Rapid Changes in Arctic Biogeochemistry and Marine Ecosystems:

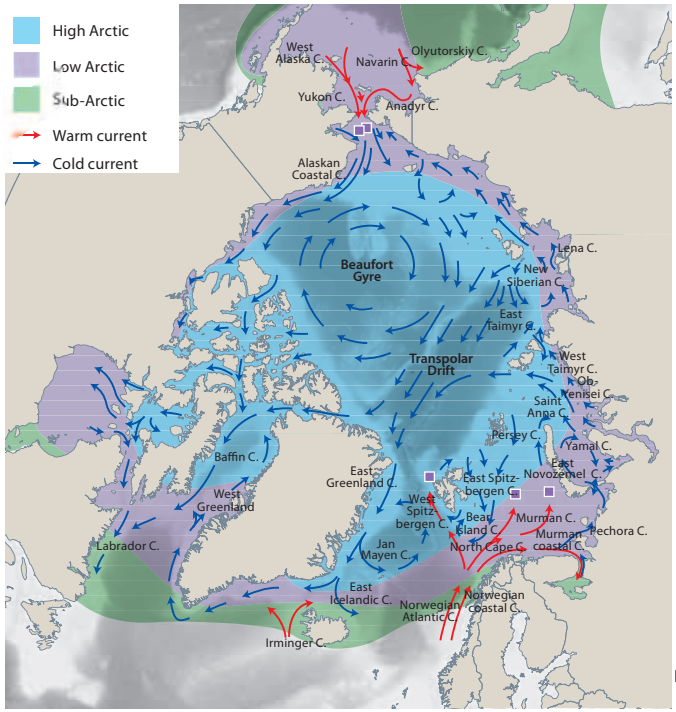
Biogeochemistry and CO_2 Fluxes

A Planning Workshop for an International Research Program on the Coupled North Atlantic-Arctic System
April 14th – 16th, 2014

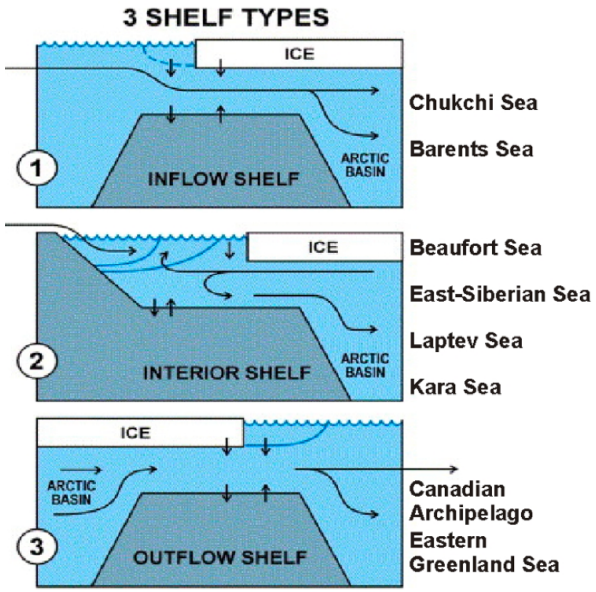
Jeremy T. Mathis
Pacific Marine Environmental Lab

Contributors: Rik Wanninkhof, Galen McKinley, Wiley Evans and Jessica Cross

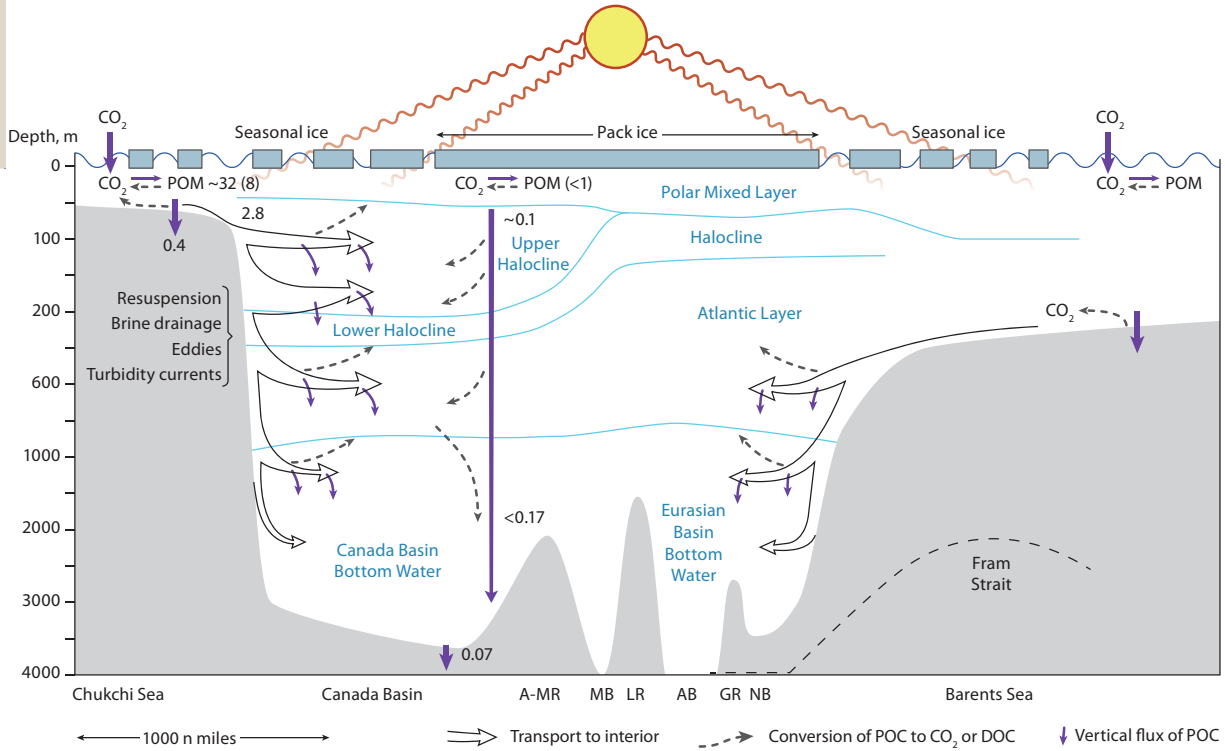
Biogeochemical Modifications and Drivers of Sea-Air Fluxes



Reductions in sea ice extent and thickness are driving a rapid transition in arctic biogeochemistry leading to enhanced productivity, changes in sea-air fluxes of CO_2, increased upwelling, and a broad expansion of waters that are undersaturated in carbonate minerals.



