Climate connections to polar marine ecosystems

Dr. Patricia Yager

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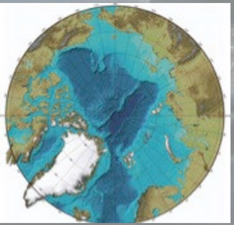



B. Heimlich (UGA)

Themes and ideas

High latitude ecosystems
are changing rapidly

Sea Ice losses
Ice sheet loses

Ecosystem impact is both
regional and global

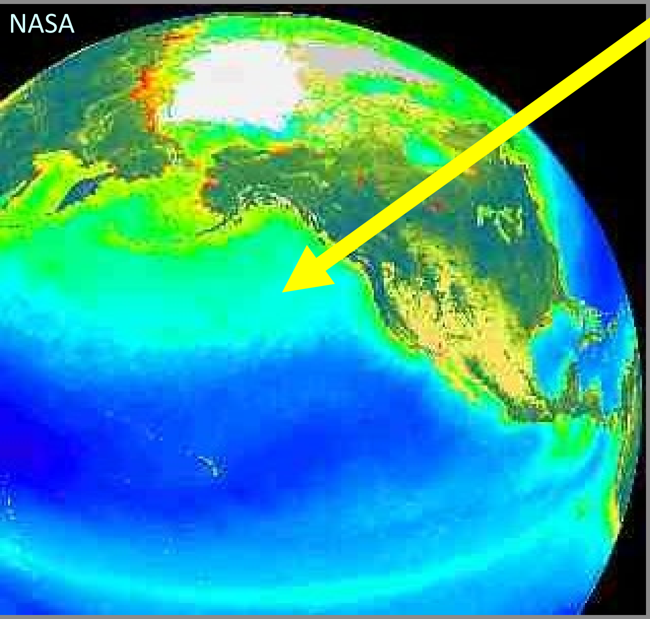
Winners and losers

Biosphere feedbacks to
climate are complex

The source is anthropogenic
– and so is the solution

- Atmospheric CO_2
- Energy Budget
- Temperature
- Precipitation/Runoff
- Winds

Climate change

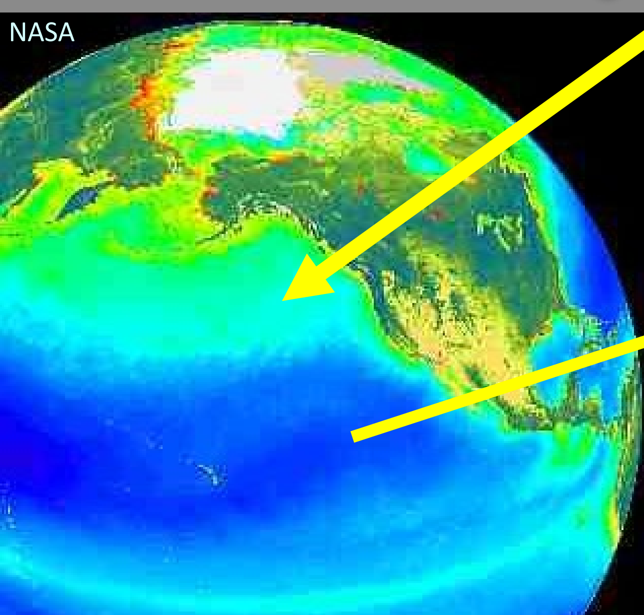


Aris Multimedia Entertainment, Inc. 1994

- Atmospheric CO_2
- Energy Budget
- Temperature
- Precipitation/Runoff
- Winds

Climate change

Ocean response



- Heat and CO_2 absorption
- Currents
- Stratification/Mixing
- Upwelling
- Gas exchange
- Light
- Nutrients

- Atmospheric CO_2
- Energy Budget
- Temperature
- Precipitation/Runoff
- Winds

Climate change

- Heat and CO_2 absorption
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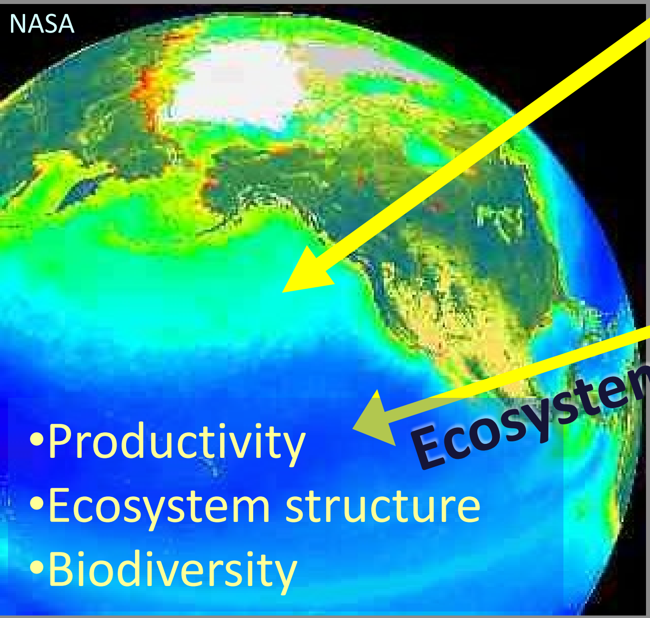
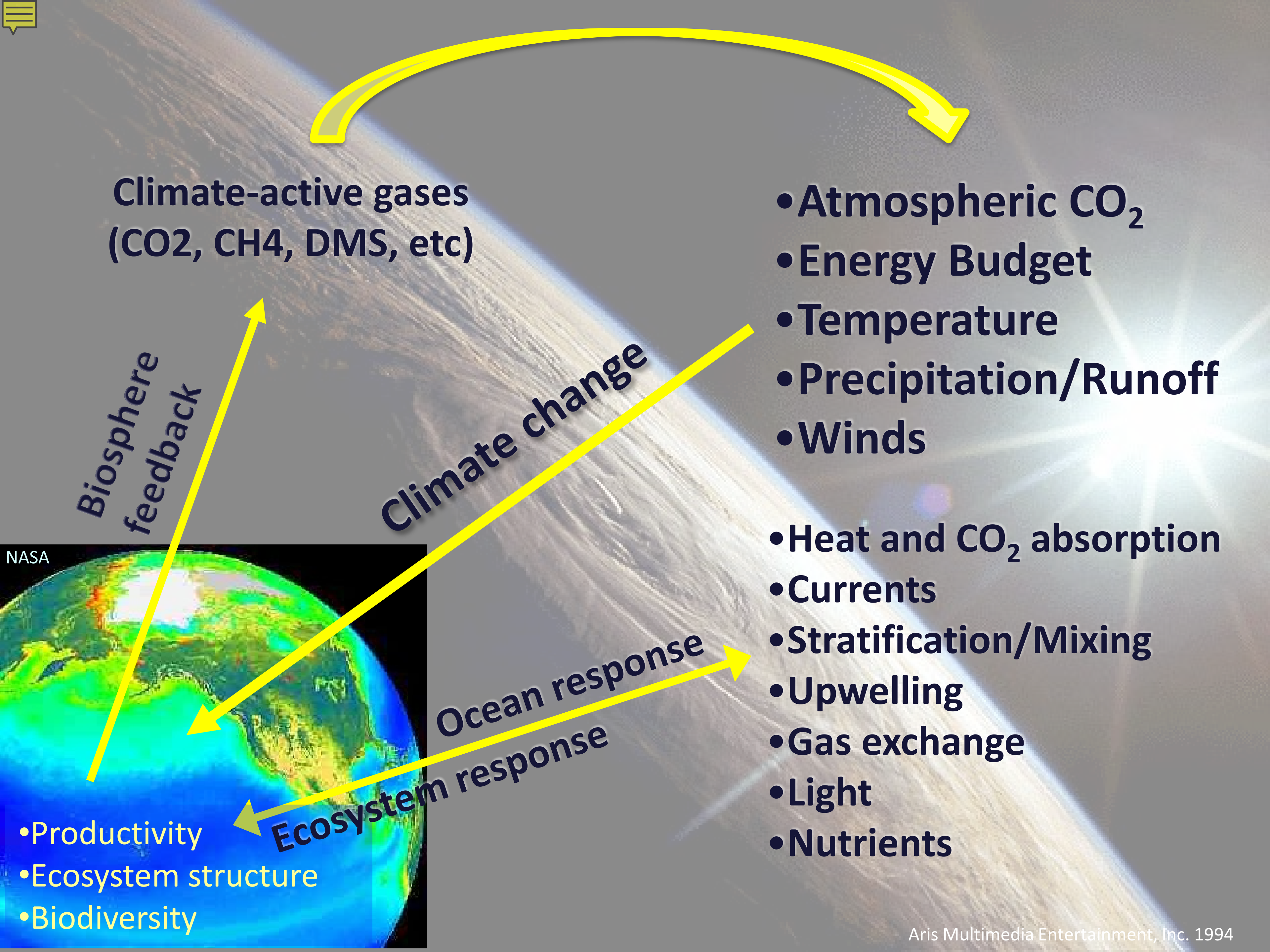
Ocean response

Ecosystem response



- Productivity
- Ecosystem structure
- Biodiversity

Aris Multimedia Entertainment, Inc. 1994



Climate-active gases
(CO2, CH4, DMS, etc)
•Atmospheric CO_2
•Energy Budget
•Temperature
•Precipitation/Runoff
•Winds
Biosphere feedback
Climate change
NASA
•Heat and CO_2 absorption
•Currents
•Stratification/Mixing
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Ecosystem response
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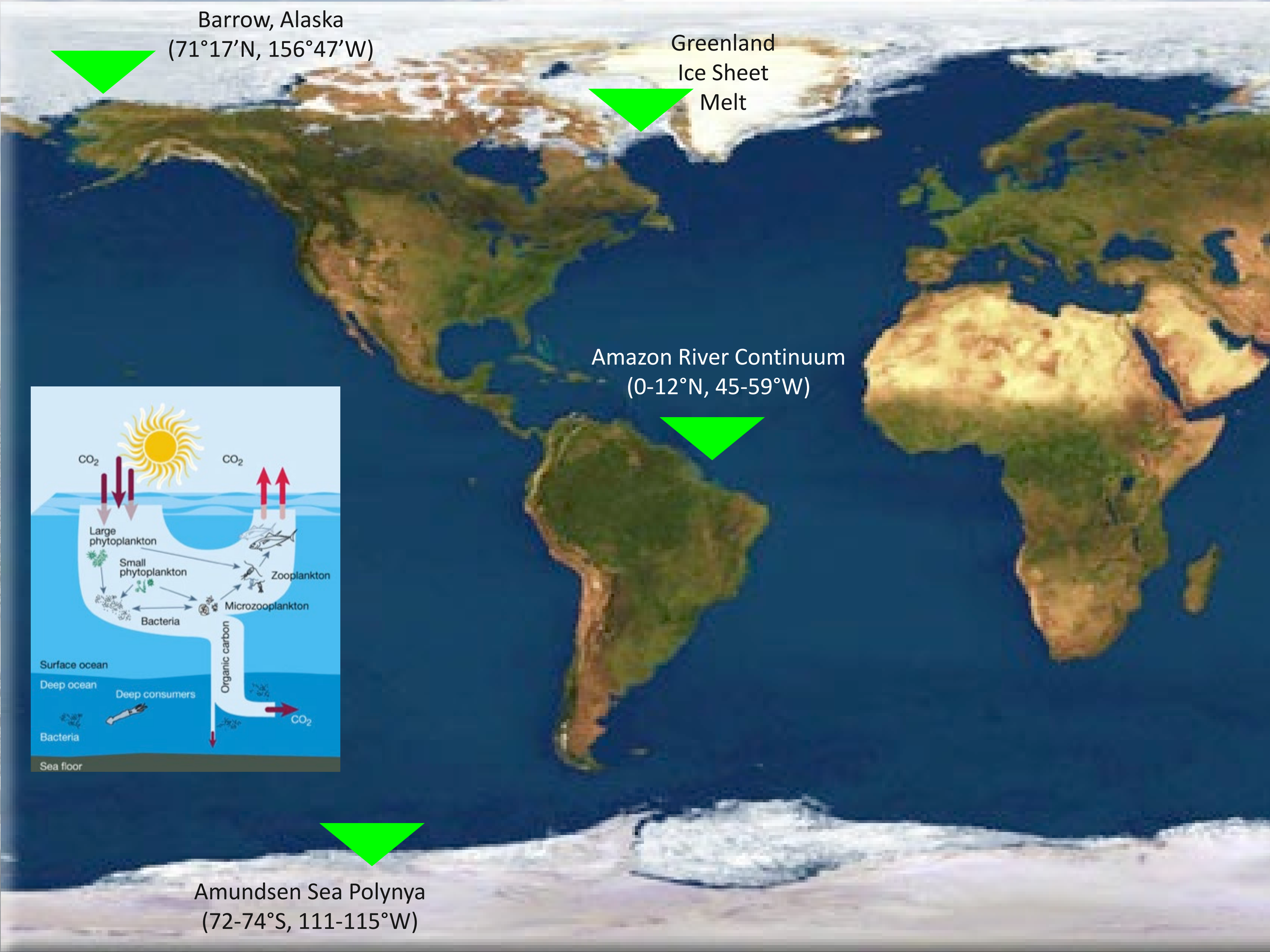
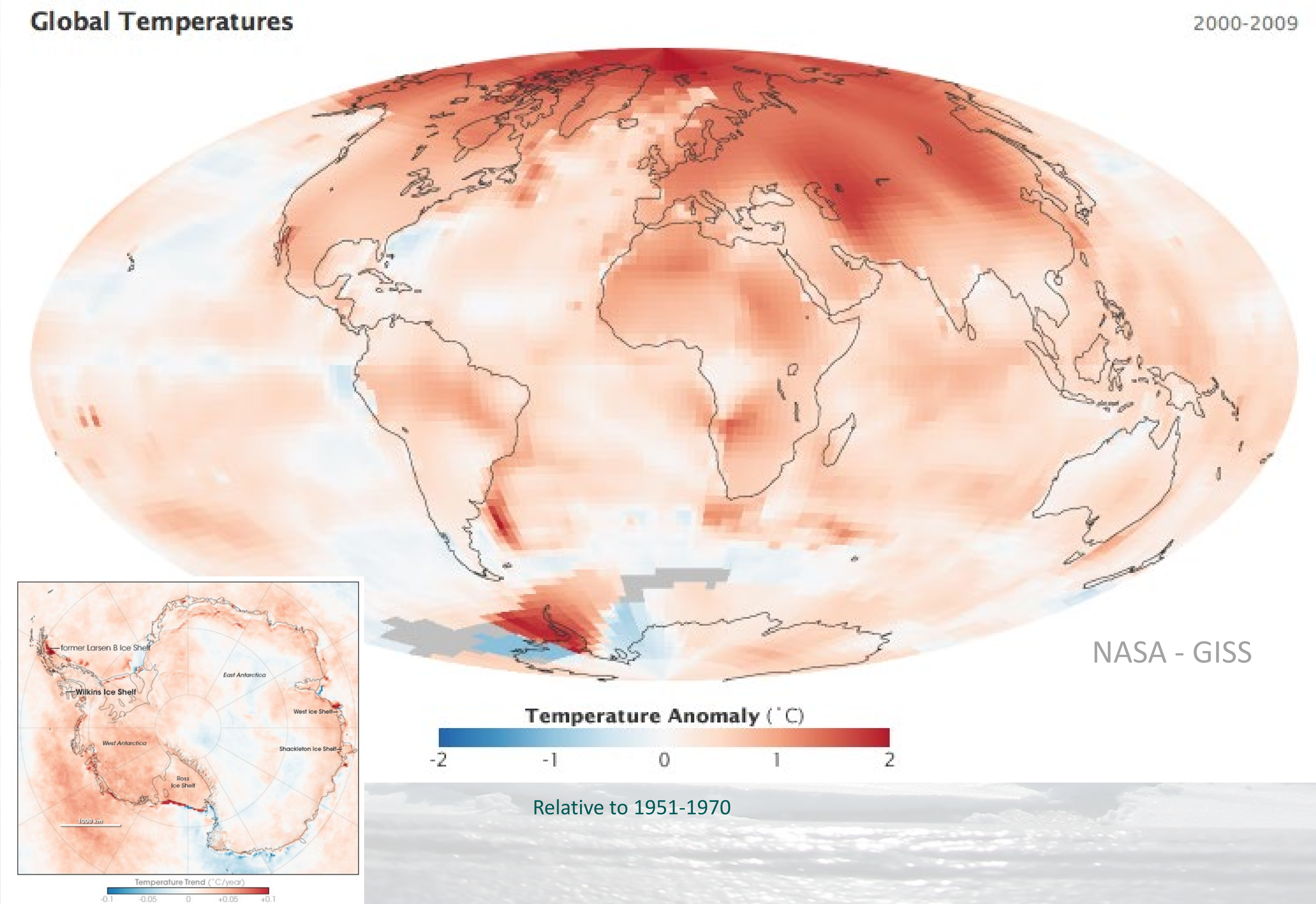


Barrow, Alaska
(71°17’N, 156°47’W)
Greenland
Ice Sheet
Melt
Amazon River Continuum
(0-12°N, 45-59°W)
Amundsen Sea Polynya
(72-74°S, 111-115°W)
CO_2
CO_2
Large
phytoplankton
Small
phytoplankton
Zooplankton
Microzooplankton
Bacteria
Organic carbon
Surface ocean
Deep ocean
Deep consumers
CO_2
Bacteria
Sea floor

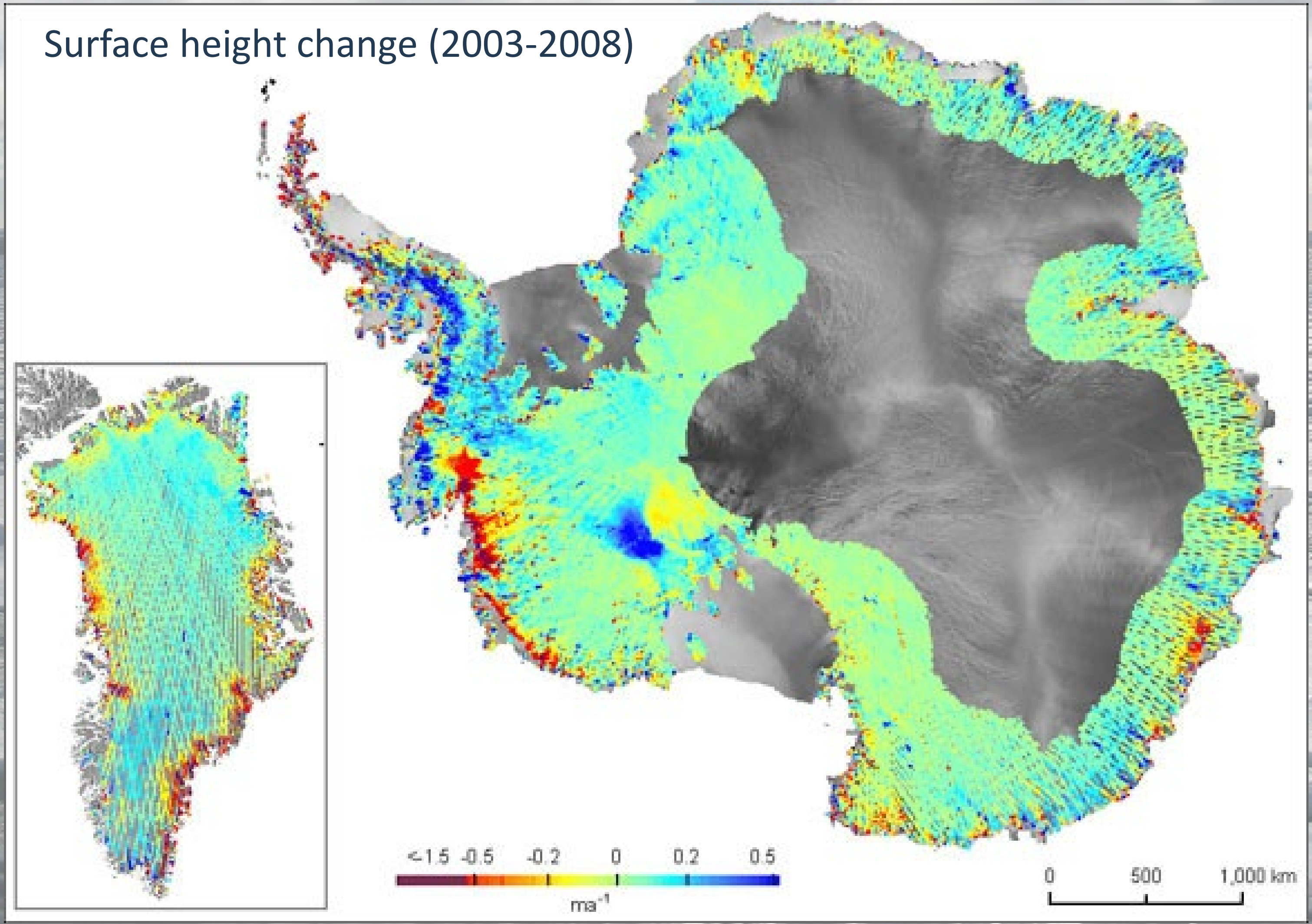
Global average is sum of regional variation…



