Sea Ice in the Changing Climate: Modeling a Multiscale Nonlinear System

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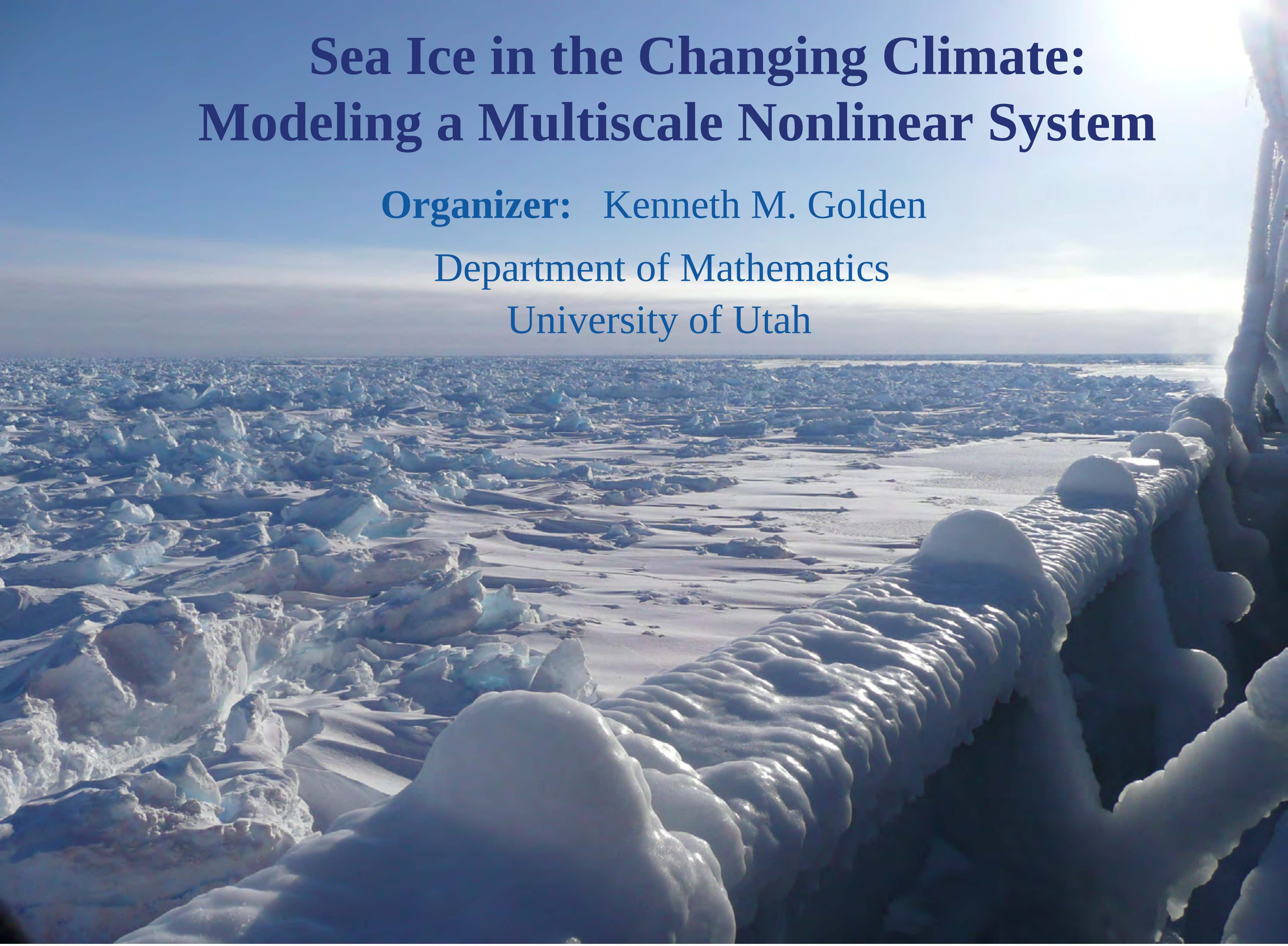


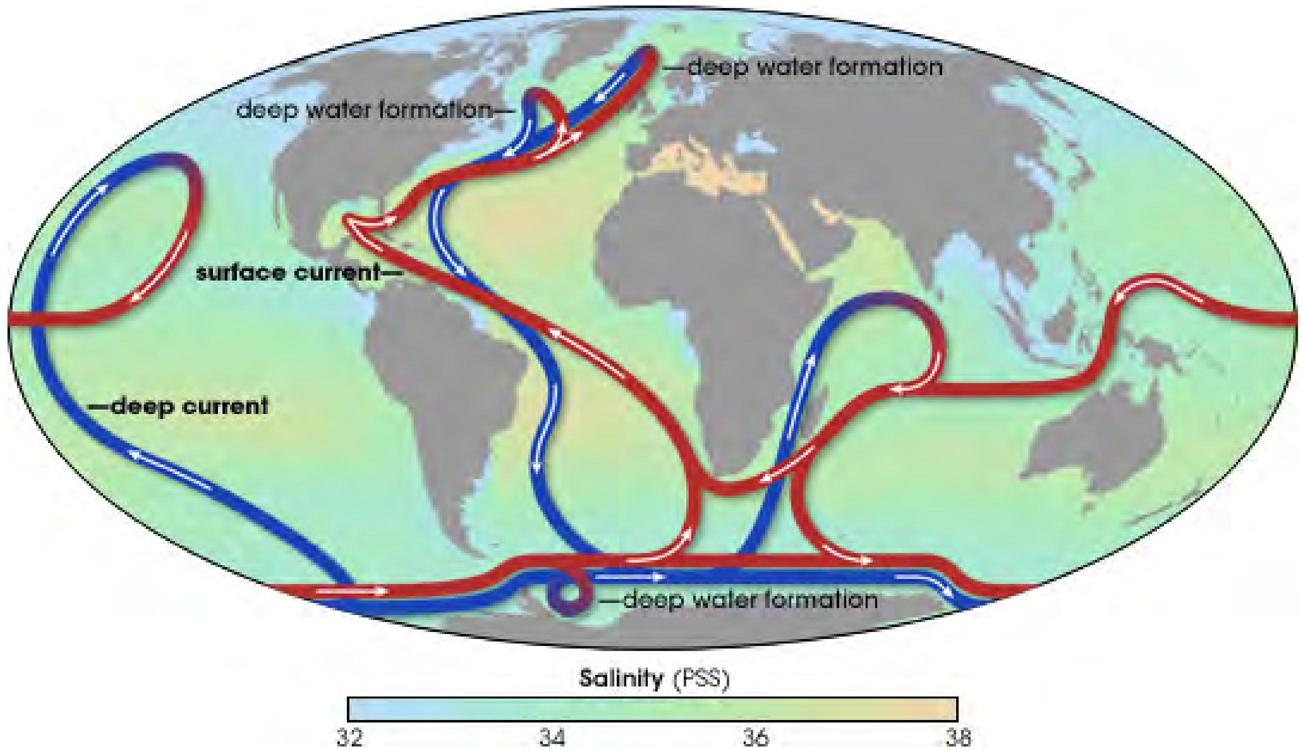
AAAS Annual Meeting, 19 February 2010

SEA ICE covers 7 - 10% of earth's ocean surface

- boundary between ocean and atmosphere
- mediates exchange of heat, moisture, momentum
- indicator and agent of climate change

