Sea ice: physical properties, processes and trends

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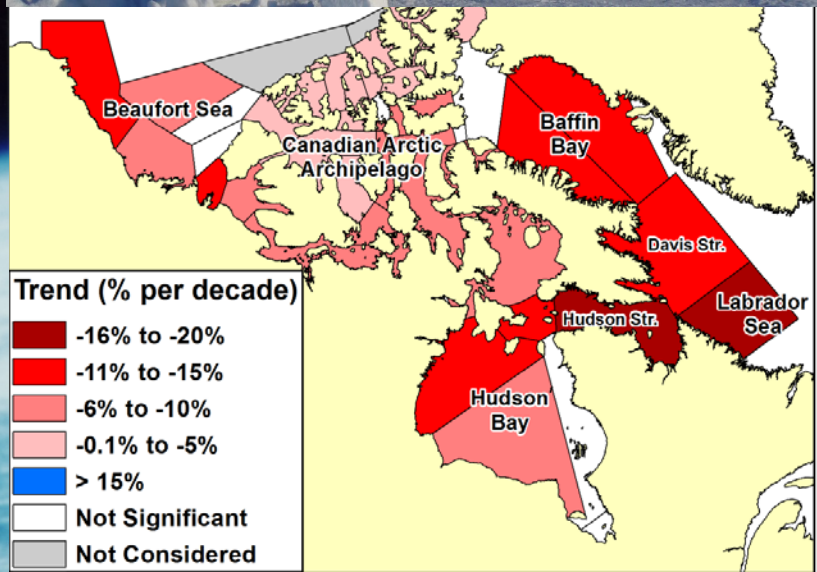
3-Part Sea Ice Lecture Overview

- 1. Physical properties, processes and trends
- 2. Observations
- 3. Canadian Arctic

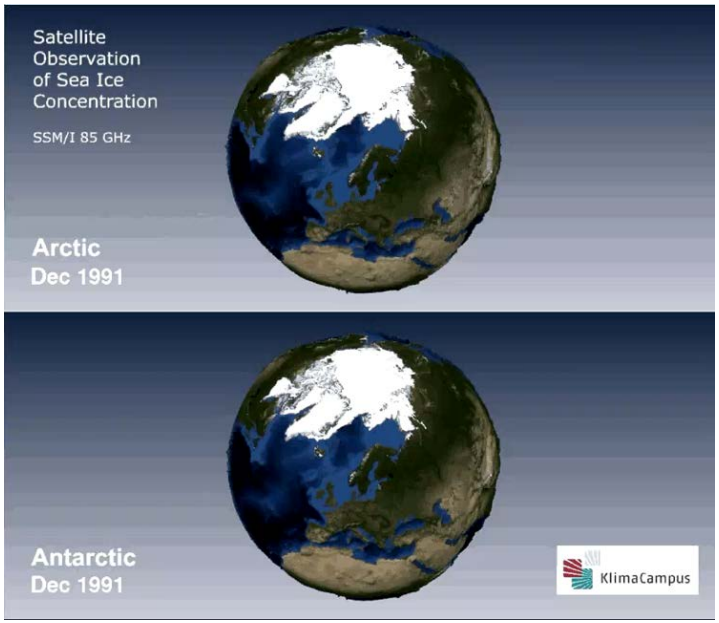


Outline

- Introduction
- Ice types
- Seasonal cycle
- Sea ice dynamics
- Snow on sea ice
- Recent trends

Introduction: global distribution

- Sea ice is any form of ice that is found at sea and has originated from the freezing of sea water
- On average, sea ice covers about 25 million km^2 of the Earth, or about two-and-a-half times the area of Canada

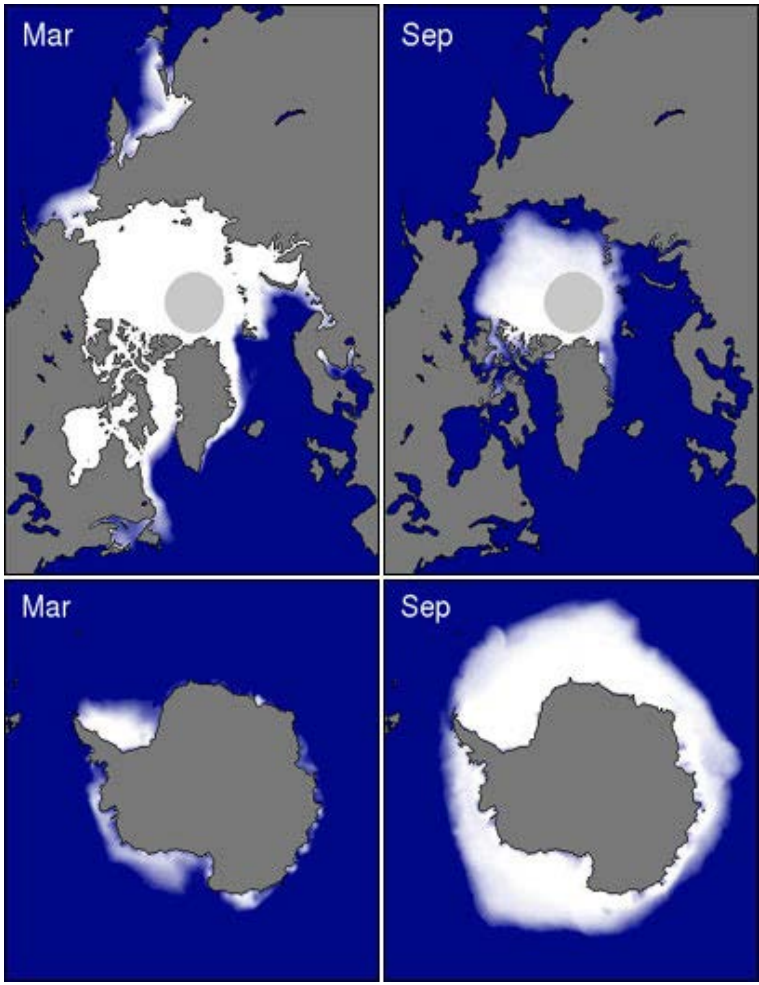


- Arctic
  - Min: 7 million km^2*
  - Max: 15 million km^2
- Antarctica
  - Min: ~3 million km^2
  - Max: 18 million km^2

Introduction: importance

- 1. Has a high albedo and this keeps the planet cool.
- 2. Fills a central role in the lives and customs of Inuit.
- 3. Provides a place for polar bears, seals, and other animals to live.
- 4. Influences ocean circulation.

- **Does not raise sea level when it melts, because it forms from ocean water.**



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Sea Ice Types

Sea ice types

- ***New Ice:*** Recently formed ice composed of ice crystals that are only weakly frozen together (if at all) and have a definite form only while they are afloat.
- ***Nilas***: A thin elastic crust of ice (up to 10 cm in thickness), easily bending on waves and swell and under pressure growing in a pattern of interlocking "fingers" (finger rafting).

- **Young Ice:** Ice in the transition stage between nilas and first-year ice, 10-30 cm in thickness.

CIS

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Sea ice types

- ***First-Year Ice***: Sea ice of not more than one winter's growth, developing from young ice, with a thickness of 30 cm to ~2 m.

Sea ice types

- ***Multi-year/old ice***: Sea ice that has survived at least one summer's melt. Hummocky topography from freeze-thaw.

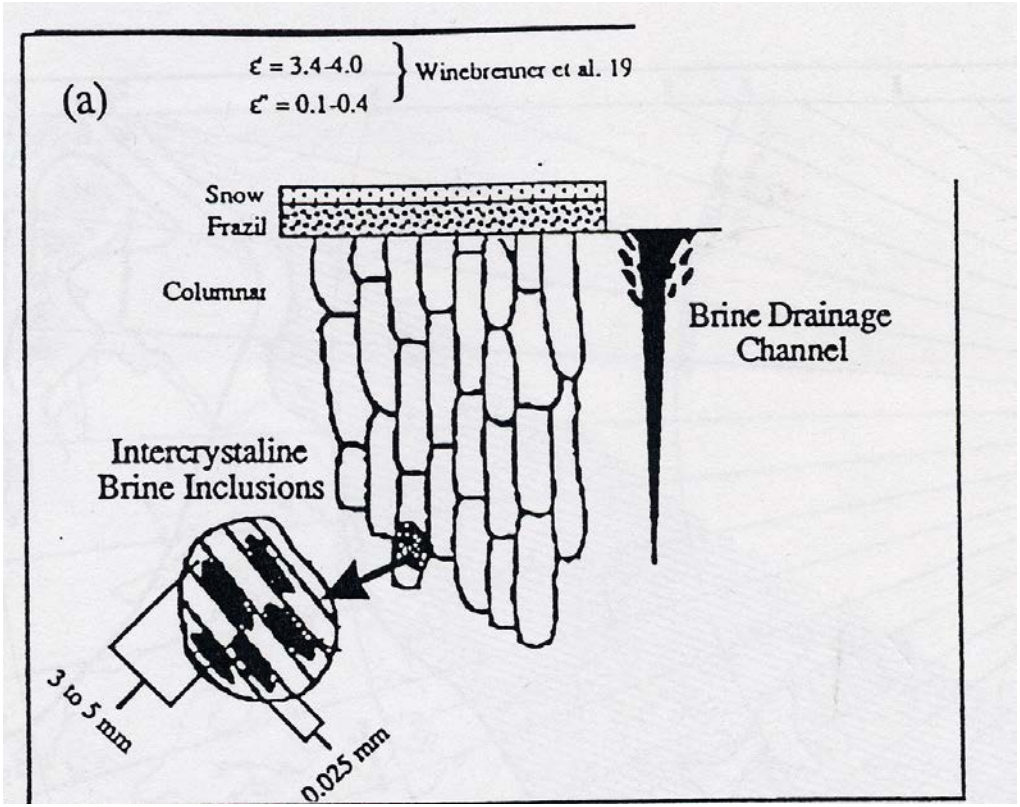
Sea ice types

- ***Multi-year/old ice***: Sea ice that has survived at least one summer's melt. Hummocky topography from freeze-thaw BUT can be heavily ridged.