NASA - GISS

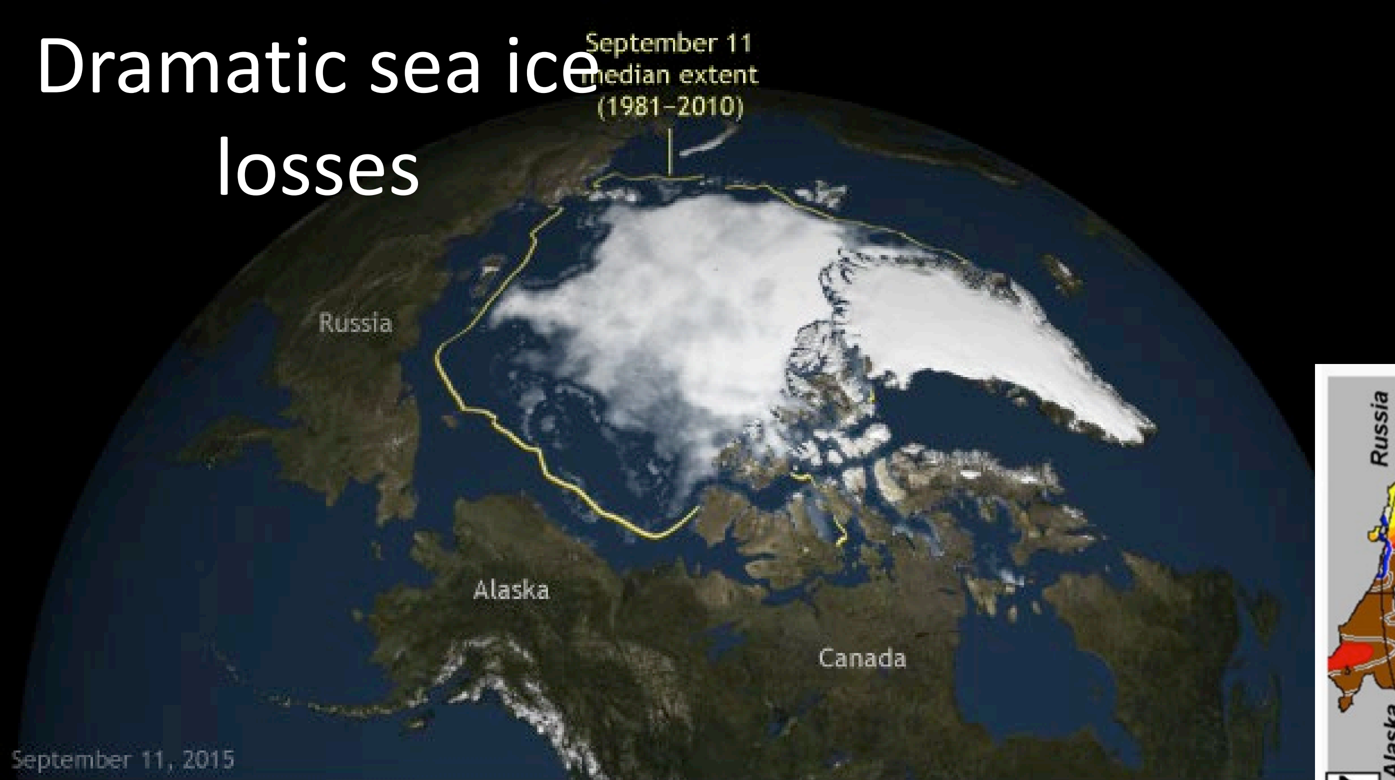
Relative to 1951-1970

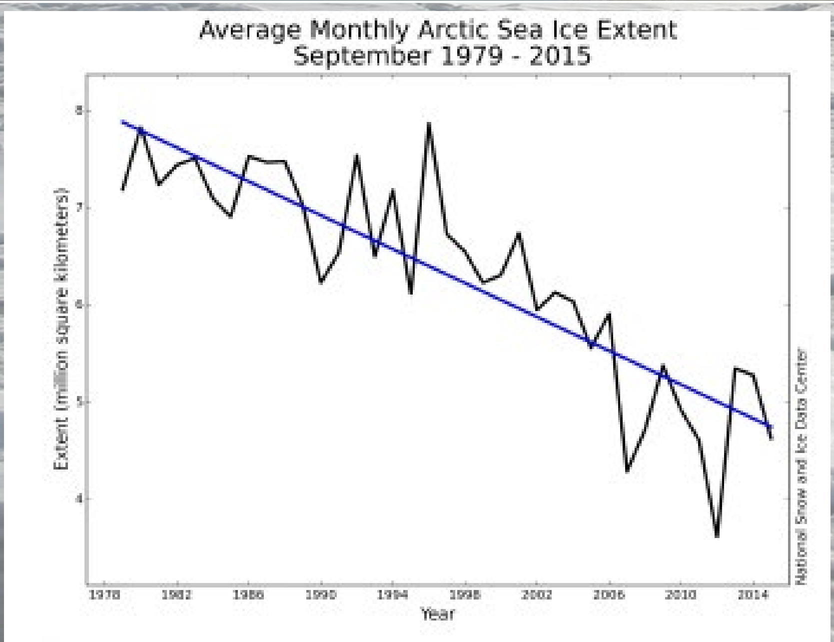
Melt water inputs to the ocean:
H_2O, nutrients, organic matter, sediments



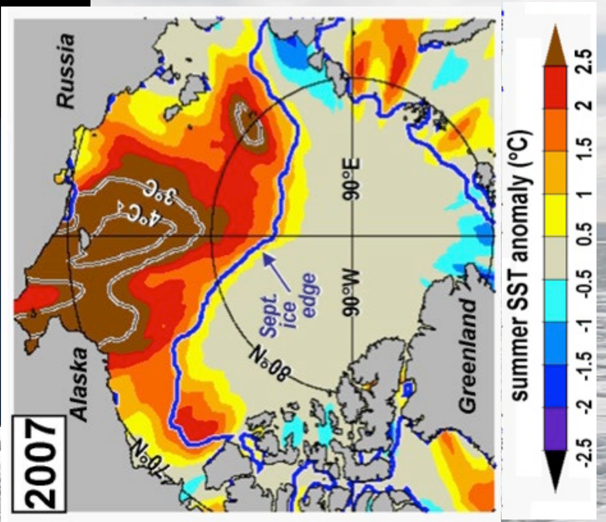
Pritchard et al. 2009

Dramatic sea ice losses

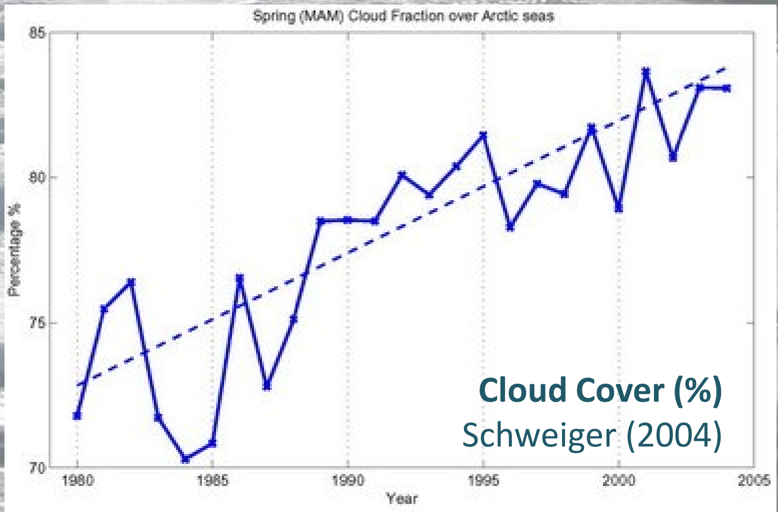




Rising sea surface temperatures and cloud cover

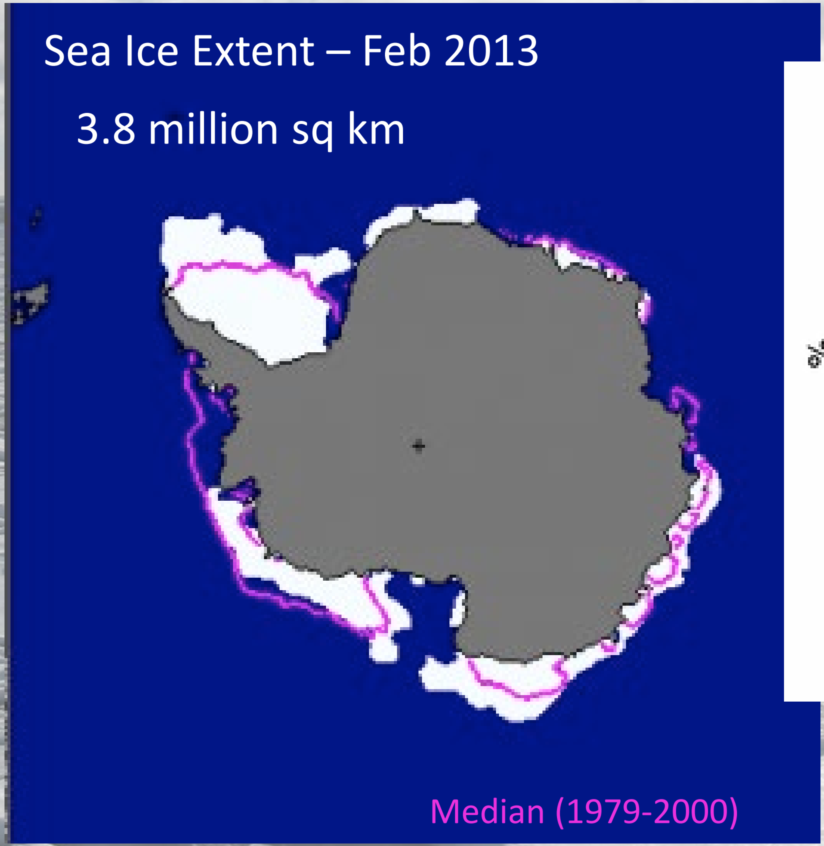


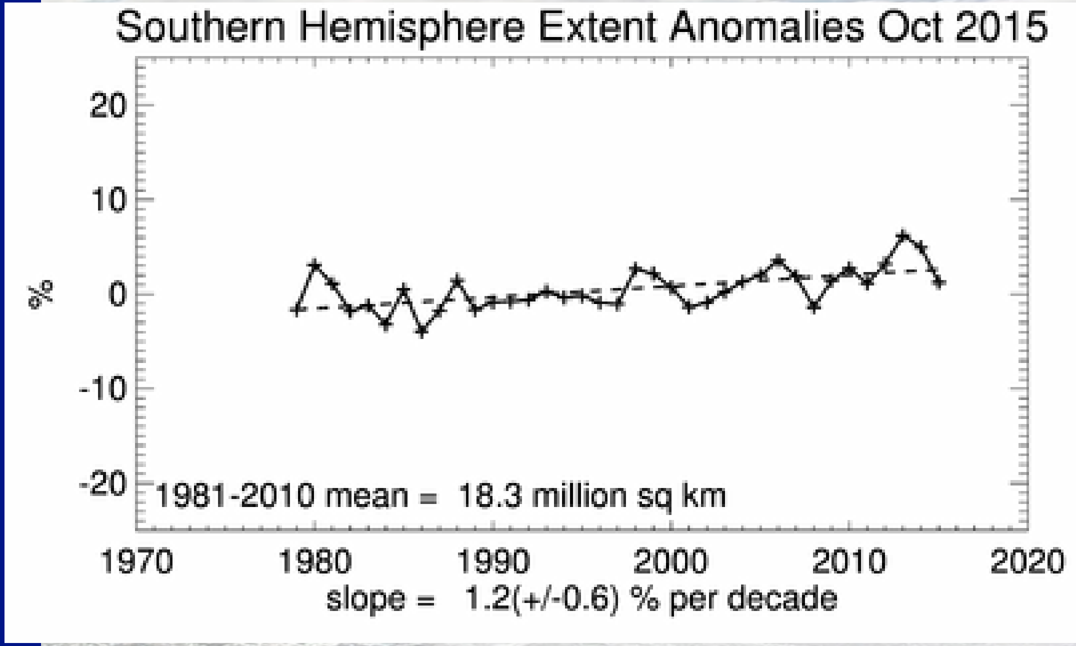
Proshutisnky et al. 2009



Cloud Cover (%)
Schweiger (2004)

Antarctic sea ice extent is a bit of a mixed bag

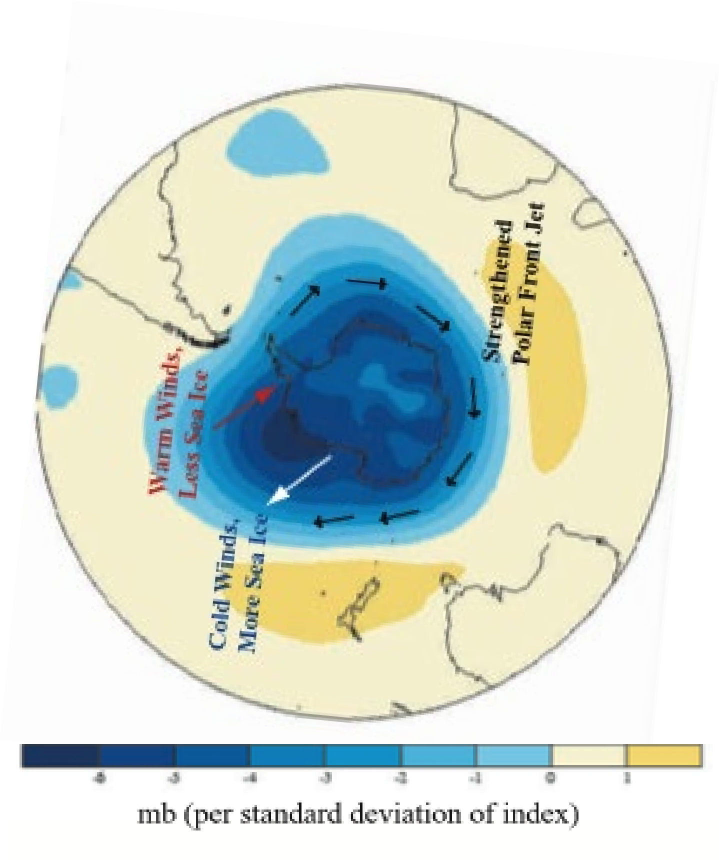




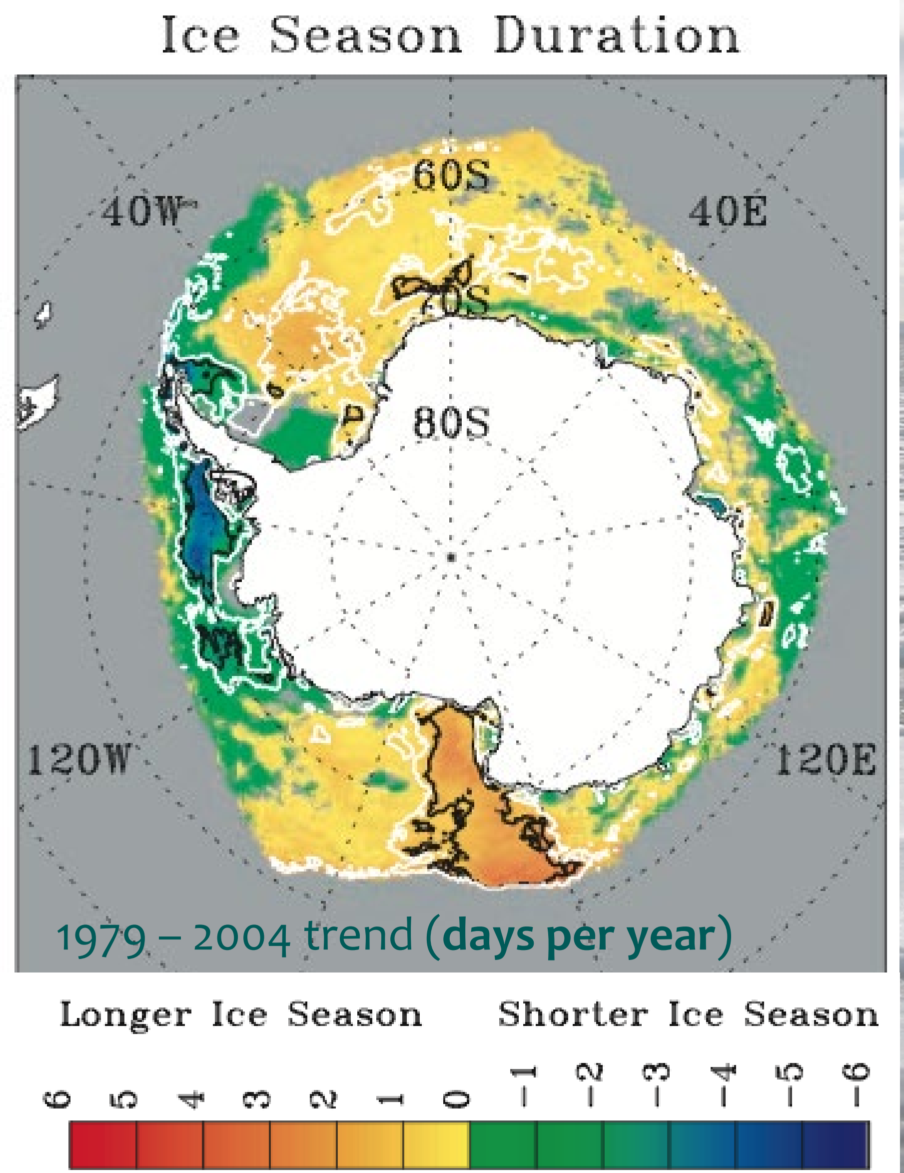
NSIDC

Sea ice in West Antarctica declining rapidly due to changing winds

Stammerjohn et al. 2008, 2012

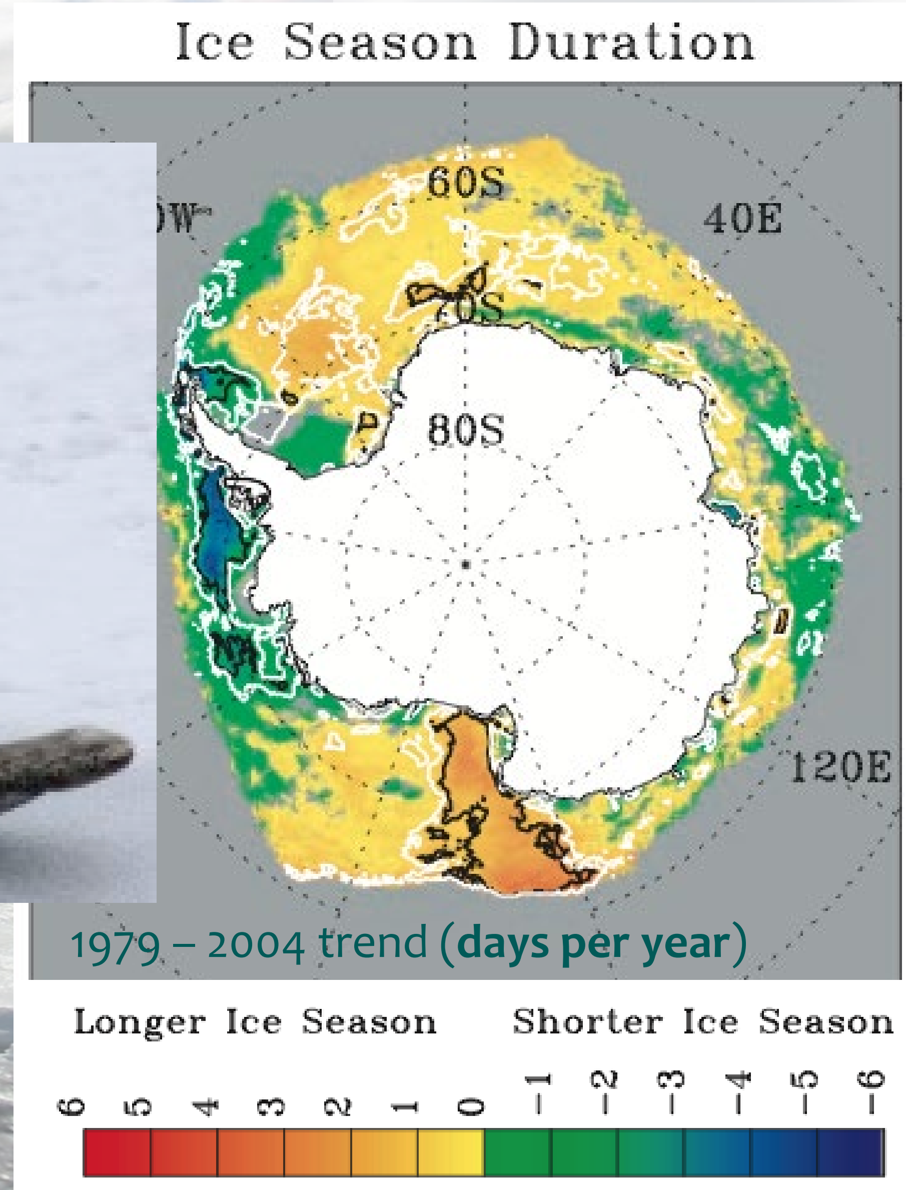


3-4 fewer days of sea ice cover each year over 25 years means
~ 3 months of extra open water yearly



Where would you rather be?

Stammerjohn et al. 2008, 2012



1979 – 2004 trend (**days per year**)

Marine life responds to physical change

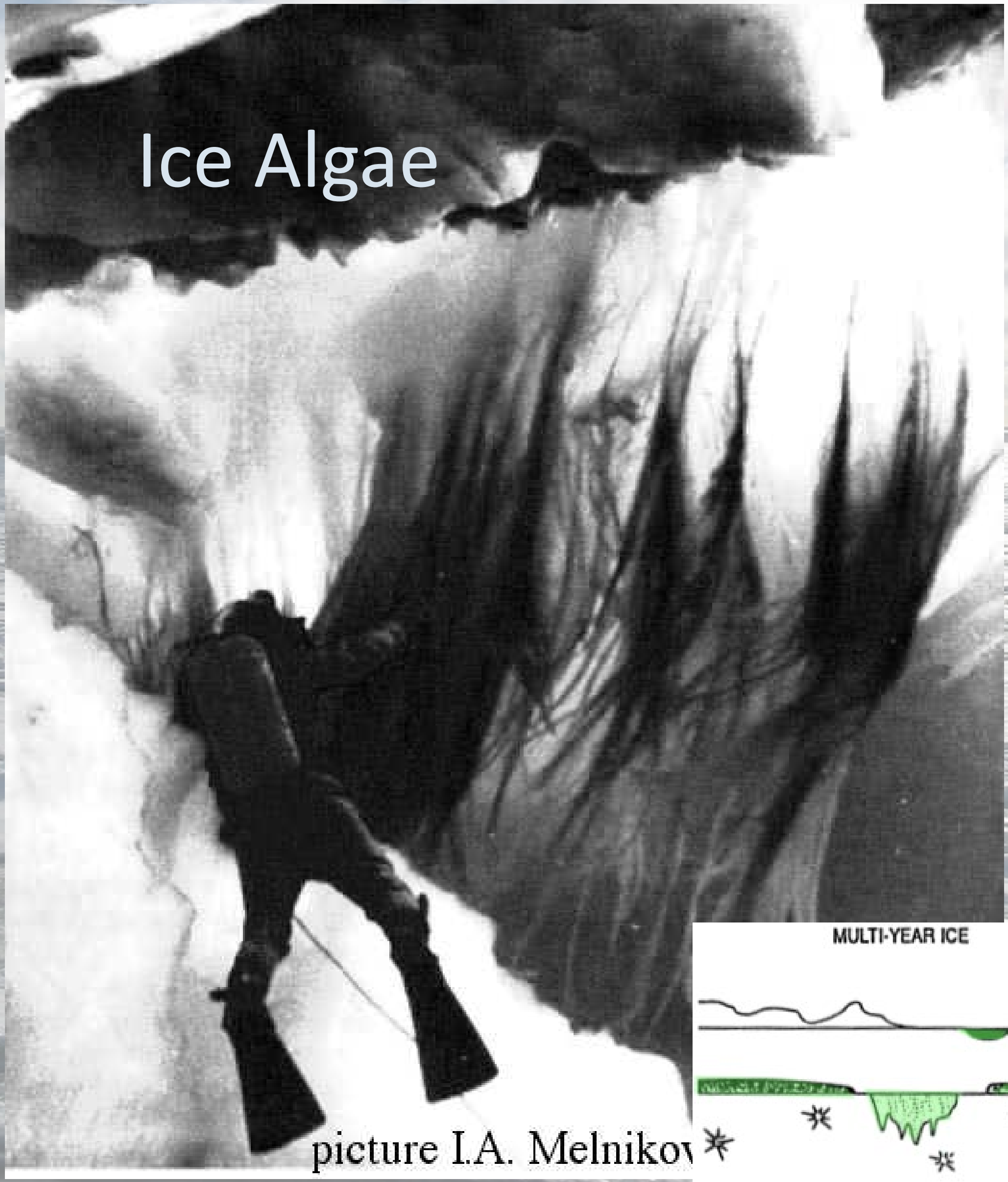
Sea ice itself is critical habitat

Phytoplankton productivity depends on light and nutrients – impacted by freshwater input, mixing, upwelling

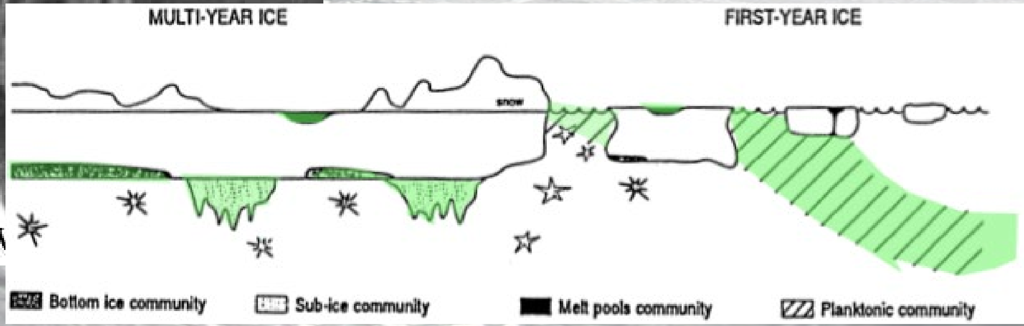
Higher trophics – zooplankton/zoobenthos; birds, mammals, humans depend on productivity

