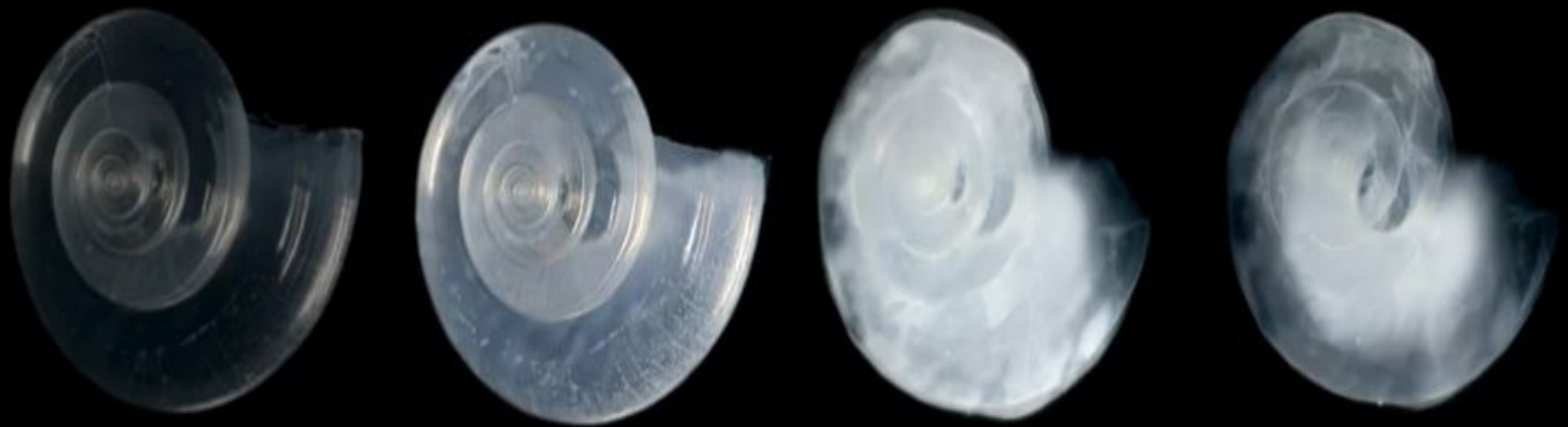
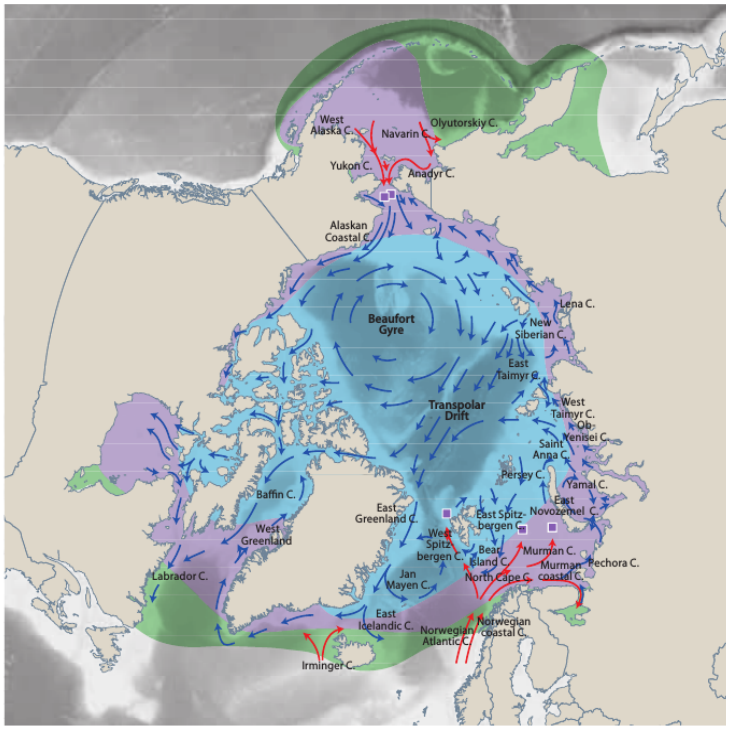
Arctic Ocean Acidification



Nadja Steiner[1,2,3]
Jim Christian[1,2], Tessa Sou[1] , Ken Denman[3] , Warren Lee[2],
Lisa Miller[1], Eric Mortenson[3], Hakase Hayashida[3]

1 Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney
2 Environment Canada, Canadian Centre for Climate Modelling and Analysis
3 School of Earth and Ocean Sciences, University of Victoria

Arctic Ocean Acidification



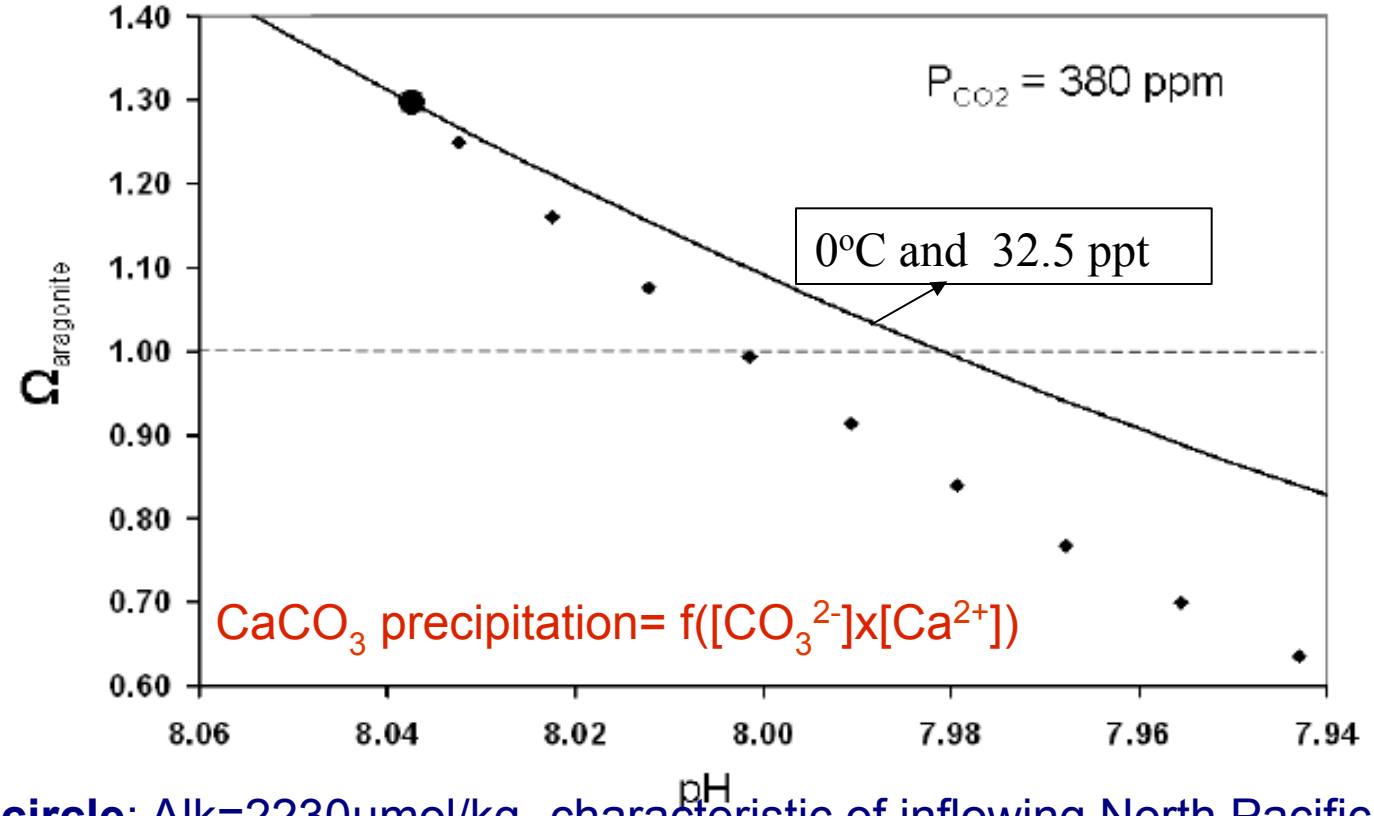
1. Introduction – Why is the Arctic particularly vulnerable to acidification
2. AMAP Arctic Ocean Acidification Assessment
3. Observations of Arctic Ocean Acidification
4. Model projections of Arctic Ocean Acidification
5. Summary - Needs

Arctic Ocean Acidification

1. Atmospheric CO2 increase
2. Low Temperatures - high CO2 solubility
3. Large contribution of freshwater (increased river inflow and sea ice melt) - dilution - ocean pCO2 decreases - increased CO2 uptake, also lower [Ca^{2+}] - reduced CaCO3 saturation.