sea ice formation

cold dense brine is rejected, forming ***bottom water***

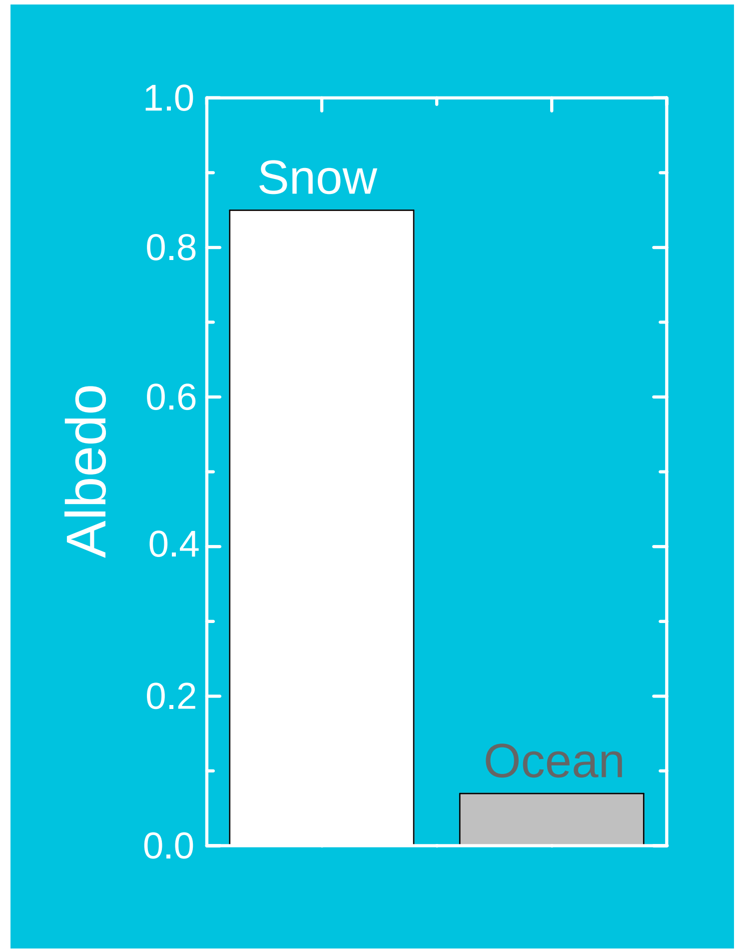


bottom-water formation drives deep circulation throughout the world's oceans

GLOBAL THERMOHALINE CONVEYOR BELT

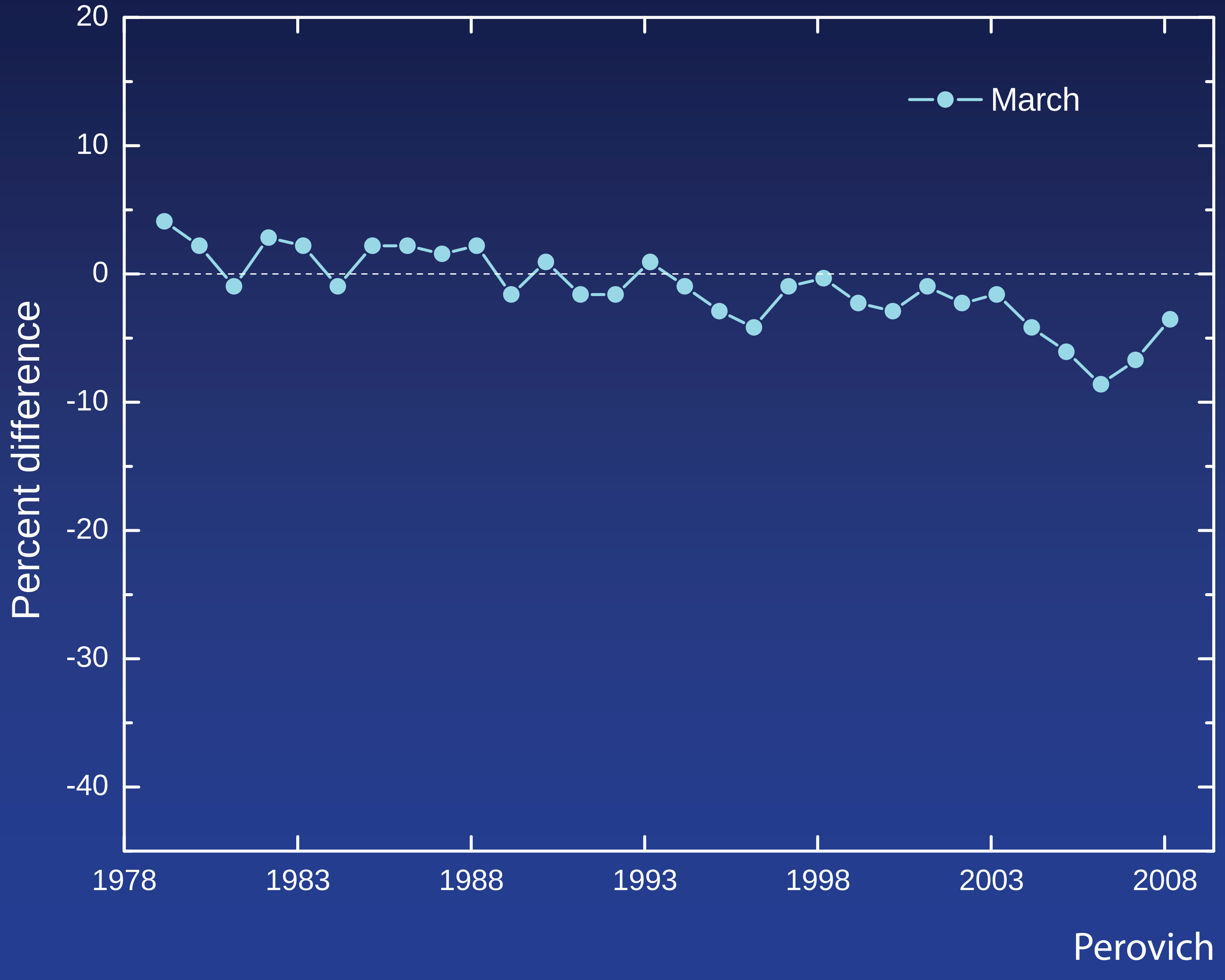
polar ice caps critical to global climate in reflecting incoming solar radiation

white snow and ice reflect

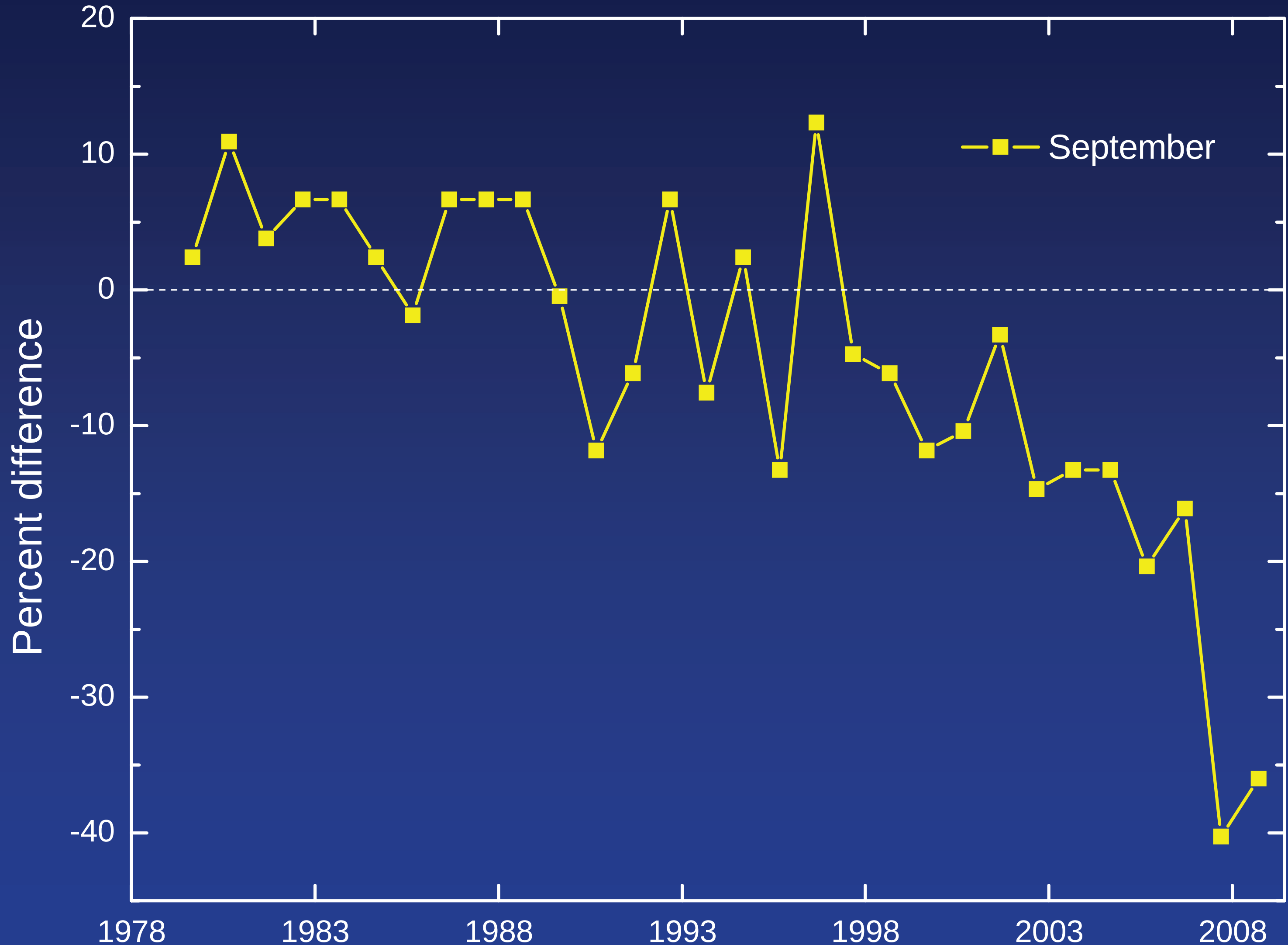


dark water and land absorb

Change in winter Arctic sea ice extent



Change in summer Arctic sea ice extent



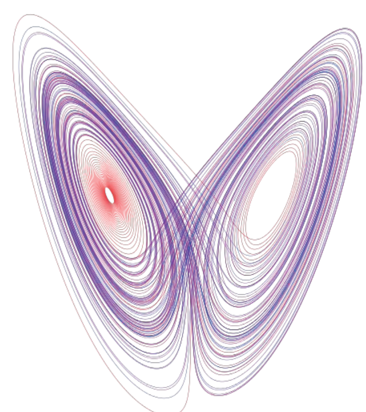
Much of the thick multiyear ice is gone.

