Climate Change and the Melting Polar Ice Caps

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Antarctic Lecture Series — *University of Utah Marriott Library* — *April 14, 2011*

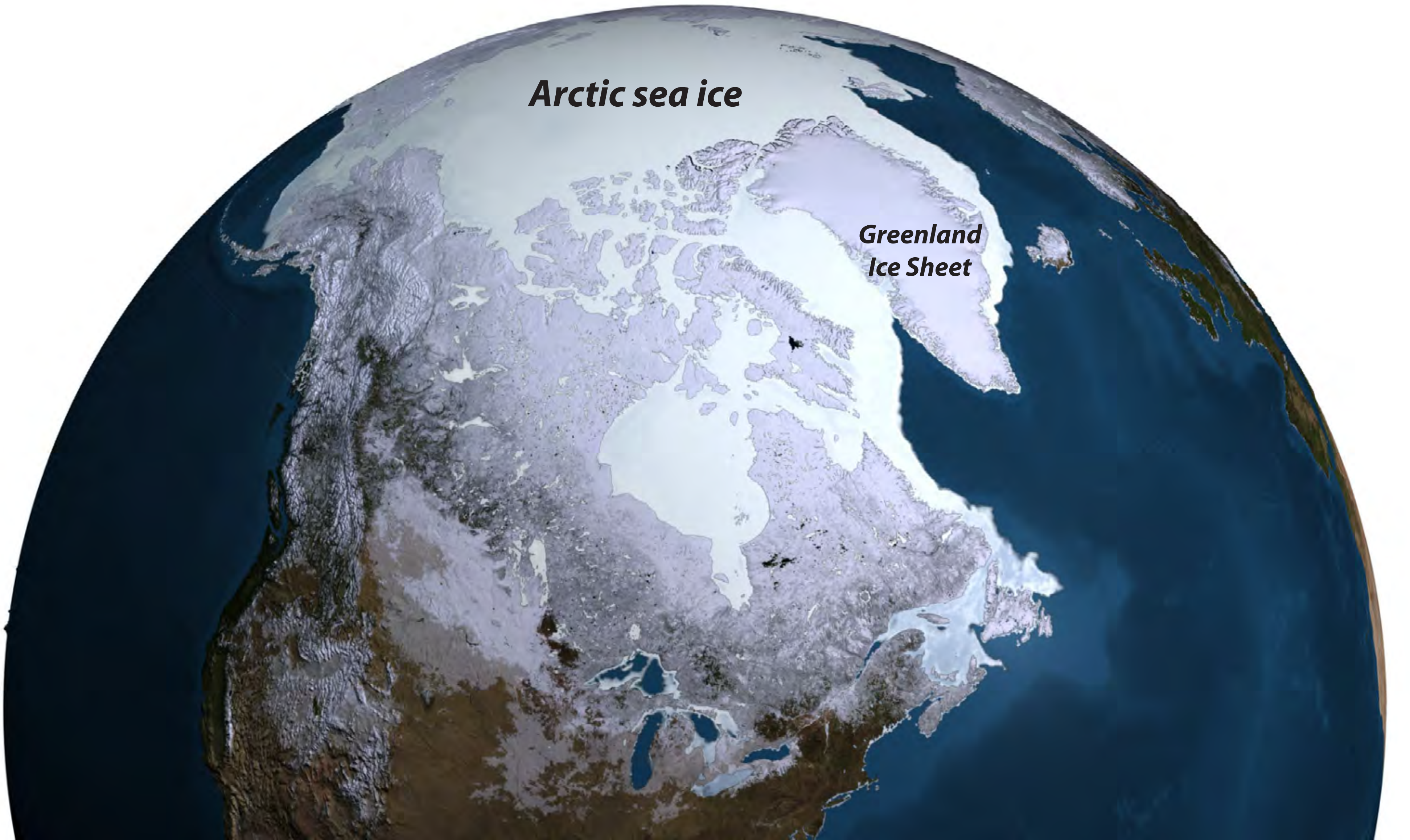
ANTARCTICA

southern cryosphere

South America

Australia

northern cryosphere



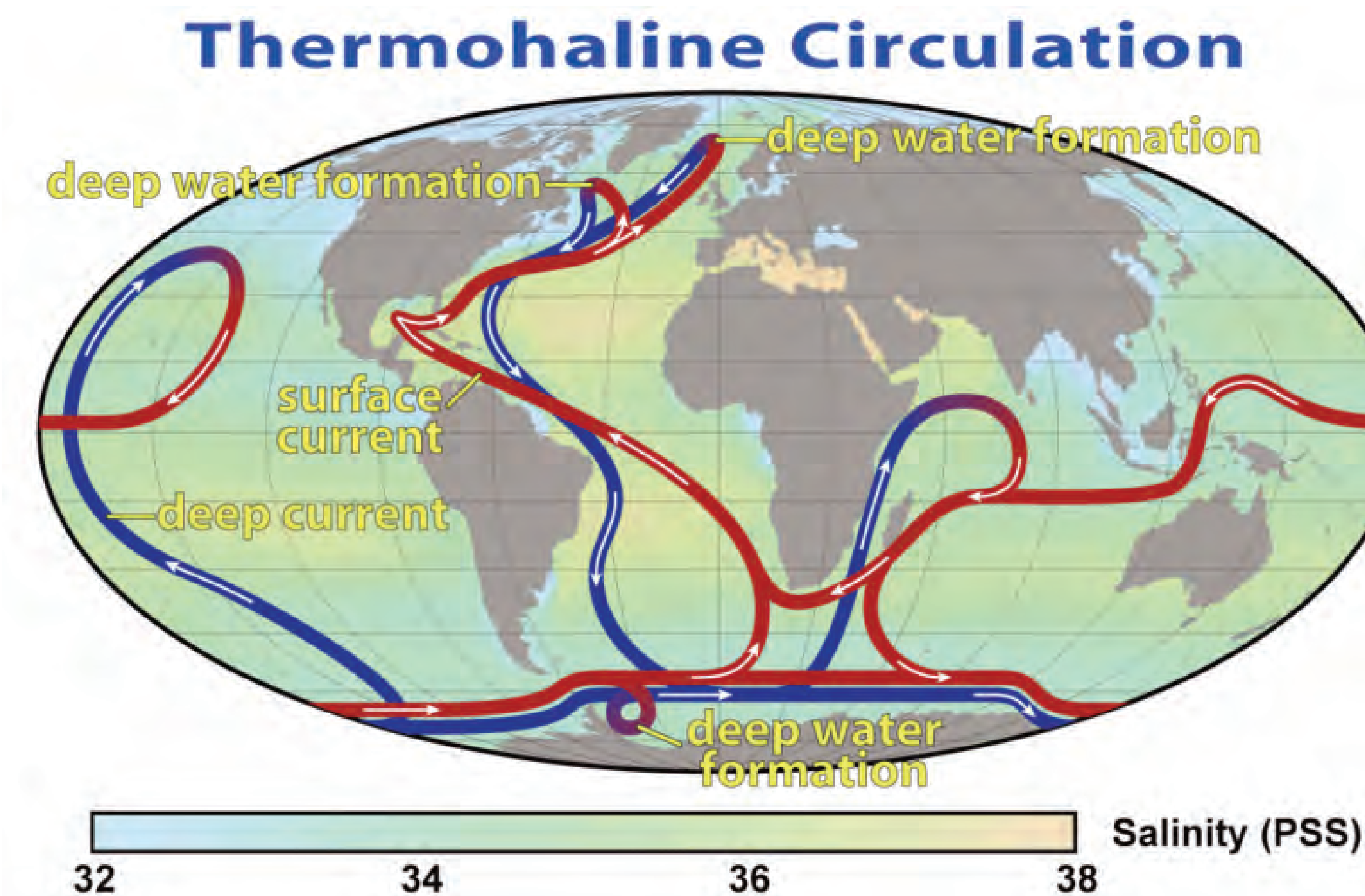
SEA ICE covers 7 - 10% of earth's ocean surface

- boundary between ocean and atmosphere
- indicator and agent of climate change

sea ice formation

brine expulsion from sea ice formation results in water beneath the ice becoming cooler and saltier → **this denser water sinks rapidly to great depths**

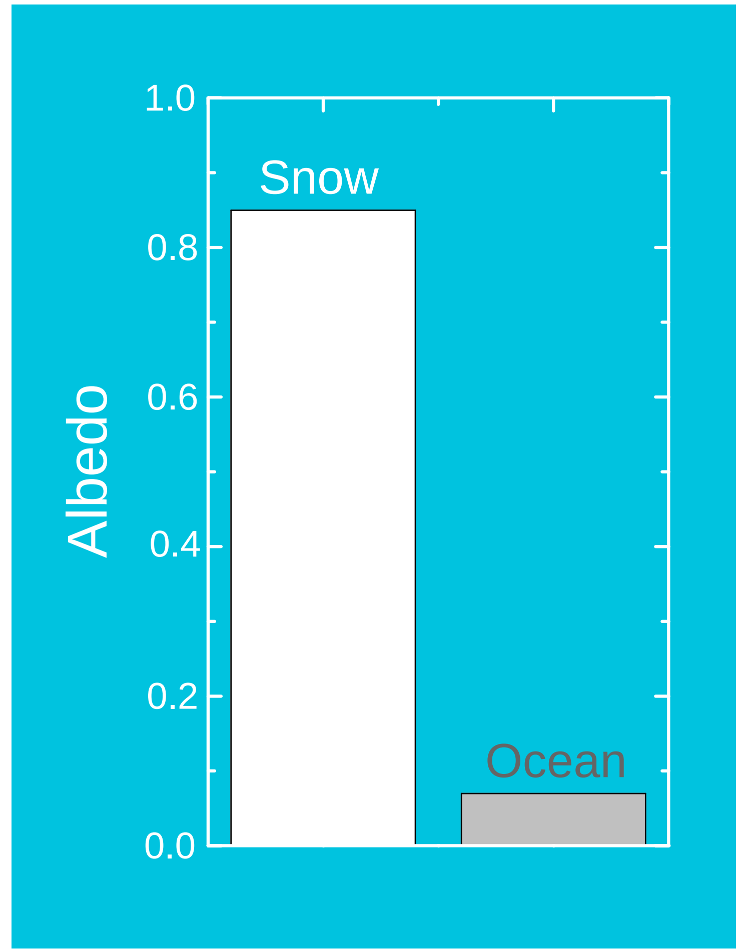
deep-water formation drives circulation in the world's oceans



GLOBAL THERMOHALINE CONVEYOR BELT

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

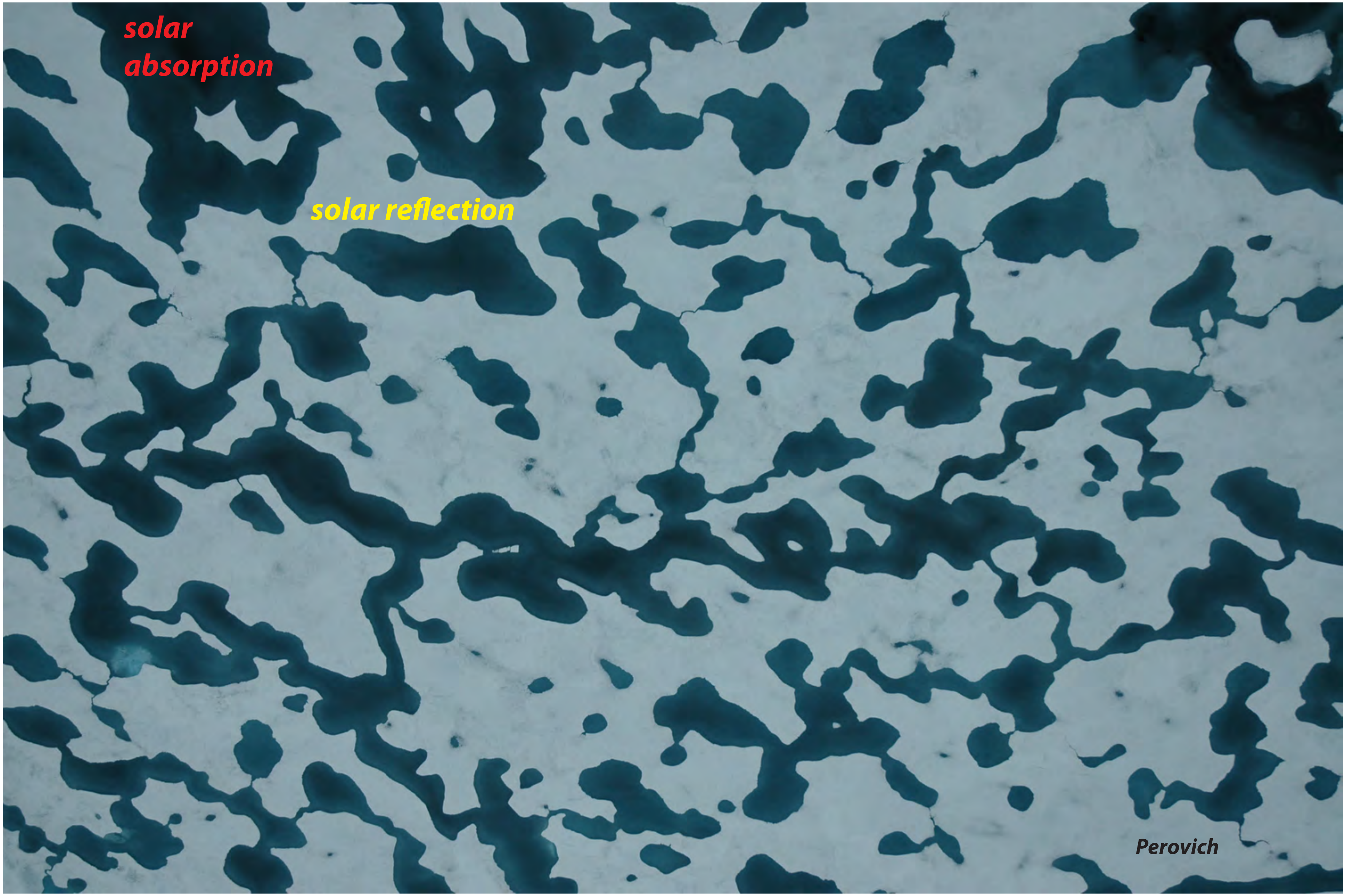
white snow and ice reflect



dark water and land absorb

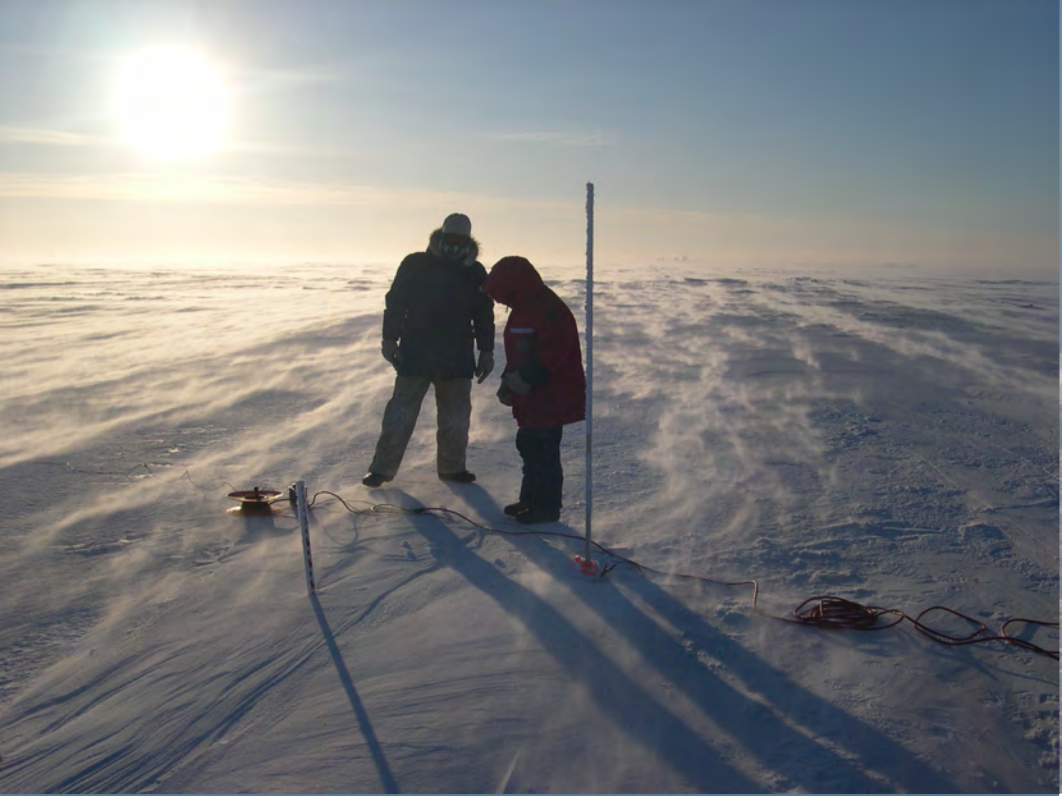

first year Antarctic sea ice
solar reflection
solar absorption
Tony Worby

Arctic melt ponds



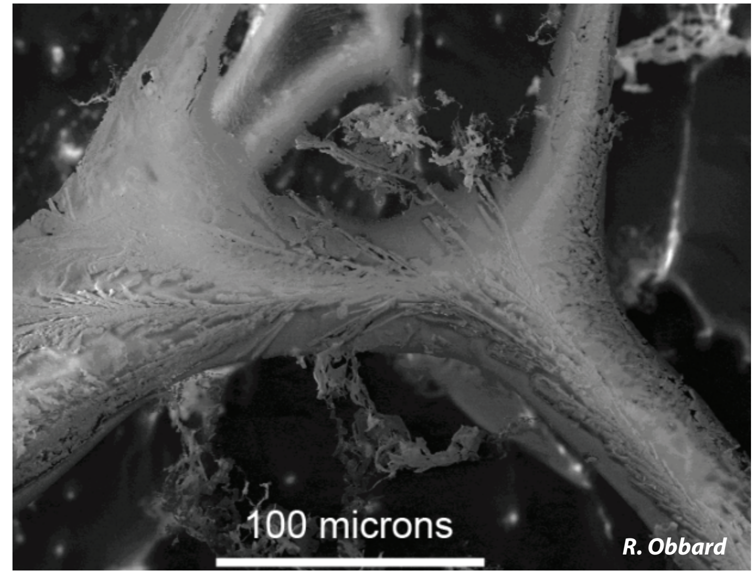
melt pond formation and albedo evolution -- major drivers in polar climate

key challenge for global climate models



sea ice may appear to be a barren, impermeable cap ...

brine inclusions in sea ice (mm)



micro - brine channel (SEM)

brine channels (cm)

sea ice is a porous composite

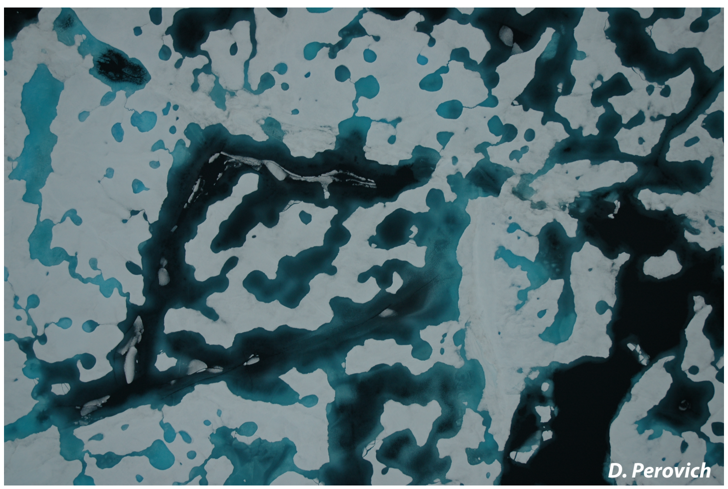
pure ice with brine, air, and salt inclusions

horizontal section

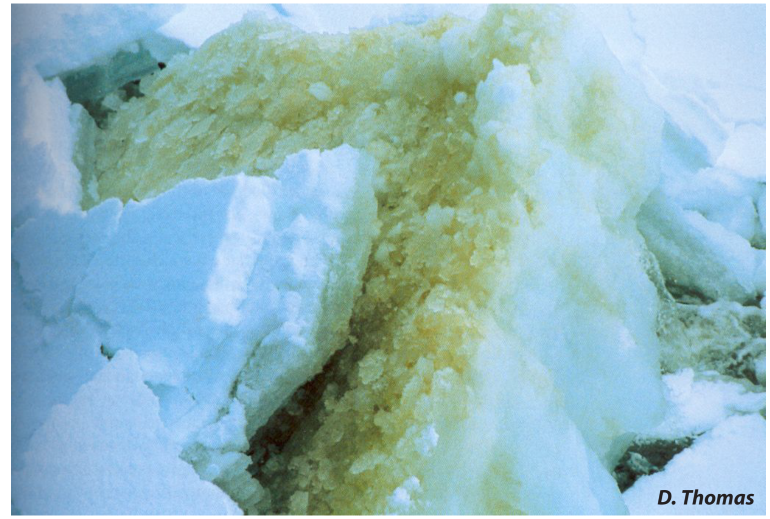
vertical section

fluid flow through porous sea ice mediates key processes in polar climate and ecosystems:

evolution of Arctic melt ponds



algal communities



- ***formation and melting of sea ice***
- ***ocean-ice-atmosphere exchanges of heat, brine, CO2***
- ***growth and decline of microbial communities***

What is this talk about?

... using science and math to study sea ice structures and processes which will improve our understanding and projections of climate change.

1. ***Sea ice in the climate system*** - Arctic decline & global climate models

2. ***Multiscale structure*** -- fractal behavior of sea ice pack and melt ponds

3. ***Fluid flow through sea ice*** - geophysical and biological processes
   microphysics and percolation

4. ***Electromagnetic remote sensing*** - monitoring climate change and
   key sea ice transport processes

5. ***Antarctic experiments*** on fluid and electrical transport in sea ice

video and photos from 2007 & 2010 Antarctic expeditions

mathematical themes of the talk

composite structures - sea ice structures and processes exhibit composite behavior on many scales

critical behavior - small changes in system parameters can induce large changes in behavior

(phase transitions)

linkage of scales - how do smaller scales influence larger scale behavior

the math doesn't care
if a "composite" has microstructure
on millimeter, meter, or kilometer scale

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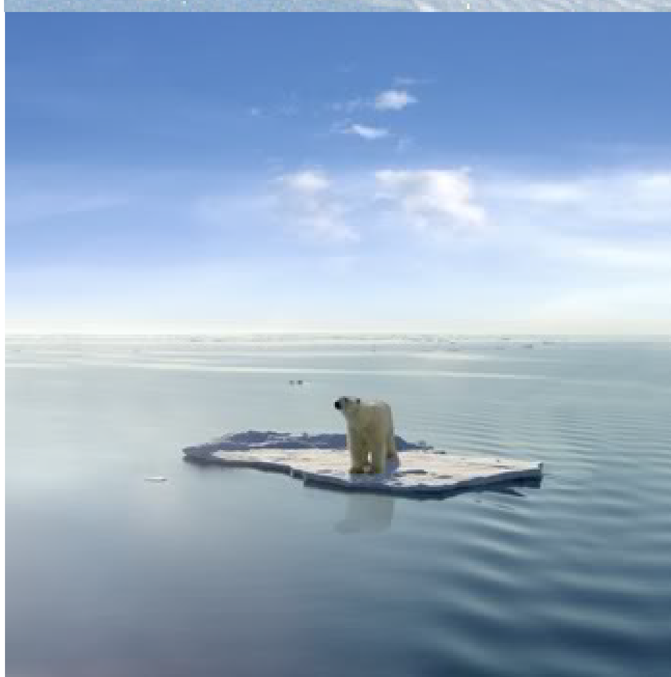
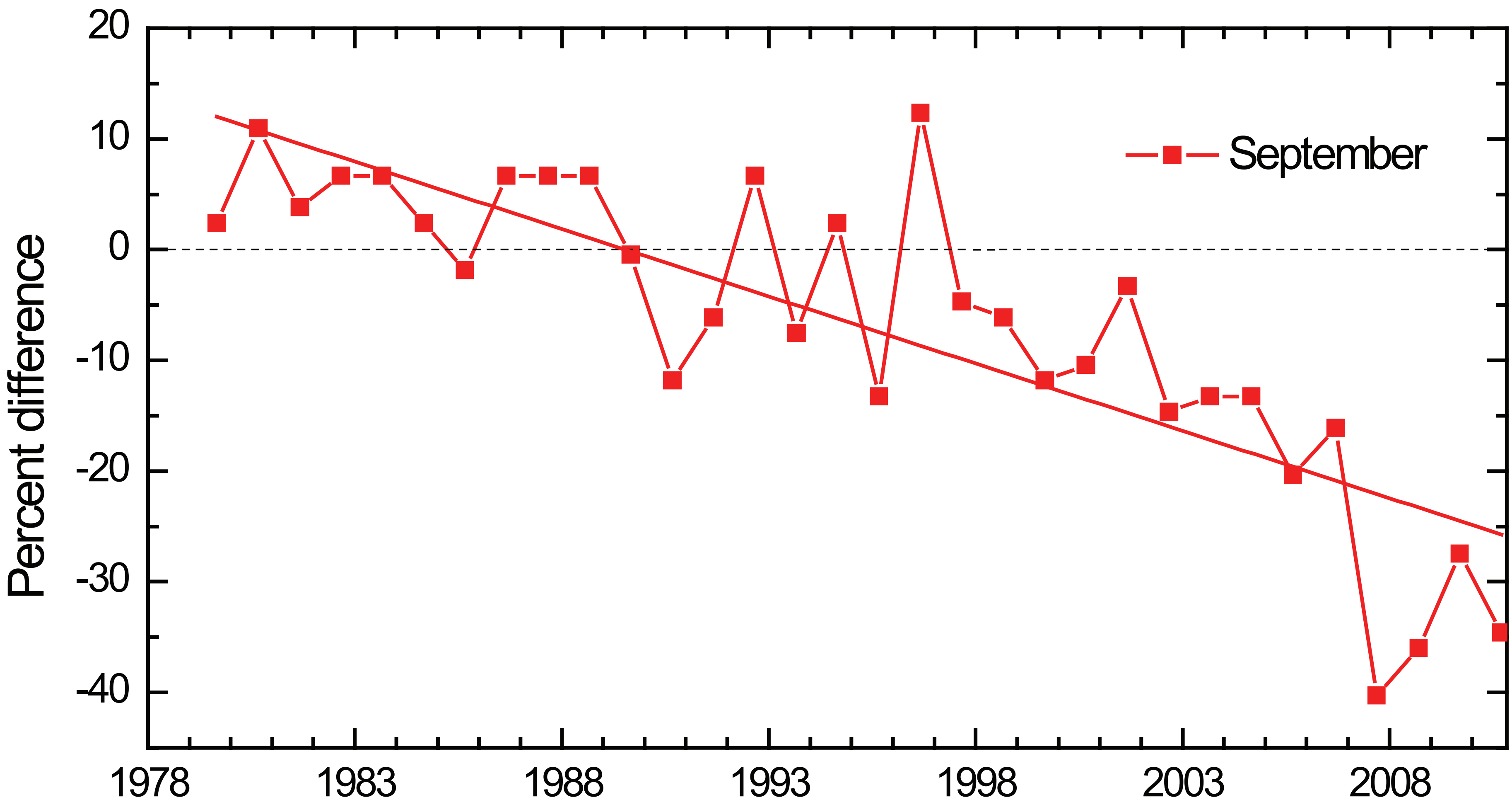
Don Perovich