$CaCO_3$ precipitation = f([CO_3^{2-}]x[Ca^{2+}])

Aragonite saturation – pH relationship



Solid circle: Alk=2230µmol/kg- characteristic of inflowing North Pacific surface water in the Canadian Basin (Yamamoto-Kawaii et al. 2009).
Solid diamonds: successive dilution with freshwater to salinities from 32 to 24 with increments of 1 => additional reduction in saturation state

Arctic Ocean Acidification

1. Atmospheric CO_2 increase
2. Low Temperatures - high CO_2 solubility
3. Large contribution of freshwater (increased river inflow and sea ice melt)
4. Inflow of low pH Pacific water
5. Localized upwelling of low pH waters - shelf interaction
6. Input of terrigeneous organic carbon – oxidized to CO_2
7. Primary Production temporarily increases the saturation state at the surface (shelves) => subsequent remineralization of sinking material reduces the saturation state in the subsurface

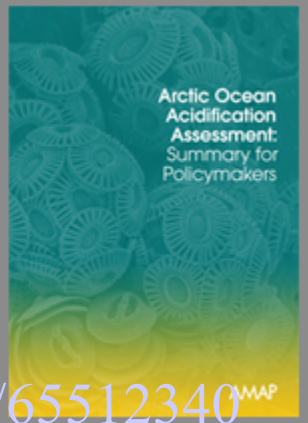
The AMAP Arctic Ocean Acidification Assessment

AMAP ASSESSMENT 2013: ARCTIC OCEAN ACIDIFICATION

AMAP, 2013. AMAP Assessment 2013: Arctic Ocean Acidification. AMAP, Oslo. 2013.

AMAP ARCTIC OCEAN ACIDIFICATION ASSESSMENT: SUMMARY FOR POLICY-MAKERS

AMAP, 2013. AMAP Arctic Ocean Acidification Assessment: Summary for Policy-makers. This document presents the Executive Summary of the 2013 Arctic Ocean Acidification (AOA) Assessment.



=> Educational Movie on AOA:
http://vimeo.com/groups/189916/videos/65512340

AMAP AOA 2 : Case studies & AOA in a multistressor environment

Observations: Temporal and spatial snapshots

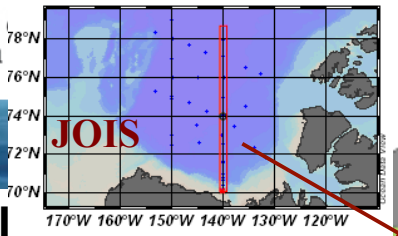
a) low Ω_a in the Beaufort Sea (0.7-1.3), higher Ω_a in the European Basin (1.7) and North Atlantic (1.7-2.3)

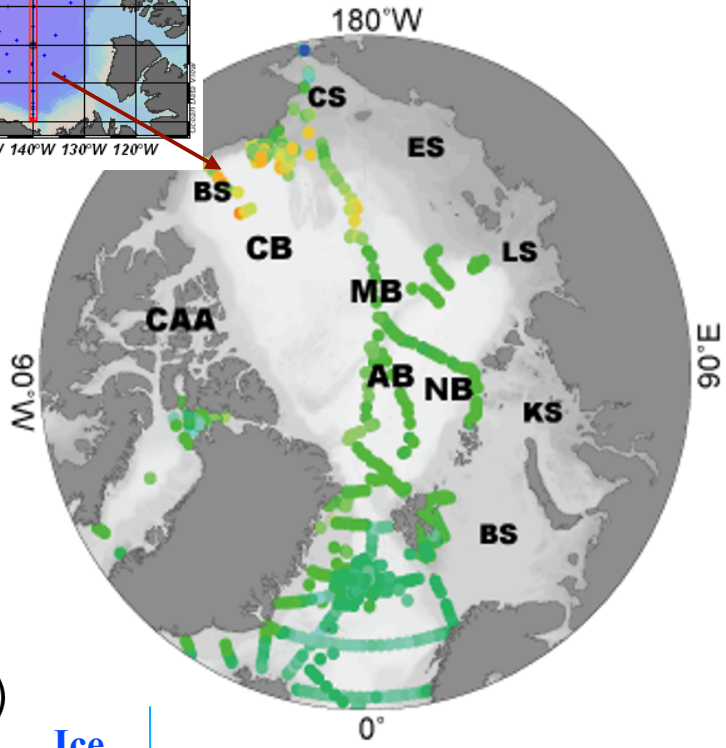
b) Undersaturation of surface waters crossing the Beaufort gyre.

Supersaturation between 20-100m <= advection of Pacific Summer Water, photosynthesis at subsurface Chl max.

Undersaturation below the deep halocline (100-200m) <=advection of Pacific Winter Water (high N and pCO2 due to remineralisation)

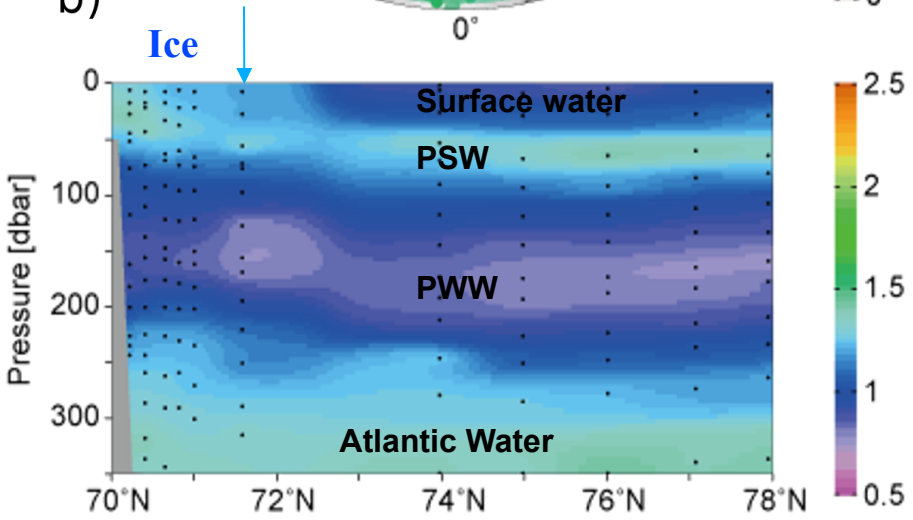
Supersaturation in Atlantic laye below





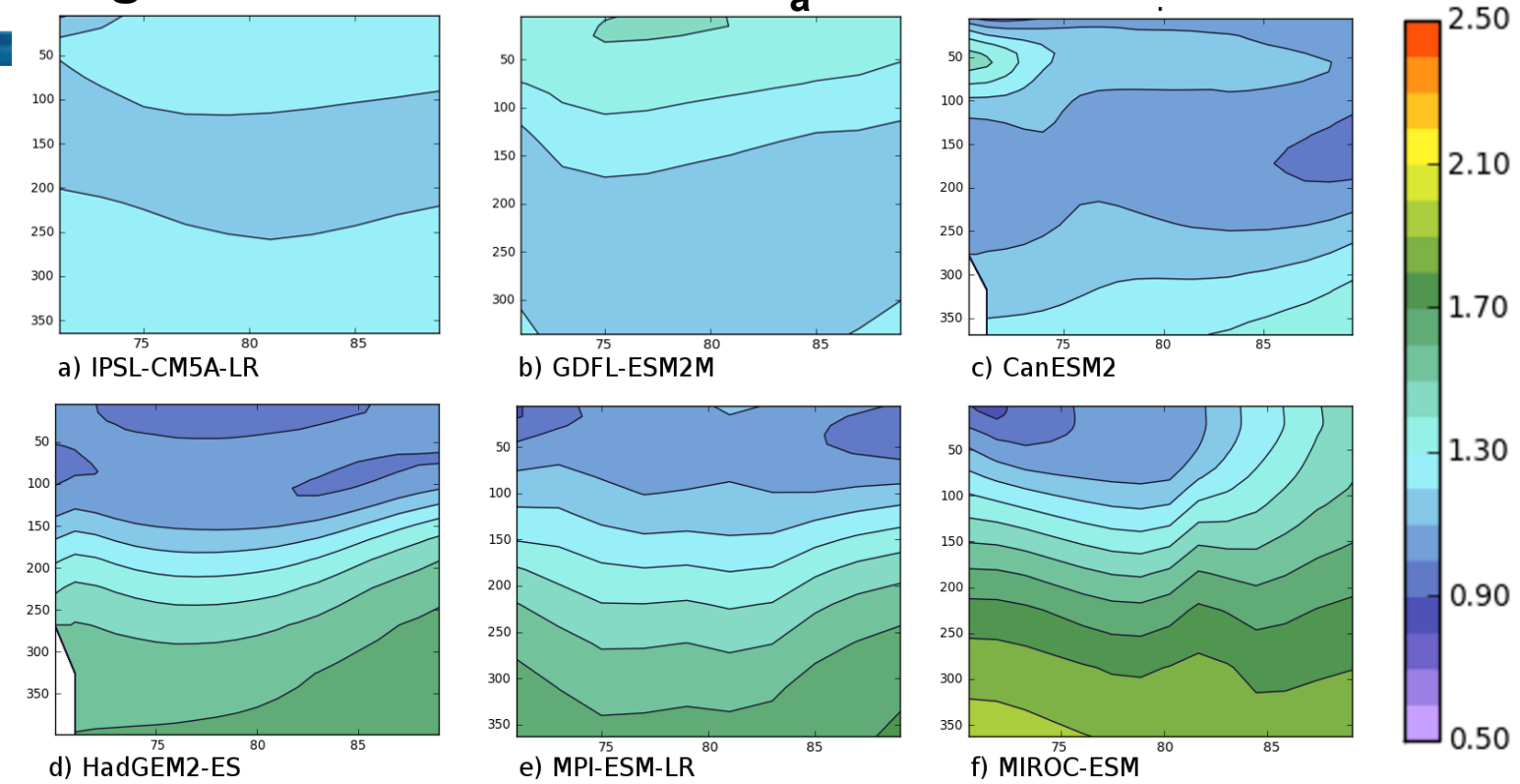
CARINA Data Synthesis Project 1986-2005

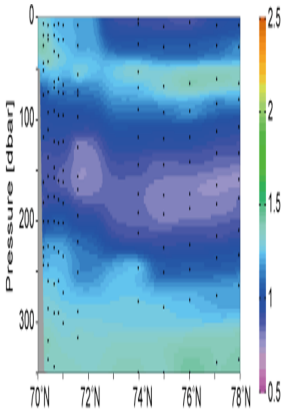
b)