Carmack and Wassmann (2006)

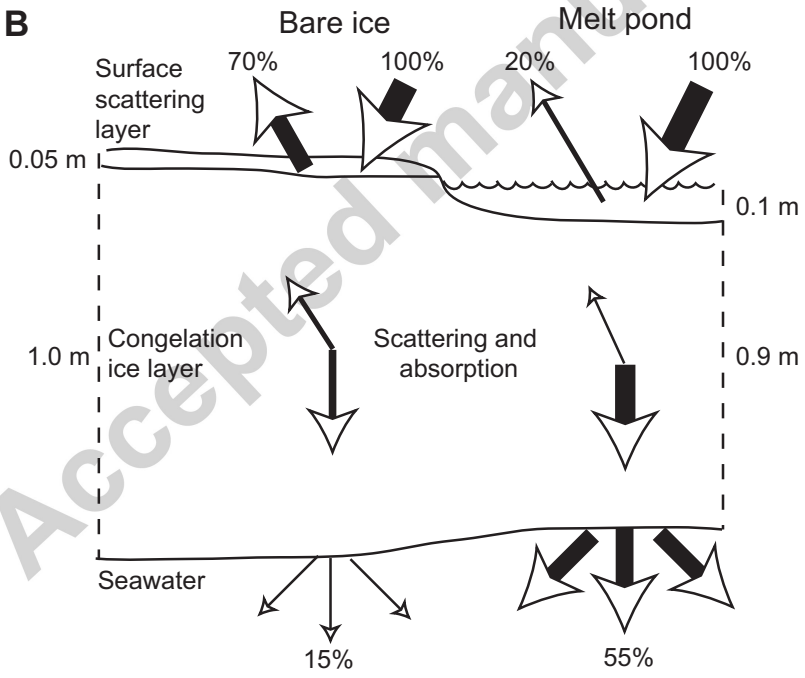


AMAP Assessment 2013: Arctic Ocean Acidification

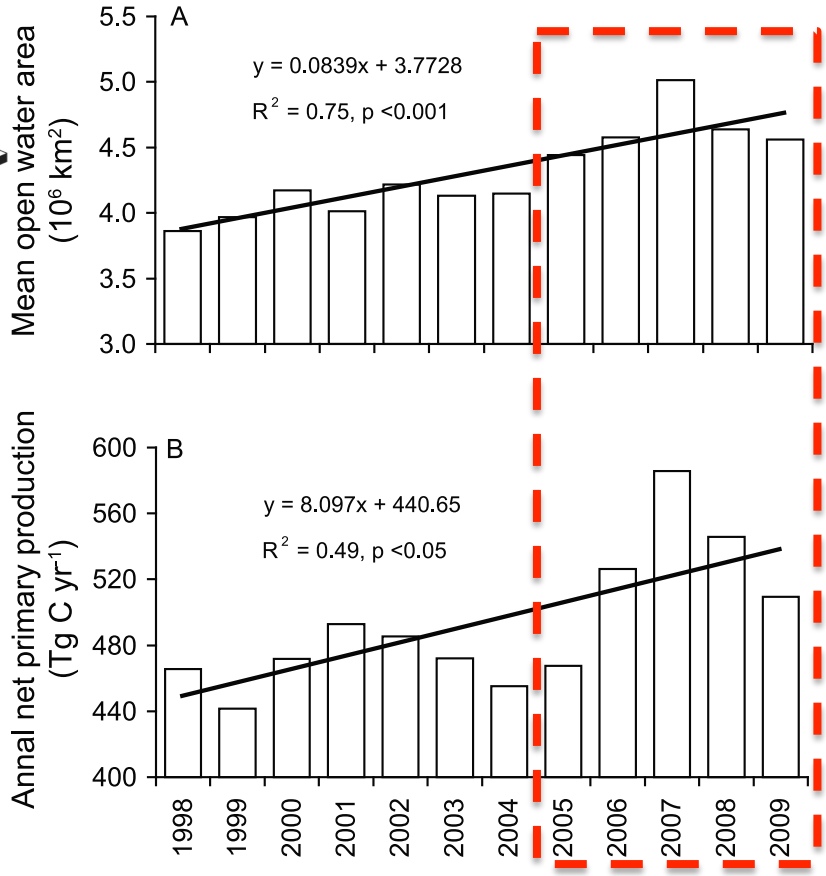
Secular Trends in Arctic Ocean Primary Production

A regime shift may have occurred in primary production across the Arctic due to thinning ice, not just enhanced ice melt.

Regional distribution of POC export fluxes (mmol C m^{-2} d^{-1}) in the Arctic Ocean determined using sediment traps (in Mathis et al., 2014)