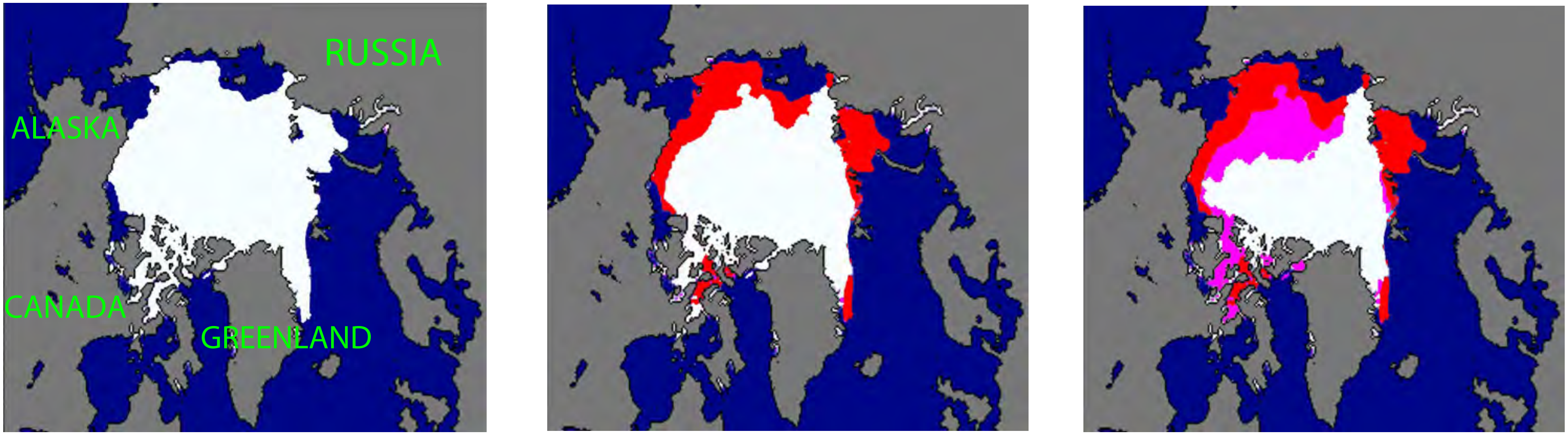


Arctic meltdown and global climate models

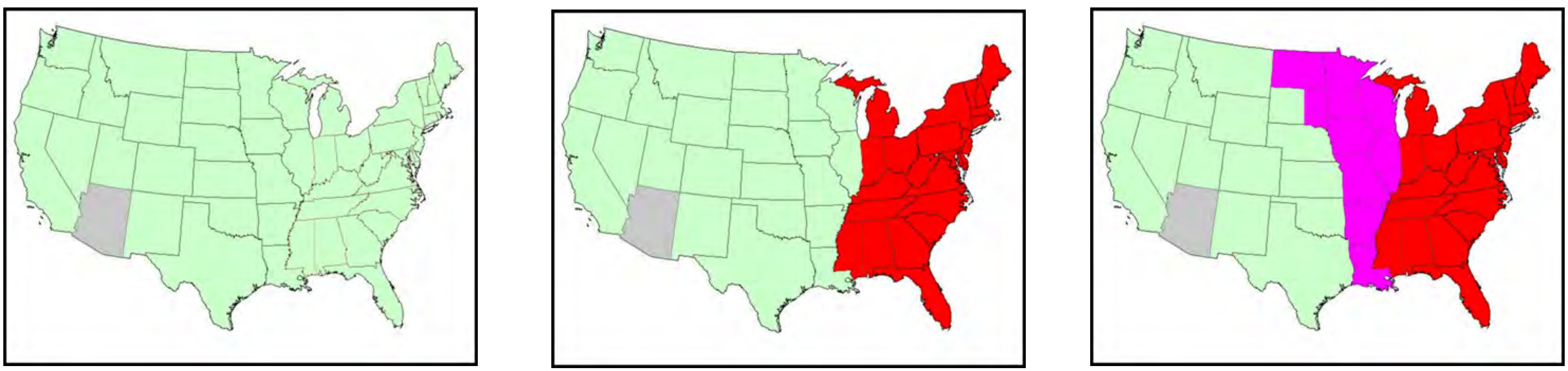
Change in summer Arctic sea ice extent



Perovich



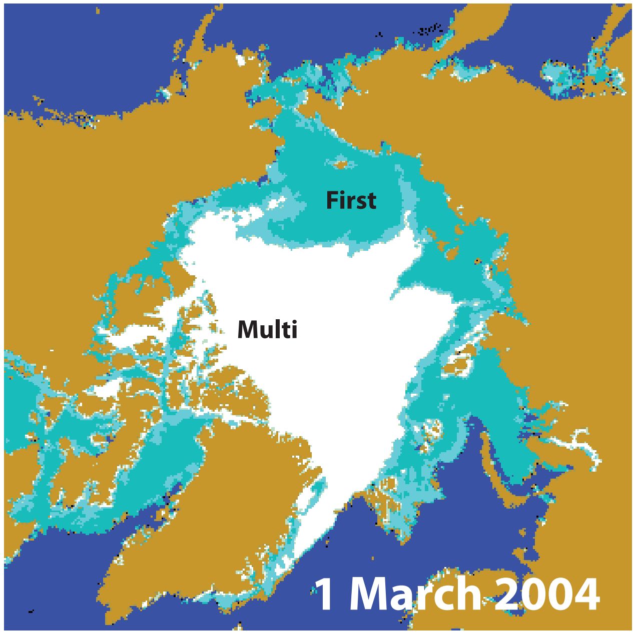
1980 2005 2007



Perovich

thicker multiyear ice being replaced by thinner first year ice

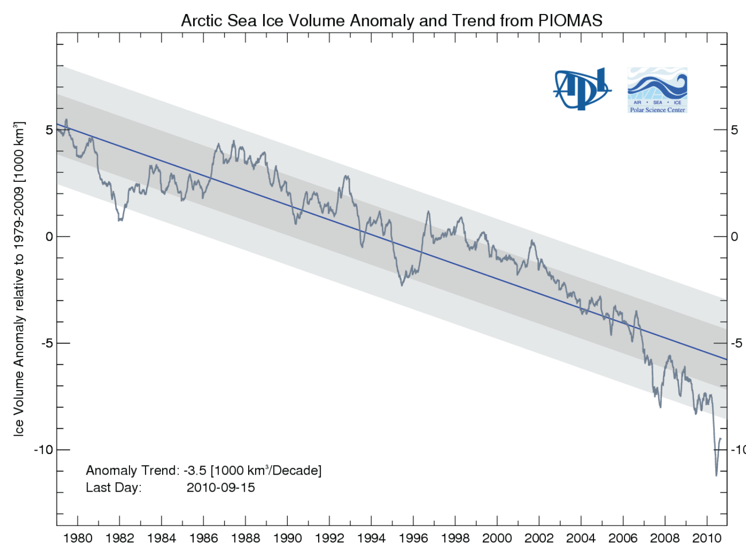
Winter 2004



Winter 2008

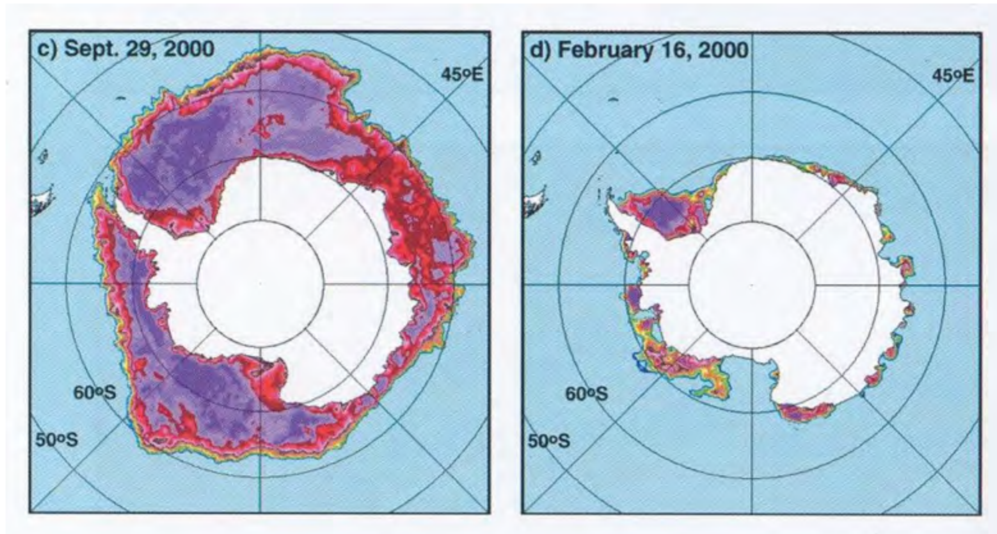
Son Nghiem

... and sea ice volume is declining



Antarctic sea ice pack is already seasonal

winter summer



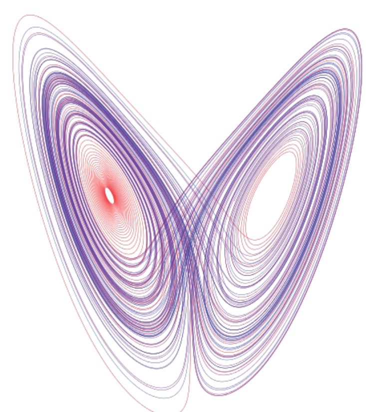
Is global warming **Antarctifying** the Arctic ?

Can Arctic sea ice rebound?

.... or have we passed a critical threshold,
a "tipping point" in a transition from an
ice-covered to ice-free Arctic Ocean?

unlikely in transition from current perennial
sea-ice conditions to seasonally ice-free

may be likely with further warming and
sudden loss of wintertime-only ice cover



Lorenz butterfly

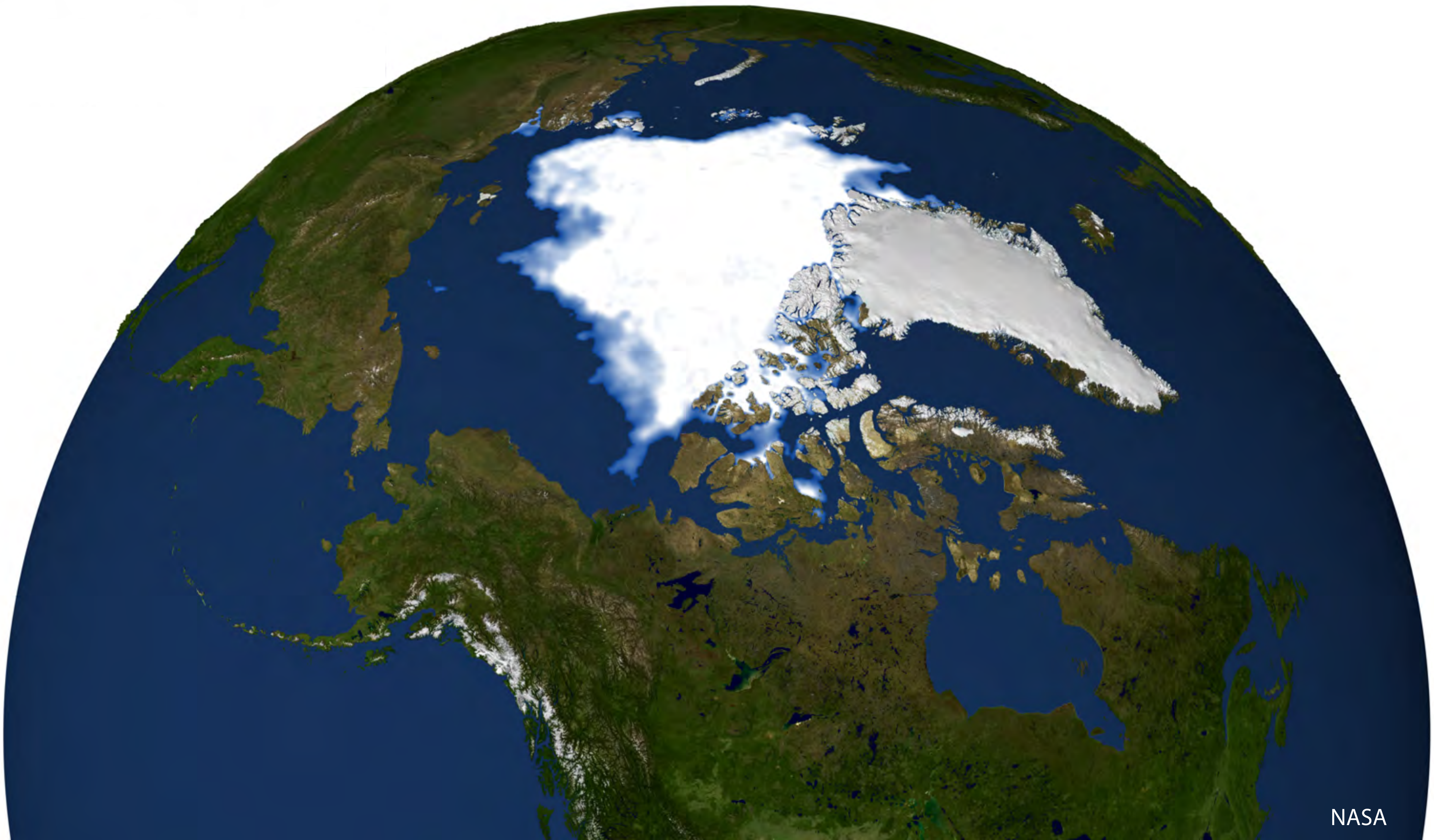
"I stand by my previous statements that the
Arctic summer sea ice cover is in a ***death spiral***.
It's not going to recover."
Mark Serreze, Director of the National Snow and
Ice Data Center 9/20/10

Eisenman, Wettlaufer 2009

Notz 2009
Abbot, Silber, Pierrehumbert 2011

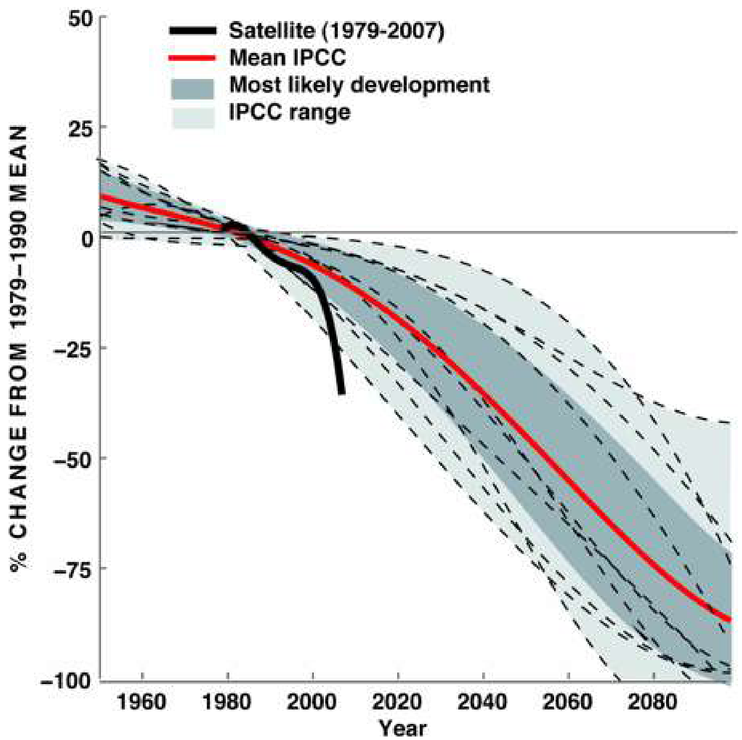
climate change is amplified in the polar regions

14 September 2008

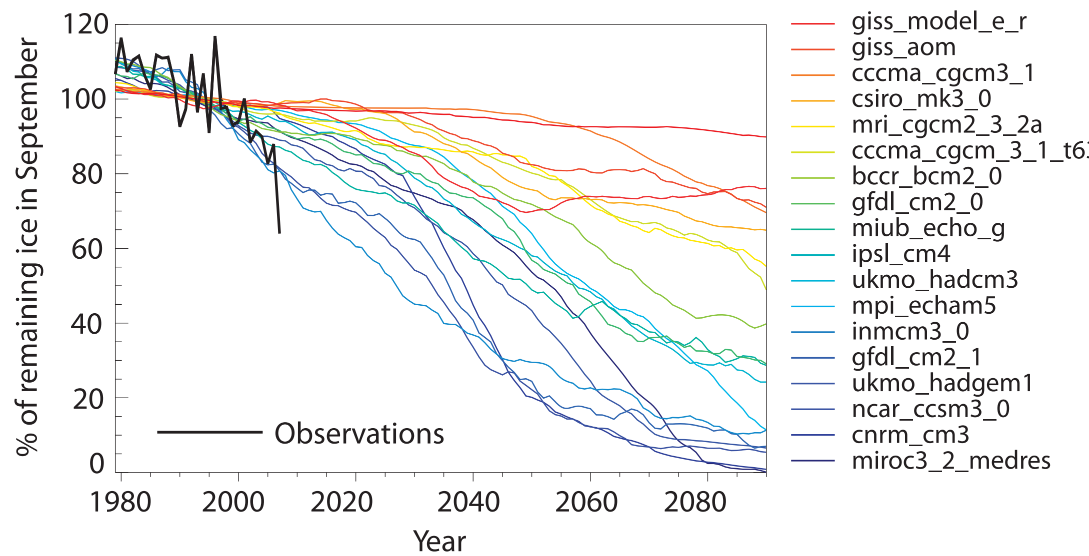


IPCC (Intergovernmental Panel on Climate Change) projections

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

What is essential in a numerical sea ice model for climate studies?

Simulate the climatological mean annual cycle of the ice and snow

Represent the sensitivity to perturbations - must have the key feedbacks

Physics appropriate to the model's spatial scale, parameterizations for sub-scale behaviors

What are the key ingredients -- or ***governing equations*** that need to be solved on powerful computers?

1. Ice thickness distribution evolution equation (Thorndike et al. 1975)

   dynamics
   +
   thermodynamics

   nonlinear PDE incorporating ice velocity field, ice growth and melting mechanical redistribution - ridging and opening

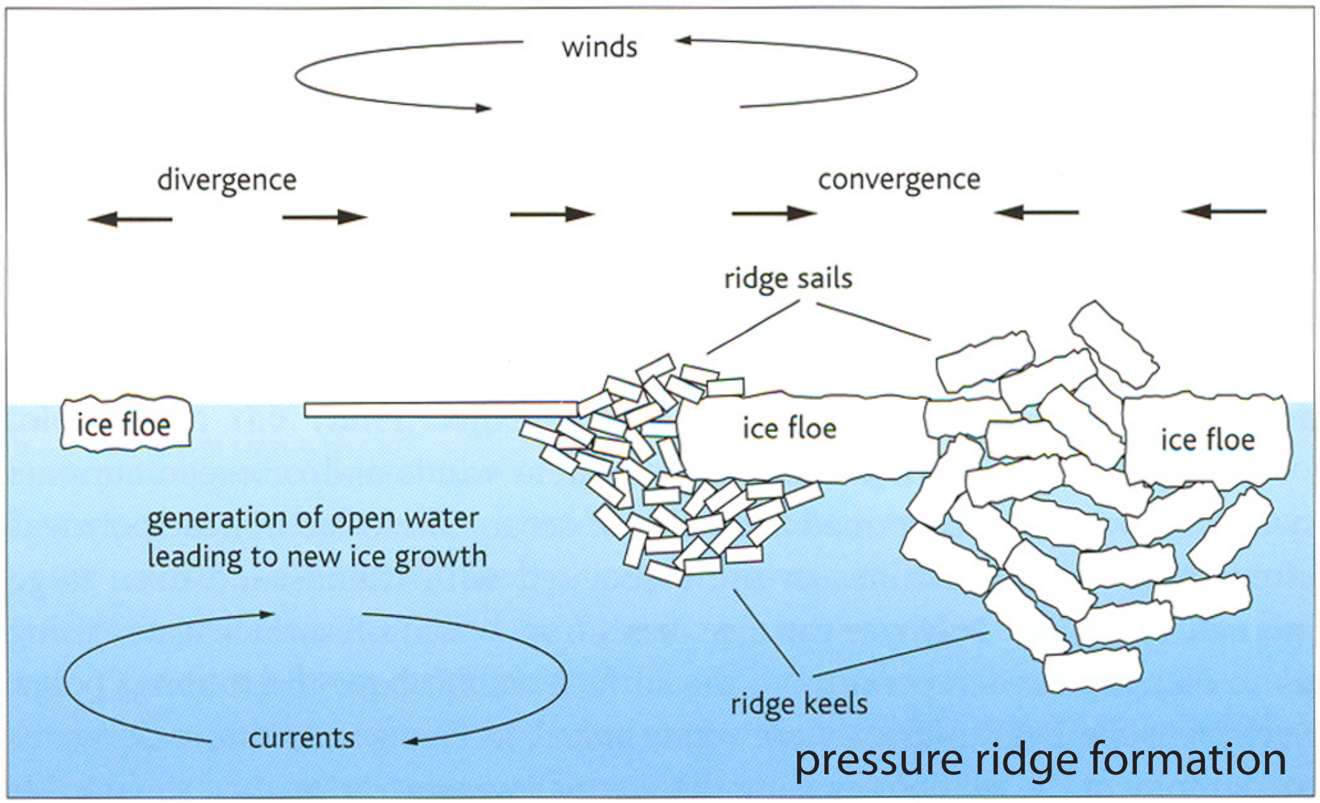
2. Conservation of momentum (Hibler 1979)

   dynamics

3. Heat equation of sea ice and snow (Maykut and Untersteiner 1971)

   thermodynamics

dynamically modifying the ice thickness distribution



thinning thickening

David Thomas 2004

measuring ice depth in ridges off Barrow, AK

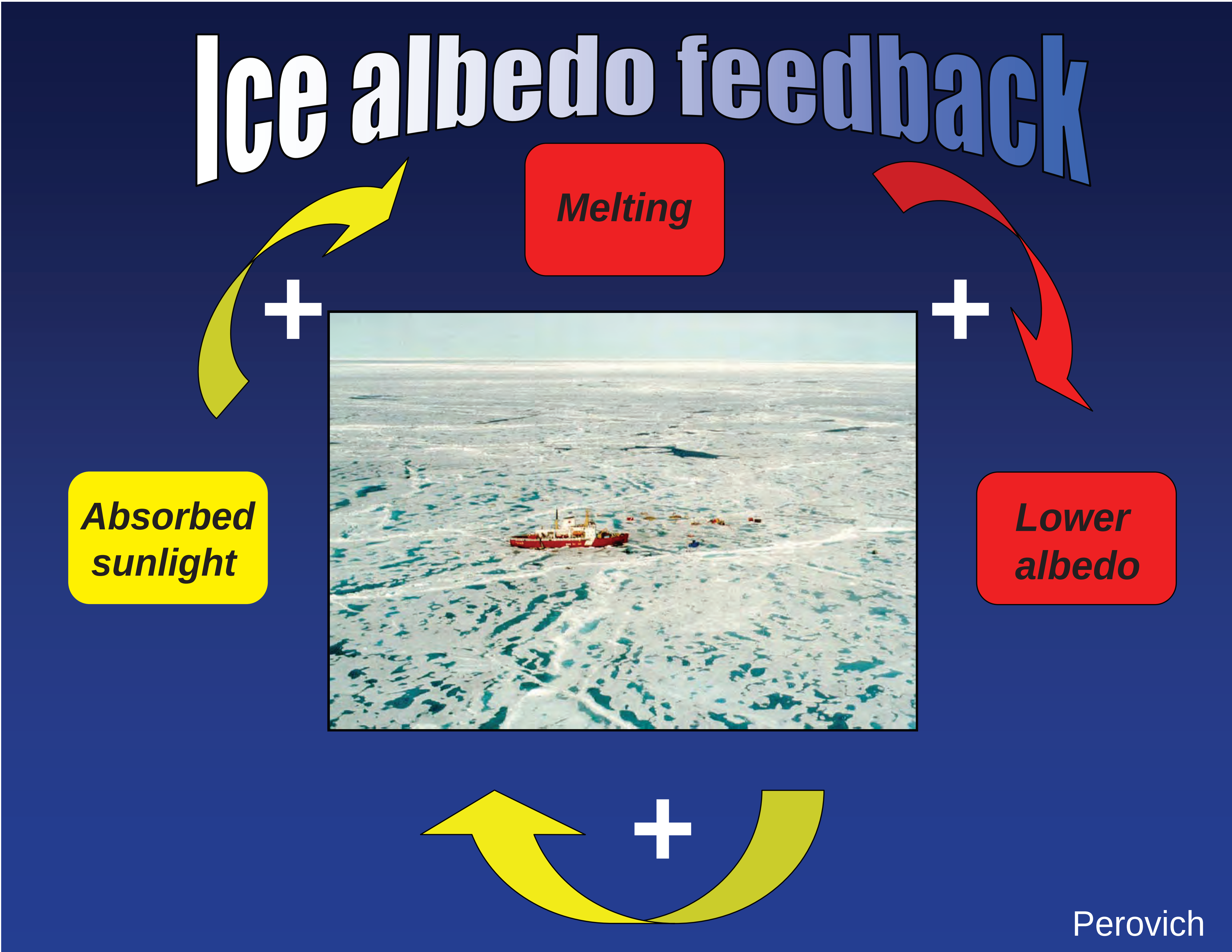
dynamic sea ice

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?



Ice albedo feedback
Melting
+
+
Absorbed sunlight
Lower albedo
+
Perovich

ice-albedo feedback played key role in the 2007 decline:

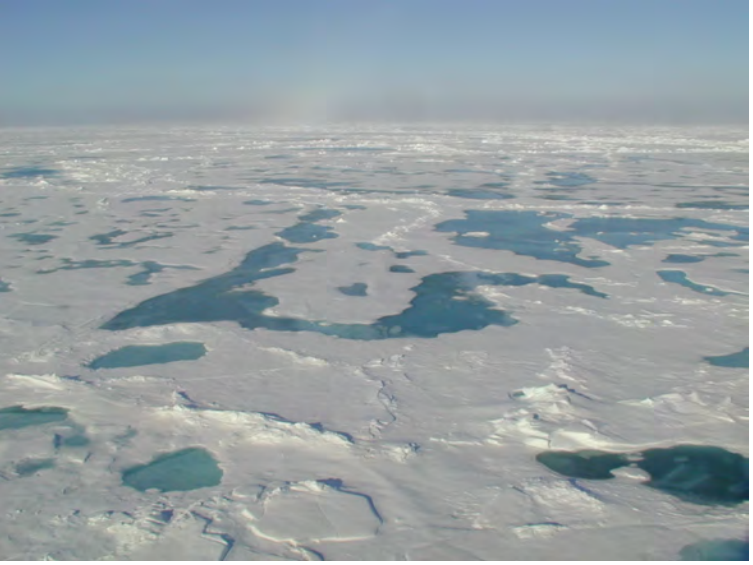
1. Ice mass balance observations show extraordinary amount of ***bottom melting*** in the Beaufort Sea in summer of 2007.

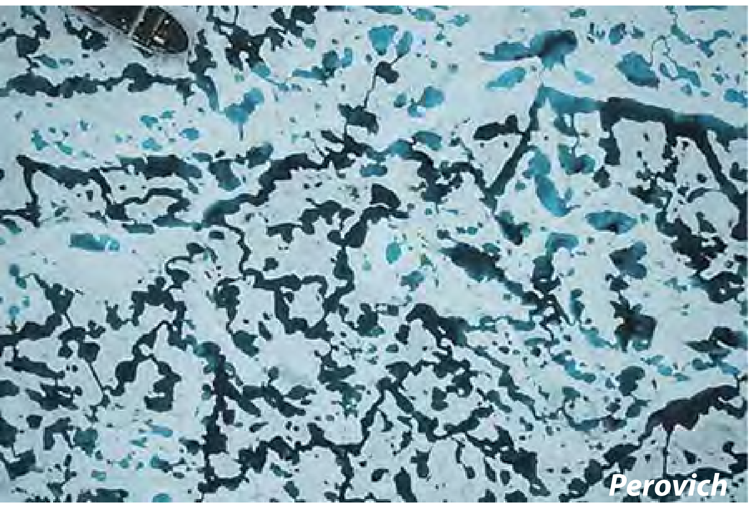
2. Calculations indicate that ***solar heating of the upper ocean*** was the primary source of heat for this observed melting.