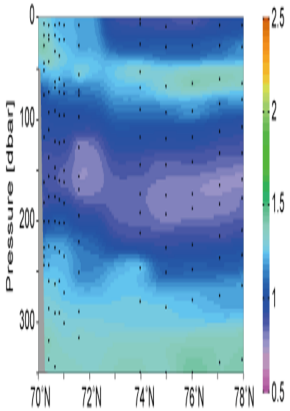


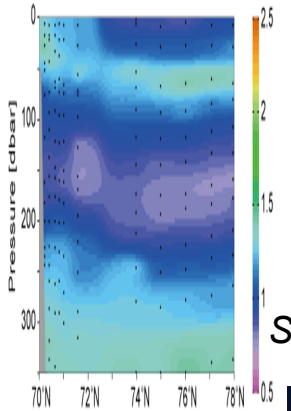
JOIS August 2011

Aragonite saturation state Ω_a – JOIS section 140W





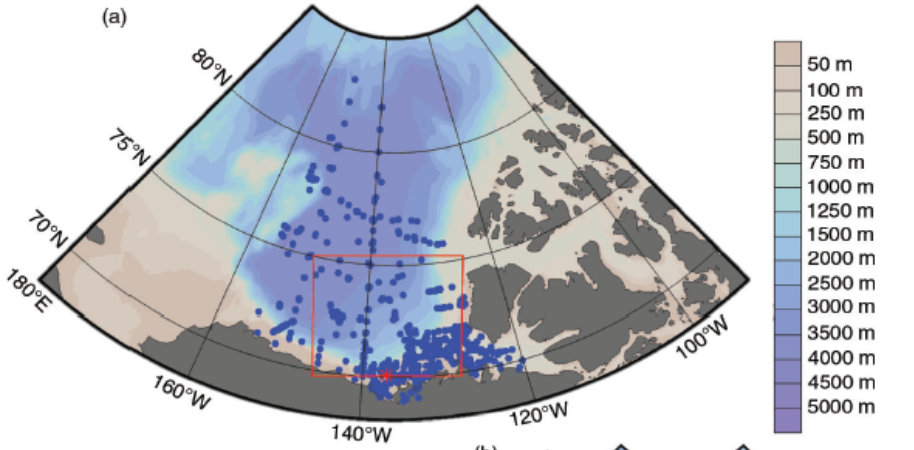


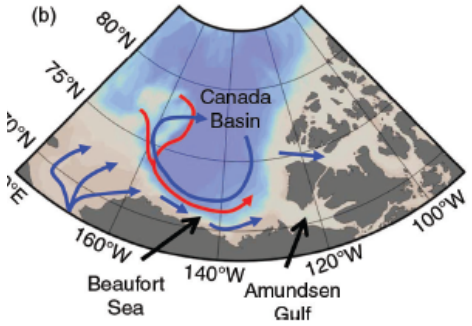


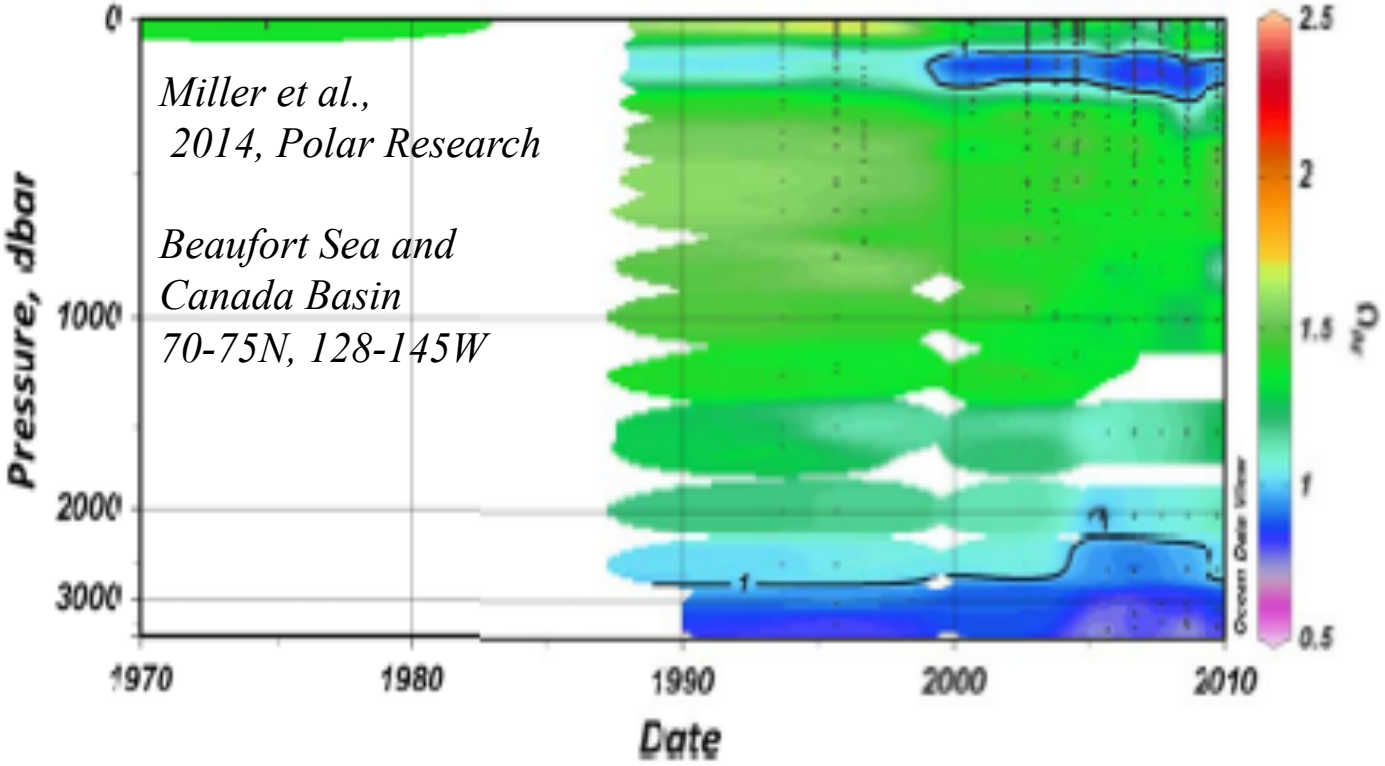
CMIP5 models:
2006-2025
Annual mean

Steiner et al. 2014, JGR Oceans

Canada



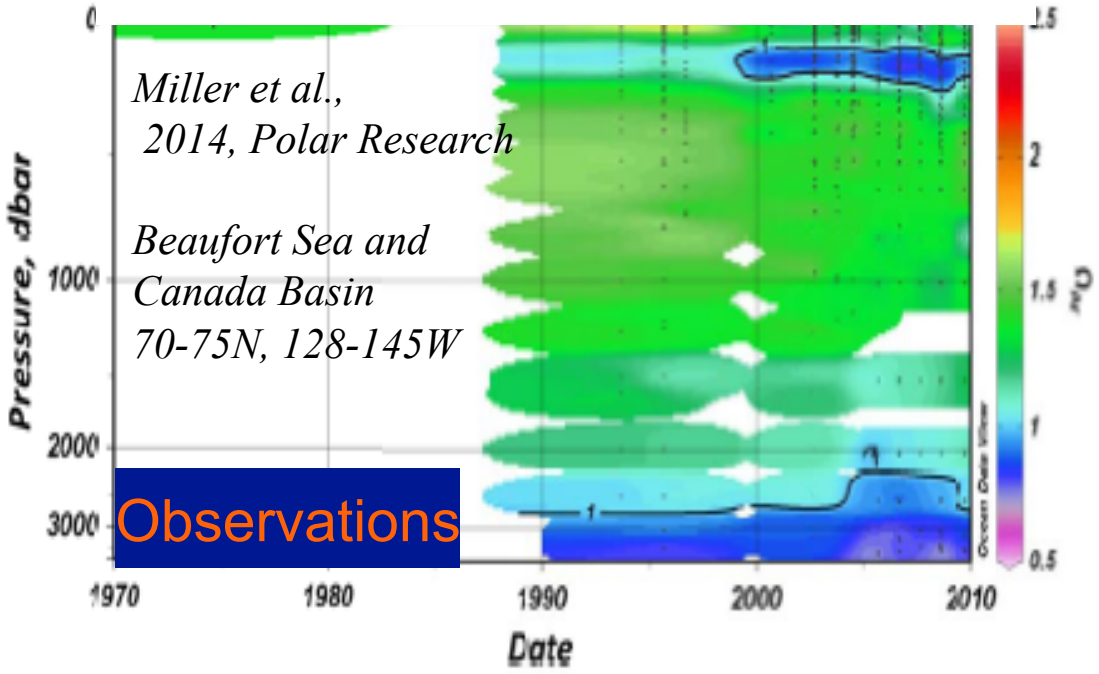


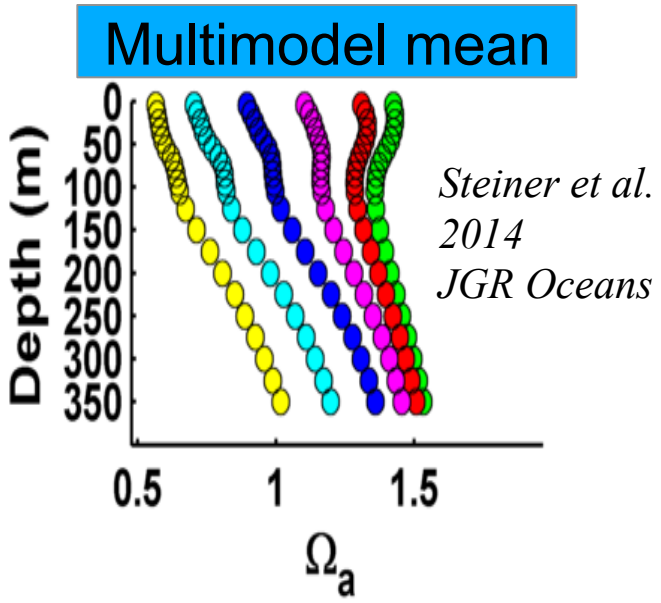


Miller et al.,
2014, Polar Research

Beaufort Sea and
