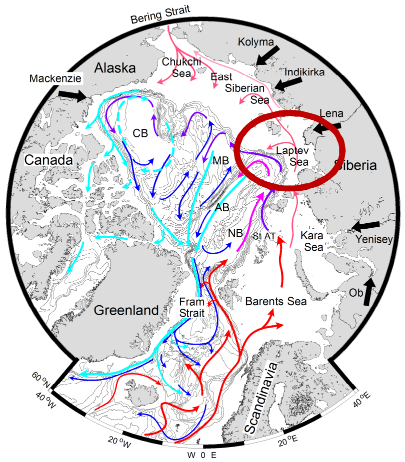
At the Laptev Sea

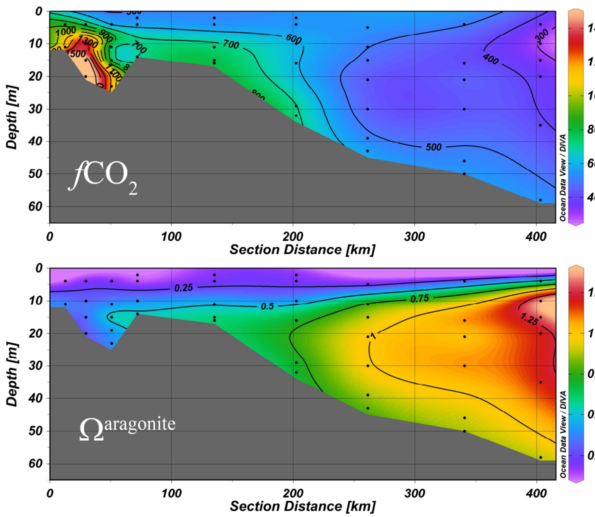


Here we see;

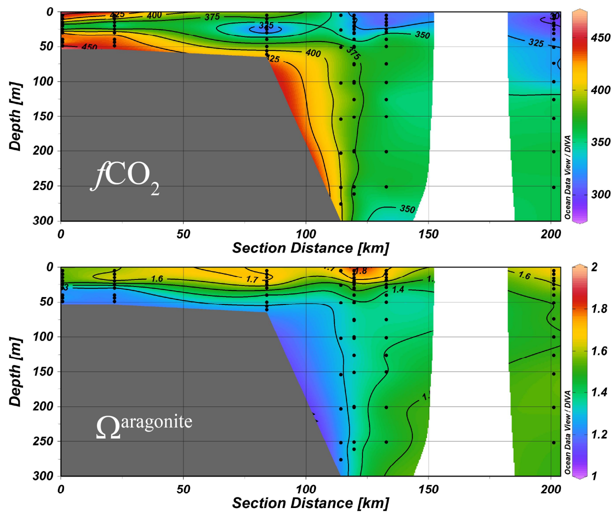
i) The impact by rivers giving high pCO_2 both in the low salinity river plume and in the bottom water when organic matter decays