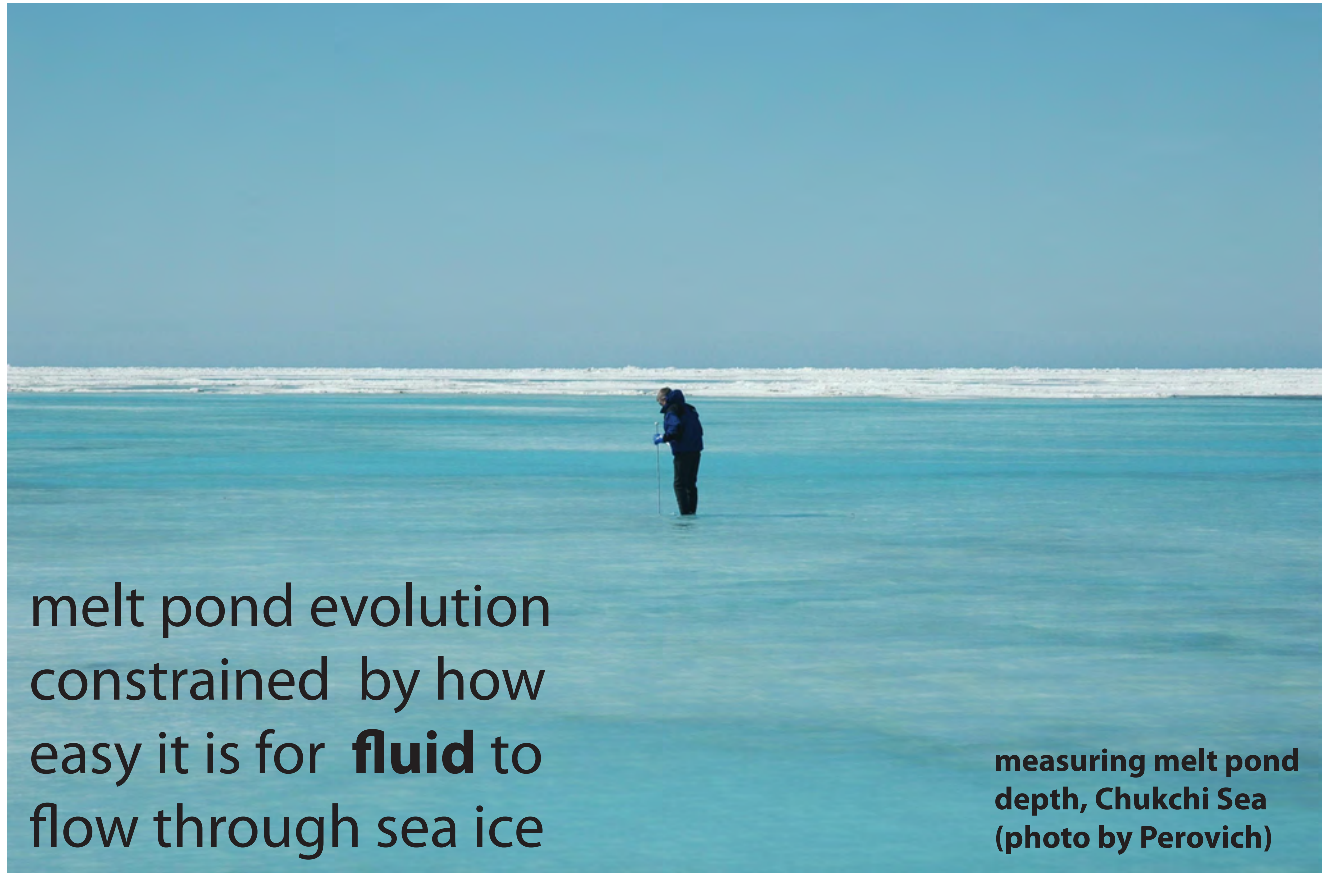
3. ***Increase in open water fraction*** resulted in 500% positive anomaly in solar heat input to the upper ocean, triggering an ice–albedo feedback.

Perovich *et al.* , *GRL*, 2008

sea ice albedo determined by melt ponds







fluid permeability

depends on microstructure

melt pond evolution depends also on large-scale "pores" in ice cover

photos courtesy of C. Polashenski and D. Perovich


http://www.alaska-in-pictures.com/picture-of-a-harbor-seal-8057-pictures.htm

Does melting sea ice contribute to sea level rise? - not directly

glacial ice
(iceberg, ice shelf)

sea ice

sea ice is in isostatic balance with the ocean
when it melts, sea level doesn't change

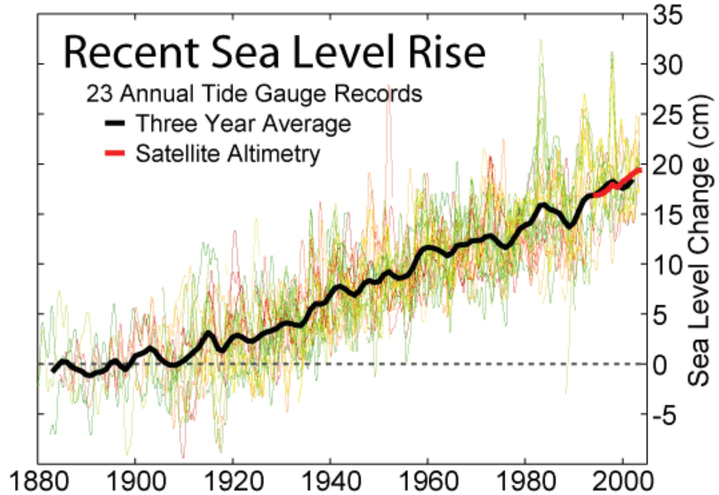
... but indirect effects and feedbacks can influence sea level rise

ice sheet and glacier modeling in climate projections not mature

no coupling yet of ice sheets and ocean in climate models
-- no feedback effects

(David Holland)

As Earth's climate warms, why does sea level rise?



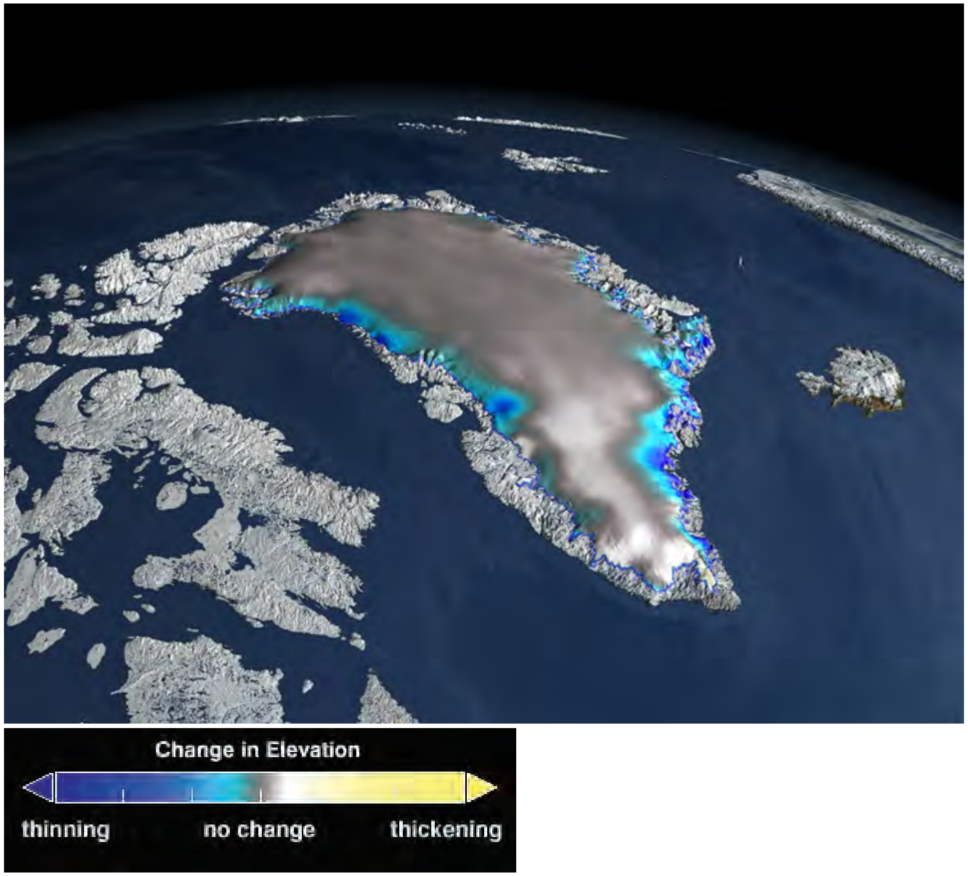
- ***melting land ice: Antarctica, Greenland, mountain glaciers***

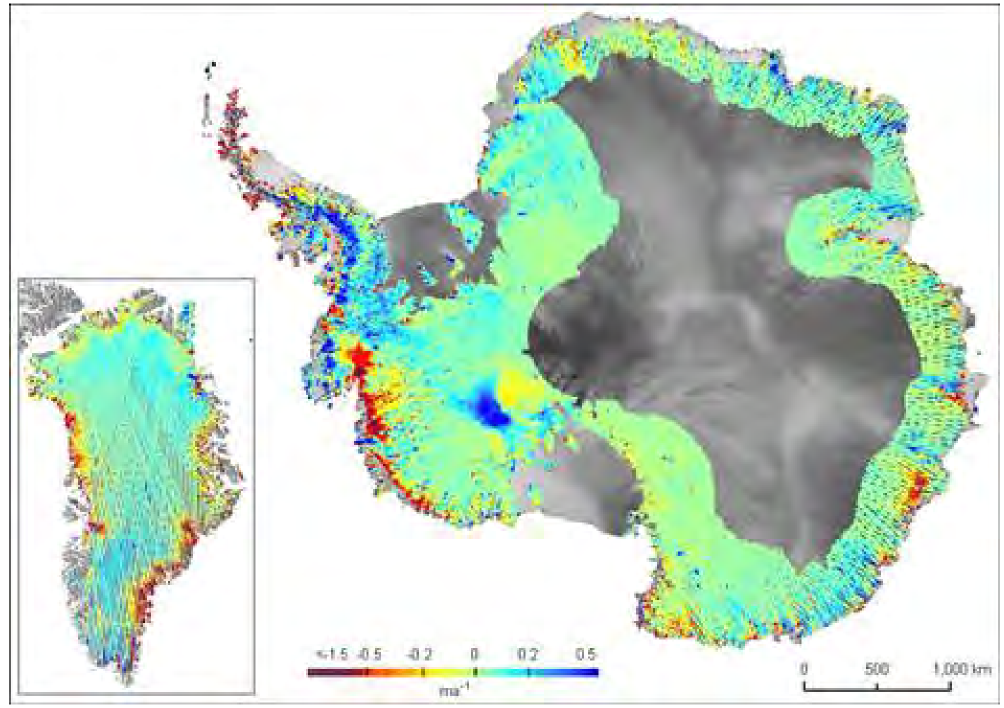
- ***thermal expansion of warming ocean***

  accounts for about 25% of rise in last half of 20th century, rate ~ tripled in 21st century

- ***continental rebound***

  rise of land masses that were depressed by the huge weight of ice sheets

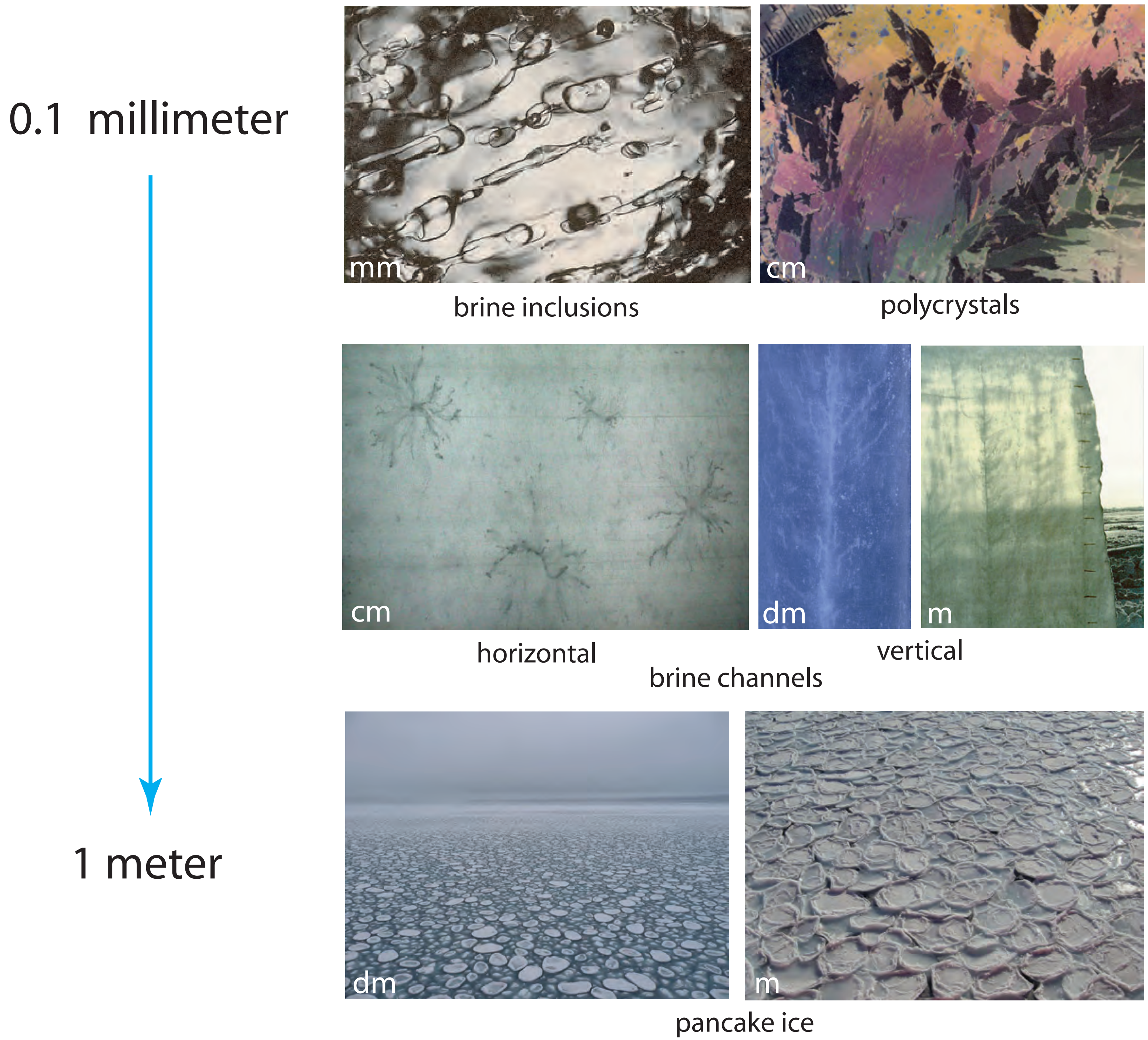


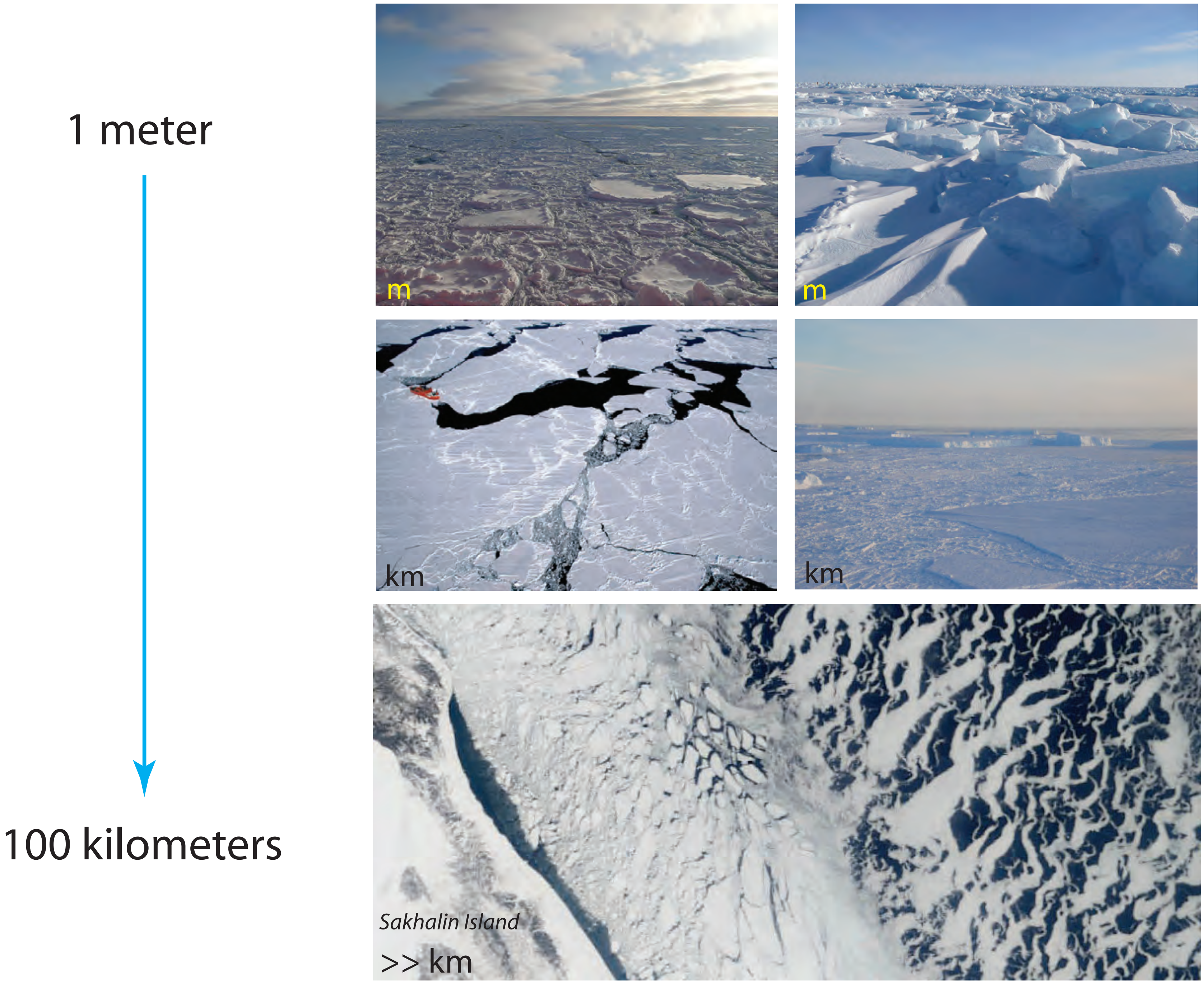


if all land ice melted, contributions to SLR:

Antarctica -- 57 m
Greenland -- 7 m
mountain glaciers -- 0.5 m

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




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

fractals have self-similar structure on many length scales

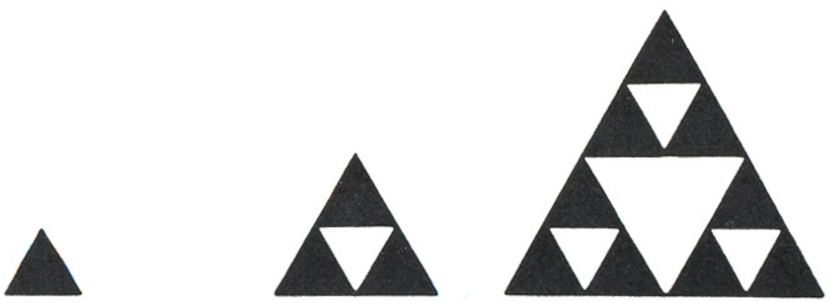
fractal dimension

$L = 1$, $A = 1$; $L = 2$, $A = 4$; $L = 3$, $A = 9$ ....

$$A \sim L^d$$

$$d = 2$$

Euclidean



$L = 1$, $A = 1$; $L = 2$, $A = 3$; $L = 4 = 2^2$, $A = 9 = 3^2$ ....

$$\mathrm{A} \sim L^D$$

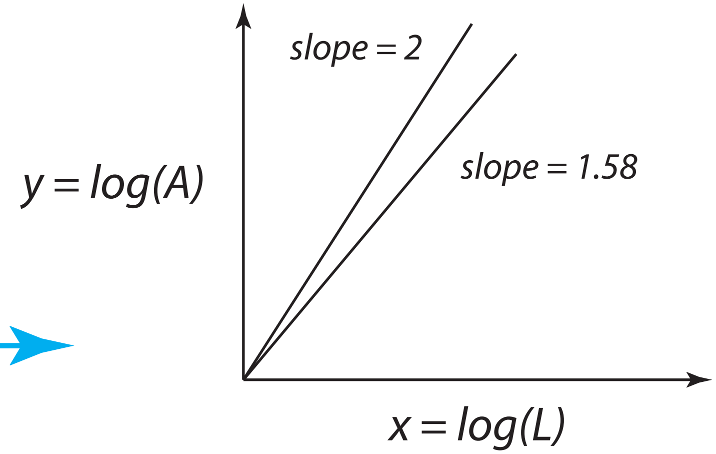
$$D = \frac{\log 3}{\log 2} = 1.58...$$

fractal

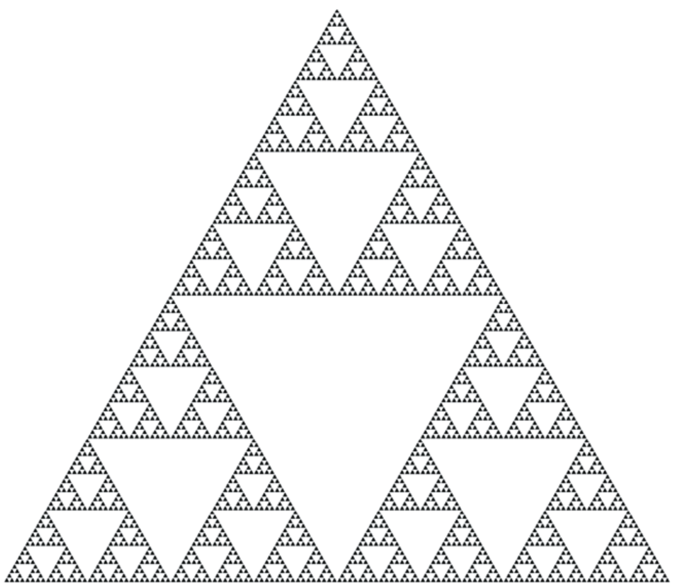
$$A = L^D$$

$$\log(A) = \log(L^D) = D\log(L)$$

$$y = D\,x$$



$D = 1.58...$

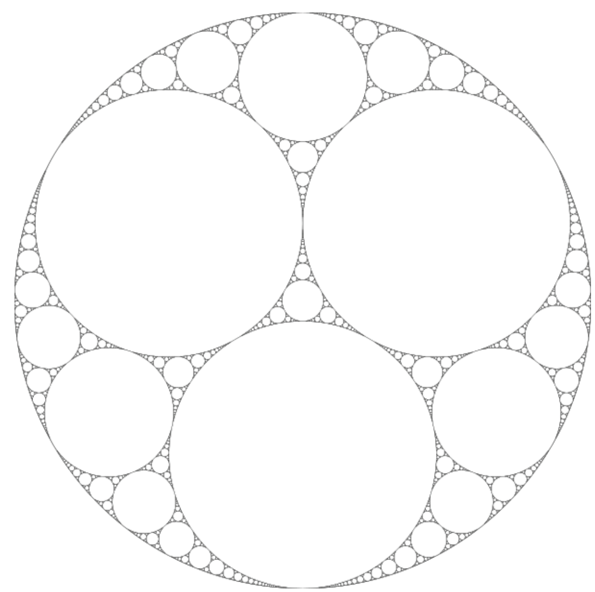


Sierpinski triangle

self-similar structure with fractal dimension

fractal dimension < 2
no longer two dimensional
-- too much removed

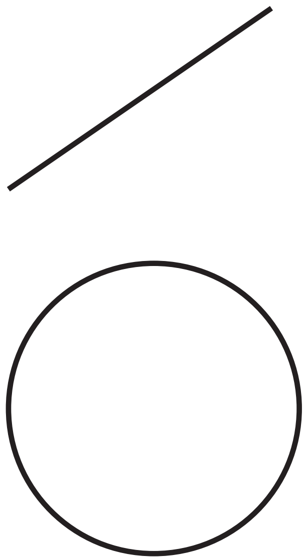
$D = 1.31...$

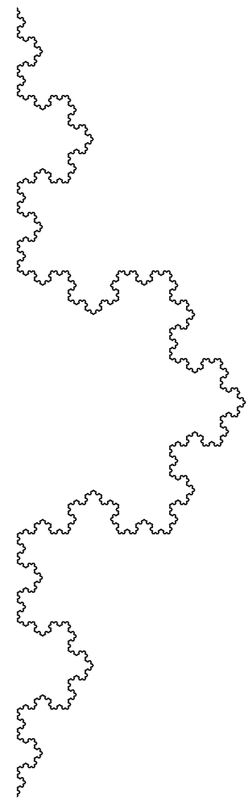


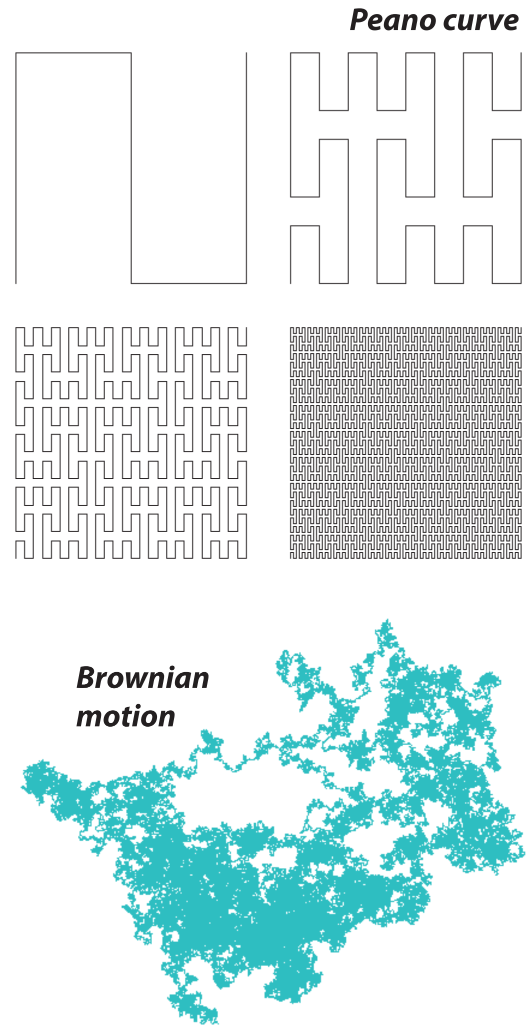
Apollonian gasket

fractal curves in the plane

they wiggle so much that their dimension is >1







simple curves

D = 1

Koch snowflake

D = 1.26

space filling curves

D = 2

the sea ice pack is a ***fractal***

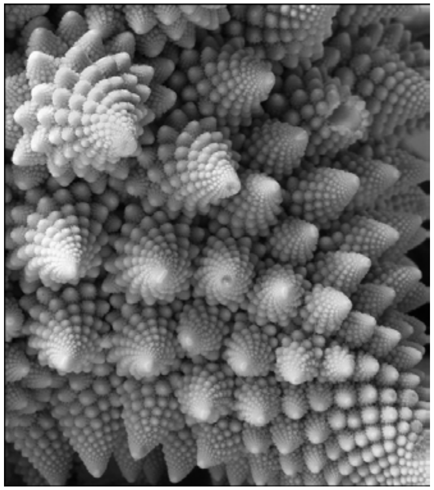
displaying self-similar structure on many scales

floe size distribution, areas, perimeters, etc. important
in dynamics (fracture), thermodynamics (melting)