Carbon cycle feedback

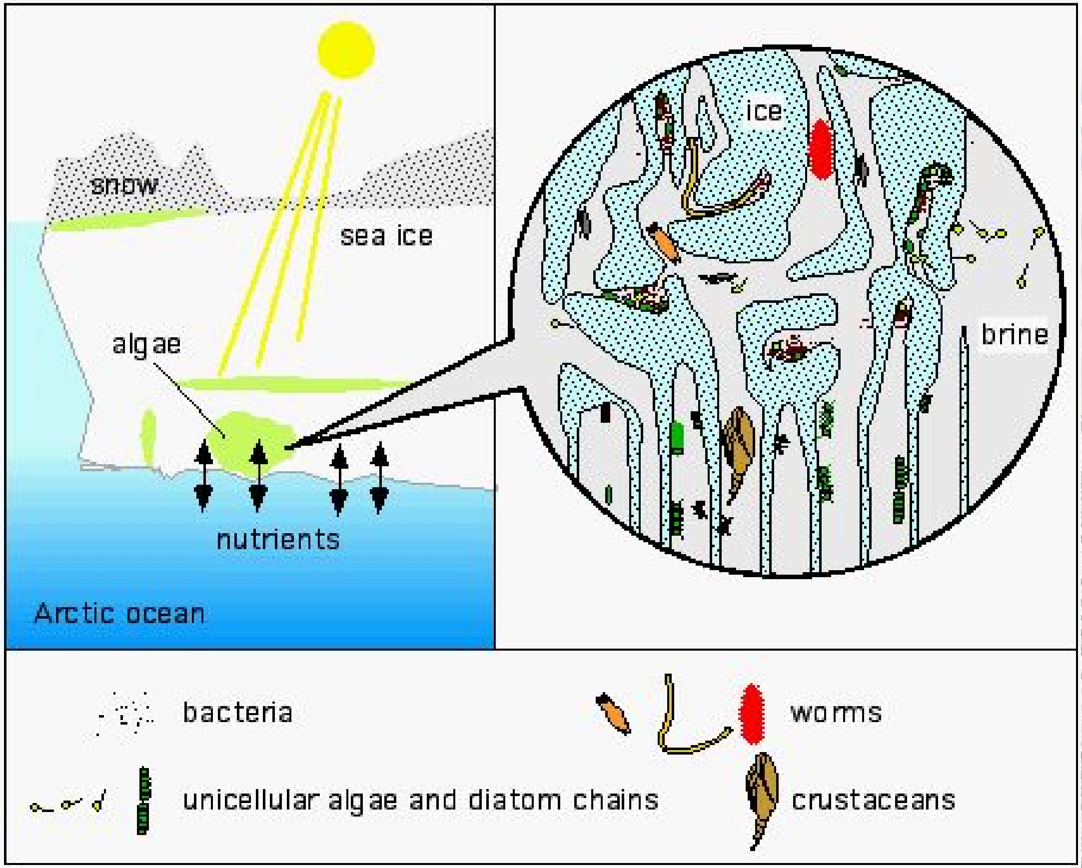
Sea ice itself is critical habitat



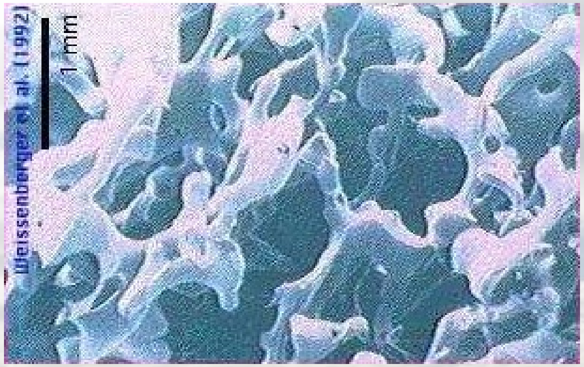
Melnikov and Bondarcher 1987



Sea ice itself is critical habitat

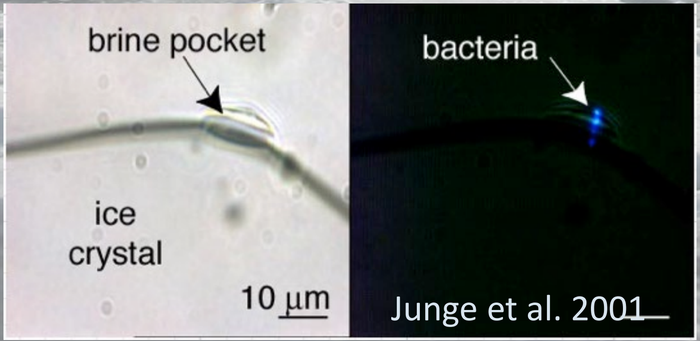


Deming and Krembs



Sea Ice microbiota

Thomas and Dieckmann 2003



Junge et al. 2001

Sea ice itself is critical habitat

Feed
Breed
Hide

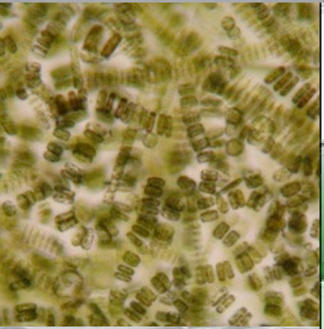
Thomas and Dieckmann 2003

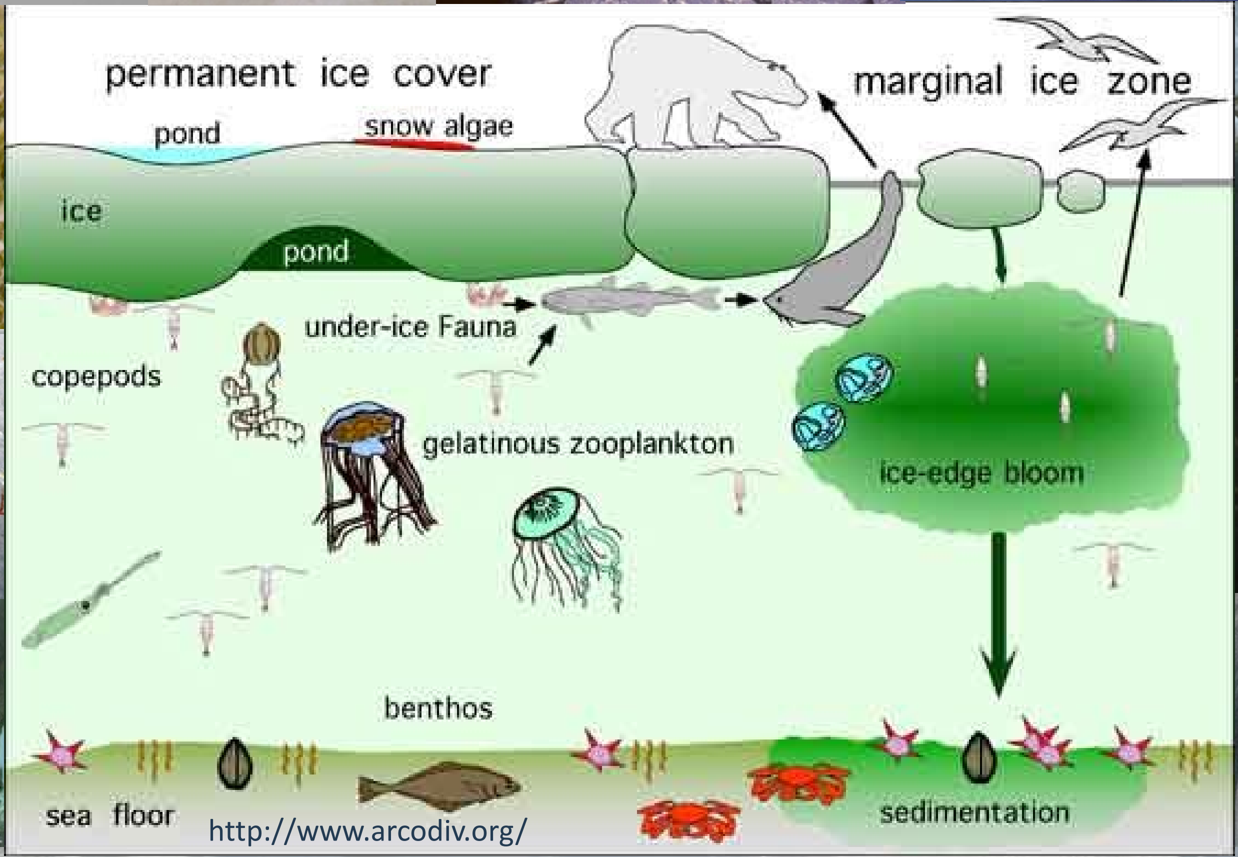
Gradinger and Bluhm 2004

Arctic Marine Food Web





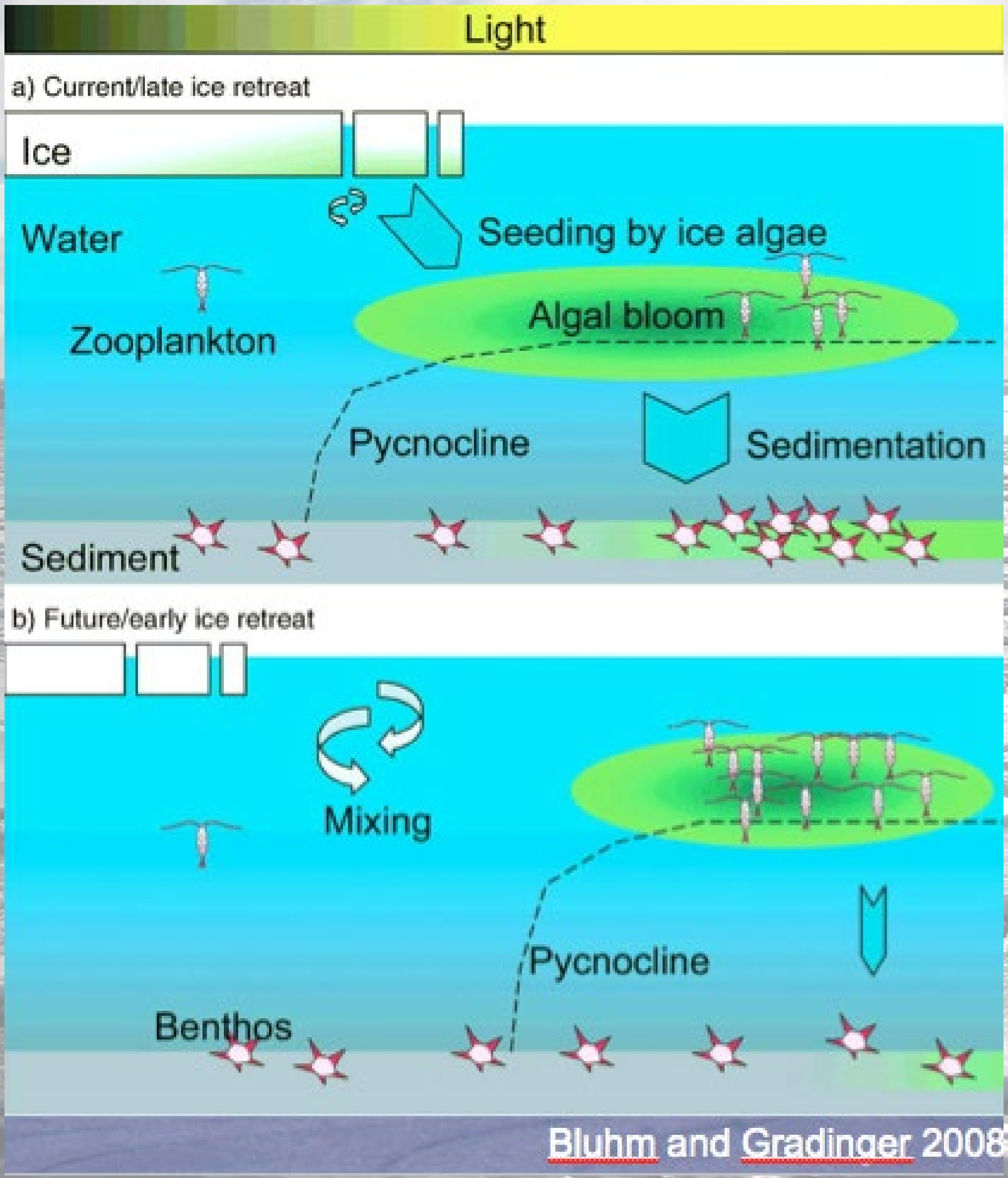





Loss of sea ice reduces sea-ice and benthic food webs

Courtesy J.Grebmeier

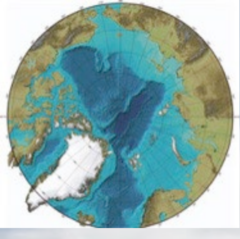
Marine life responds to physical change



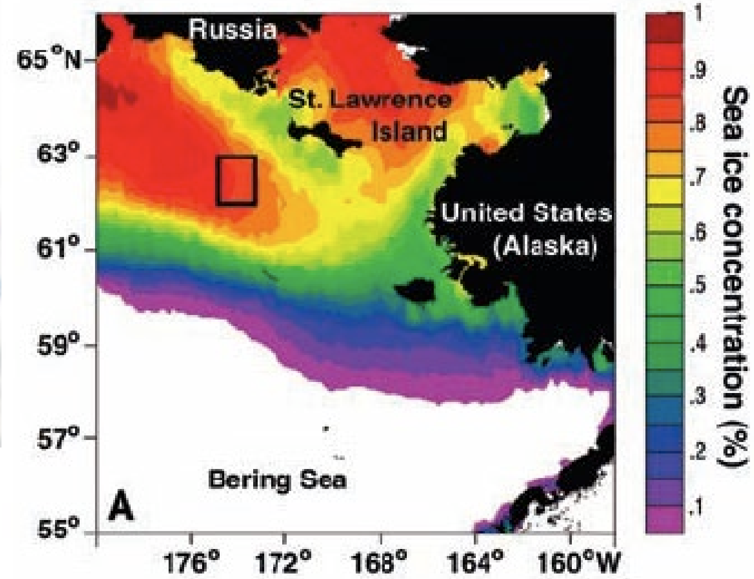
Sunlight cycle not changing

Late ice retreat
- Early bloom
- Benthic production

Early ice retreat
- Late bloom
- Pelagic production



Shifting strengths of benthic versus pelagic food webs – moving north into Arctic



www.sciencemag.org SCIENCE VOL 311 10 MARCH 2006

A Major Ecosystem Shift in the Northern Bering Sea

Jacqueline M. Grebmeier,[1*] James E. Overland,[2] Sue E. Moore,[3] Ed V. Farley,[4] Eddy C. Carmack,[5] Lee W. Cooper,[1] Karen E. Frey,[6] John H. Helle,[4] Fiona A. McLaughlin,[5] S. Lyn McNutt[7]

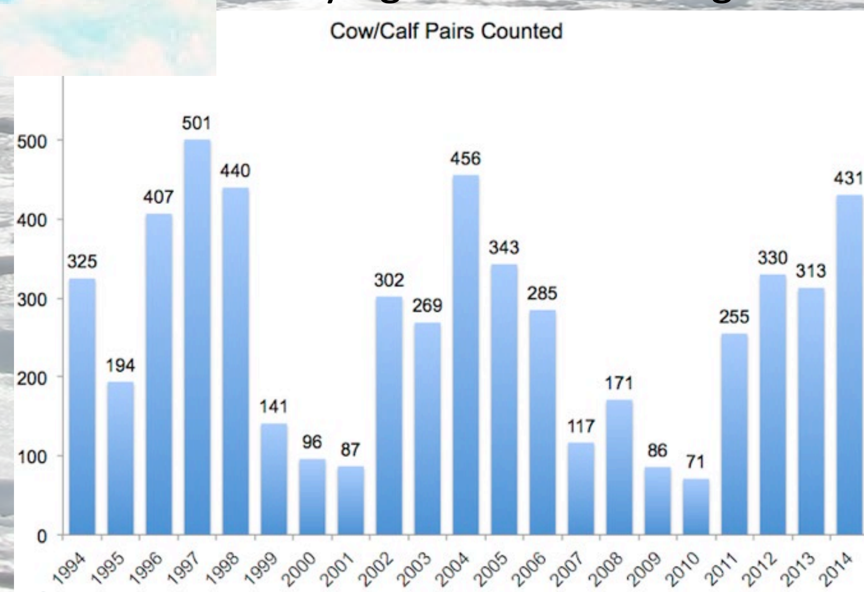
Until recently, northern Bering Sea ecosystems were characterized by extensive seasonal sea ice cover, high water column and sediment carbon production, and tight pelagic-benthic coupling of organic production. Here, we show that these ecosystems are shifting away from these characteristics. Changes in biological communities are contemporaneous with shifts in regional atmospheric and hydrographic forcing. In the past decade, geographic displacement of marine mammal population distributions has coincided with a reduction of benthic prey populations, an increase in pelagic fish, a reduction in sea ice, and an increase in air and ocean temperatures. These changes now observed on the shallow shelf of the northern Bering Sea should be expected to affect a much broader portion of the Pacific-influenced sector of the Arctic Ocean.

Bowhead whale

Planktivorous
Populations improving

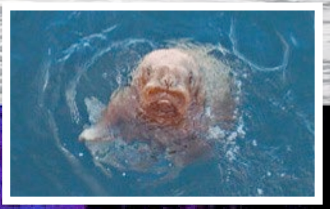
Feeding further north
Delaying southbound migration

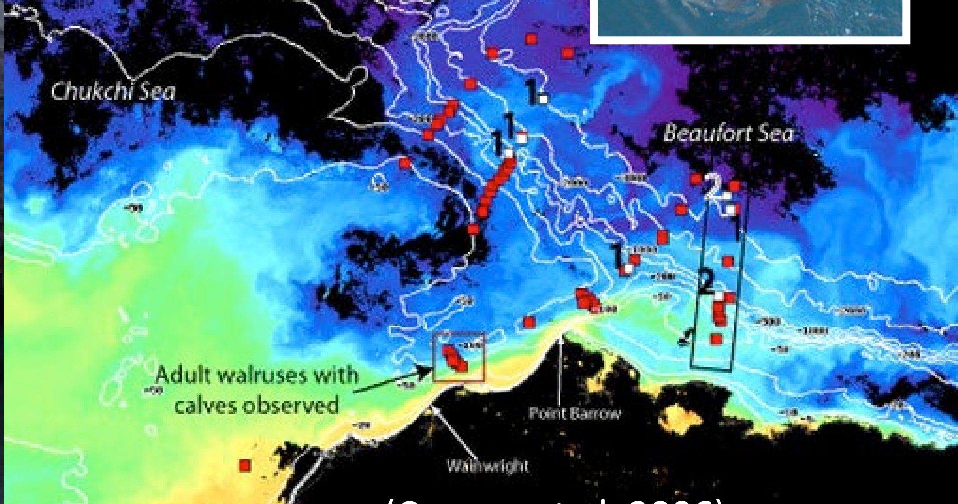
Migrating Gray Whales



Moore et al. 2008

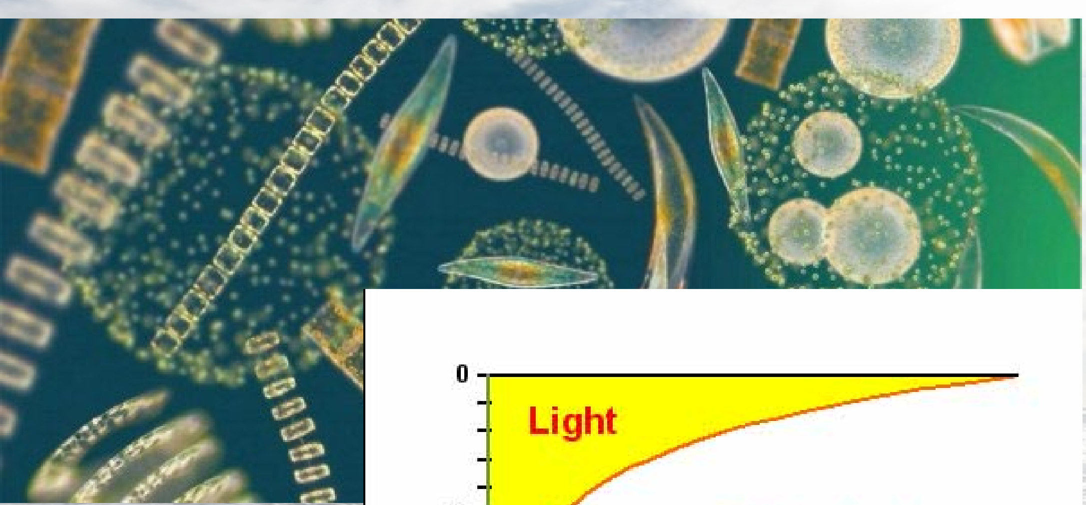
Pacific walrus

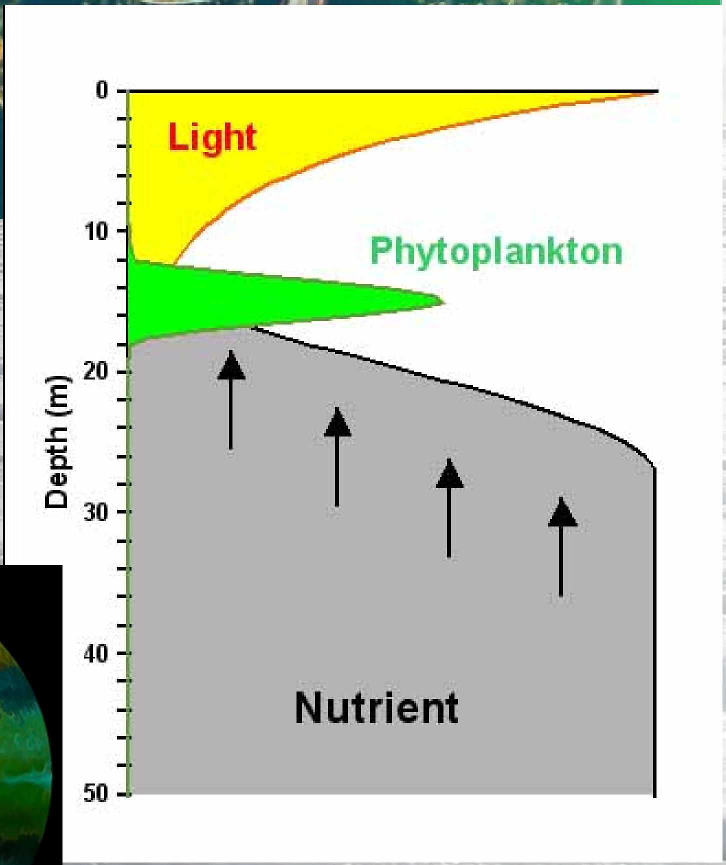


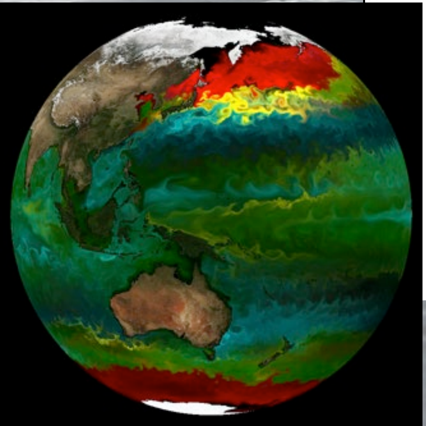


(Cooper et al. 2006)