ii) Variability in time

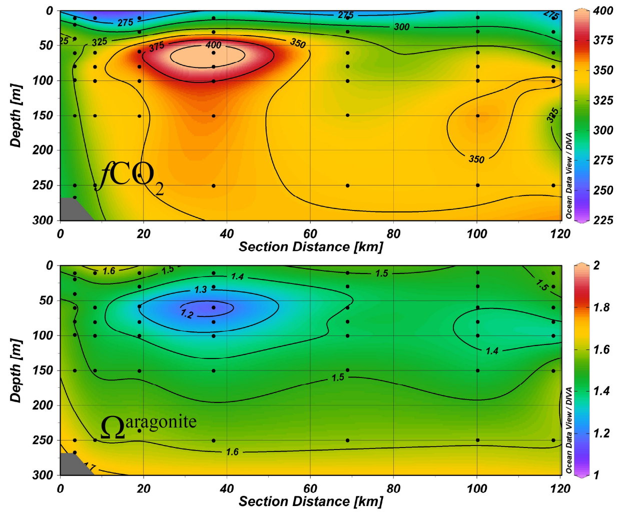




2008



2014



1996

Lets move eastward

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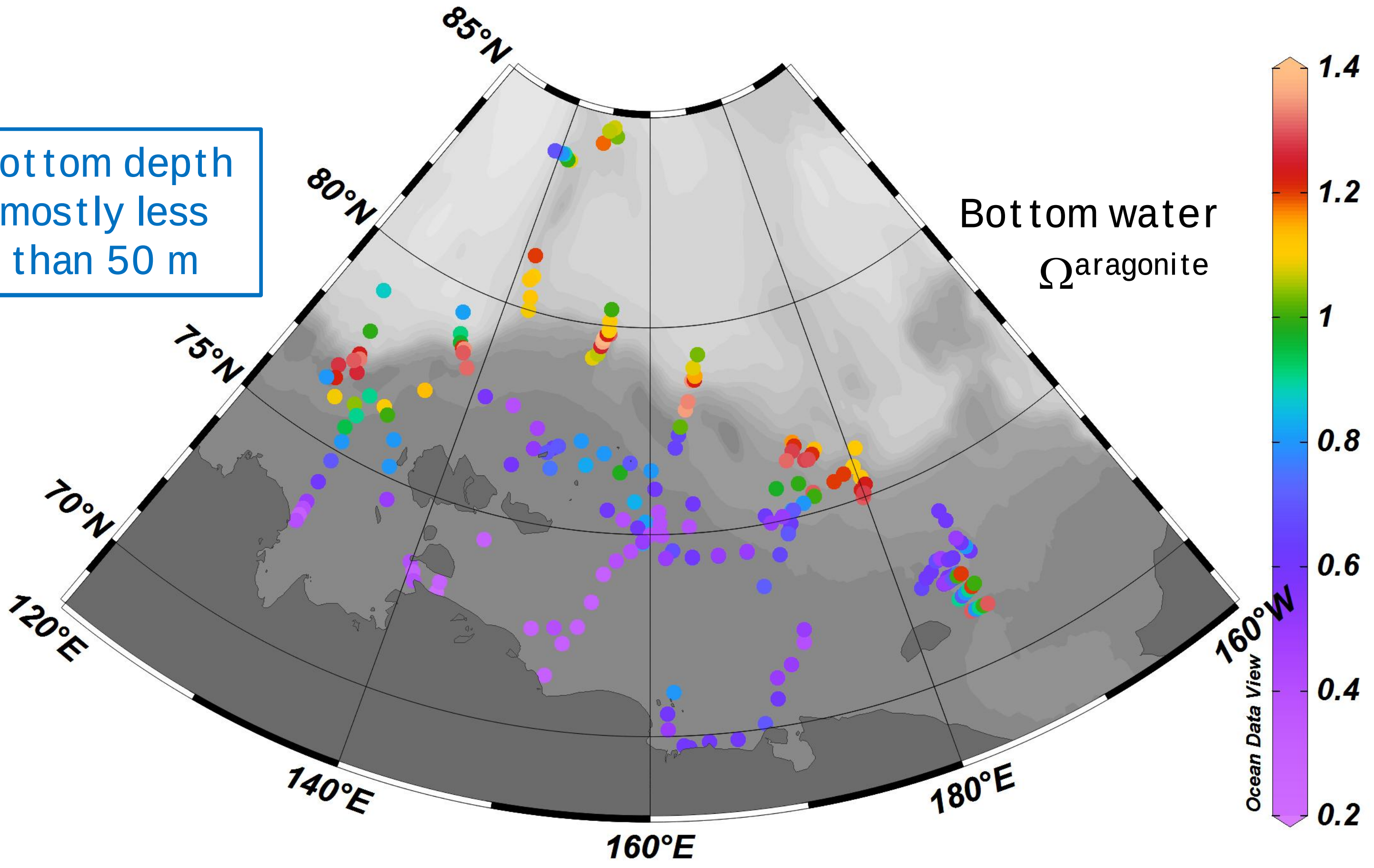
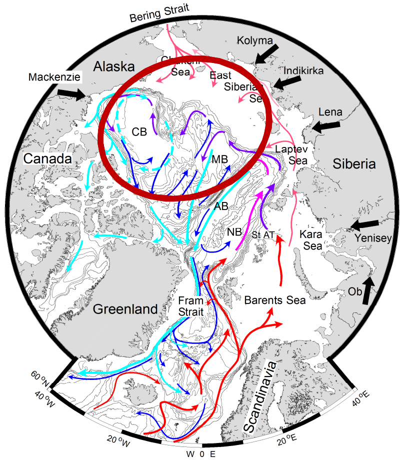
Siberian shelf seas

