The Cryosphere

ES 383

Colby at Bigelow, September 2018

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Three components

- Sea ice = frozen seawater.
- Ice sheets, only two exist today in the modern world: Greenland and Antarctica.
- Glaciers, both coming down from ice sheets and from mountain glaciers => Ice shelves, icebergs, and permanent and seasonal snowfields.

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Sea ice

- Frozen sea water
- Forms, grows, melts in the ocean
- Grows in winter, melts in summer, can survive multiple years
- Typical thickness:
  - first year ice <= ~1.8m
  - 2-3 year old 2–3m,
  - 10 year old ~ 5 – 6 m

Sea ice formation

First-year ice
30-150 cm thick, typically snow covered

http://nsidc.org/cryosphere

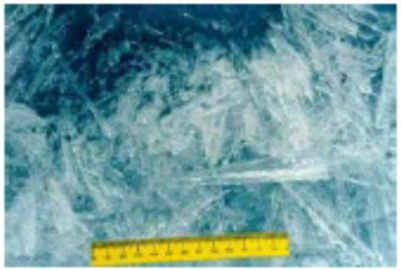
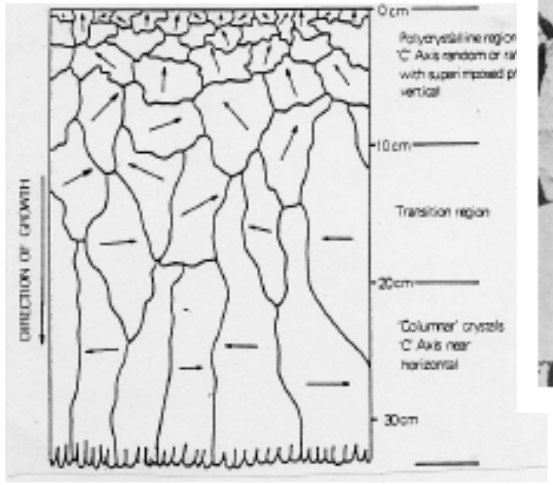



Photo D. Perovich


0 cm
Polycrystalline region
'C' Axis random or ra
with superimposed pl
vertical
10 cm
Transition region
20 cm
'Columnar' crystals
'C' Axis near
horizontal
30 cm
DIRECTION OF GROWTH

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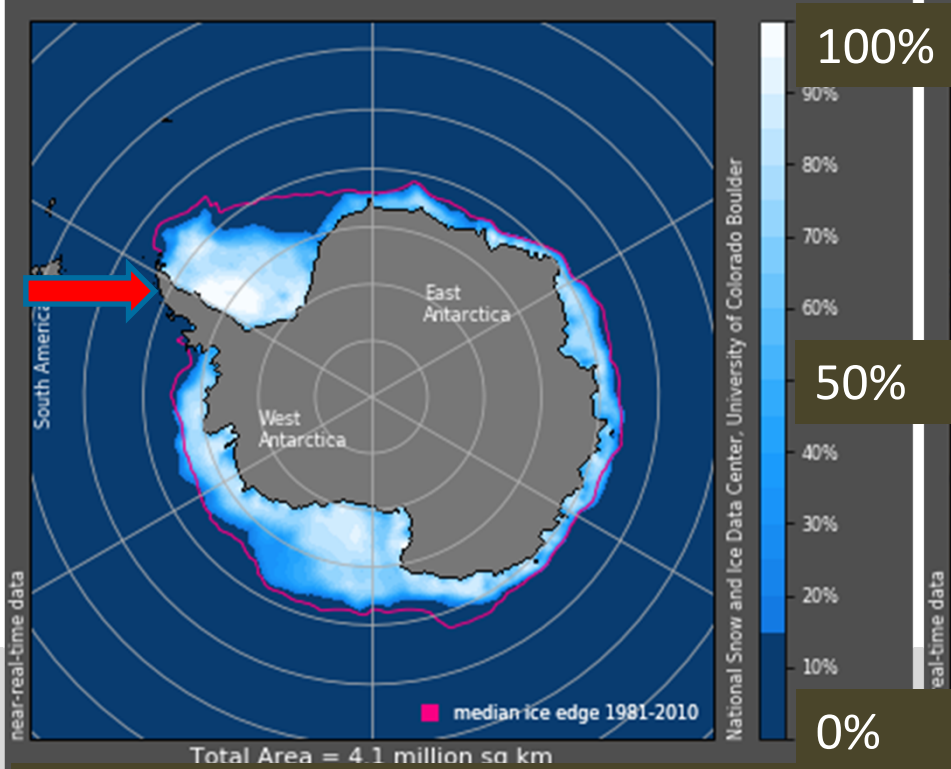
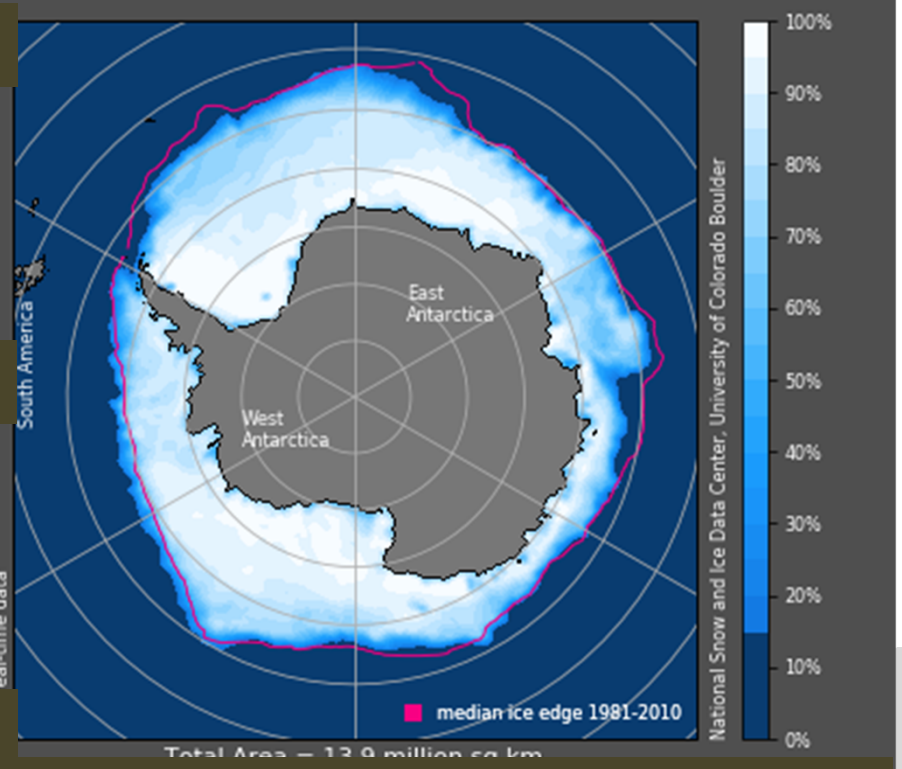
Sea ice minimum April ‘18



Total ice area 4 M sq km

Sea ice maximum Aug ‘18



Total ice area 14 M sq km

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Arctic sea ice extent

min = https://www.youtube.com/watch?v=HgyQyyqa4tM
max = https://www.youtube.com/watch?v=RTslvm60aI4
https://www.youtube.com/watch?v=c6jX9URzZWg

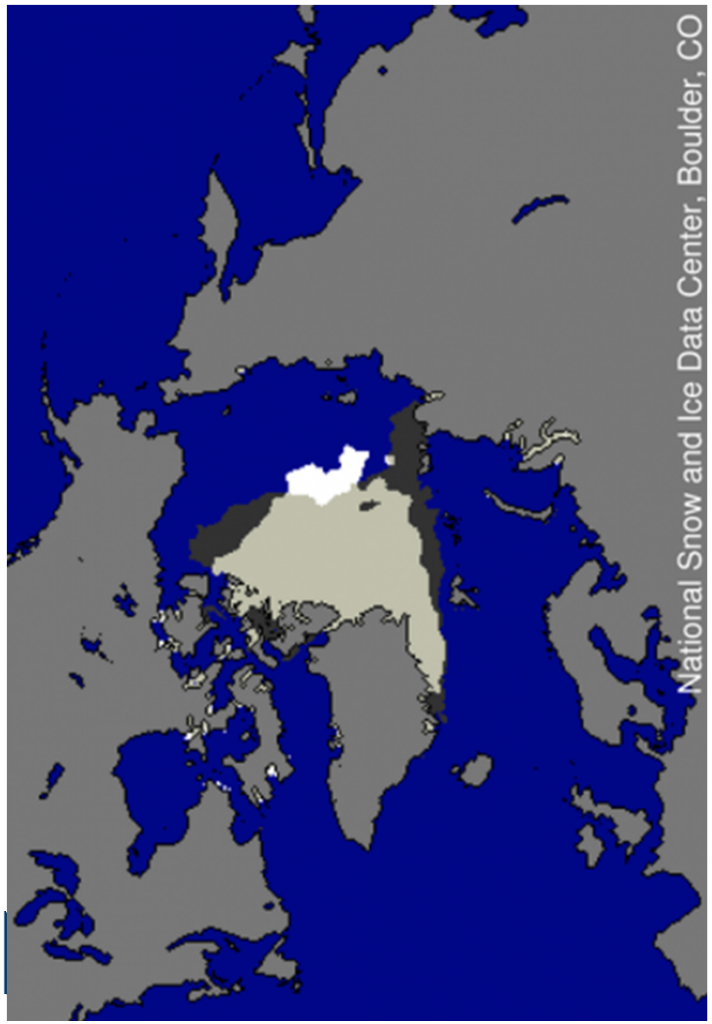
2007 vs. 2012

SEPT. ICE EXTENT

Dark gray = 2007 only;

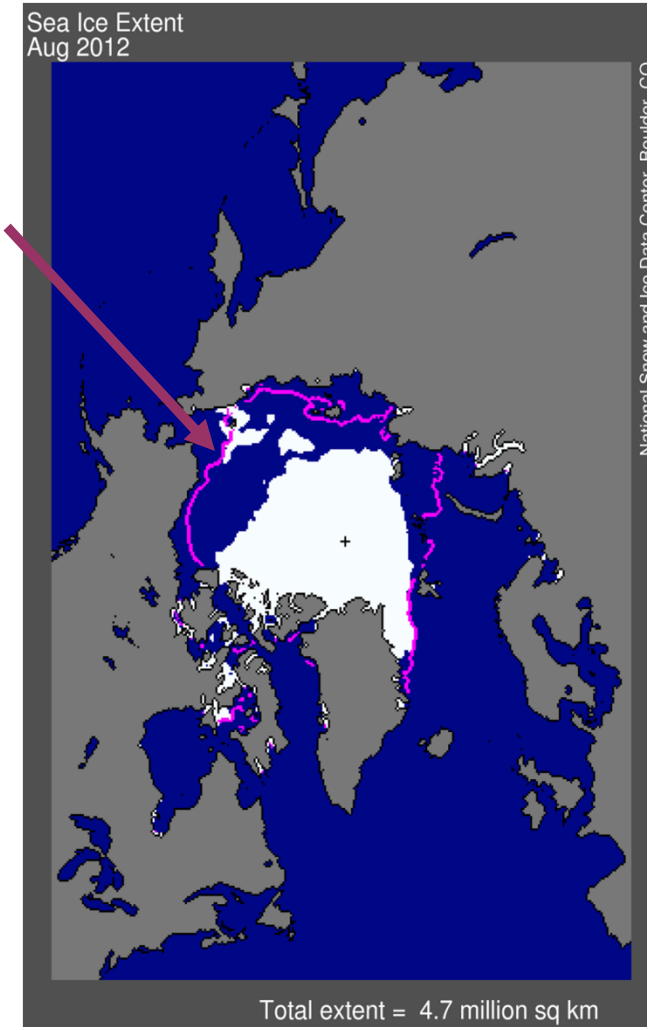
white = 2012 only;

light gray = both 2007 and 2012.