Open water productivity





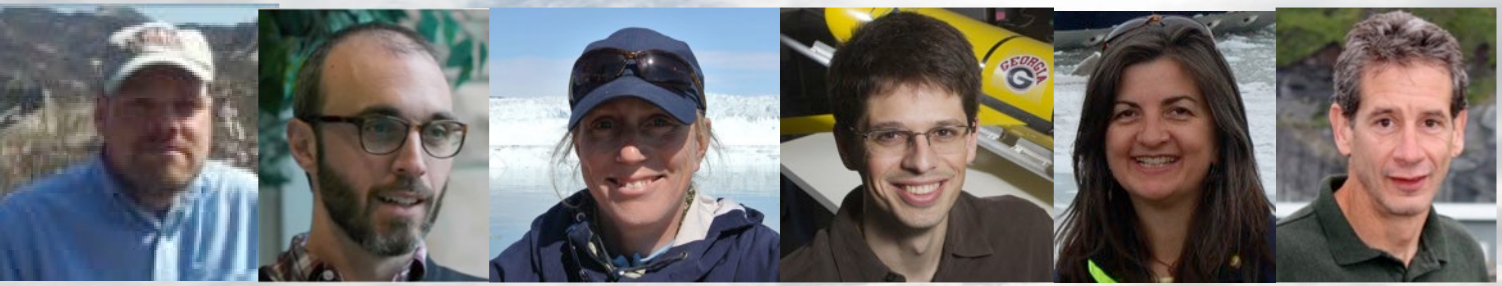


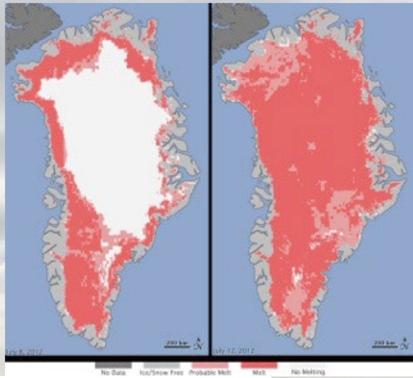
Warmer sea surface temp
Lower sea surface salinity

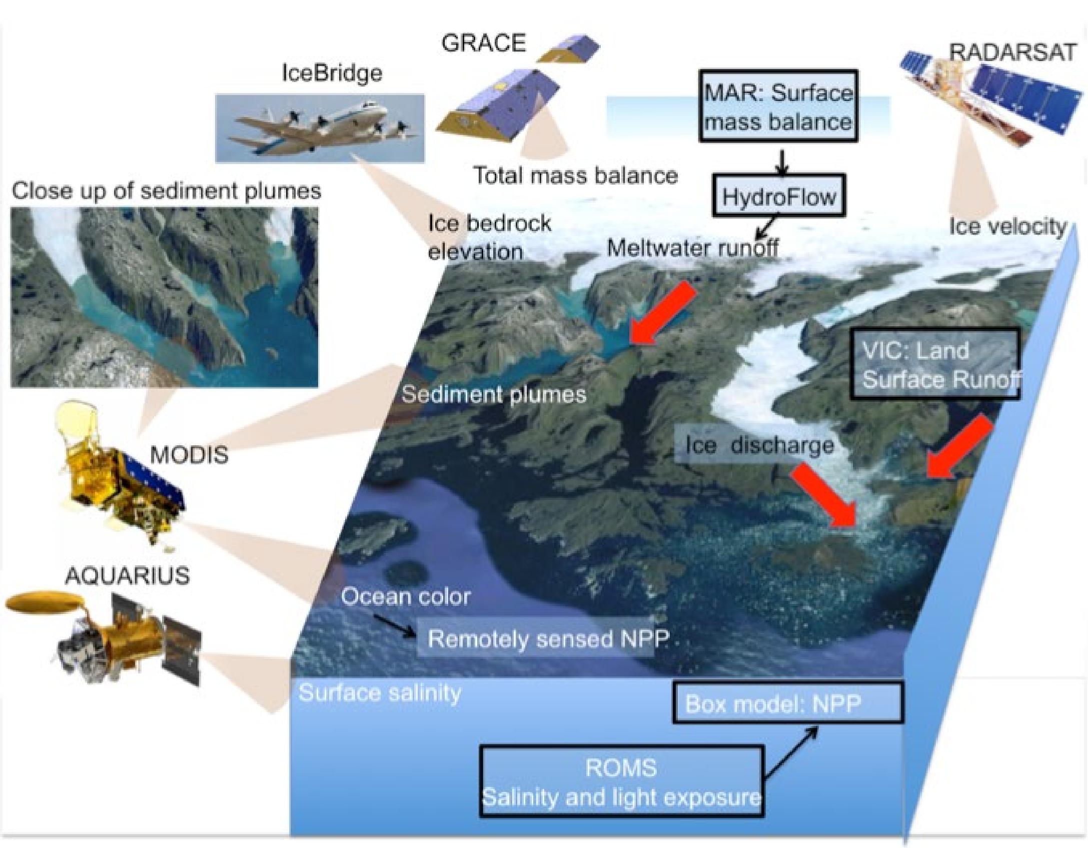
→ Stratification
→ Shallow mixed layer
MORE LIGHT

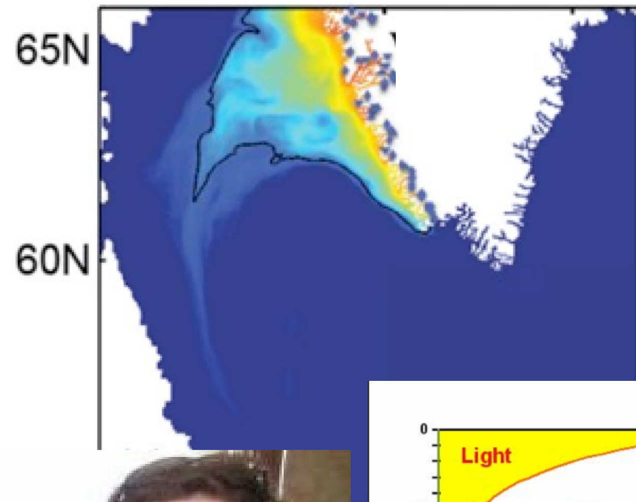
Open water
- → More clouds
- → Greater fetch
- → Deeper mixed layer
- → Wind-driven upwelling
- → Longer growing season

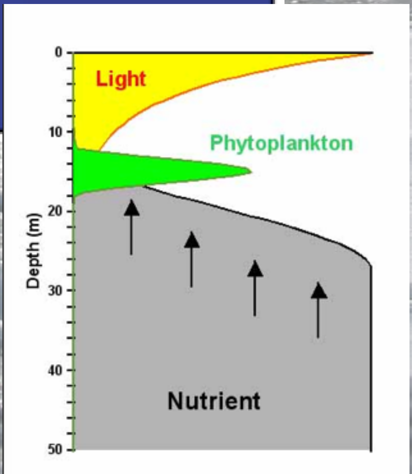
From the Ice Sheet to the Sea: An Interdisciplinary Study of the Impact of Extreme Melt on Ocean Stratification and Productivity near West Greenland



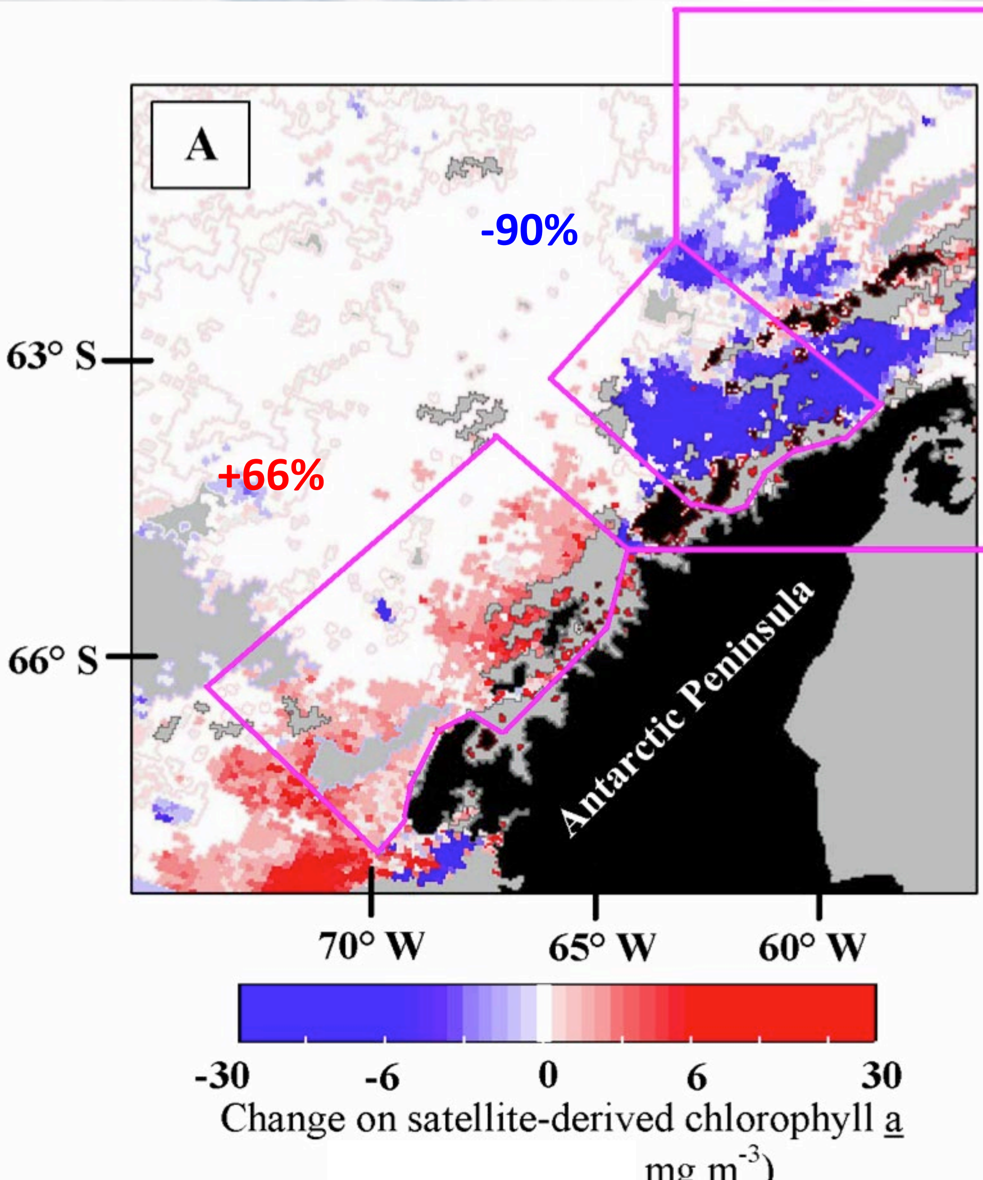








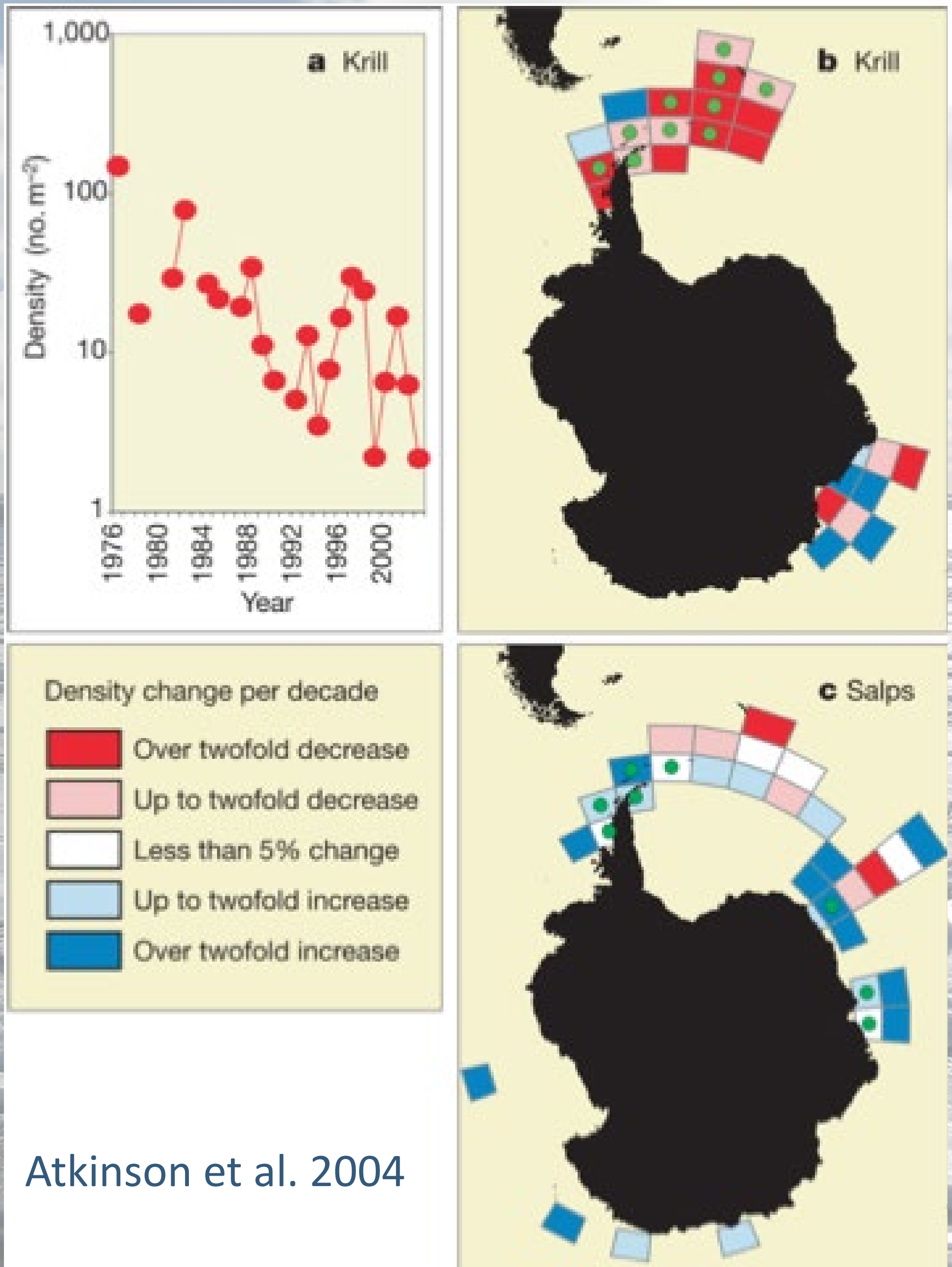
1978-86 (CZCS) to 1998-2006 (SeaWiFS) Phytoplankton Changes:



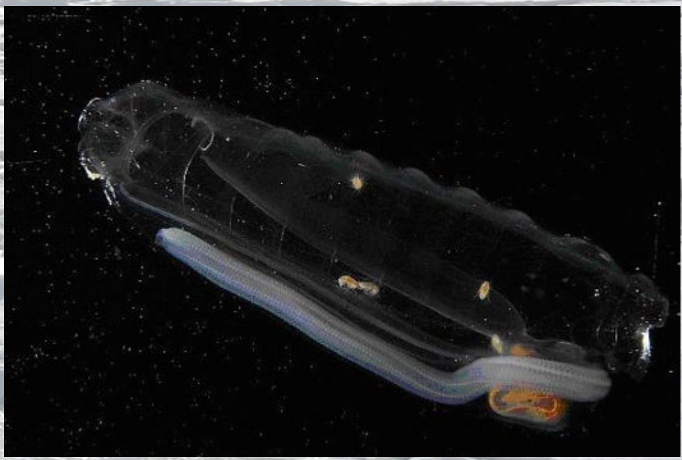
Shift from marginal sea ice zone to open water causes significant decline in productivity

Shift from Ice-covered to marginal sea ice zone causes significant increase in productivity

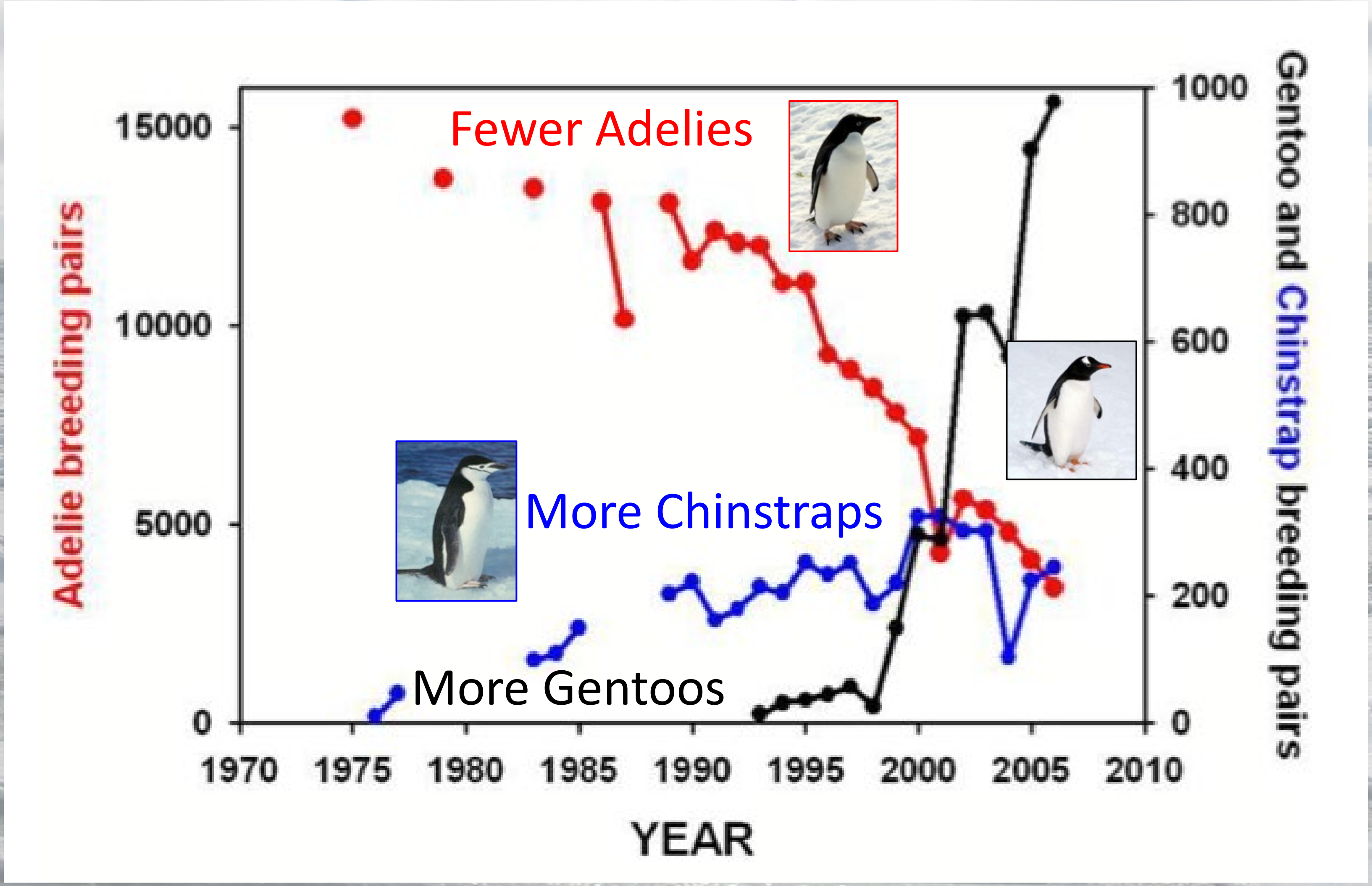
Montes-Hugo et al Science, 2009



Atkinson et al. 2004



Penguin Populations in the Palmer Station region
(75% decline since 1975)



Population trends for three penguin species in the Anvers Island vicinity (West Antarctic Peninsula), 1975-2003, 1975-2006. Graph courtesy of W.R. Fraser and Palmer LTER, see also Ducklow et al., 2007

Seabirds


Atlantic puffin

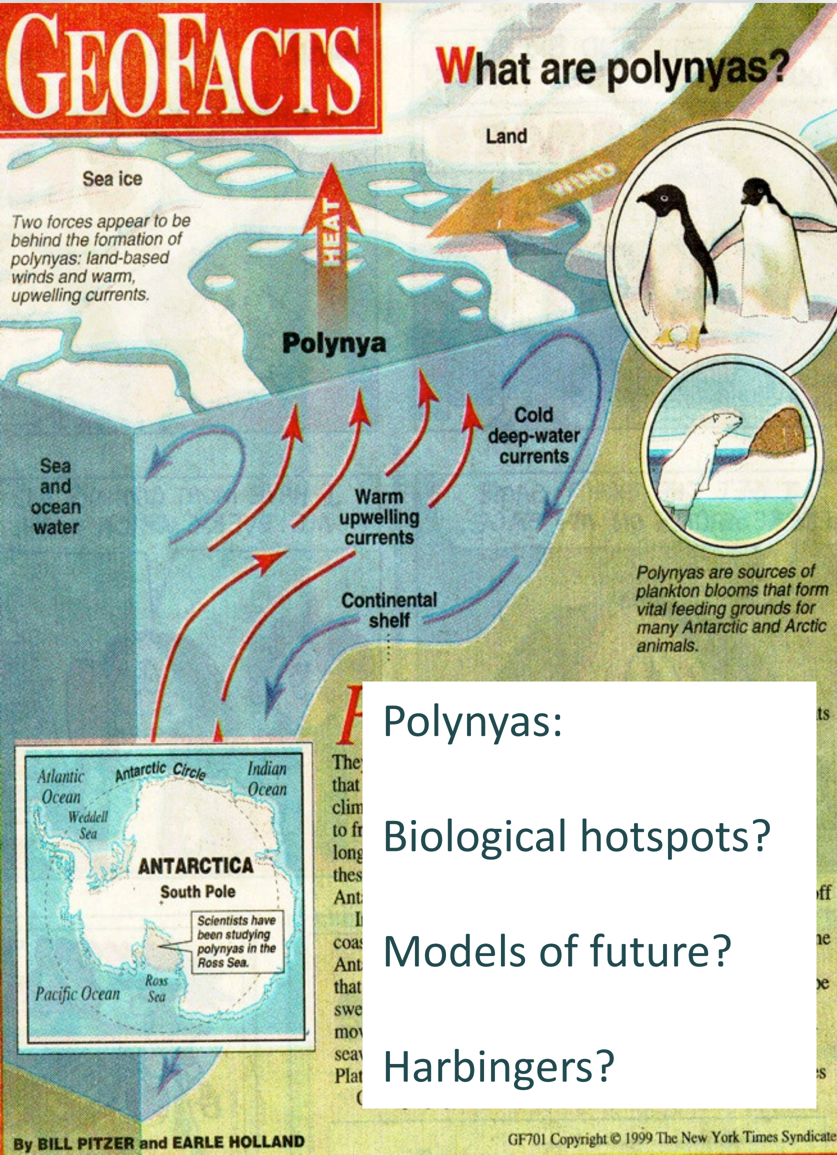

Razorbills


Arctic tern


Dovekie


Arctic tern chick

What's a Polynya?