Canada Basin
70-75N, 128-145W

Aragonite saturation Ω_a in the Canada Basin 75N, 140W





6 ESMs submitted to CMIP5 & IPCC AR5

CanESM2
GFDL-ESM2M
HadGEM2-ES
IPSL-CM5A-LR
MPI-ESM-LR
MIROC-ESM
2005 observations

1966-1985
1986-2005
2006-2025
2026-2045
2046-2065
2066-2085

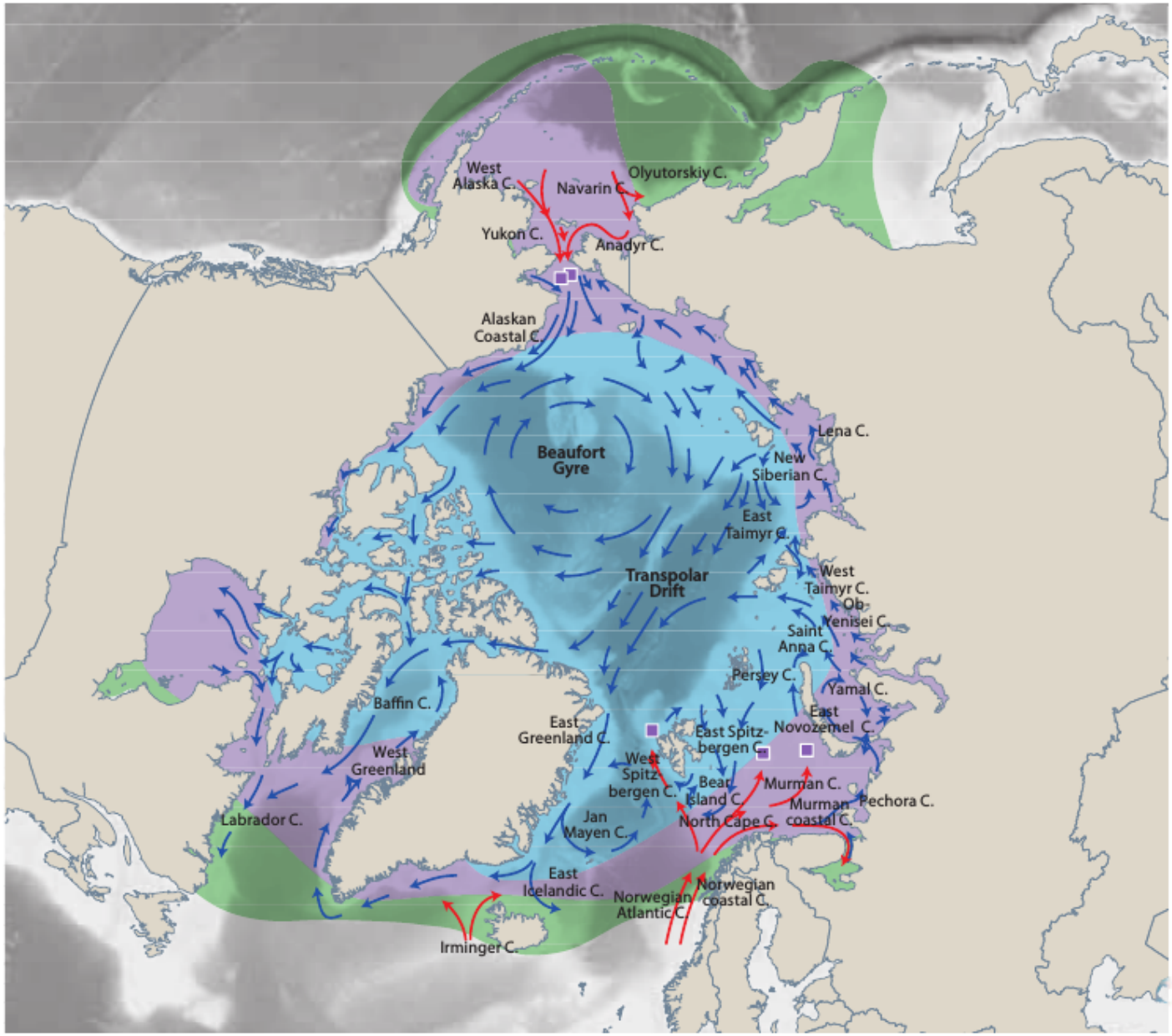
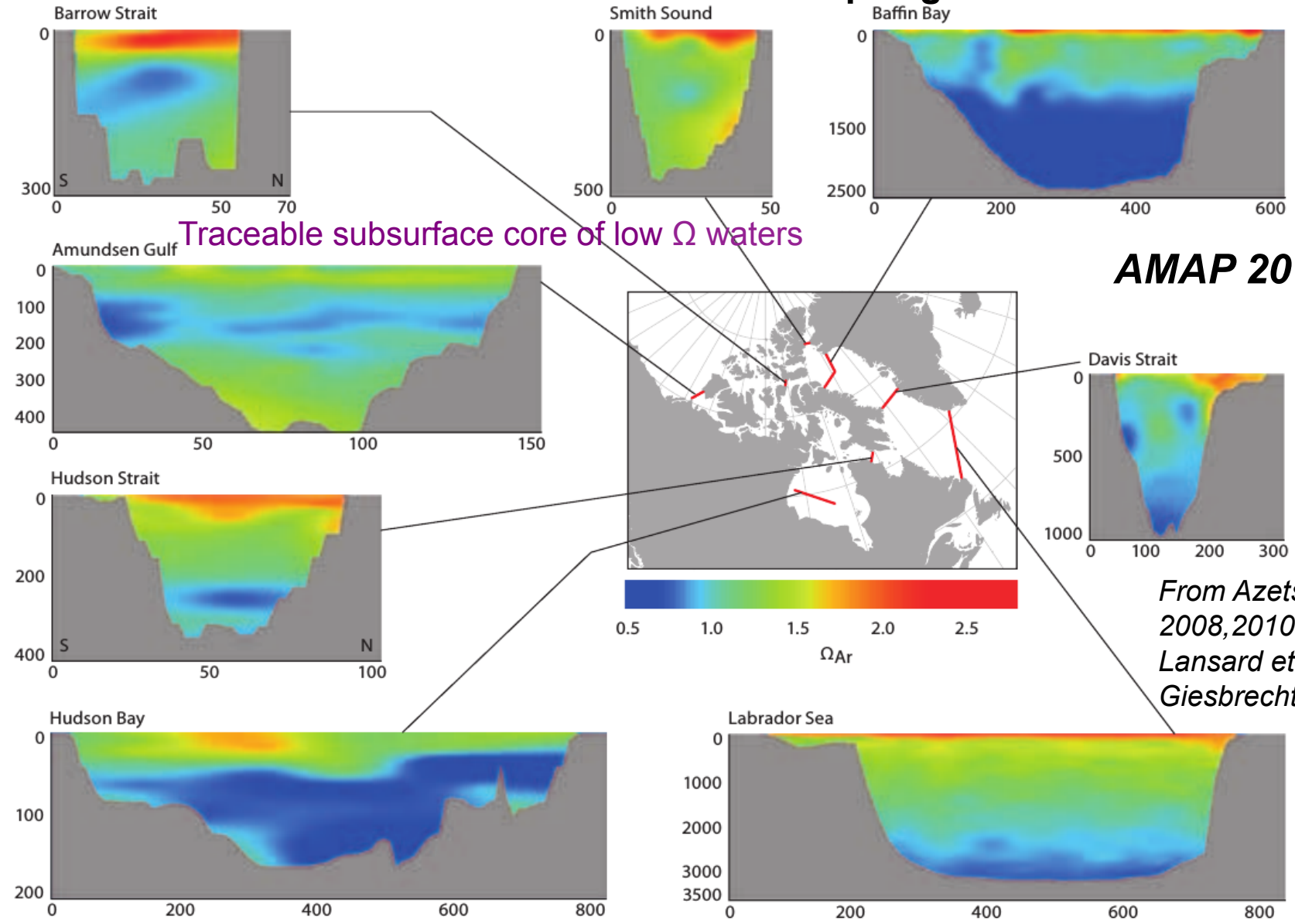


Figure 1.4. Major surface ocean currents within the High Arctic, Low Arctic and sub-Arctic areas of the Arctic Ocean and its marginal seas.