Canada

Sea ice microstructure

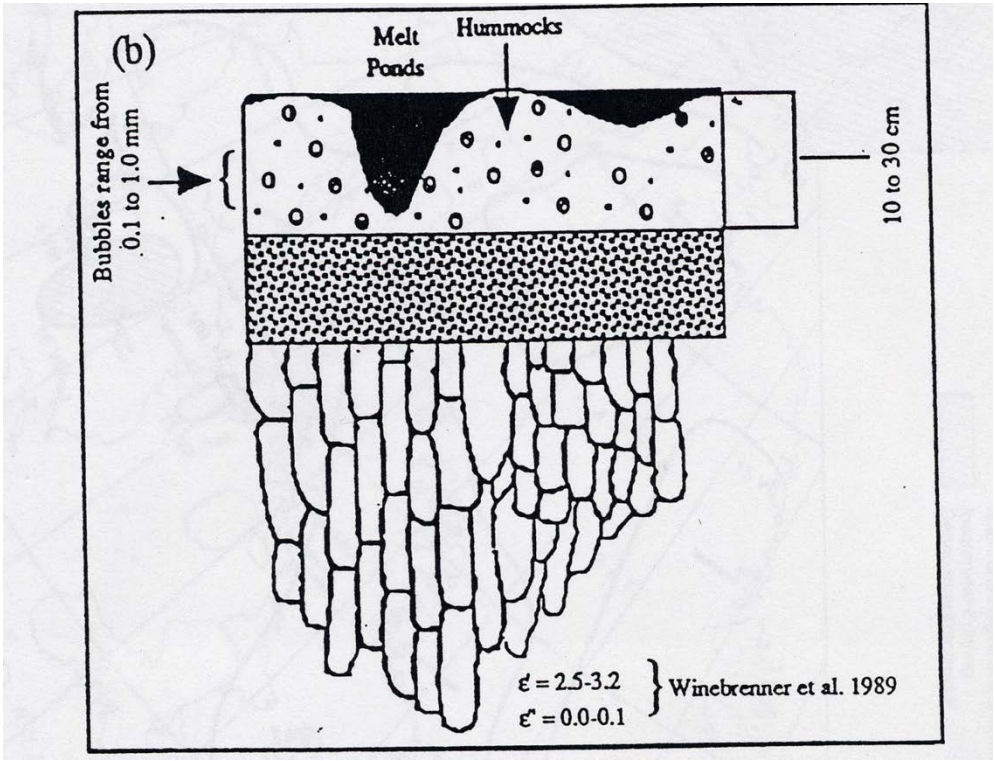
- First-year ice:



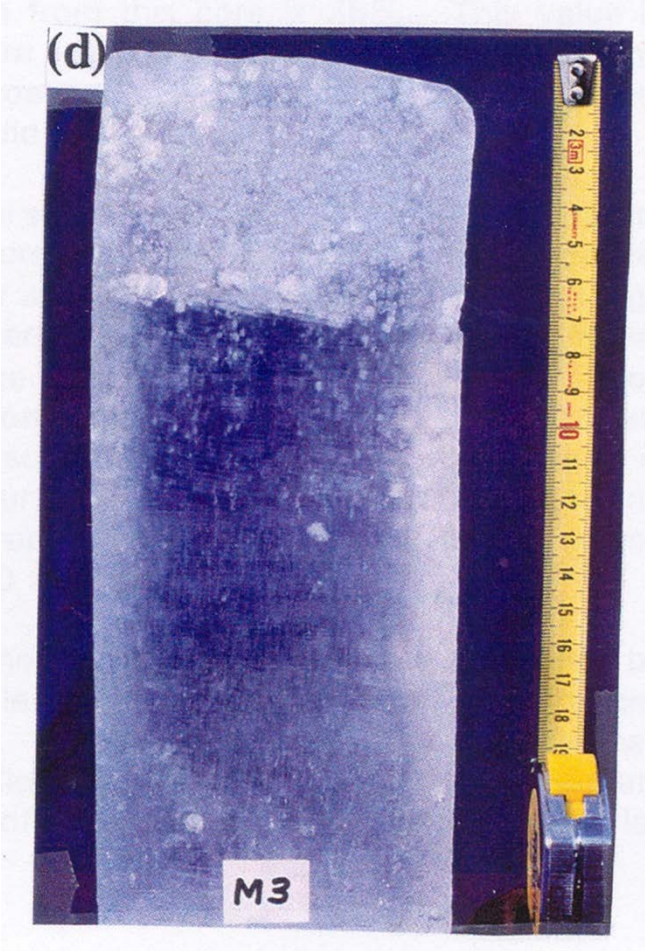
Winebrenner et al., 1988

Sea ice microstructure

- Multi-year ice:

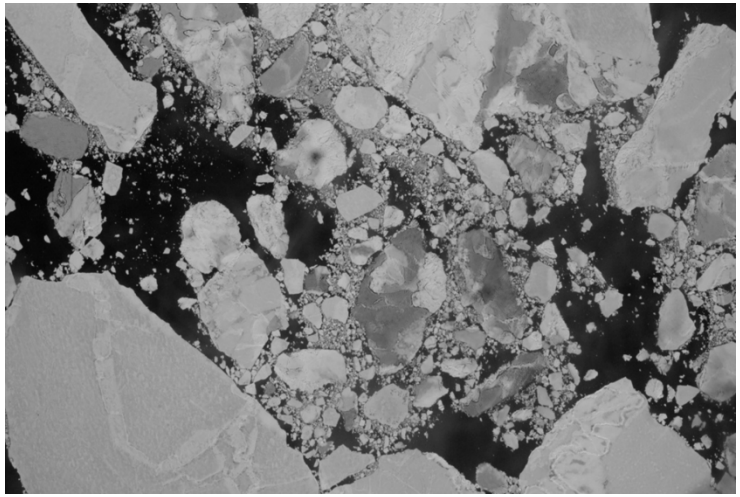


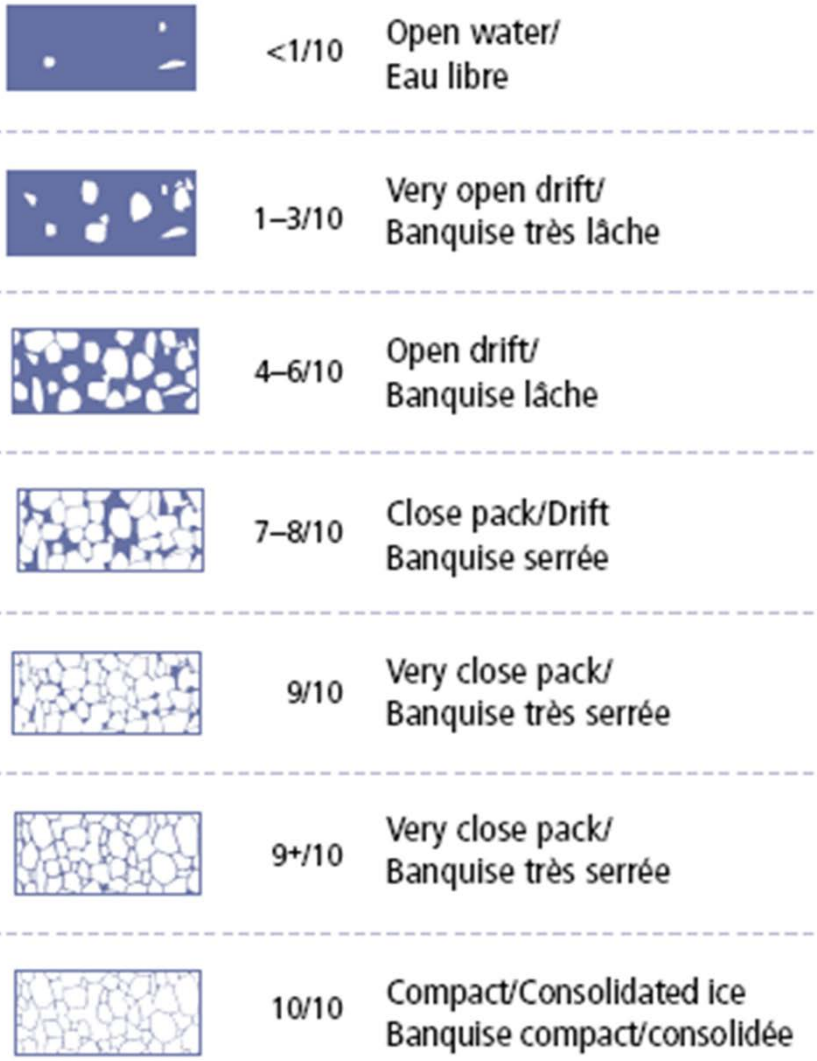
Winebrenner et al., 1988



Sea ice concentration

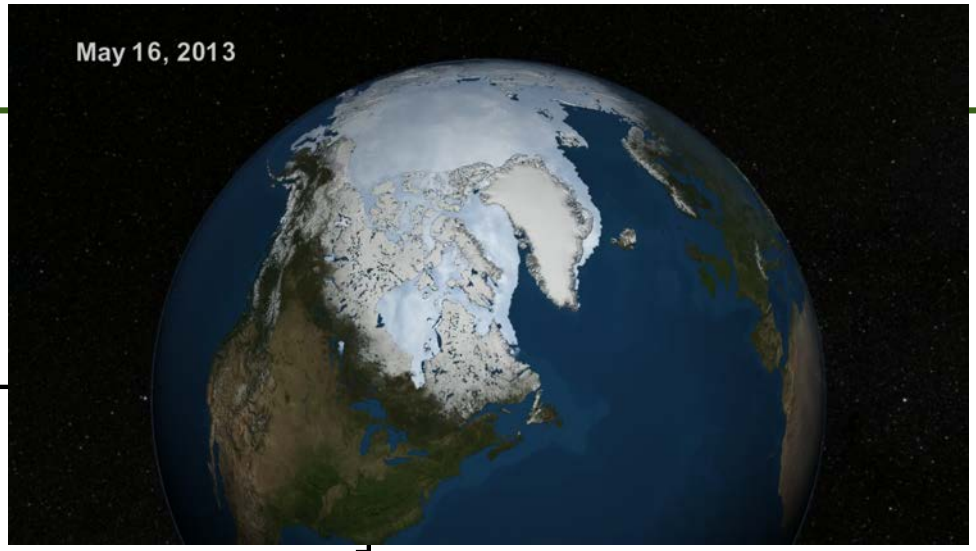
- Given in tenths
  - e.g. 10/10 is 100% covered
- Extent = concentration$_{1.5/10}$ x area
- Coverage = concentration x area