Perovich

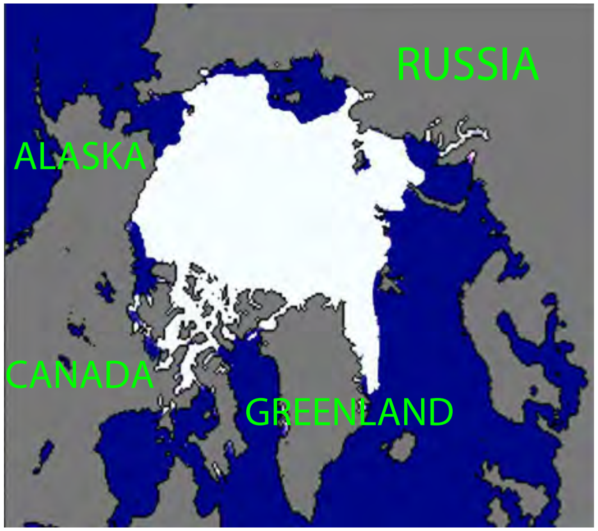
Can Arctic sea ice rebound?

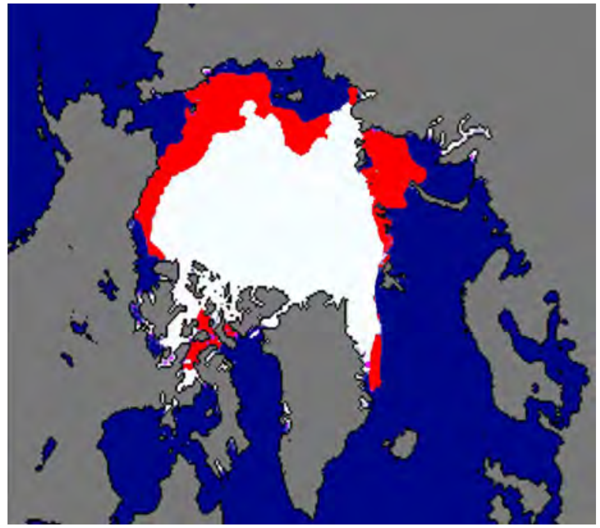
.... or have we passed a critical threshold,

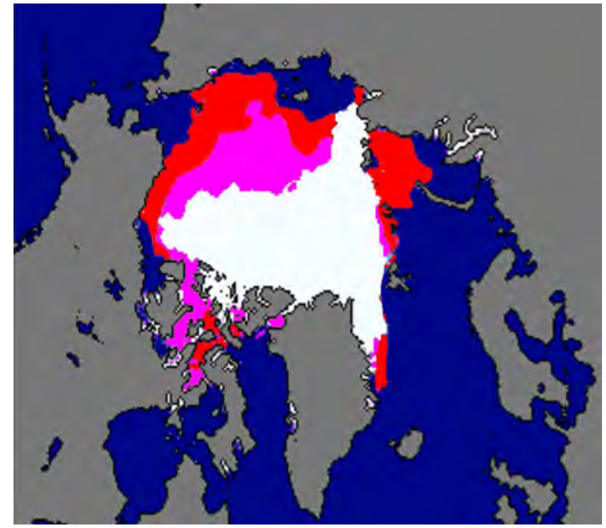
a “tipping point” ?