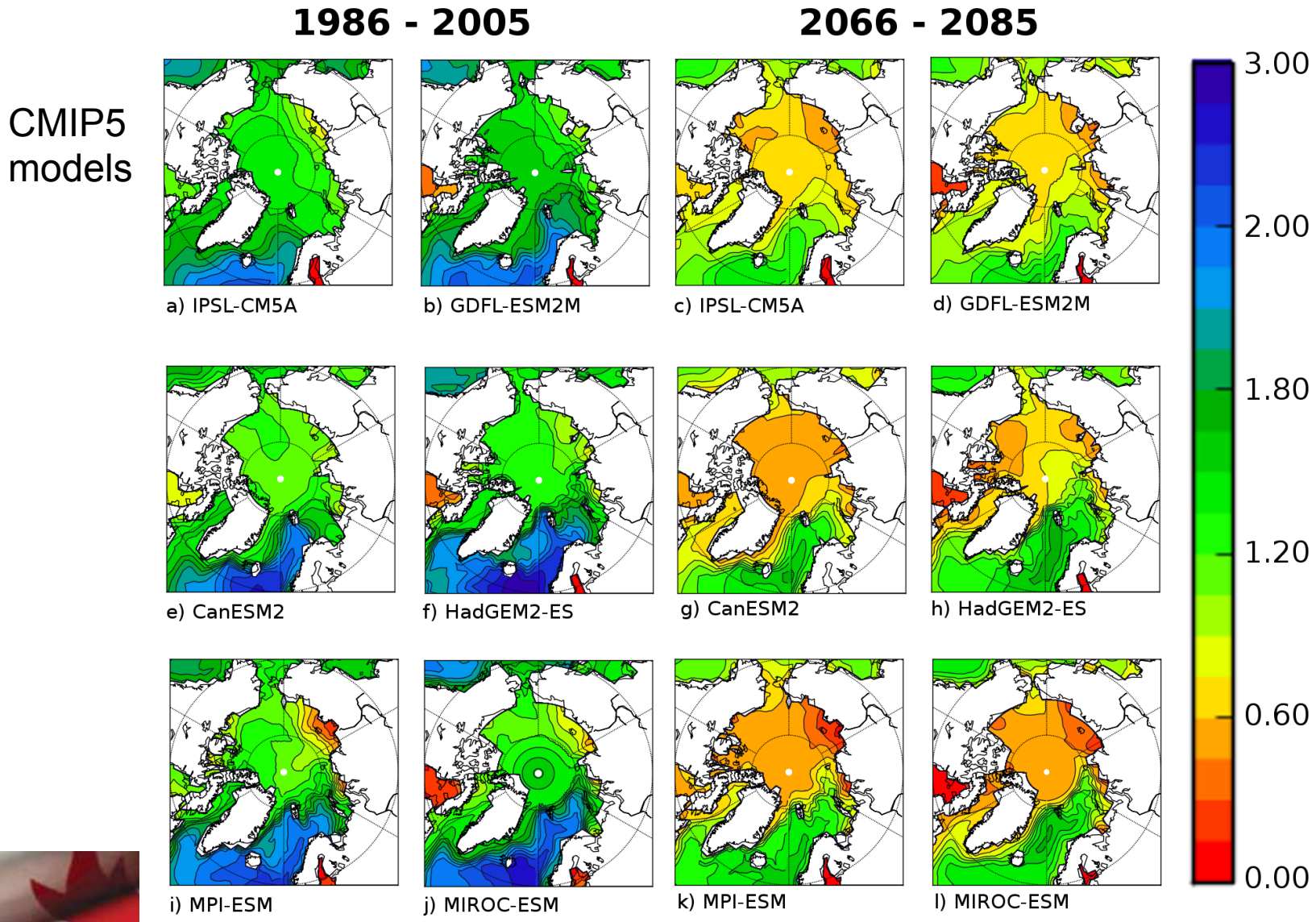
AMAP, 2013

Current aragonite saturation states across critical gateways in the Canadian Arctic Archipelago

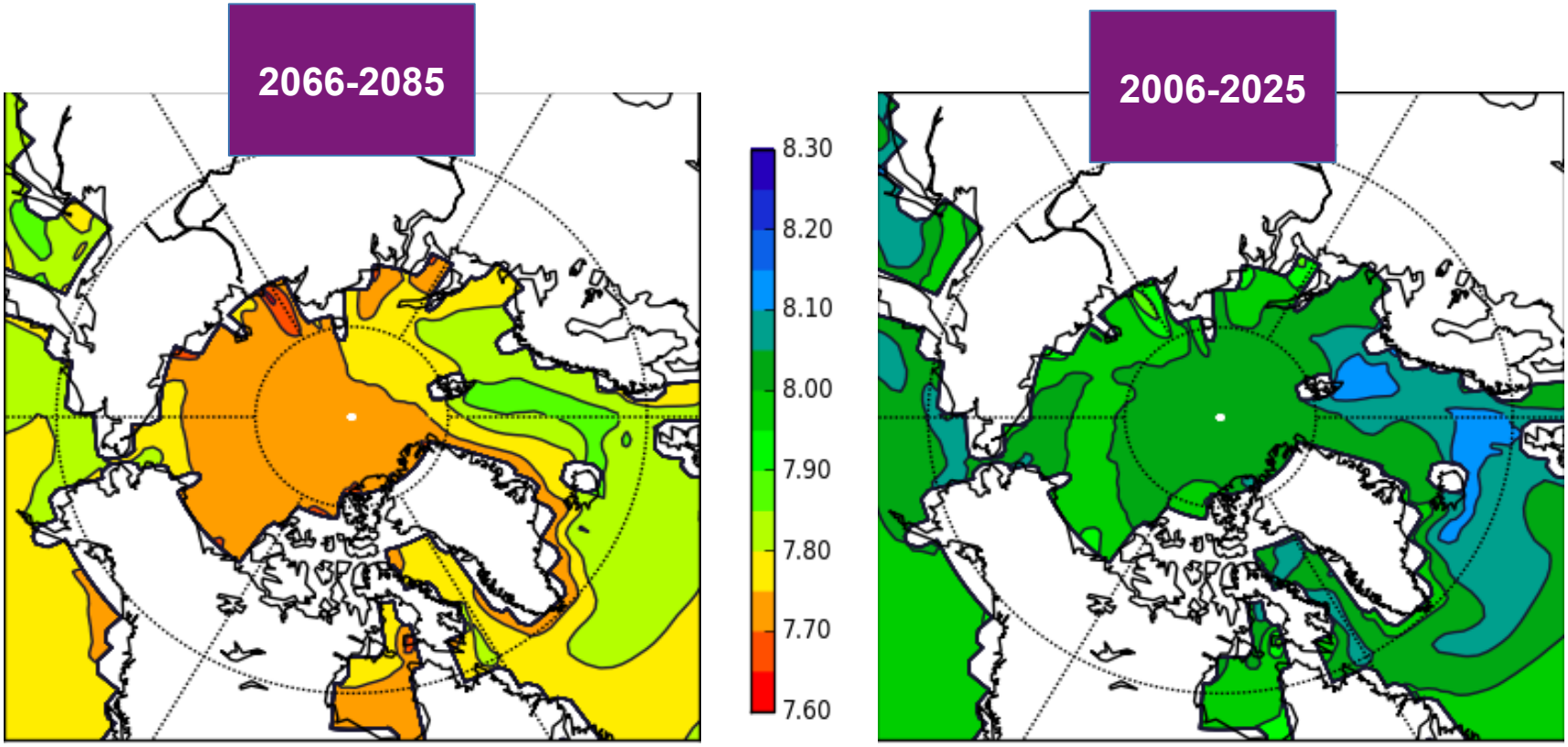


Steiner et al. 2014, JGR Oceans)

Aragonite saturation state Ωa at the surface (RCP8.5)



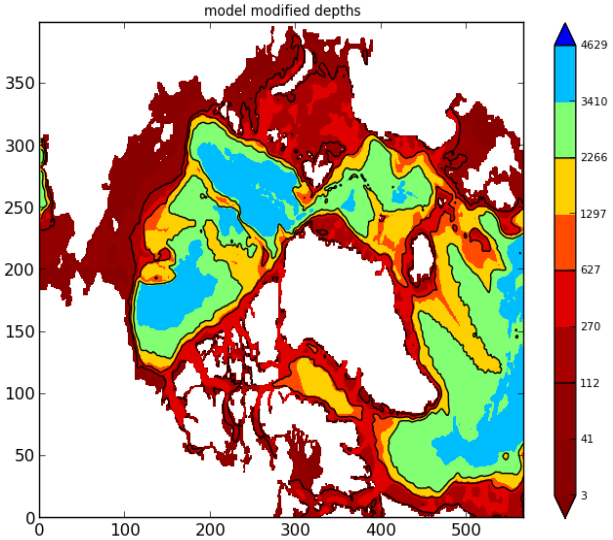
Surface PH in CanESM2 (RCP8.5)