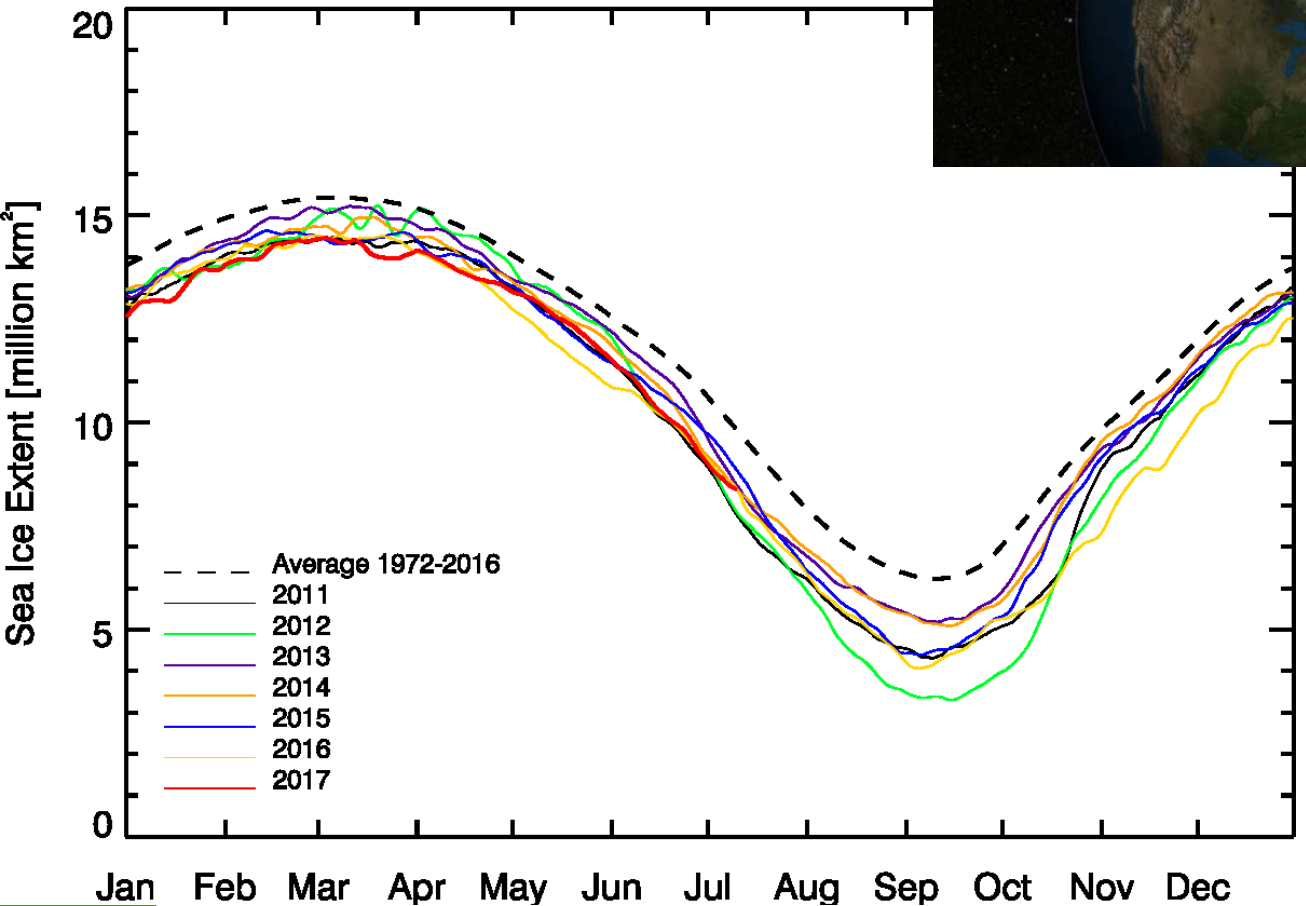




Seasonal Cycle

The seasonal cycle of Arctic sea ice: extent





University of Bremen/NASA

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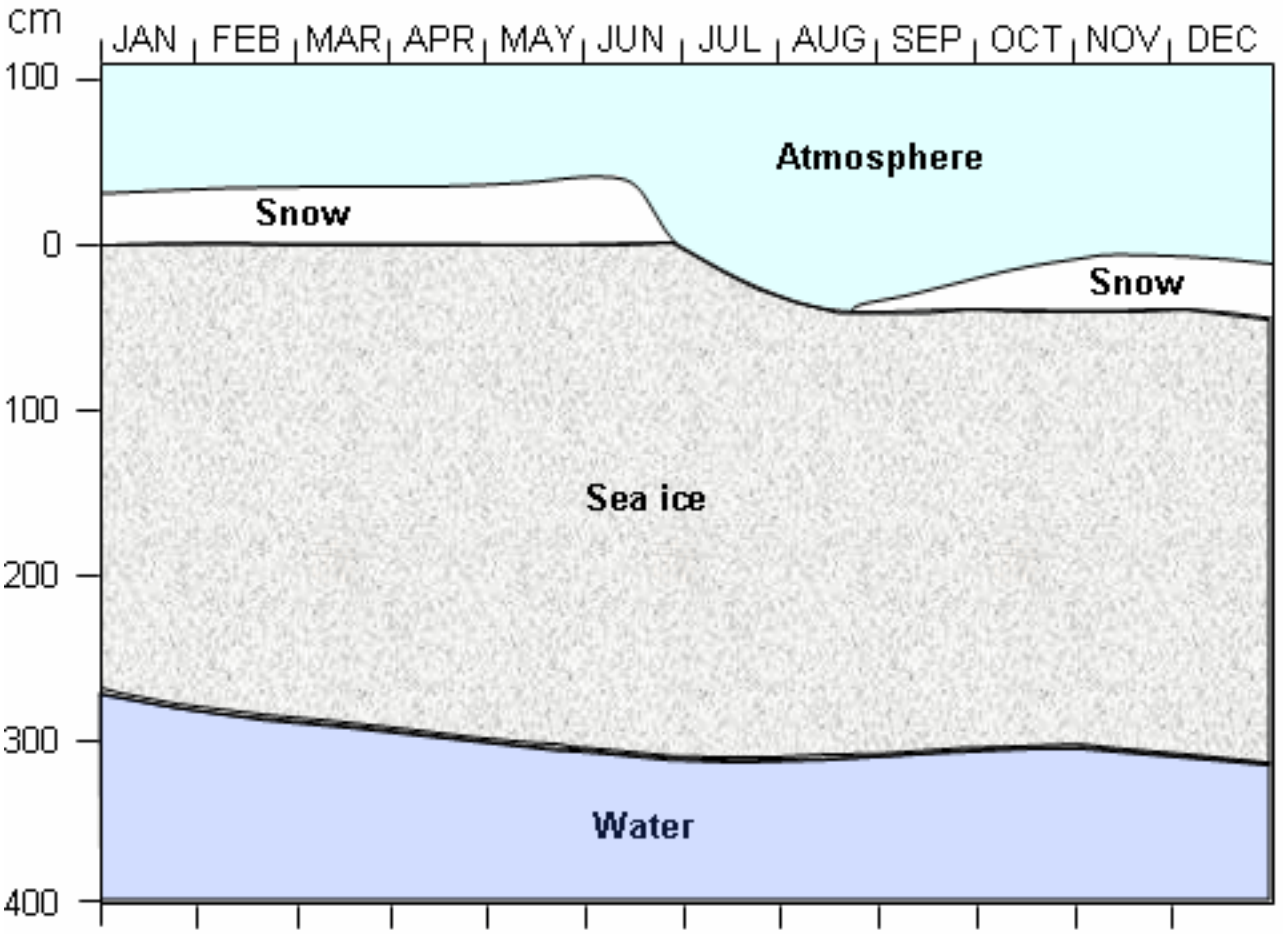
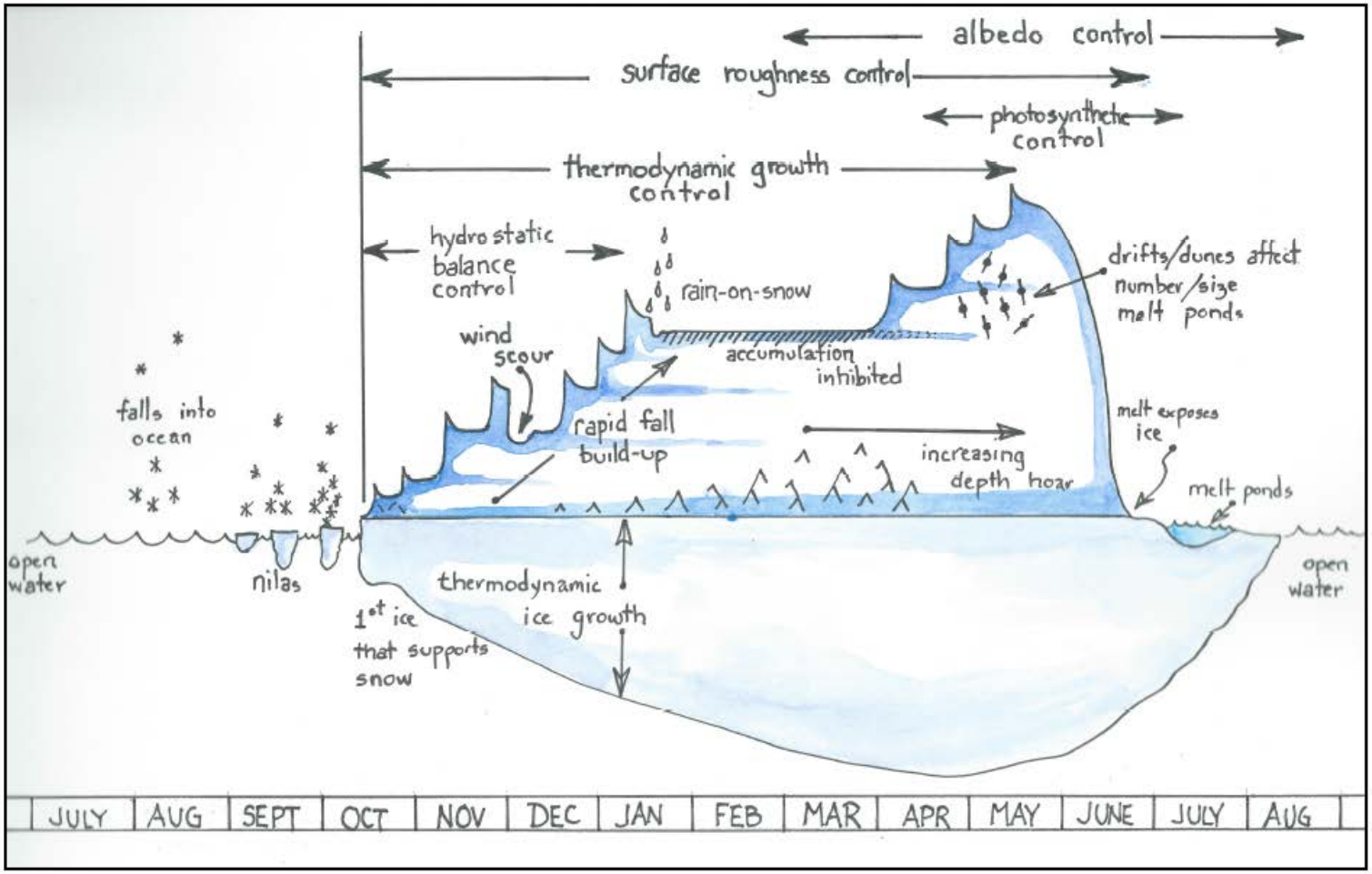
The seasonal cycle of sea ice: thickness