Lorenz butterfly



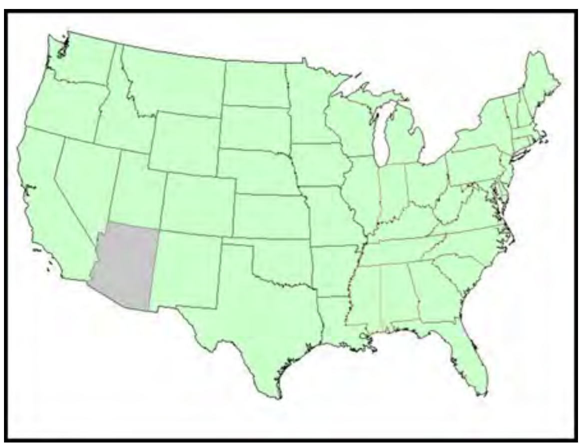


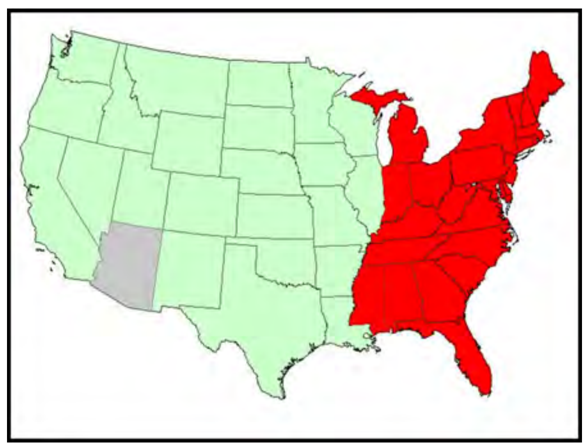


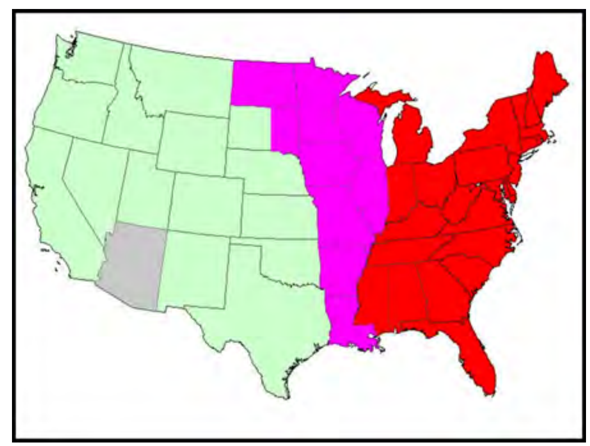
1980

2005

2007





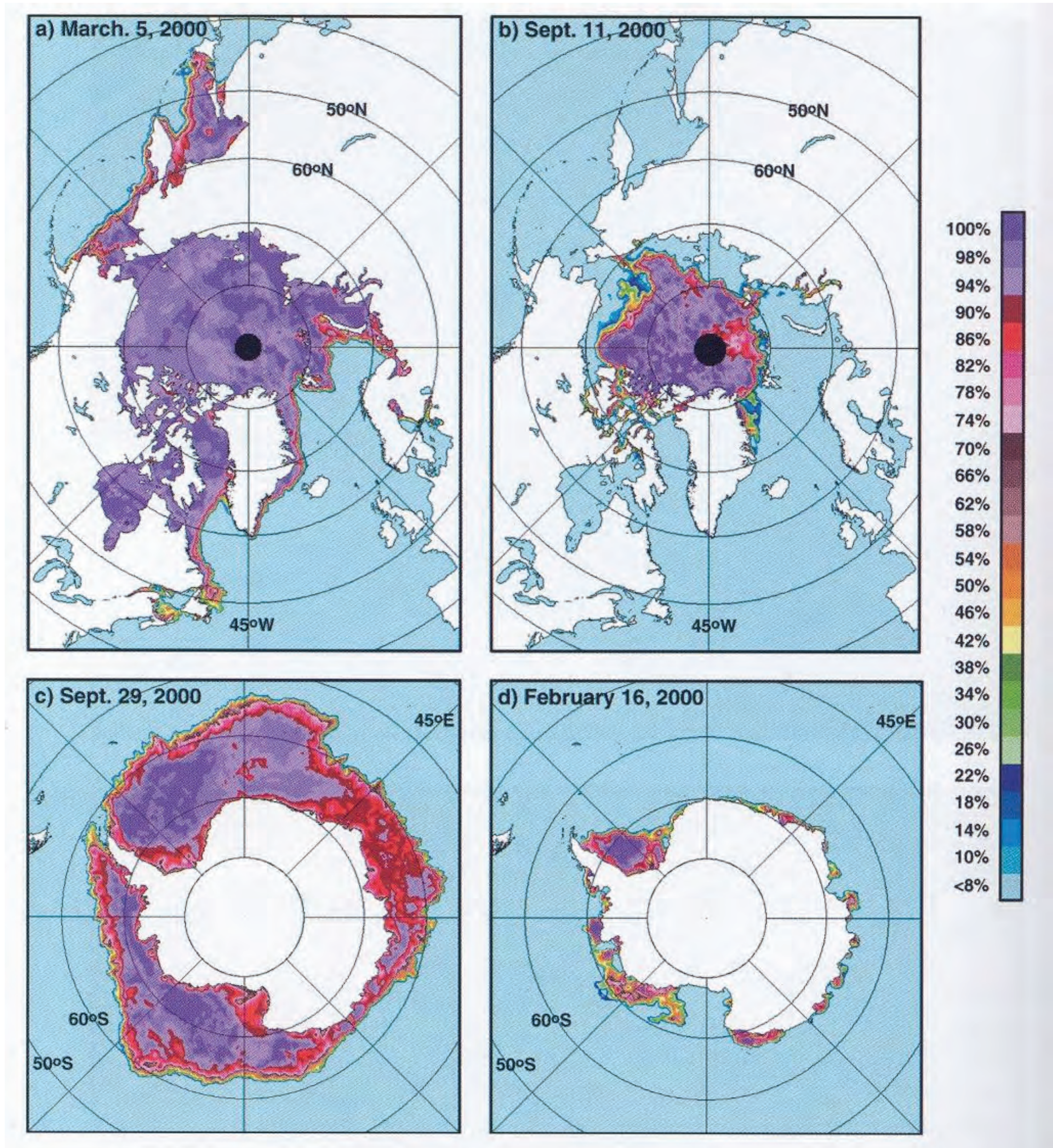


Perovich

Extent & seasonal variation of sea ice

Arctic

Antarctic



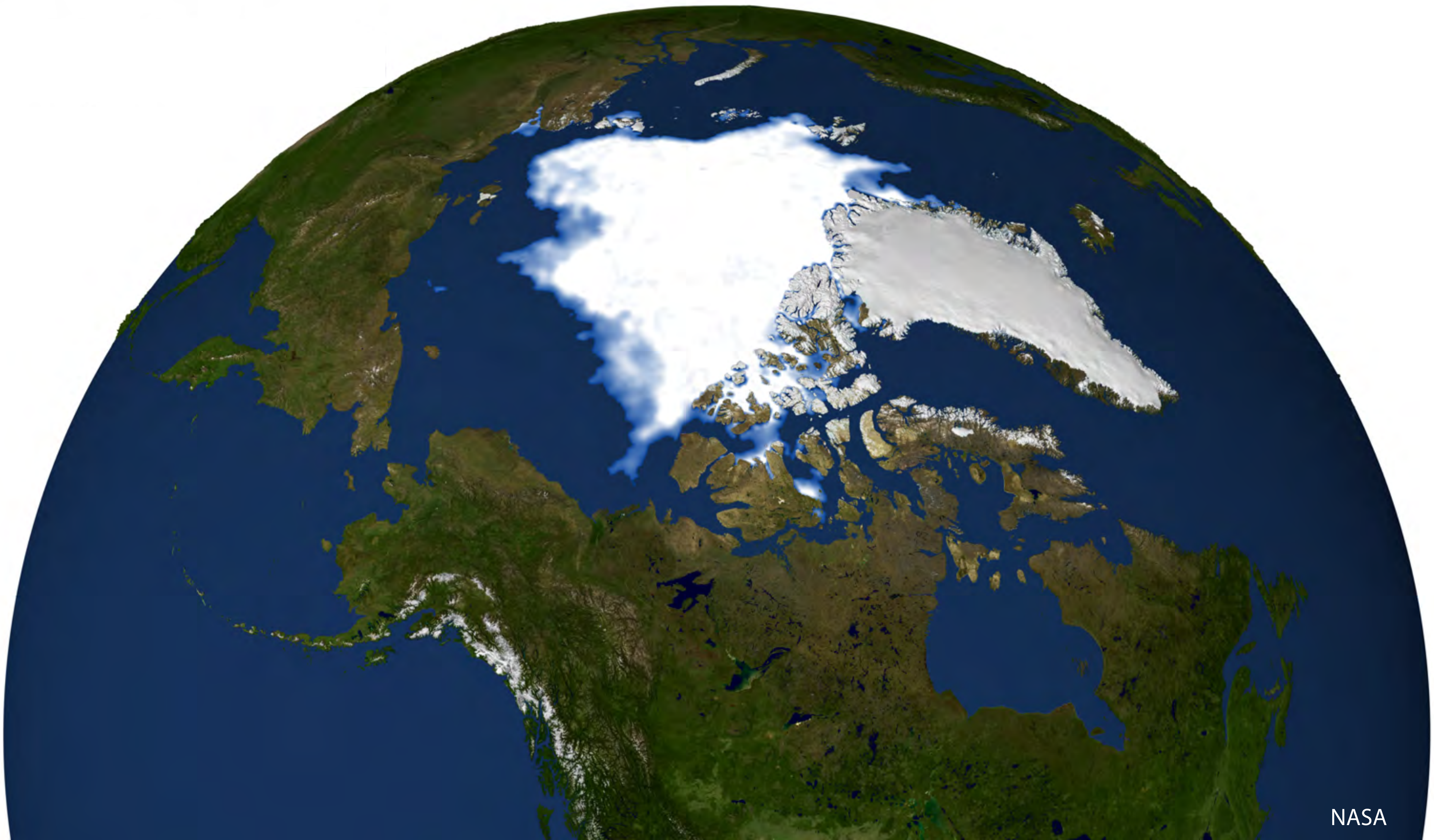
Is global warming

Antarctifying

the Arctic ?

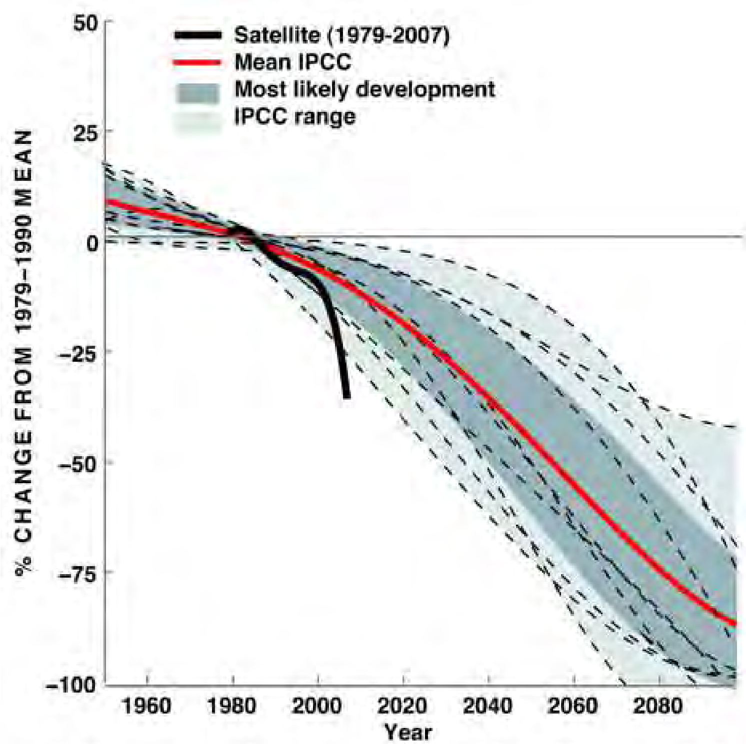
climate change is amplified in the polar regions

14 September 2008

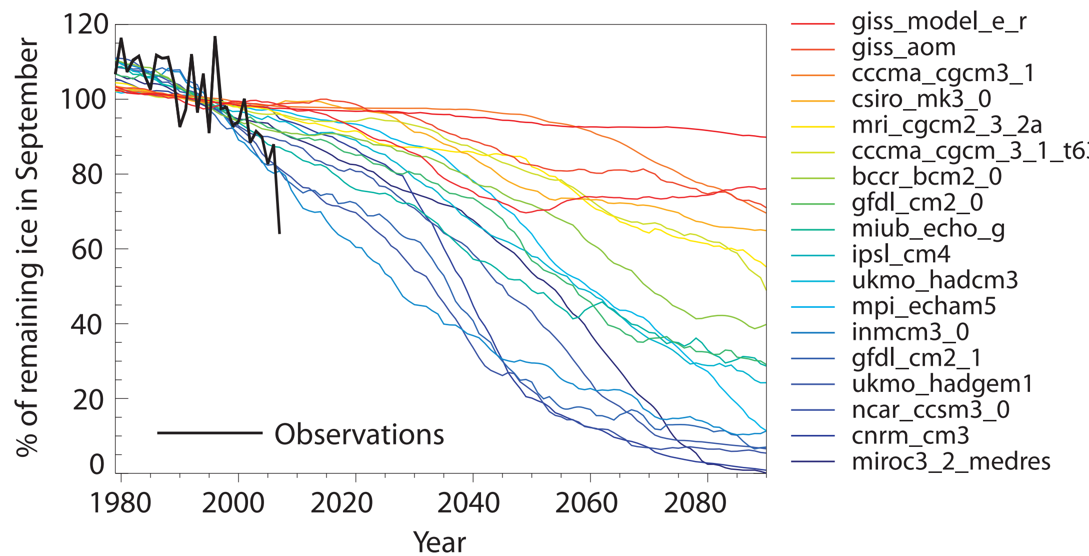


IPCC (Intergovernmental Panel on Climate Change) projections

global climate models ***underestimate*** observed decline in summer Arctic sea ice extent