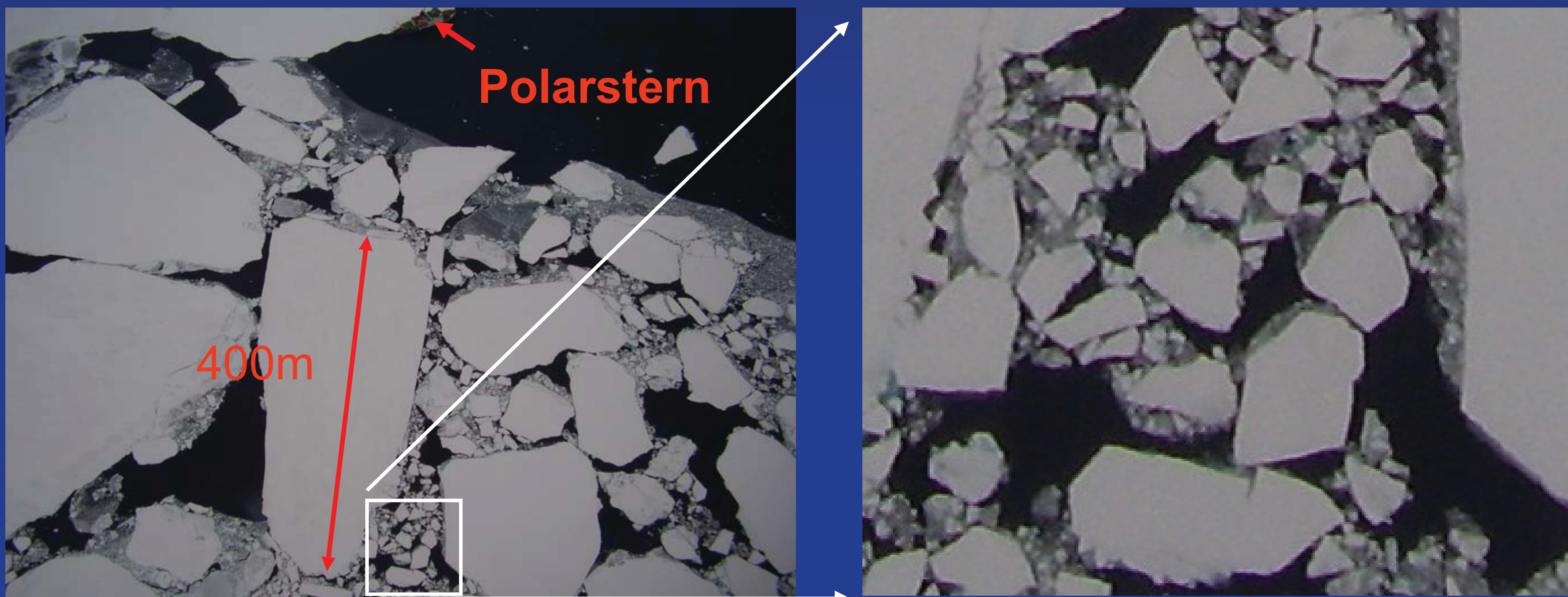
bigger floes easier to break, smaller floes easier to melt


J. Robertson


E. Walker



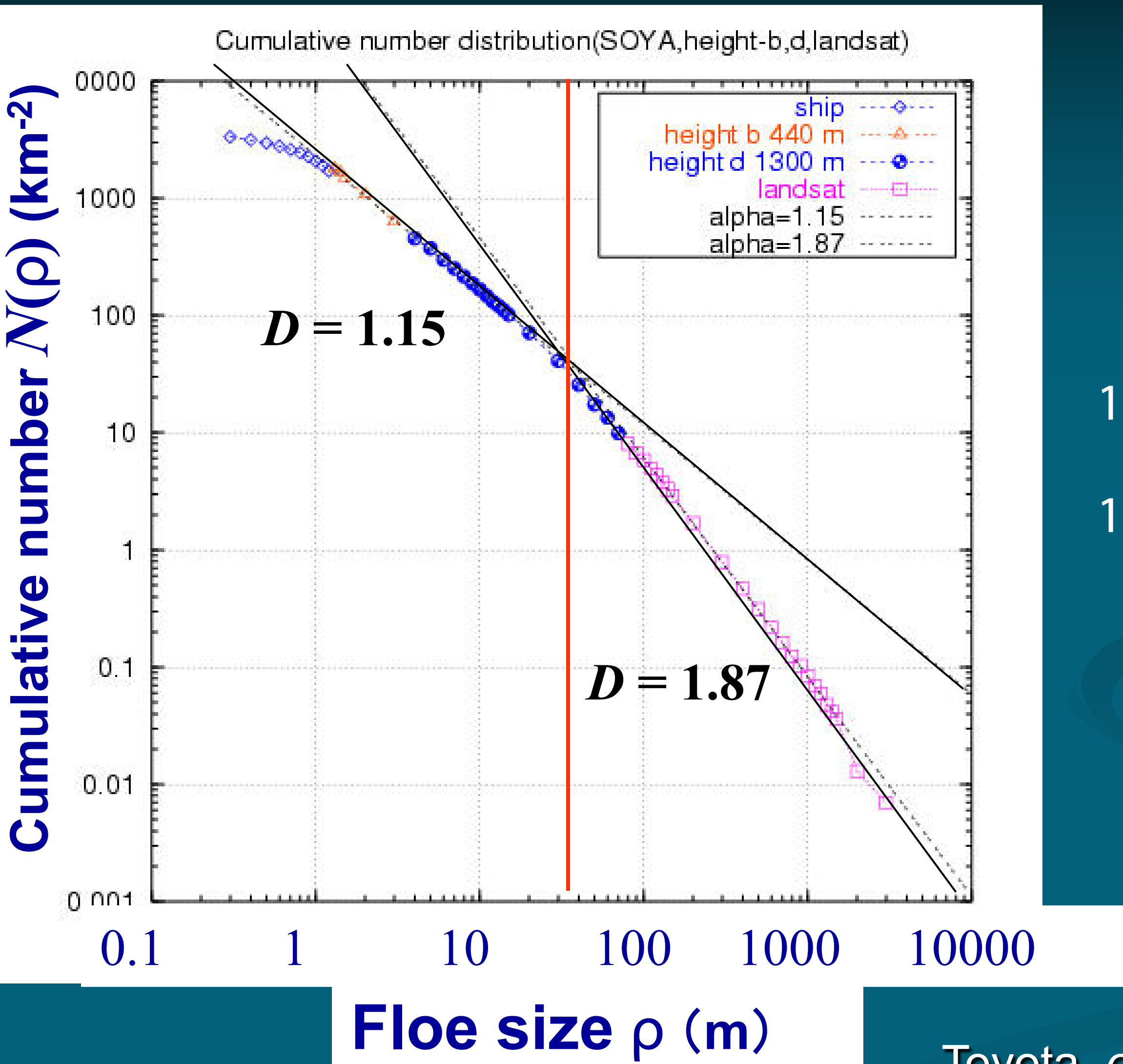
Self-similarity of sea ice floes



Weddell Sea, Antarctica
2006

Takenobu Toyota

Self-similar structure in Okhotsk Sea ice pack



Two regimes in floe size distribution:

size	fractal dimension
1〜20 m :	$D = 1.15 \pm 0.02$
100〜1500 m:	$D = 1.87 \pm 0.02$

$$N(\rho) \sim \rho^{-D}$$

Number of floes per unit area no smaller than ρ

Toyota, *et al., Geophys. Res. Lett*. 2006

(Rothrock and Thorndike, *J. Geophys. Res.* 1984)

Do melt ponds exhibit interesting multiscale structure?

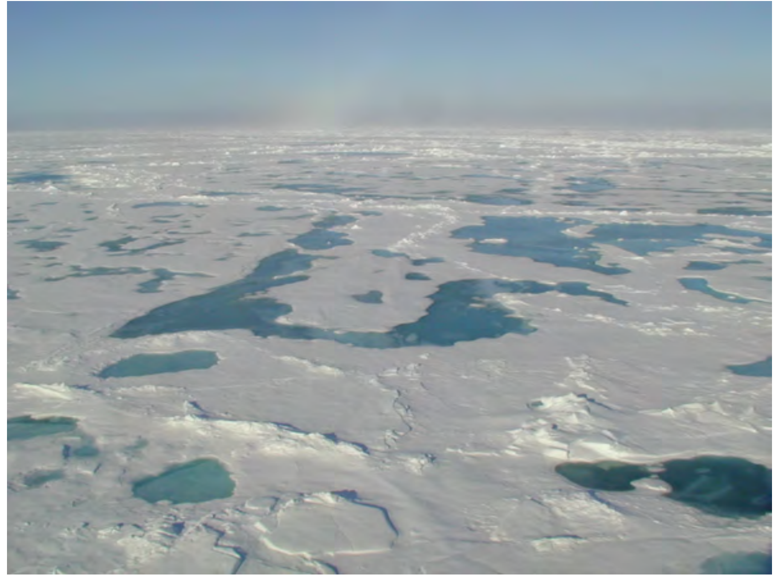
Are there universal features of the evolution not yet uncovered by detailed, mechanistic models?

Space filling curves and the evolution of Arctic melt ponds

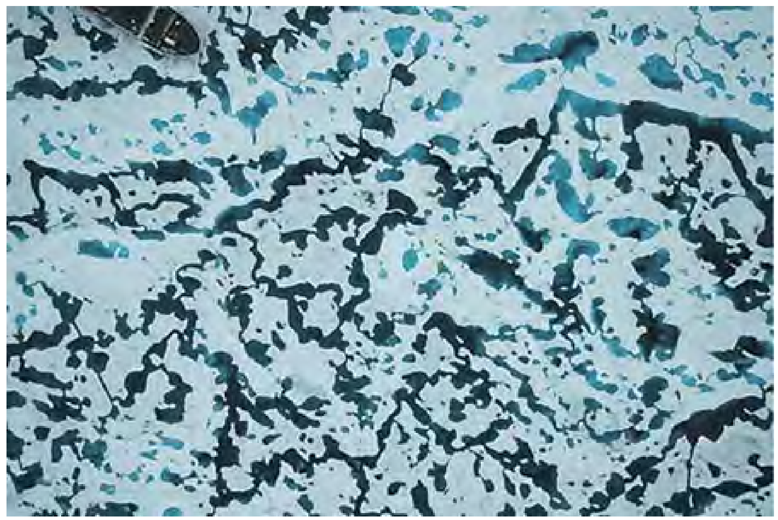
Christel Hohenegger, Kyle Steffen, Don Perovich, Ken Golden

melt pond connectivity

ponds disconnected
ice connected



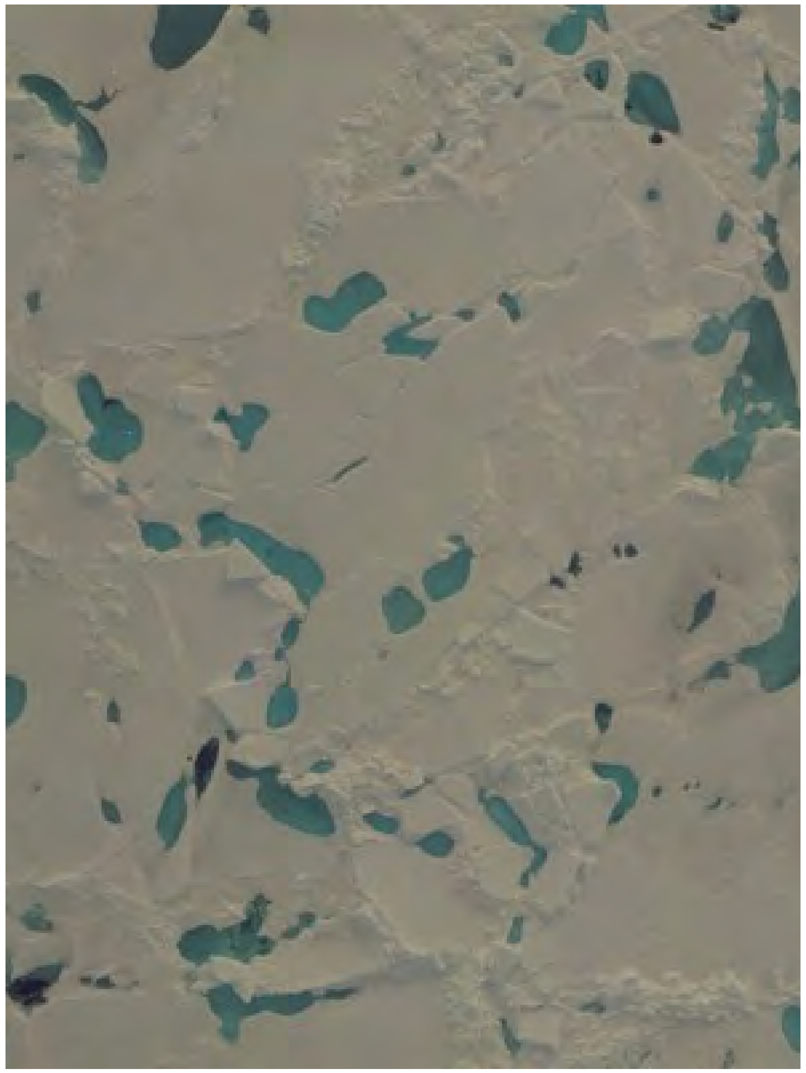
ponds connected
ice connected



as ponds coalesce and grow, the boundaries become increasingly complex and contorted with self-similar structure

ponds connected
ice disconnected

characterize the geometry with the fractal dimension



July 8 (SHEBA)

July 8 (SHEBA)

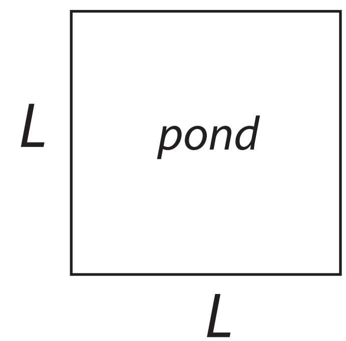
August 18 (HOTRAX)

Surface Heat Budget of the Arctic (SHEBA), 1998

Healy-Oden Trans-Arctic Expedition (HOTRAX), 2005 use Area - Perimeter relation to investigate melt pond geometry

$$P \sim \sqrt{A}$$

simple shapes



$A = L^2$

$P = 4L$

in general, for fractals with dimension D

$$P \sim \sqrt{A}^{\,D}$$

$D = 1.26...$	*Sierpinski triangle*
$D = 2$	$P \sim A$ *plane filling curves*
$D = 1$	*simple boundary curves*

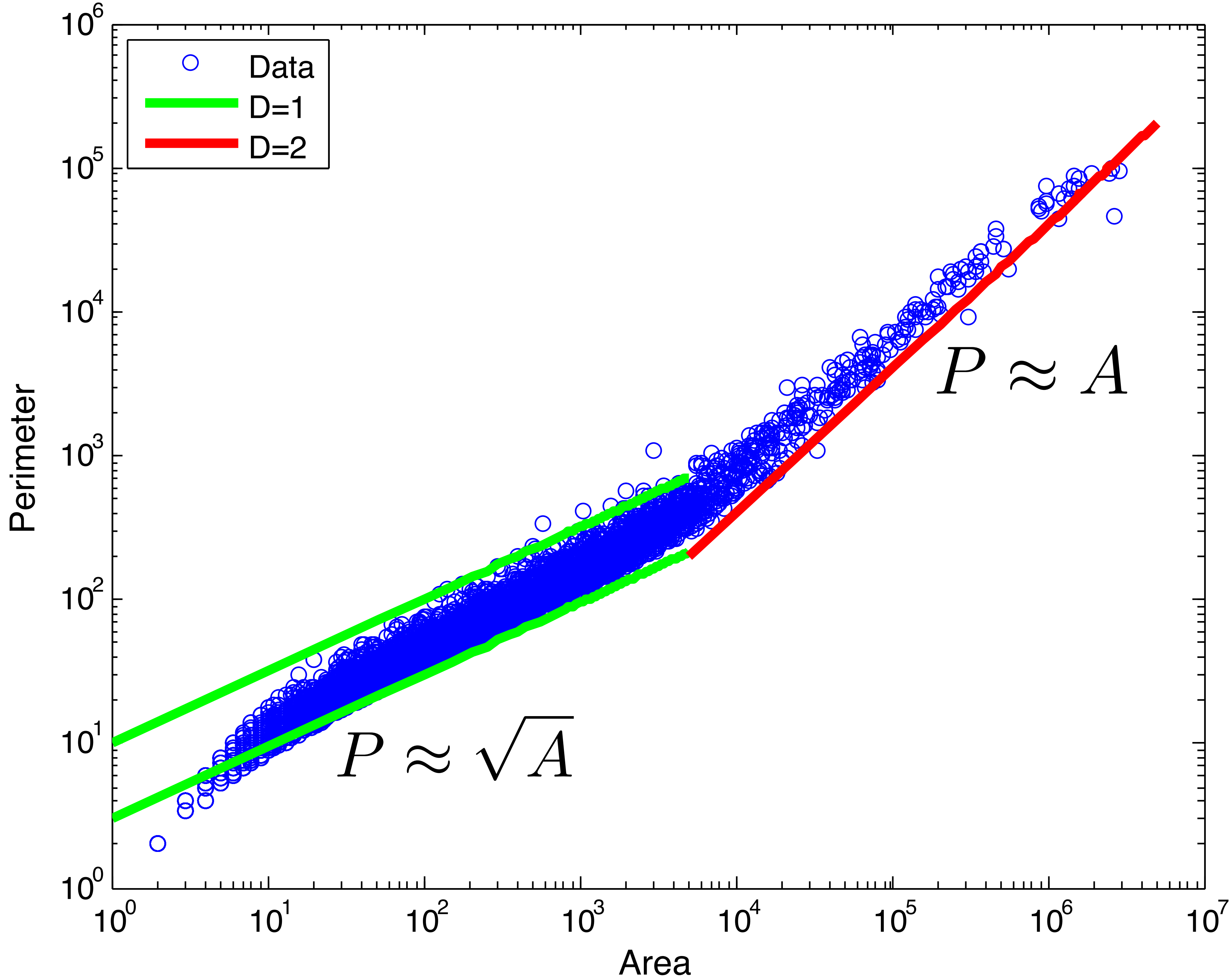
clouds exhibit fractal behavior from 1 to 1000 km

clouds a critical component of climate models -- significant source of uncertainty
they trap warmth and reflect sunlight in spring and summer

S. Lovejoy, Science, 1982

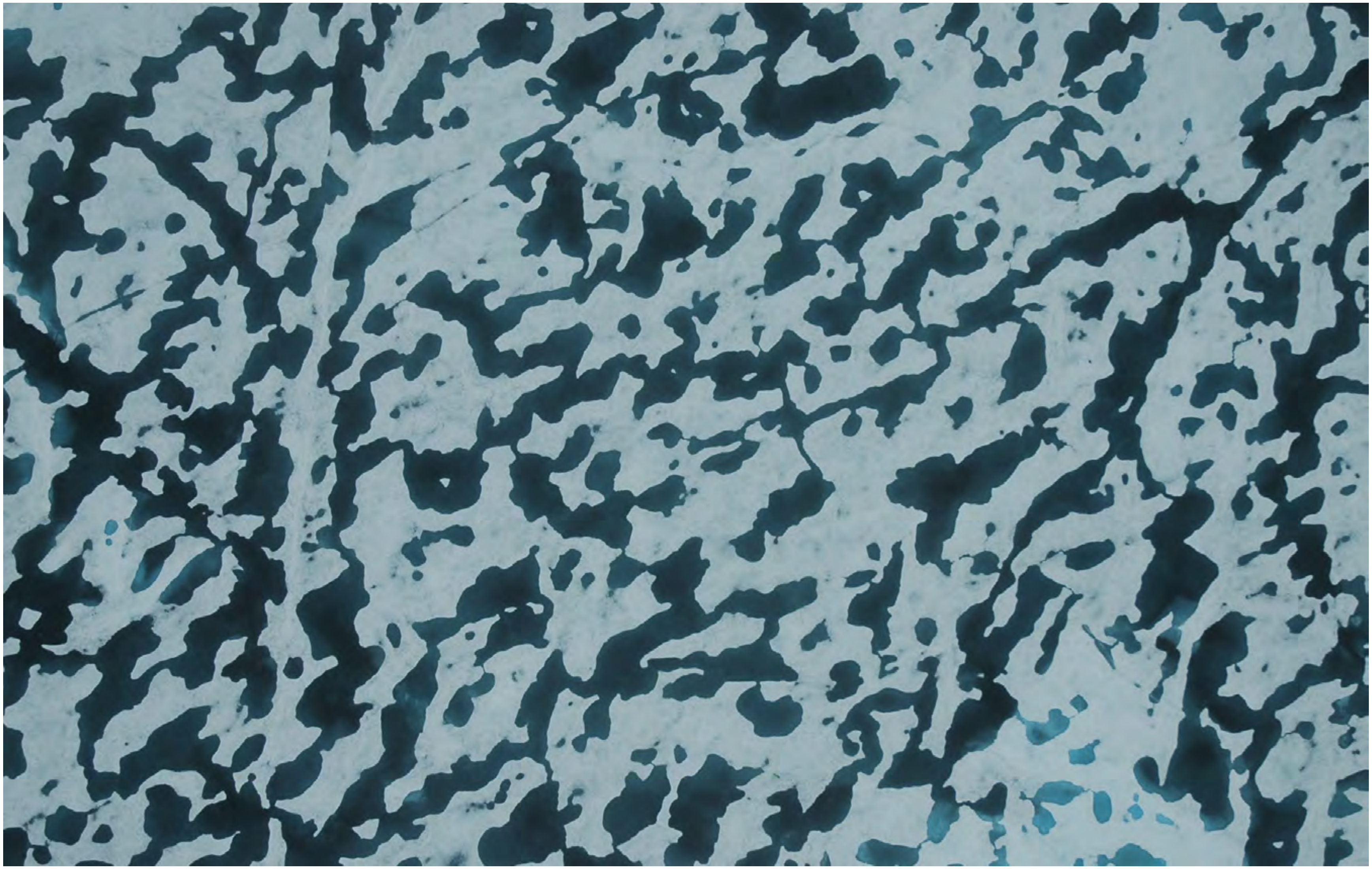
use ***perimeter-area*** *relation* to find that cloud and rain perimeters are fractals

$$D \approx 1.35$$



A-P for melt ponds

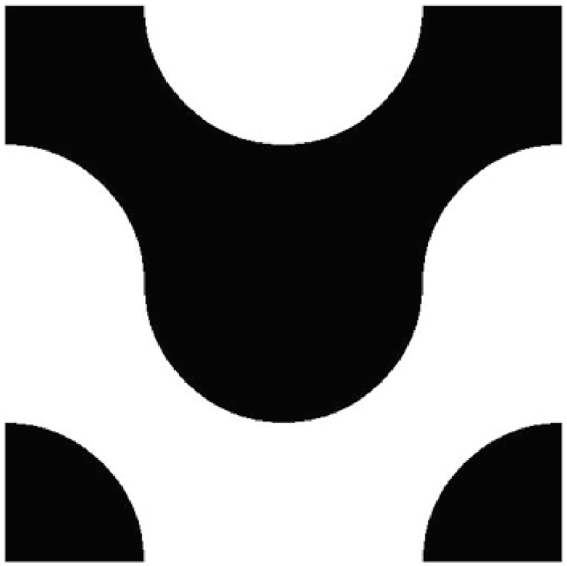
August 14 (HOTRAX): 22 images with fully developed melt ponds



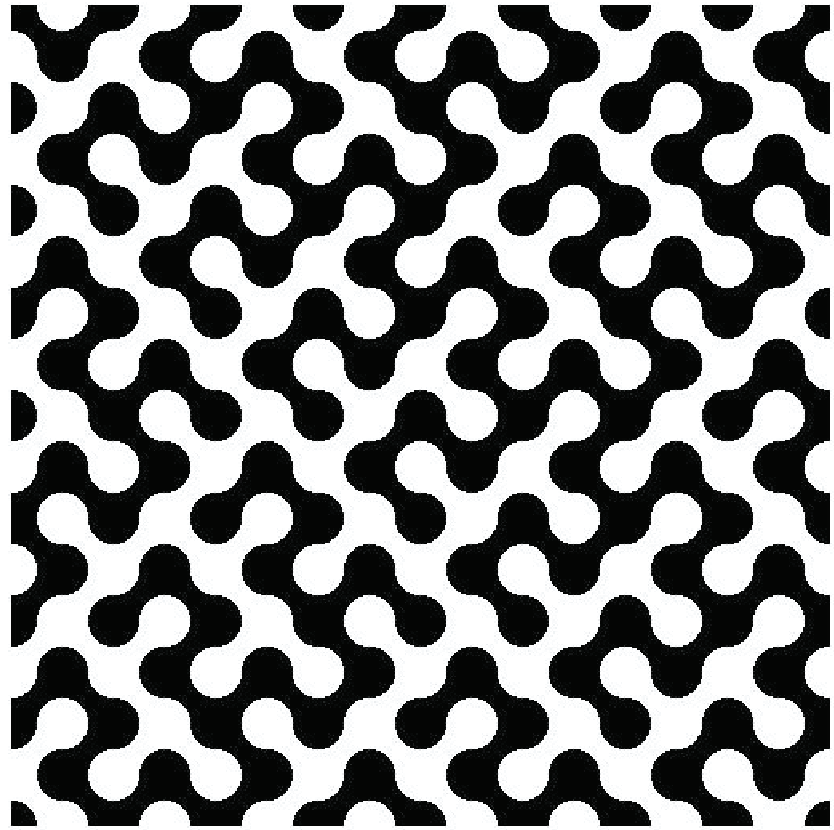
August 14, 2005

Healy-Oden Trans Arctic Expedition (HOTRAX)