Maykut and Untersteiner, 1971

The seasonal cycle of sea ice: snow



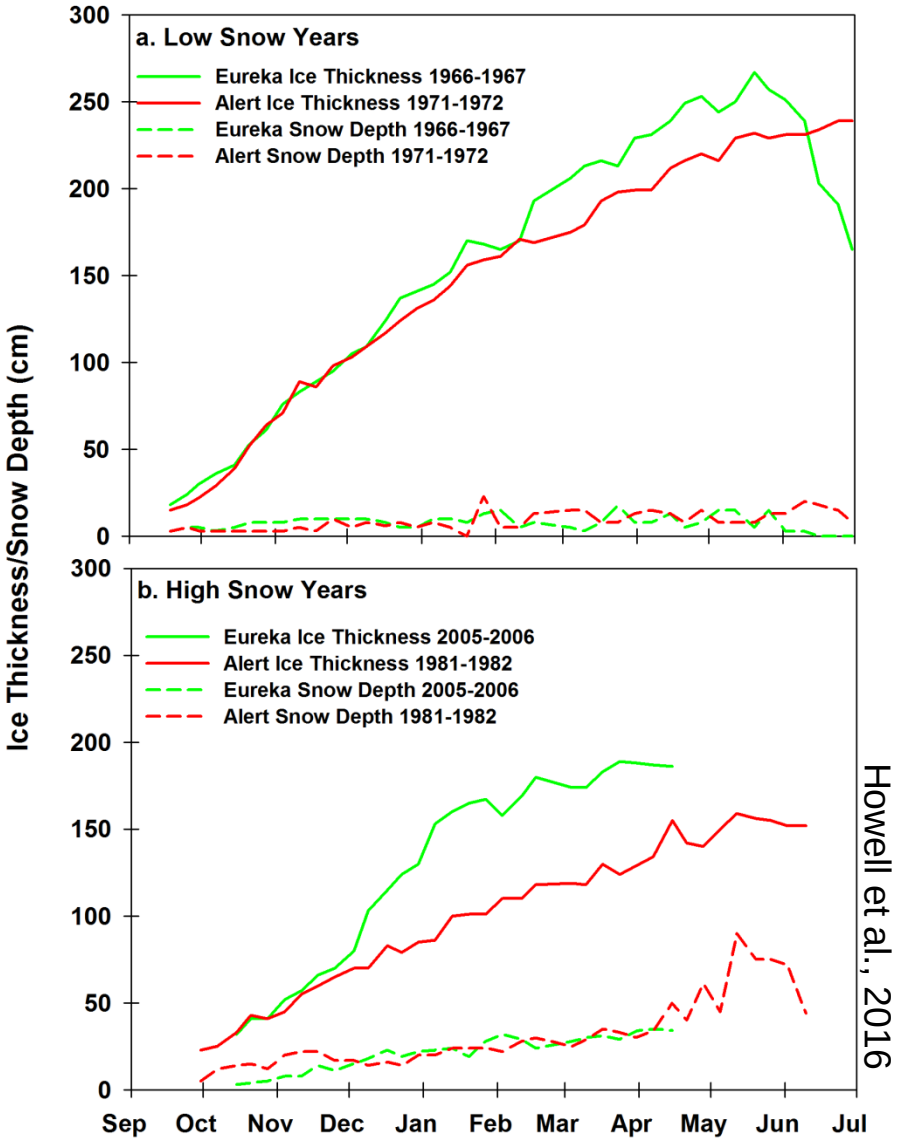
Matthew Sturm

The seasonal cycle of sea ice: snow

- Snow cover acts as a blanket, slowing down the flow of heat from the water.
  - Snow cover plays an important role during ice growth. This is because its large air content makes it a poor conductor of heat (but a good insulator) with a thermal conductivity between 0.1 and 0.4 Wm^{-1} K^{-1} compared to 2 Wm^{-1} K^{-1} for sea ice.

5 cm of various snow types:	Equivalent to an ice thickness of:
Newly fallen soft snow	264 - 381 cm
Slightly settled snow	175 - 193 cm
Normal Snow	61 - 97 cm
Old Snow	41 - 61 cm
Hard packed snow	24 - 31 cm
Extremely cold, wind swept snow	19-24

The seasonal cycle of sea ice: snow



Howell et al., 2016

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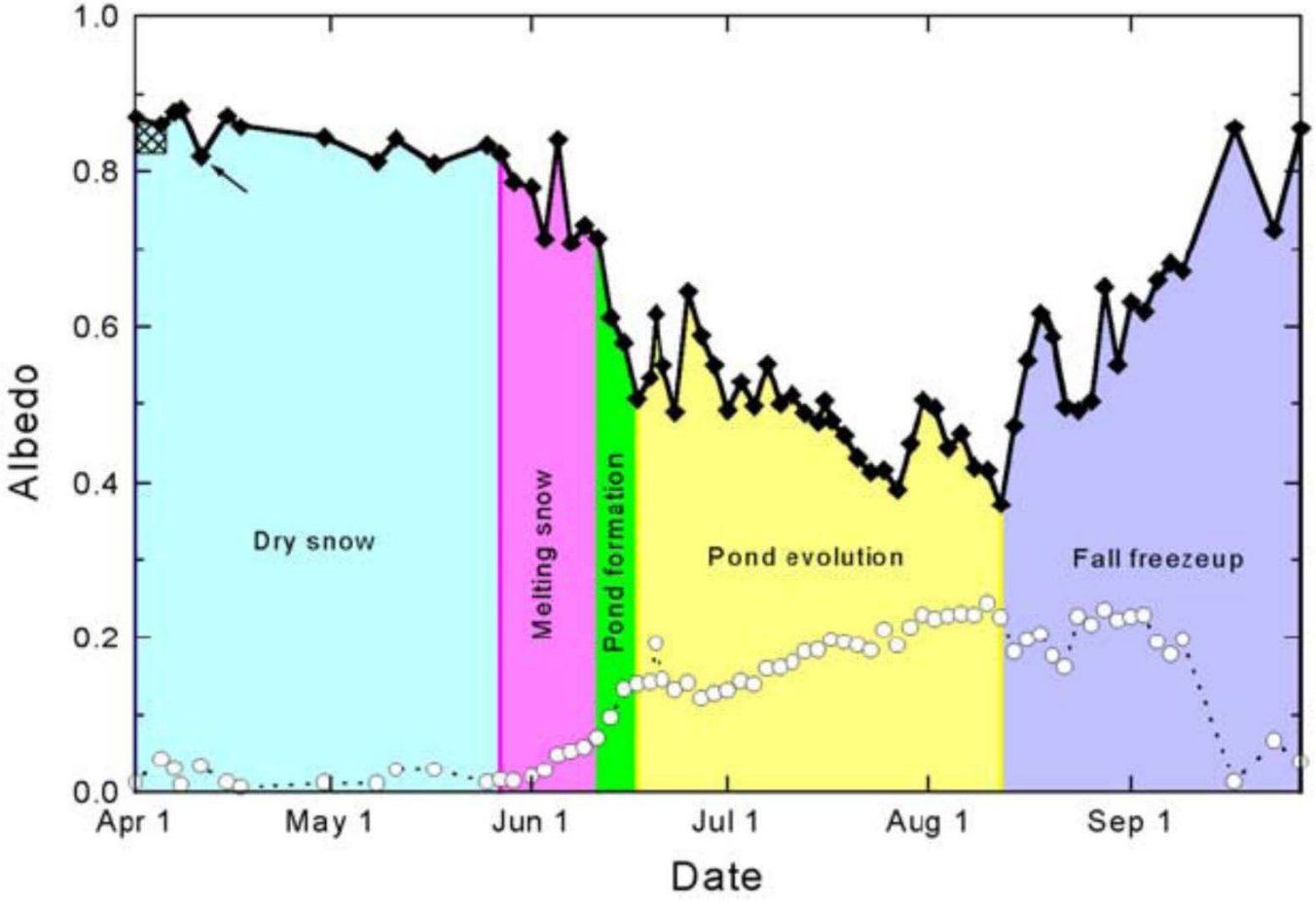
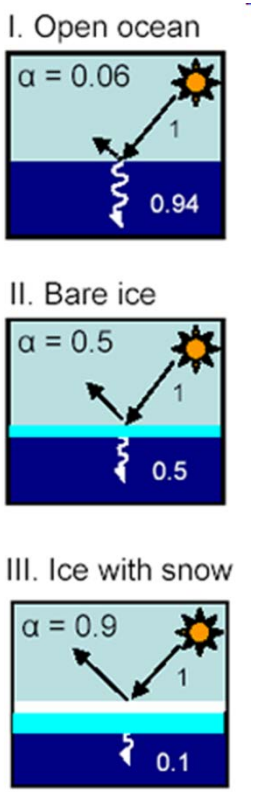
The seasonal cycle of sea ice: albedo

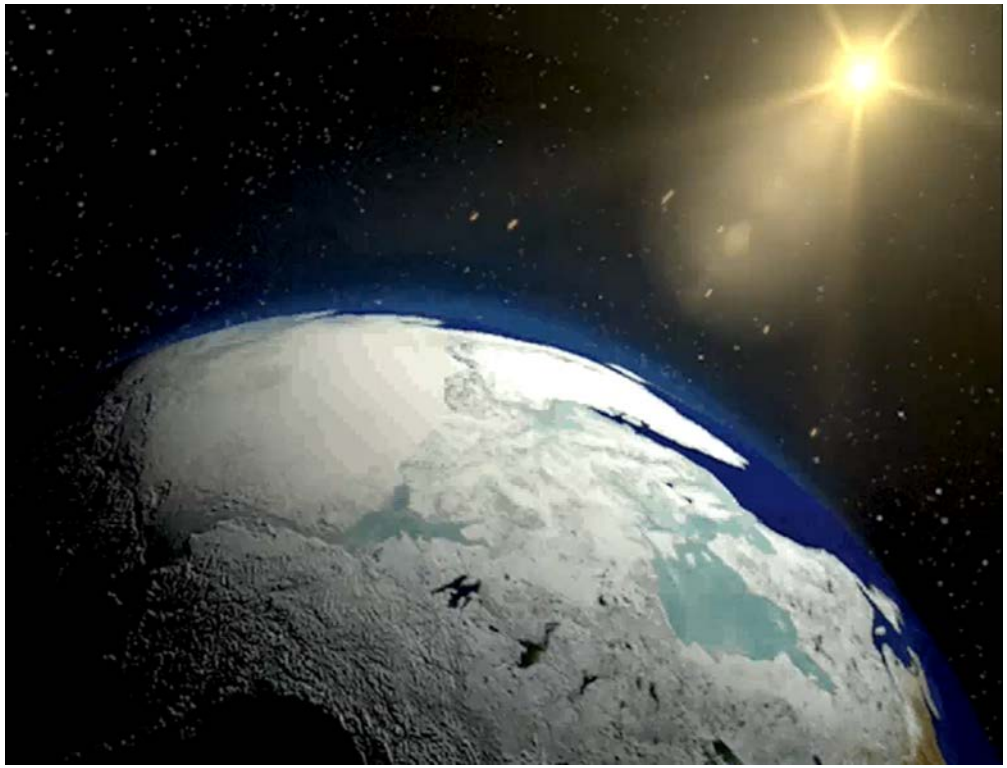


Perovich et al., 2002

The seasonal cycle of sea ice: albedo feedback

- The transition to melt conditions is directly related to the albedo of the surface warming of the snowpack.