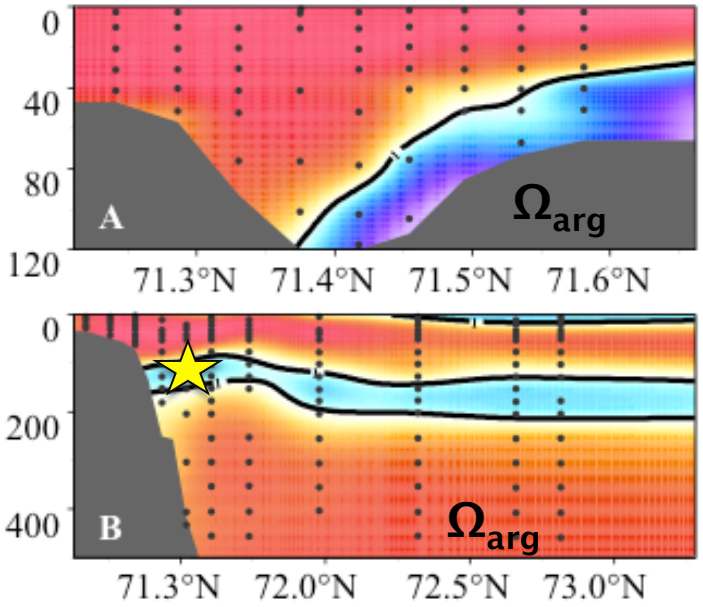


Arrigo et al., 2012; Arrigo et al., in press

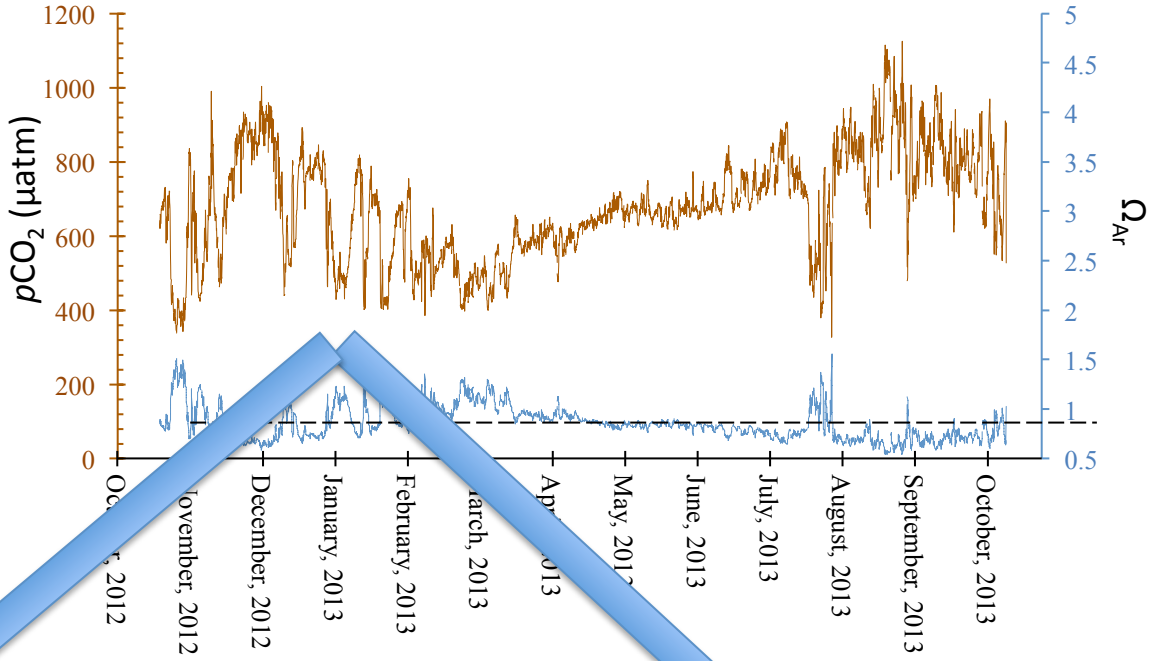


Arrigo and van Dijken, 2011

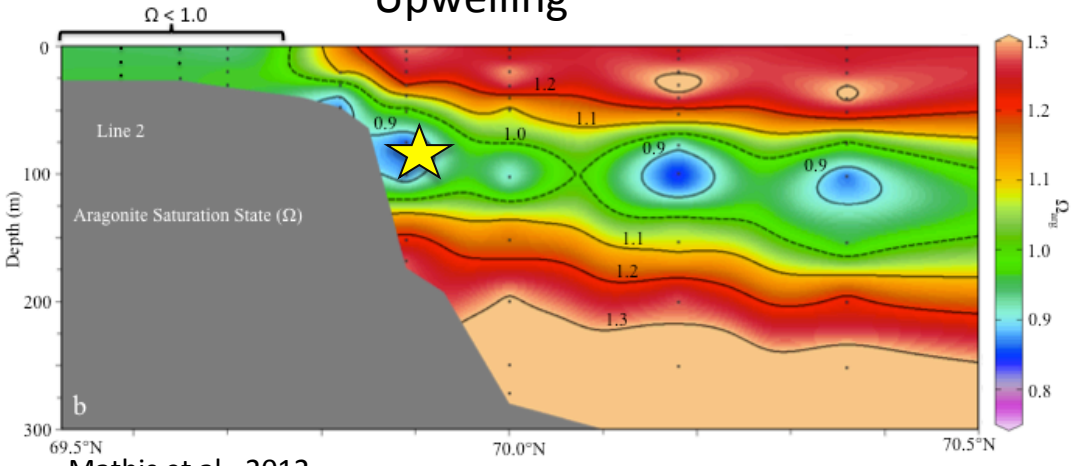
The Fate of Shelf Modified Inflow Waters



Cross et al., in prep.