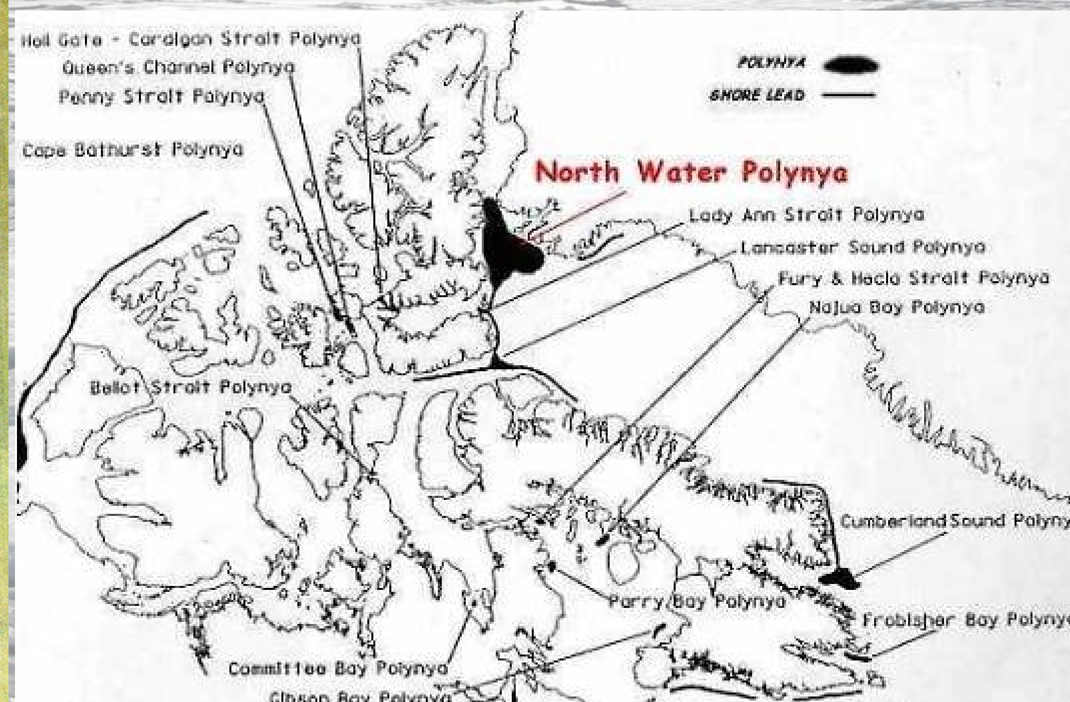


Polynyas:

Biological hotspots?

Models of future?

Harbingers?



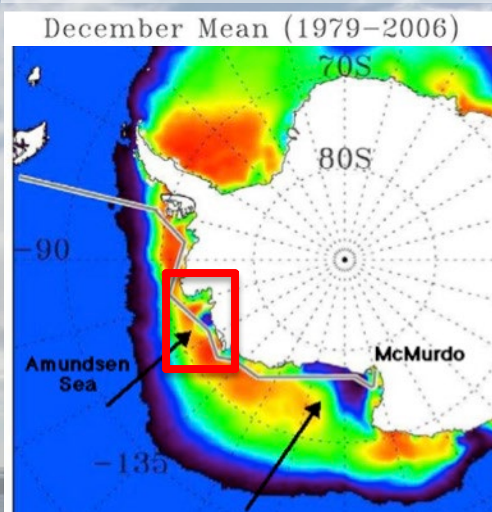
Amundsen Sea Polynya International Research Expedition

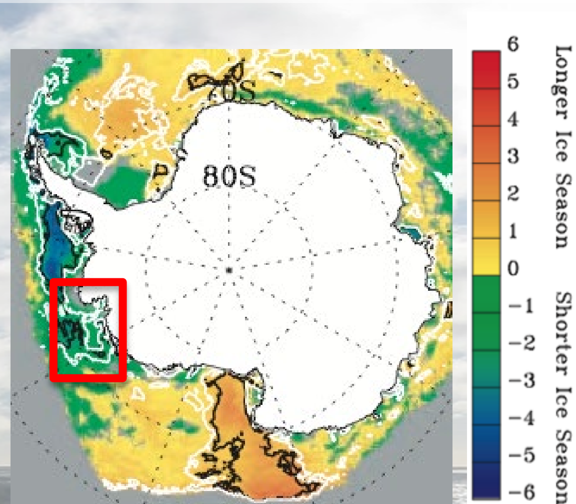
ASPIRE

AntarcticASPIRE.org

Yager et al. 2012; *Oceanography*

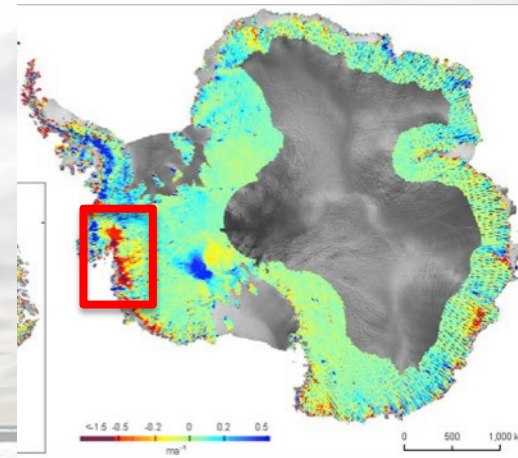
The Amundsen Sea Polynya





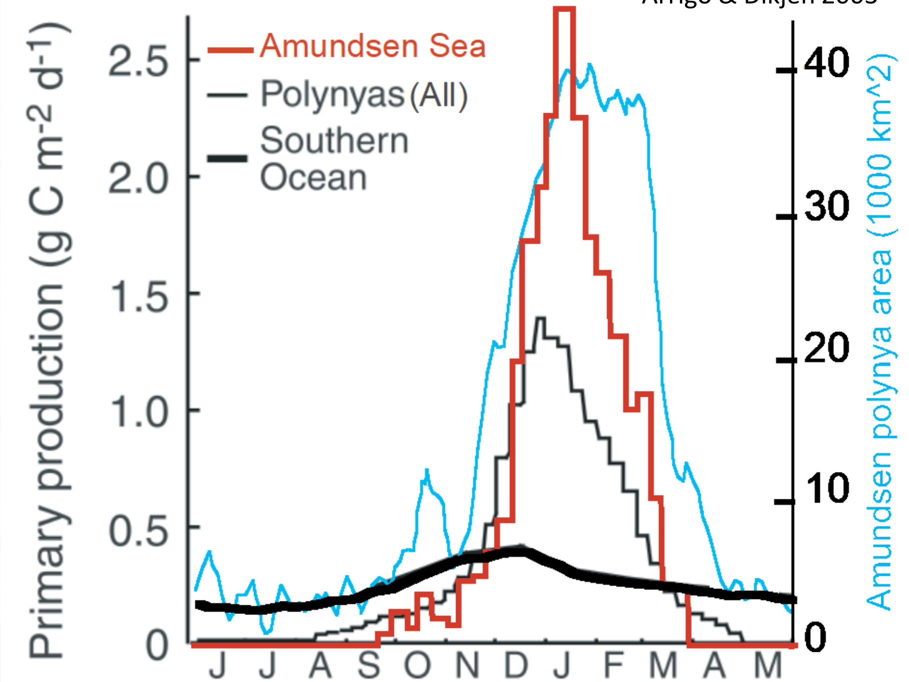
Stammerjohn et al. 2008

Surface height change (2003-2008)

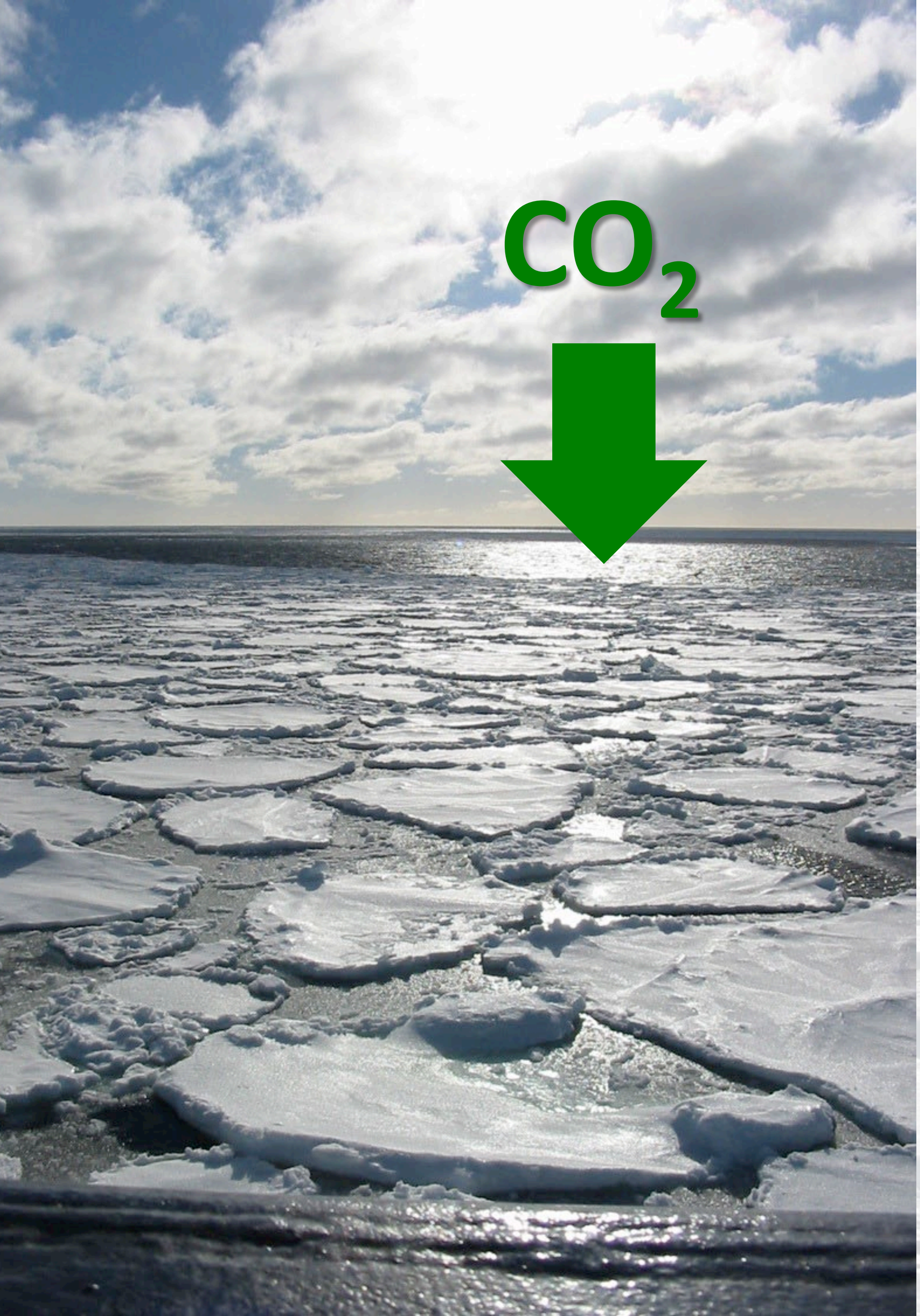


Pritchard et al. 2009

Arrigo & Dikjen 2003

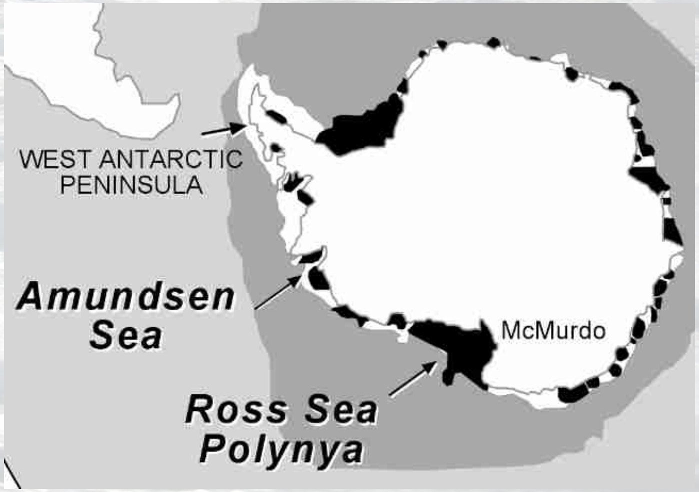


- Fourth largest Antarctic polynya
- Highest peak + seasonal mean chlorophyll *a*
- Greatest primary productivity per unit area
- Greatest interannual variability - *WHY?*
- Experiencing large declines in sea ice cover
- Experiencing rapid ice sheet melt nearby



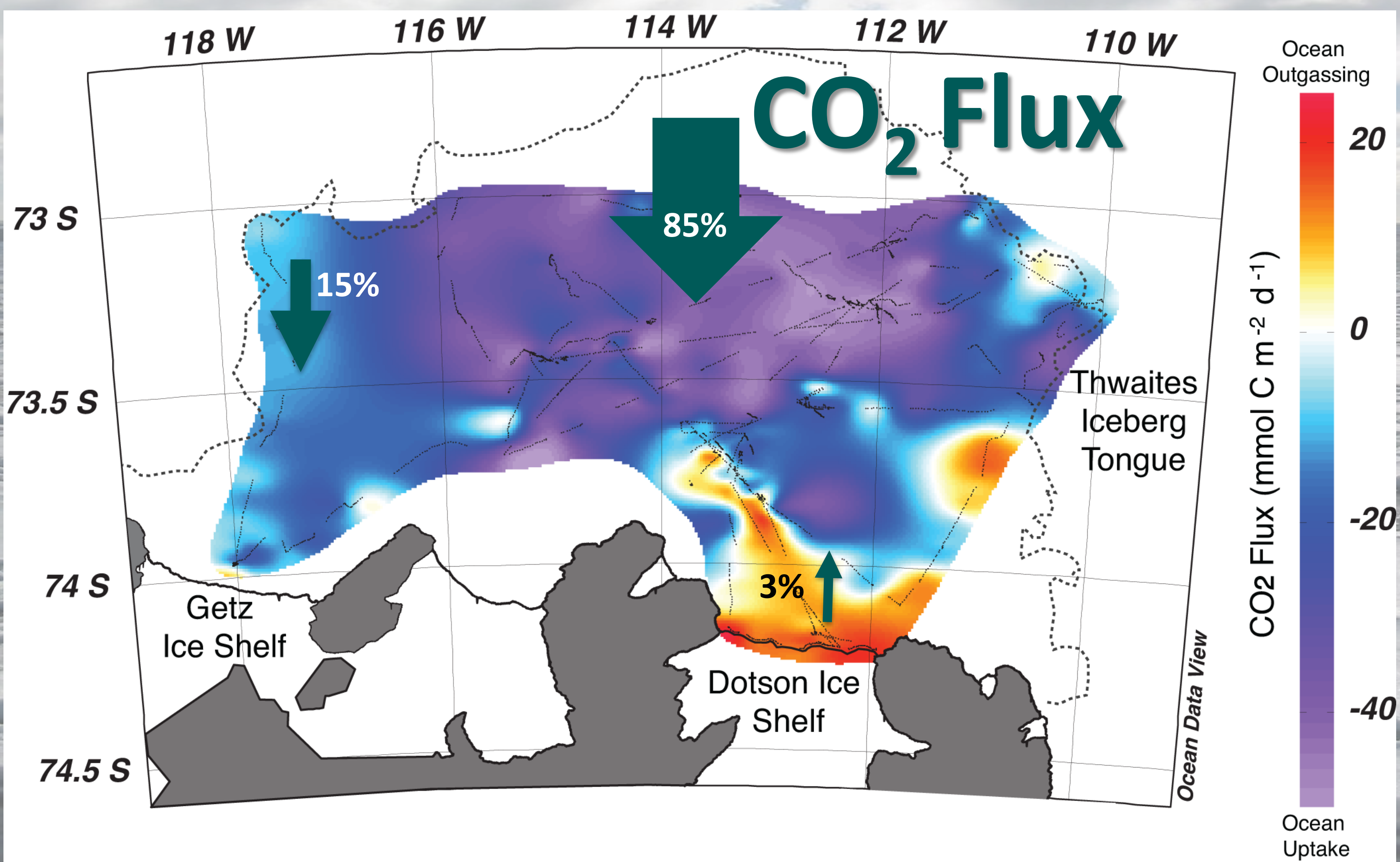
How is the Amundsen Sea polynya taking up so much CO_2 from the atmosphere?

Is this sink climate sensitive?



High spatial variability (-52 to 25 mmol C m^{-2} d^{-1})
Central polynya: UPTAKE = -36 ± 8 mmol C m^{-2} d^{-1}
(greater than most shelves; 50% larger than Ross Sea; ~ Chukchi Sea)

Mu et al. 2014



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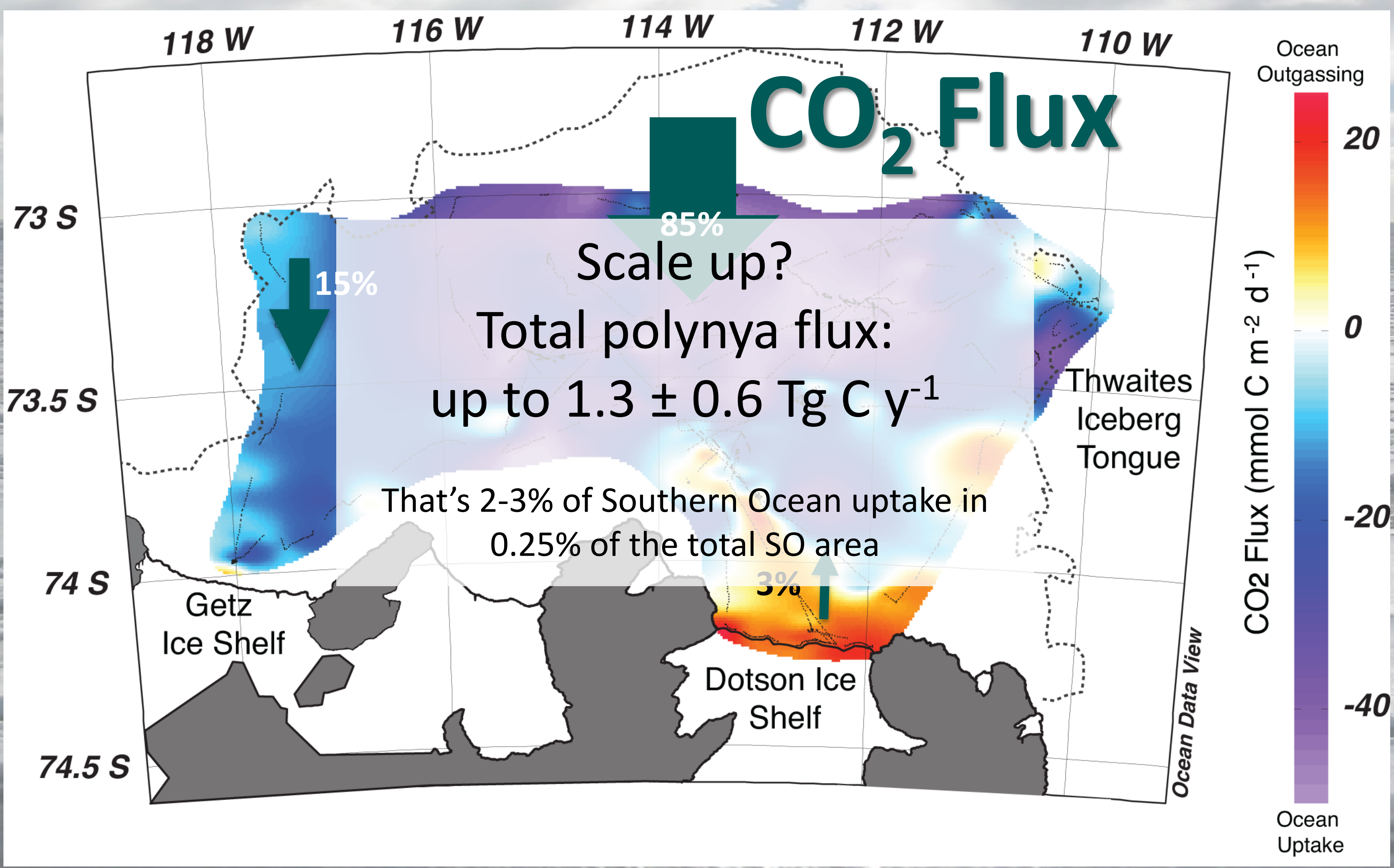
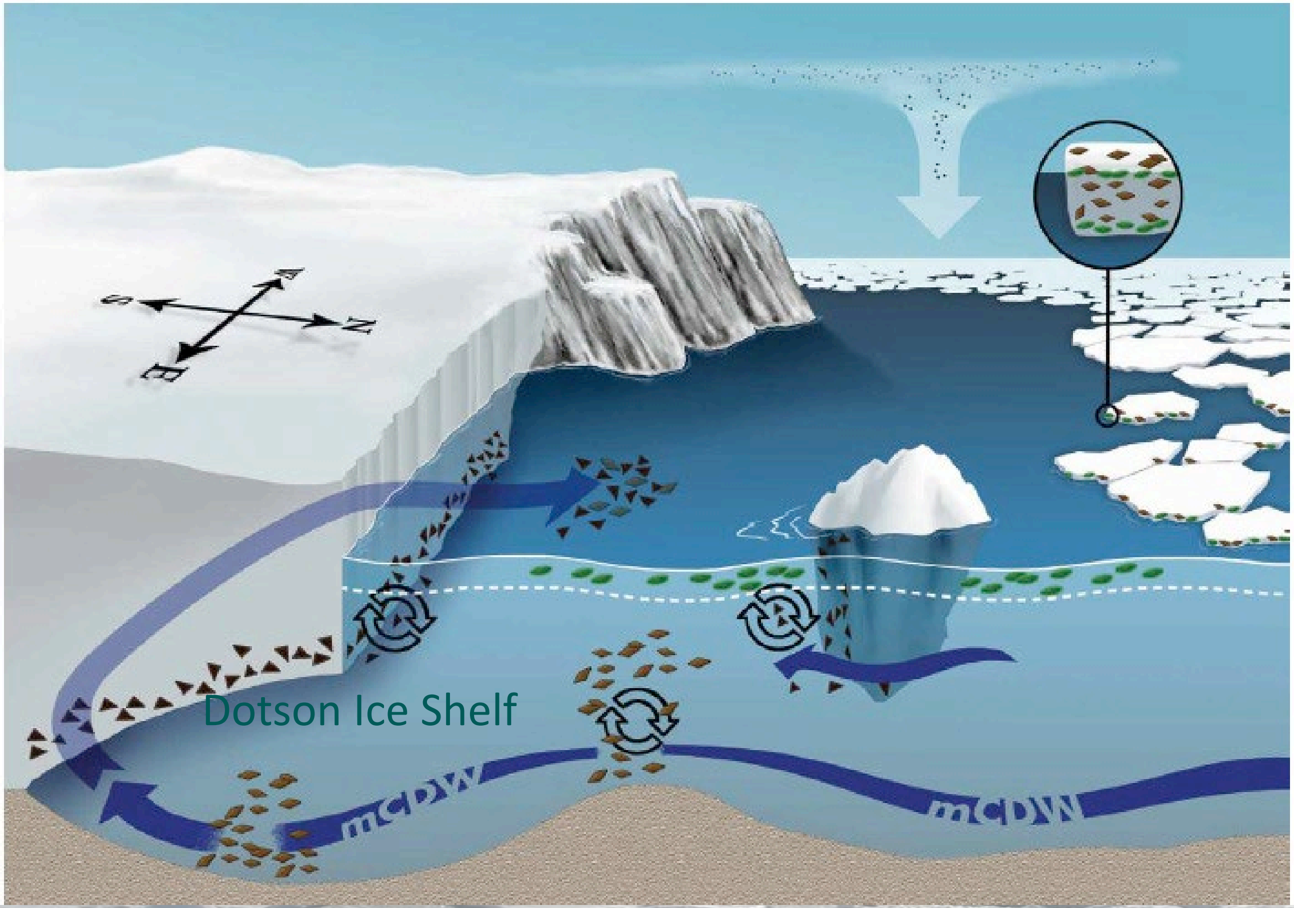
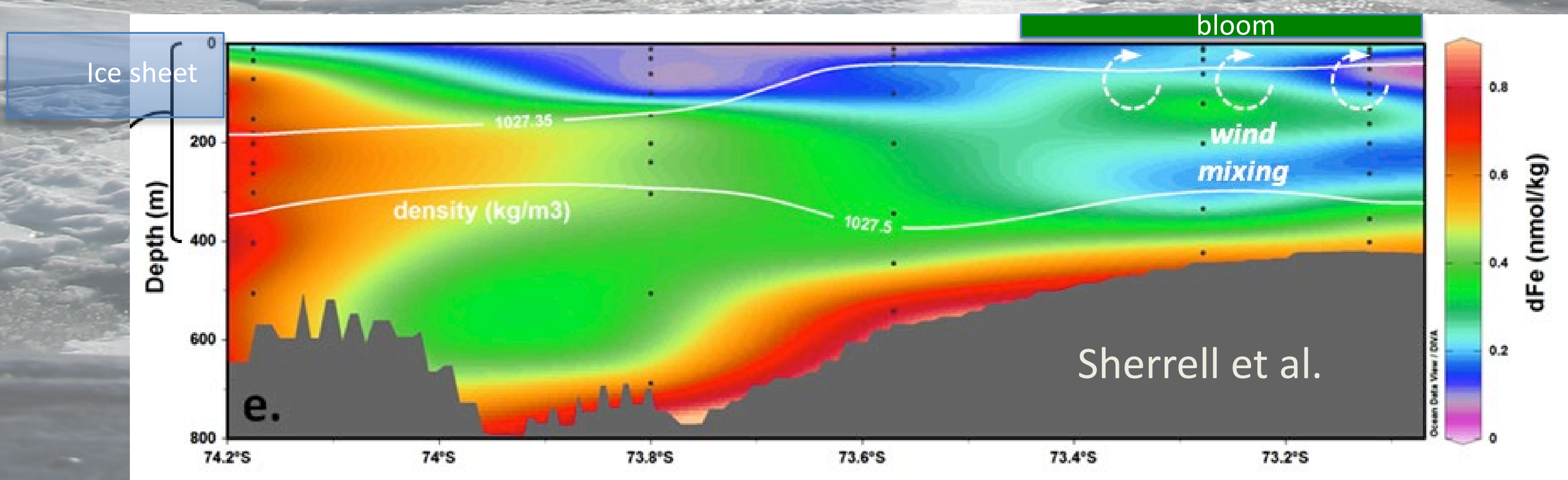