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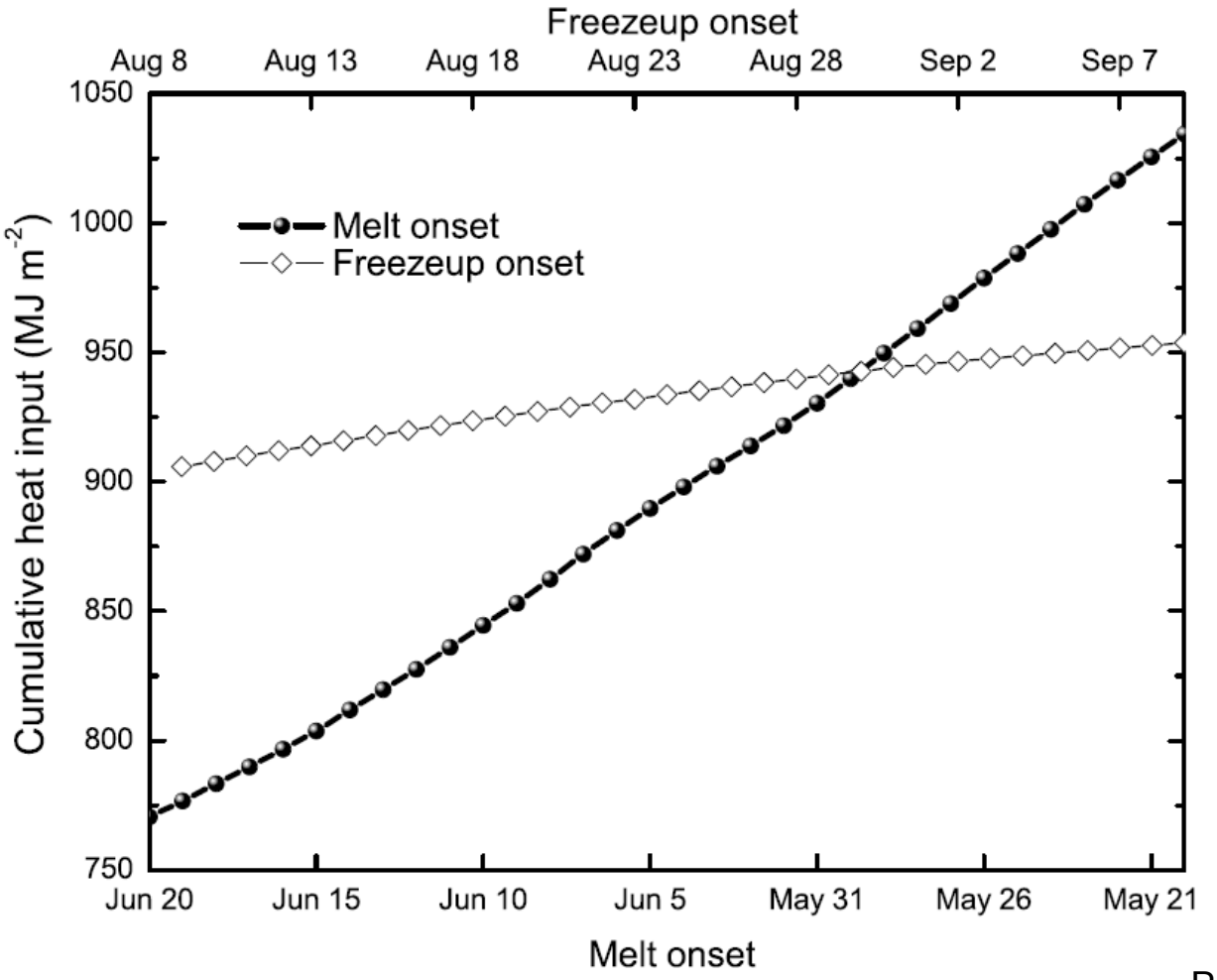
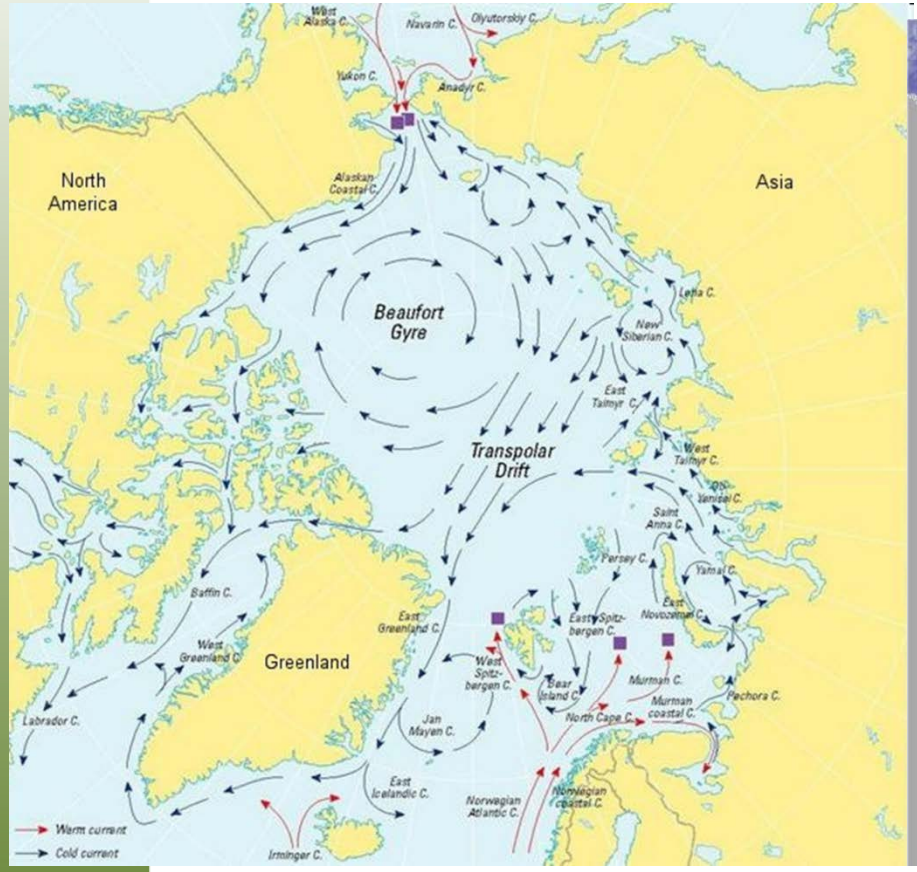
The seasonal cycle of sea ice: timing of melt and freeze onset