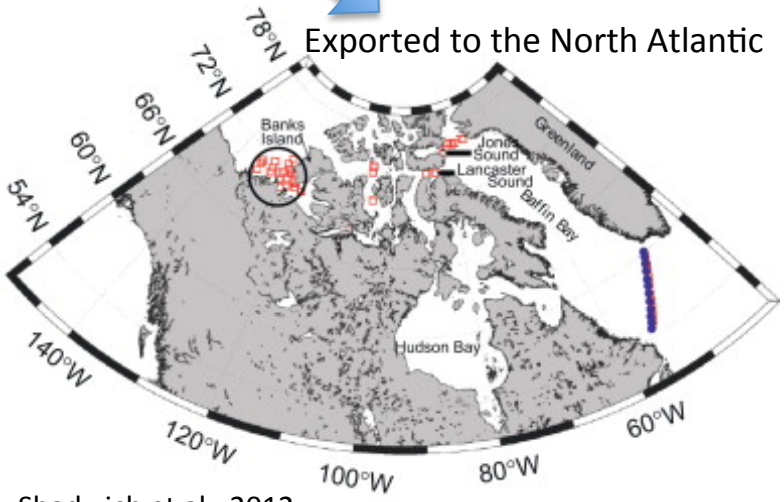


Upwelling



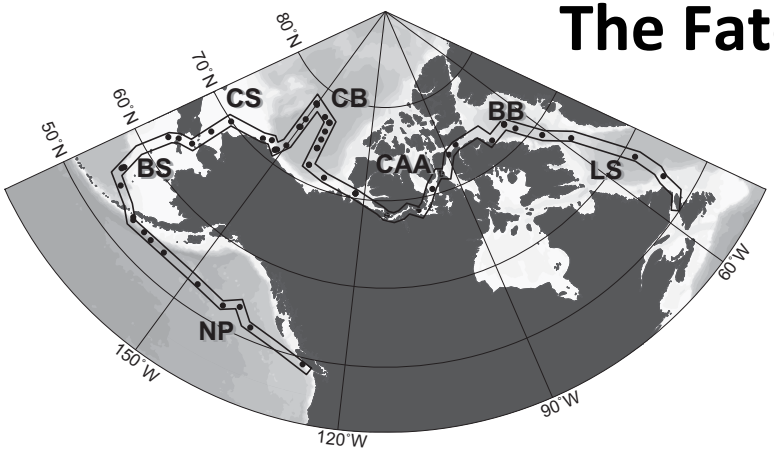
Mathis et al., 2012

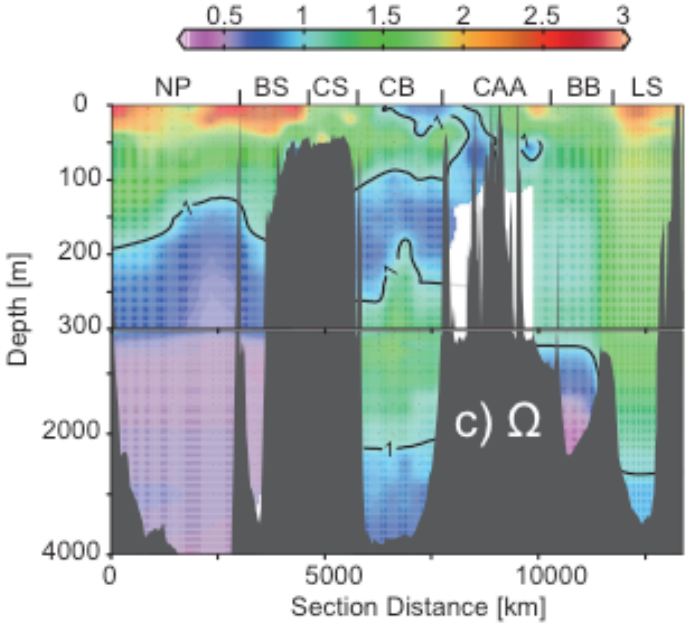
Exported to the North Atlantic



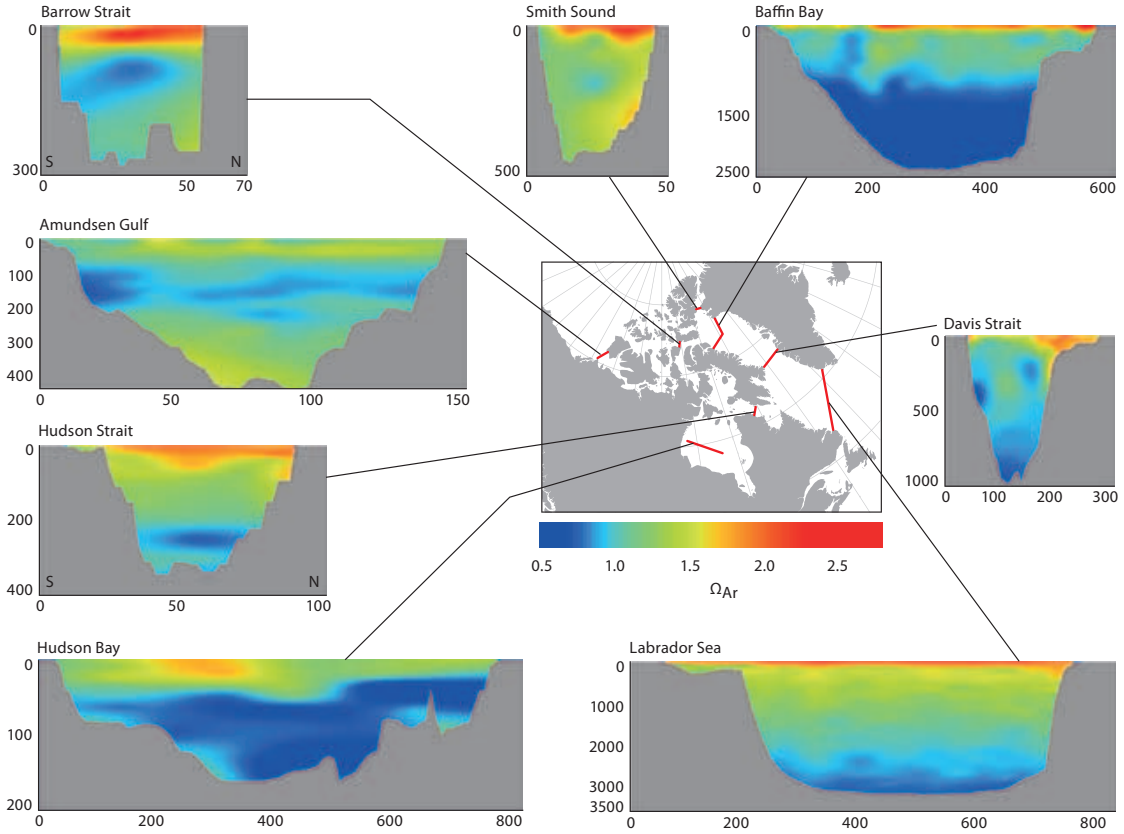
Shadwich et al., 2012

The Fate of Shelf Modified Inflow Waters





Yamamoto-Kawai et al., 2013

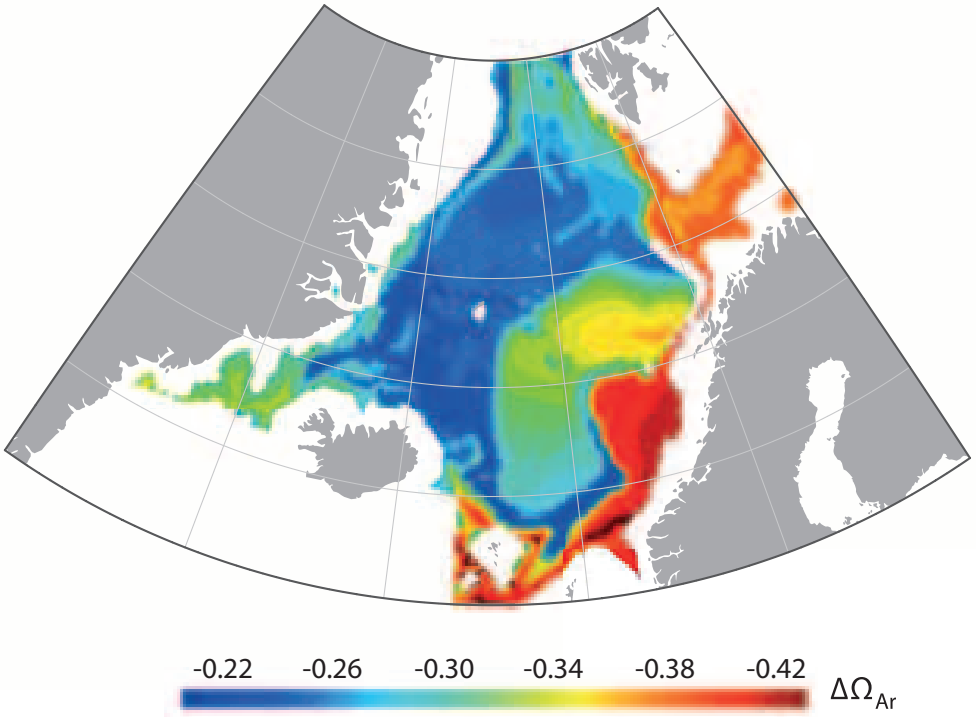


(Azetsu-Scott et al., 2008, 2010; Lansard et al., 2012, Giesbrecht et al., 2013)

- Natural processes in the Arctic conditioning inflowing waters to leave with higher pCO_2 and lower Ω.