The importance of organic matter decay at the sediment surface gives a strong undersaturation with respect to aragonite throughout most of Siberian shelf seas

Bottom depth mostly less than 50 m



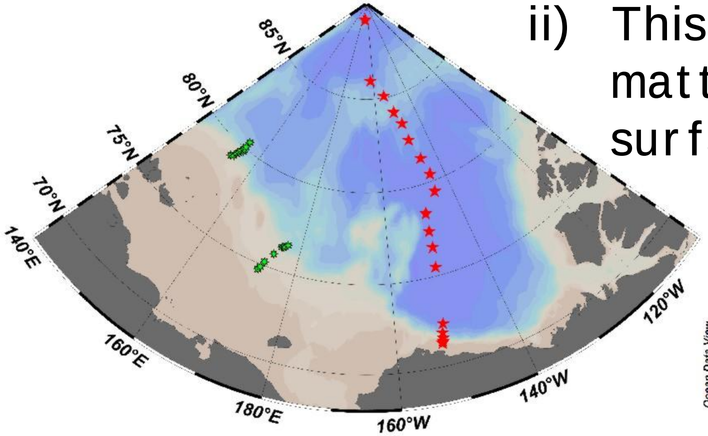
East Siberian Sea and Canadian Basin

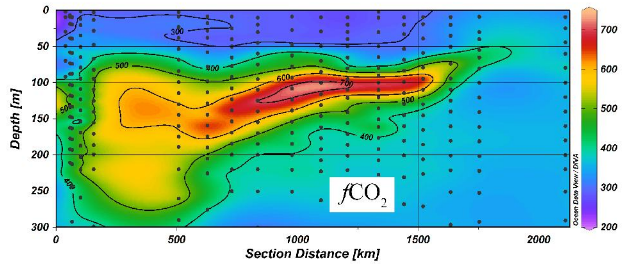


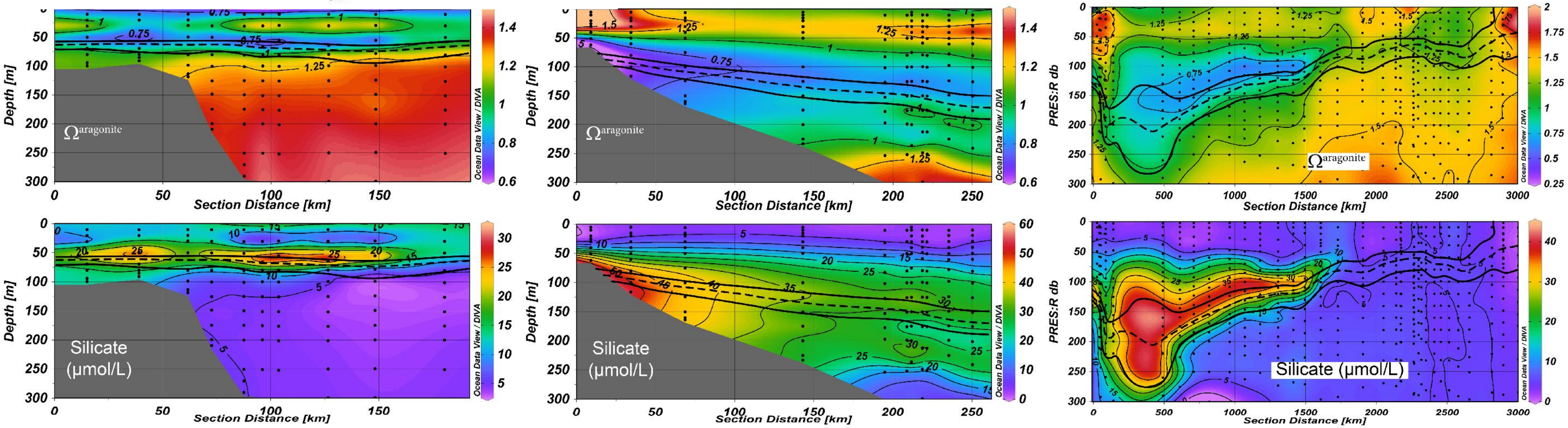
i) A bottom water of low Ω^{arag} and high silicate is formed in the ESS and flow out into the Beaufort Gyre