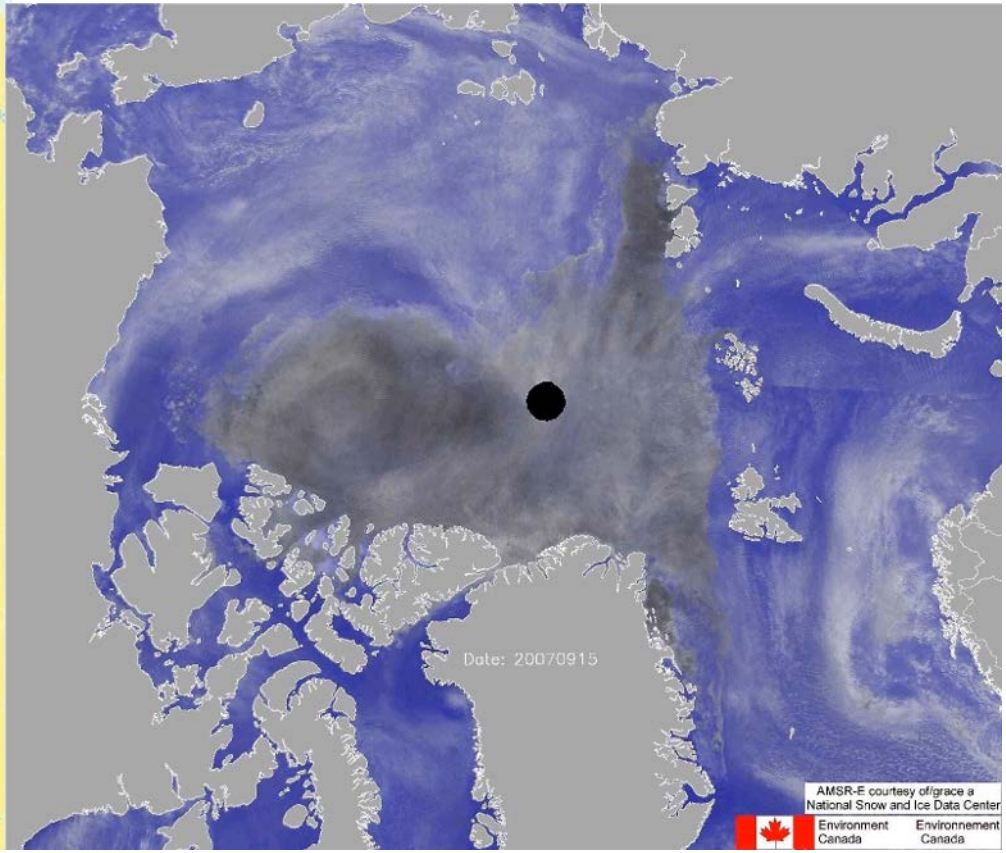


Perovich et al., 2011

Sea Ice Dynamics

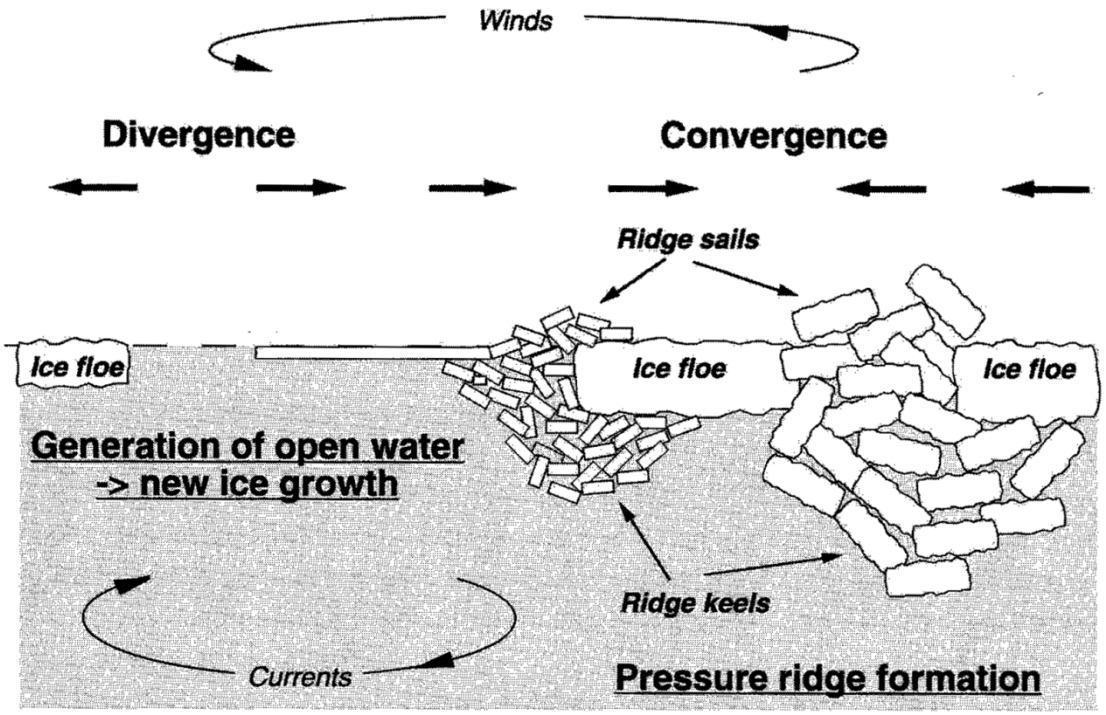
Sea Ice Dynamics





Sea Ice Dynamics

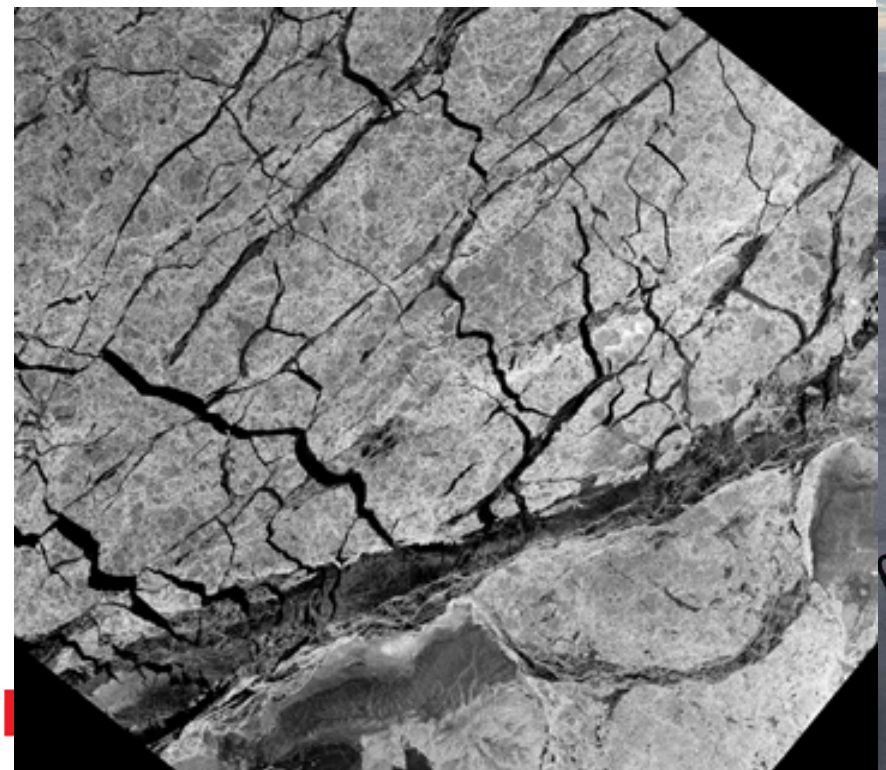
- The exchange of momentum due to turbulent process controls sea ice motion.
  - most important related processes are divergence and convergence.



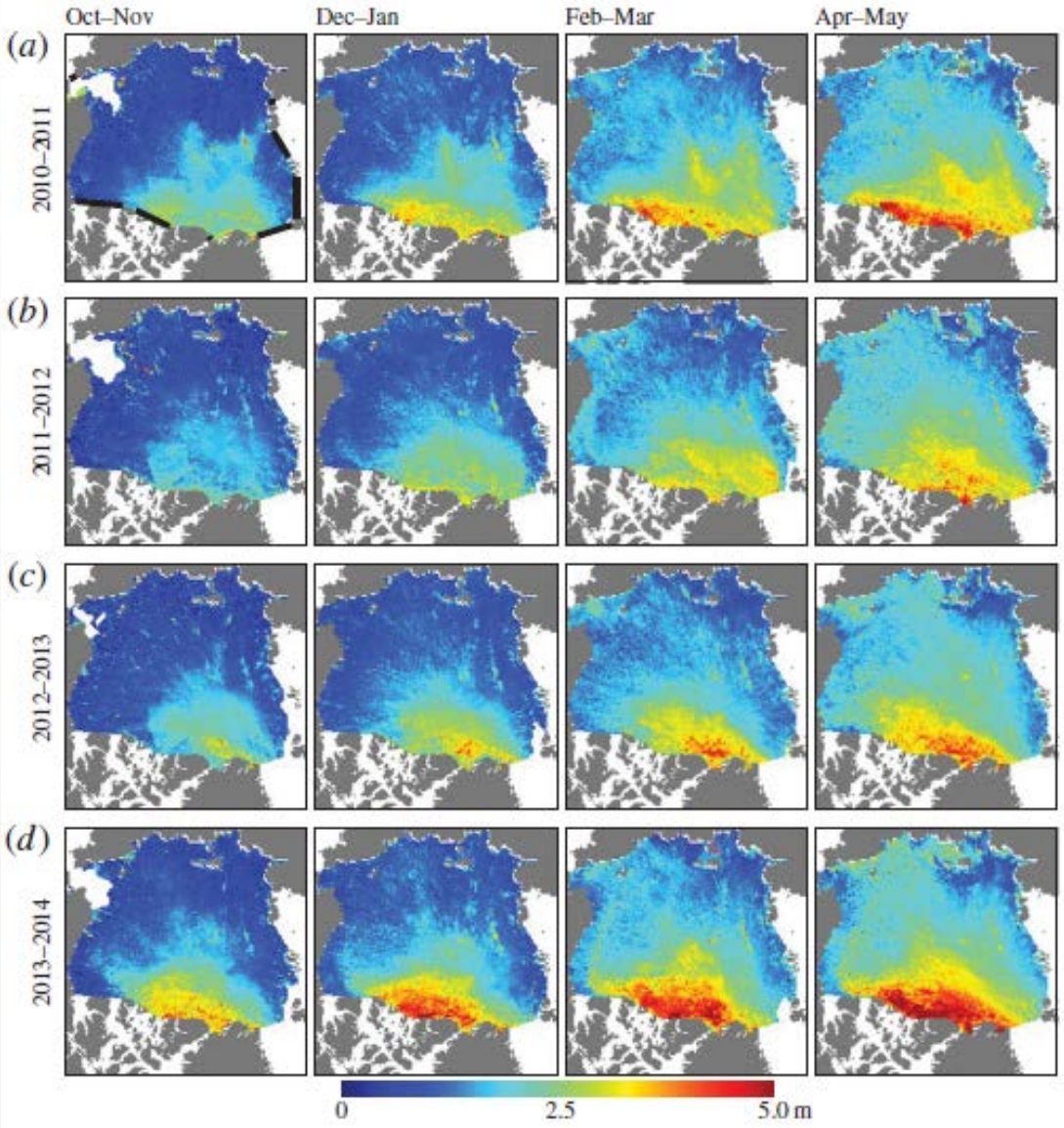
C. Haas

Sea ice dynamics: divergence

- Leads result from local ice divergence creating long narrow channels also induced by tides.
- Flaw leads form along the edge of landfast ice and the polar pack.



Sea ice dynamics: convergence



- Mean thickness of a region is more dependent on the number (and thickness) of ridges than the thickness of level ice
- The overall volume within an ice region, dynamics are more important than thermodynamics

Kwok and Cunningham, 2015

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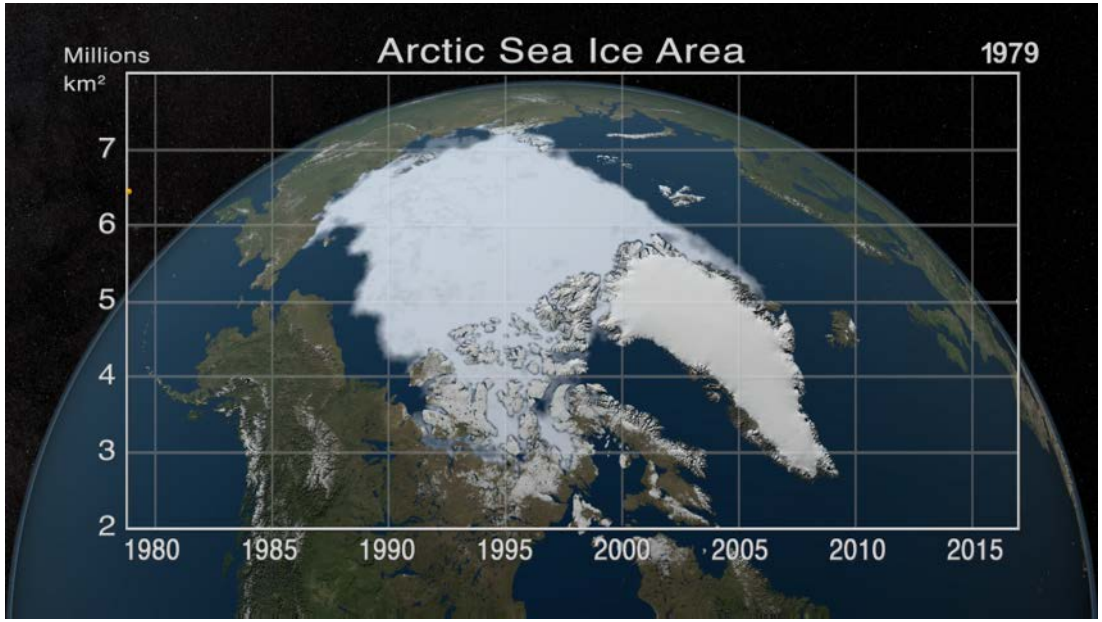
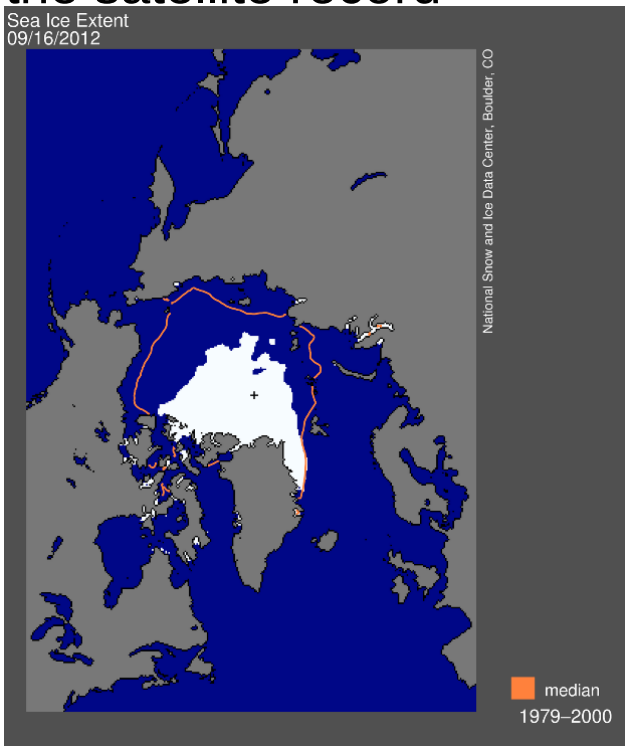
Trends