Climate-driven processes delivering dissolved and particulate iron to the Amundsen Sea Polynya



Yager et al., *Oceanography*, 2012



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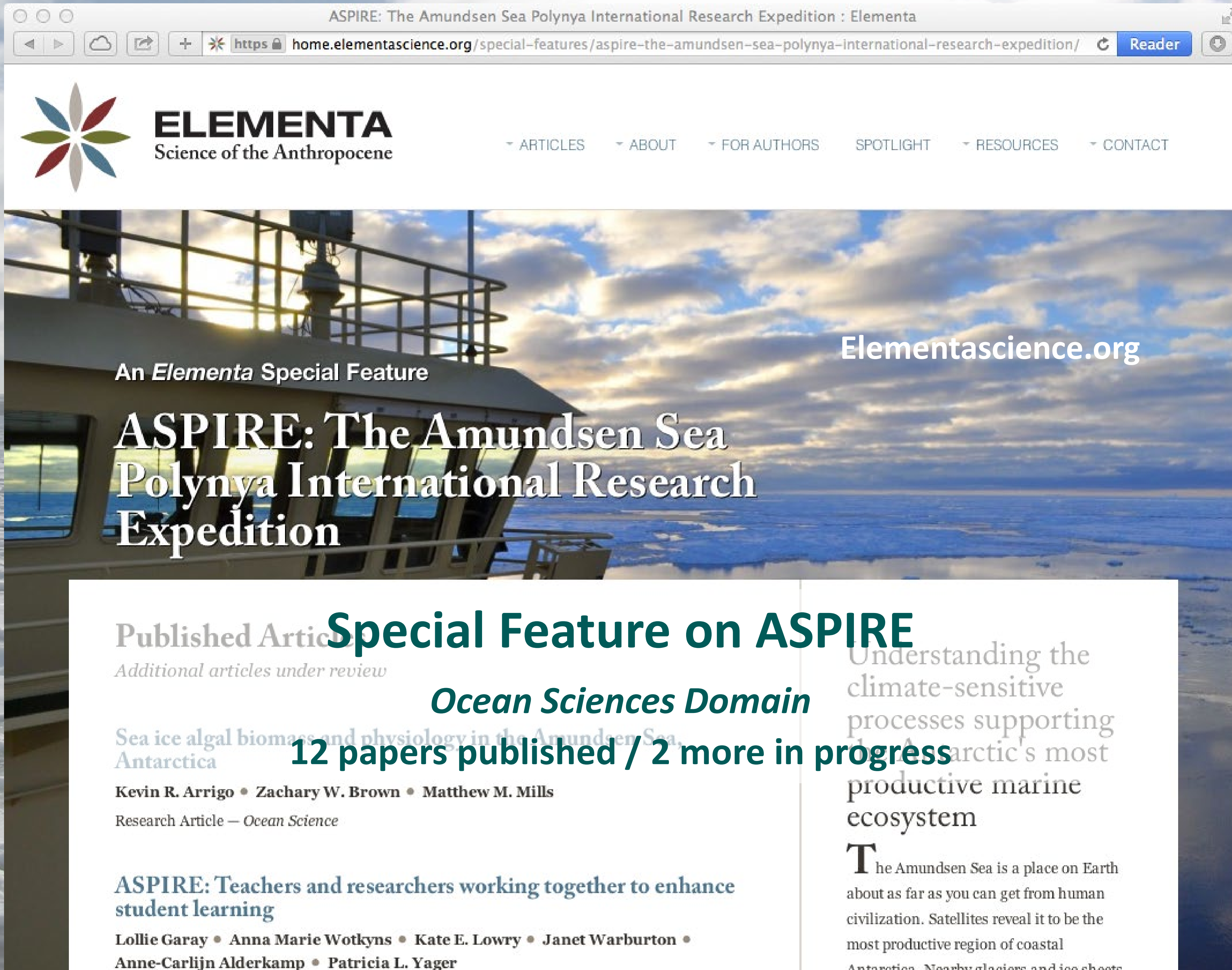
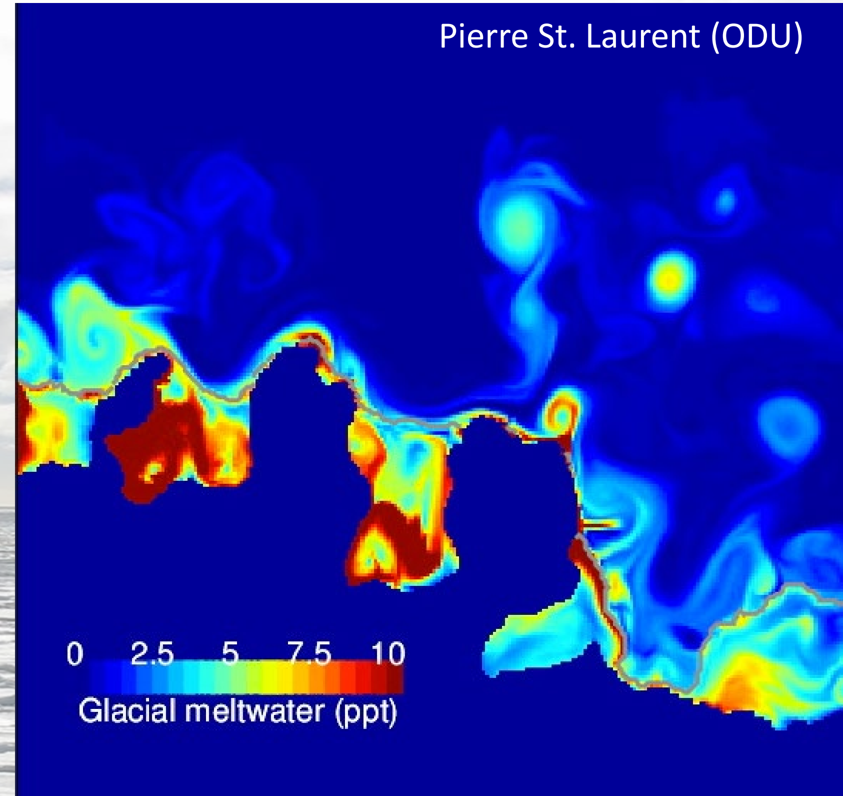
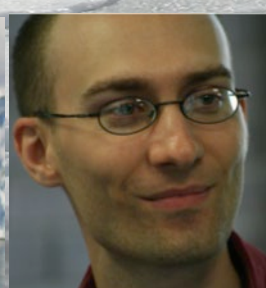


"INSPIRE"

Teaming up with Pierre St. Laurent, Eileen Hofmann, and Mike Dinniman to model the region.

1. How is the iron transported from the shelf to the polynya?
2. What is the long-term fate of the sequestered carbon?
3. How linked to the ice shelf dynamics?





See you at AGU and Ocean Sciences!

Themes and ideas

High latitude ecosystems
are changing rapidly

Sea Ice losses
Ice sheet loses

Ecosystem impact is regional
and global

Winners and losers

Biosphere feedbacks to
climate are complex

The source is anthropogenic
– and so is the solution

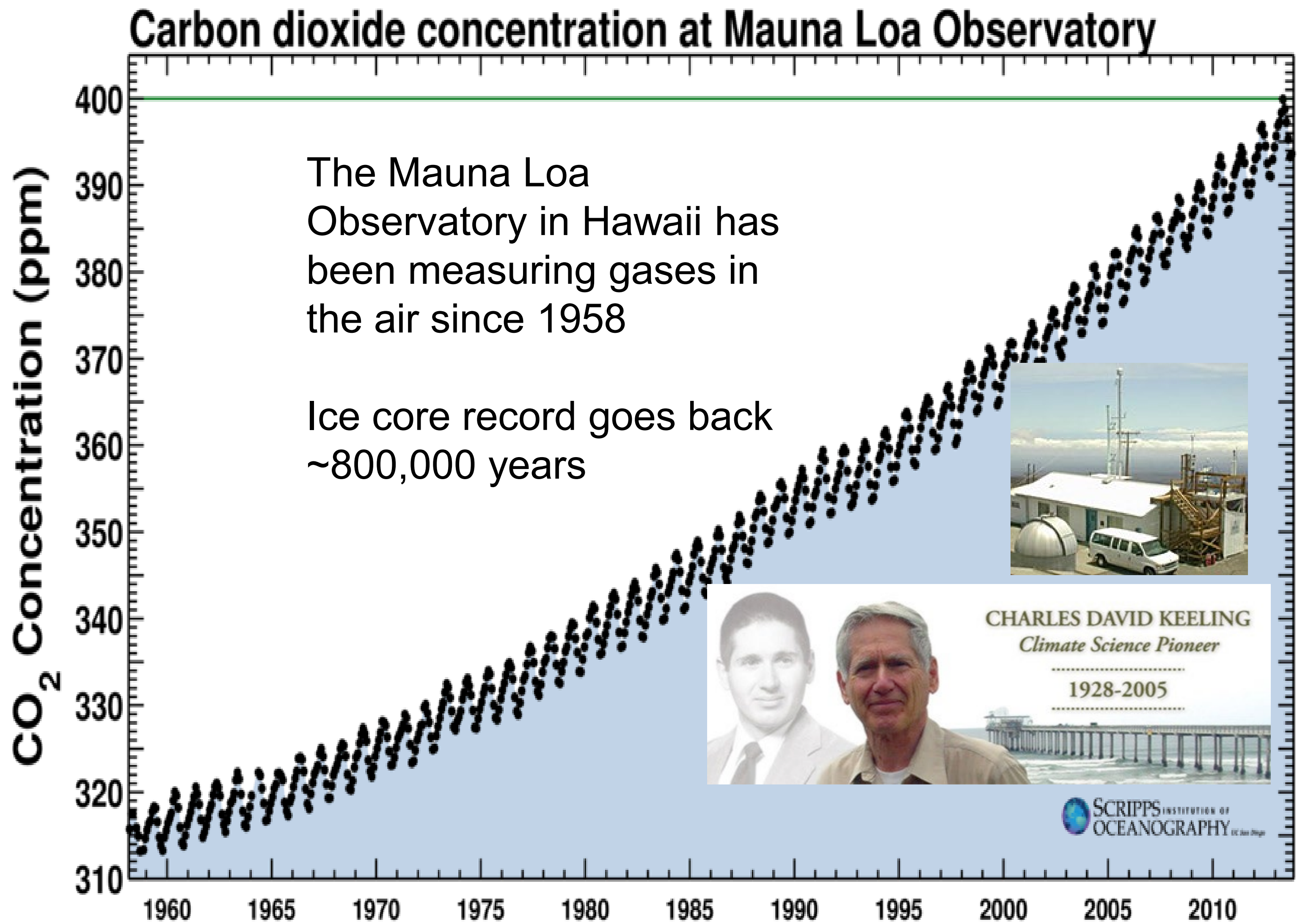
This research was funded by NSF Office of Polar Programs,
Antarctic Organisms and Ecosystems
and also NASA IDS

As should be obvious from the presentation, I had many, many great collaborators – too numerous to mention here. I've tried to attribute data, figures, and photos wherever possible.

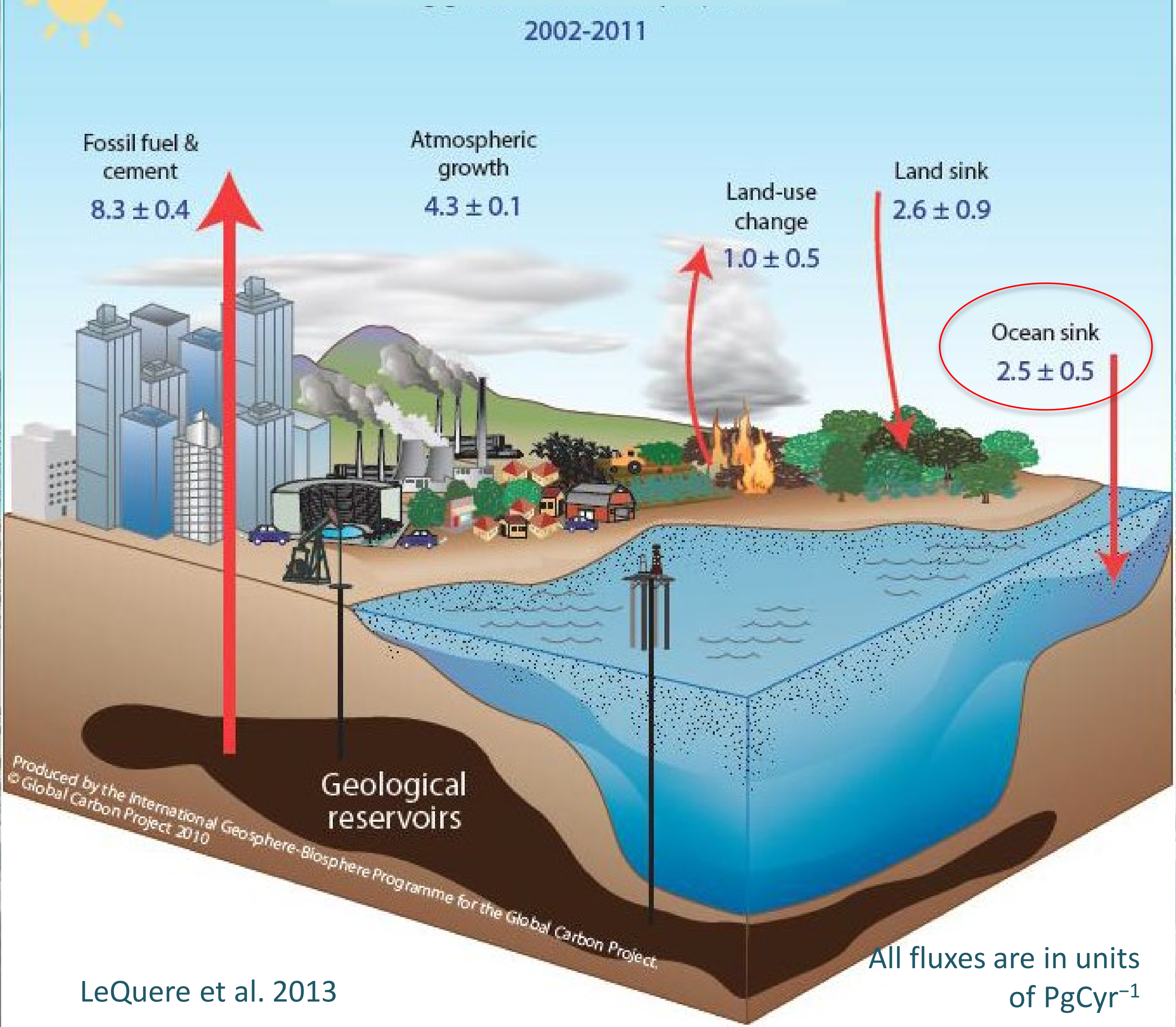
Thank you!

Atmospheric CO_2

We have increased by ~50% the concentration of CO_2 in the atmosphere since the start of the industrial revolution (280 ppm)



Anthropogenic carbon budget

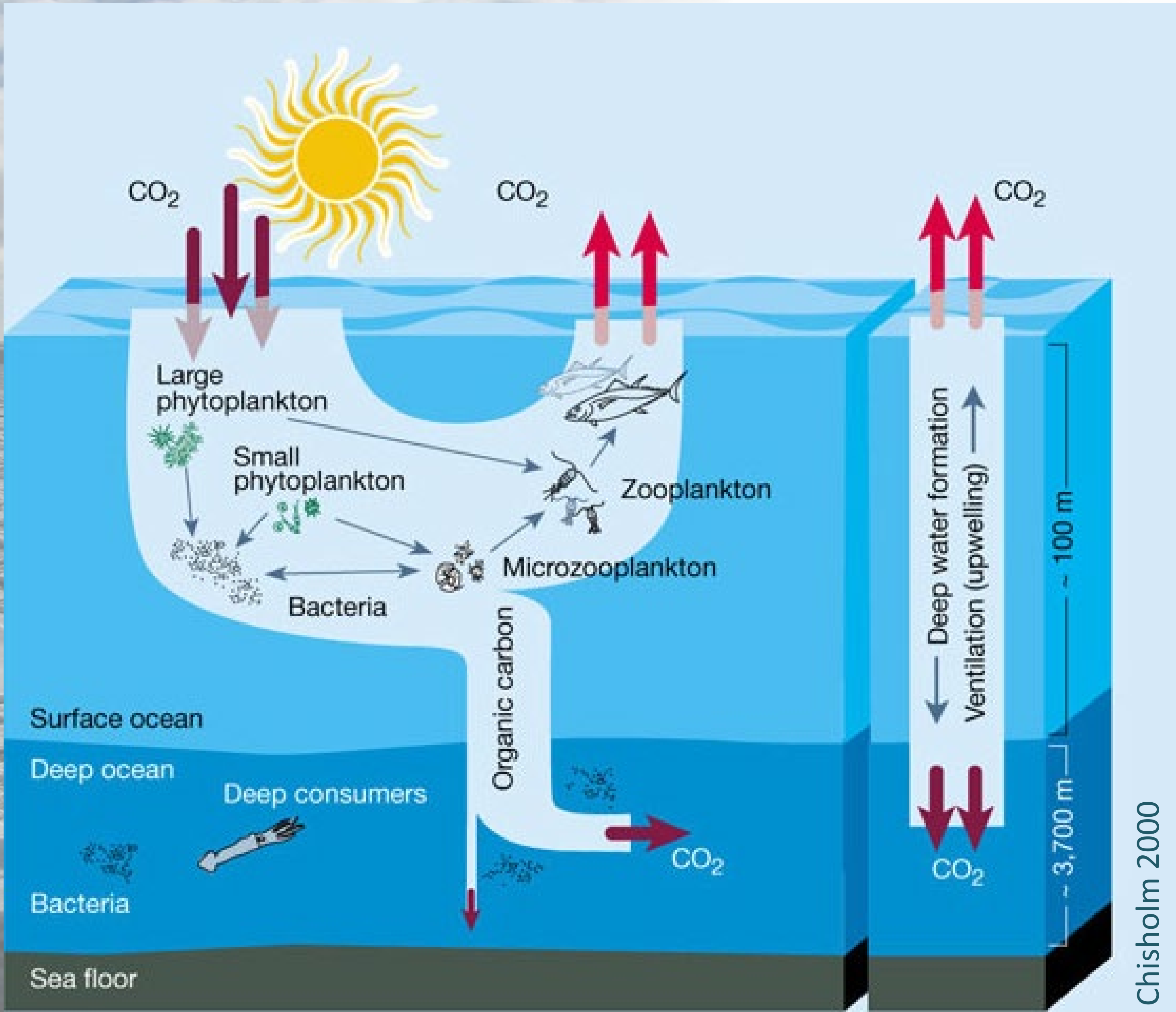


LeQuere et al. 2013

All fluxes are in units of $PgCyr^{-1}$

The ocean is taking up a large share of the extra CO_2

Atmospheric CO_2 controlled by "ocean pumps"



- **Solubility pump**
  f(Temperature, Salinity, Pressure)
- **Biological pump**
  Photosyn > Respir
  Efficiency = f(nutrients)

Results from carbon cycle box models:

Solubility pump	Biological pump	Atm. pCO_2 (ppm)	Source
No	No	720	Volk and Hoffert 1985
Yes	No	450, 530	Wenk 1985; Bacastow and Maier-Reimer 1990; Baes and Killough 1986
Yes	Partial	280	Neftel et al. 1985
Yes	Full	165	Sarmiento and Toggweiler 1984

Sarmiento and Orr (1991)

Pre-industrial pCO_2 was ~280 according to ice cores
Glacial pCO_2 was ~180 according to ice cores
We are ~400 today due to fossil fuel combustion