ii) This signature is typical of organic matter decay at the sediment surface

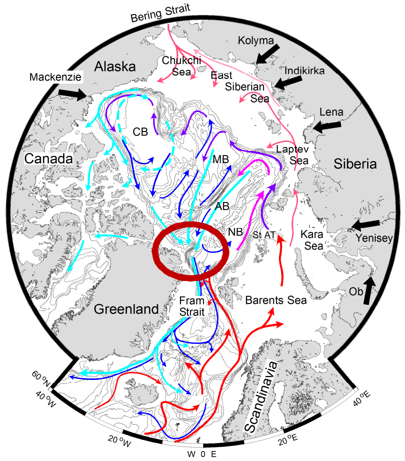
iii) The nutrient rich water has a salinity of 33-34

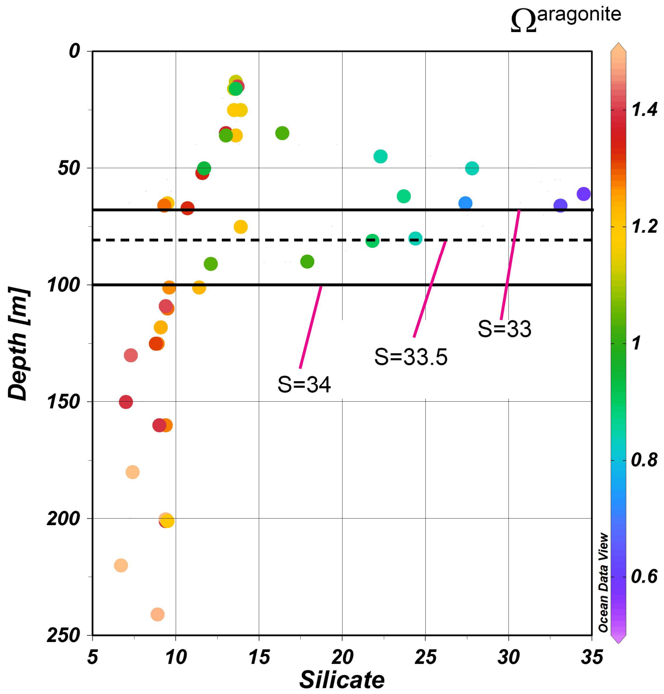


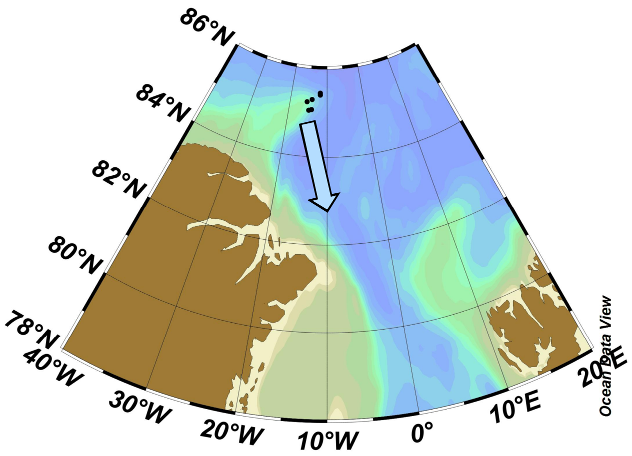




The outflow region







The high silicate, low Ω^{arag} water of the Beaufort Gyre was clearly seen north of Greenland, at the Morris Jesup Rise, in 1991. Here the salinity is somewhat lower.