Arctic sea ice loss compared to IPCC models



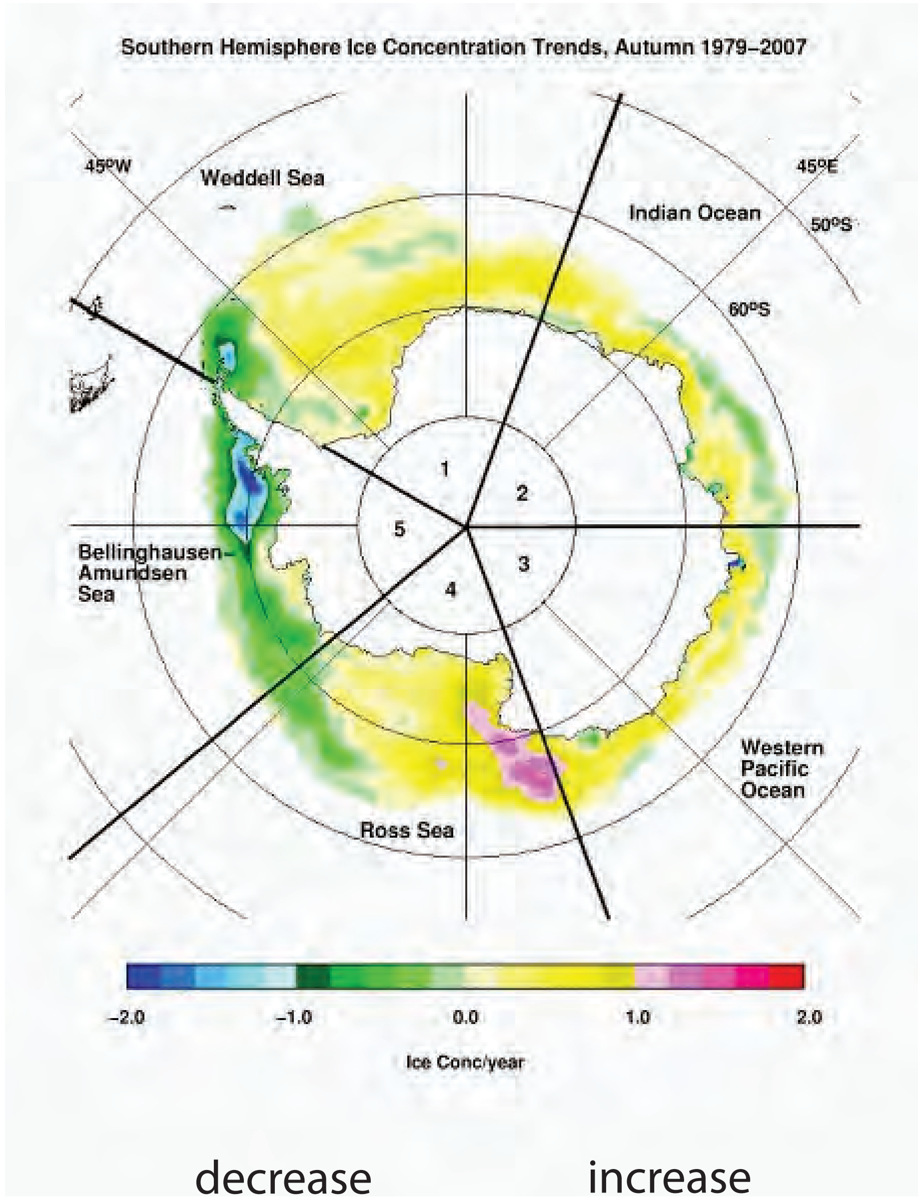
September 2007

March 2009

Boé, Hall, Qu 2009

Antarctic sea ice

climate models predict declines in annual average ice area and volume, ***however ...***

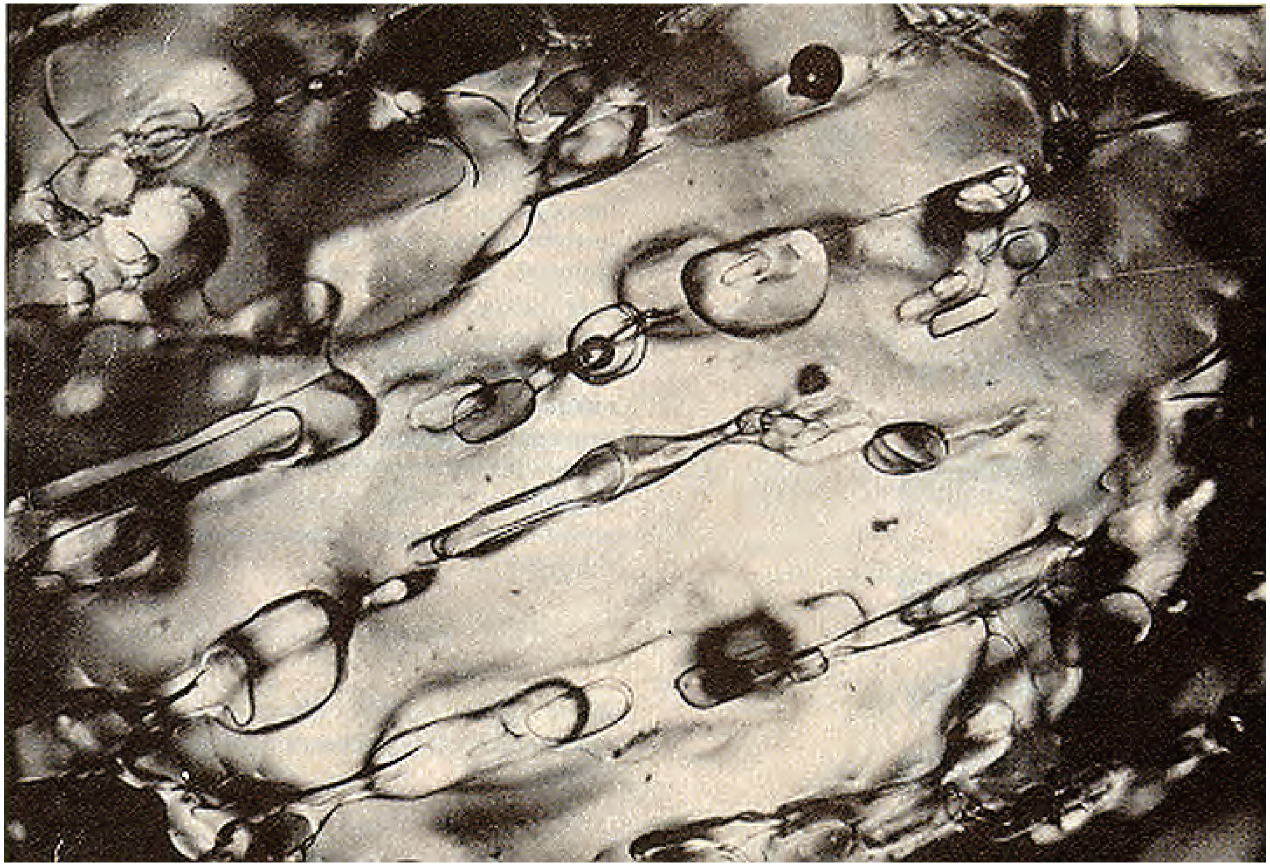


Southern Hemisphere Sea Ice Concentration Trends for Autumn 1979 – 2007

John Turner
(Tony Worby)

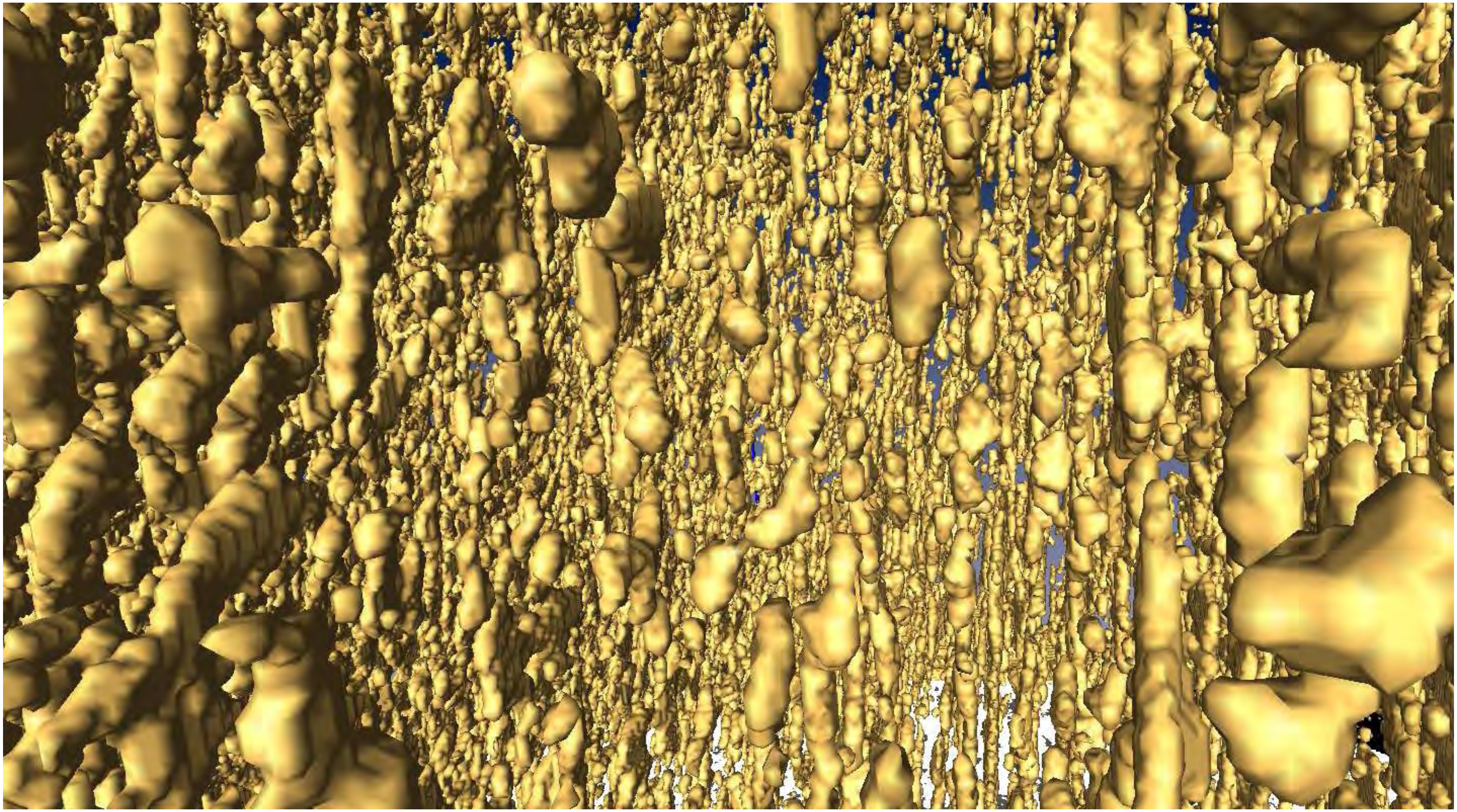
some features of sea ice
and its marine environment
relevant to climate modeling