Arctic sea ice trends: extent

- September Arctic sea ice is declining at a rate of 13.3% per decade over the 1979-2016 period.
- The ten lowest September ice extents over the satellite record have all occurred in the ten years.





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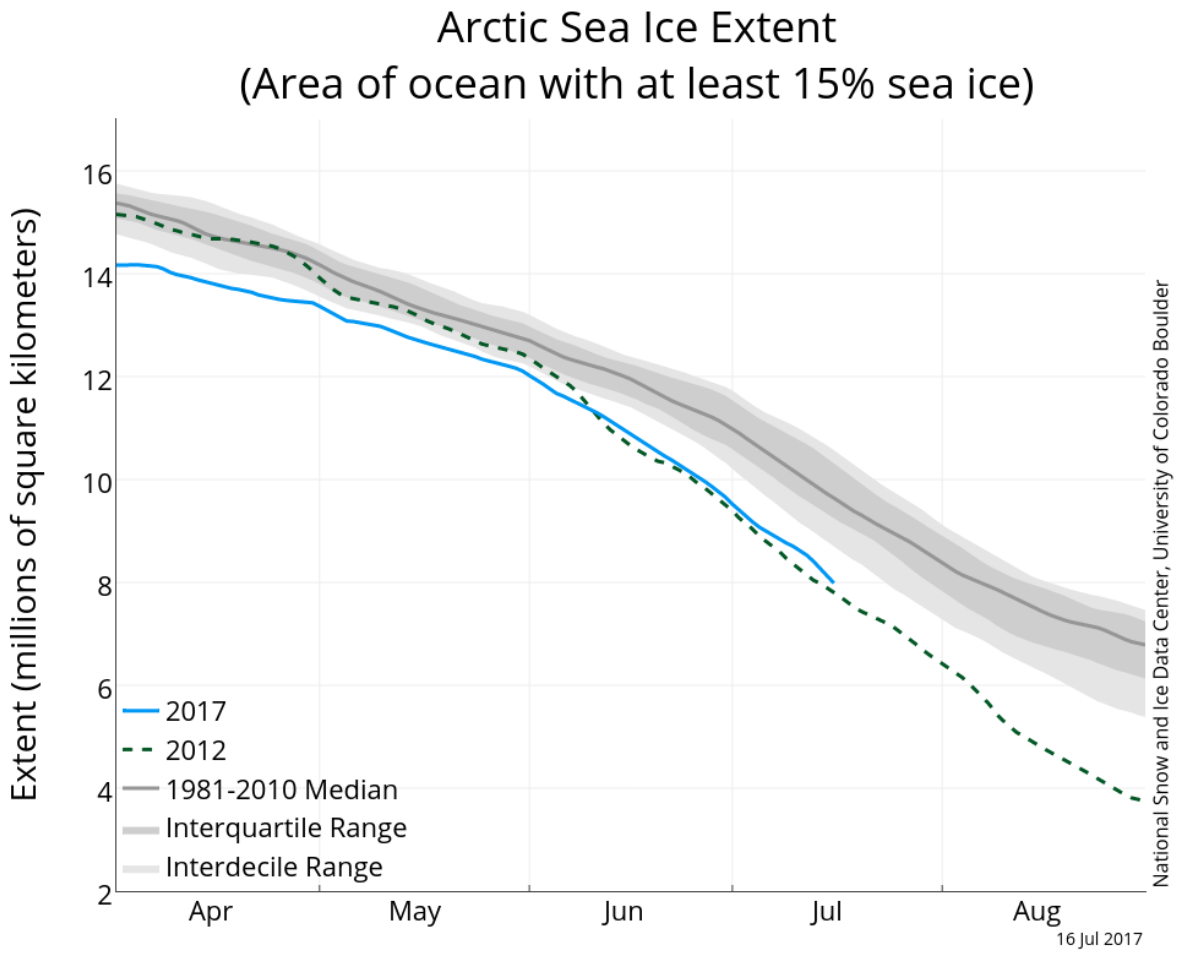
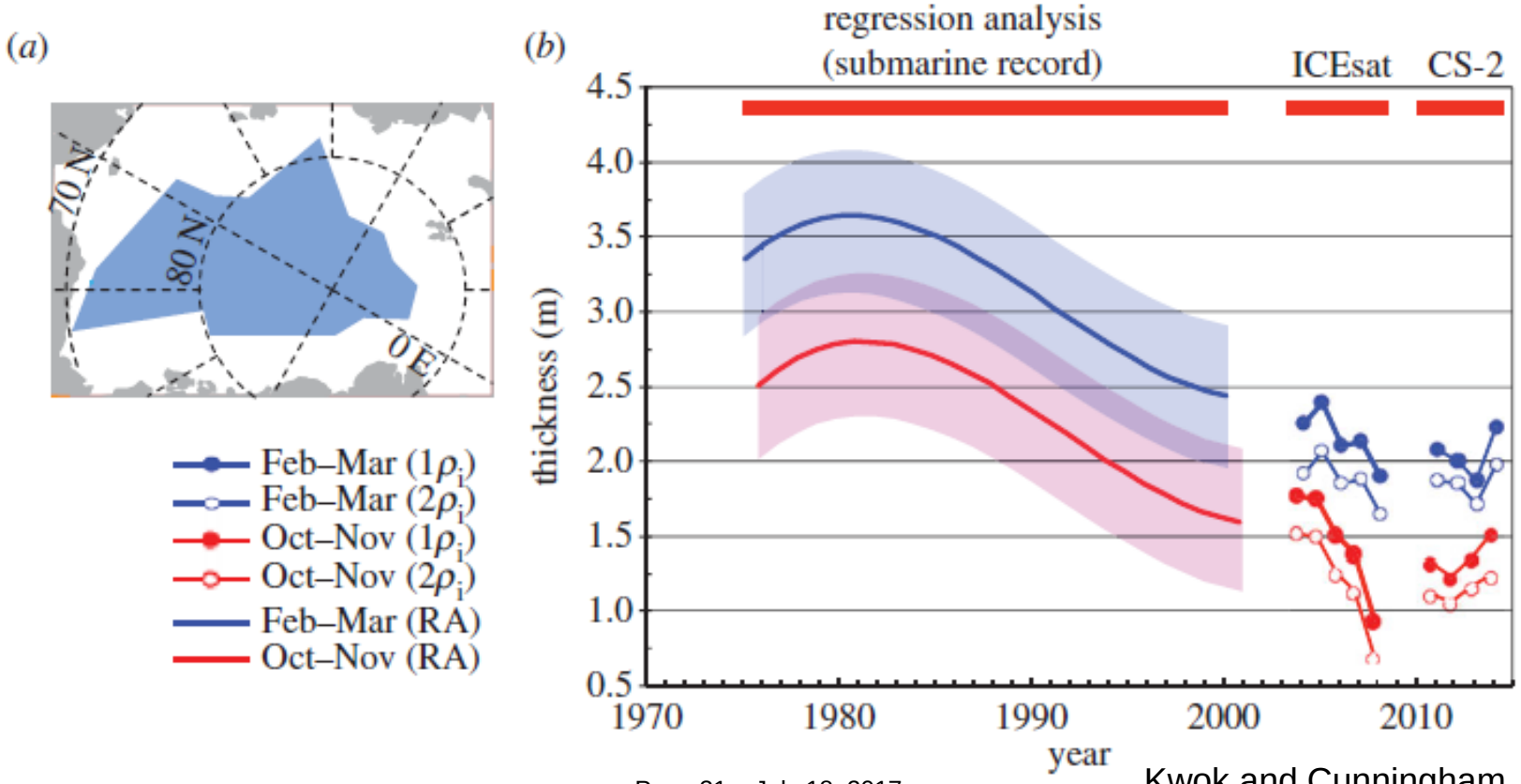
Arctic sea ice trends: 2017 extent



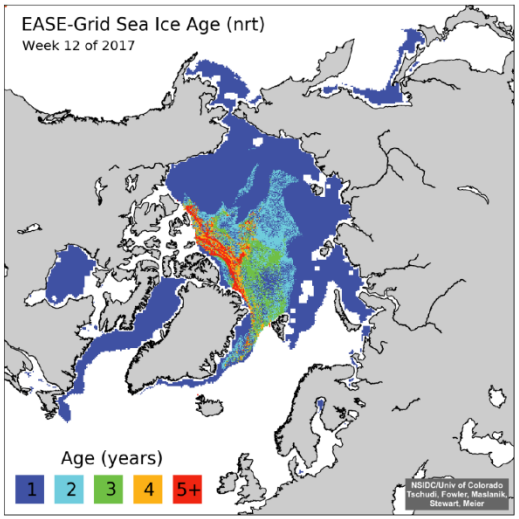
Arctic sea ice trends: thickness

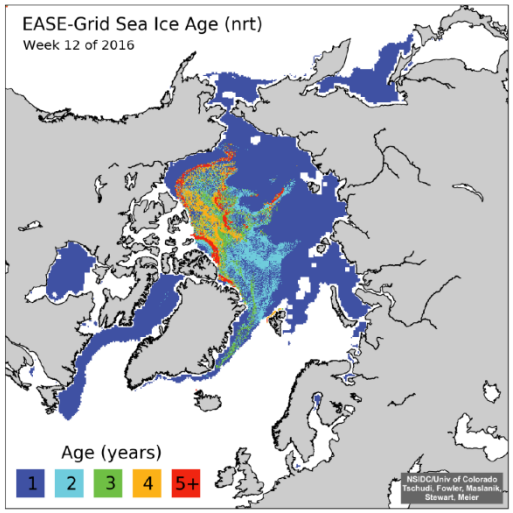
- Arctic sea ice volume between 1980-2014