Anthropogenic Impacts and the Underlying Carbonate Chemistry

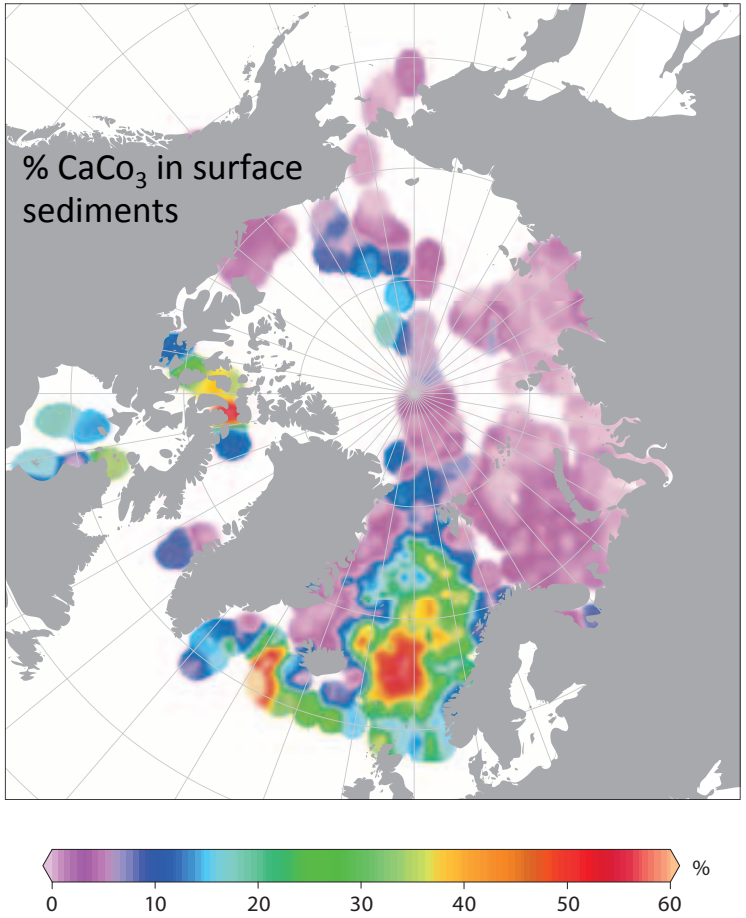
Increased inventories of ant. CO_2 are exacerbating the natural processes that lower Ω in the Arctic.



Estimated changes in surface aragonite saturation state in the Nordic Seas between 1860 and 2004, based on anthropogenic CO_2 concentrations

Olsen et al., 2010

Little, if any burial of carbonate on the shelves of the Arctic Ocean.



Percentage of calcium carbonate in surface sediments in the Arctic Ocean.

AMAP Assessment 2013: Arctic Ocean Acidification

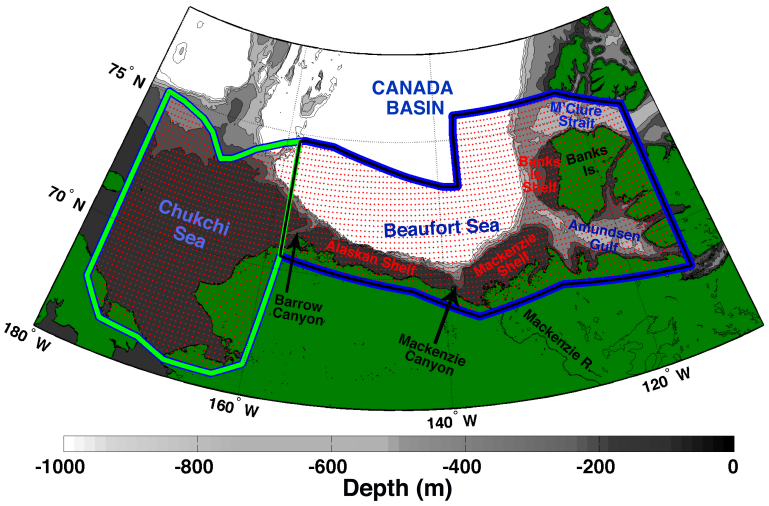
Quantifying CO_2 Fluxes in a System in Rapid Transition (with virtually no data)

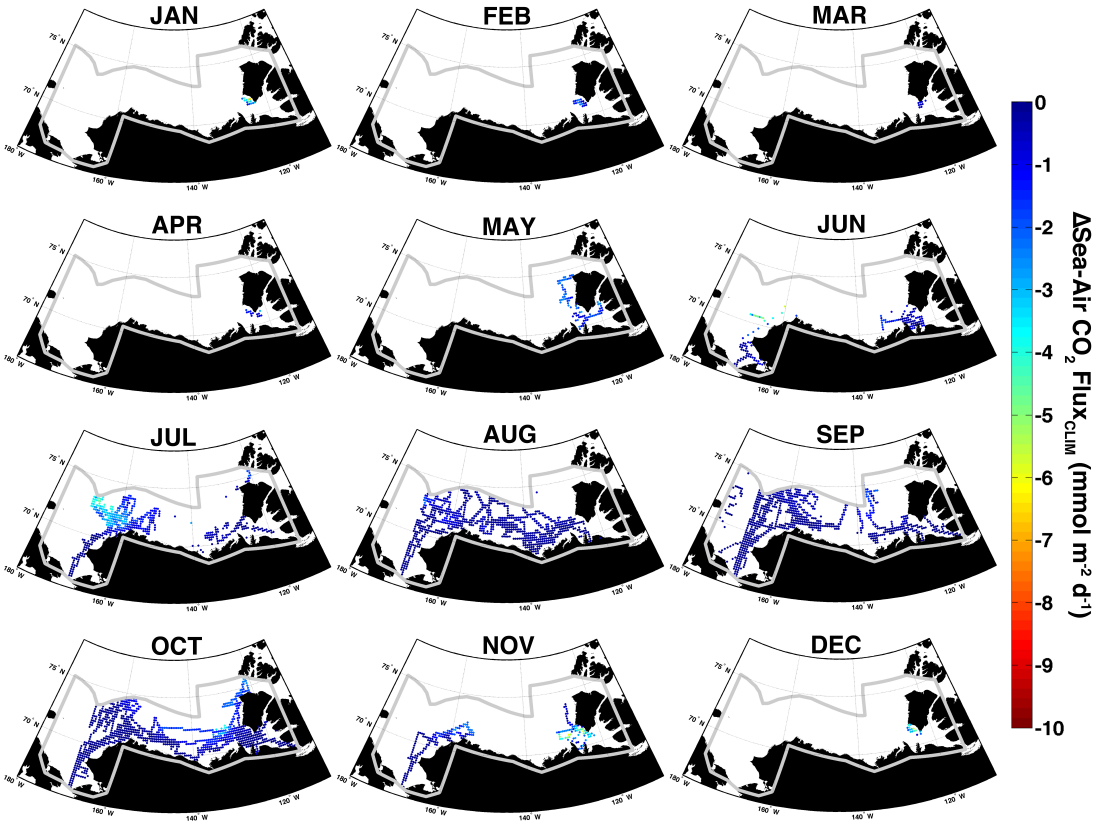
Region	Sea-air exchange		Source
	(mmol/m²/d)[a]	10^{12} mol/y	
Central Basins	-0.3 to 1		Bates et al., 2006
Barents Sea	-3.7±0.9[b]	-0.8	Fransson et al., 2001
		-2.4±1	Kaltin et al., 2002
		-3.8±1.5	Nakaoka et al., 2006
		-4.3±0.7	Omar et al., 2007
		-1.8±1	Kivimäe et al., 2010
Nordic Seas		-5.8	Jeansson et al., 2011
Kara Sea	-0.1[b]		Fransson et al., 2001
Laptev Sea		-2.1	Nitishinsky et al., 2007
	-1.2 to 1.7		Semiletov et al., 2007
East Siberian Sea	-2 to 10	0.04 to 0.28	Pipko et al., 2011
Chukchi Sea	~ -30 to -90	-2.6 to -3.8	Bates, 2006
	-15±13	-1.8	Pipko et al., 2002
	-18 to 3		Murata and Takizawa, 2003
			Kaltin and Anderson, 2005
Beaufort Sea	-2		Mucci et al., 2010
	-17 to 0		Murata and Takizawa, 2003
	-17 to 3		Shadwick et al., 2011
	-25 to -9		Else et al., 2011
Canadian Archipelago	-7 to 0		Miller et al., 2002
	-140 to 18		Fransson et al., 2009
All Arctic Ocean		-2 to ~ -8	McGuire et al., 2009

[a] Data are from the summer period with limited ice coverage; [b] annual mean estimate.