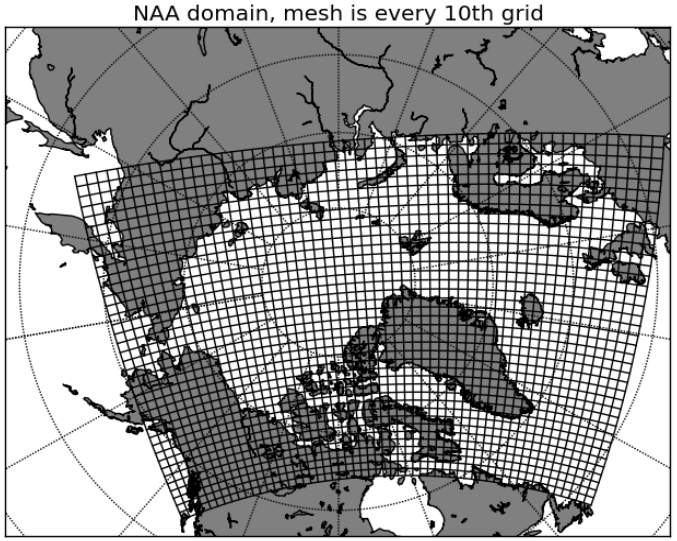
CanESM2

A higher resolution biogeochemical model for the Arctic

Physical model & configuration: NEMO-LIM2 (*Hu & Myers 2014*)
Ecosystem Models: PISCES, CMOC (CCCma CanESM2),
TO DO: new ecosystem (CCCma CanESM5) $N_3P_2Z_2D_2$, Alk, DIC, O_2, N_2O, DMS, Sea ice ecosystem (P, DMS=> D_3)
(Testing in 1-D => Poster E. Mortenson/H. Hayashida)



resolution:
11-15km
horizontally,
6-250m
vertically

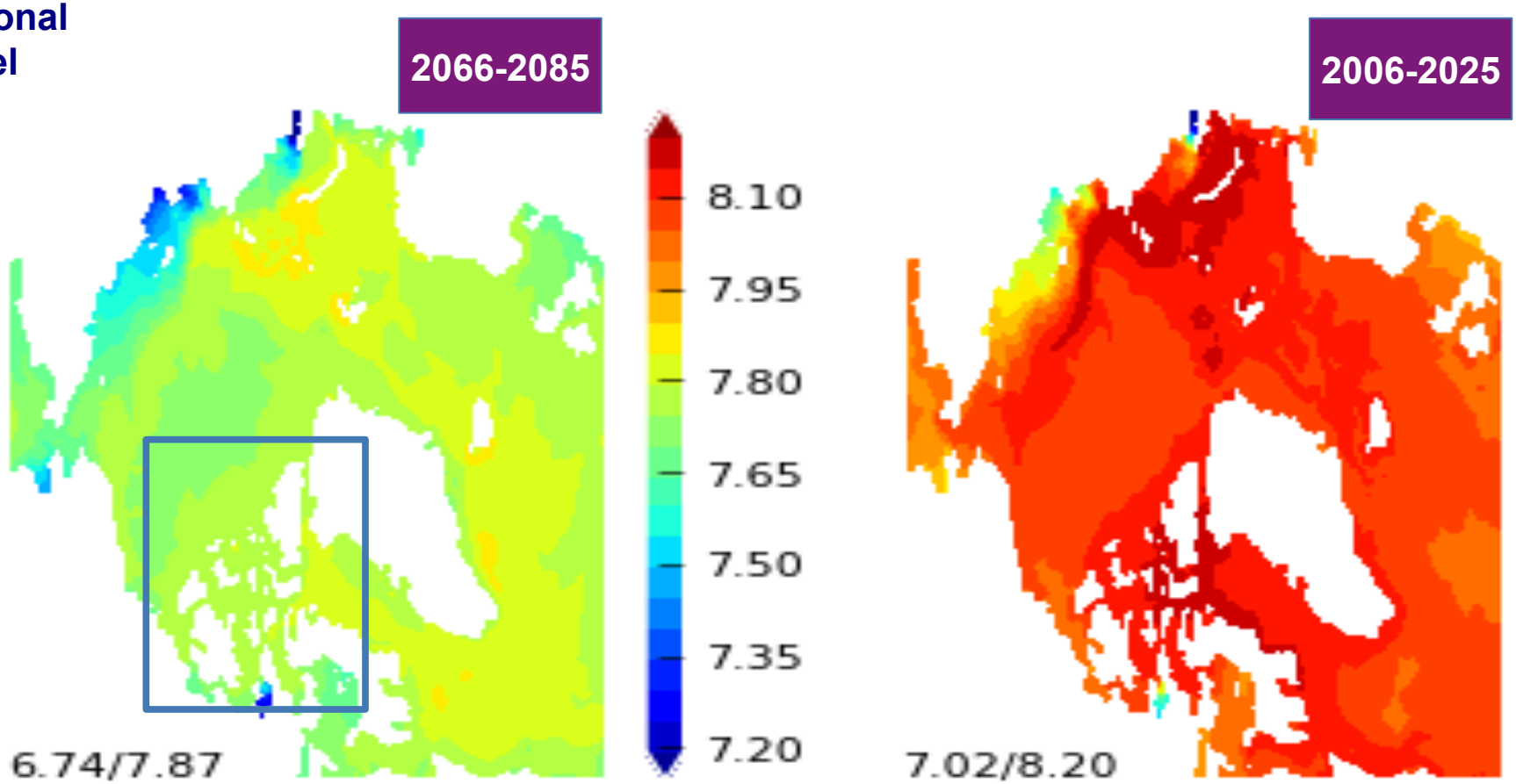


Forcing: CanRCM4 + CanESM2, Initialization: CanESM2
Runs: Climatological means for 2006-2025 and 2066-2085

Courtesy T. Sou

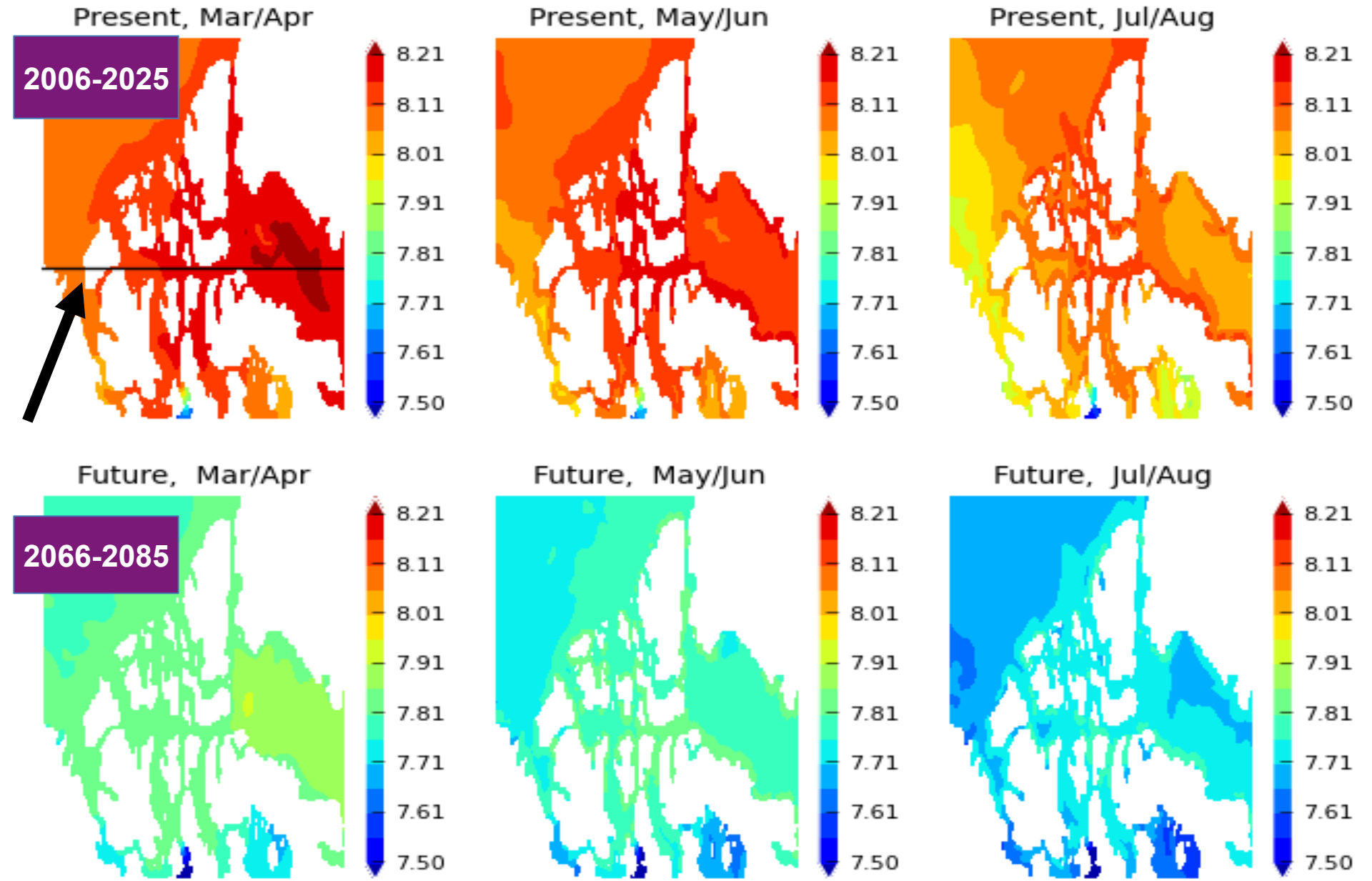
Surface PH in the Canadian Arctic Ecosystem Model