sea ice is a ***composite material***



pure ice with **brine**, air, and salt inclusions

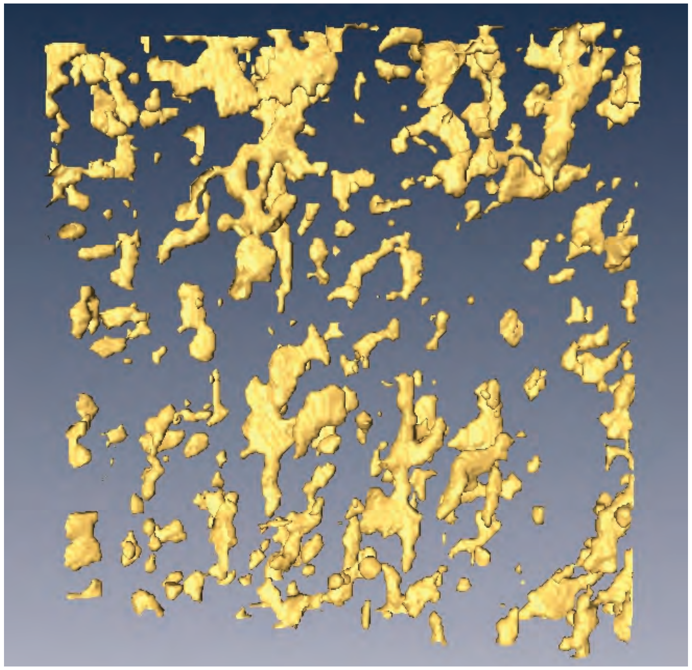
X-ray computed tomography of brine inclusions in sea ice



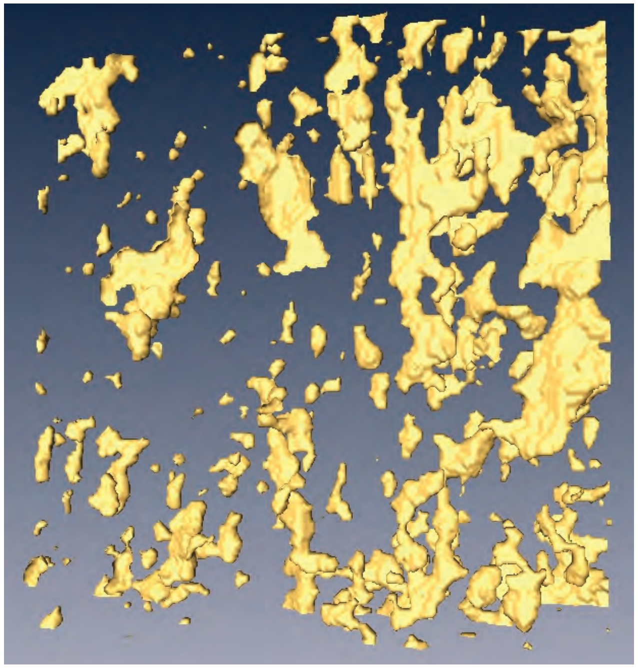
brine volume fraction $\phi = 5.7\ \%$ $T = -\,8^{\circ}C$

Golden, Eicken, Heaton, Miner, Pringle, Zhu, *Geophys. Res. Lett.* 2007

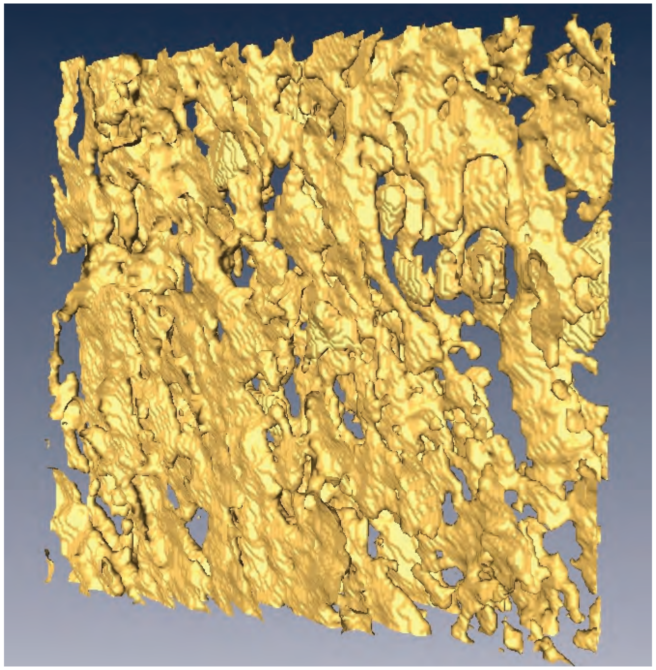
volume fraction and ***connectivity*** of brine phase increase with temperature