Most of the data is seasonally biased (summer and fall), there is very limited spatial coverage, and the estimates have huge ranges.

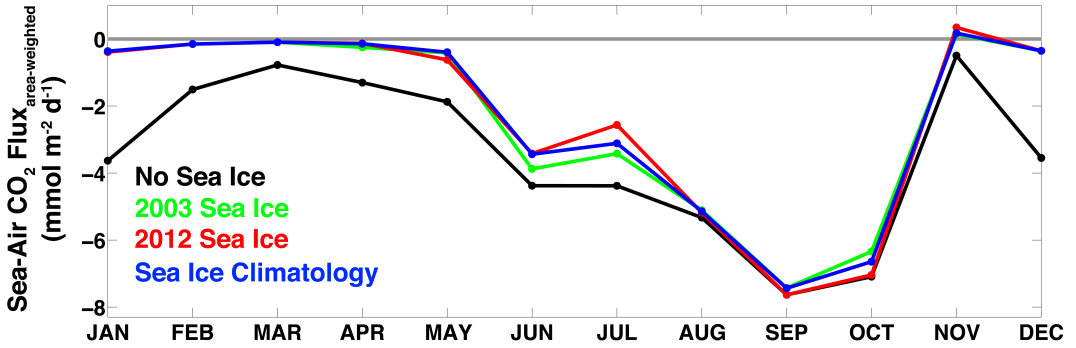
Western Arctic CO_2 Flux Synthesis





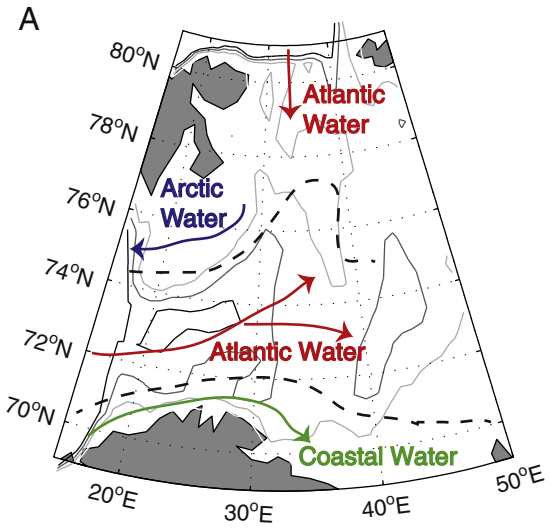
(1) Synthesized available 2003-2012 data for western Arctic coastal ocean

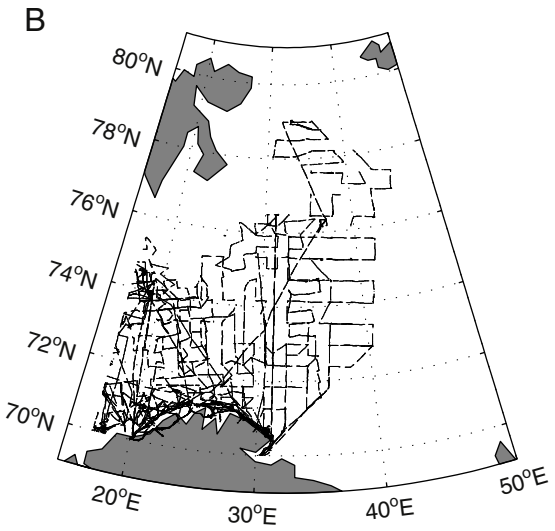
(2) First comprehensive data-based carbon sink estimate for this region of 12 Tg yr^{-1}

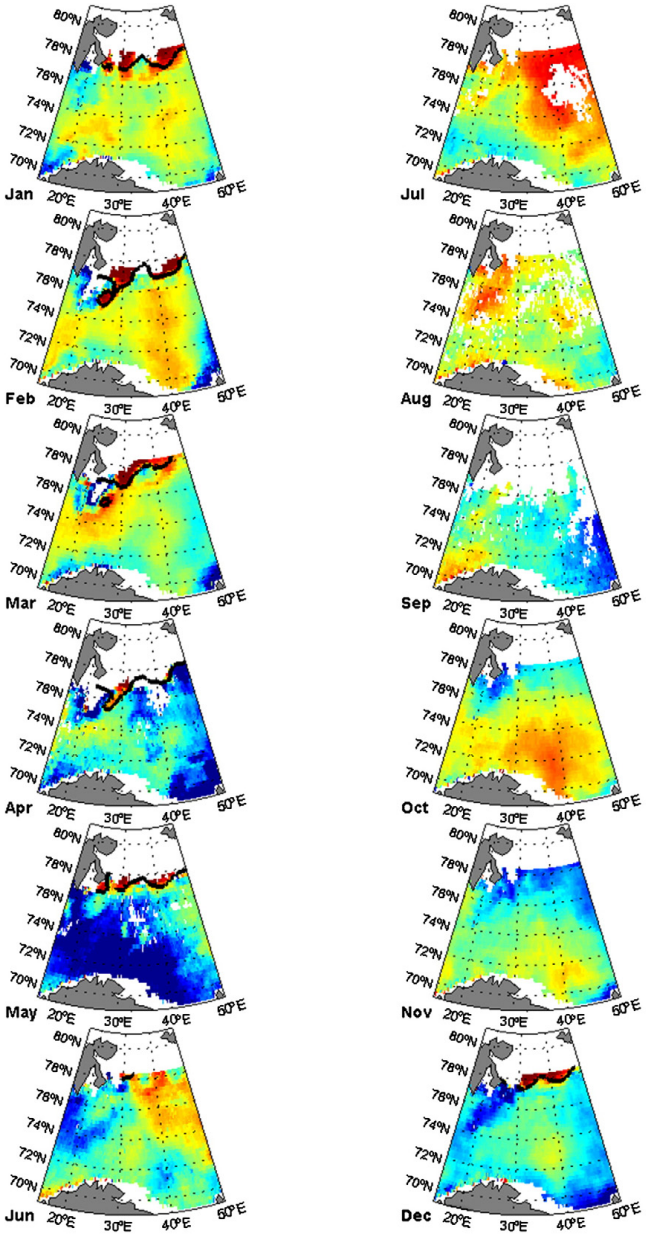


Evans et al., in prep.