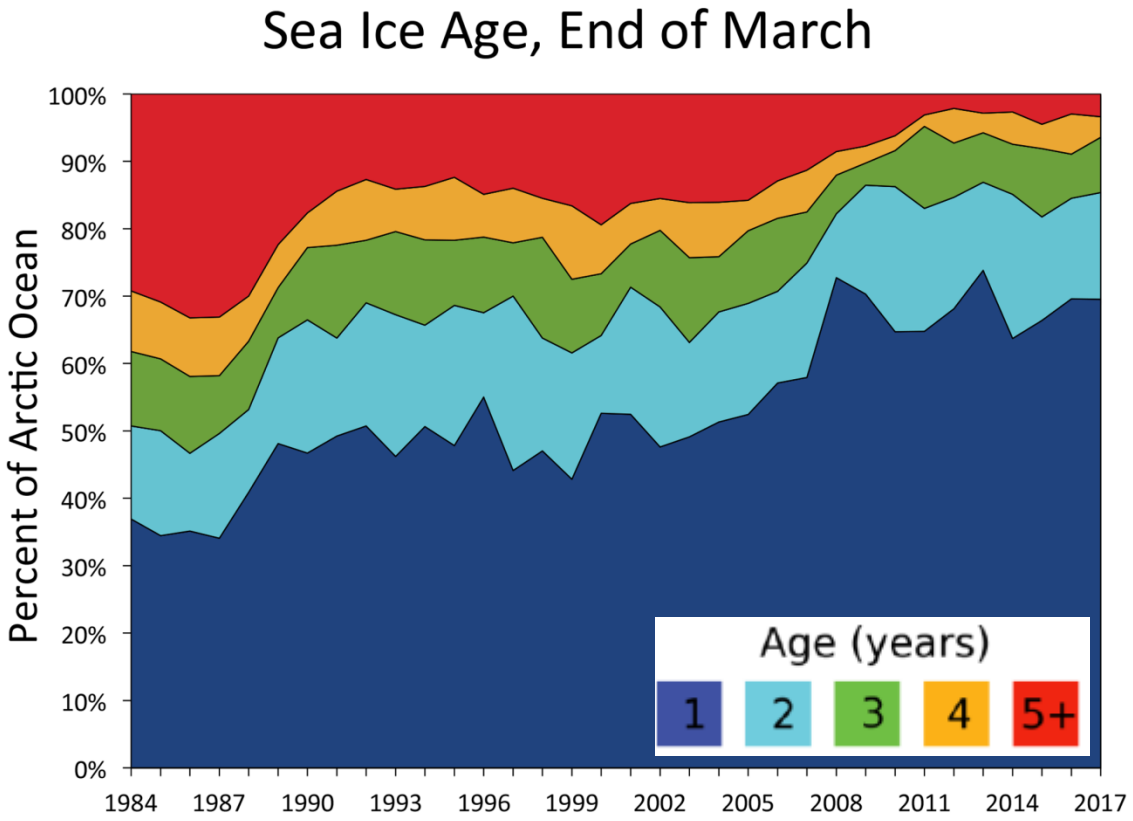


Kwok and Cunningham, 2015

Arctic sea ice trends: age







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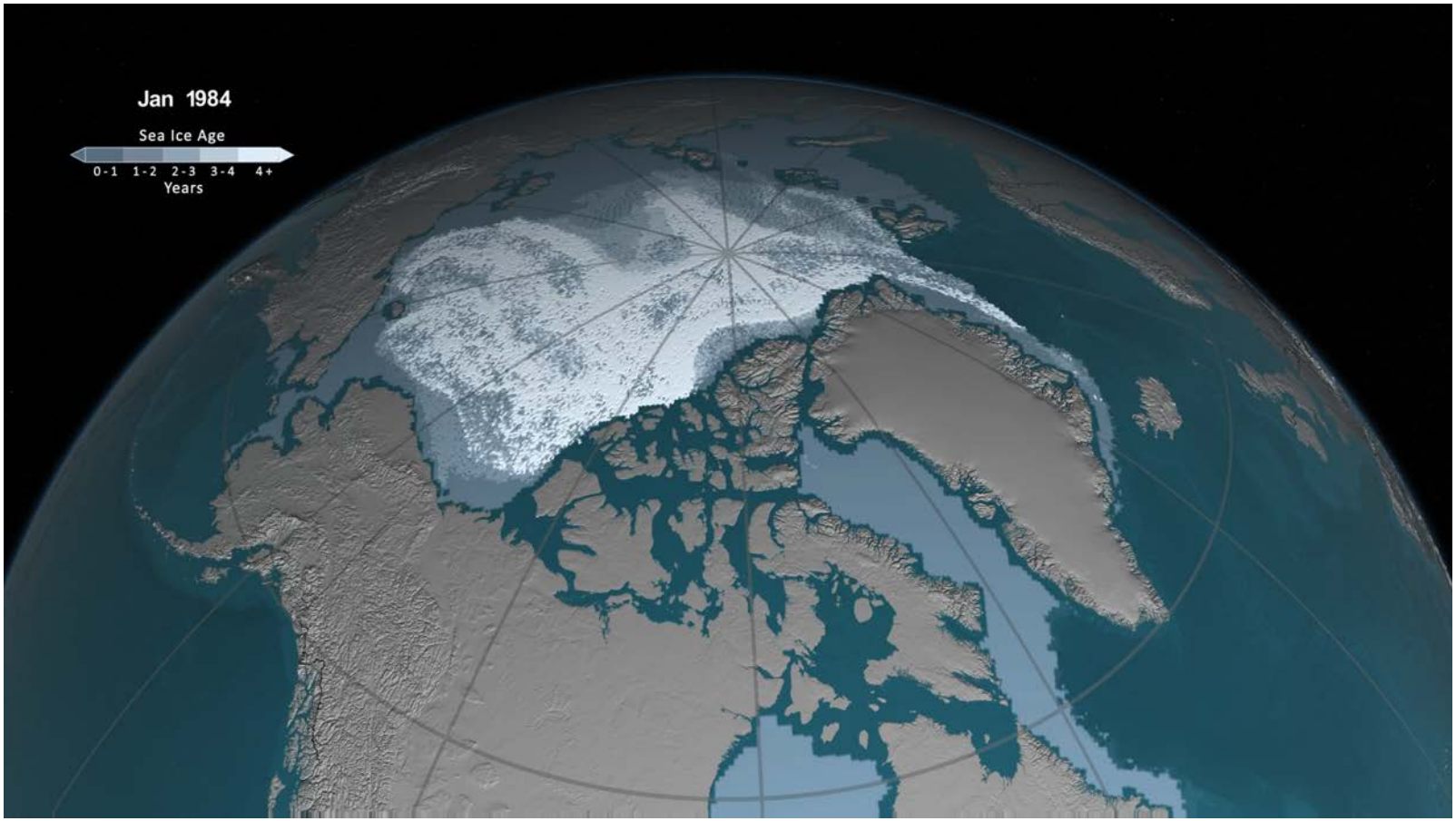
Arctic sea ice trends: age



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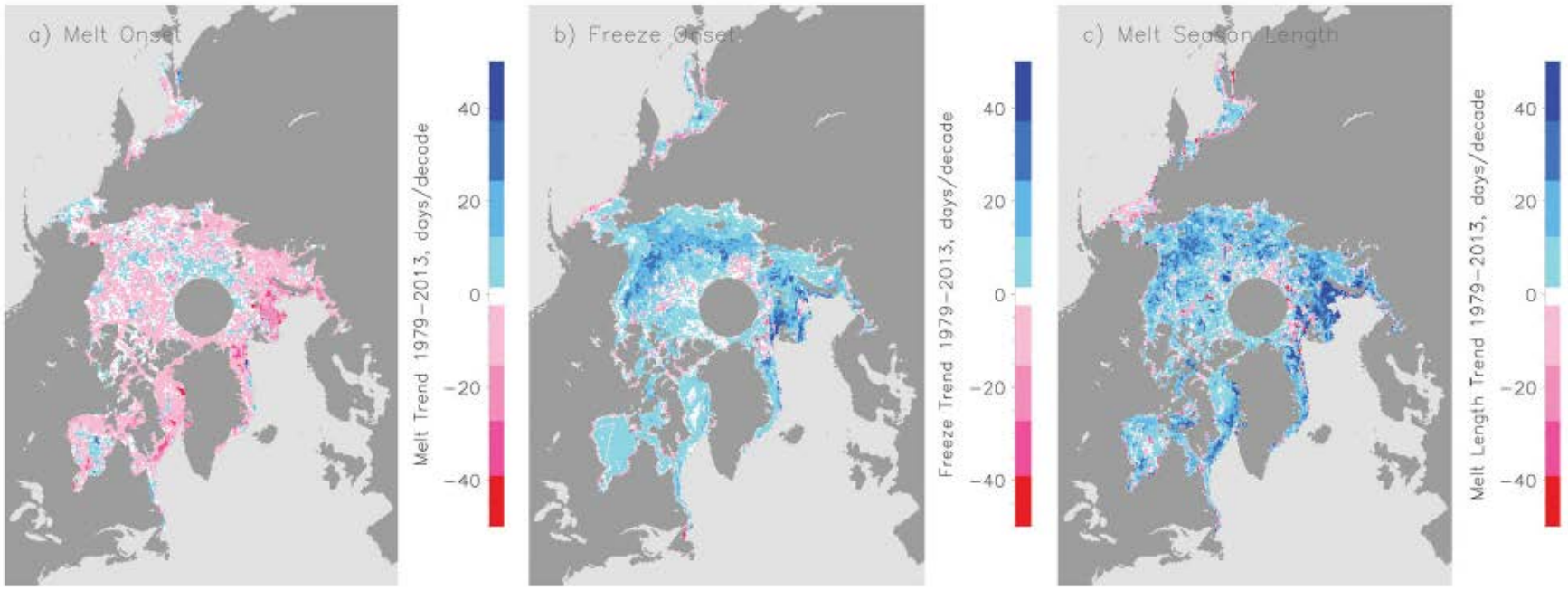
Arctic sea ice trends: melt/freeze

- All Arctic: melt onset earlier by 2 days per decade, freeze onset delayed by 3 days per decade and melt season length is increasing at 5 days per decade.



Stroeve et al., 2014

Next Lecture: Observations