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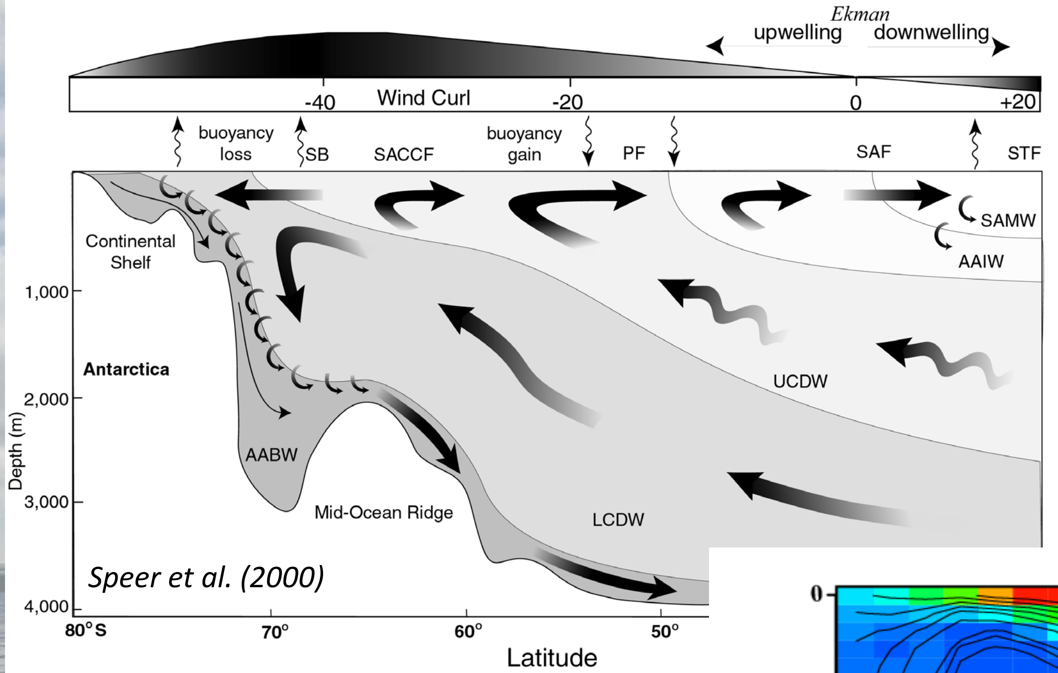
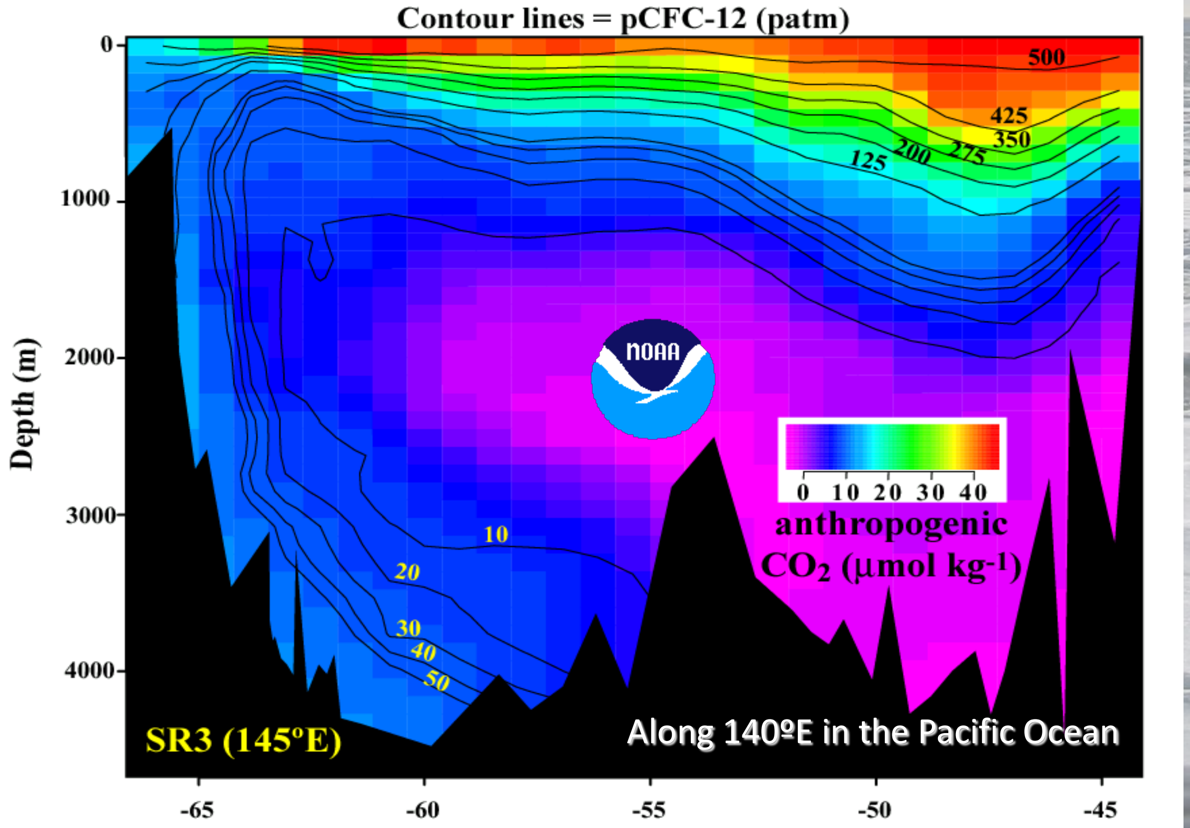
Solubility pump

Antarctic Bottom Water carries some of the excess CO_2 to the deep ocean

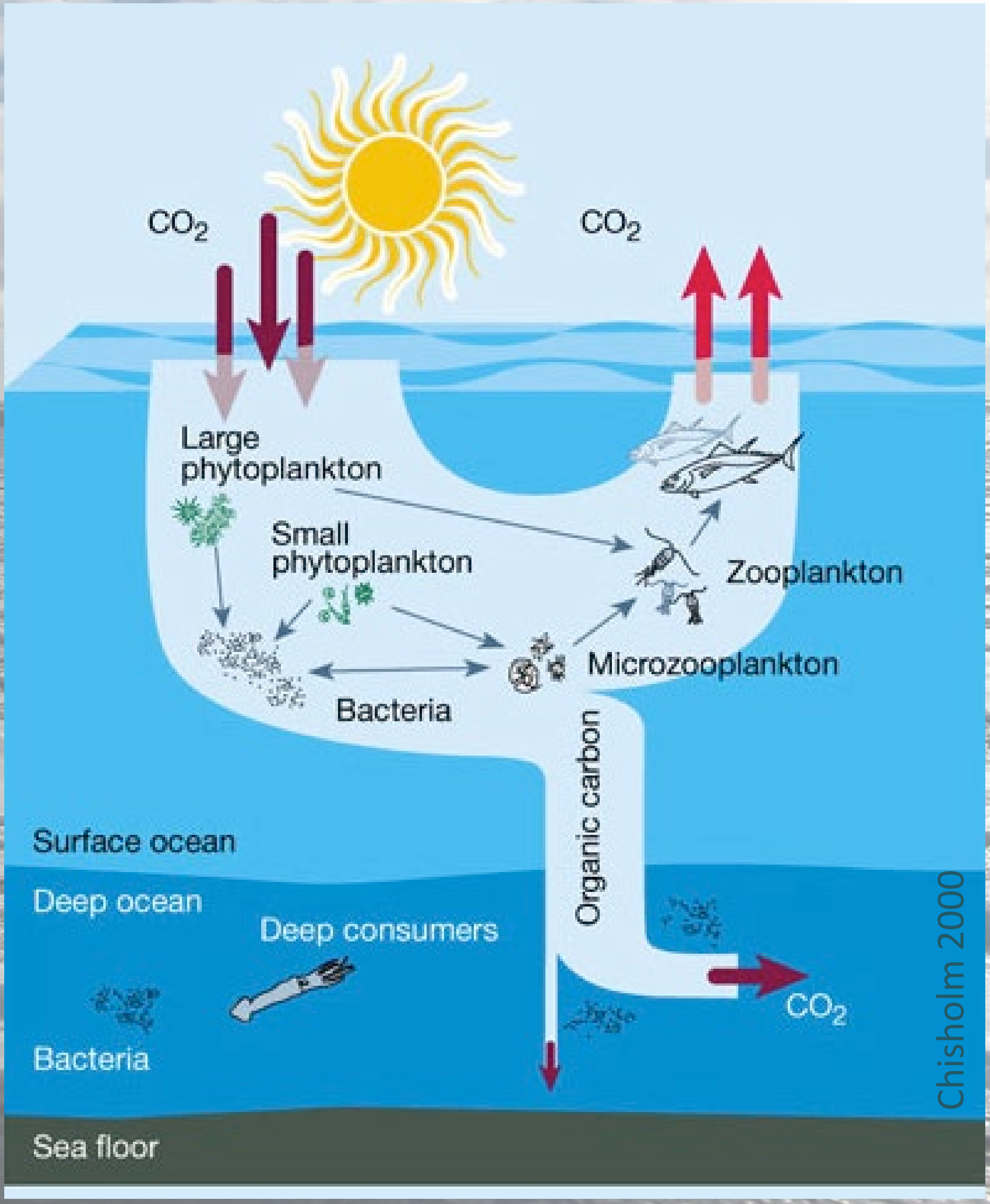


Speer et al. (2000)

But the solubility pump is expected to slow down with climate change

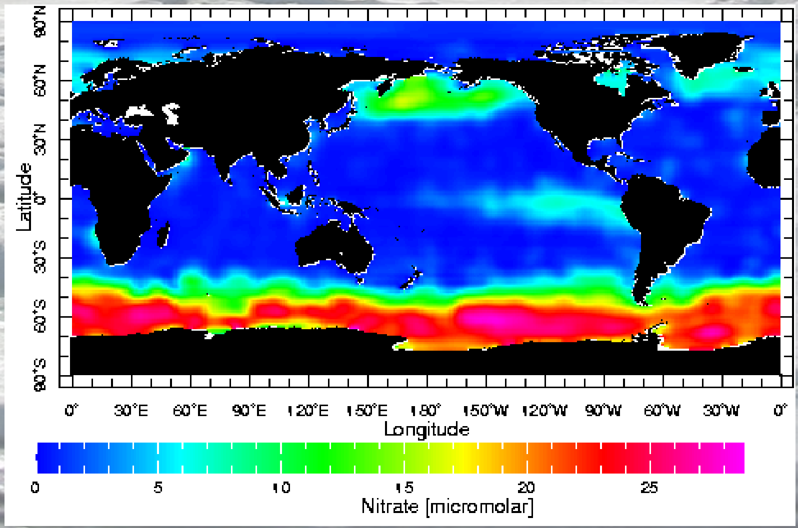


Courtesy of C. Sabine



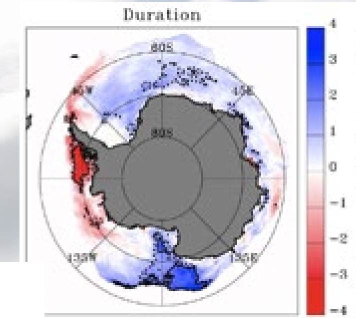
How do you make a more efficient Biological Pump?

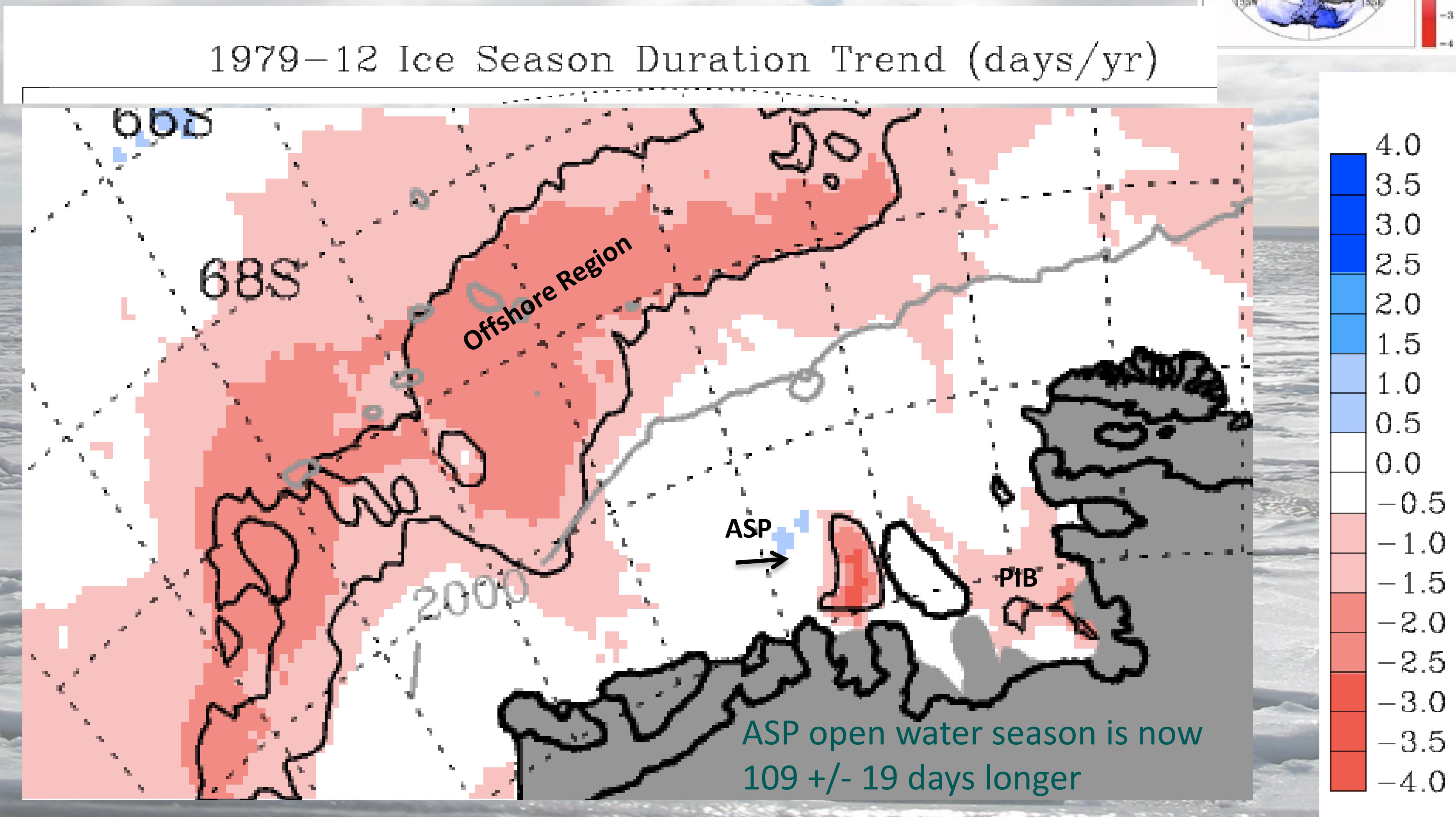
Use "unused" nitrate



http://www.nodc.noaa.gov/OC5/WOA01/ World Ocean Atlas 2001

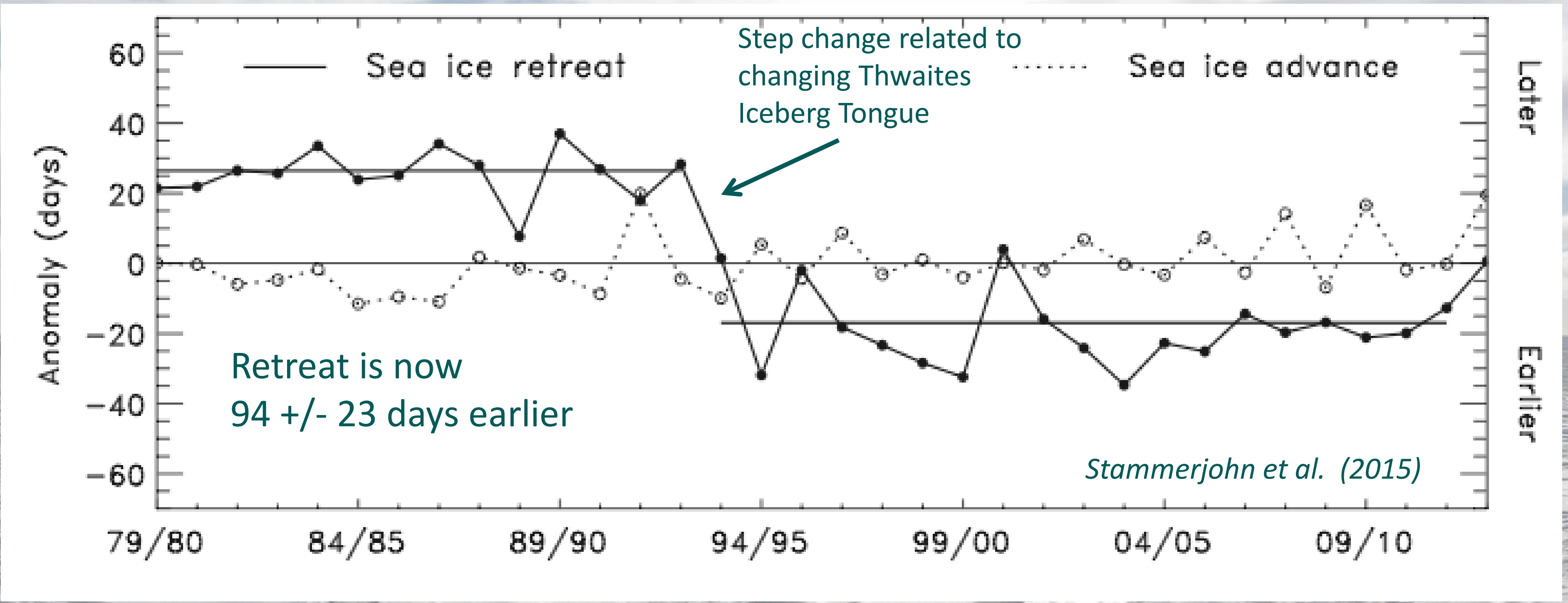
Climate sensitivity?





Stammerjohn et al. (2015)

Here is the climate perturbation affecting the carbon uptake:

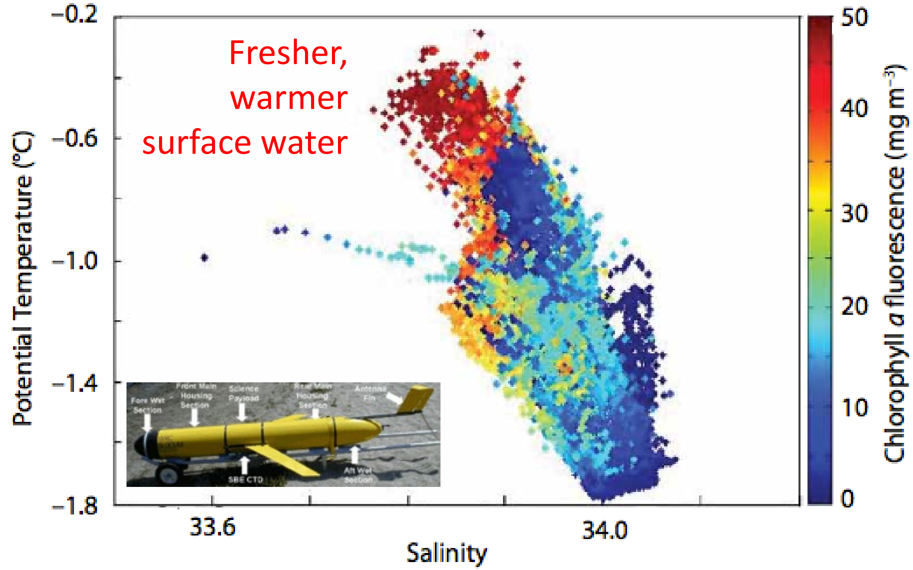


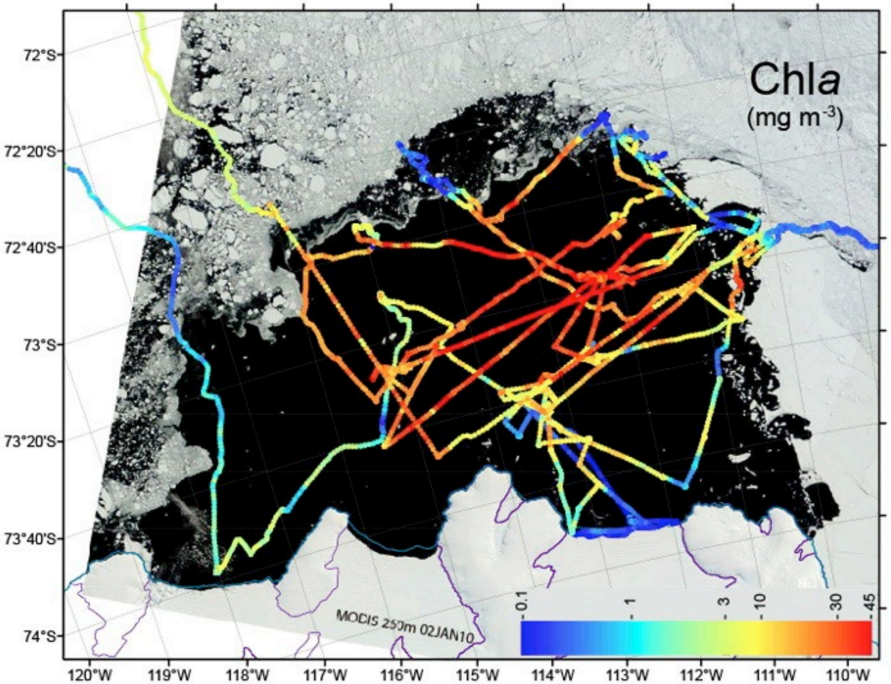
The polynya would have been much smaller and open for shorter duration during an ASPIRE cruise in 1979

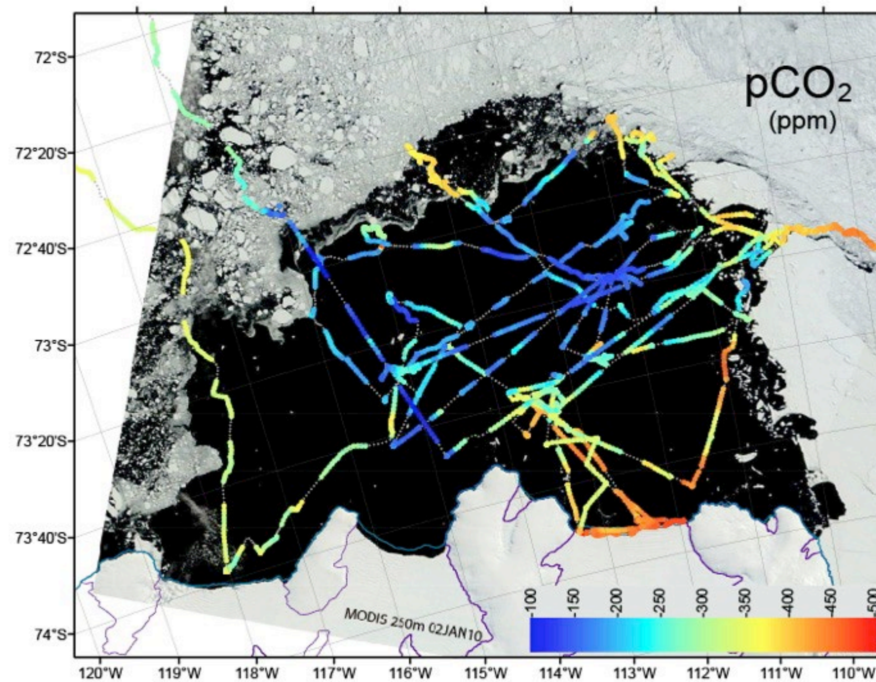
Future? More/longer open water?