Barents Sea CO_2 Flux Synthesis





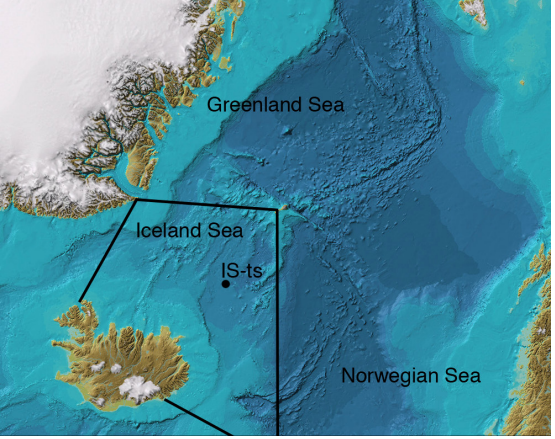


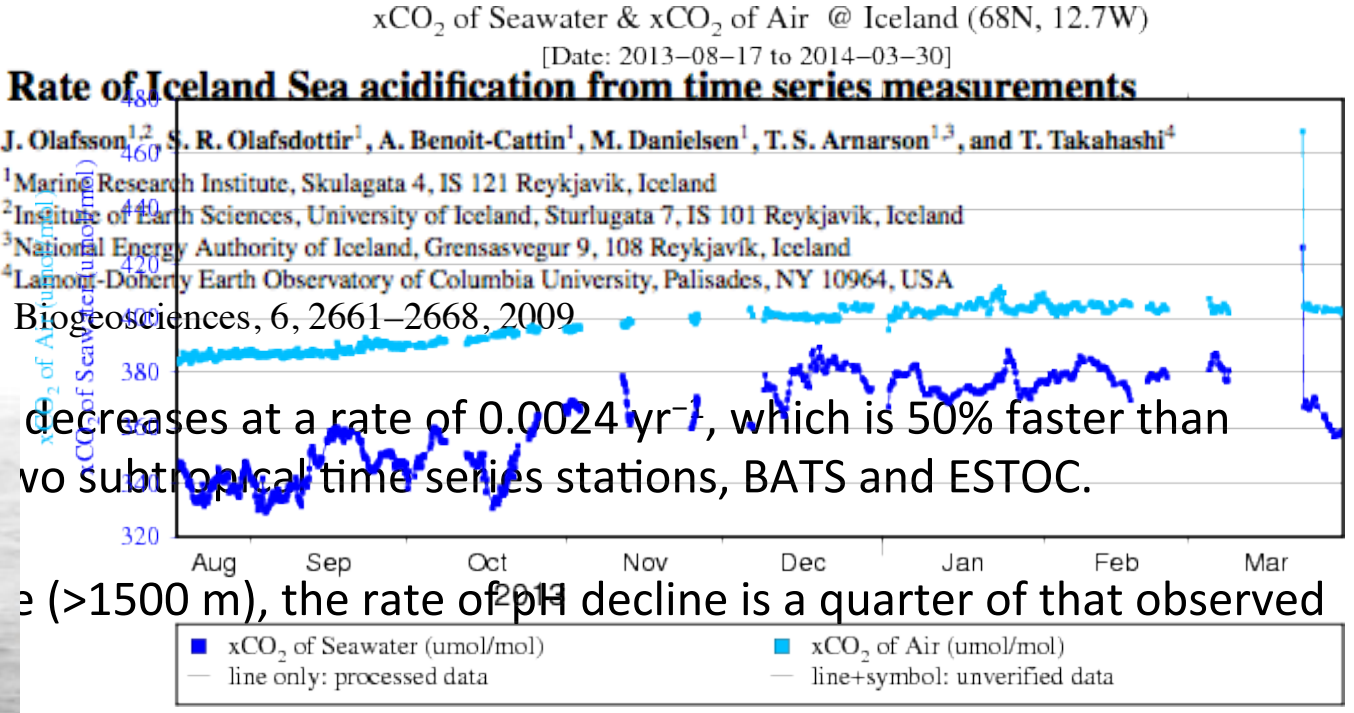
The seasonal cycle show peaks in the total air–sea CO_2 influx in May and September, caused by respectively biological drawdown of CO_2 and low sea ice concentration leaving a large open water area.

For 2007 the annual average air–sea CO_2 flux is -48 ± 5 gC m^{-2}, which is comparable to previous estimates.

Lauvset et al., 2013

OA and CO_2 in the North Atlantic





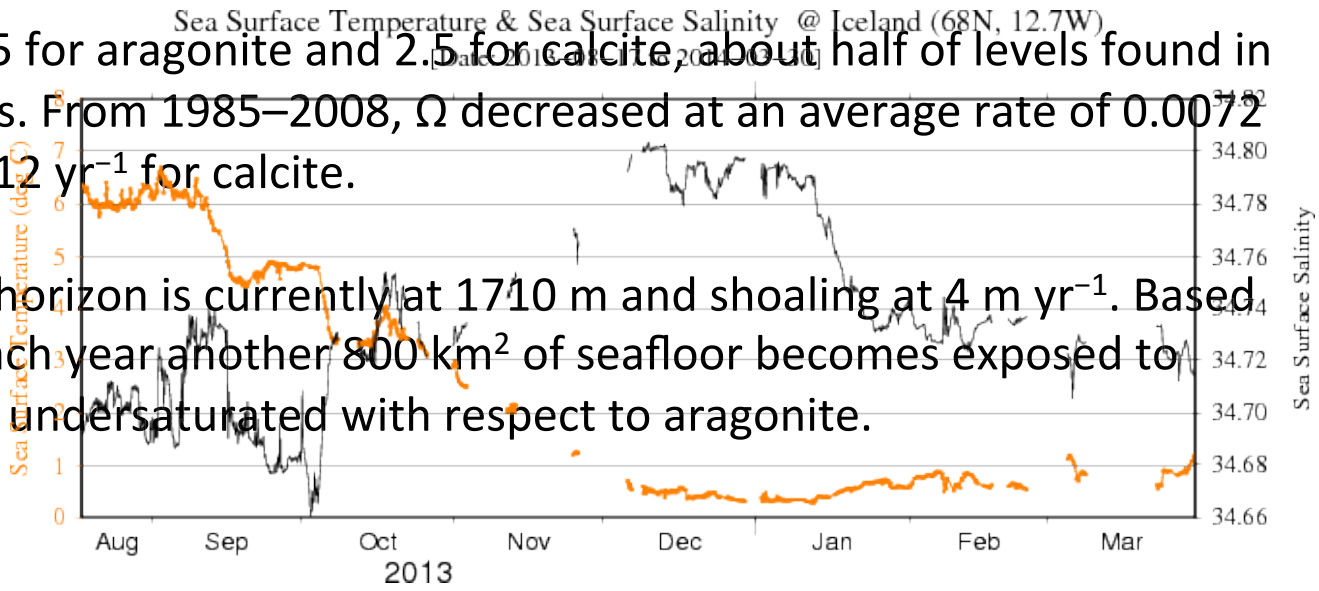
Rate of Iceland Sea acidification from time series measurements

J. Olafsson[1,2], S. R. Olafsdottir[1], A. Benoit-Cattin[1], M. Danielsen[1], T. S. Arnarson[1,3], and T. Takahashi[4]

[1]Marine Research Institute, Skulagata 4, IS 121 Reykjavik, Iceland
[2]Institute of Earth Sciences, University of Iceland, Sturlugata 7, IS 101 Reykjavik, Iceland
[3]National Energy Authority of Iceland, Grensasvegur 9, 108 Reykjavik, Iceland
[4]Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY 10964, USA

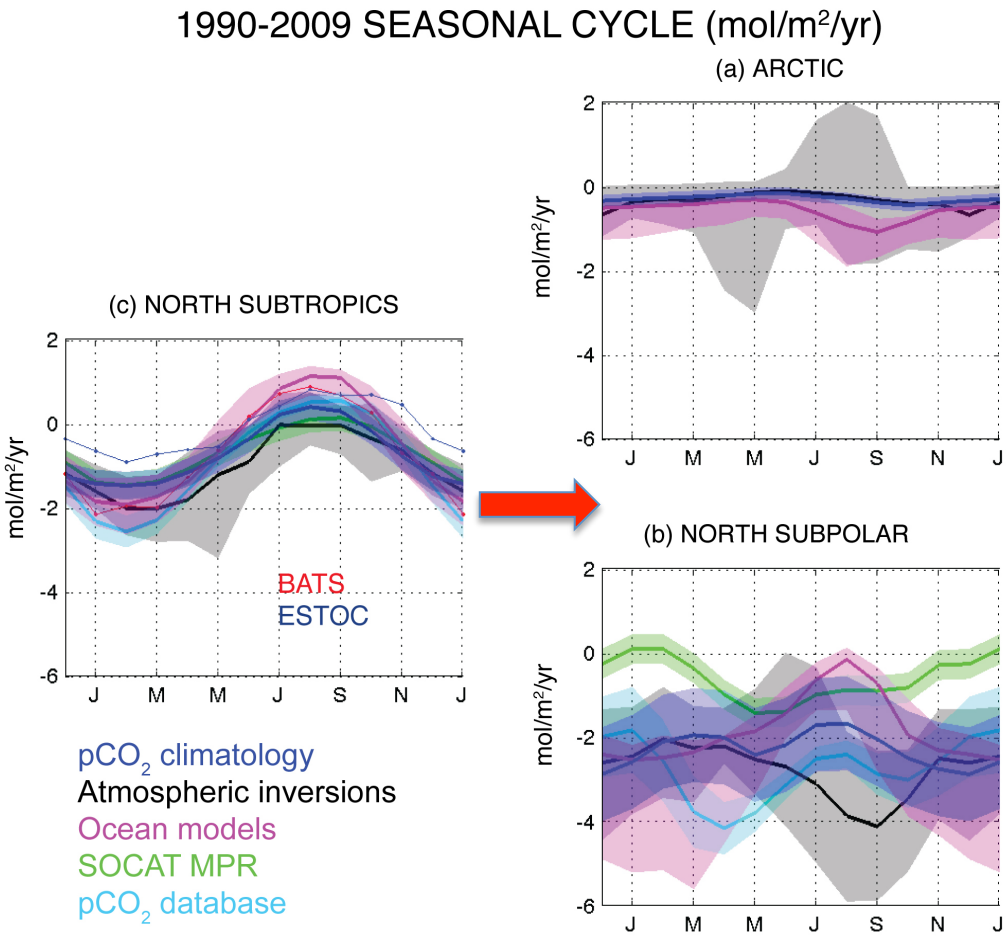
Biogeosciences, 6, 2661–2668, 2009

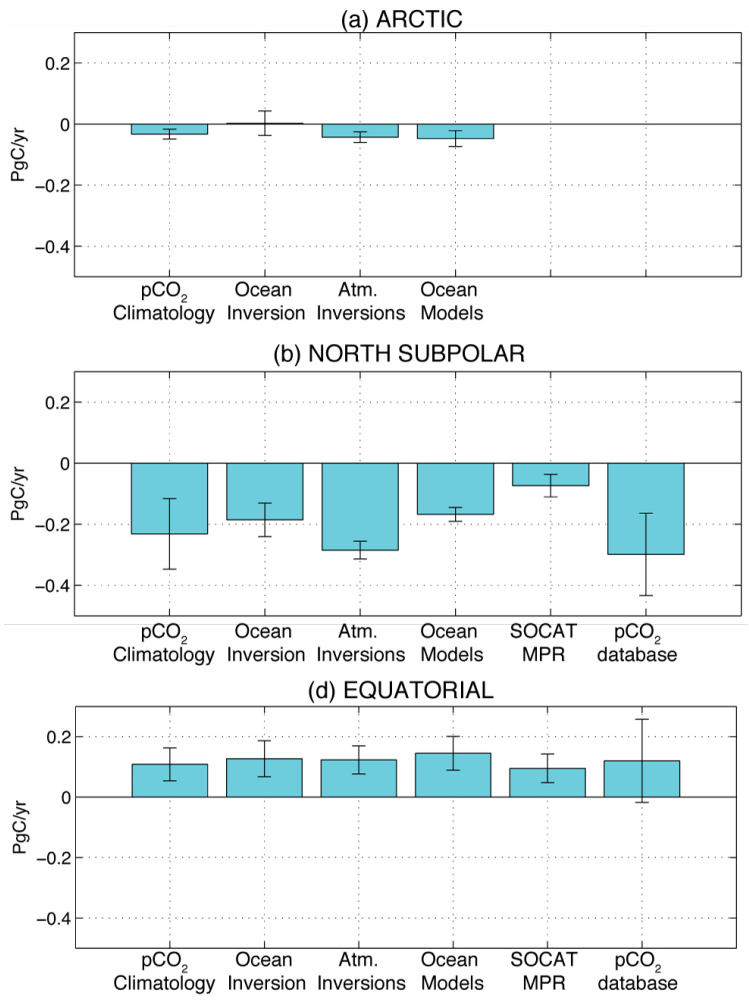
- decreases at a rate of 0.0024 yr^{-1}, which is 50% faster than vo subtropical time series stations, BATS and ESTOC.
- e (>1500 m), the rate of pH decline is a quarter of that observed
- 5 for aragonite and 2.5 for calcite, about half of levels found in rs. From 1985–2008, Ω decreased at an average rate of 0.0072 012 yr^{-1} for calcite.
- horizon is currently at 1710 m and shoaling at 4 m yr^{-1}. Based ach year another 800 km^2 of seafloor becomes exposed to waters that have become undersaturated with respect to aragonite.



Regional Perspective on CO_2 in the North Atlantic

1990-2009 Mean CO_2 Flux, Atlantic and Arctic (PgC/yr)





- *"The subtropical seasonality of pCO_2/CO_2 flux is well-constrained across the different methods, the subpolar seasonality is all over the place. To me, this suggests significant mechanistic uncertainty, and thus limited predictability."* – Galen McKinley