Aug 2012 vs. 21-yr mean

1979-2000 sea ice mean



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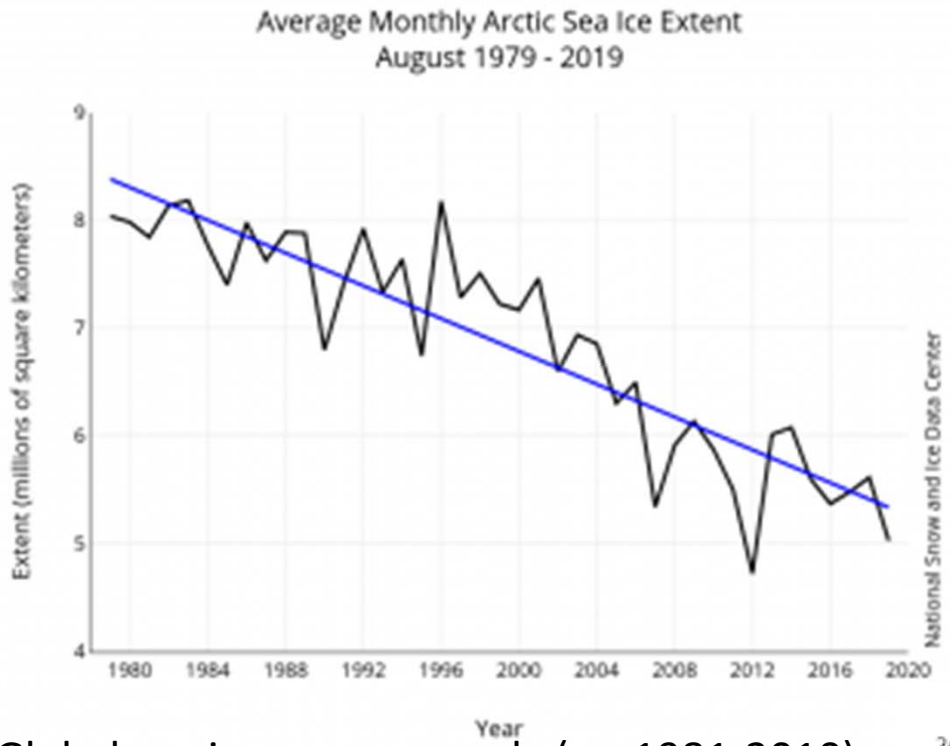
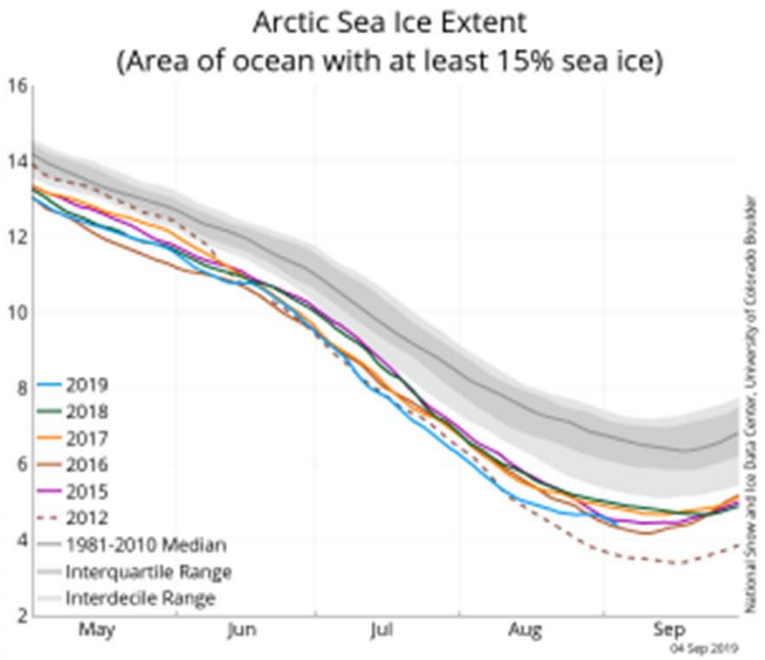
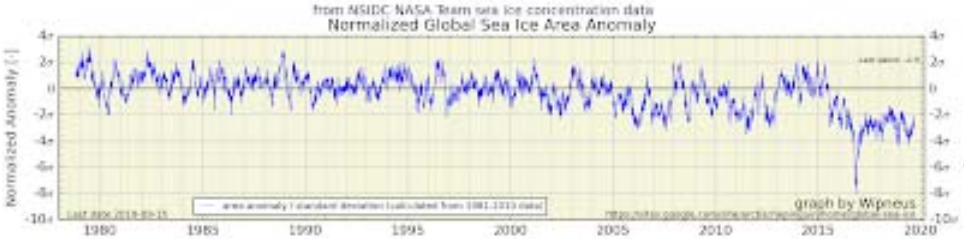
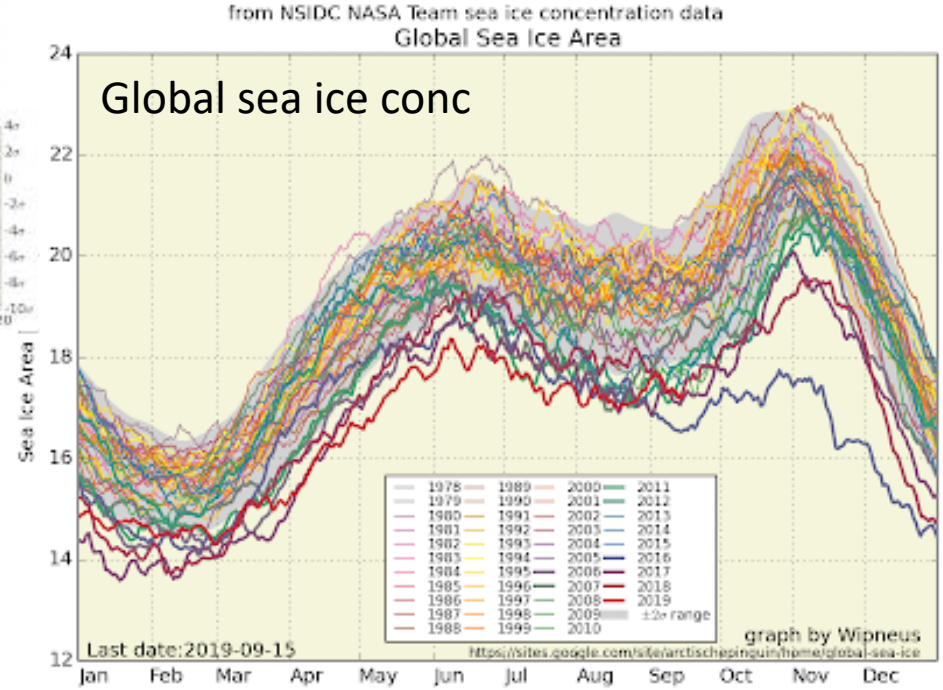




Global sea ice conc anomaly (vs. 1981-2010)





Global = Arctic + Antarctic sea ice

https://nsidc.org/arcticseaicenews/
https://sites.google.com/site/arctischepinguin/home/sea-ice-extent-area/grf/nsidc_global_area_byyear_b.png