- **Earlier retreat may not trigger bloom if light limited**
- **Winter outgassing?**
- **Link to melting ice sheet intriguing**

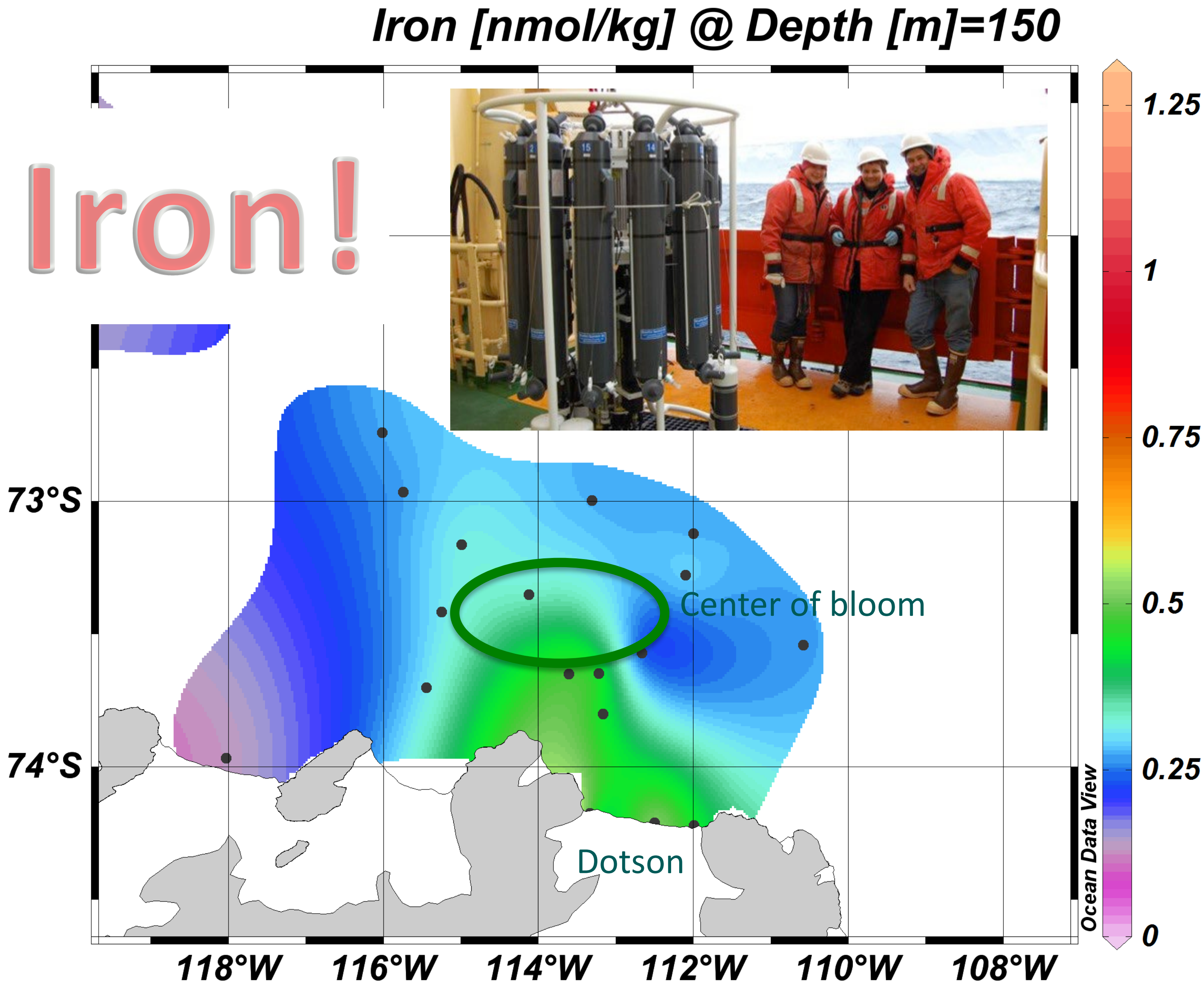
Upper 100 m glider data







Iron!



Courtesy R. Sherrell and M. Lagerstrom (Rutgers)

Sherrell et al., in prep.

Current anthropogenic inventory dominated by North Atlantic Deep Water formation (similar to heat uptake)

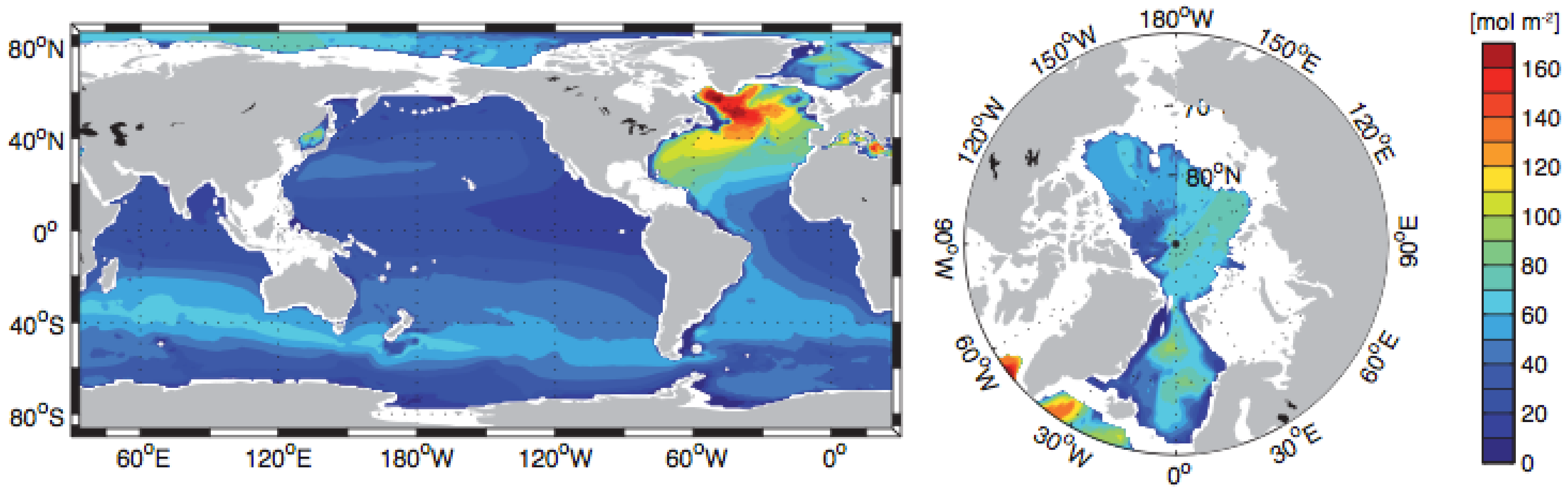
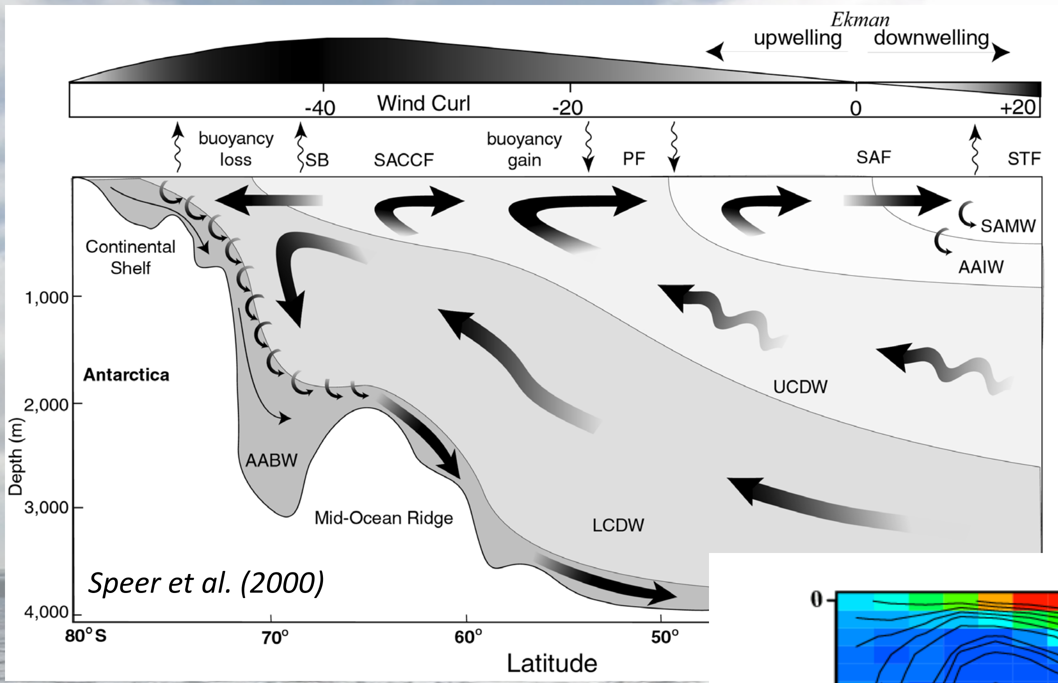
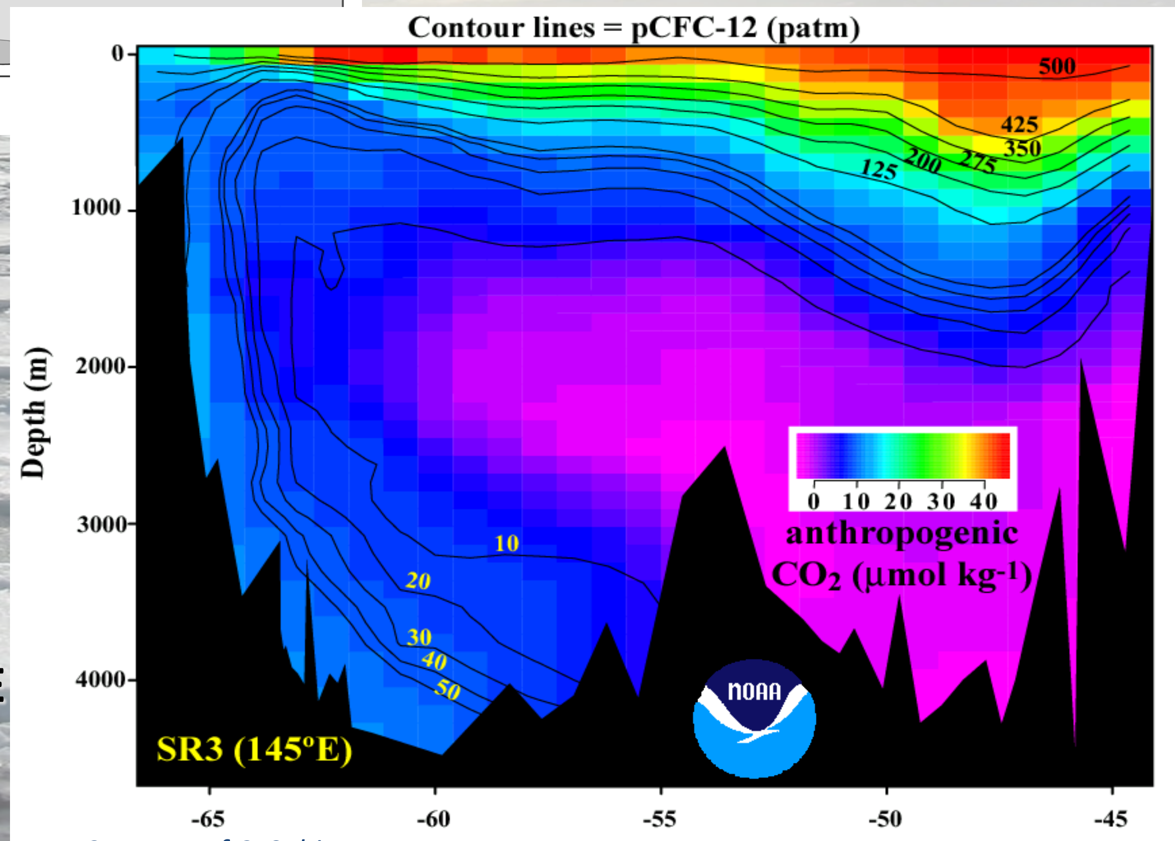


Figure 3.16: Compilation of the 2010 column inventories (mol m^{-2}) of anthropogenic CO_2: the global Ocean excluding the marginal seas (updated from Khatiwala et al., 2009) 150 ± 26 PgC; Arctic Ocean (Tanhua et al., 2009) 2.7–3.5 PgC;

IPCC 2013

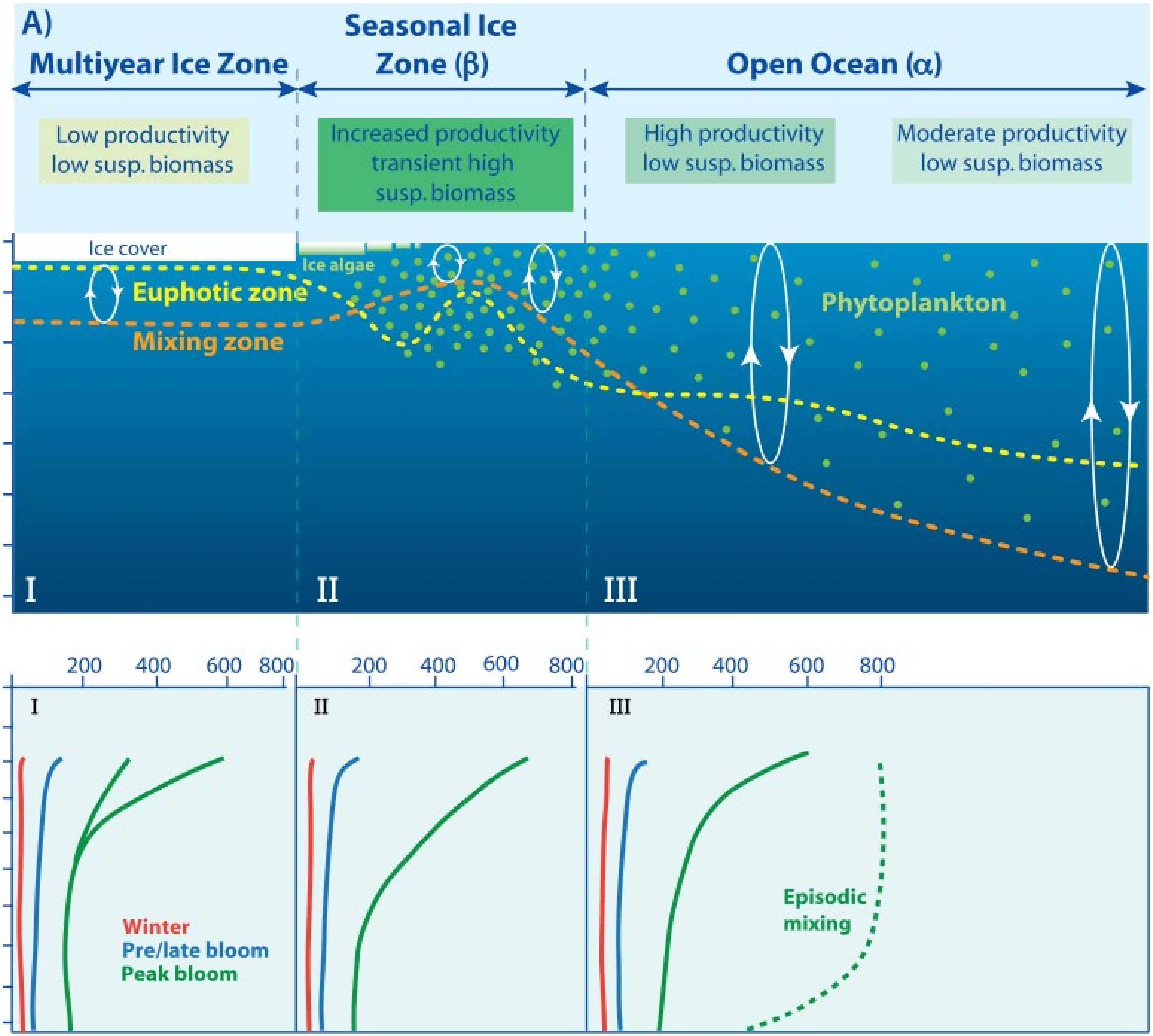


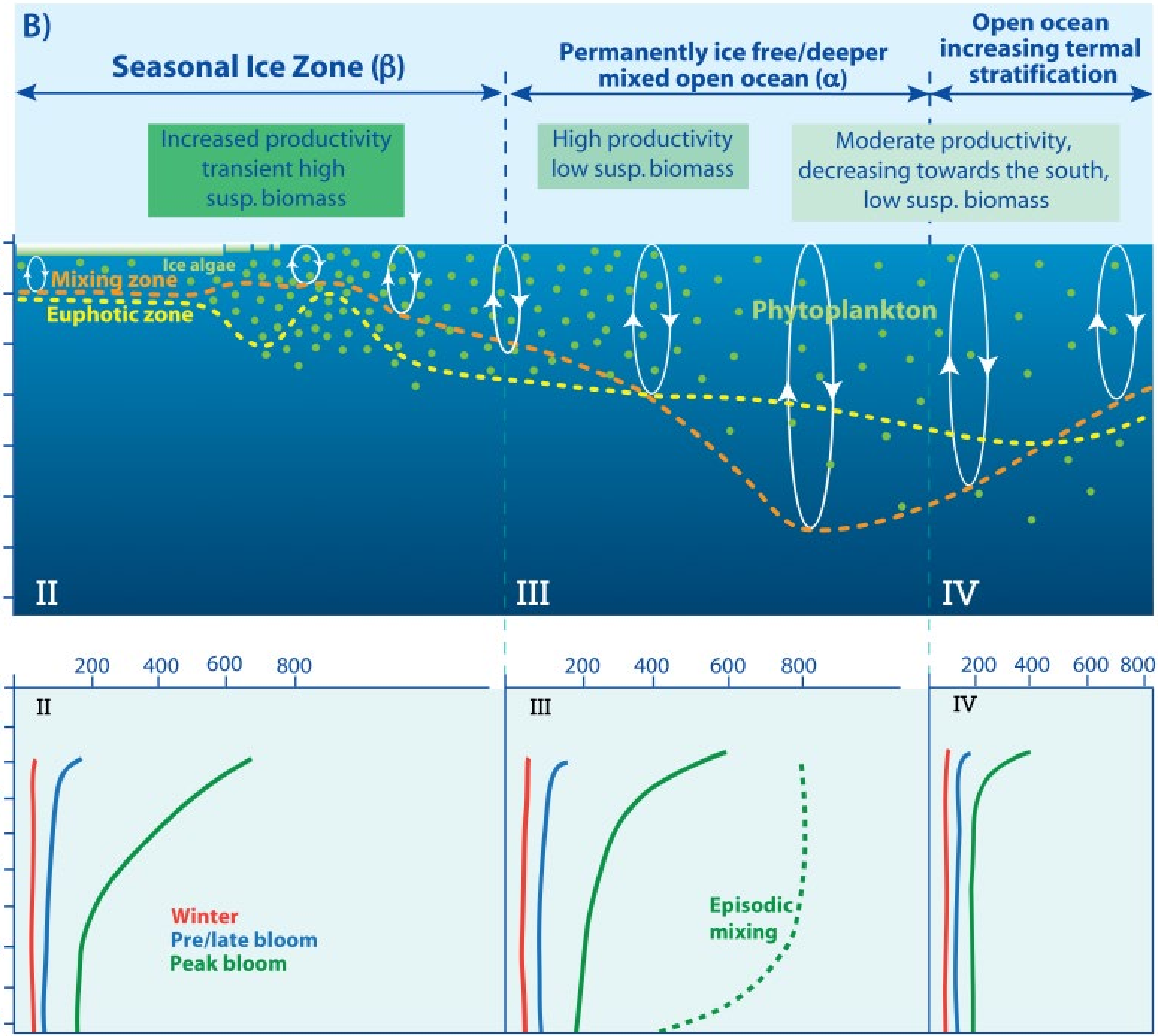
Antarctic Bottom Water is also carrying excess CO_2 to the deep ocean

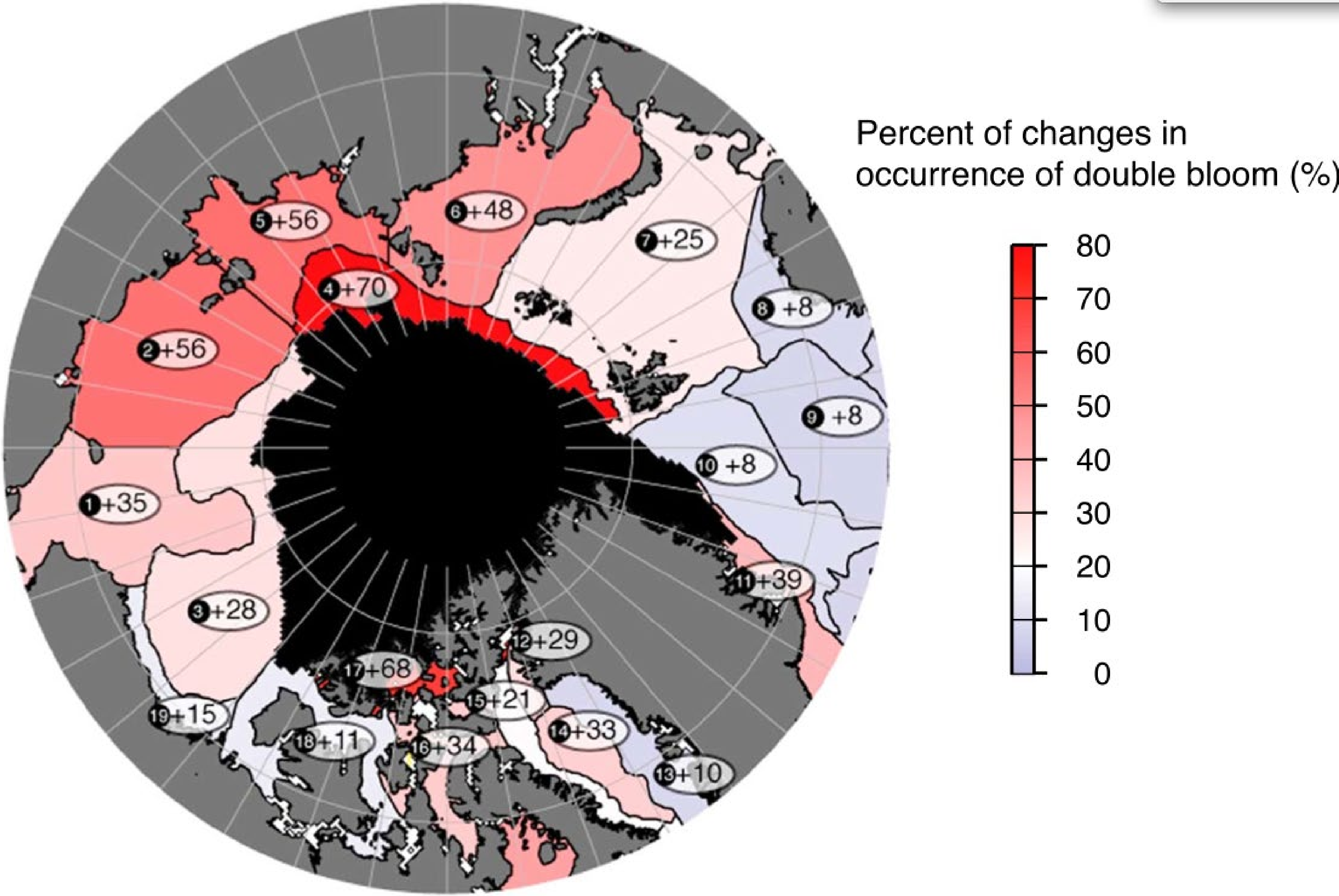


Courtesy of C. Sabine

Anthropogenic CO_2 along 140ºE in the Pacific Ocean


A)
Multiyear Ice Zone
Seasonal Ice Zone (β)
Open Ocean (α)
Low productivity low susp. biomass
Increased productivity transient high susp. biomass
High productivity low susp. biomass
Moderate productivity low susp. biomass
Ice cover
Ice algae
Euphotic zone
Mixing zone
Phytoplankton
0m
10m
30m
50m
70m
90m
I
II
III
200
400
600
800
Winter
Pre/late bloom
Peak bloom
Episodic mixing


B)
Seasonal Ice Zone (β)
Permanently ice free/deeper mixed open ocean (α)
Open ocean increasing termal stratification
Increased productivity transient high susp. biomass
High productivity low susp. biomass
Moderate productivity, decreasing towards the south, low susp. biomass
Ice algae
Mixing zone
Euphotic zone
Phytoplankton
0m
10m
30m
50m
70m
90m
II
III
IV
200
400
600
800
Episodic mixing
Winter
Pre/late bloom
Peak bloom


1 +35
2 +56
3 +28
4 +70
5 +56
6 +48
7 +25
8 +8
9 +8
10 +8
11 +39
12 +29
13 +10
14 +33
15 +21
16 +34
17 +68
18 +11
19 +15
Percent of changes in
occurrence of double bloom (%)
80
70
60
50
40
30
20
10
0

Wassmann & Reigstad, 2011