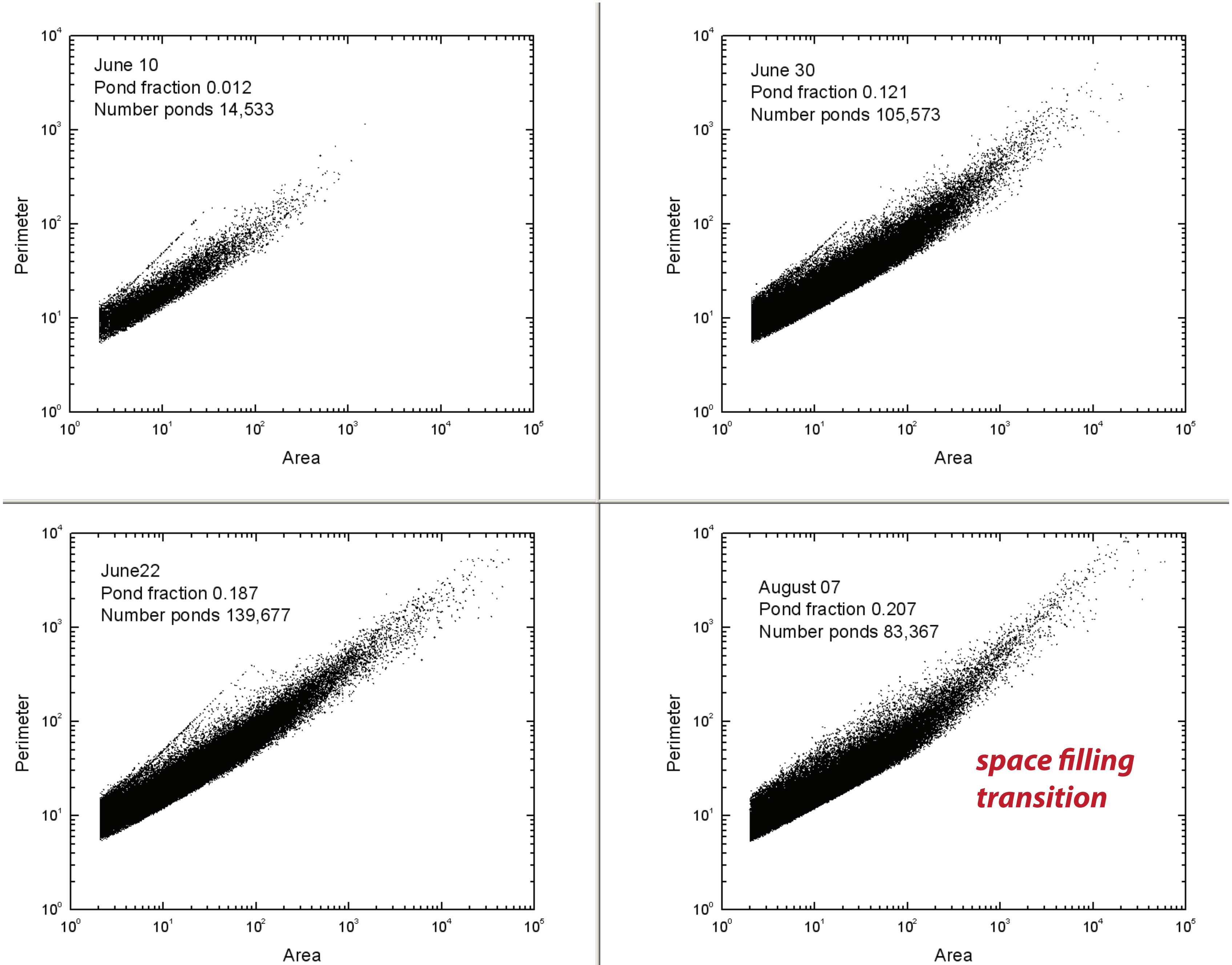
initial shape



4th generation



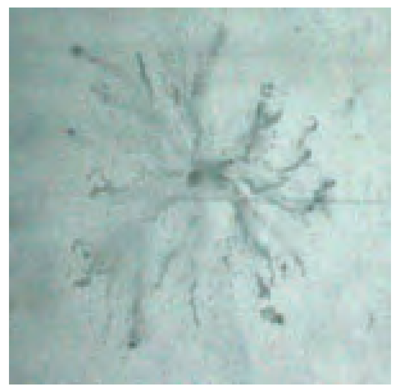
Time evolution of melt pond structure



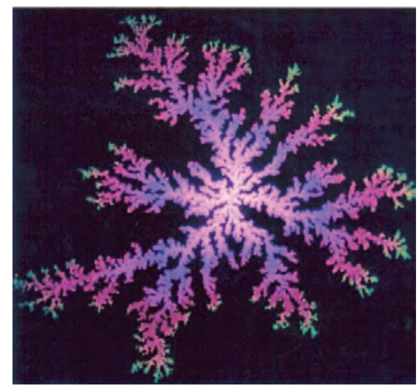
SHEBA 1998

fractal microstructures

electrorheological fluid
with metal spheres



brine channel
in sea ice



diffusion limited
aggregation

sea ice microphysics

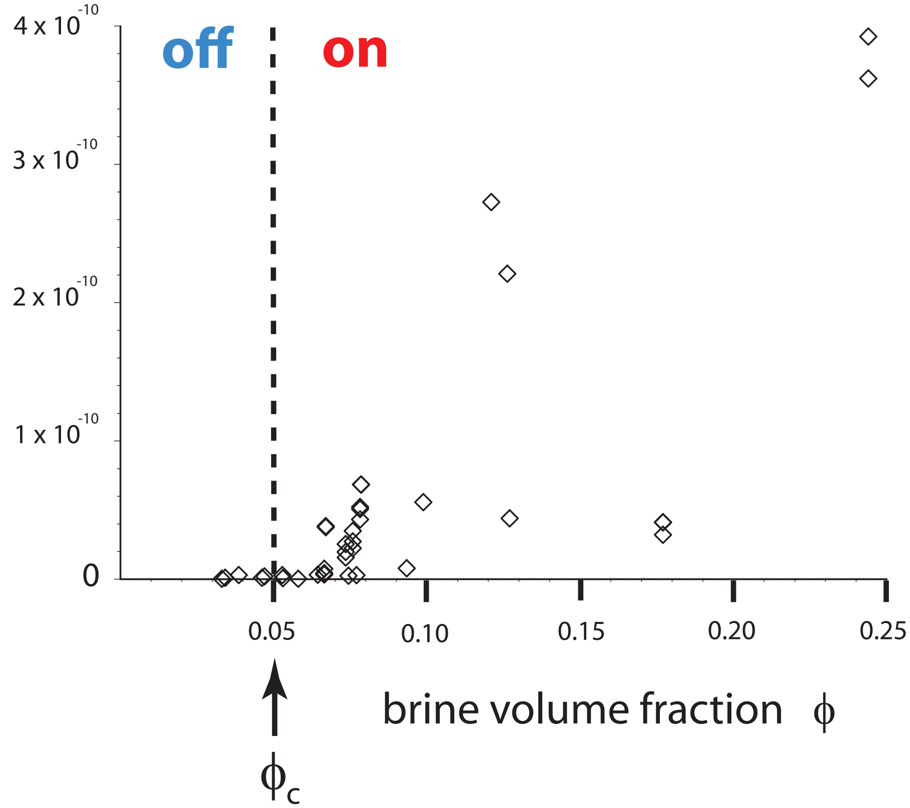
fluid transport

Critical behavior of fluid transport in sea ice

Arctic field data

vertical fluid permeability k (m^2)

impermeable permeable



on - off switch for fluid flow

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

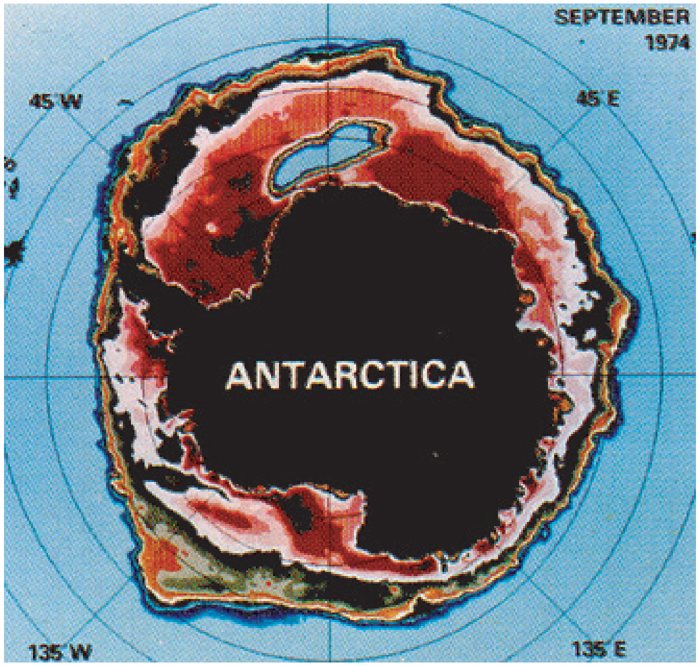
RULE OF FIVES

Golden, Ackley, Lytle *Science* 1998

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

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

sea ice permeability constrains:



Antarctic Zone Flux Experiment
(ANZFLUX)

Eastern Weddell Gyre
July - August, 1994

- ***snow-ice production*** - freezing of flooded ice surfaces

  increased precipitation in changing climate can thicken ice pack

  Ackley, Lytle, Golden, Darling, Kuehn, 1995
  Maksym and Jeffries, 2001, ...
  D. C. Powell, T. Markus, A. Stossel, 2005

- evolution of ***salinity profiles***

  currently assumed constant in climate models

- enhancing ***thermal fluxes and exchanges***

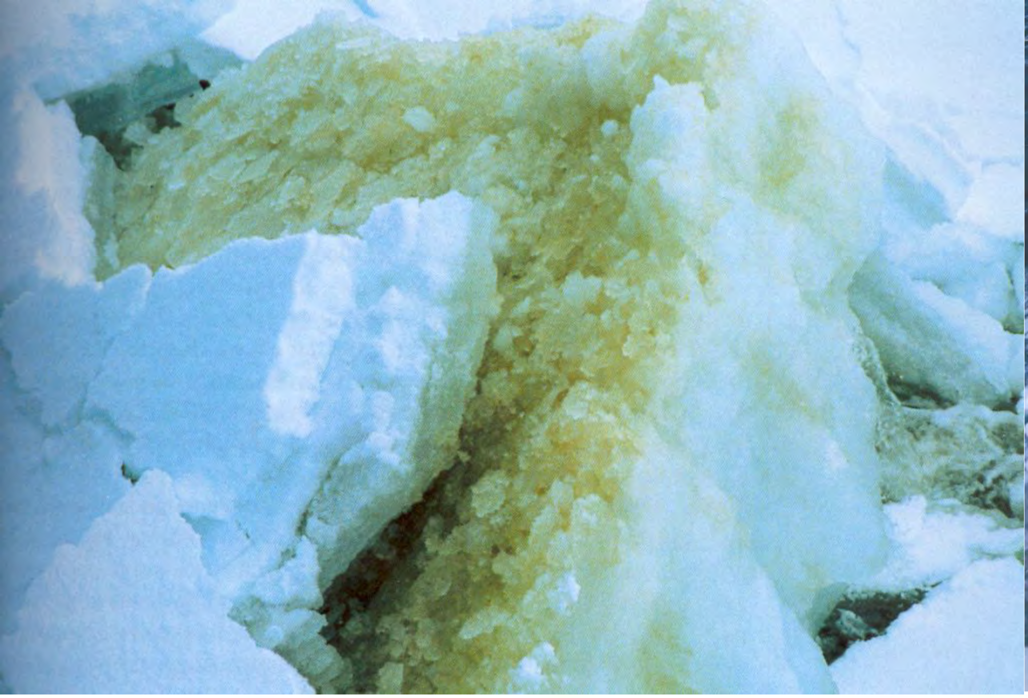
  Lytle and Ackley, 1996
  Trodahl, *et. al.,* 2000, 2001
  Wang, Zhu, Golden, 2011

- microwave signatures in ***remote sensing***

  Lytle and Golden, 1995
  Hosseinmostafa, *et. al.,* 1995, ...

sea ice ecosystem

sea ice algae
support life in the polar oceans



sea ice algal communities

D. Thomas 2004

nutrient replenishment controlled by ice permeability

biological activity turns on or off according to ***rule of fives***

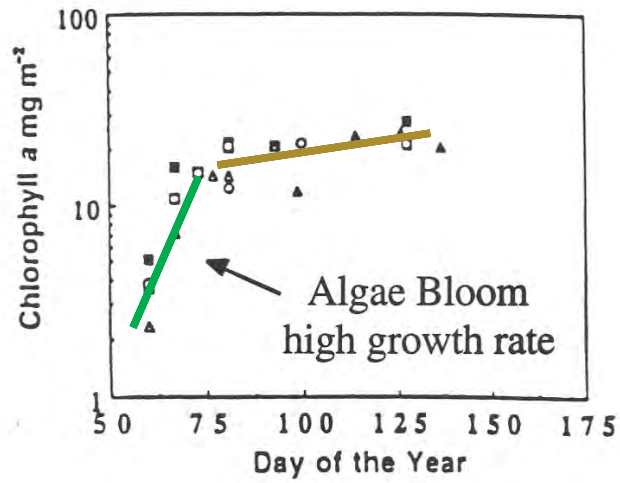
Golden, Ackley, Lytle ***Science 1998***

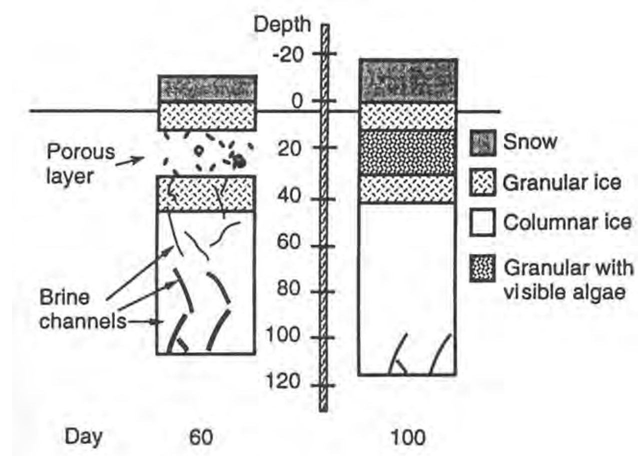
Fritsen, Lytle, Ackley, Sullivan ***Science 1994***

critical behavior of microbial activity

Convection-fueled algae bloom
Ice Station Weddell

(Fritsen, Lytle, Ackley, Sullivan, *Science* 1994)





Golden, Ackley, Lytle Science 1998

Darcy's Law for slow viscous flow in a porous medium

averaged fluid velocity → $\mathbf{v}$

pressure gradient → ∇p

$$\mathbf{v} = -\frac{\mathbf{k}}{\eta}\nabla p$$

viscosity → η

$\mathbf{k}$ = fluid permeability tensor

example of *homogenization*

mathematics for analyzing effective behavior of heterogeneous systems

Unified approach to understanding fluid permeability in sea ice:

Thermal evolution of permeability and microstructure in sea ice,
K. M. Golden, H. Eicken, A. L. Heaton, J. Miner, D. Pringle, and
J. Zhu, *Geophysical Research Letters*, vol. 34, 2007 (+ cover).

1. Homogenization and Darcy's law
2. Rigorous bounds
3. Percolation theory
4. Hierarchical models
5. Network model

+

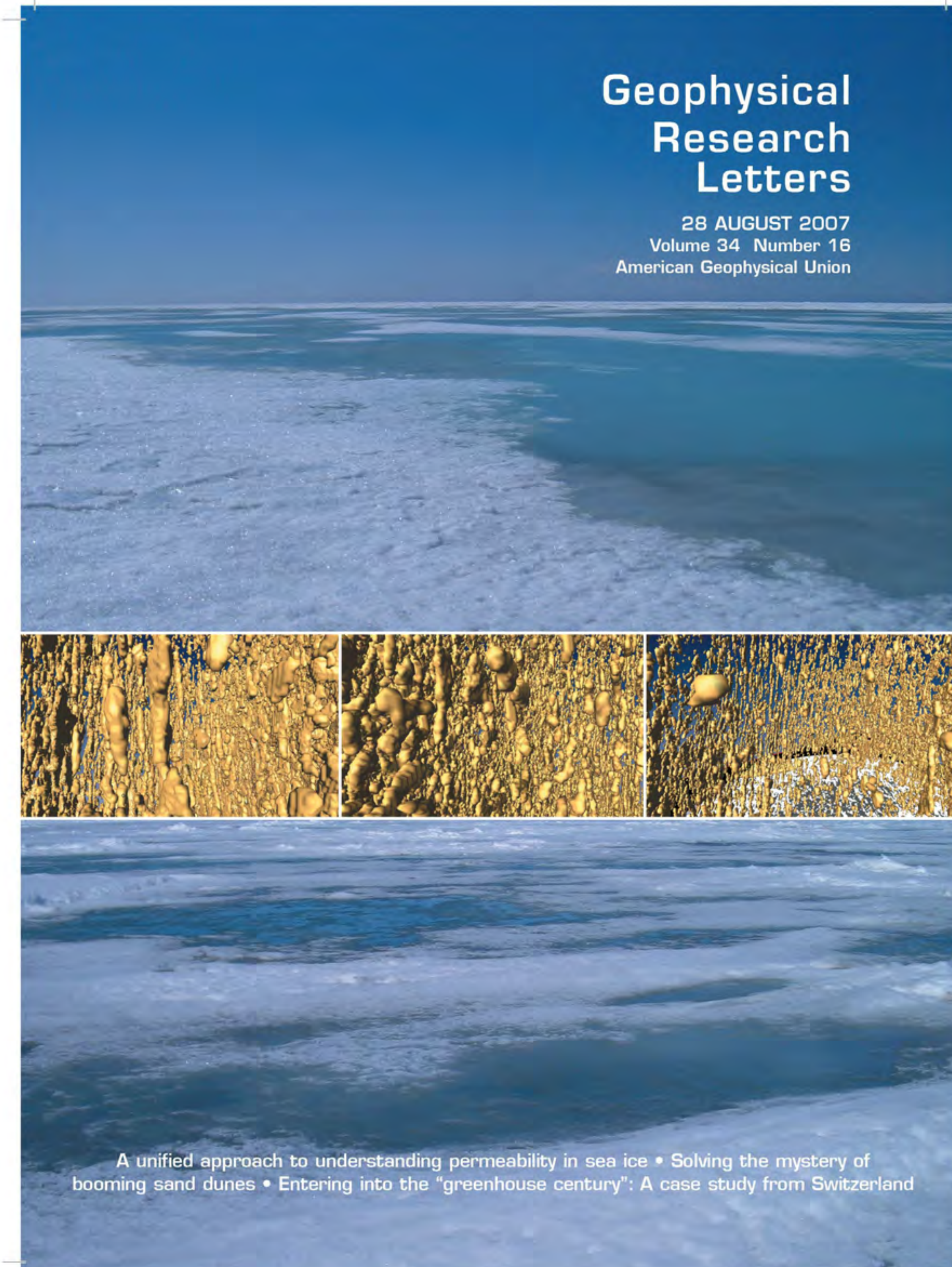
X-ray CT imaging and pore analysis provide unprecedented look at temperature evolution of brine phase and its connectivity

Validated with lab and Arctic field data.

micro-scale

controls

macro-scale
processes in
global climate



Arctic Ocean near
Point Barrow, June 2007

brine inclusion tomography

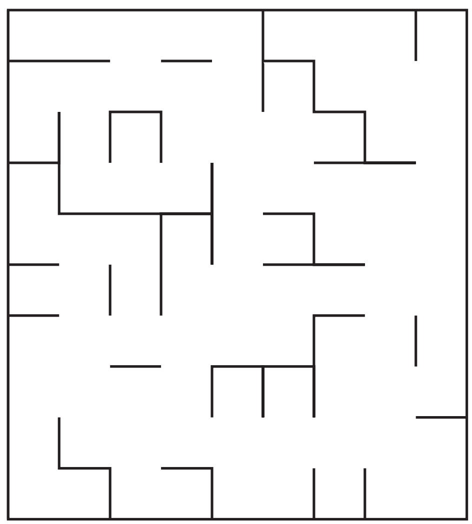
Arctic Ocean near
Point Barrow, June 2004

Theoretical predictions of ice permeability using percolation and hierarchical models

percolation theory

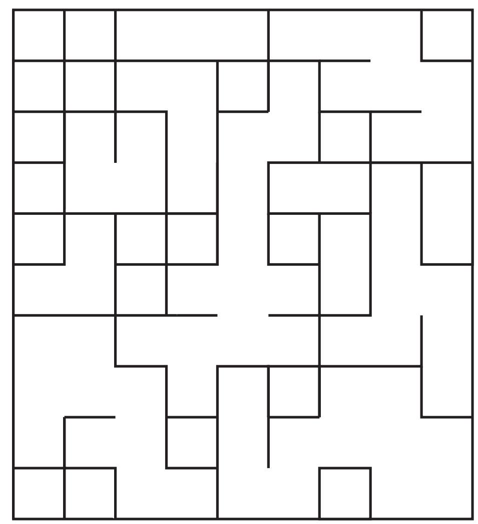
mathematical theory of connectedness

impermeable



$p = 1/3$

permeable



$p = 2/3$

a bond is open with probability p
closed with probability 1-p

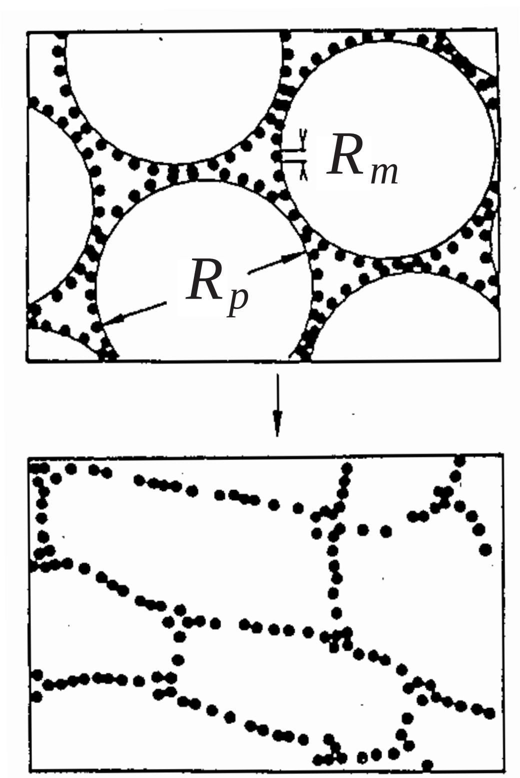
percolation threshold

$p_c = 1/2$ for $d = 2$

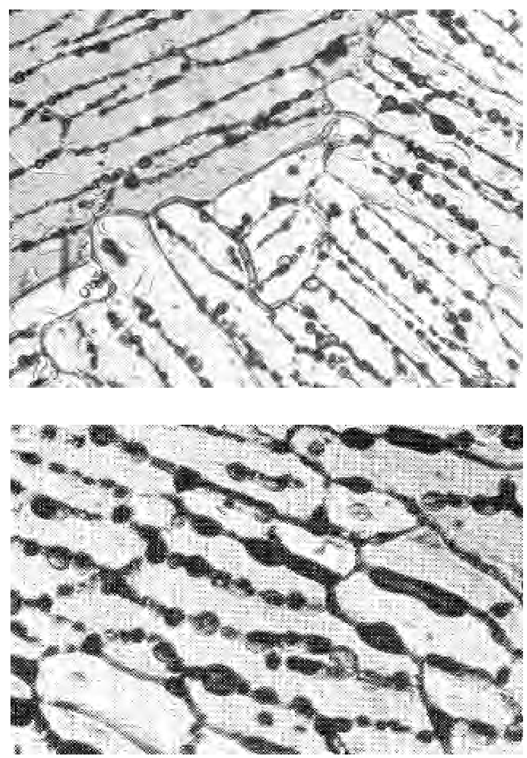
first appearance of infinite cluster

Continuum percolation model for stealthy materials applied to sea ice microstructure explains **Rule of Fives** and Antarctic data on ice production and algal growth

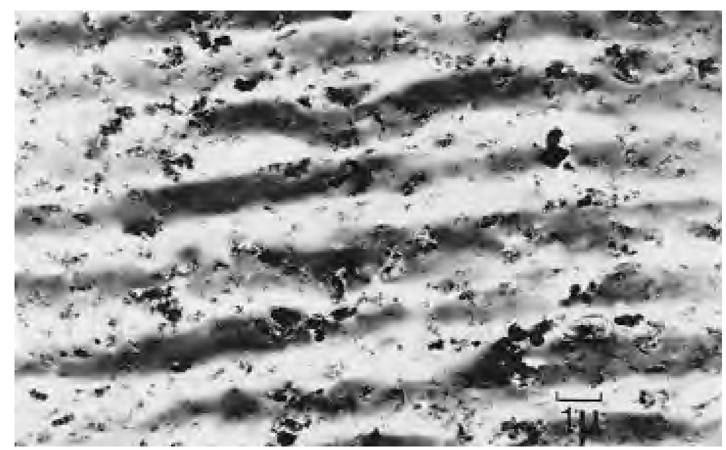
$\phi_c \approx 5\ \%$ Golden, Ackley, Lytle, *Science*, 1998



compressed powder



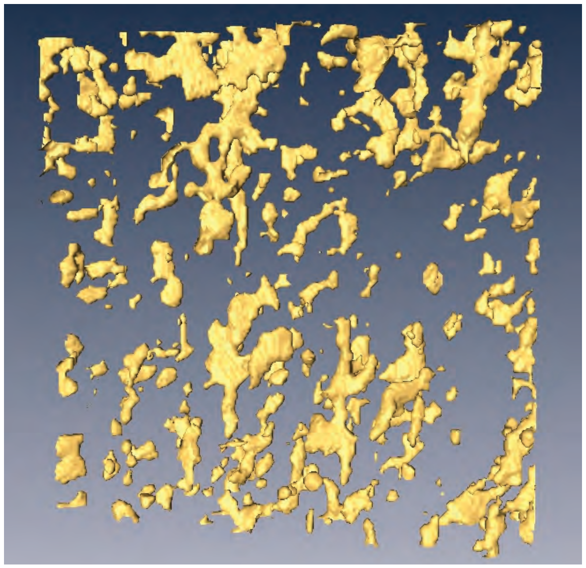
sea ice



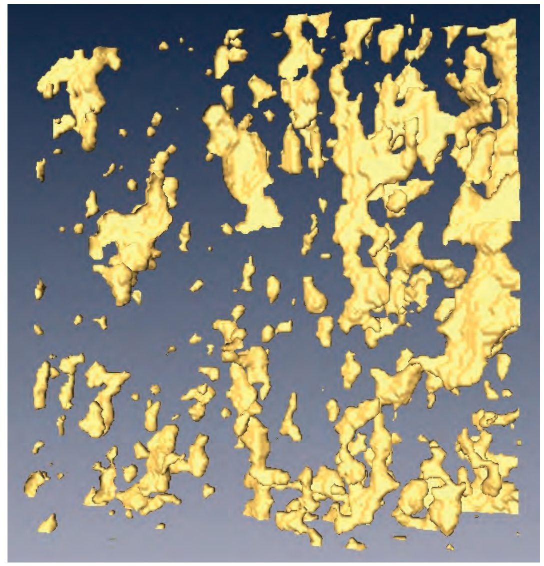
microstructure of radar absorbing composite

brine connectivity (over cm scale)

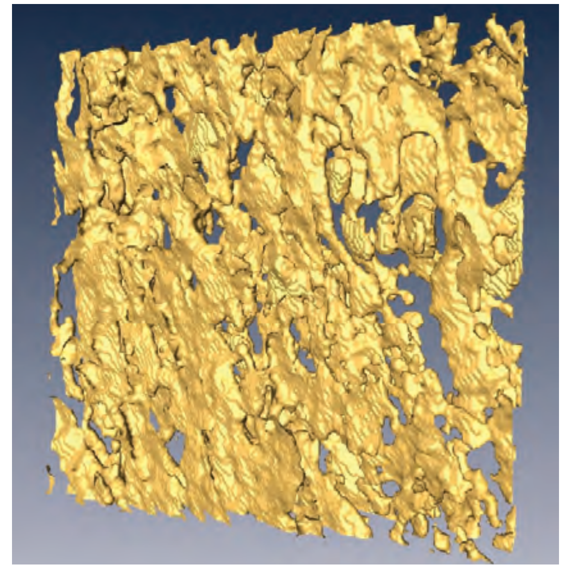
8 x 8 x 2 mm



-15 °C, $\phi = 0.033$



-6 °C, $\phi = 0.075$



-3 °C, $\phi = 0.143$

first direct evidence of conjectured transition in connectivity

3-D images pores and throats	→	3-D graph nodes and edges

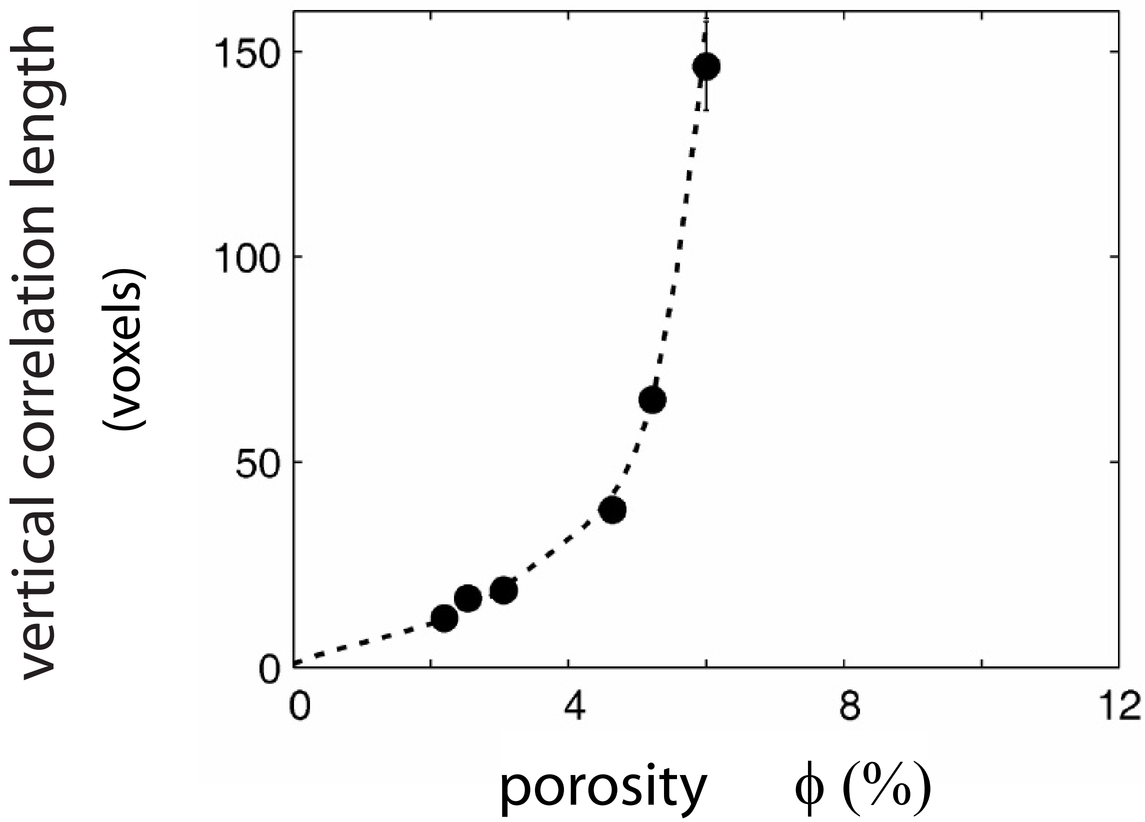
analyze graph connectivity as function of temperature and sample size

use finite size scaling techniques to confirm rule of fives

The key connectivity functions of percolation theory have been computed extensively for many lattice models, but NOT for natural materials.