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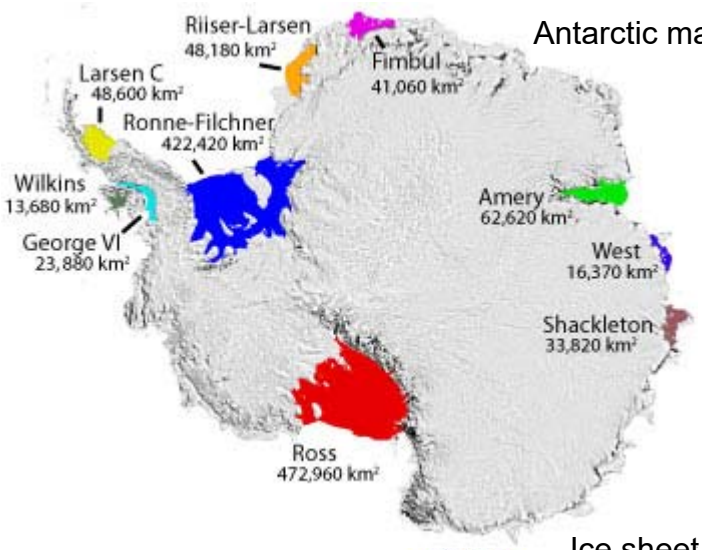
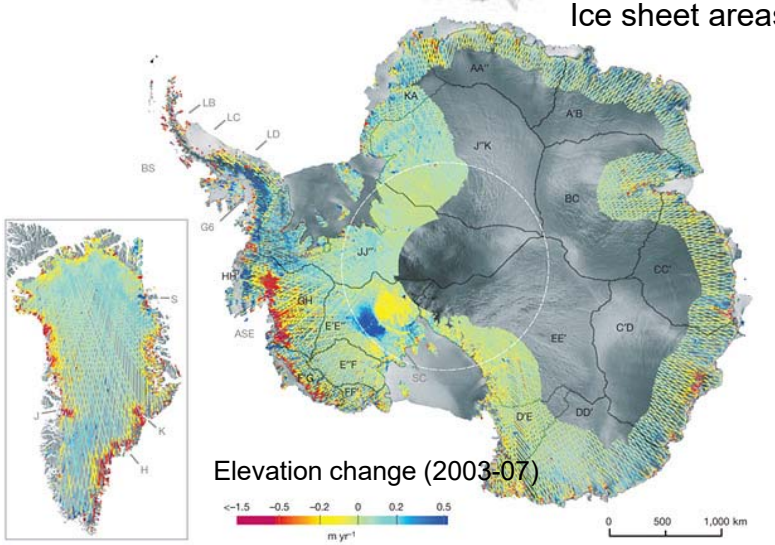
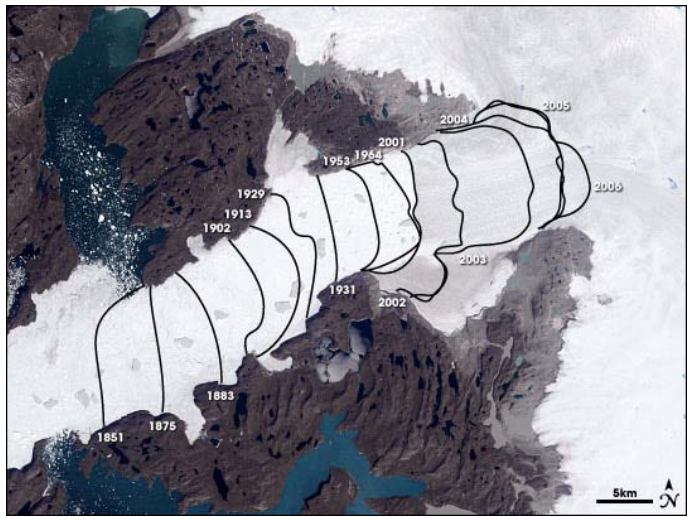
Ice sheets, shelves and glaciers: calving, retreat, disintegration



Antarctic major ice shelf areas

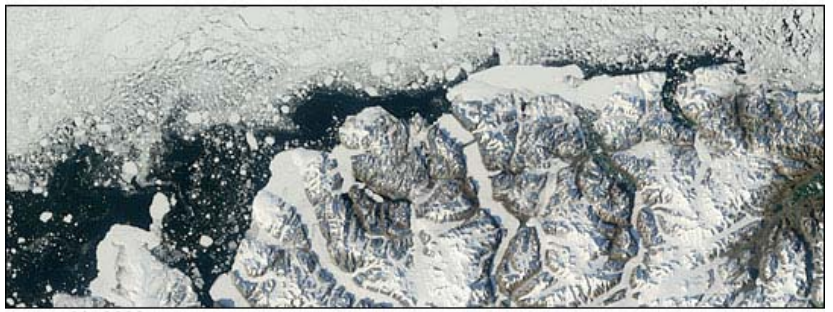


Ice sheet areas



Greenland's Jacobshavn Glacier retreat

July 22, 2008



August 29, 2008

Ice Shelf Retreat along the Ellesmere Coast: Between 22 July (top) and 29 August (bottom) 2008, the five ice shelves remaining in the Canadian Arctic experienced major losses. By late August, Ellesmere ice shelves had lost a total of 214 km² (83 mi²).

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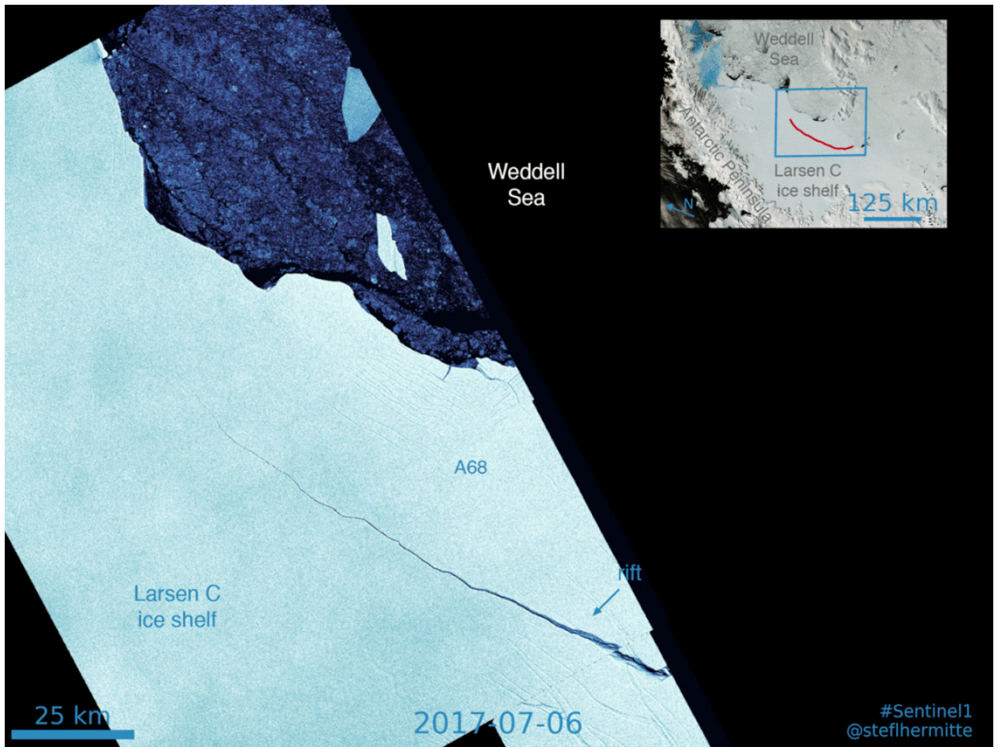
http://nsidc.org/cryosphere

Muir Glacier, Alaska



Larsen C Iceberg
(size of Delaware)

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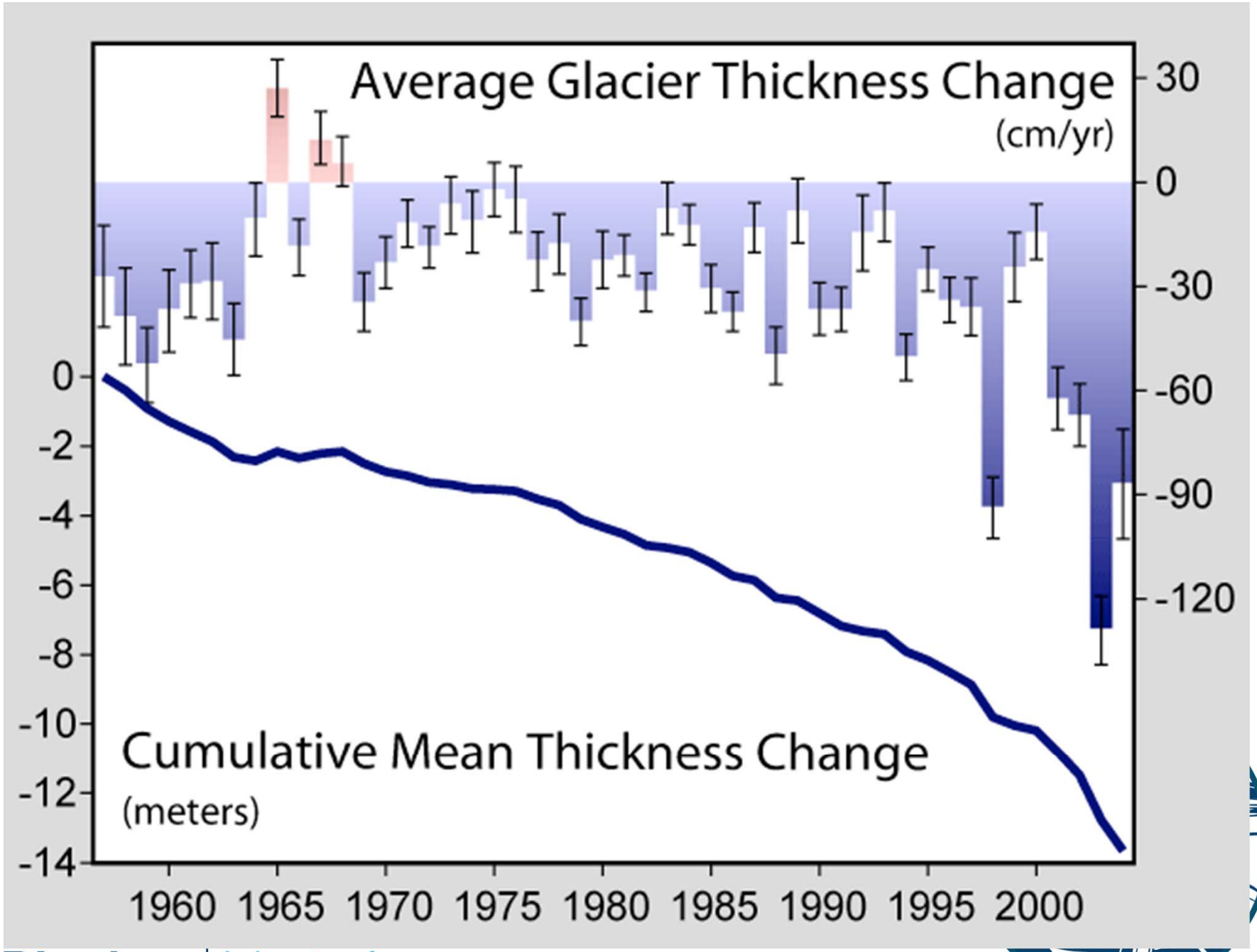