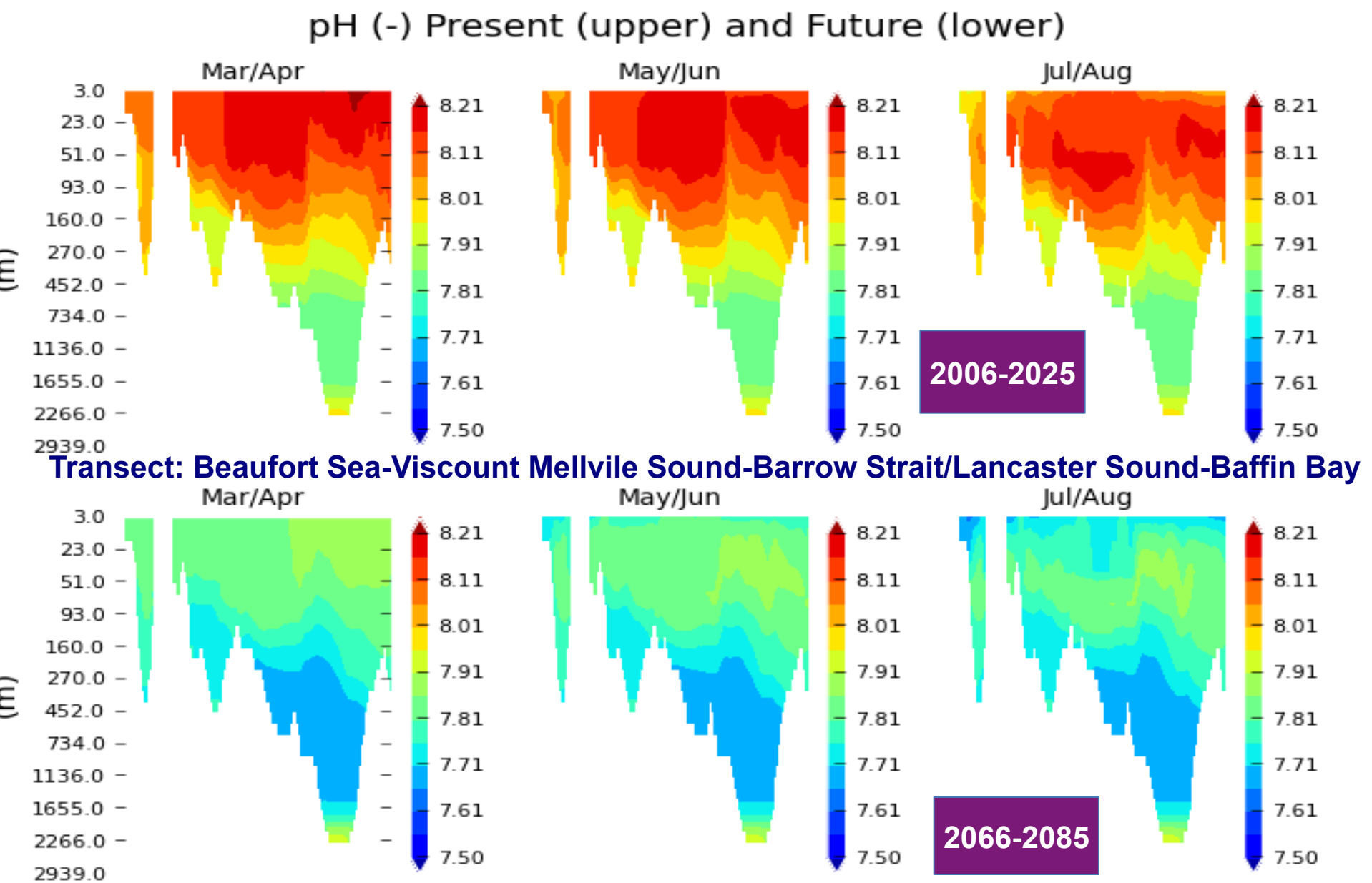
Regional Model



Courtesy T. Sou

Surface pH (-)


Present, Mar/Apr
Present, May/Jun
Present, Jul/Aug
2006-2025
Future, Mar/Apr
Future, May/Jun
Future, Jul/Aug
2066-2085
8.21
8.11
8.01
7.91
7.81
7.71
7.61
7.50


pH (-) Present (upper) and Future (lower)
Mar/Apr
May/Jun
Jul/Aug
(m)
3.0
23.0
51.0
93.0
160.0
270.0
452.0
734.0
1136.0
1655.0
2266.0
2939.0
8.21
8.11
8.01
7.91
7.81
7.71
7.61
7.50
2006-2025
Transect: Beaufort Sea-Viscount Mellvile Sound-Barrow Strait/Lancaster Sound-Baffin Bay
2066-2085

Summary

* Arctic Ocean is the 1st ocean region with a widespread geochemical destabilisation of $CaCO_3$ (*Opportunity*: a "fast pace laboratory" for the global ocean)

* Current acidification projections are largely limited to ESMs: show consistent pH and $\Omega_{a,c}$ decrease
  Issues: low resolution, inconsistencies in sea-ice projections (retreat & ocean stratification).
  Lack of base line observations for carbon system variables

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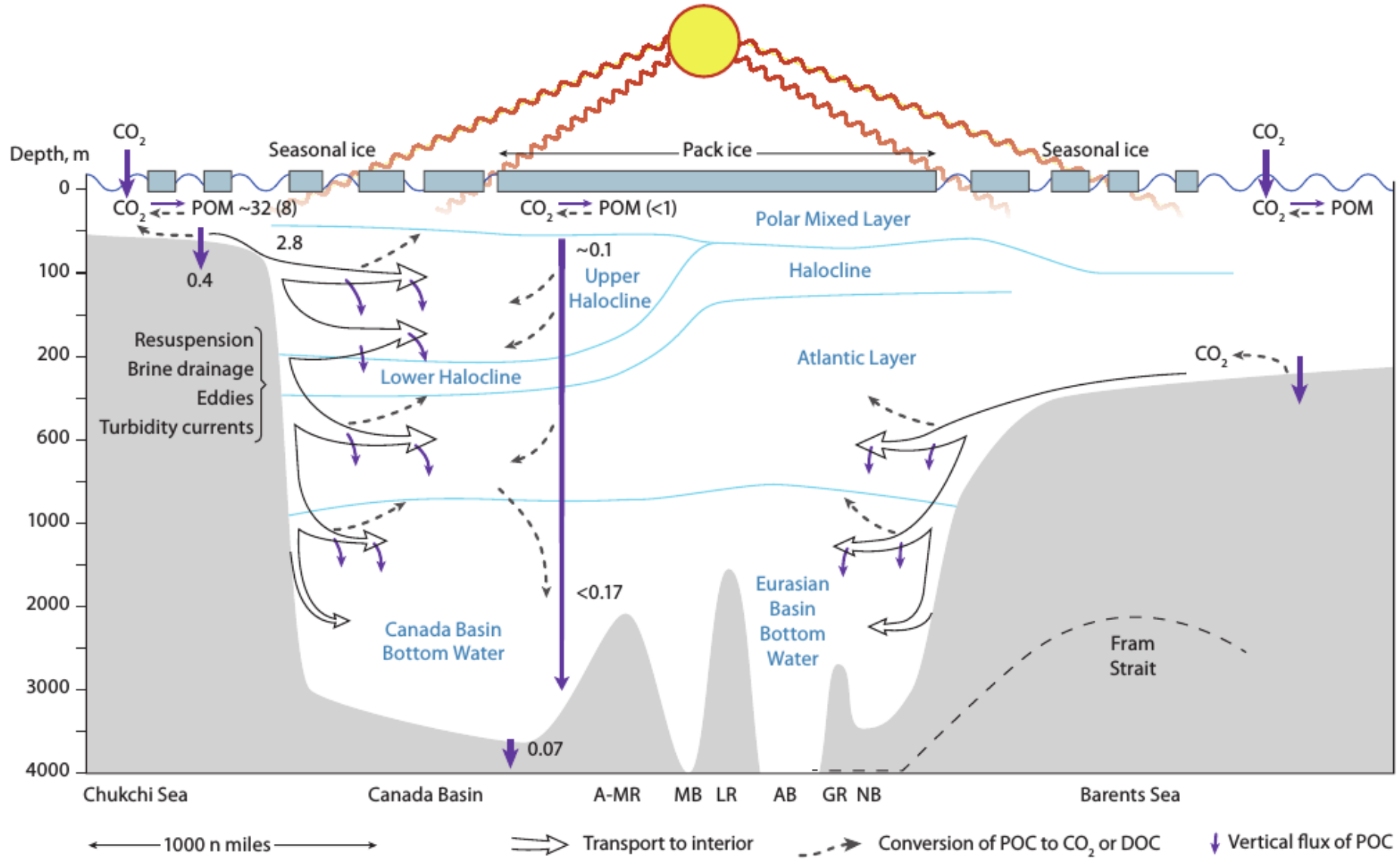
  Issues: low resolution, inconsistencies in sea-ice projections (retreat & ocean stratification).
  Lack of base line observations for carbon system variables