This water is on its way out of the Arctic Ocean.

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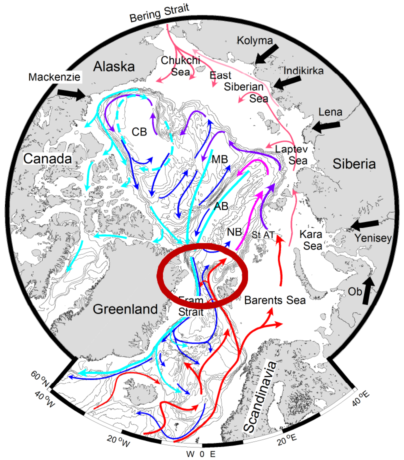
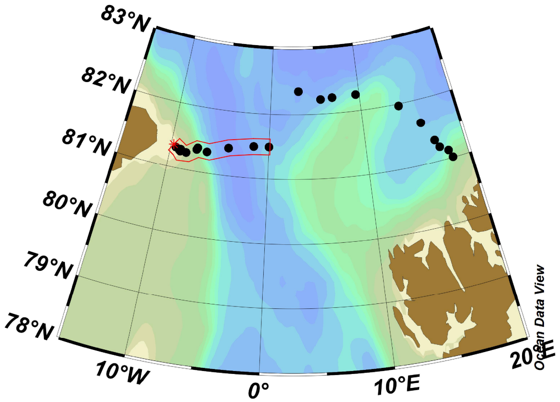
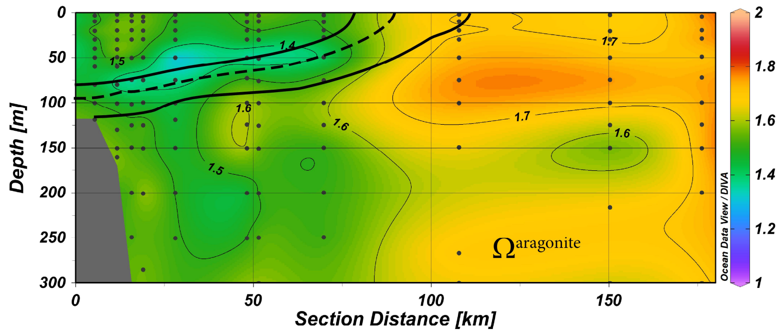
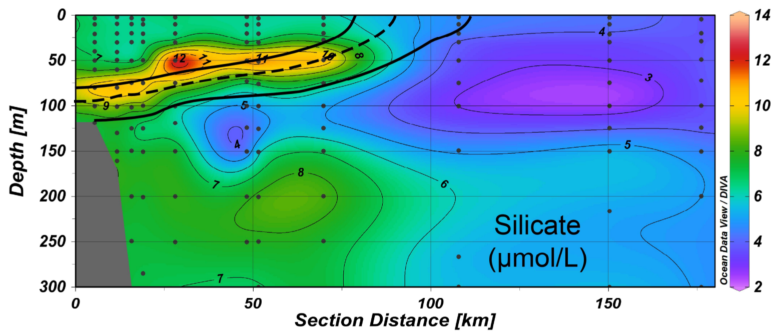
The outflow region, Fram Strait









Further south, in Fram Strait, the signature was also seen in the East Greenland Current in May 2002, even if it was less pronounced.

It is known that depending on the atmospheric pressure field the dominating outflow from the Beaufort Gyre either go east or west of Greenland