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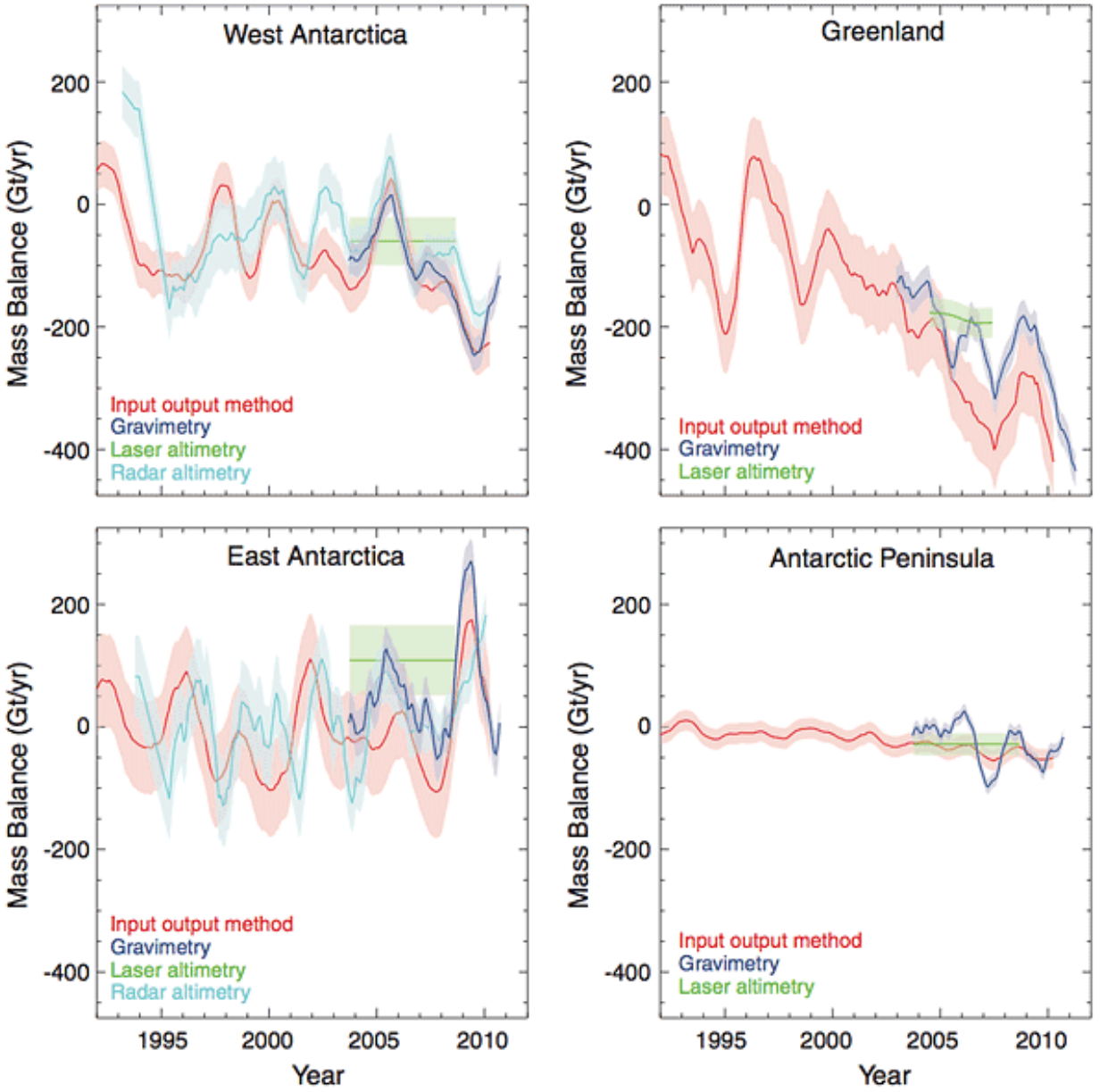
Changes in ice sheet mass (1992-2012)



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http://nsidc.org/cryosphere

Why is sea ice important?

1. **Affects polar ecosystem, wildlife**

- Important habitat for algae, seals, bears, walrus
- Ice algae contributes 10 – 20% to Arctic primary production
- Effect of reduced ice cover uncertain

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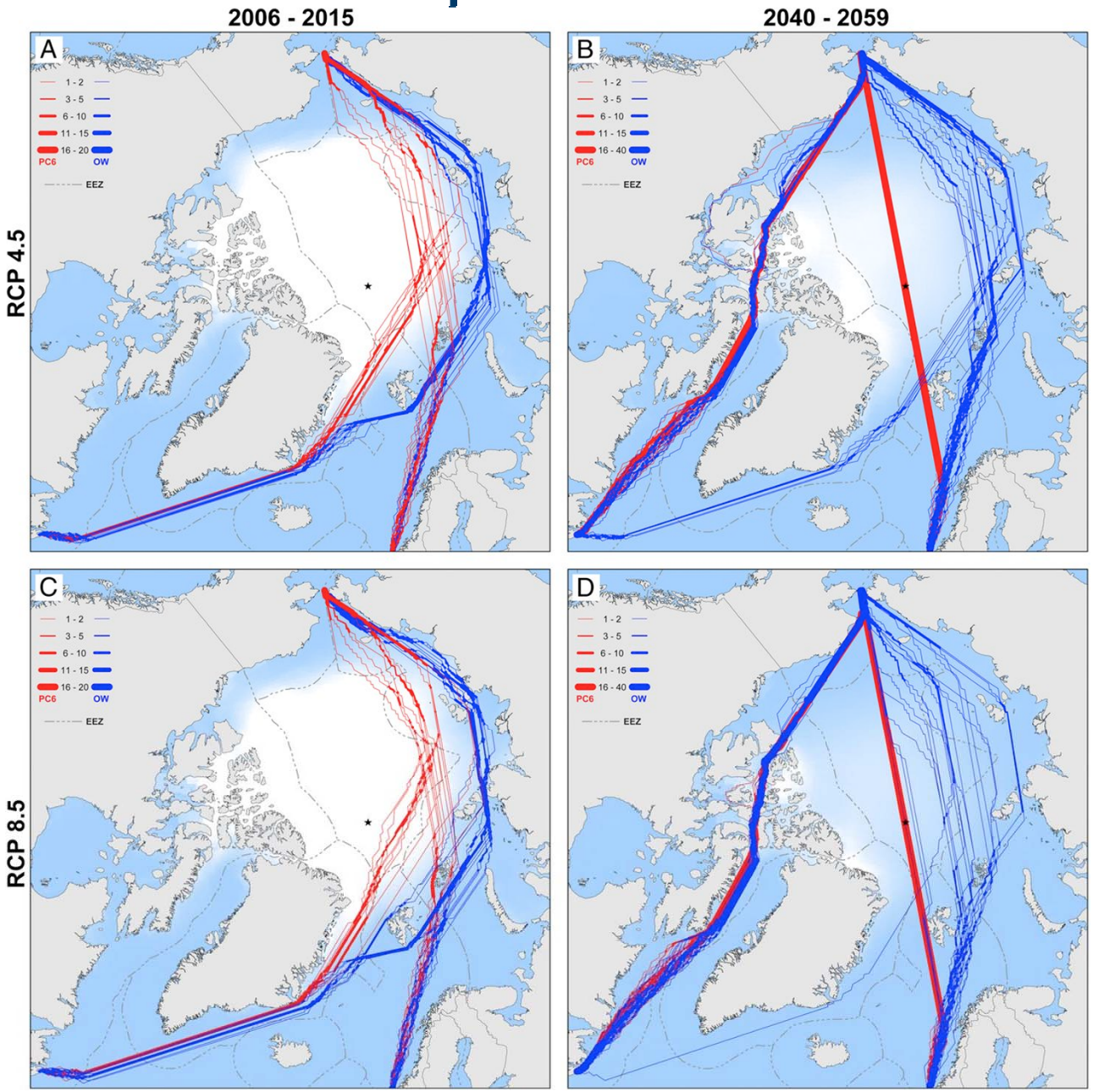
Why is sea ice important?

2. Affects people who live in polar regions (subsistence hunting, travel)

2007: Northwest passage open for first time in human memory

2008: Both Northern Sea Route and Northwest passage open for 1 week



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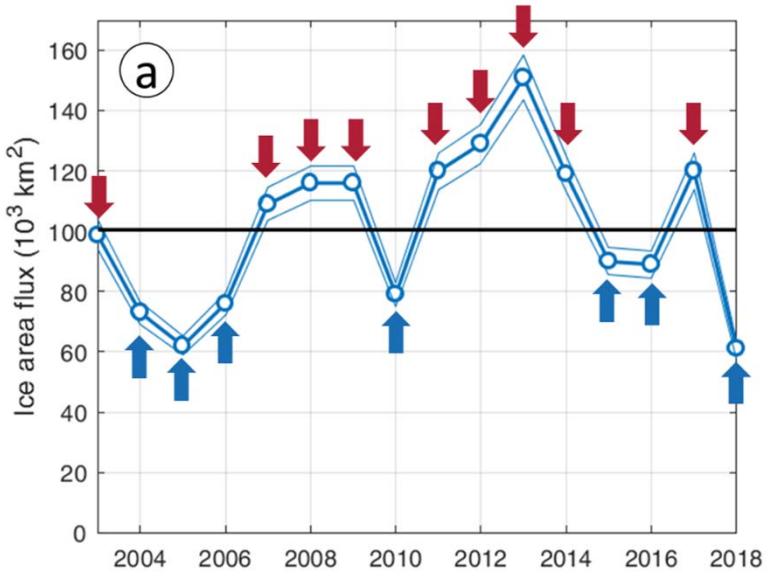
Why is sea ice important?

3. Influence on global climate

- Bright surface (**albedo**) ⇒ good reflector of sunlight (important spring and summer)
- Ice covered areas absorb little solar energy and insulate warm ocean from cold air
- Ice free areas absorb much solar energy, allow heat transfer between ocean and air
- Sea ice covers 2/3 (by area) of the Earth's permanent ice cover, **but only 0.1% of its volume**!
- Small changes in climate can produce large changes in ice thickness and coverage
- Changes in ice extent
  - ⇒ changes in atmospheric circulation
  - ⇒ changes in ocean circulation: deep water formation in Greenland Sea and Antarctic polynyas
  - ⇒ changes in surface fresh water into NAtlantic

POSITIVE FEEDBACK:
Change in climate → change in ice
Change in ice → change in climate



Mayot et al. 2019 GBC

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Sea ice: More than frozen water

1. Thermal: Conductivity; slows heat transfer,
   Implications for weather, climate

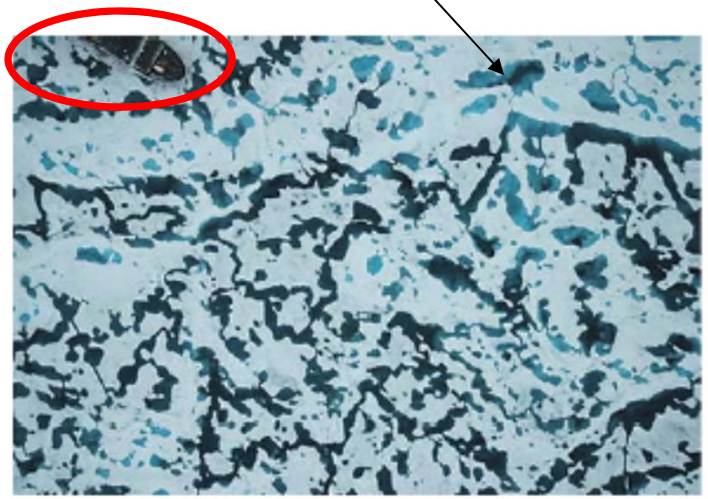
2. Mechanical: Porosity, compression
   Implications for movement