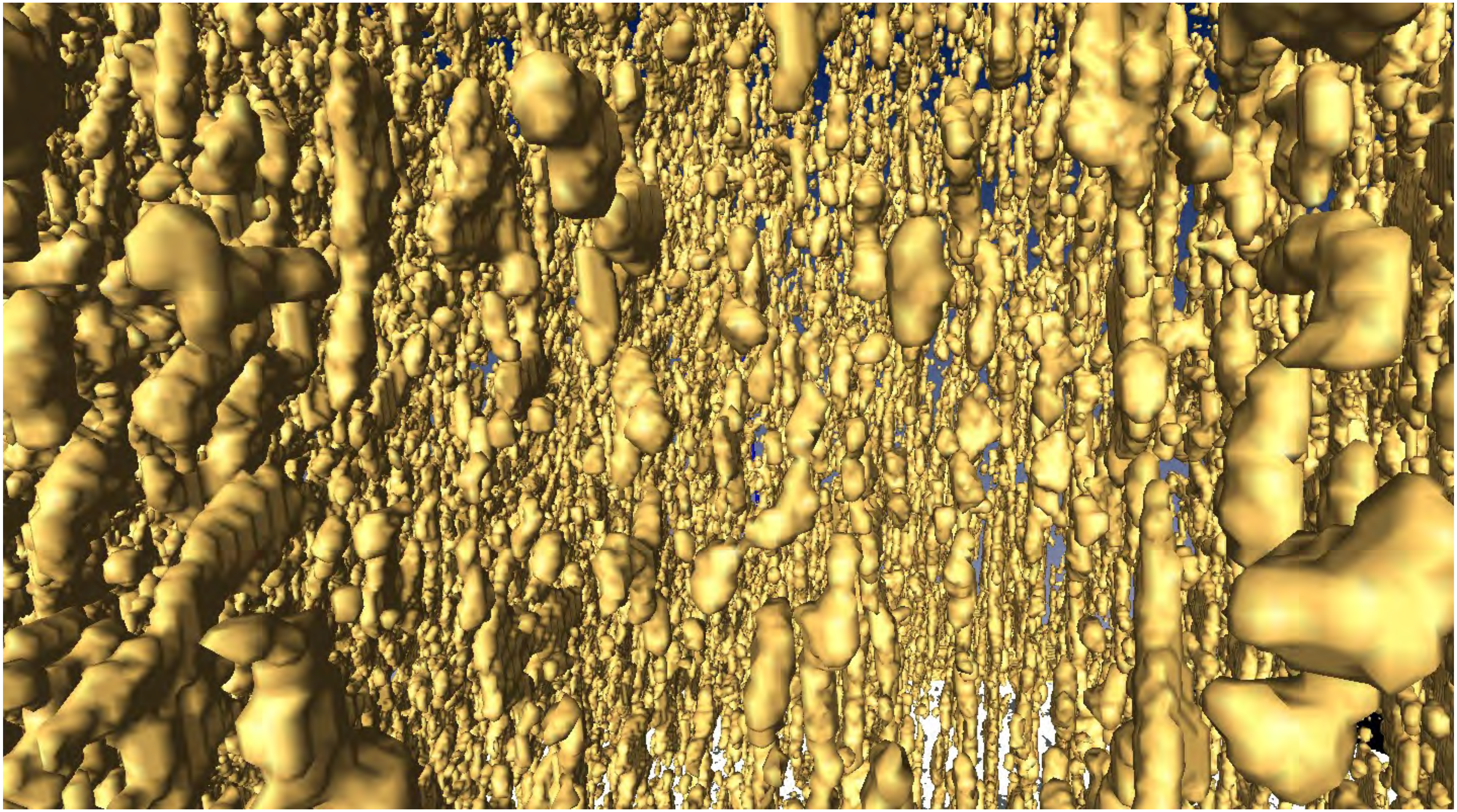
We have calculated them for sea ice single crystals -- a first for percolation investigations -- and estimated anisotropic percolation thresholds.

Pringle, Miner, Eicken, Golden, JGR (Oceans) 2009



divergence of correlation length for single crystal data

X-ray computed tomography (CT) and medial axis analysis (Prodanovic, et al., 2006) of lab-grown sea-ice single crystals doped with CsCl to improve ice/brine resolution.



$\phi = 5.7\ \%$ $T = -8$

lattice and continuum percolation theories yield:

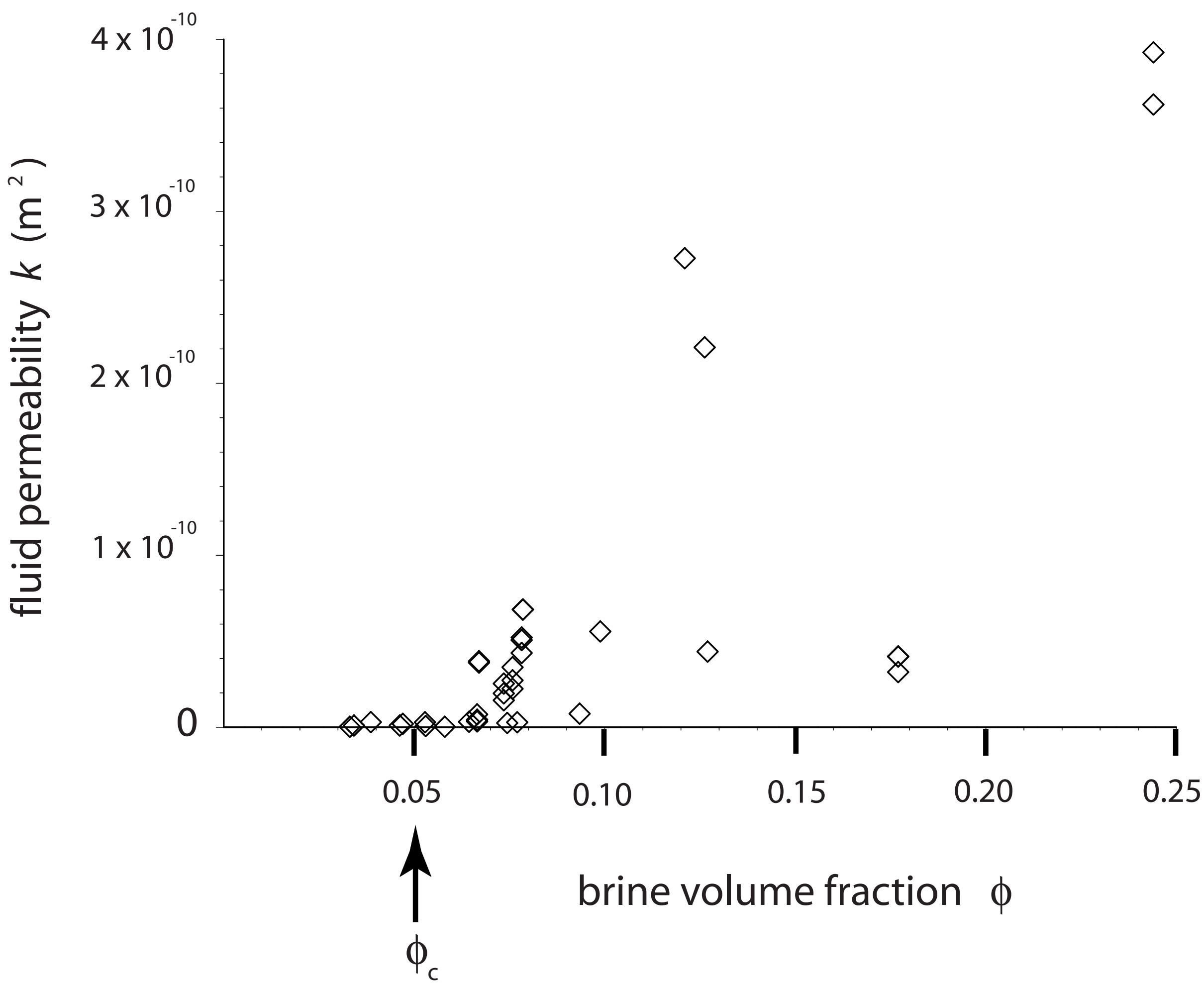
$$k(\phi) = k_0 (\phi - \phi_c)^2$$

critical exponent t

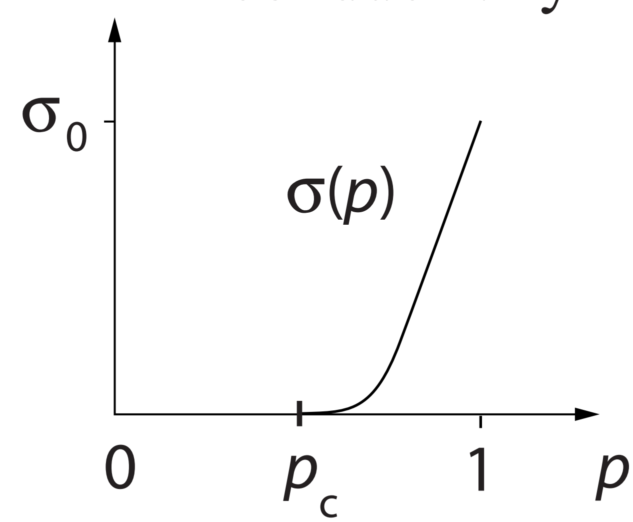
$$k_0 = 3 \text{ x } 10^{-8} \text{ m}^2$$

- exponent is UNIVERSAL lattice value $t \approx 2.0$ from general structure of brine inclusion distribution function (-- other saline ice?)
- sedimentary rocks like sandstones also exhibit universality
- critical path analysis -- developed for electronic hopping conduction -- yields scaling factor k_0
- no free parameters - microstructural input only

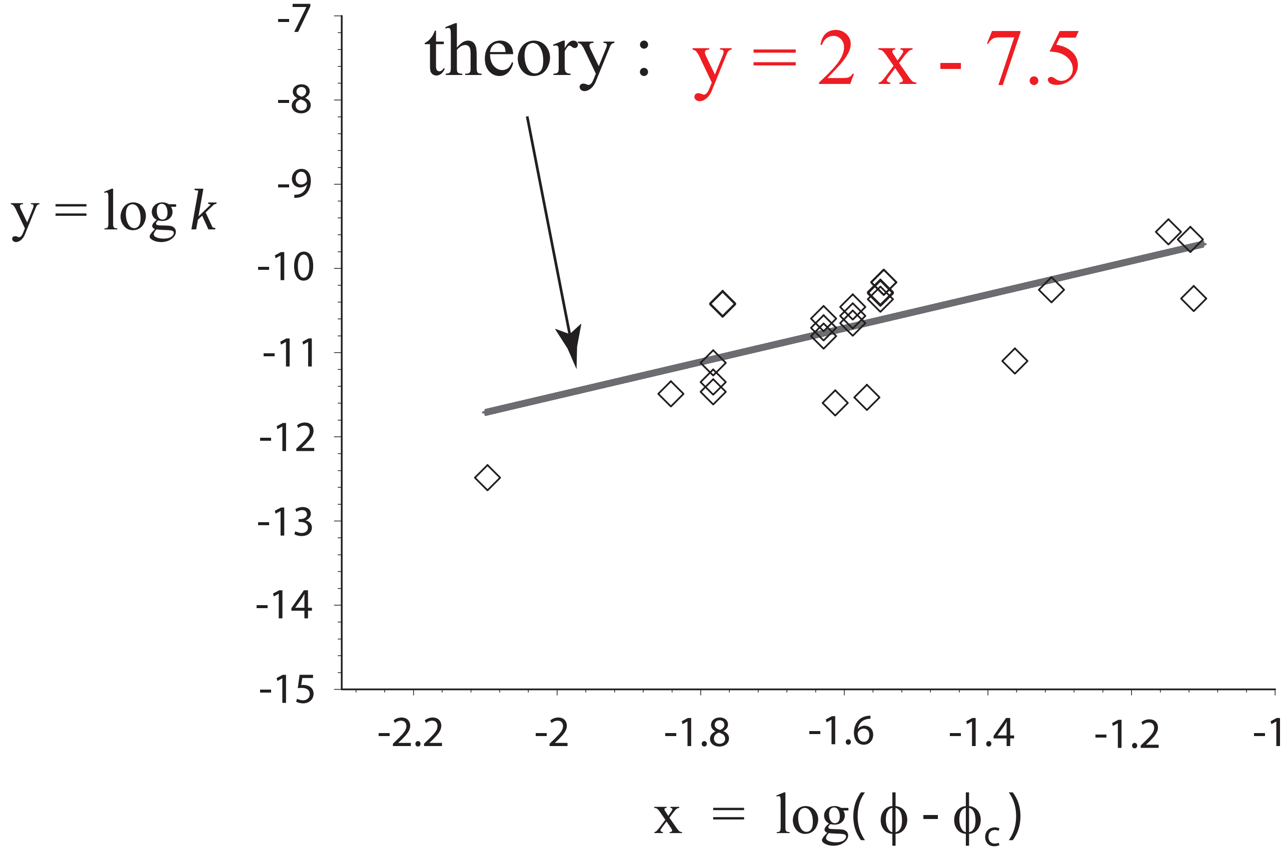
in situ data on vertical fluid permeability of Arctic sea ice



effective conductivity



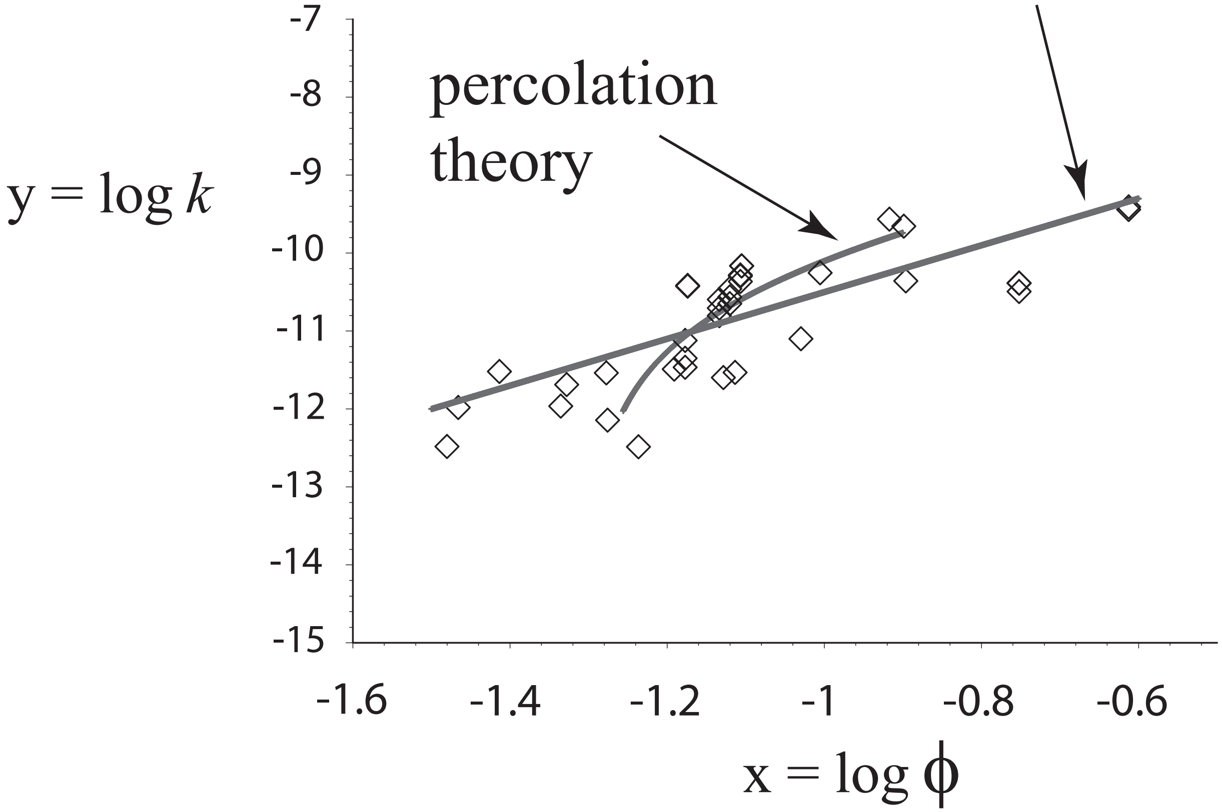
two dimensional lattice percolation



statistical best fit of data:

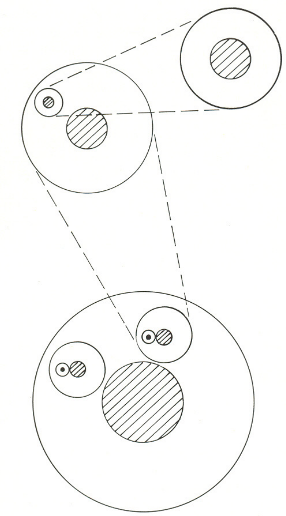
$$y = 2.07\,x - 7.45$$

hierarchical model : $y = 3x - 7.5$



statistical best fit of data: $y = 3.05x - 7.50$

brine-coated spherical ice grains



$k(\phi) = k_0 \phi^3$

over full range of porosities

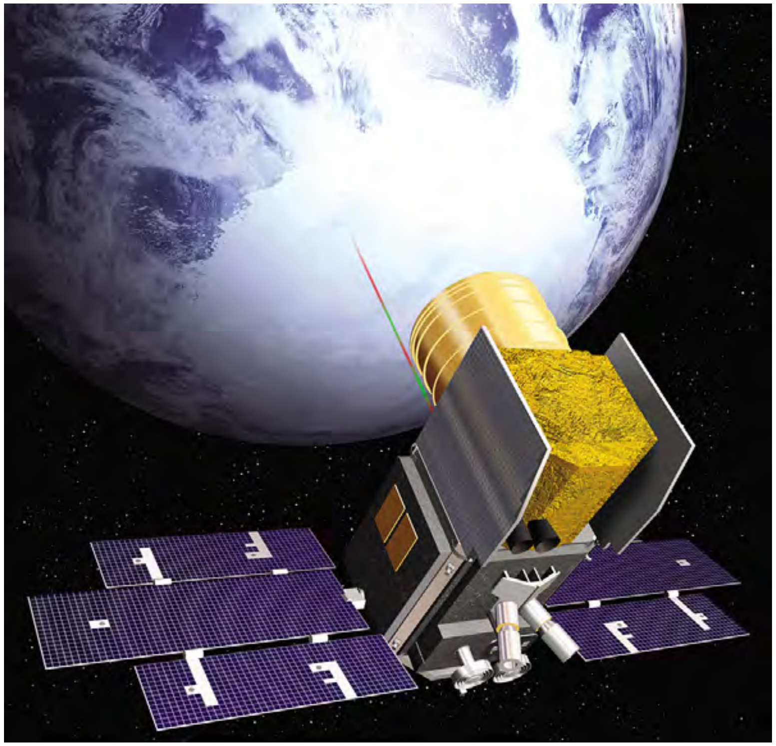
self-similar model used for porous rocks

Sen, Scala, Cohen 1981
Sheng 1990
Wong, Koplick, Tomanic 1984

Remote sensing of sea ice

Recover sea ice properties from electromagnetic (EM) data

INVERSE PROBLEM



NASA's Ice, Cloud and Land Elevation Satellite (ICESat)

The Worbot - a low frequency EM induction instrument for measuring sea ice thickness

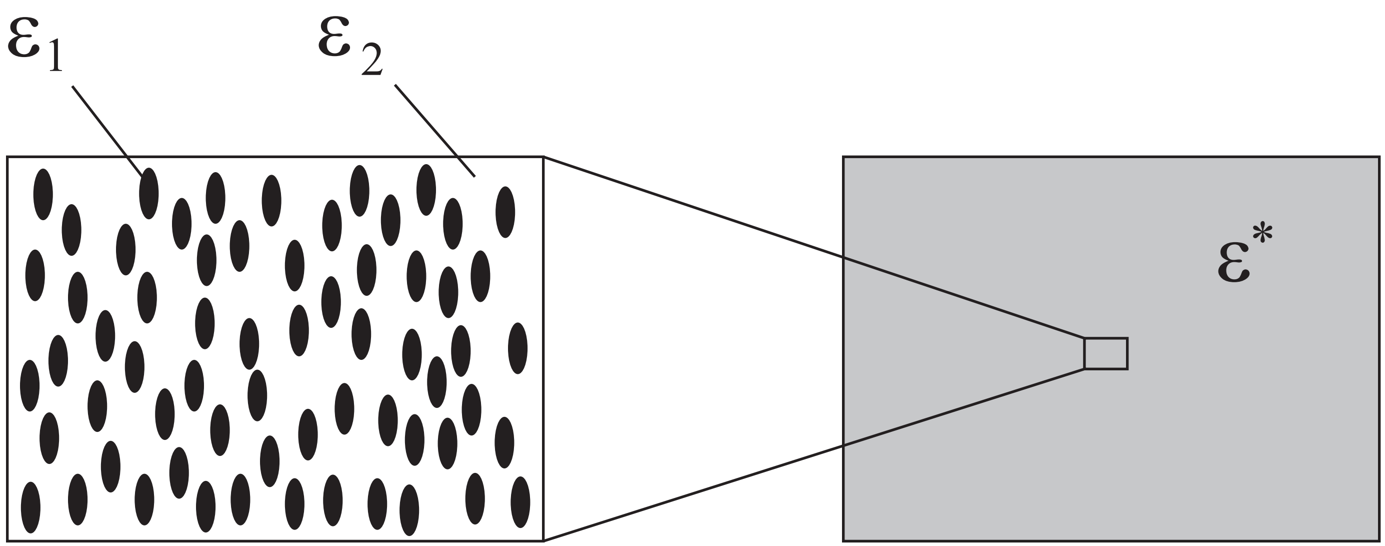
The key parameter in modeling the response of sea ice to an EM field is its

complex *permittivity* or *dielectric constant* ε^*

which depends strongly on the brine microstructure

e.g., interpretation of EM thickness data depends on knowledge of ε^*

HOMOGENIZATION



inhomogeneous medium

homogeneous medium

find the homogeneous medium which behaves macroscopically the same as the inhomogeneous medium

ocean swells propagating through a vast field of pancake ice

HOMOGENIZATION: long wave sees an effective medium, not individual floes

Theory of Effective Electromagnetic Behavior of Composites

(analytic continuation method)

Forward Homogenization Bergman (1978), Milton (1979), Golden and Papanicolaou (1983)

composite geometry (spectral measure) $\longrightarrow$ ε^*

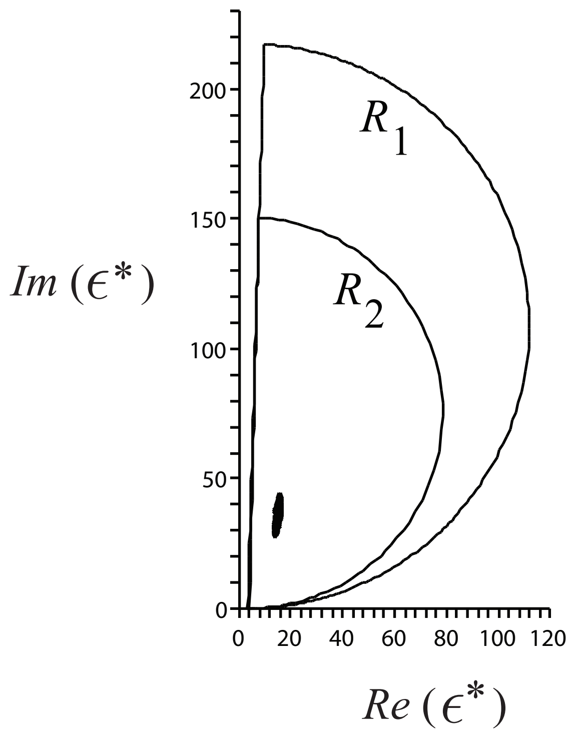
rigorous bounds, approximations, etc.

Inverse Homogenization Cherkaev and Golden (1998), Cherkaev (2001)

ε^* $\longrightarrow$ ***composite geometry (spectral measure)***

recover brine volume fraction, connectivity, etc.

forward and inverse bounds for sea ice

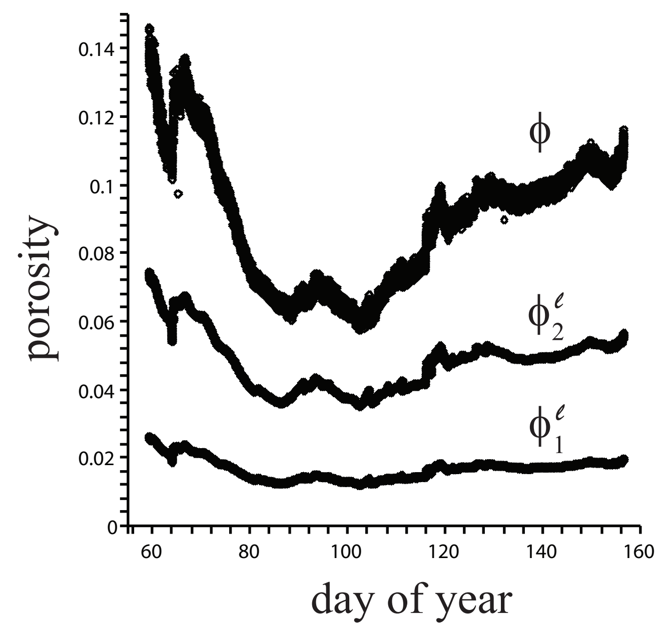


forward bounds

50 MHz capacitance probe
data taken near Barrow, AK

inverse bounds and
microstructural recovery

Gully, Backstrom, Eicken, Golden, Physica B, 2007



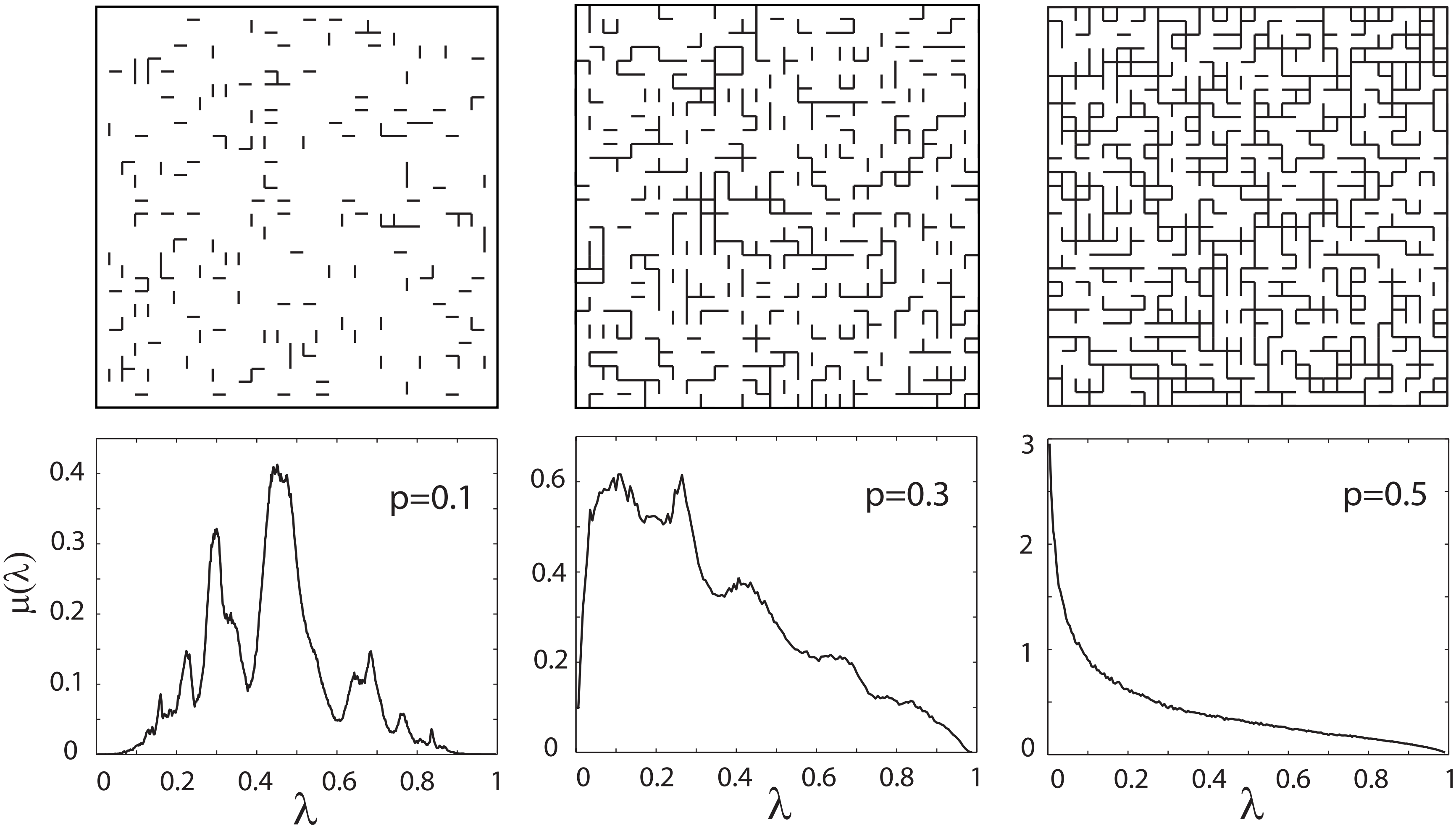
recovery of inclusion separations
Orum, Cherkaev, Golden 2011