T = -15 °C, ϕ = 0.033

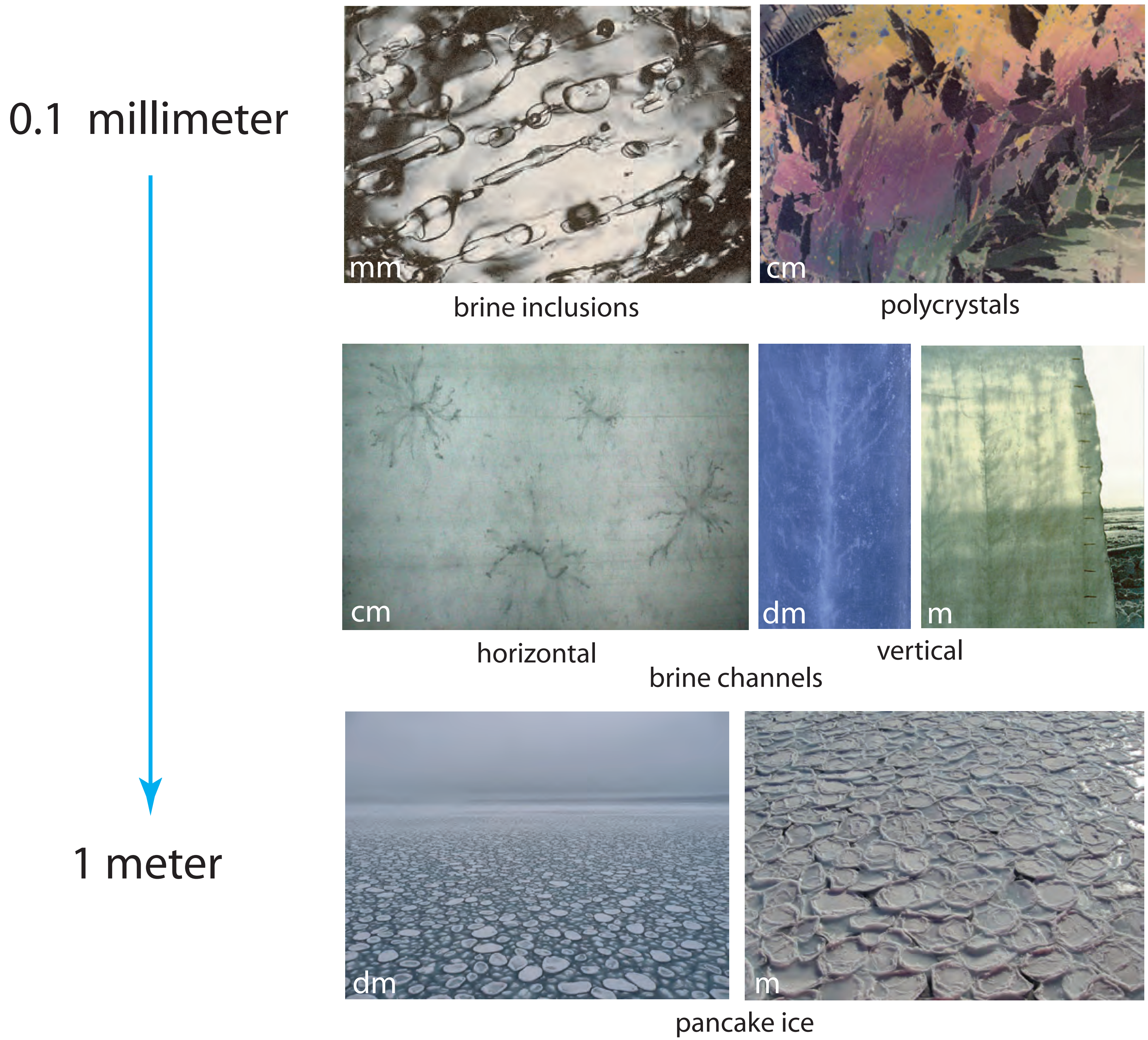


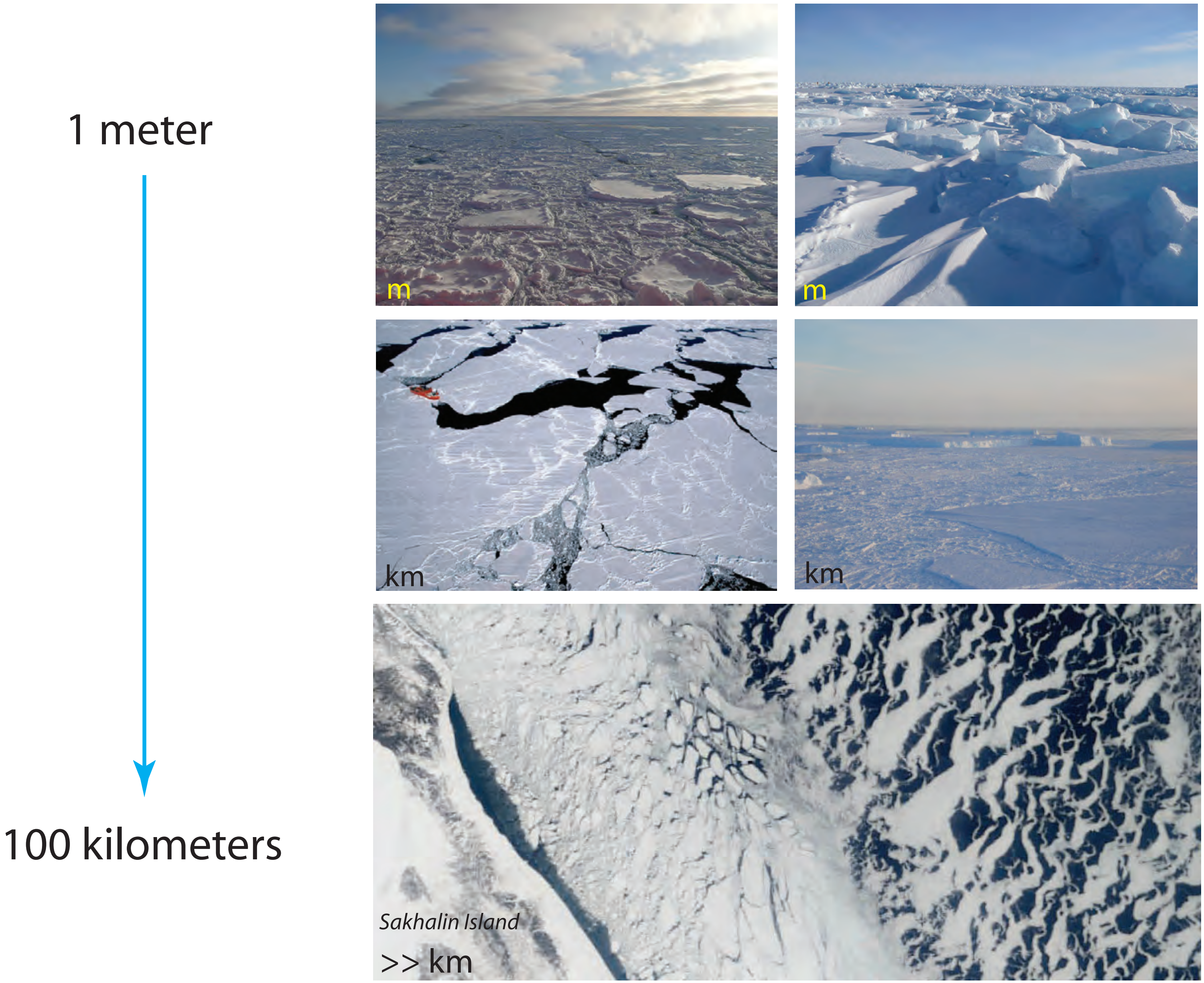
T = -6 °C, ϕ = 0.075



T = -3 °C, ϕ = 0.143

sea ice displays ***multiscale*** structure over 10 orders of magnitude

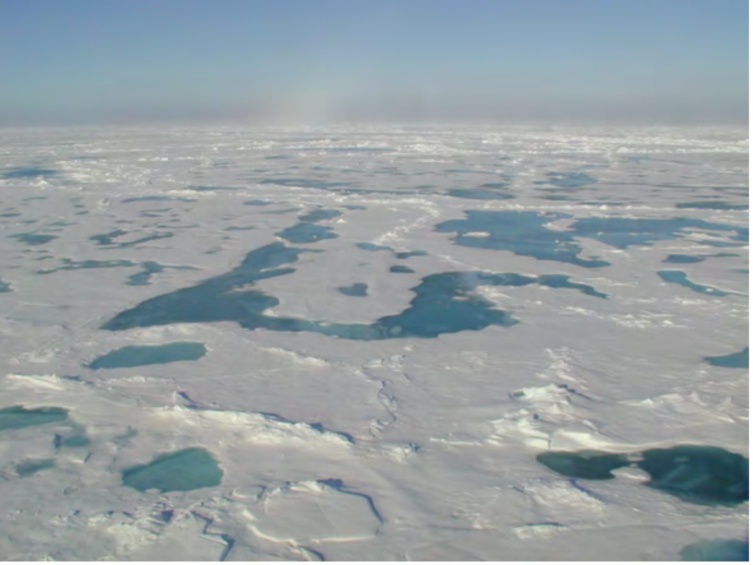


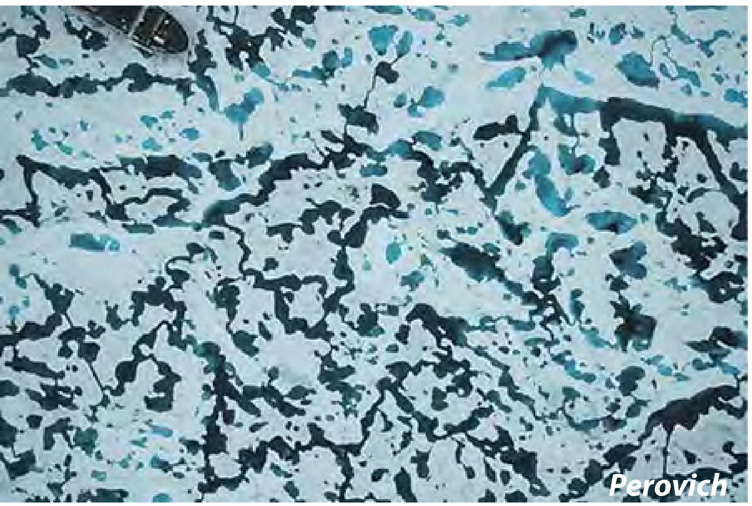

1 meter
100 kilometers
m
m
km
km
Sakhalin Island
>> km

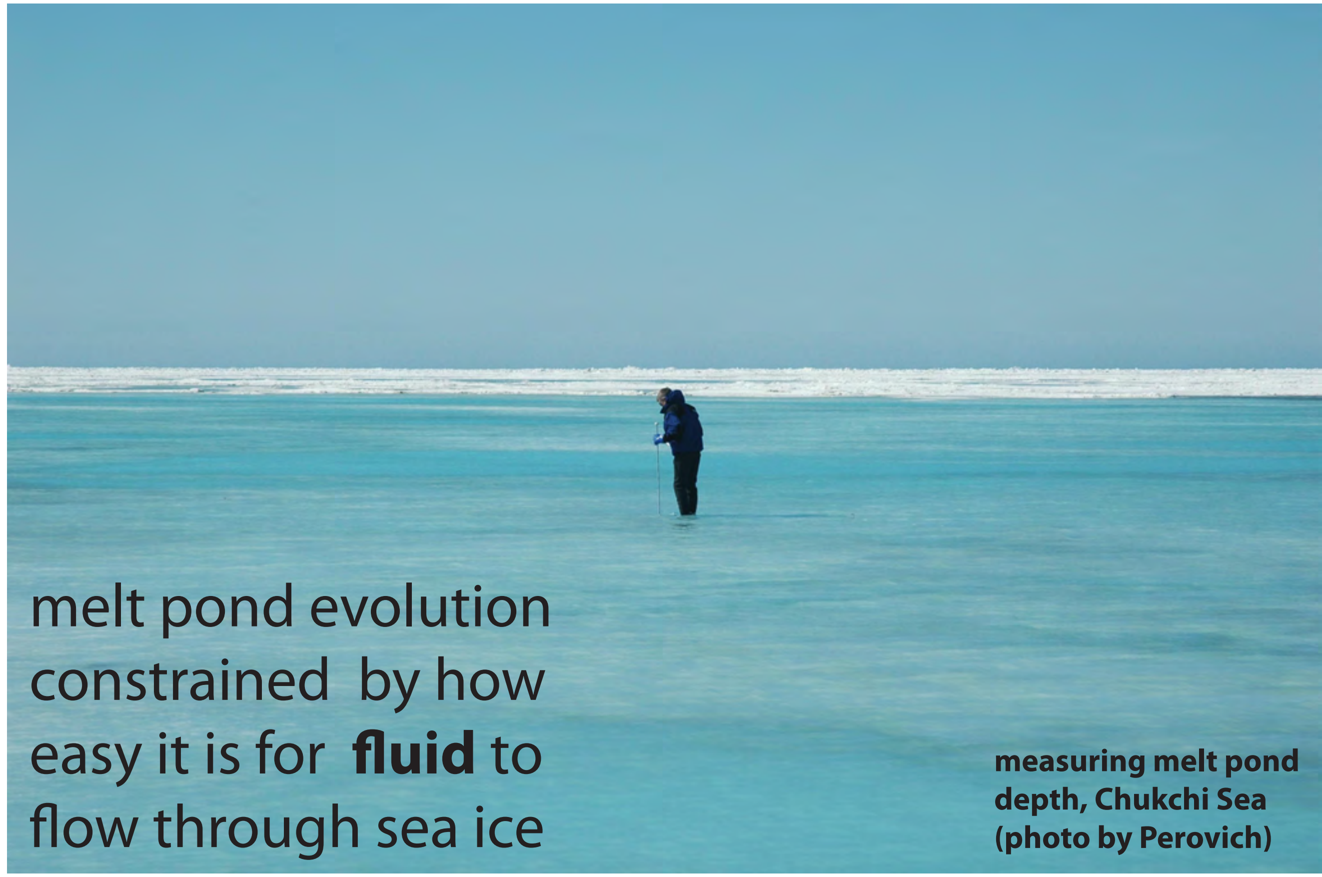
Ice albedo feedback

Perovich

sea ice albedo determined by melt ponds





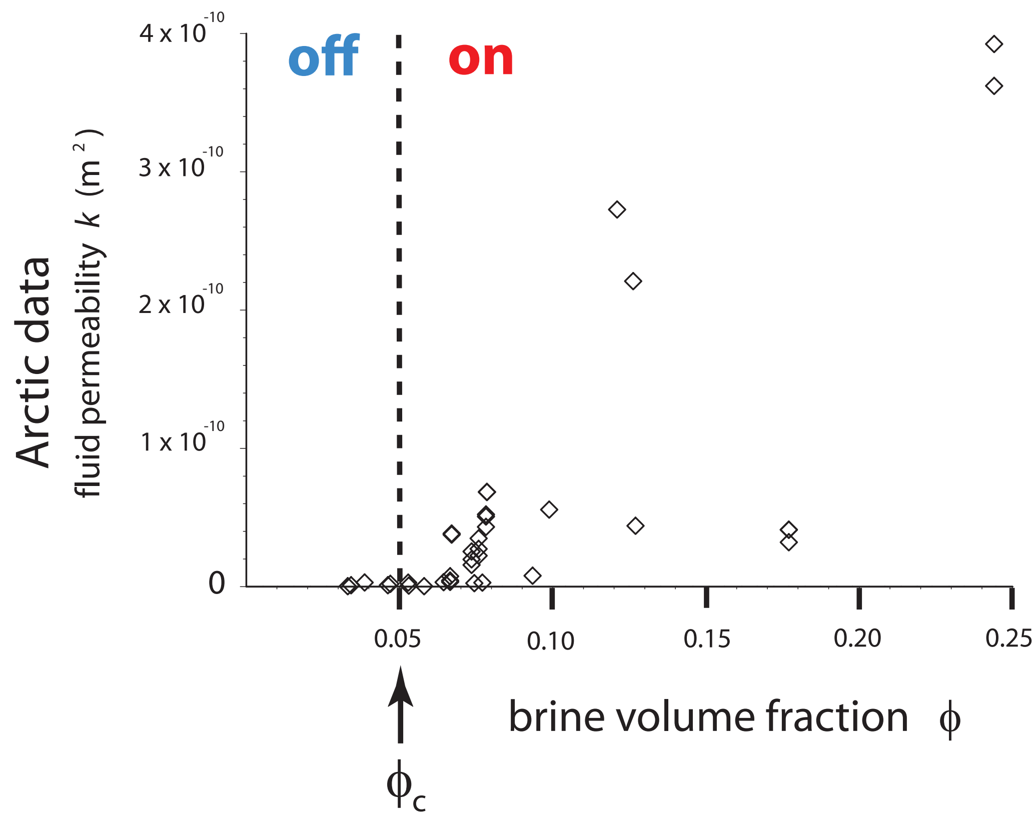


fluid permeability

depends on microstructure

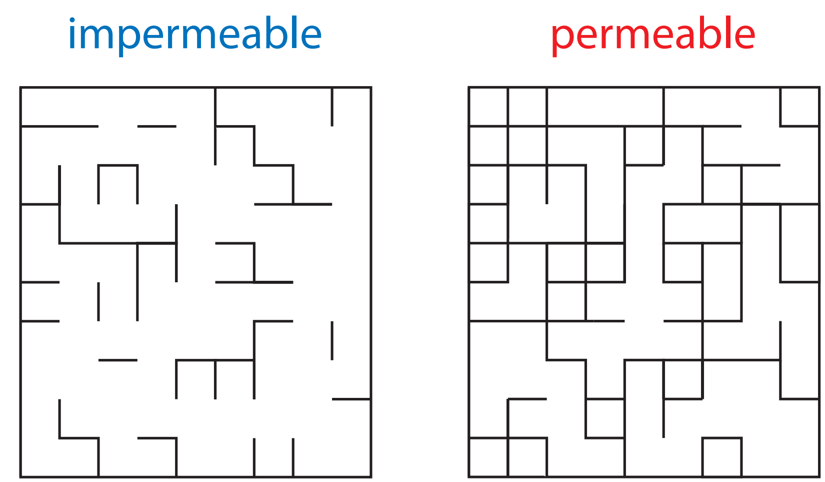
Critical behavior of fluid transport in sea ice

on - off switch for fluid flow



percolation theory

(mathematical theory of connectedness)



critical brine volume fraction $\phi_c \approx 5\%$ $\longleftrightarrow$ $T_c \approx -5^\circ C$, $S \approx 5$ ppt

RULE OF FIVES

Golden, Ackley, Lytle *Science* 1998

Golden, Eicken, Heaton, Miner, Pringle, Zhu, *Geophys. Res. Lett.* 2007

Pringle, Miner, Eicken, Golden *J. Geophys. Res.* 2009

on - ***off*** switch helps control:

1. melt pond evolution
2. surface flooding and snow-ice formation
3. salinity profile evolution and brine drainage
4. transport of heat and gases (CO_2)
5. microbial activity; nutrient replenishment
6. electromagnetic signatures; remote sensing

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Real analysis in polar coordinates *(see page 613)*

What must we understand better about

sea ice processes & air-ice-ocean interactions