3. Electromagnetic: Heat balance, albedo; melt ponds; light penetration
   a) Optical
   b) Infrared
   c) microwave

   Remote sensing; infrared and visible limited by clouds, darkness; ice emits in μwave range => monitoring of snow, ice, melt ponds, water fraction

I. LARGE scale = Almost constant motion:
   Beaufort Gyre, Transpolar Drift through Fram Strait (10% export)

II. SMALL scale = leads & polynyas; rafting & pressure ridges => ice thickness



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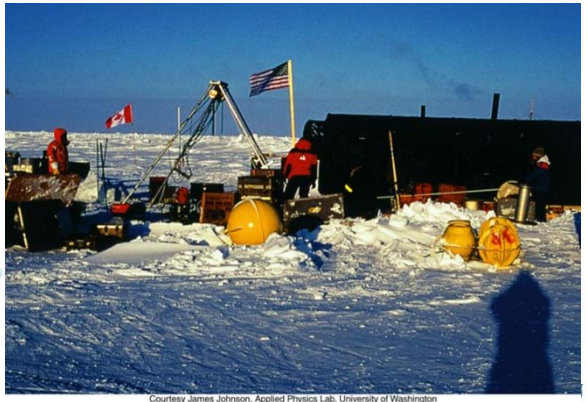
Studying sea ice: Remote locations and extreme conditions

Courtesy of Sandra Hines, University of Washington

Ice camps



Courtesy James Johnson, Applied Physics Lab, University of Washington

Hovercrafts "SABVABAA"
See www.polarhovercraft.no

http://www.youtube.com/watch?v=lBJWBA2TAnY&feature=player_embedded

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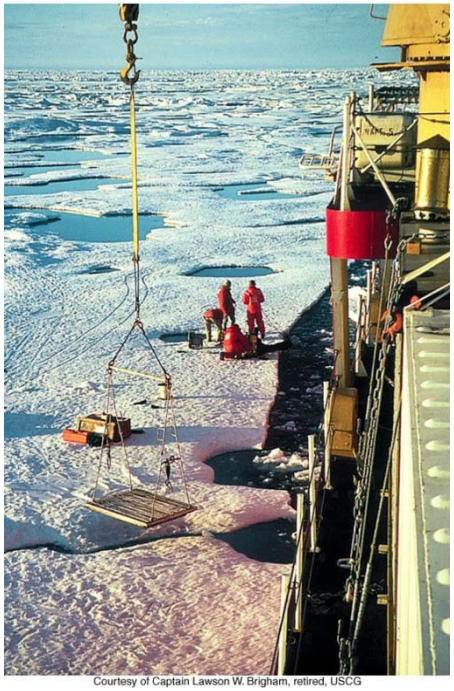
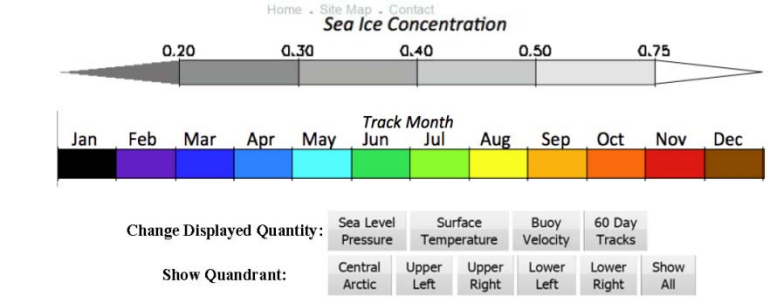
Studying sea ice: Remote locations and extreme conditions

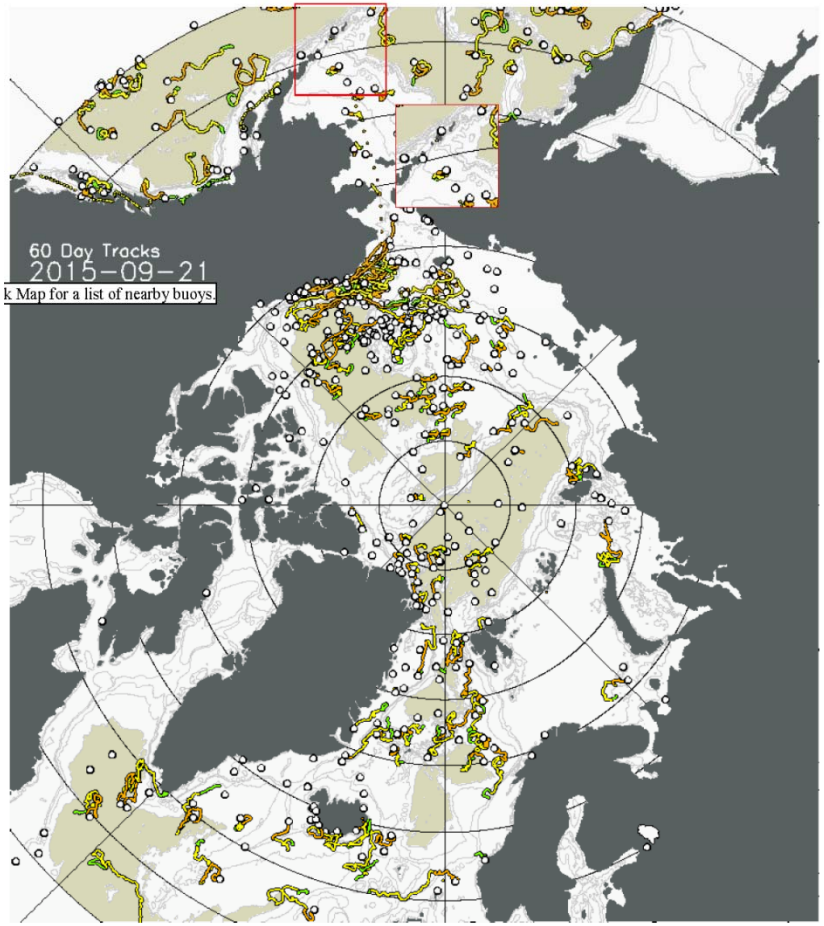
U.S.S. Pogy (SSN 647) surfaces through Arctic ice 05 November 1998, during a 45-day research mission to the North Pole.



Courtesy of Captain Lawson W. Brigham, retired, USCG

O-Buoy, CCG L St Laurent





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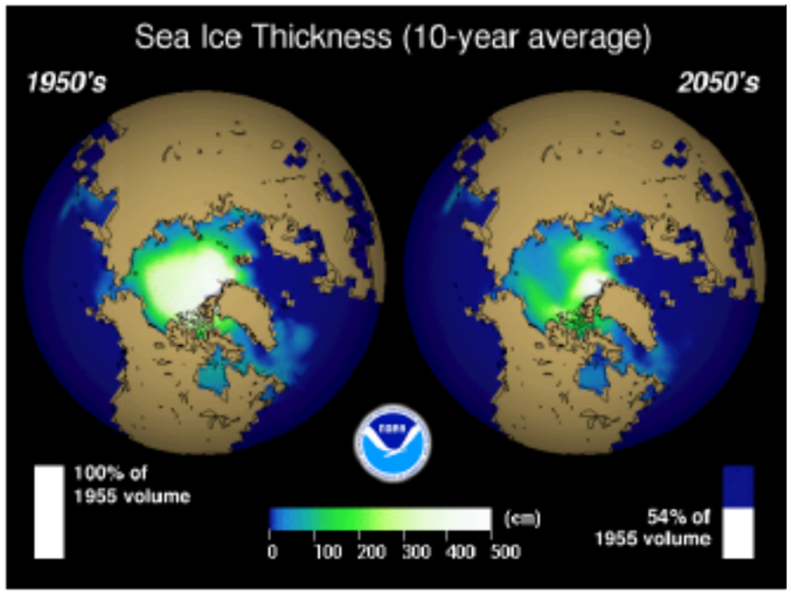
http://iabp.apl.washington.edu/

MODELS



Sea ice projections with global warming
(GFDL coupled climate GCM)

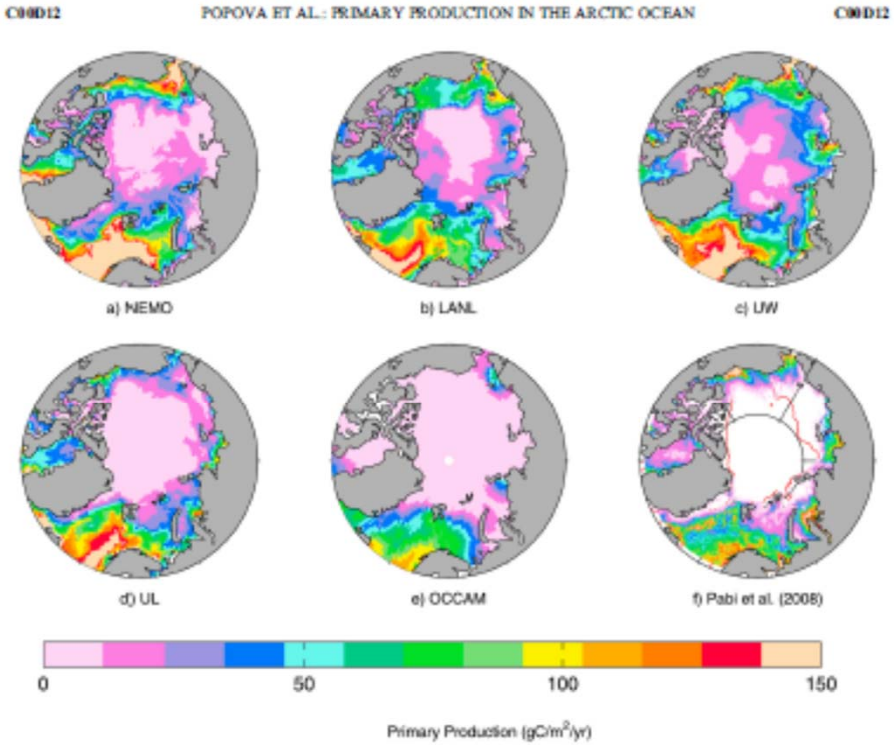


Figure 1. Mean annual water column primary production (in g C m^{-2} yr^{-1}) for (a) NEMO, (b) LANL, (c) UW, (d) UL, (e) OCCAM, and (f) satellite-derived estimates of *Pabi et al.* [2008].