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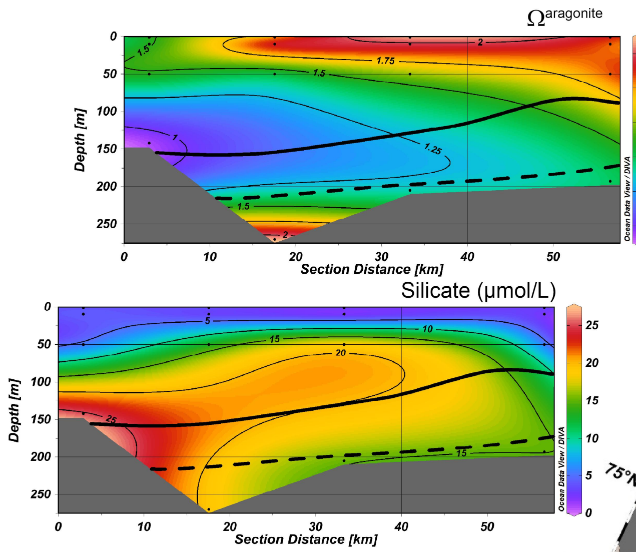
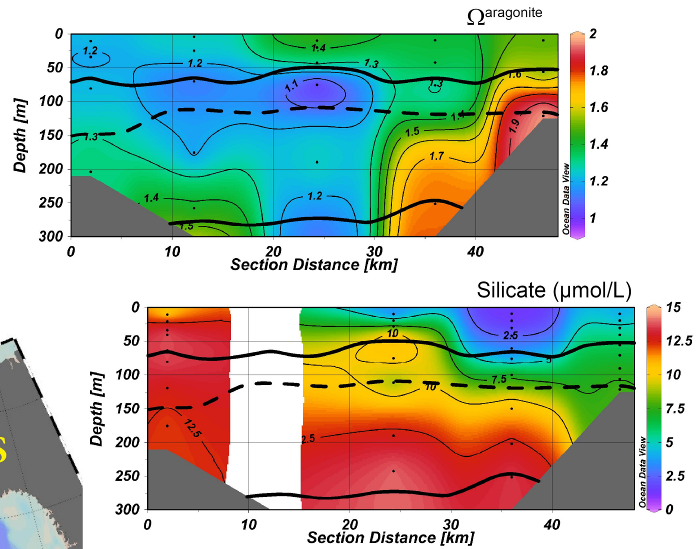
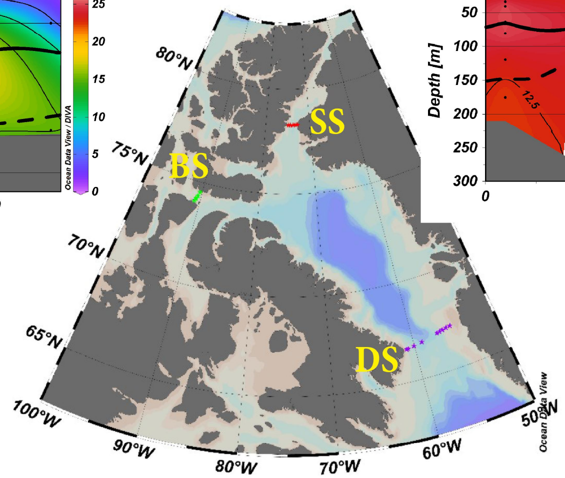
The outflow region, Canadian Archipelago

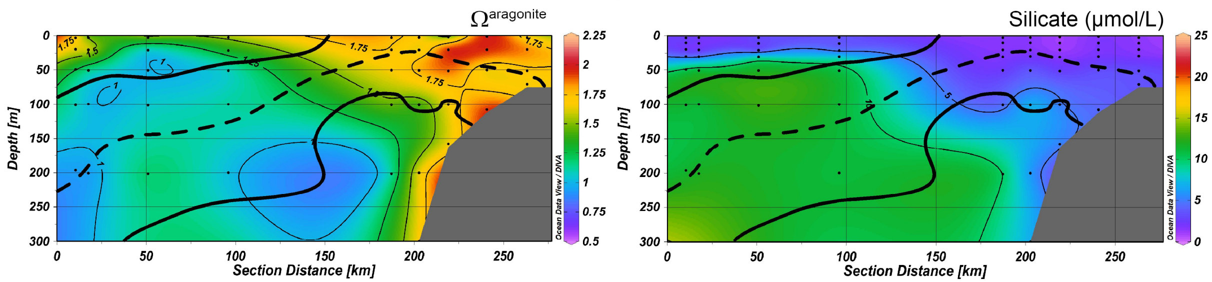






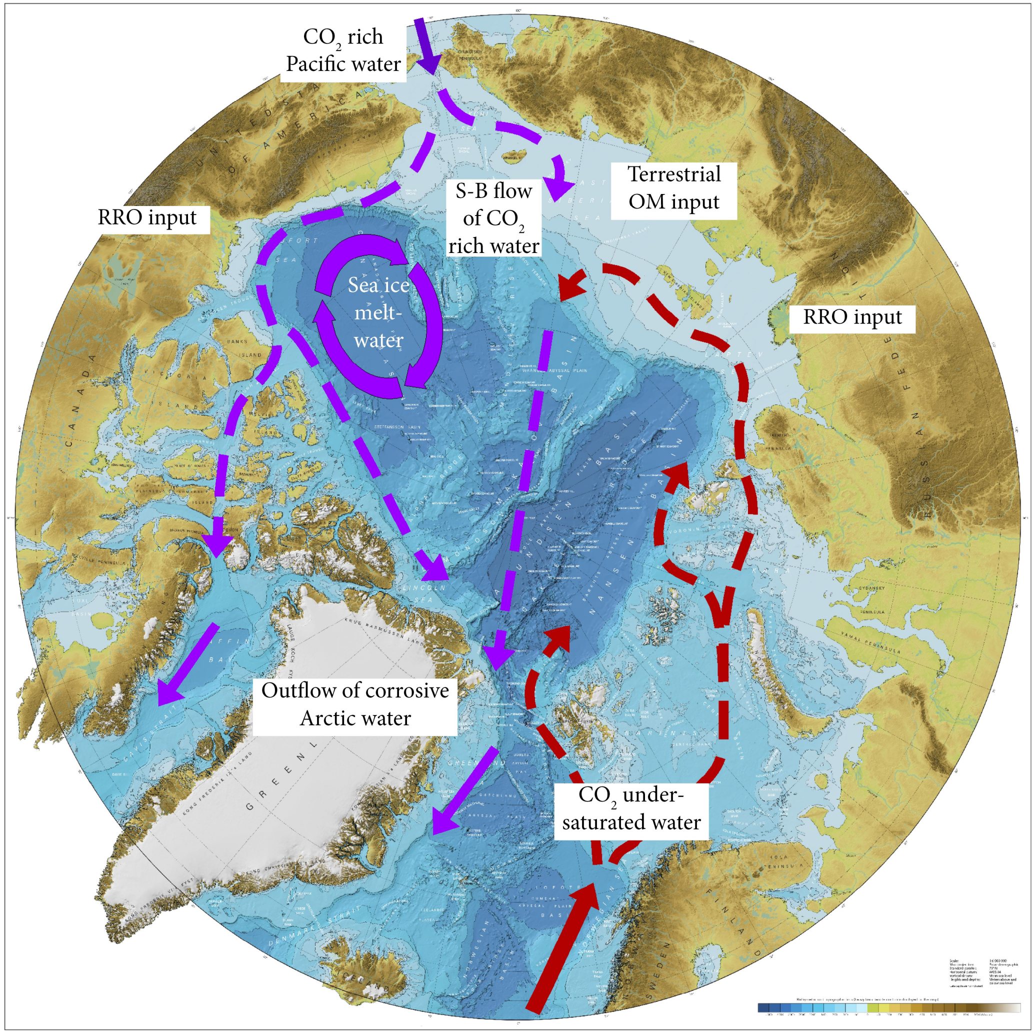
In Barrow Strait high silicate low Ω^{arag} water is observed to the south at S~33

In Smith Sound the situation is similar, as well as in Davis Strait



Azetsu-Scott, K., et al. (2010), Calcium carbonate saturation states in the waters of the Canadian Arctic Archipelago and the Labrador Sea, J. Geophys. Res., 115, C11021, doi:10.1029/2009JC005917.

Conclusions 1

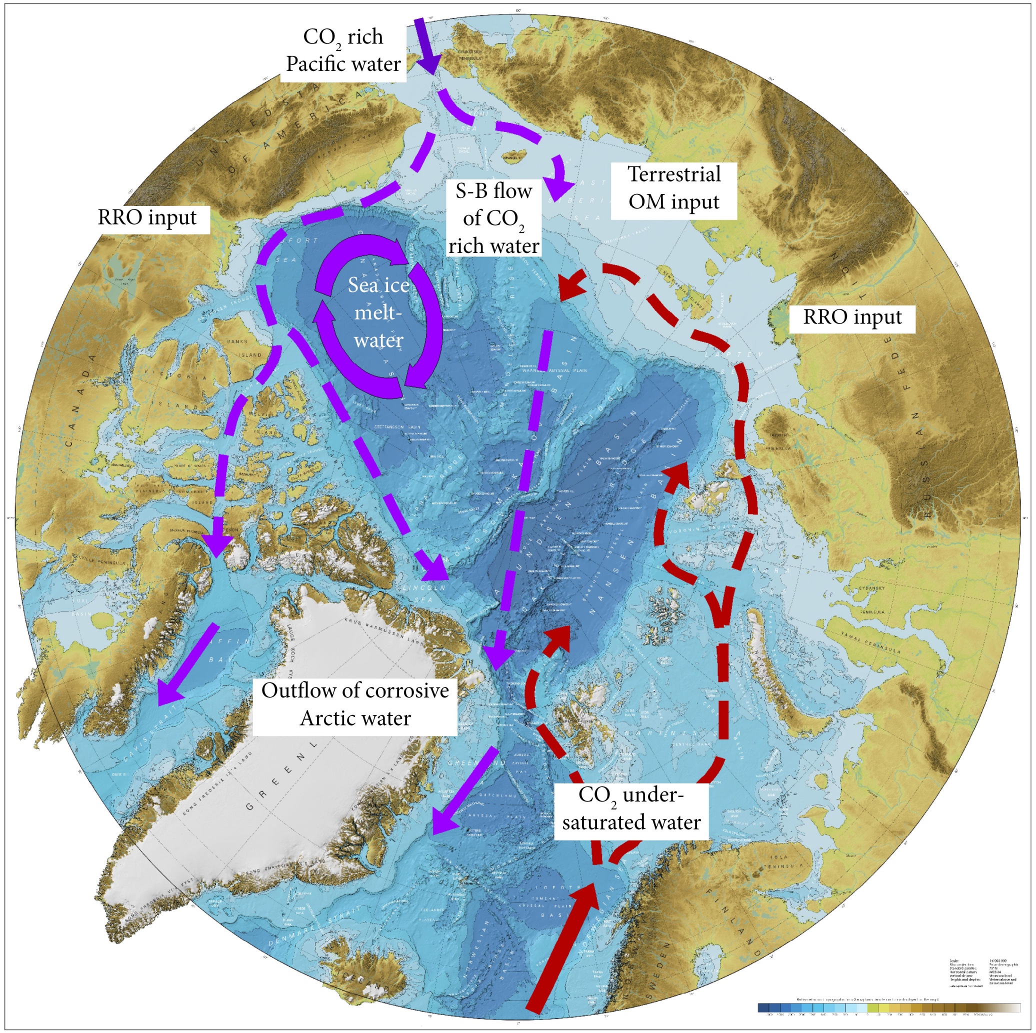


In the Arctic Ocean large volumes of water with high pCO_2 is formed on the Siberian shelves, a water that is exported to the North Atlantic both to the west and east of Greenland.

The pCO_2 is substantially higher than the atmospheric values, even higher than what is projected for the year 2100, and is caused by decay of organic matter.

There is a risk that with warmer climate the thawing of permafrost and increasing microbial activity will lead to more supply of organic matter and thus even higher pCO_2.

Conclusions 2



The resulting undersaturation of upper waters with respect to calcium carbonate is amplified by addition of freshwater from river runoff and sea ice melt, conditions that also are increasing with climate change.

Since the shelf regions of the North Atlantic flooded by the Arctic Ocean outflows are both biologically active and support important commercial fisheries, continued monitoring of the changes in the OA states and investigations of biological responses to ocean acidification in this area are urgently needed.