Spectral analysis of multiscale sea ice structures

homogenization for brine inclusions, melt ponds, and sea ice pack

N. B. Murphy, C. Hohenegger, C. S. Sampson, B. Alali, K. Steffen,
D. K. Perovich, H. Eicken, and K. M. Golden 2011

spectral measures for 2-d random resistor network

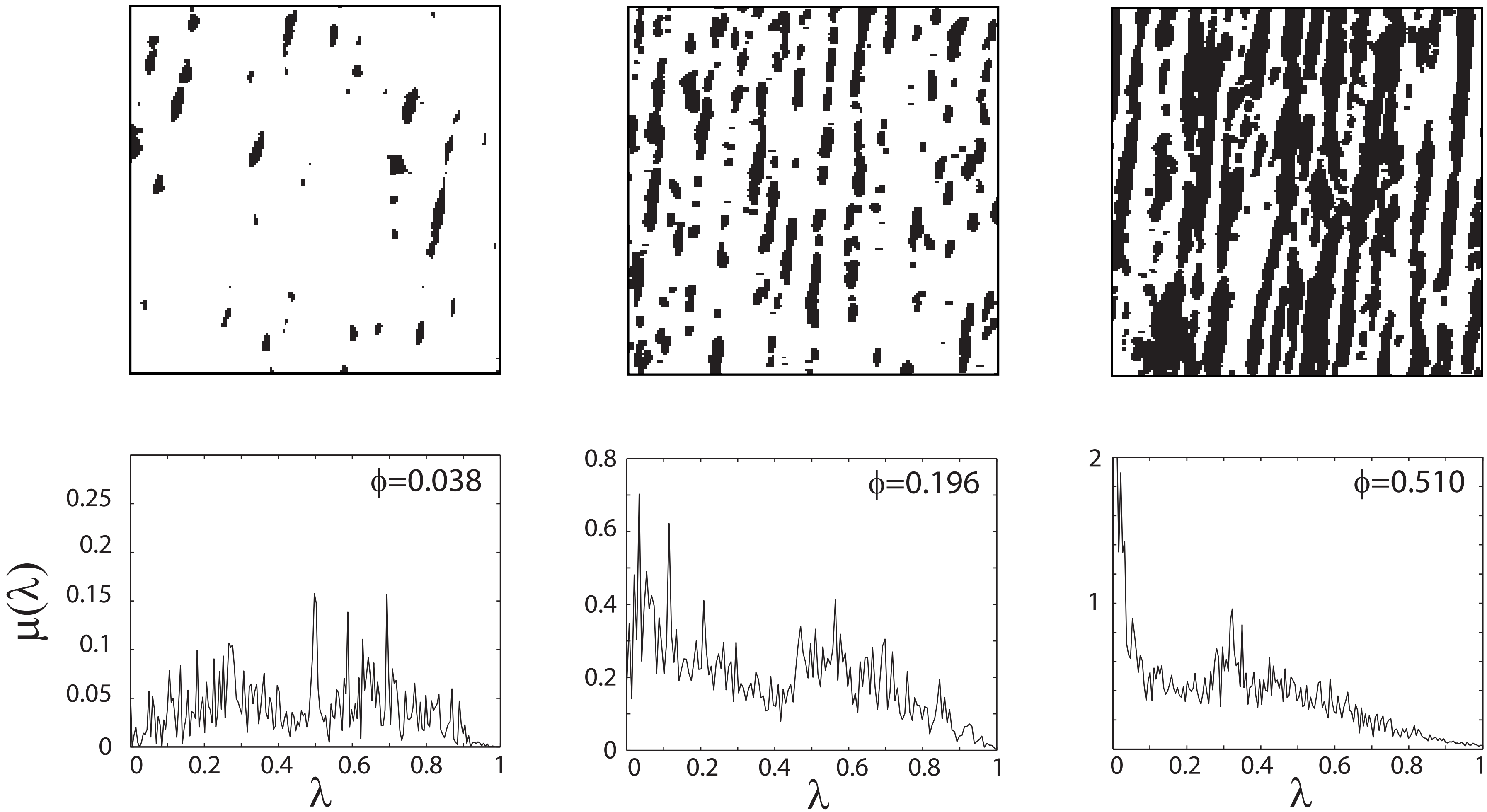


area under curve = p = probability of open bond

spectral gap closes as percolation threshold is approached

random matrix theory calculations of eigenvalue spacing distributions help characterize transitions

spectral measures for brine phase in sea ice

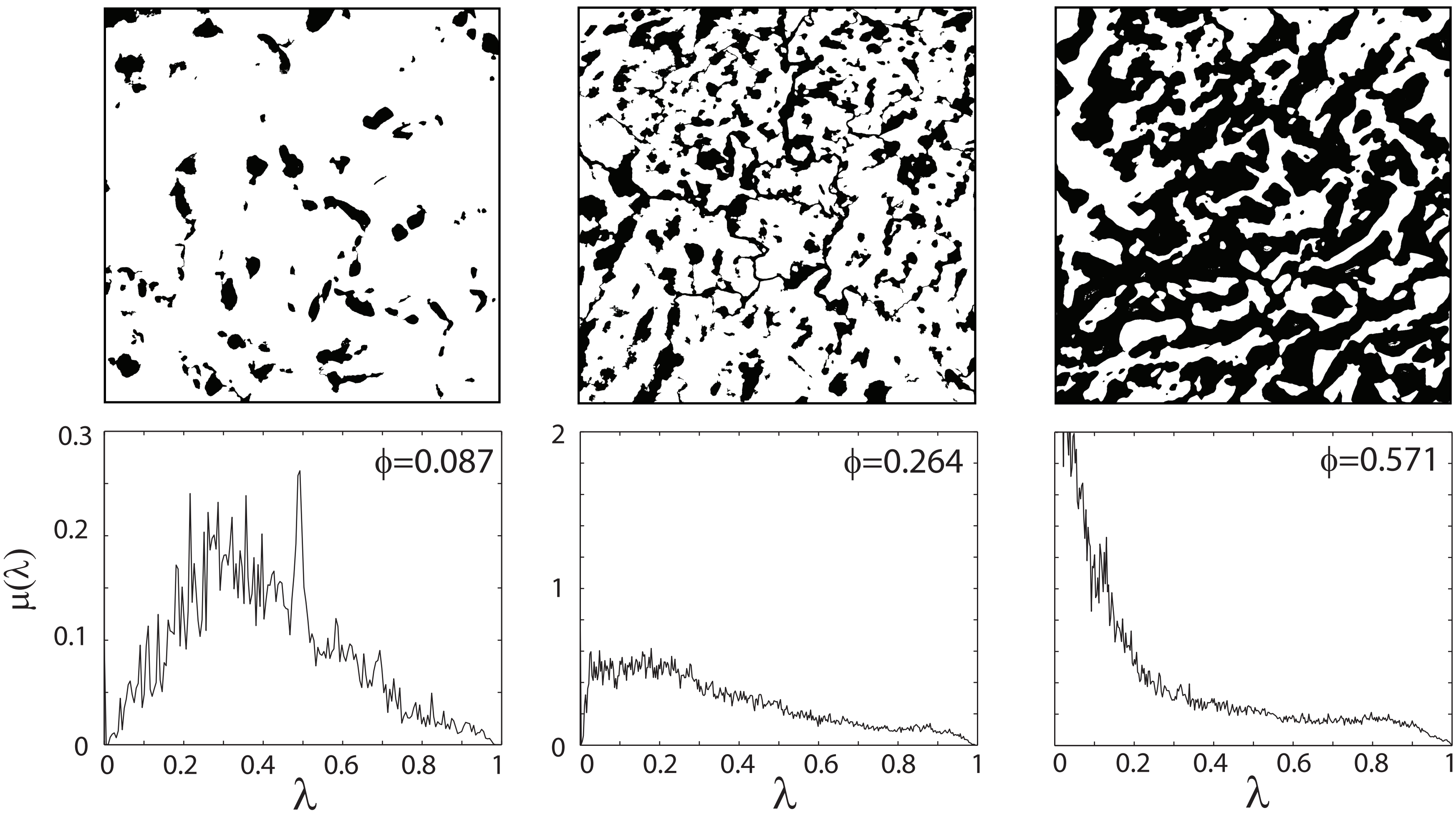


area under curve = ϕ = brine volume fraction

spectral gap closes as percolation threshold is approached

resonance structure depends on inclusion geometry

spectral measures for Arctic melt ponds

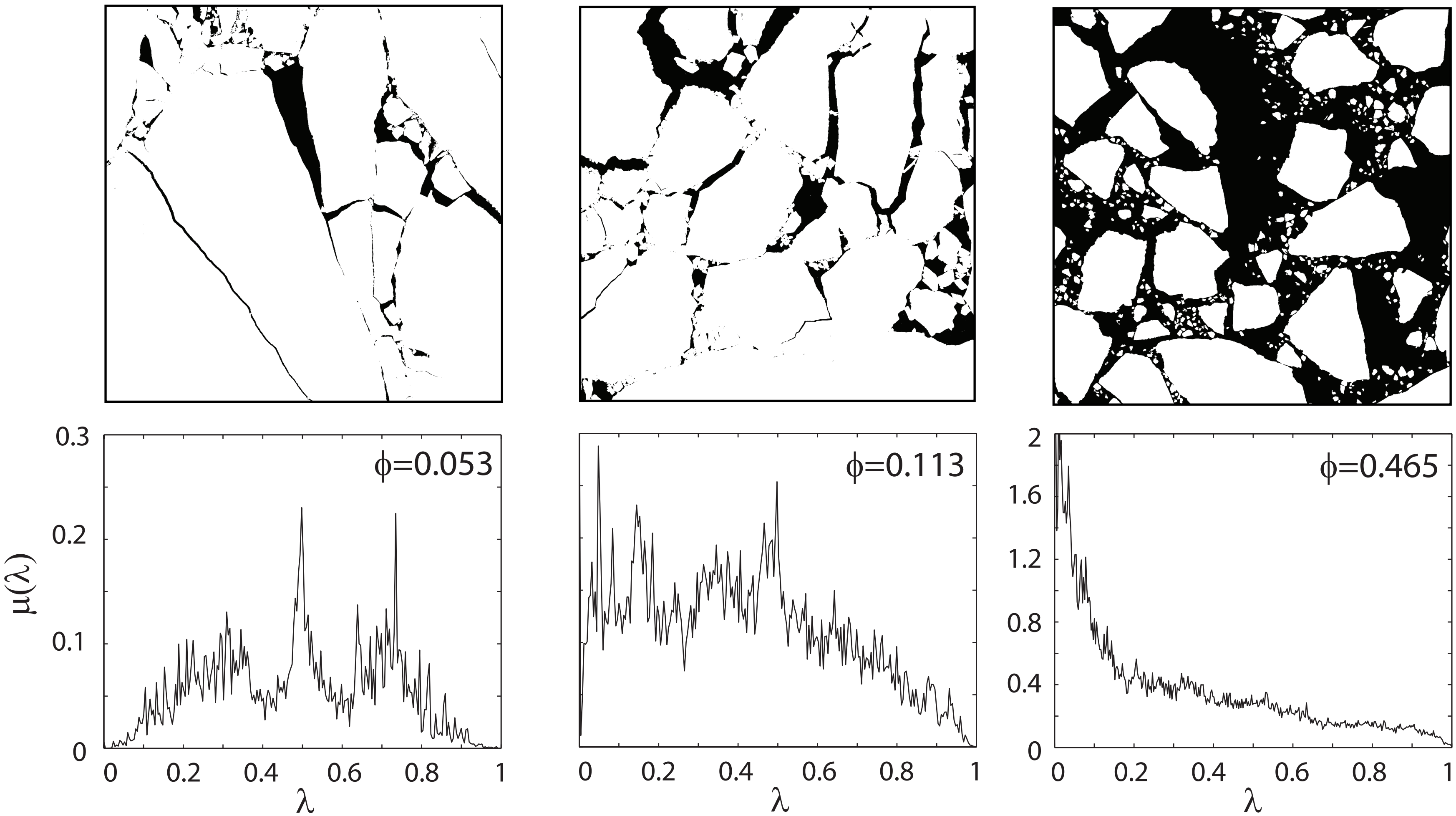


area under curve = ϕ = melt pond area fraction

spectral gap closes as melt ponds become connected

resonance structure depends on pond geometry

spectral measures for Arctic sea ice pack



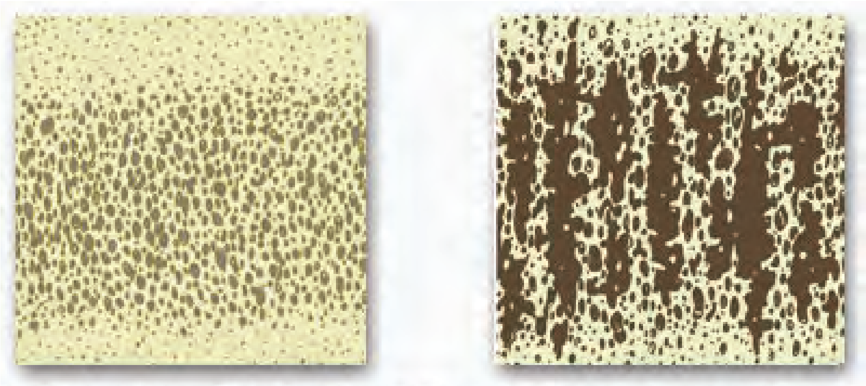
area under curve = ϕ = open water fraction

spectral gap closes as ocean phase becomes connected

Inverse Homogenization for Evaluation of Bone Structure

Carlos Bonifasi-Lista, Elena Cherkaev, 2006

bone porosity can be estimated from the effective torsional modulus
using reconstruction of spectral measure



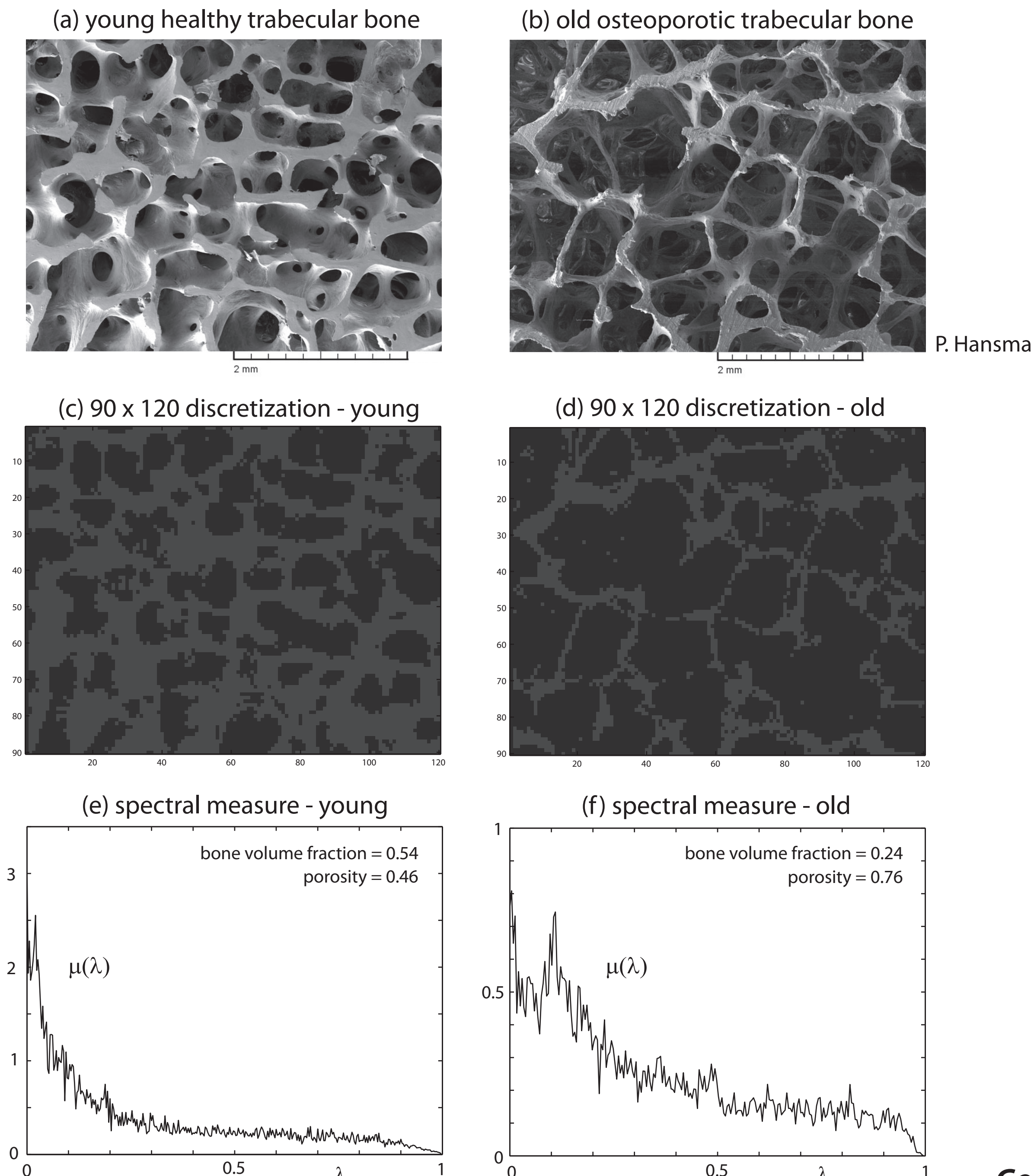
normal osteoporotic

***Application*:**

Monitoring osteoporosis

the math doesn't care if it's sea ice or bone

spectral characterization of porous microstructures in bone



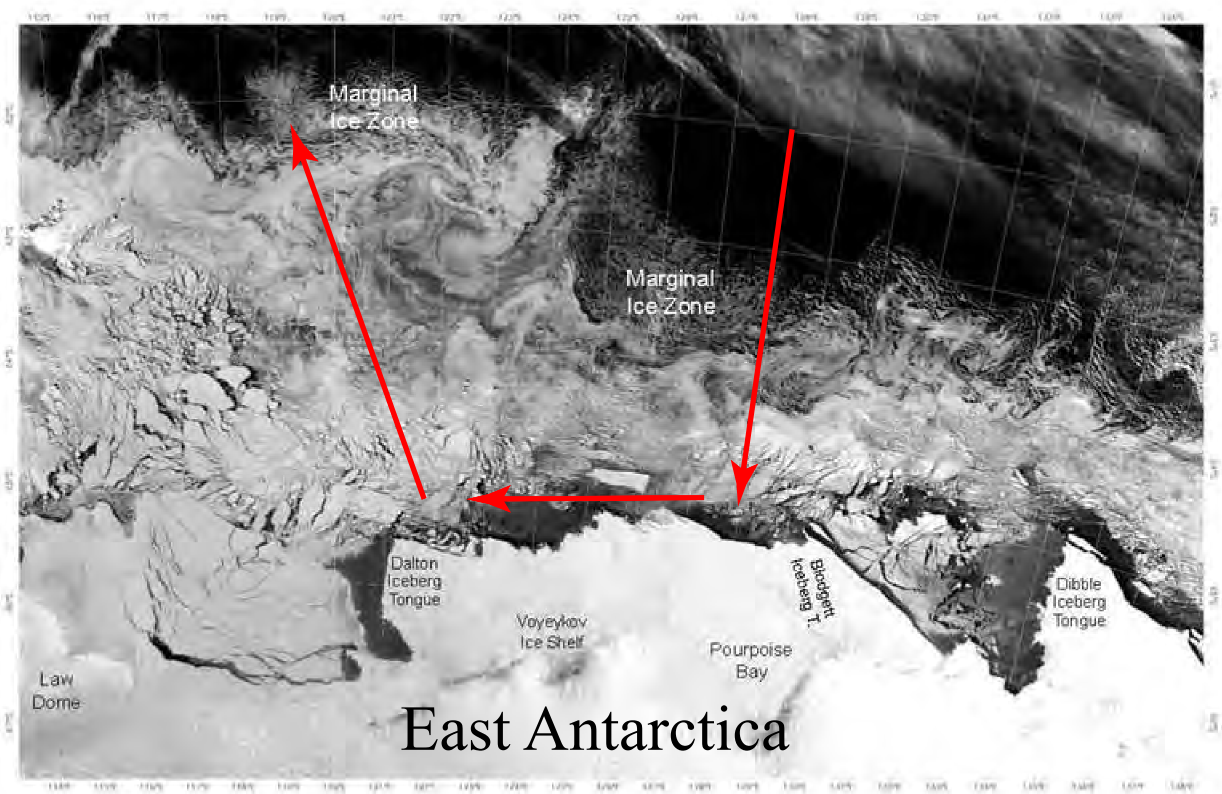
Golden, Murphy, Cherkaev
J. Biomechanics 2010

in sea ice, porosity changes significantly with small changes in temperature

if bone behaved similarly, you could get osteoporosis from a fever!

Sea Ice Physics and Ecosystem eXperiment (SIPEX)

4 September - 17 October 2007



Australian Government
Department of the Environment and Water Resources
Australian Antarctic Division

International Polar Year (IPY) 2007-2008

ace CRC
ANTARCTIC CLIMATE & ECOSYSTEMS
COOPERATIVE RESEARCH CENTRE

Measuring electrical and fluid transport during SIPEX

with Adam Gully

electrical properties --- help monitor ***fluid*** transport processses
--- important in ***thickness*** measurements, e.g. EMI

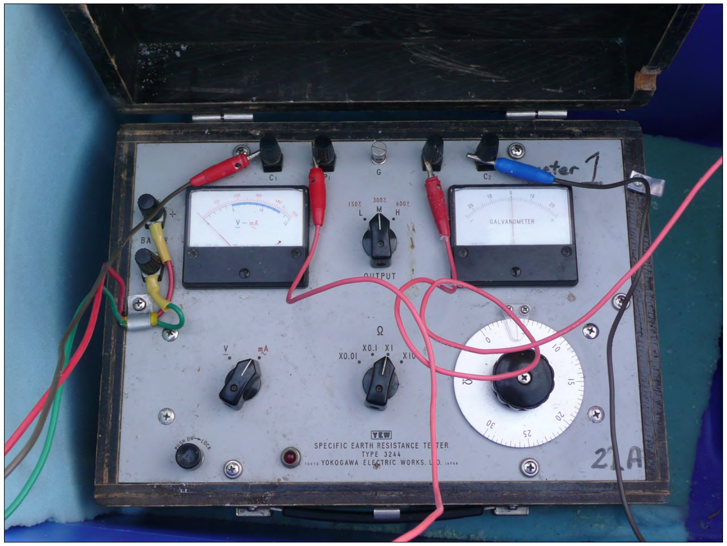
1. ***Direct measurements of DC vertical conductivity*** from extracted sea ice cores --- first experiments of this type

2. ***Surface impedance tomography*** with Wenner array --- invert DC resistance data to reconstruct profile of electrical properties

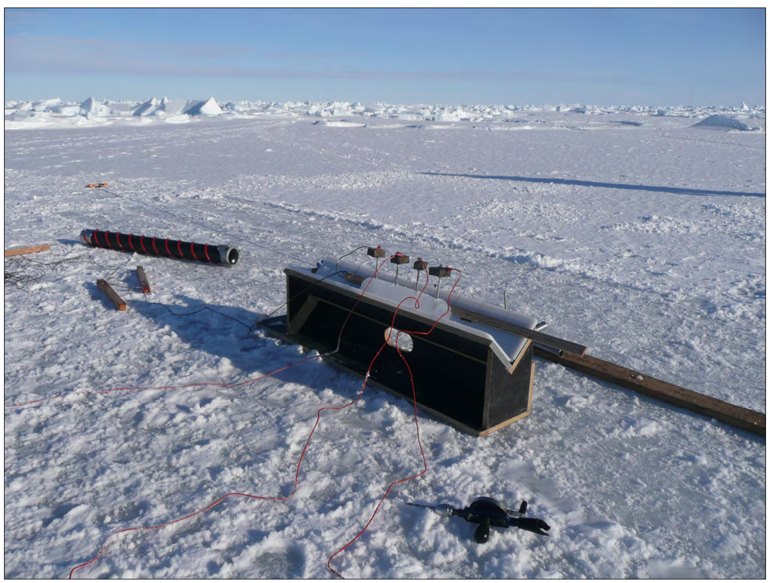
3. ***Fluid permeability*** --- first measurements in Antarctic pack ice

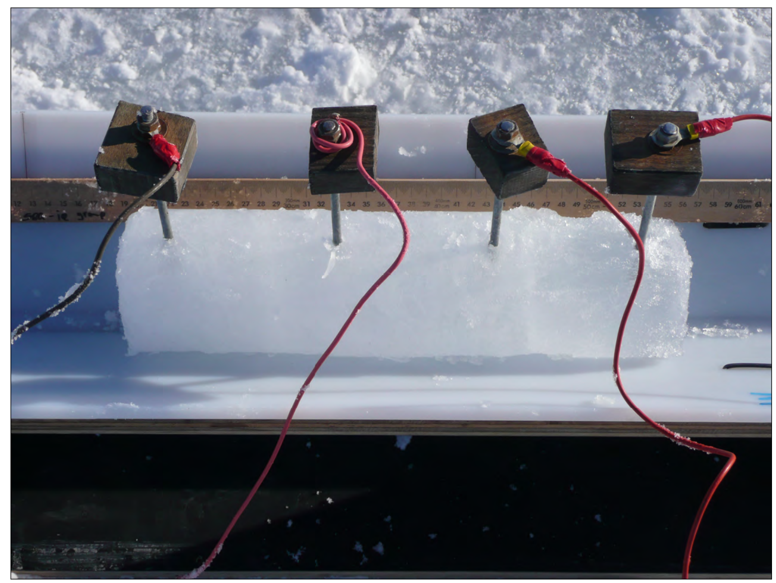
4. ***Tracer studies*** --- pour fluids through inverted sea ice blocks

electrical measurements



Wenner array





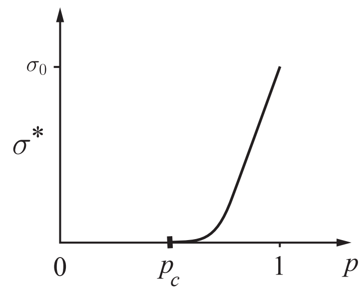
vertical conductivity

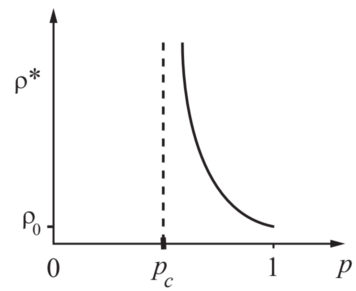
Zhu, Golden, Gully, Sampson ***Physica B*** 2010