AOMIP http://www.whoi.edu/page.do?pid=29836
FAMOS http://www.whoi.edu/projects/famos/

Goals:

1) Understanding and relative importance of processes (known and unknown)

2) Projections (hind- and fore-casts)

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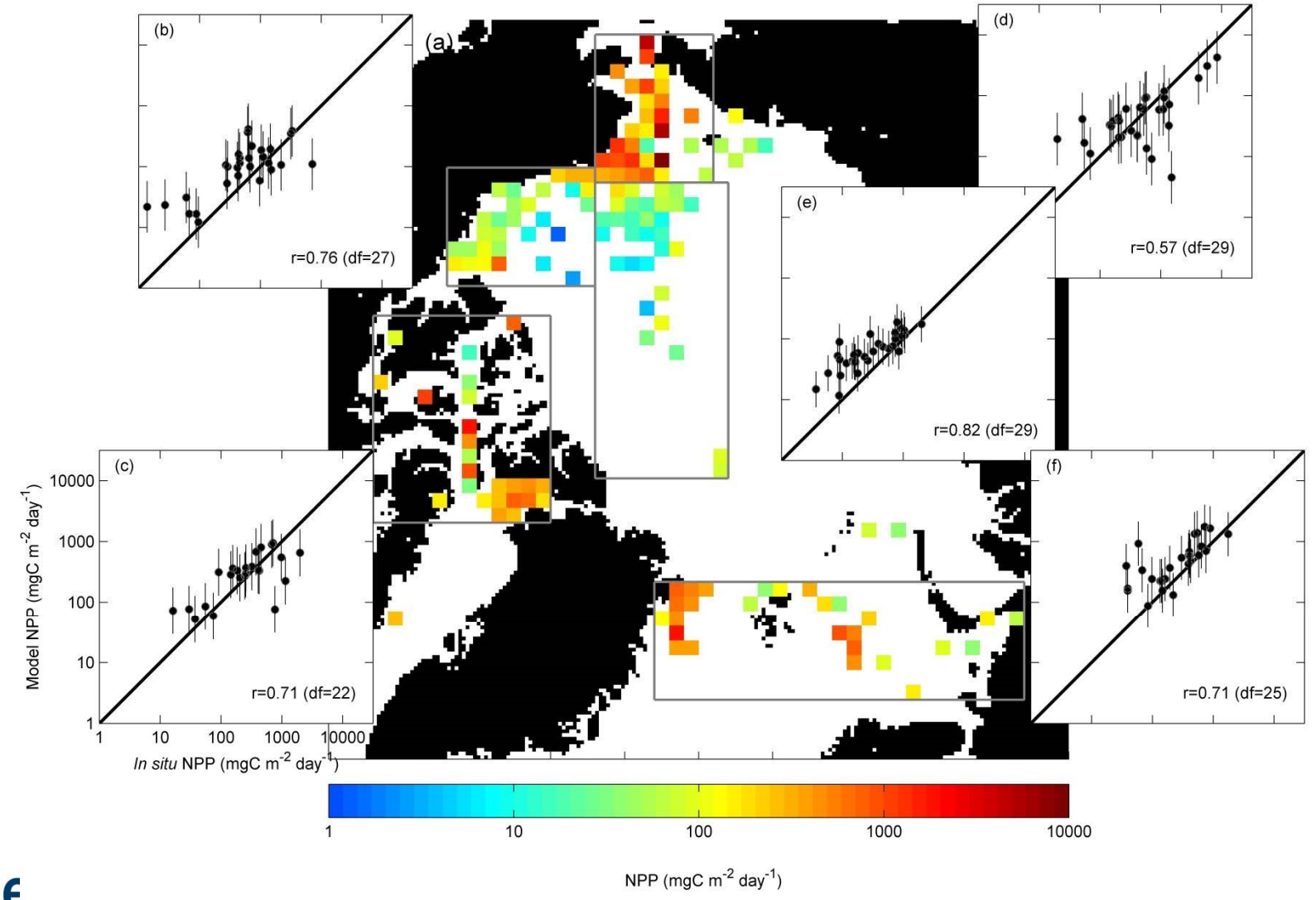
Recent results from the Primary Production Algorithm Round Robin for the Arctic Ocean (NASA-funded)

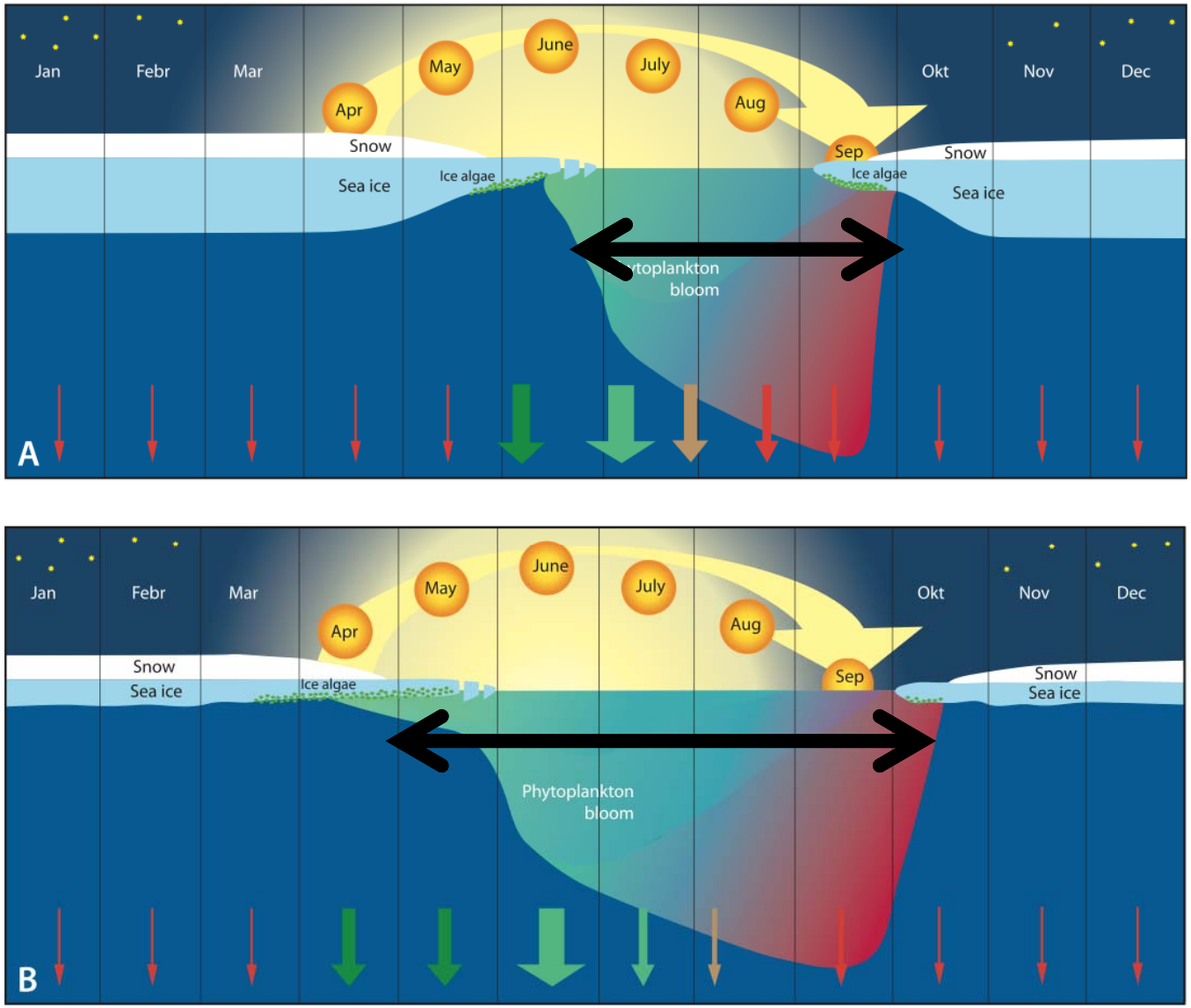
OCM model- in situ NPP



Lee et al. 2015 JGR-Oceans

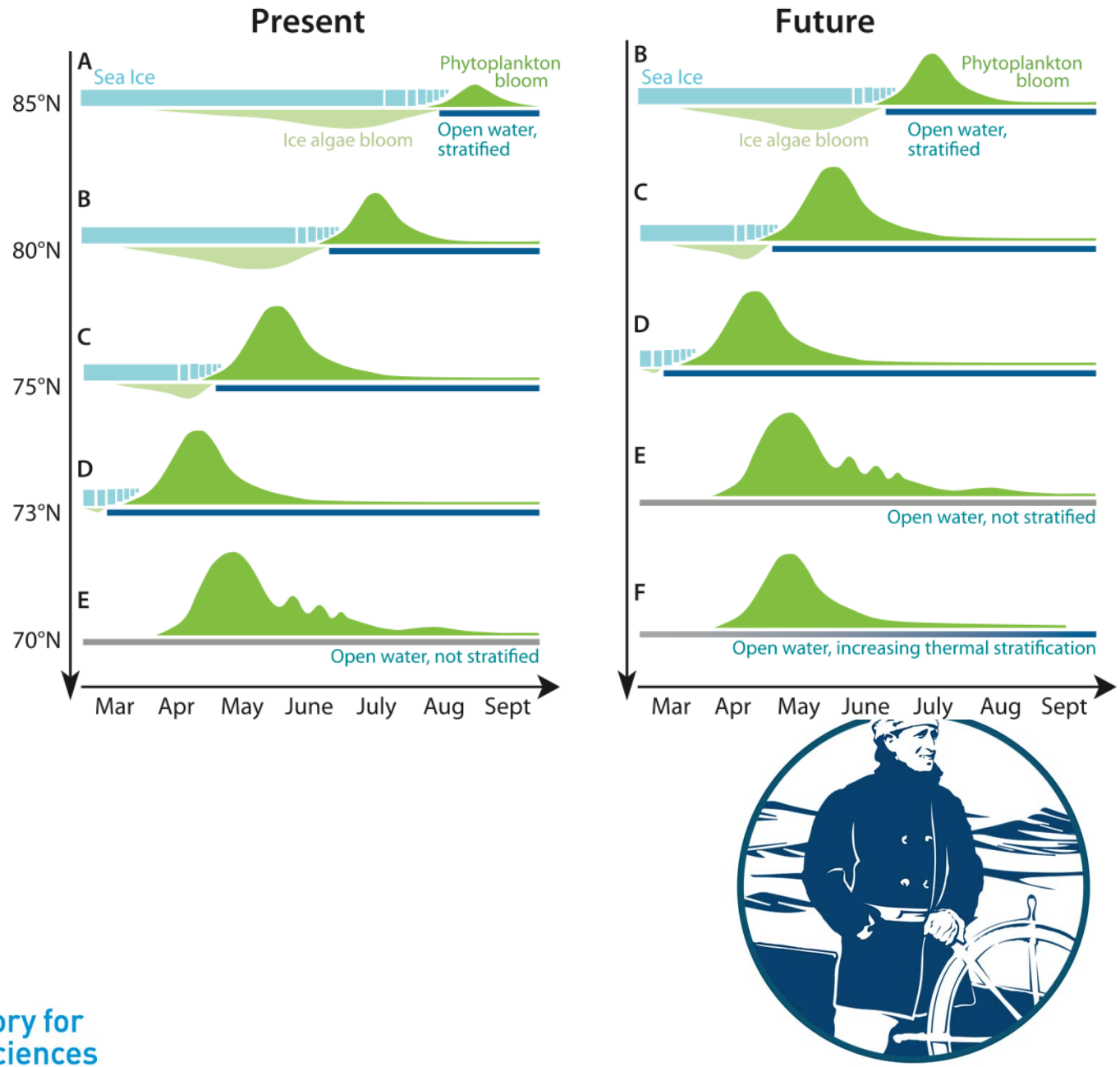
Today's extreme seasonal variation disappears