to improve climate projections?

What must be represented more realistically in models?

linkage of scales

e.g. microstructure → permeability → melt pond evolution

→ ice pack albedo → sea ice trajectory → global climate

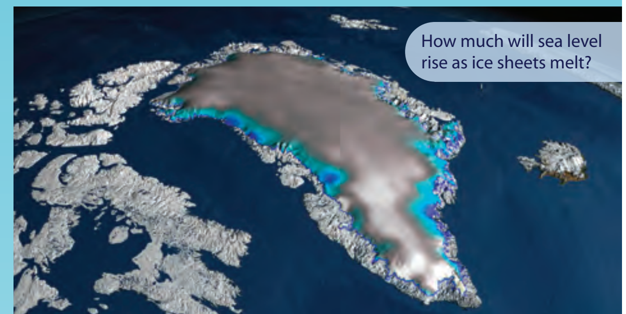
Sea Ice in the Changing Climate: Modeling a Multiscale Nonlinear System

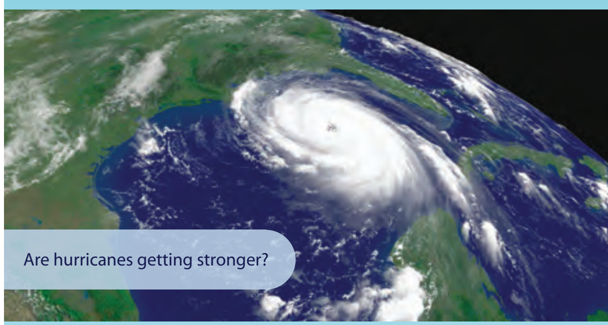
Marika Holland	Large-scale models and feedback mechanisms
Donald Perovich	Melt ponds and ice-albedo feedback
Wieslaw Maslowski	Arctic Ocean dynamics and sea ice decline
John Wettlaufer	Critical threshold for summer Arctic sea ice
Hajo Eicken	Sea ice hydraulics and melt pond evolution
Cecilia Bitz	Sea ice microphysics and brine transport

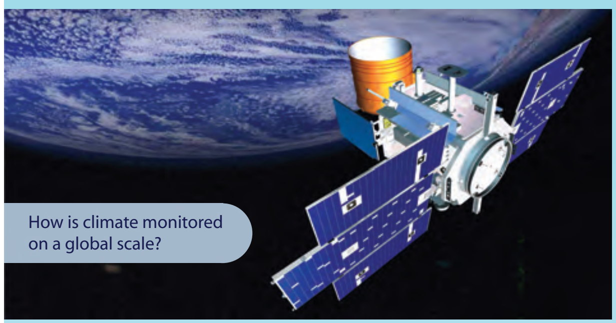
Mathematics Awareness Month - April 2009

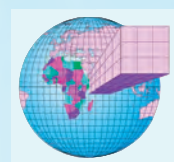
Mathematics and Climate

Find out how math and science are used to address questions of climate change:









How can we improve our understanding of climate change and what can we do about it?

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\,\mathbf{u} = -\frac{1}{\rho}\nabla p + \mathbf{F} + \frac{\mu}{\rho}\nabla^2 \mathbf{u}$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

www.mathaware.org

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Kerry Emanuel (MIT)
Margot Gerritsen (Stanford)
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Inez Fung (UC Berkeley)
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David Neelin (UCLA)
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