Sampson, Golden, Gully, Worby ***Deep Sea Research*** 2010

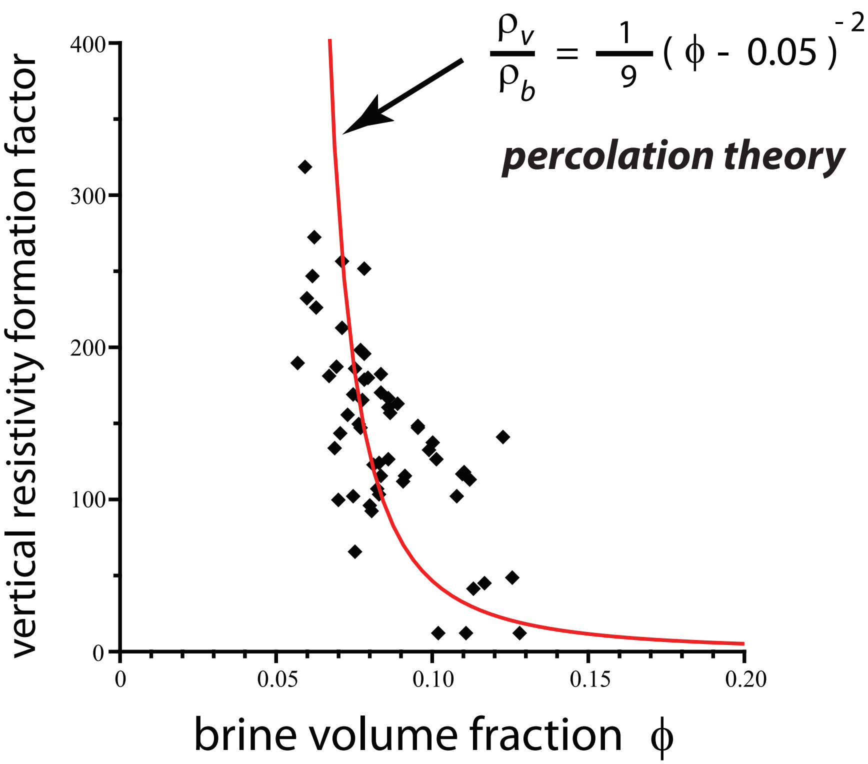
critical behavior of electrical transport in sea ice

electrical signature of the on-off switch for fluid flow

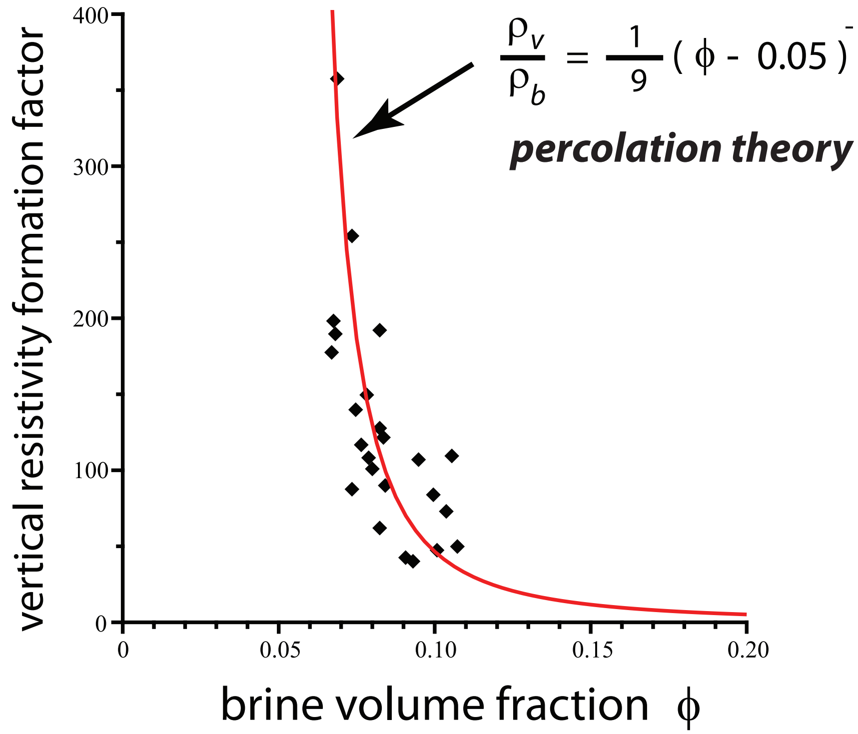




Arctic



Antarctic

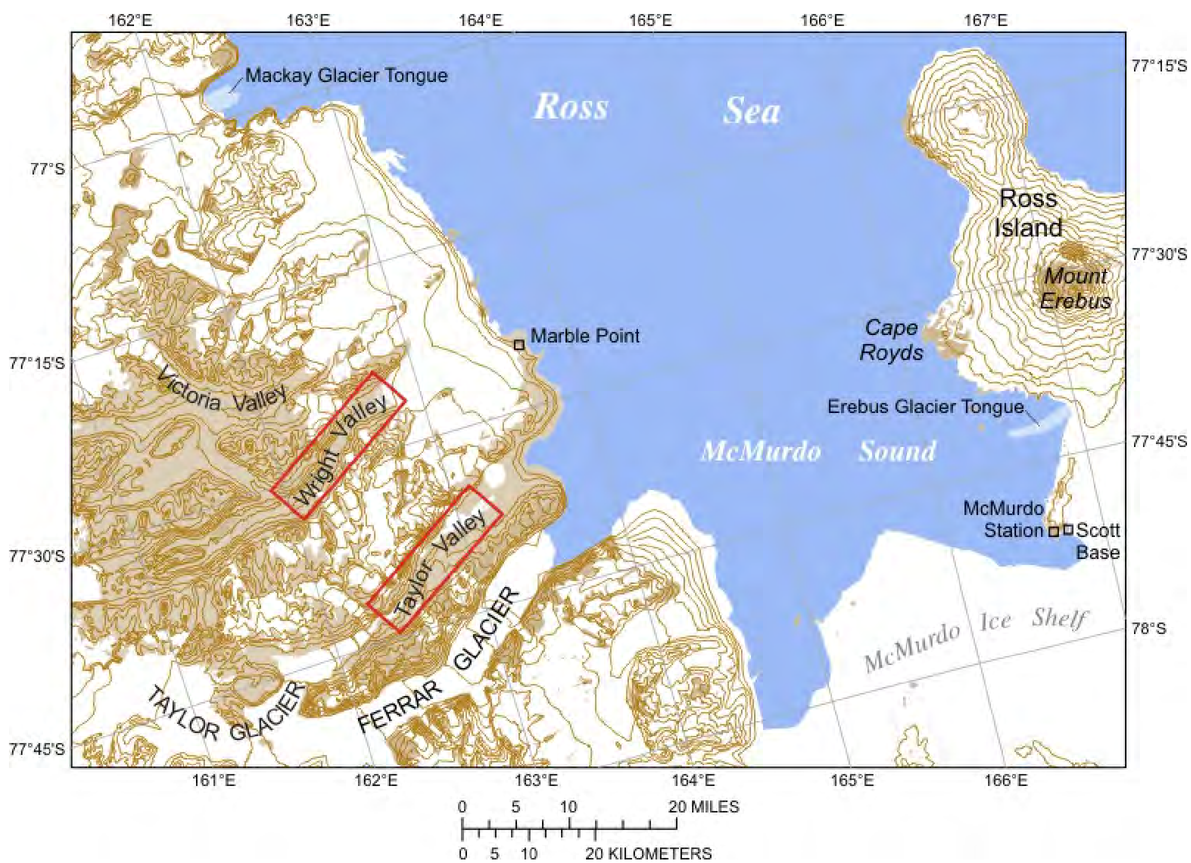


Golden, Eicken, Gully, Ingham, Jones, Lin, Reid, Sampson, Worby 2010

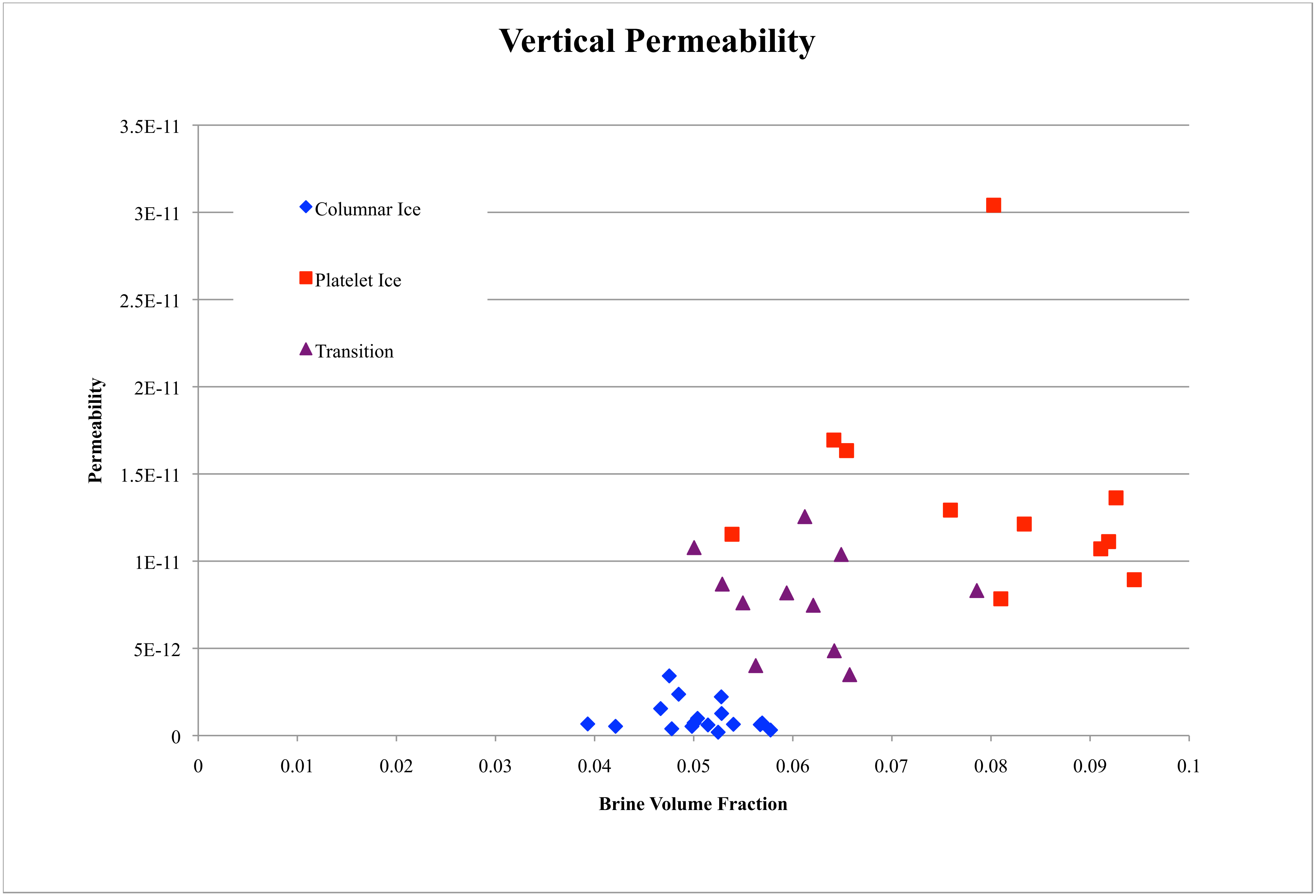
2010 Antarctic expedition to a remote NZ field camp in McMurdo Sound

Ken Golden, Joyce Lin, Cindy Furse (ECE), David Lubbers (ECE)

measure fluid, electromagnetic, and microstructural properties of sea ice
collaborate with our NZ colleagues in cross-borehole tomography

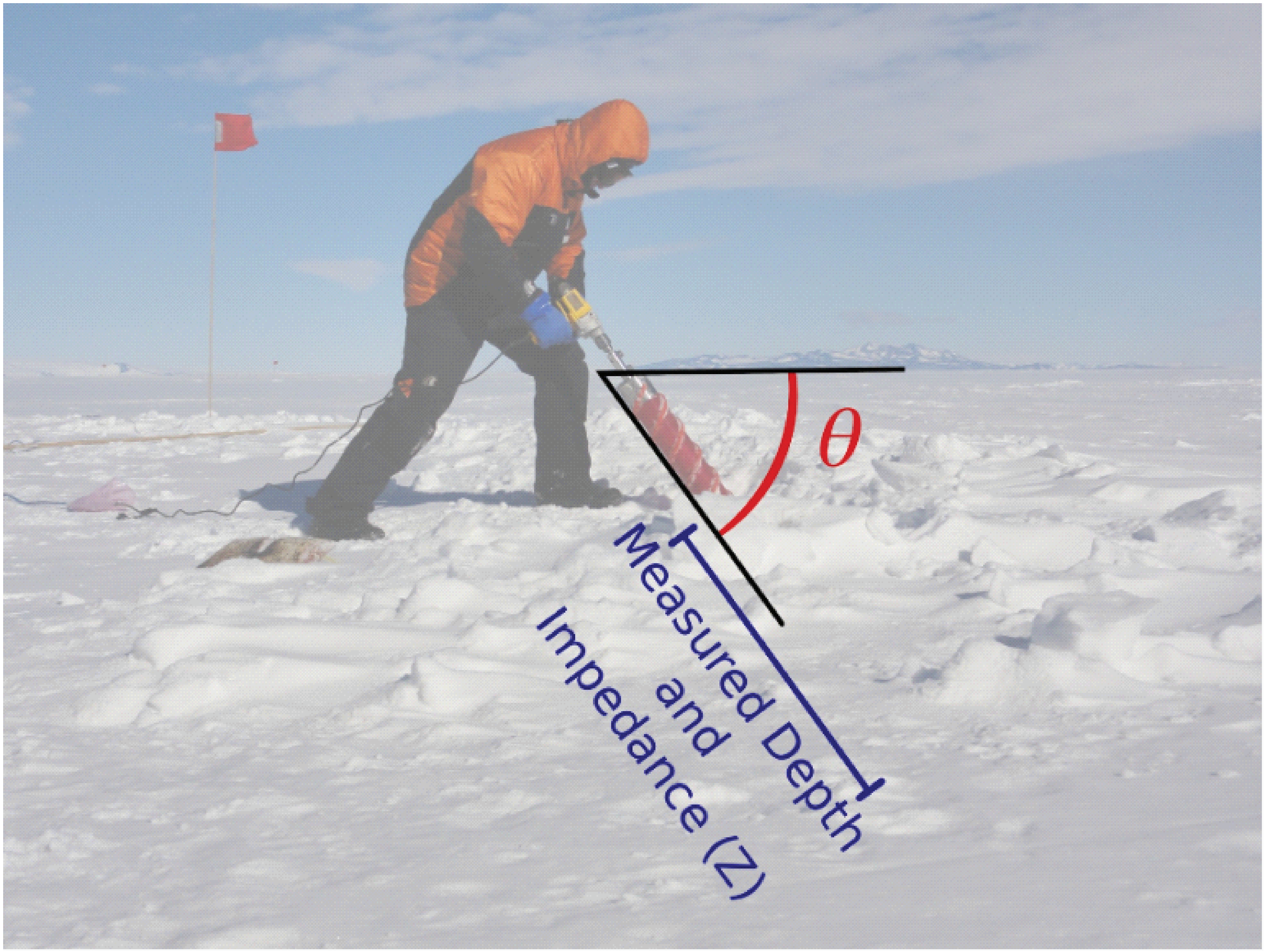


New Zealand's Scott Base



Lin, Lubbers, Haskell, Furse, Golden, 2011

“crooked core” method to measure components of anisotropic conductivity tensor



preparing for an Antarctic expedition

(can't run to Home Depot if something breaks or is forgotten!)

Math Department parking lot

Scott Base, Antarctica

"two is one, one is none"

Conclusions

1. Polar ice is melting. ***Critical behavior*** a natural part of system.

2. Melt ponds exhibit a space filling transition as they grow and coalesce.

3. Brine flow through sea ice is a key to geophysics and biology of polar regions, and displays critical behavior.

4. Developed comprehensive theory of fluid permeability and electrical conductivity, using models from statistical physics, and measured these properties in the Arctic and Antarctic.

5. Developed idea of ***spectral upscaling*** for sea ice structures.

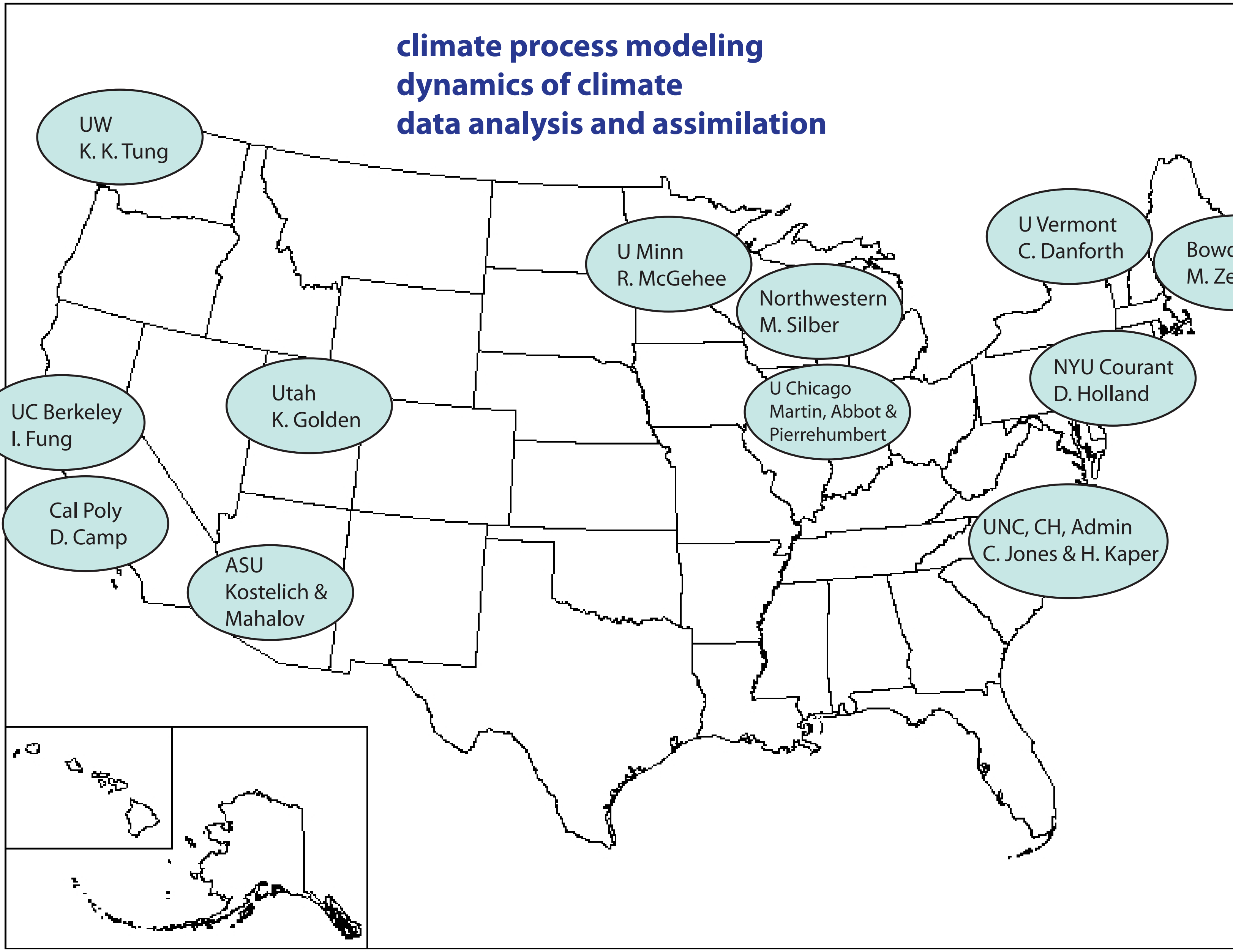
6. Sea ice processes such as melt pond evolution, snow-ice formation, nutrient flux can be modeled more realistically, and monitored electromagnetically.

our permeability results currently being used to improve how climate models treat evolution of salinity profiles and melt ponds

e.g. Los Alamos CICE -> NCAR CCSM

Buchanan Bay, Antarctica   Mertz Glacier Polynya Experiment   July 1999

Mathematics and Climate Change Research Network



NSF DMS 2010-2015, Lorenz postdocs, grad, undergrad, polar expeditions

Jones, Golden, Kaper, Zeeman

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Notices

of the American Mathematical Society

May 2009

Volume 56, Number 5

Climate Change and the Mathematics of Transport in Sea Ice

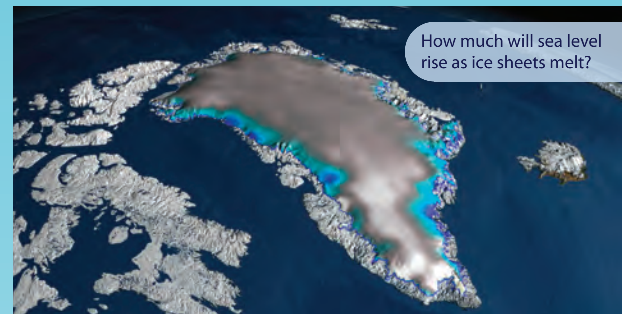
Mathematics and the Internet: A Source of Enormous Confusion and Great Potential

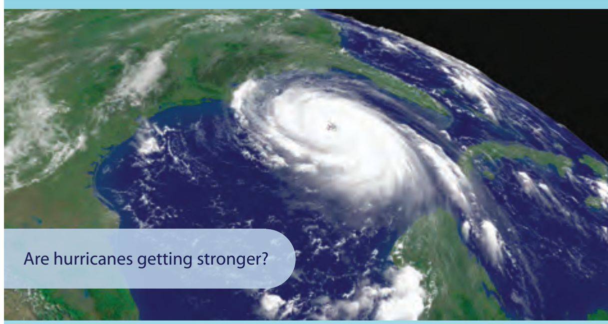
Real analysis in polar coordinates *(see page 613)*

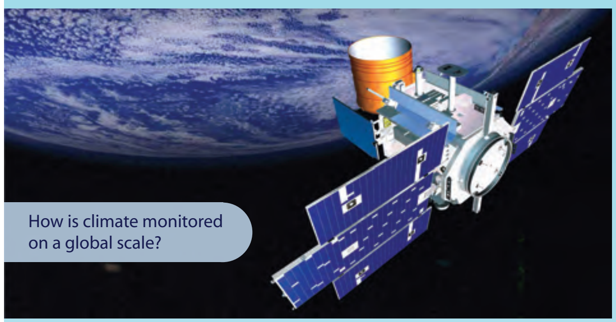
Mathematics Awareness Month - April 2009

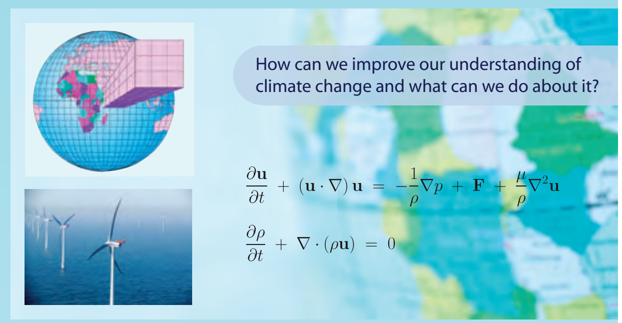
Mathematics and Climate

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









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2—THE MERCURY Thursday, July 23, 1998

Fire endangers Hobart's ice ship

By DAVID CARRIGG

AN engine-room fire has left the Hobart-based Antarctic research ship Aurora Australis without power in dangerous sea ice off the Antarctic coast.

None of the 79 people on board was injured in the blaze, which broke out early yesterday morning while the ship was in deep water 185km off the coast.

The extent of the damage is not known.

Australian Antarctic Division director Rex Moncur said the fire was extinguished by flooding the engine room with an inert gas.

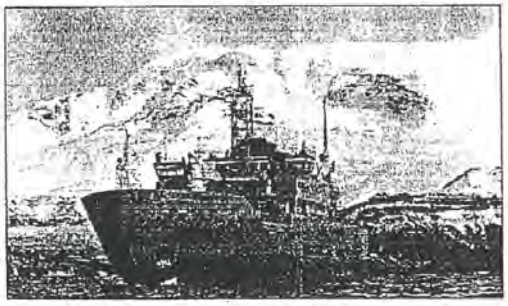
The gas had to be cleared before crew wearing breathing apparatus could enter and assess the situation.

He said it could be some time before the extent of damage was known.

The 25 crew and 54 expeditioners, mostly from Hobart, would wear thermal clothing and stay below decks to keep warm.

"There is always a risk of becoming ice-bound in these waters at this time of the year but at this stage we don't expect to launch a rescue mission from Hobart," Mr Moncur said.

The ship was in regular radio contact with the Antarctic Division's Hobart office.



A file photo of the Aurora Australis in Antarctica.

He expected the expeditioners and crew to abandon the pioneering winter voyage and return the ship to Hobart for repairs in about a week.

The Antarctic Division, which hires the ship from P&O Australia, would not be hiring another vessel for the expedition.

"It's a pretty specialist vessel so you couldn't get the sort of research capability that this ship has got readily available," Mr Moncur said.

"We hope the next voyage can still proceed on schedule, which is early September."

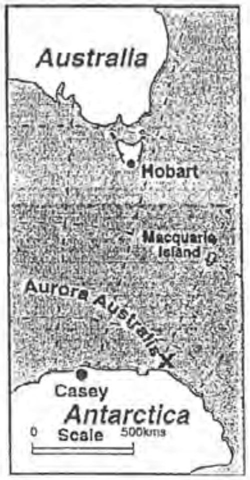
The Aurora Australis is owned by P&O Australia and charted by the Antarctic Division for about $11 million a year.

P&O Australia managing director Richard Hein said yesterday the company was assessing the situation and a number of rescue options were being considered.

It was too early to say whether P&O would be liable for the cost of the aborted mission.

The vessel left Hobart last Wednesday for a seven-week voyage mainly to study a polynya, an area where savage winds break up the sea ice and cause heavy, salt-laden water to sink to the bottom.

The ship was nearing the polynya when the fire broke out.



Oceanographers believe a closer study of the phenomenon will lead to a better understanding of climate change.

CSIRO Marine Research oceanographer Steve Rintoul said the dense bottom water, created only in a few places in Antarctica and to a lesser extent in the North Atlantic, was critical to the chemistry and biology of the world's oceans.

THE ADVERTISER (Adelaide)
Thurs 23 July 1998 Page 14

Fire strands Antarctic ship in sea ice

AN engine room fire has disabled the icebreaker Aurora Australis in sea ice, deep in Antarctic waters.

There were no injuries and the ship was not in danger after Tuesday night's fire, Australian Antarctic Division director Mr Rex Moncur said. But Mr Moncur said he expected it would have to abandon its pioneering mid-winter voyage to the edge of the Antarctic continent and return to Hobart for repairs.

The cause of the fire was not known but the engines have been turned off, with the ship 100 nautical miles from the Antarctic coast.

THE CANBERRA TIMES
Thursday 23 July 1998 Page 4

Antarctic voyage stopped by fire

HOBART: An engine room fire has disabled the Australian icebreaker Aurora Australis in sea ice, deep in Antarctic waters.

Australian Antarctic Division director Rex Moncur said there were no injuries and the ship was not in danger after Tuesday night's fire.

But Mr Moncur said he expected Aurora Australis would have to abandon its pioneering mid-winter voyage to the edge of the Antarctic continent to return to Hobart for repairs.

The fire had been extinguished and the engines were turned off, leaving the ship in sea ice about 100 nautical miles from the Antarctic coast, he said. The weather was good.

Crew had to wear breathing apparatus to enter the engine room and it was likely to be 24 hours before the damage could be fully assessed.

The Aurora, with 54 expeditioners and 25 crew, left Hobart last Wednesday for a seven-week voyage which was to have focused on a polynya, an area where savage winds break up the sea ice and cause heavy, salt-laden water to sink to the bottom.

Mr Moncur said, the cause of the fire was not yet known.

Sydney Morning Herald
23 July, 1998

ICEBREAKER BURNS

A pioneering $2 million Australian scientific voyage to the mid-winter Antarctic pack-ice is expected to be scrapped following an engine-room fire on the Aurora Australis yesterday.

The 54 people on board were forced on deck in the

2:45 am July 22, 1998

``Please don't be alarmed but we have an uncontrolled fire in the engine room ...."

about 10 minutes later ...

``Please don't be alarmed but we're lowering the lifeboats ...."