Sub-ice blooms increase?



Wassmann 2011, and those before him

ASSUMPTIONS!!



Wassmann & Reigstad
2011 Oceanography

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Upper trophic ecology

ARCTIC

Copepods

- *Calanus glacialis, Calanus hyperboreus*
- Lipid sac for hibernation
- Creates a fatty prey resource for predators for long periods of time despite low productive periods

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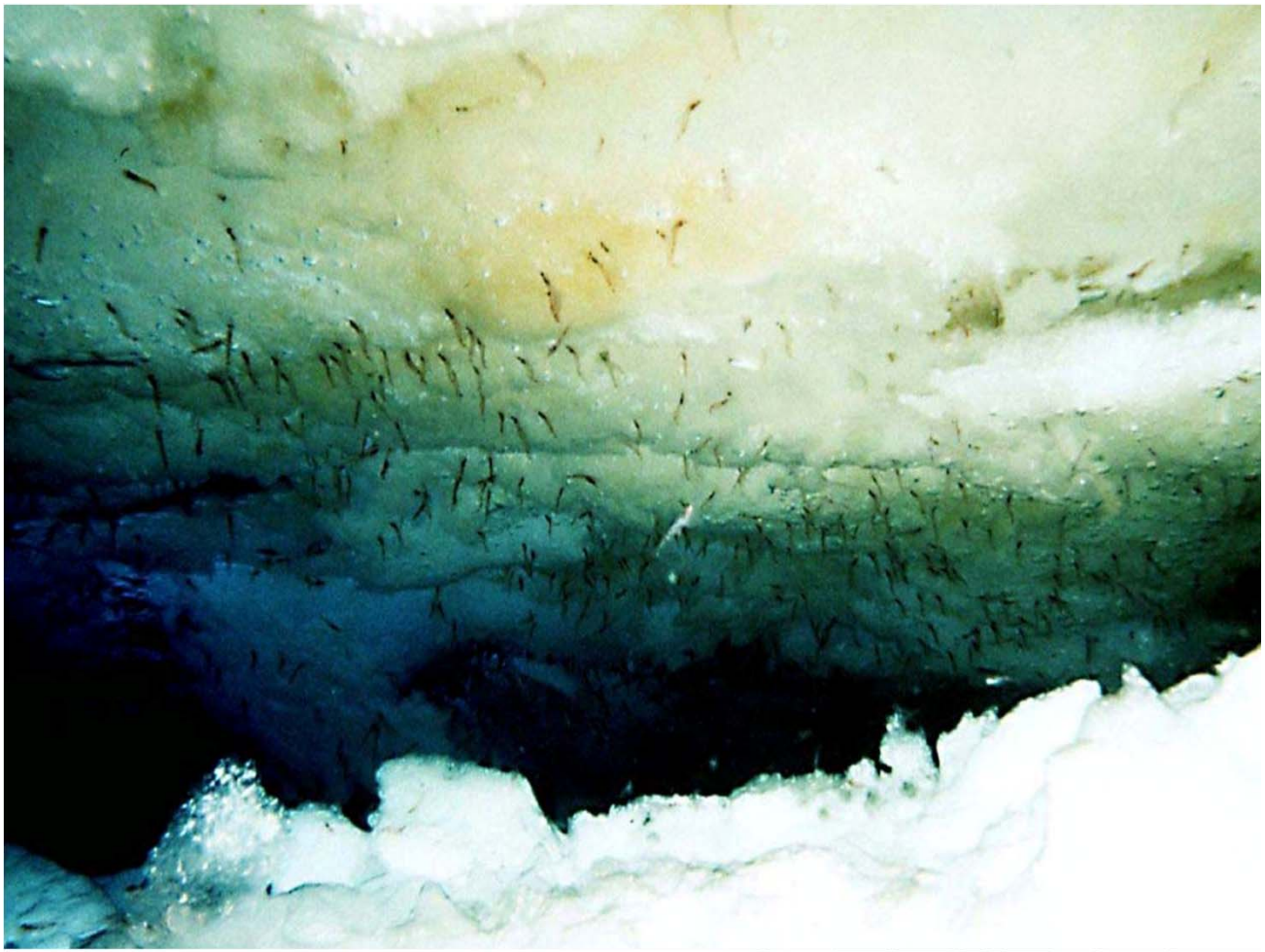
Upper trophic ecology

ANTARCTIC

Krill

- *Euphausia superba*
- Feeds on ice algae
- Possibly largest biomass of a single species
- Supports penguins, whales, etc.



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Upper trophic ecology

Polynyas – open water surrounded by ice, important for marine mammals.

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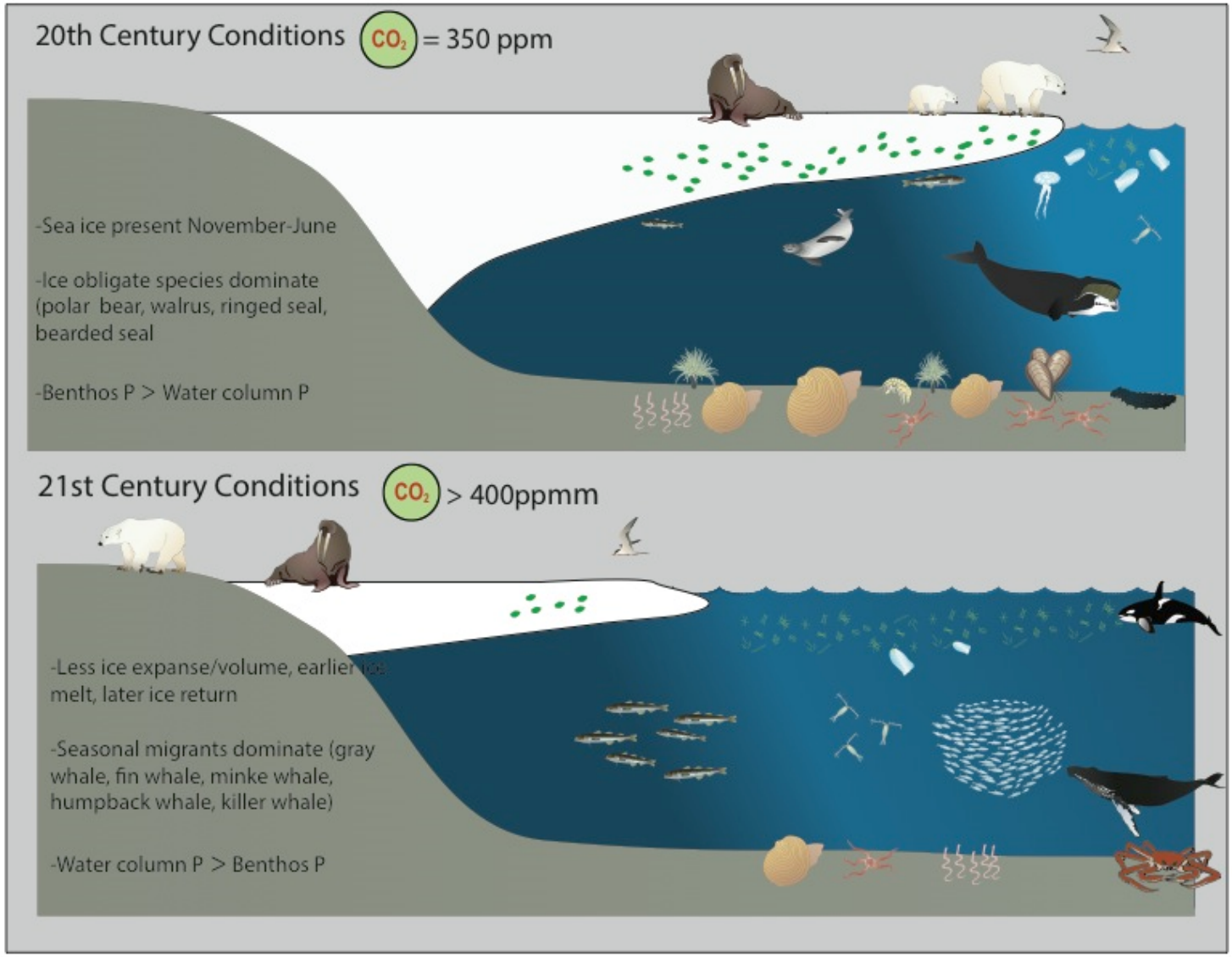
Photo:National Geographic

Major ecological shifts expected with reduced sea ice conditions



[Cooper and Grebmeier - Chukchi Sea case study, 2016, "*Climate Change and Biodiversity*", Lovejoy and Hannah [eds.], Yale University Press]

Courtesy JM Grebmeier, U. Maryland

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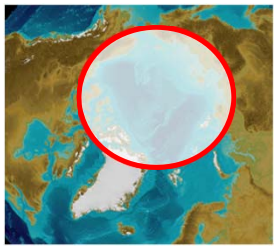
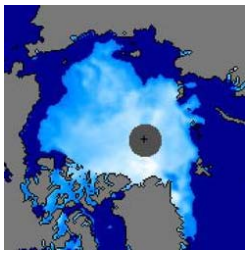


Ice thaw or freeze-up?