Needs:

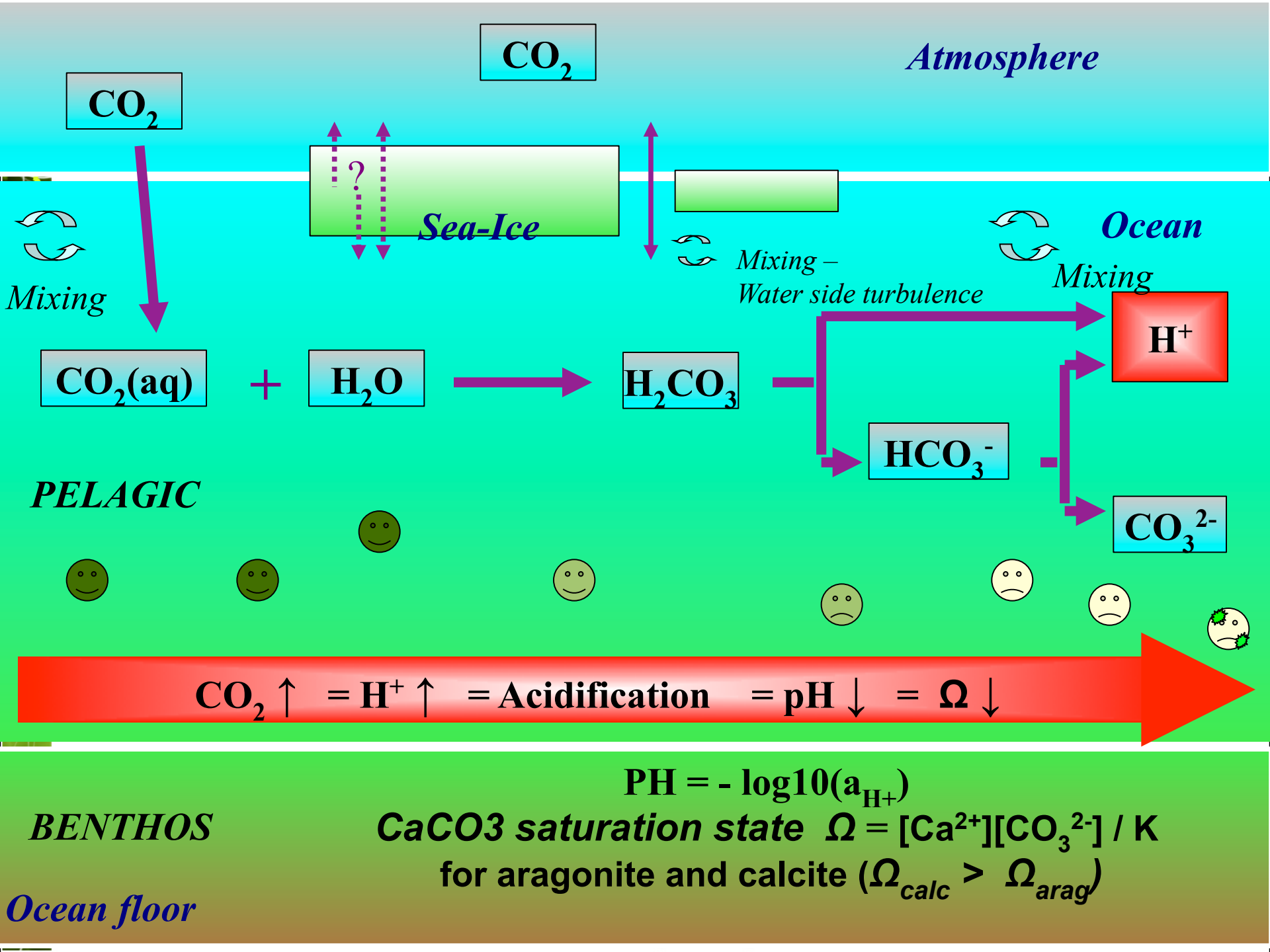
1. Continued (longterm) monitoring stations/sections
2. Combination/Coordination with modelling efforts
3. Increased focus on high resolution/basin scale biogeochemical modelling in the Arctic
4. Consideration of physiological responses in marine organisms to acidification and multi-stressor environments in models

nadja.steiner@ec.gc.ca - nadja.steiner@dfo-mpo.gc.ca

AMAP, 2013



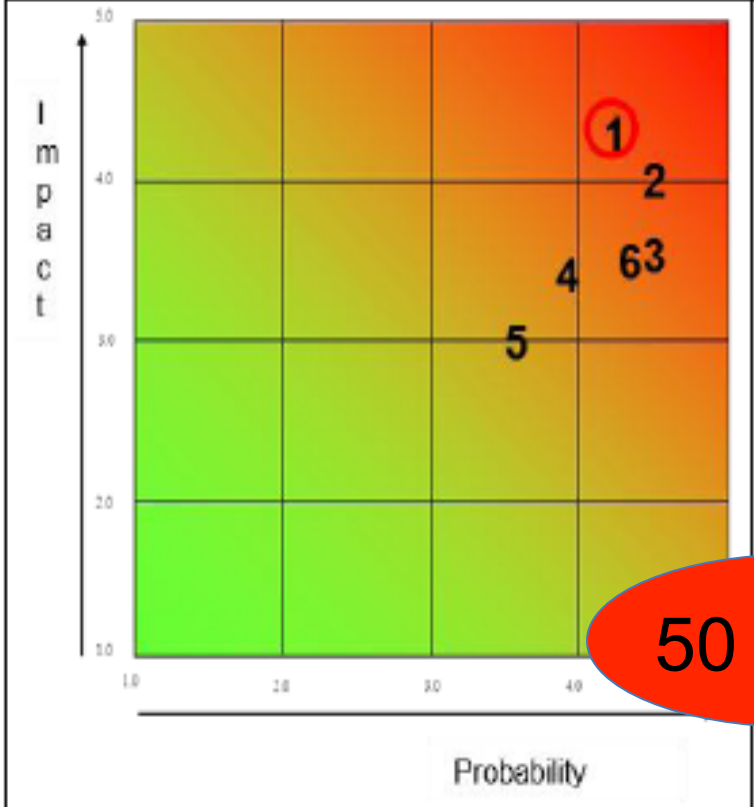
Canada


CO_2
CO_2
Atmosphere
?
Sea-Ice
Mixing
Mixing –
Water side turbulence
Ocean
Mixing
$CO_2(aq)$
+
H_2O
H_2CO_3
H^+
HCO_3^-
CO_3^{2-}
PELAGIC
$CO_2 \uparrow = H^+ \uparrow$ = Acidification = pH ↓ = Ω ↓
BENTHOS
Ocean floor
$PH = - \log10(a_{H+})$
CaCO3 saturation state $\Omega = [Ca^{2+}][CO_3^{2-}] / K$
for aragonite and calcite ($\Omega_{calc} > \Omega_{arag}$)

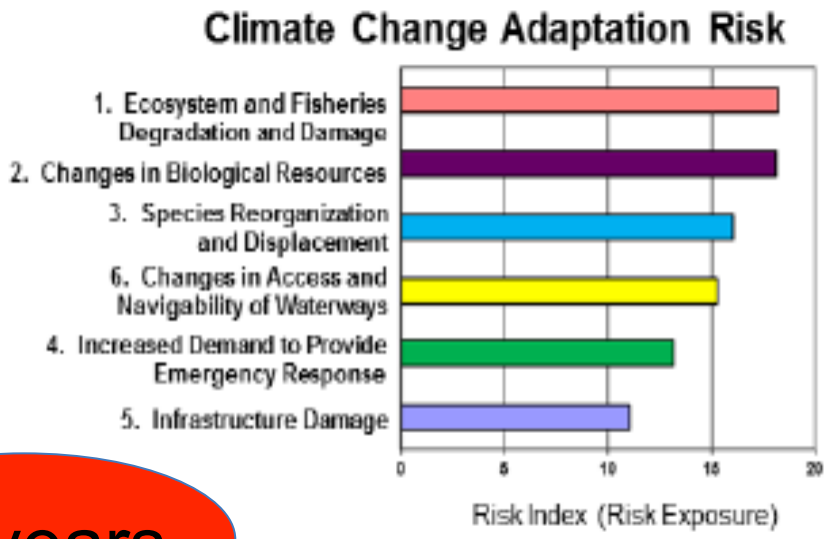
CSAS (Canadian Science Advisory Secretariat) - Risk Analysis

DFO Aquatic Climate Change Adaptation and Services Program (ACCASP- Arctic) "Heat maps" from CSAS reports

Position on Heat Map (50 year Horizon)



Risk Index (Probability x Impact) (50 year Horizon)



50 years

Input: Projections from ESMs