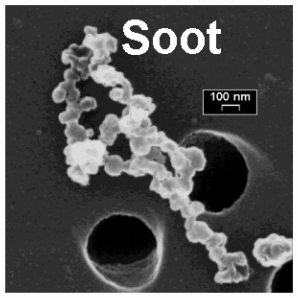


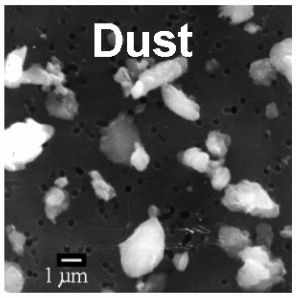
CLOUDS: during late summer when the albedo of the sea ice is at a minimum, cloud-albedo can control the timing of the autumn freeze-up

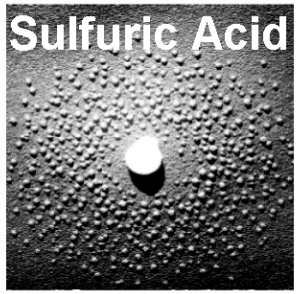
Aerosols = Particles in the Air

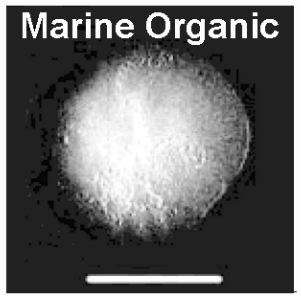
?

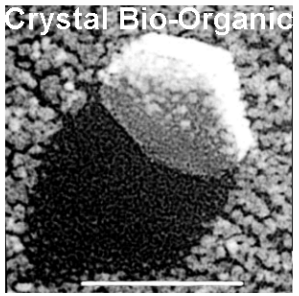
Tiny ones

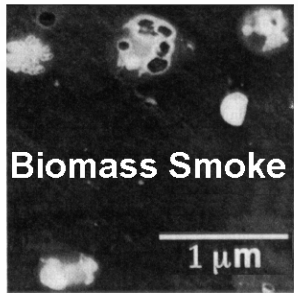


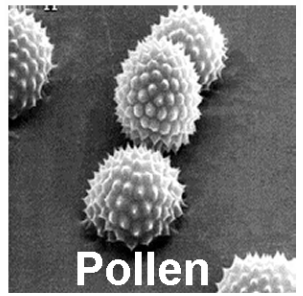












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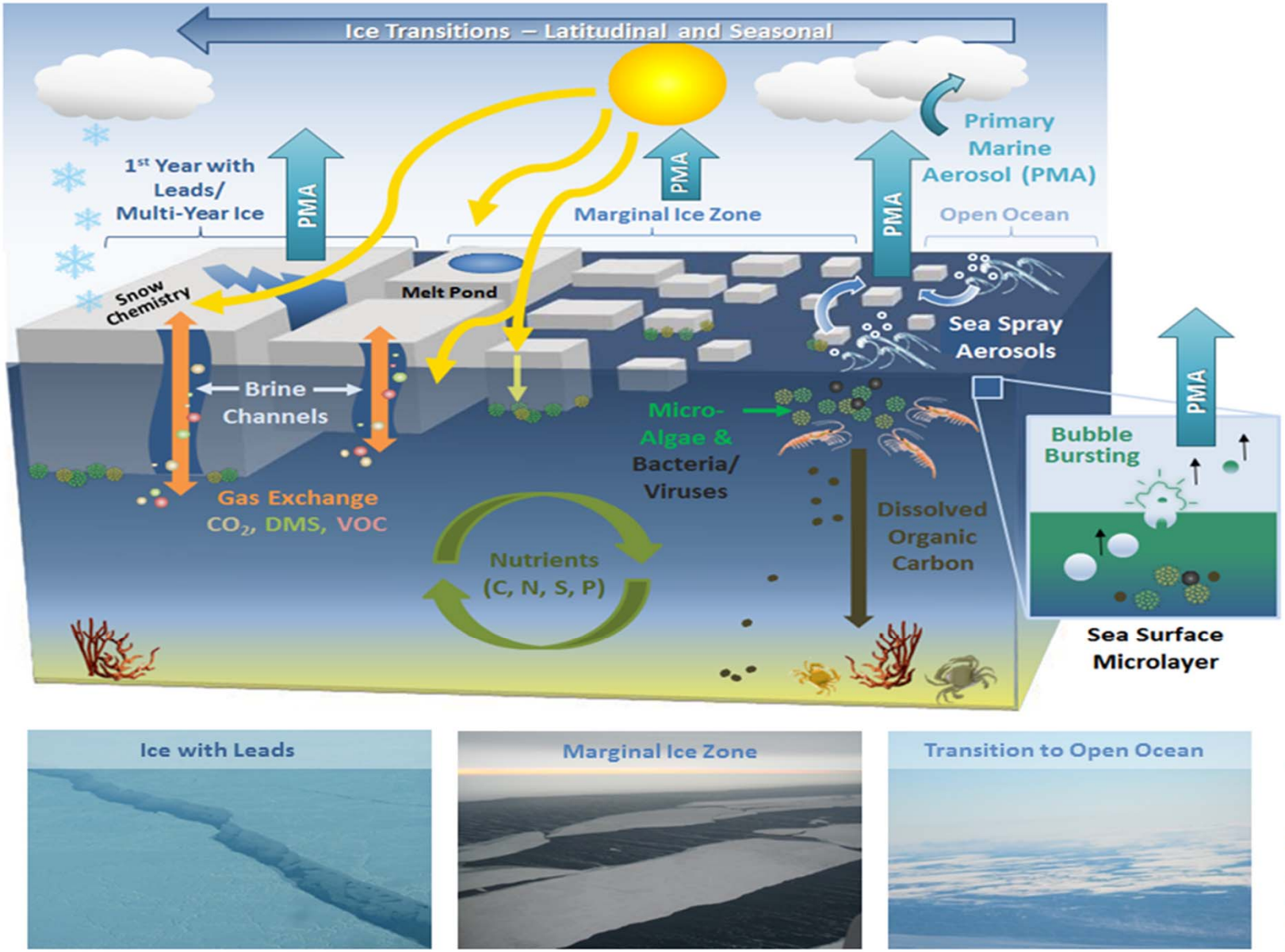

Fig. 1: *Schematic of ocean/atmosphere interactions, with a focus on primary marine aerosol production –across sea ice types.*

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No particles no fog!!!

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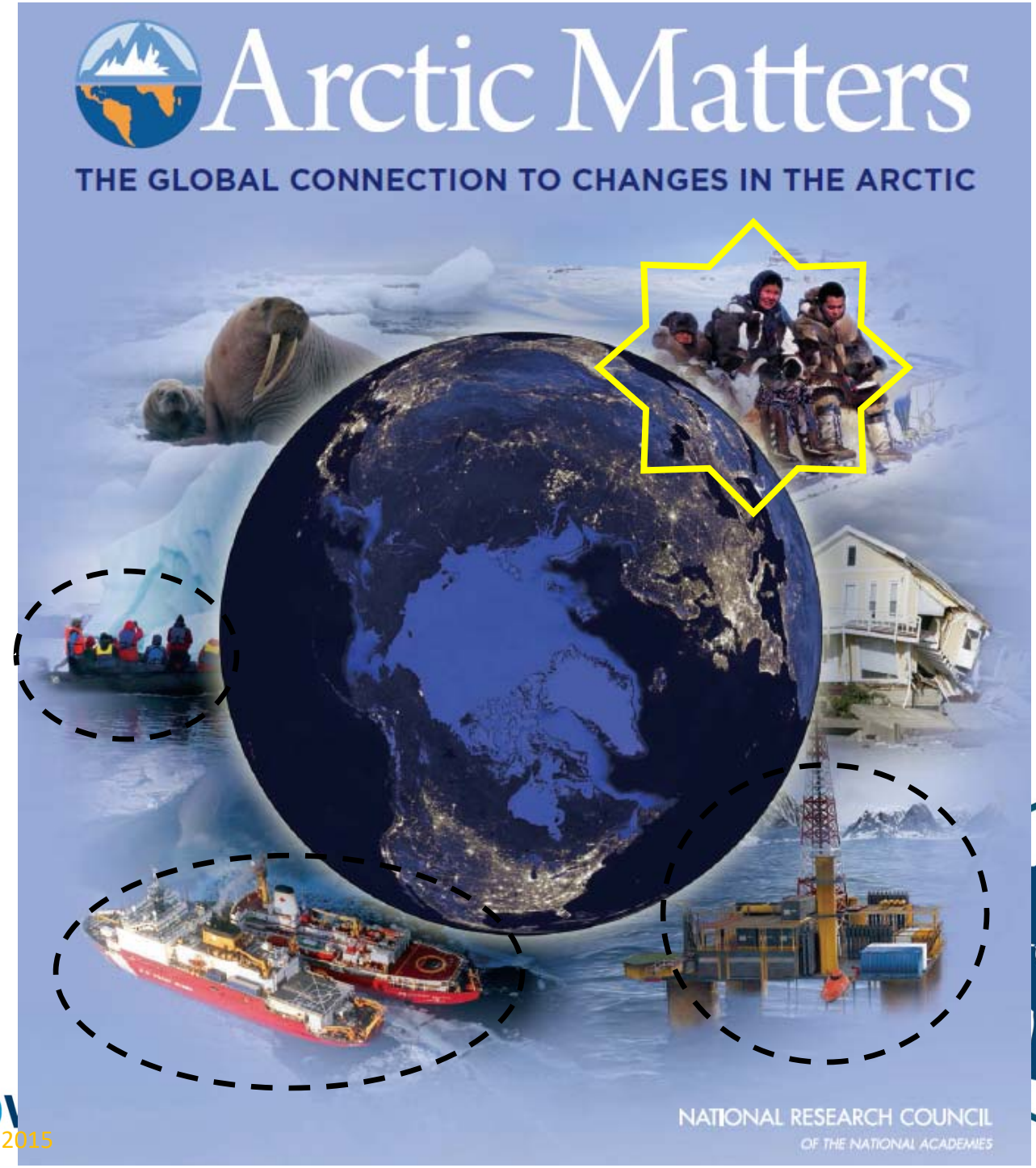
Arctic Matters
THE GLOBAL CONNECTION TO CHANGES IN THE ARCTIC
NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES