INTERNATIONAL YEAR OF STATISTICS

A CELEBRATION OF THE CONTRIBUTIONS OF THE STATISTICAL SCIENCES TO SOCIETY

http://statistics2013.org

Recipe for a Bernoulli Sponsored* 2013 Regional Public Event

1. Form a small local committee from universities in your region.

2. Develop a small budget for promotion of a 2013 public event to include local professionals, students, teachers and legislators.

3. Secure official sponsorship of the Bernoulli Society at http://www.bs2013.org/, and join the list of institutions on the international web page http://www.statistics2013.org/

4. Request funding from local participating universities.

5. Select a speaker, location and time for your 2013 event.

6. Invite local news media.

7. Don't miss this historic* opportunity to communicate the importance of education and research in probability and statistics to the world.

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* 300th Anniversary of the publication of Jacob Bernoulli's Ars Conjectandi and 250th Anniversary of the publication of Bayes' theorem.

Mathematics and the Melting Polar Ice Caps

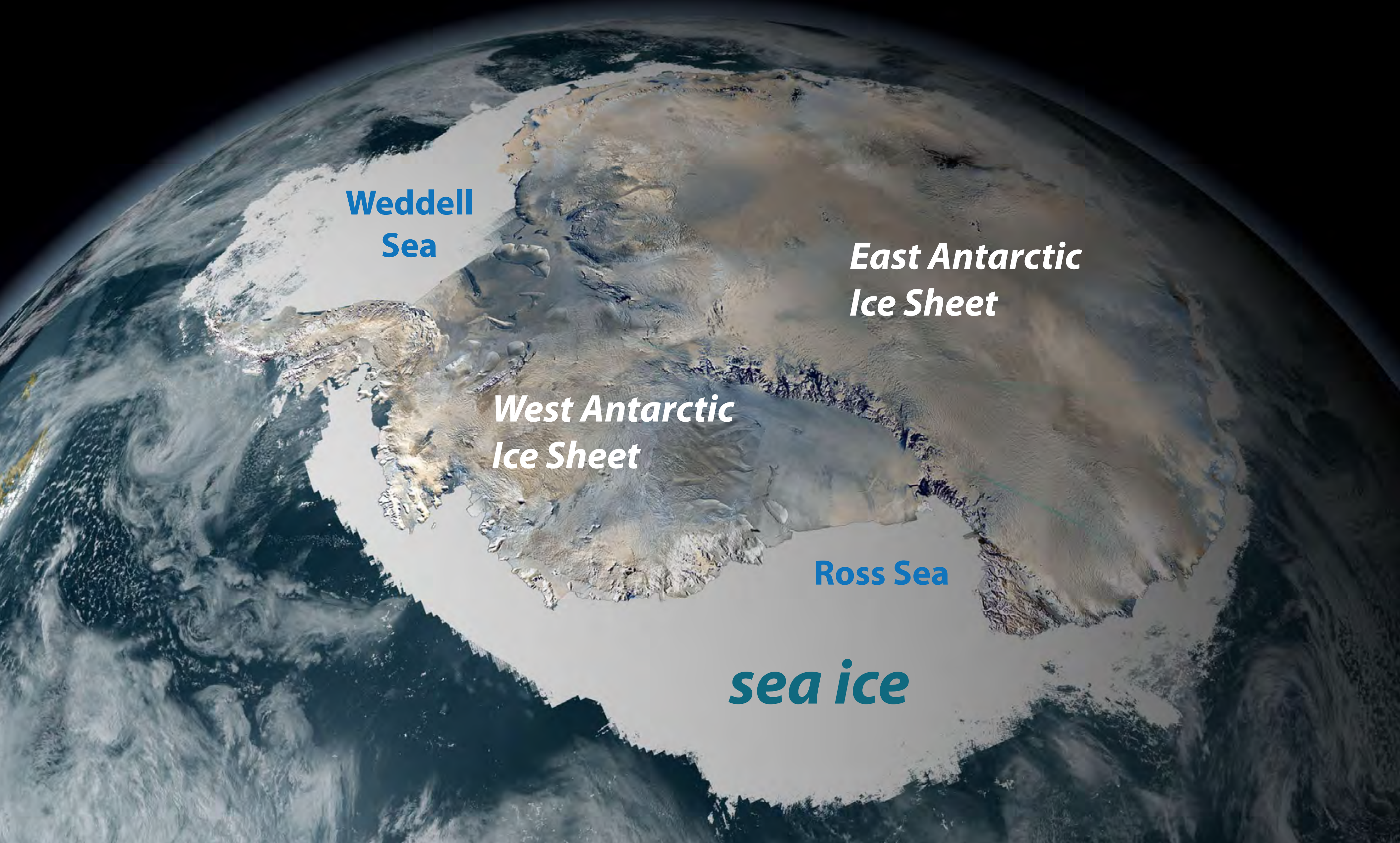
Kenneth M. Golden
Department of Mathematics
University of Utah

36th Conference on Stochastic Processes and Their Applications

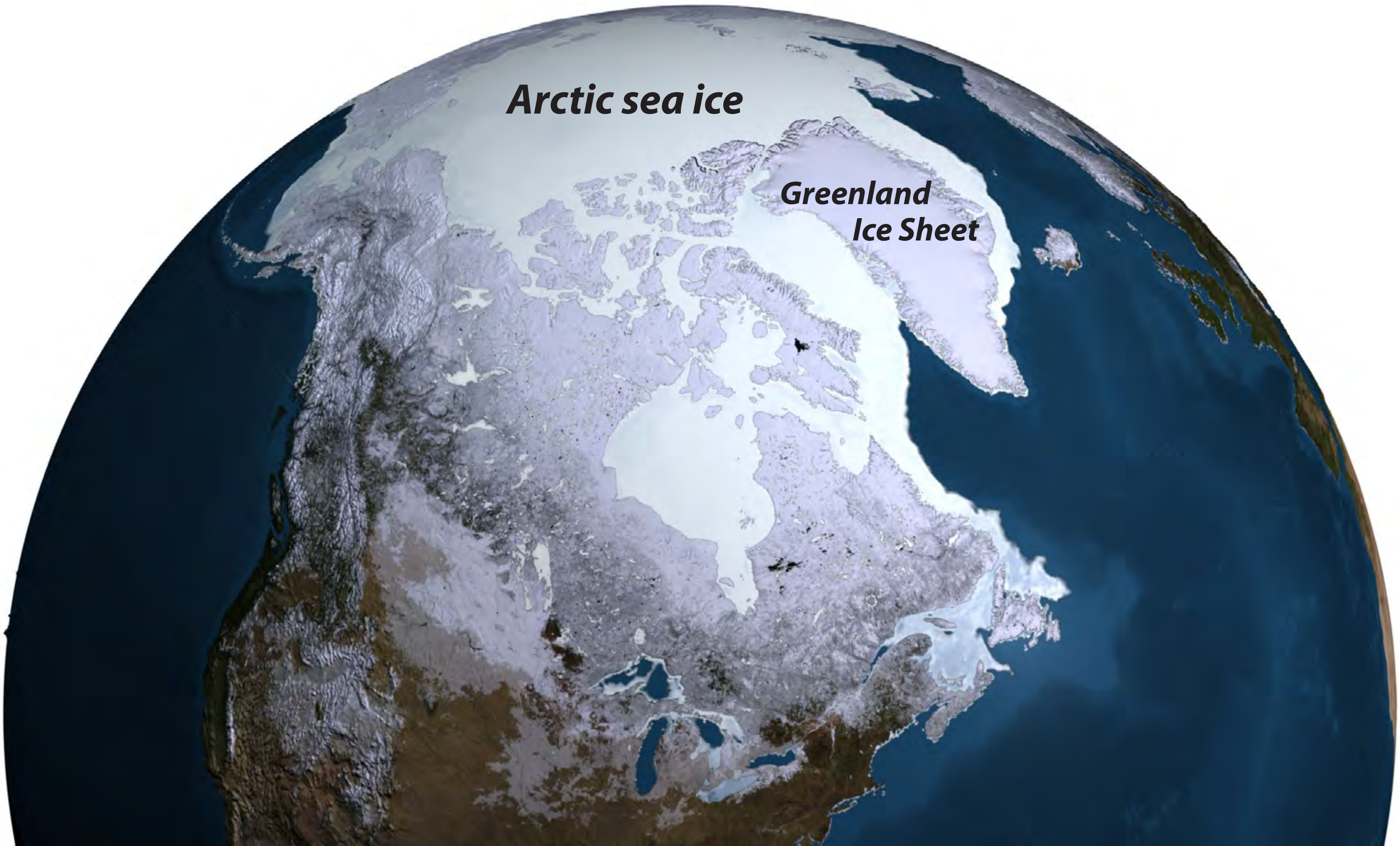
Bernoulli Society Open Lecture   UC Boulder   August 1, 2013

ANTARCTICA

southern cryosphere



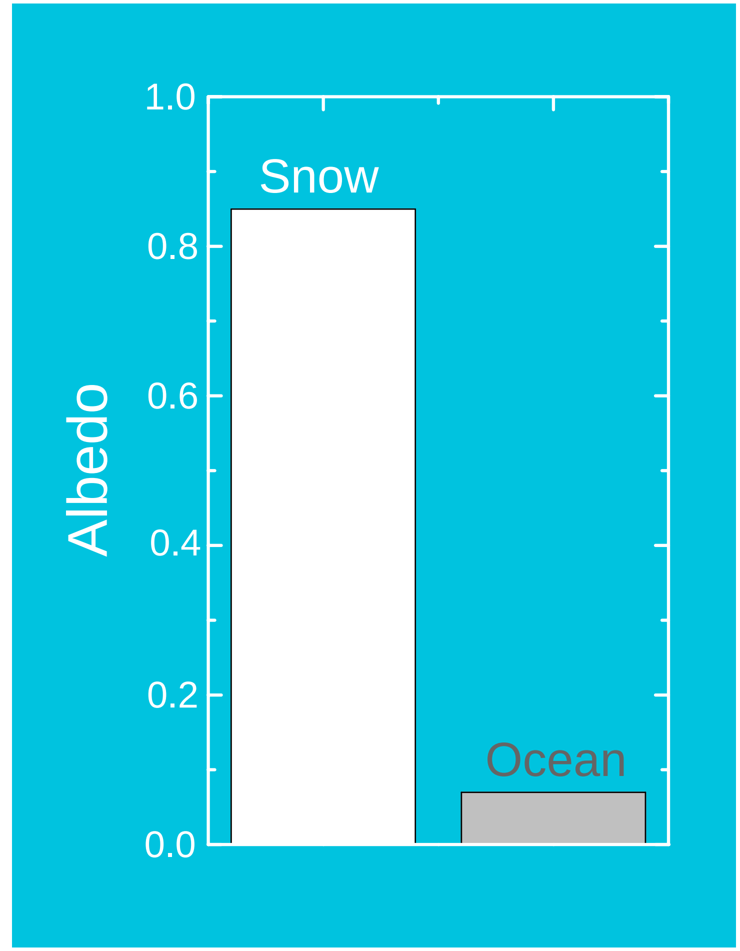
northern cryosphere




SEA ICE covers 7 - 10% of earth's ocean surface
• boundary between ocean and atmosphere
• mediates exchange of heat, gases, momentum
• global ocean circulation
• indicator and agent of climate change

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

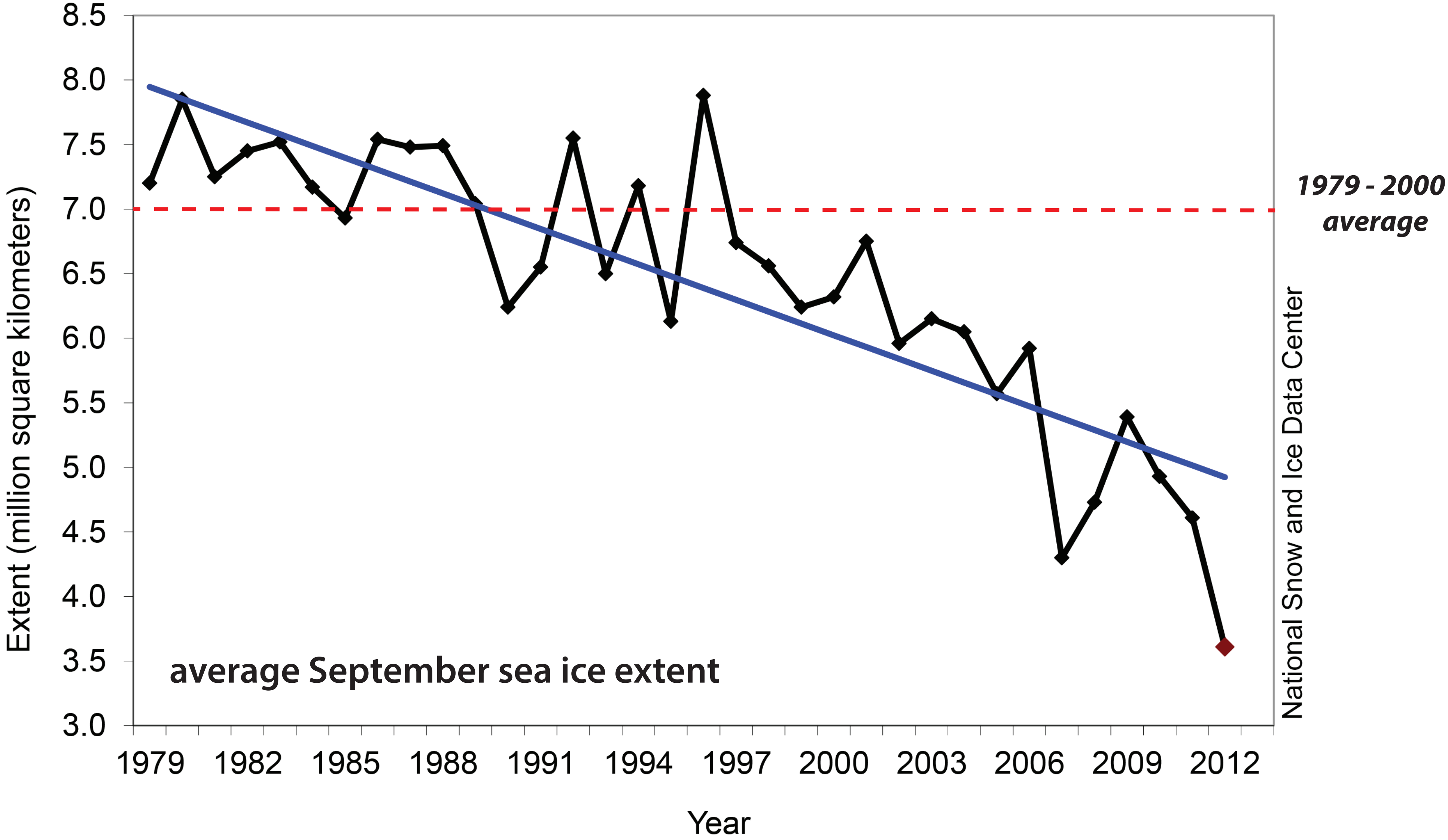
white snow and ice reflect



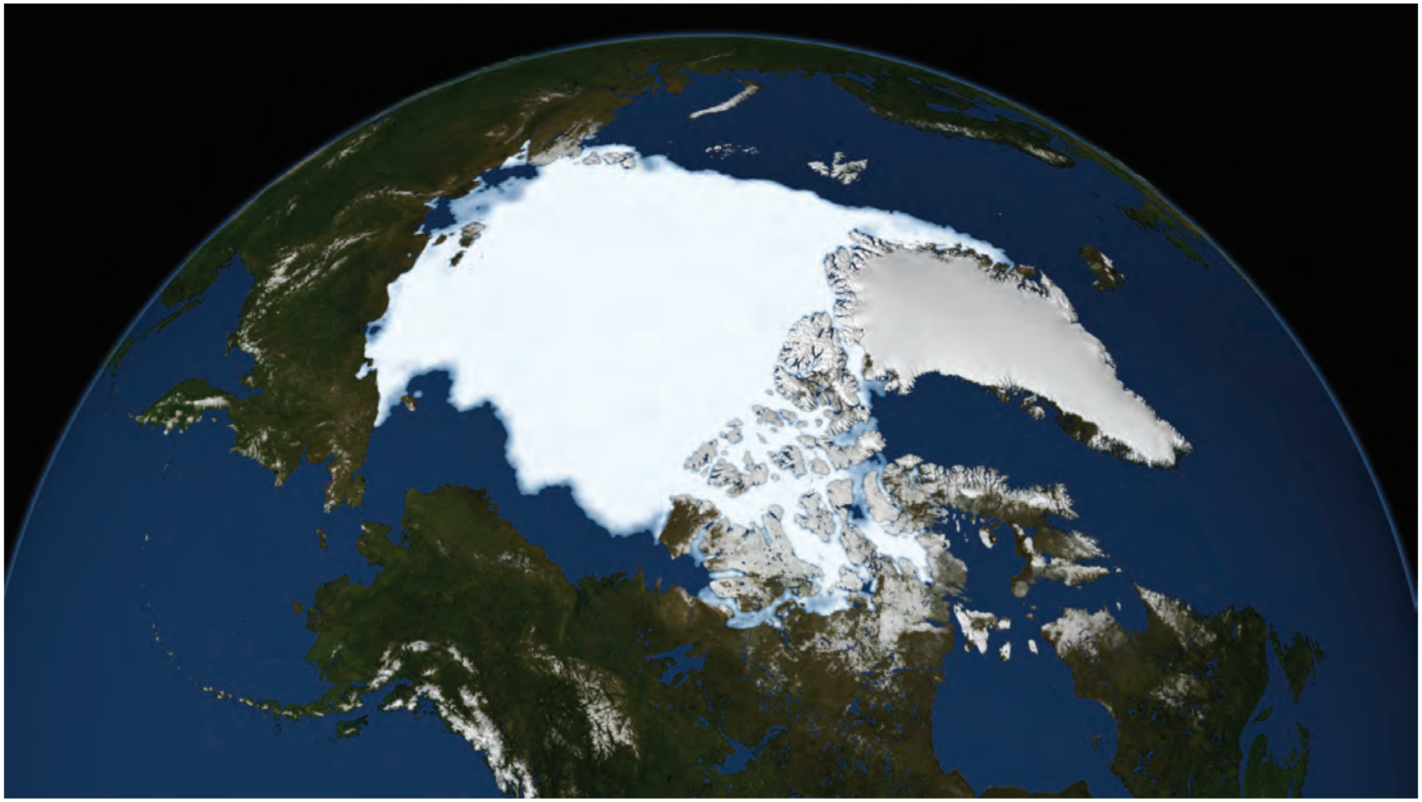
dark water and land absorb

$$\textit{albedo}\ \alpha = \frac{\text{reflected sunlight}}{\text{incident sunlight}}$$

the summer Arctic sea ice pack is melting

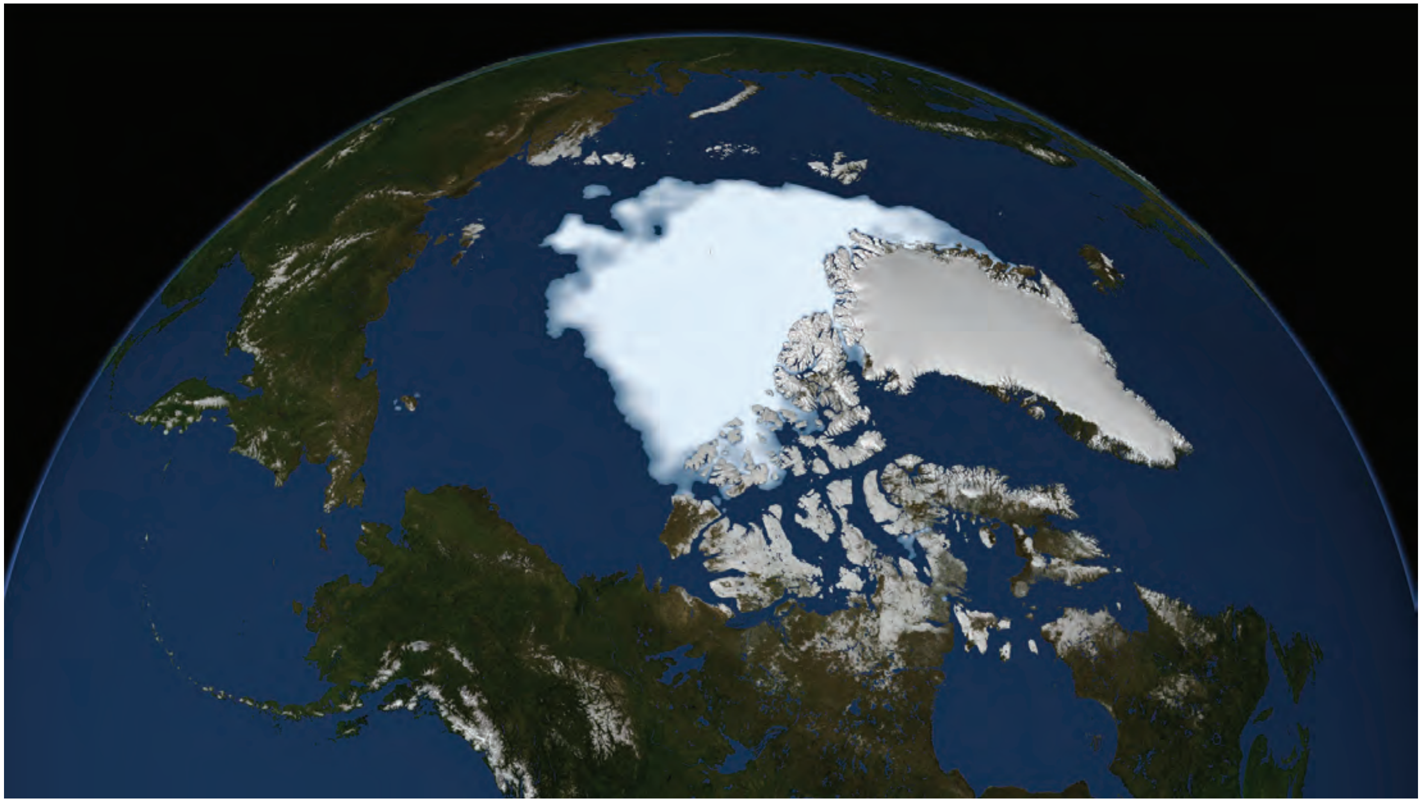


21 September 1979



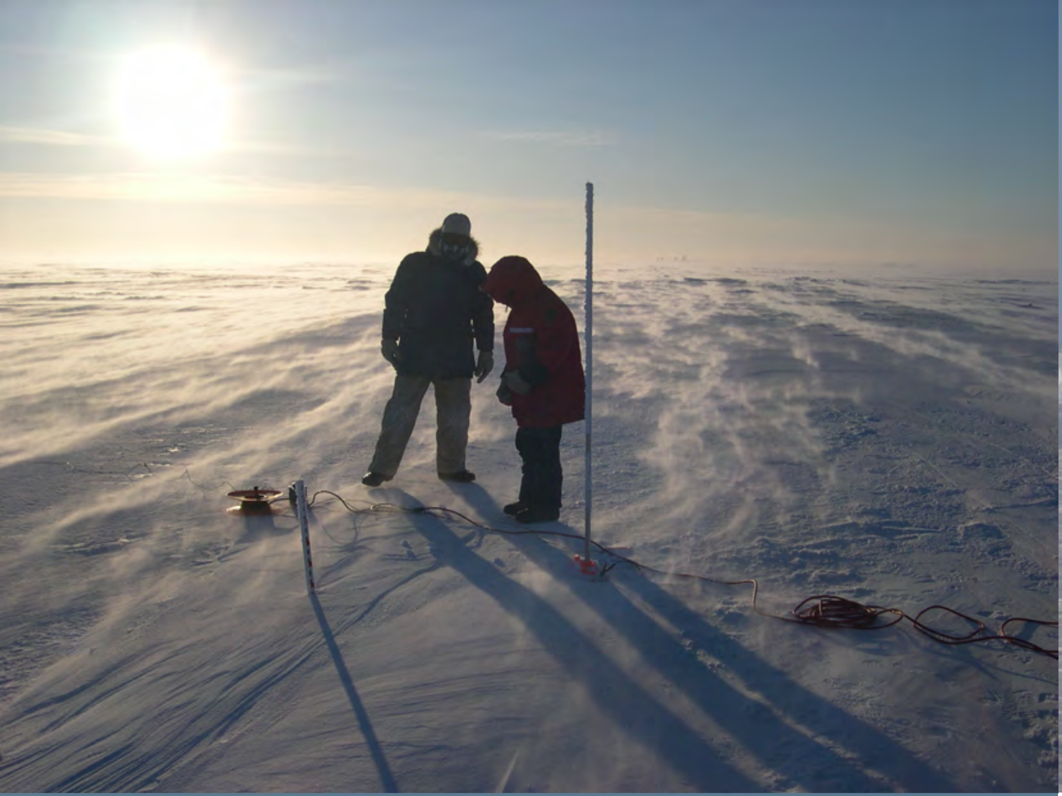
Polar Amplification

13 September 2012



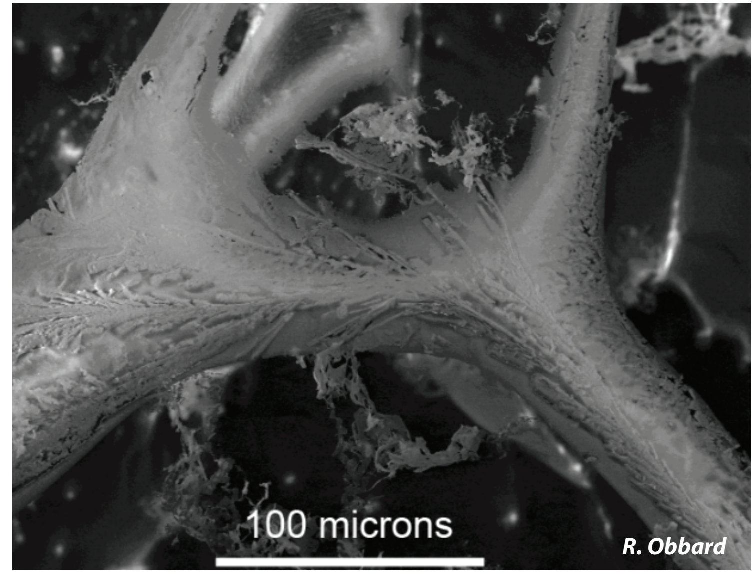
Ice albedo feedback

Perovich



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

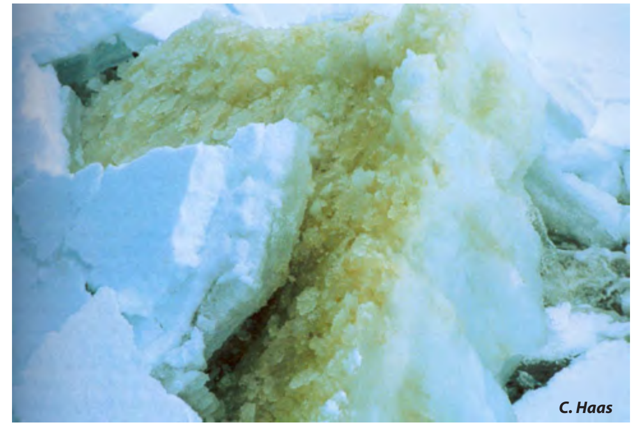
horizontal section

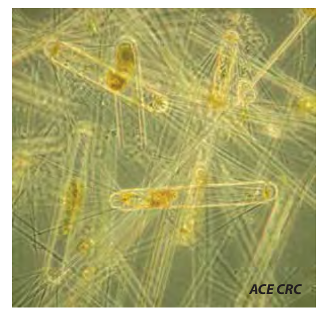
vertical section

fluid flow through the porous microstructure of sea ice governs key processes in polar climate and ecosystems:

evolution of Arctic melt ponds and sea ice albedo

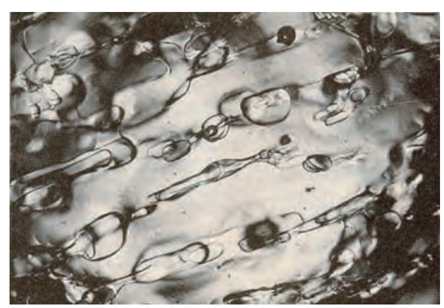
nutrient flux for algal communities





- *drainage of brine and melt water*
- *ocean-ice-air exchanges of heat, CO_2*

linkage of scales



What is this talk about?

SPA in climate science

(**S**tochastic **P**rocesses and **A**pplications)

Using the mathematics of composite materials and statistical physics to study sea ice structures and processes ... to improve projections of climate change.

1. ***Fluid flow through sea ice - percolation***

   homogenzation for composite materials

2. ***Electromagnetic monitoring of sea ice***

   homogenzation for larger scale structures

3. ***Arctic and Antarctic experiments***

4. ***Fractal geometry of Arctic melt ponds***

critical behavior ***linkage of scales***

cross-pollination

Develop rigorous representations of sea ice in climate models.

Collaborators

University of Utah

FACULTY:

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Elena Cherkaev (Math)
Court Strong (Atmospheric Sci.)
Cynthia Furse (Elec. & Comp. Eng.)

POSTDOCS:

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Bacim Alali
Ivan Sudakov

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Rajath Thekkedath (Mech. Eng., Math)
Brady Bowen (Math, Physics)

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Marc Mueller-Stoffels

Victoria University, NZ School of Chemical & Physical Sciences

Malcolm Ingham, Keleigh Jones

Australian Antarctic Division

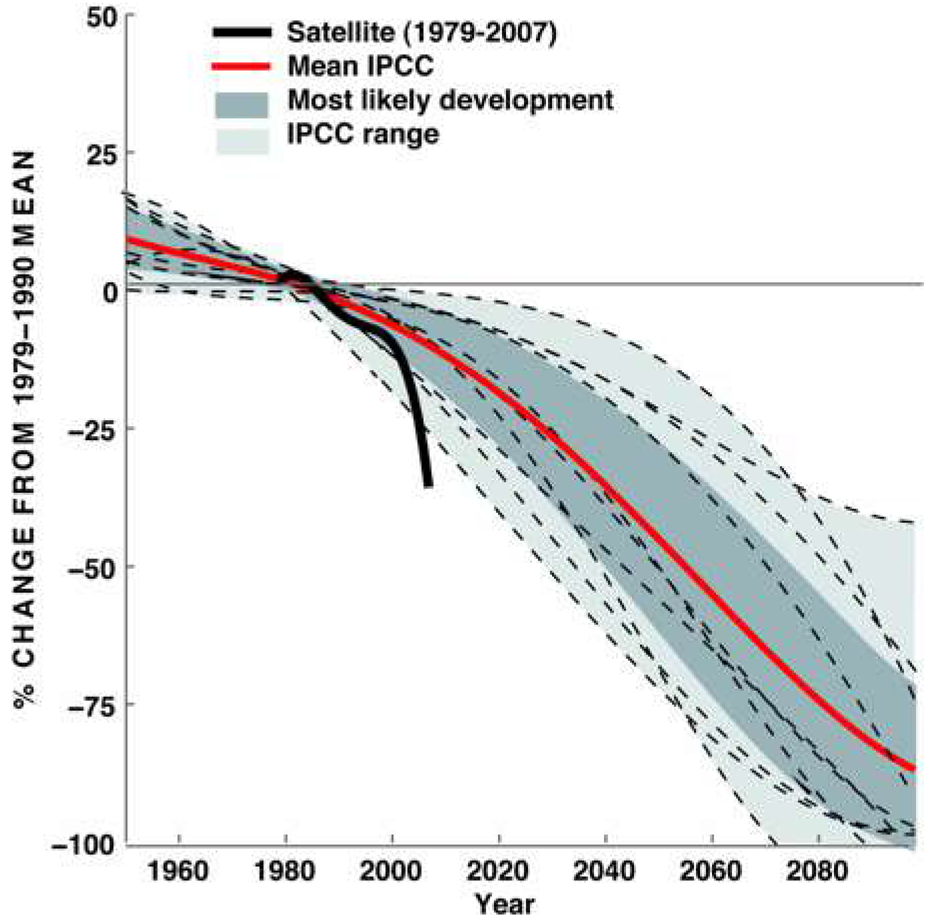
Tony Worby, Klaus Meiners

CRREL

Don Perovich, Chris Polashenski

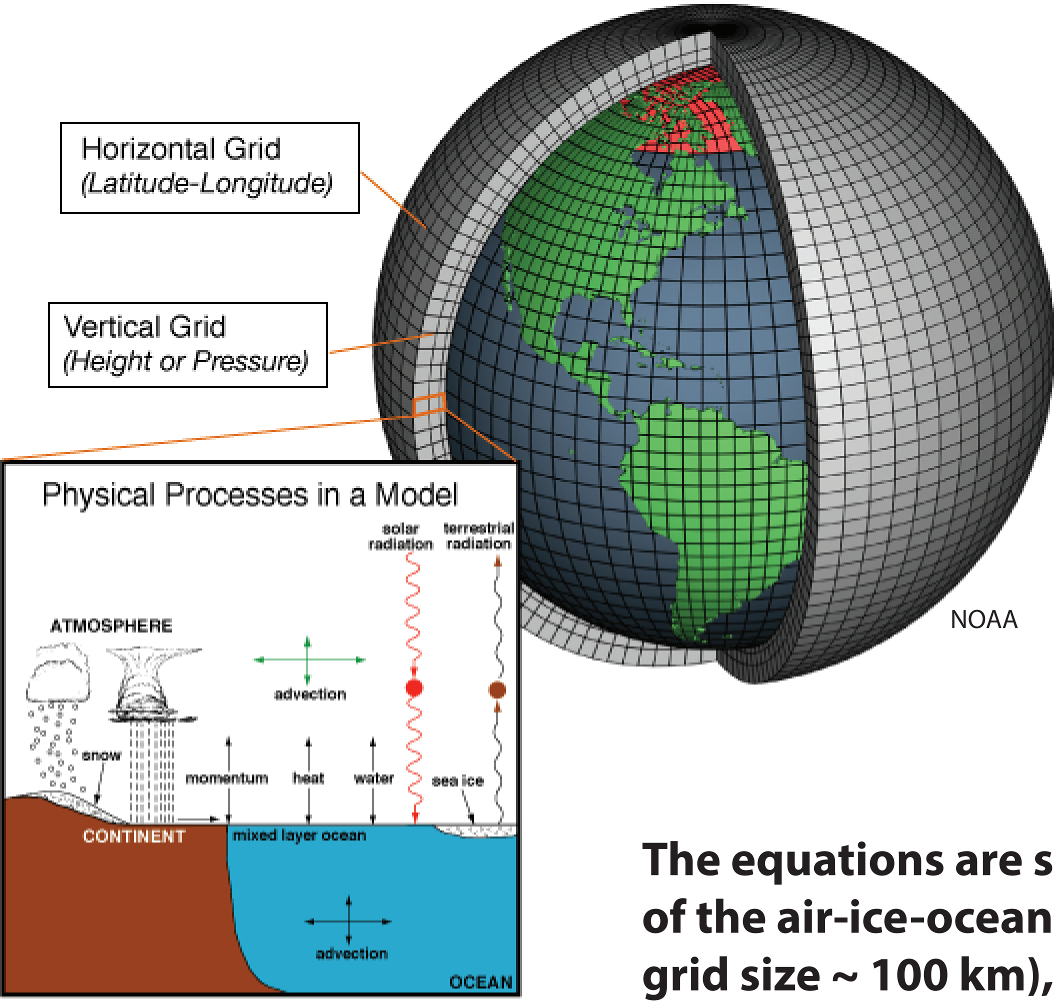
Intergovernmental Panel on Climate Change (IPCC) 2007 projections

observed decline in summer Arctic sea ice outpacing global climate models



Arctic sea ice loss compared to IPCC models

Global Climate Models



NOAA

Climate models are systems of partial differential equations (PDE) derived from the basic laws of physics, chemistry, and fluid motion.

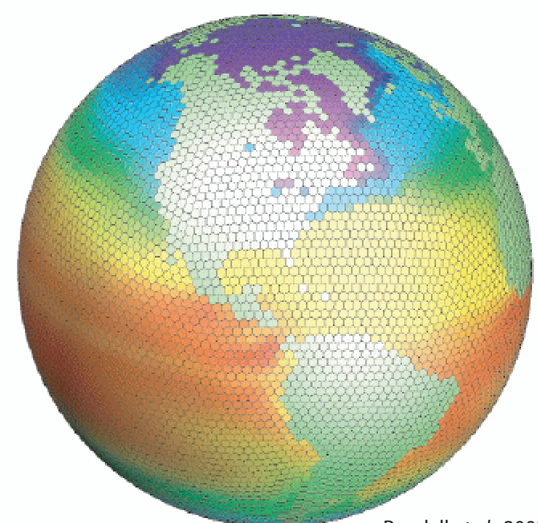
They describe the state of the ocean, ice, atmosphere, land, and their interactions.

The equations are solved on 3-dimensional grids of the air-ice-ocean-land system (with horizontal grid size ~ 100 km), using very powerful computers.

sub - grid scale processes

sea ice components of GCM:

- ***ice thickness distribution***
- ***balance of forces (F=ma)***
- ***heat and radiation fluxes***



Randall *et al.*, 2002

Who cares if Arctic sea ice disappears?

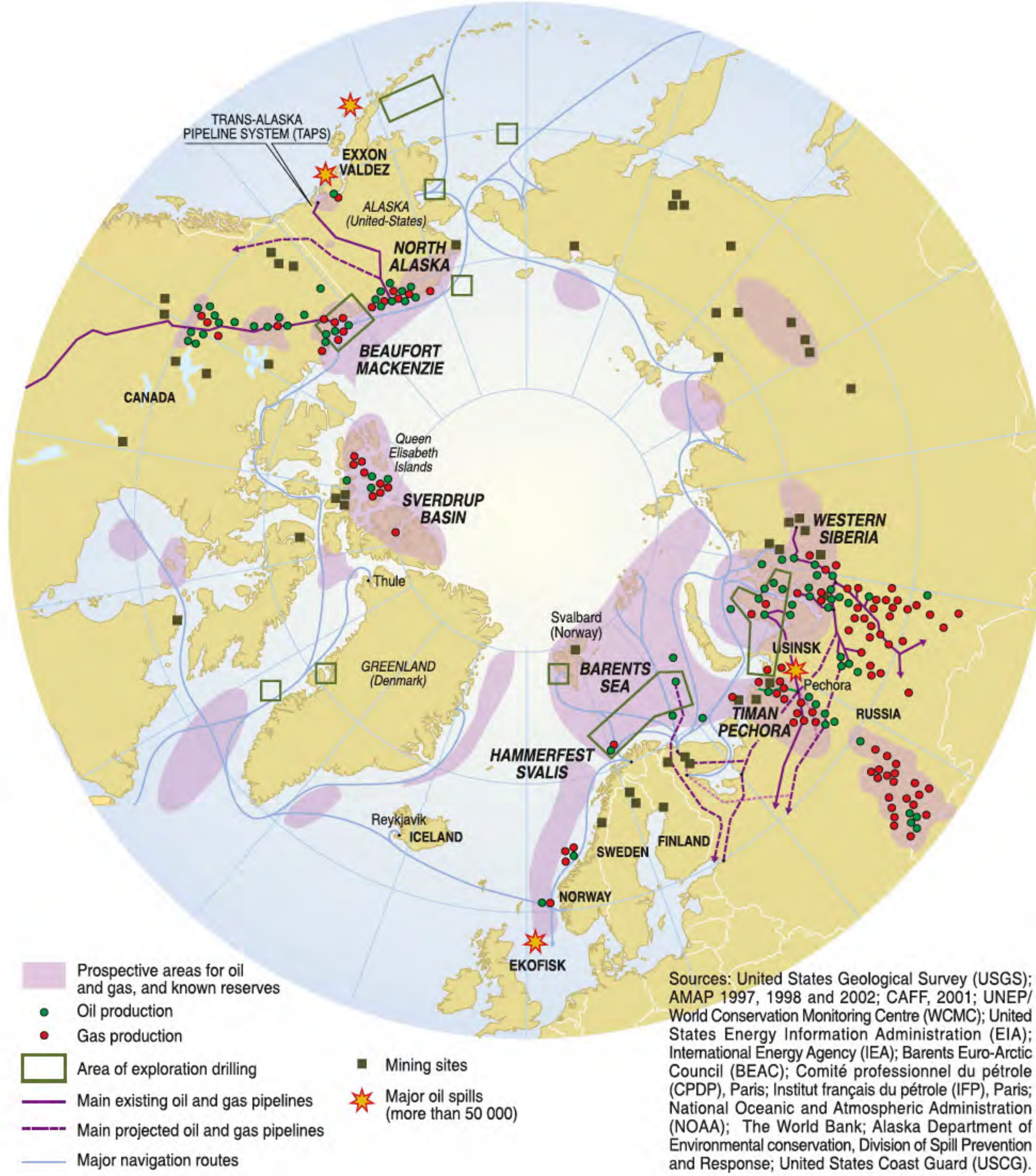
Ralph (Malik) Ahkivgak, c. 20 Oct 1988


Drew Barrymore
John Krasinski
INSPIRED BY THE INCREDIBLE TRUE STORY
that united the world
BIG MIRACLE

• The Arctic holds 25% of the world's undiscovered oil & gas reserves

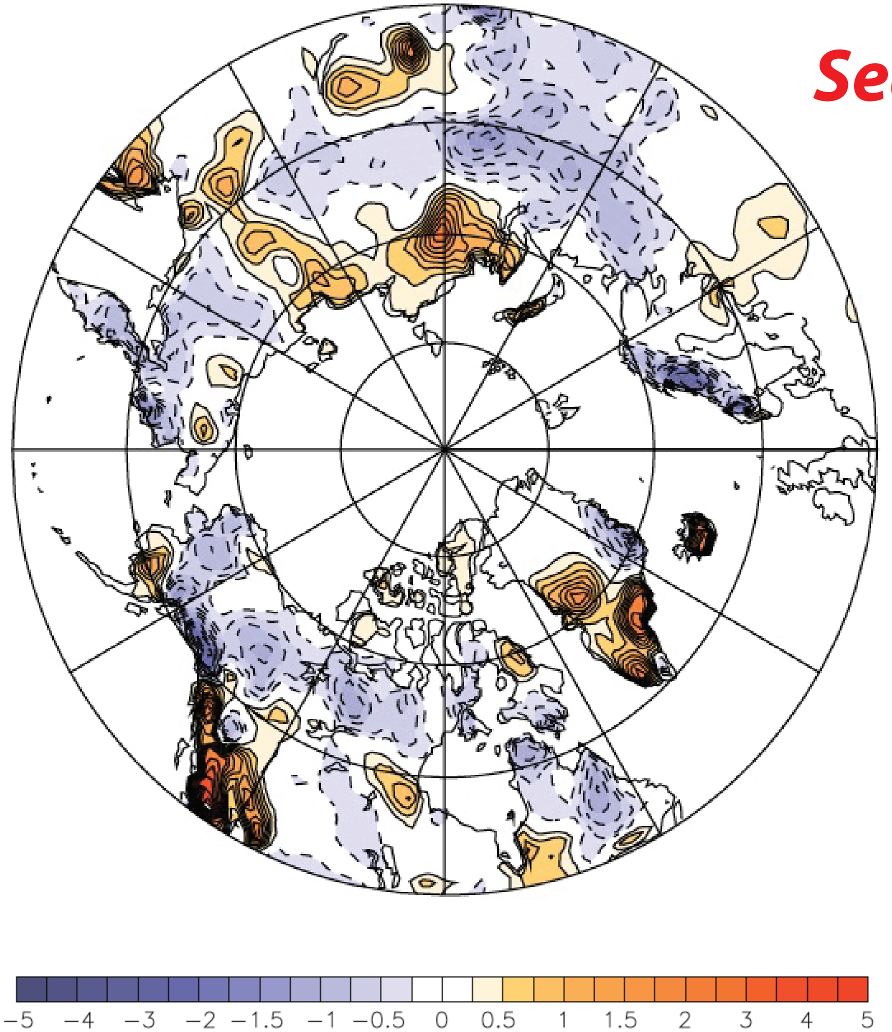
• Sea ice is both a hazard and a supporting feature for hydrocarbon exploration & production

oil companies care about Arctic sea ice loss



Source: UNEP/GRID-Arendal

Sea-ice loss: impacts beyond the Arctic



Orsolini et al., 2011

changes in precipitation and temperature patterns, storm tracks, ...

- One climate model projects reduced precipitation in American West (Sewall & Sloan, 2005)
  Utah - greatest snow on Earth?
- Analysis of 2007 ice minimum suggests above normal snow deposition in NW North America (Orsolini et al., 2011)
- Colder weather in SE Asia, possibly in Eastern US (Hondo et al., 2009)

sea ice microphysics

fluid transport

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

averaged fluid velocity

pressure gradient

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

viscosity

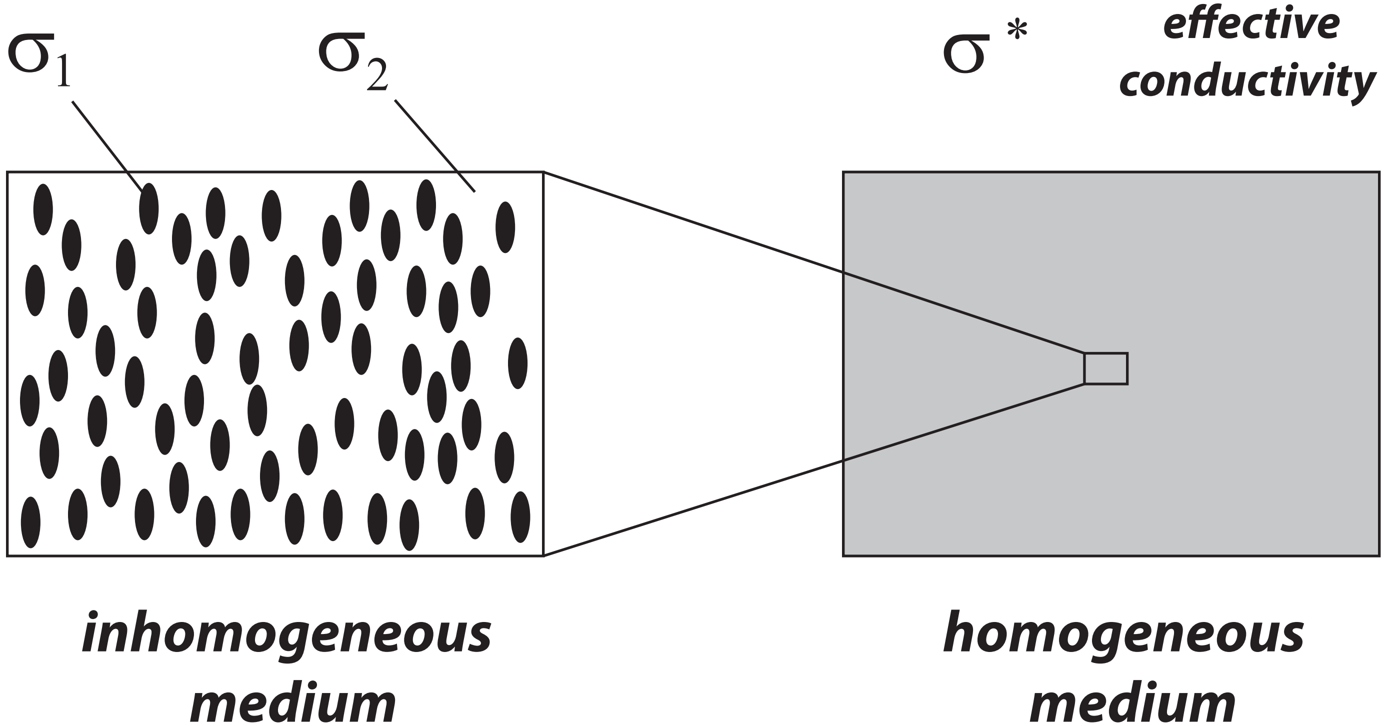
$\mathbf{k}$ = fluid permeability tensor

example of *homogenization*

mathematics for analyzing effective behavior of heterogeneous systems

e.g. transport properties of composites - electrical conductivity, thermal conductivity, etc.

HOMOGENIZATION



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

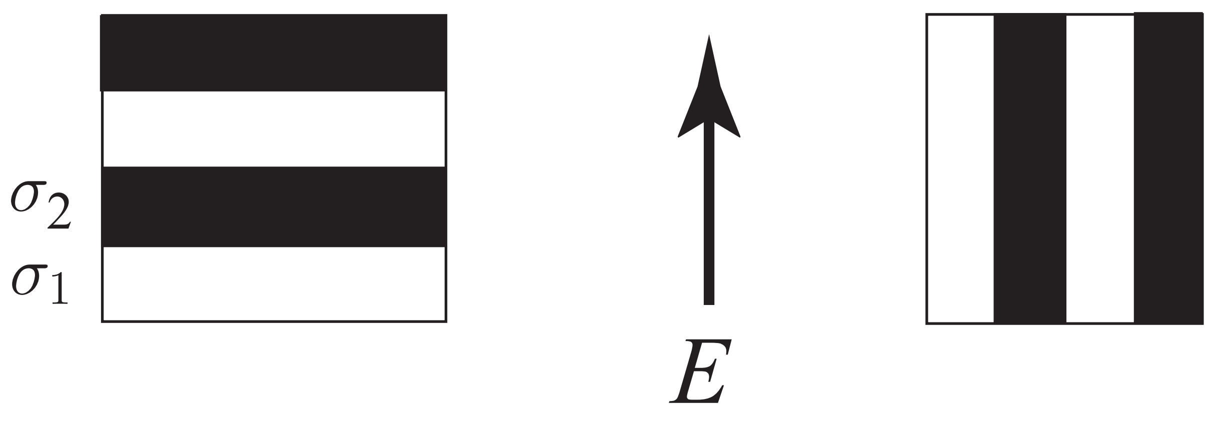
Maxwell 1873 : effective conductivity of a dilute suspension of spheres
Einstein 1906 : effective viscosity of a dilute suspension of rigid spheres in a fluid

arithmetic and harmonic mean bounds on transport properties

effective electrical conductivity σ^* for two phase composite of σ_1 and σ_2

optimal bounds on σ^* for known volume fractions p_1 and p_2:

$$\frac{1}{\frac{p_1}{\sigma_1} + \frac{p_2}{\sigma_2}} \leq \sigma^* \leq p_1\sigma_1 + p_2\sigma_2$$



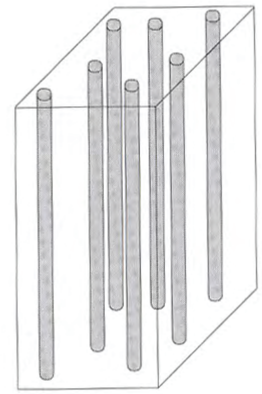
Wiener, 1912

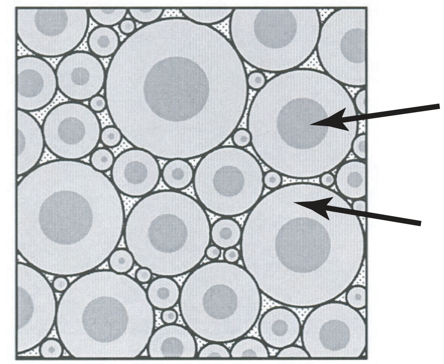
PIPE BOUNDS on vertical fluid permeability k

vertical pipes

with appropriate radii

maximize k

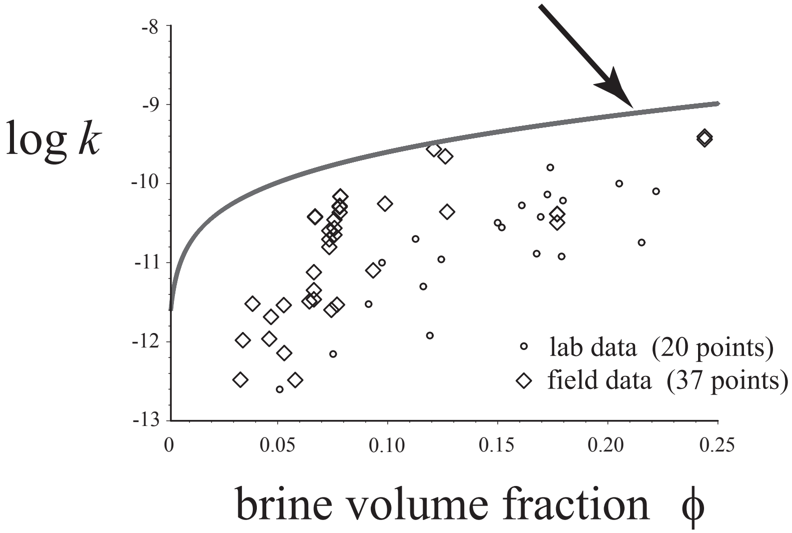




optimal coated cylinder geometry

fluid analog of arithmetic mean upper bound for effective conductivity of composites (Wiener 1912)

lognormal pipe bound



inclusion cross sectional areas A lognormally distributed

$$k \;\le\; \frac{\phi\langle R^4\rangle}{8\langle R^2\rangle} \;=\; \frac{\phi}{8}\langle R^2\rangle e^{\sigma^2}$$

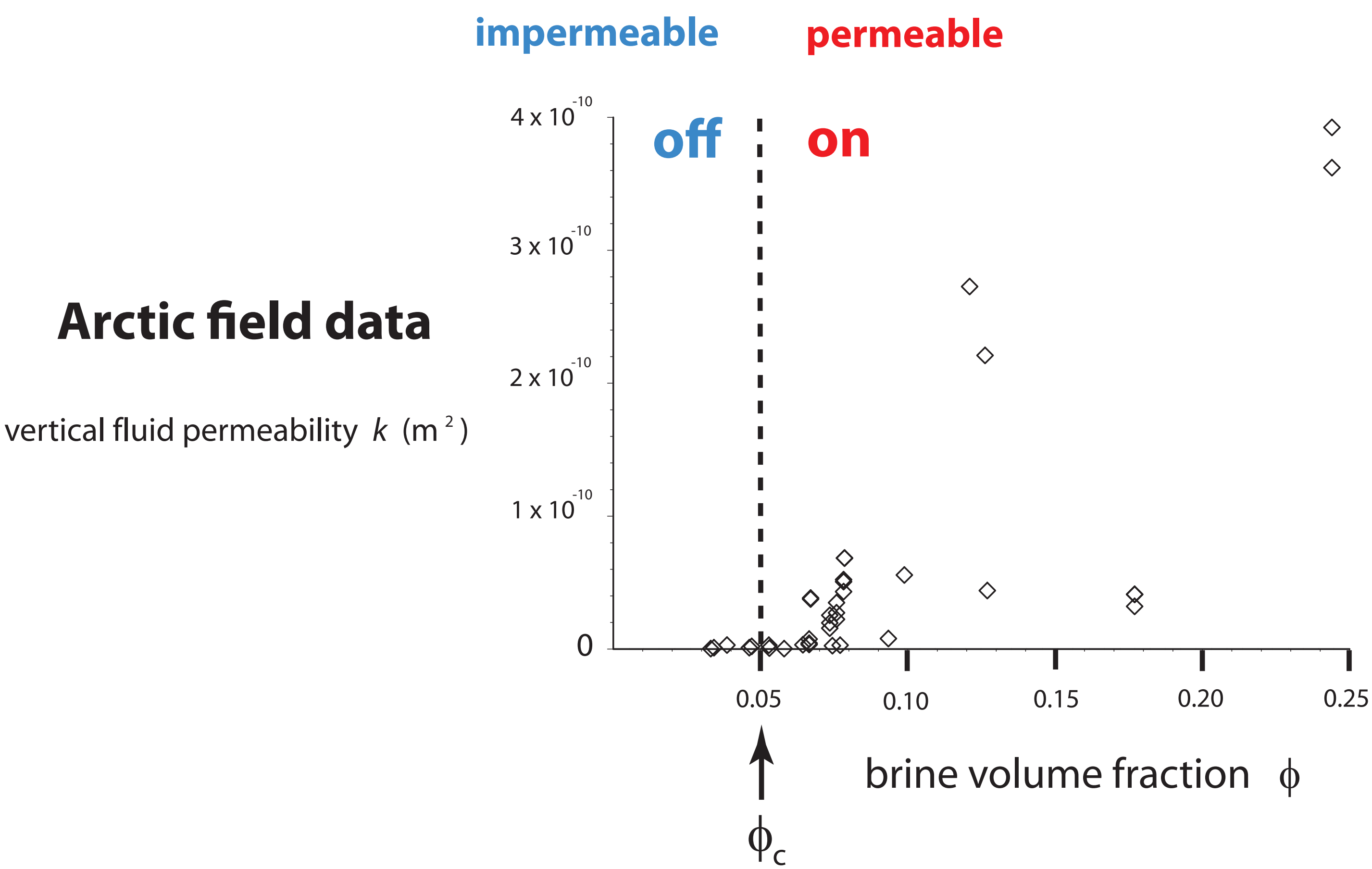
get bounds through variational analyis of ***trapping constant*** γ for diffusion process in pore space with absorbing BC

$$\mathbf{k} \;\le\; \gamma^{-1}\mathbf{I}$$

for any ergodic porous medium (Torquato 2002, 2004)

Golden, Eicken, Heaton, Miner, Pringle, Zhu, Geophys. Res. Lett. 2007
Golden, Heaton, Eicken, Lytle, Mech. Materials 2006

Critical behavior of fluid transport in sea ice



on - off switch for fluid flow

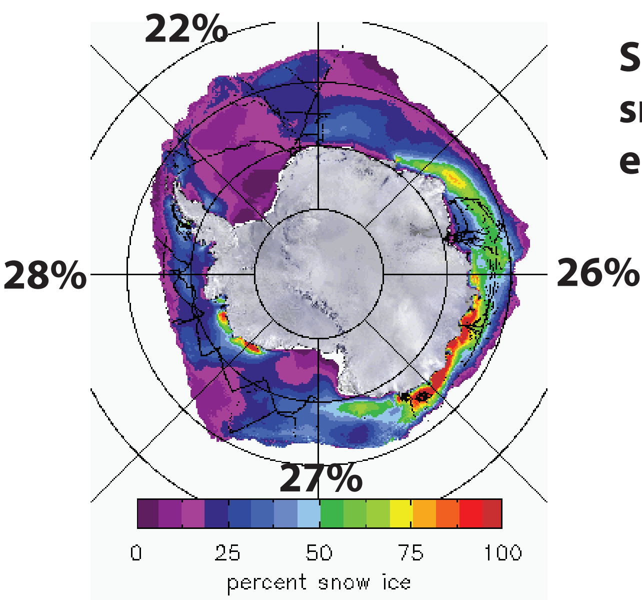
critical brine volume fraction $\phi_c \approx 5\%$ $\longleftrightarrow$ $T_c \approx -5^\circ C$, $S \approx 5$ ppt

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

rule of fives constrains:

Antarctic surface flooding and snow-ice formation

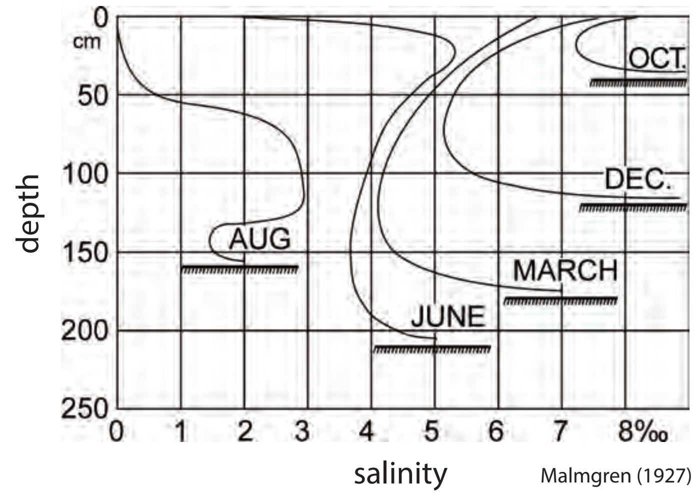


September snow-ice estimates

Antarctic snow-to-ice conversion from passive microwave imagery

T. Maksym and T. Markus, 2008

evolution of salinity profiles



currently assumed constant in climate models

convection - enhanced thermal conductivity

Lytle and Ackley, 1996
Trodahl, et. al., 2000, 2001
Wang, Zhu, Golden, 2012

evolution of melt ponds and sea ice albedo

sea ice algal communities

D. Thomas 2004

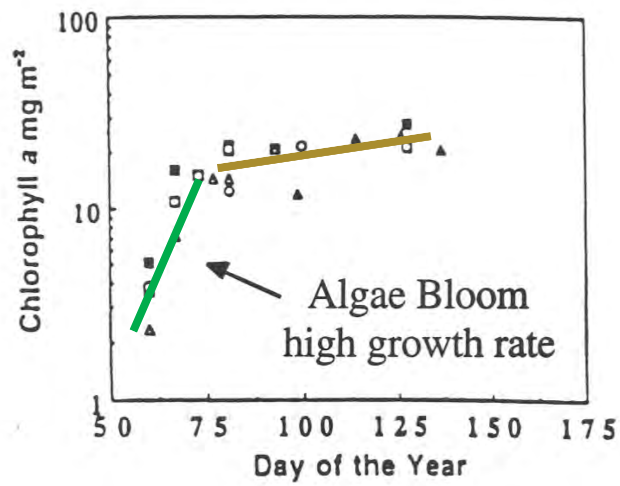
nutrient replenishment controlled by ice permeability

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

sea ice ecosystem

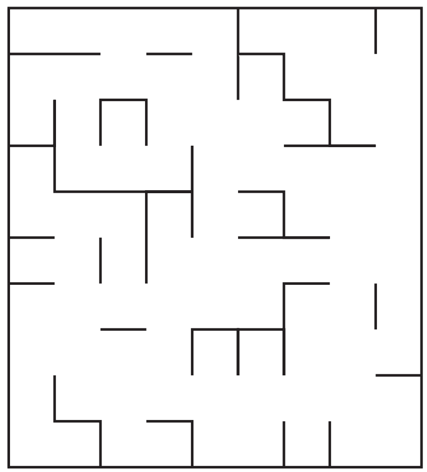
sea ice algae
support life in the polar oceans

Why is the rule of fives true?

percolation theory

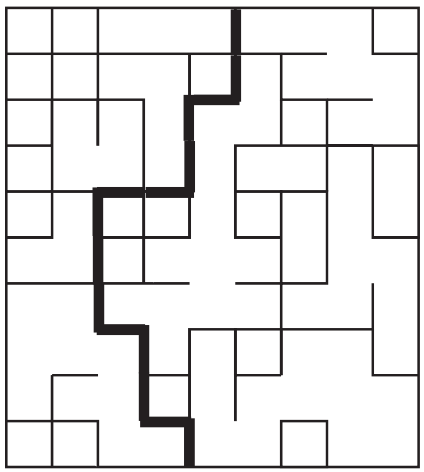
mathematical theory of connectedness

impermeable



$p = 1/3$

permeable



$p = 2/3$

bond → *open* *with probability p*
closed *with probability 1-p*

percolation threshold

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

first appearance of infinite cluster ***"tipping point" for connectivity***

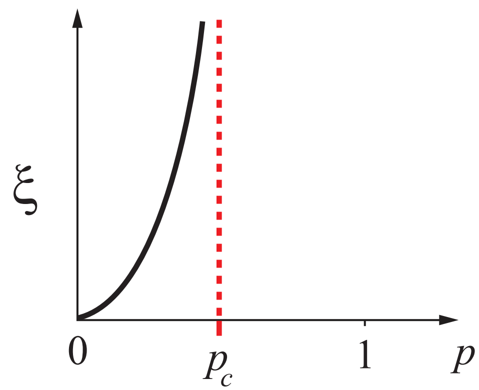
order parameters in percolation theory

geometry

transport

correlation length

characteristic scale
of connectedness

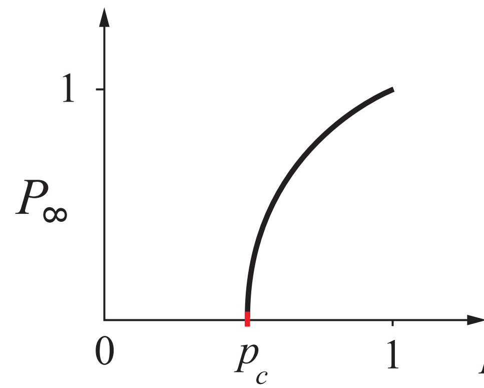


$$\xi(p) \sim |p - p_c|^{-\nu}$$

$$p \to p_c$$

infinite cluster density

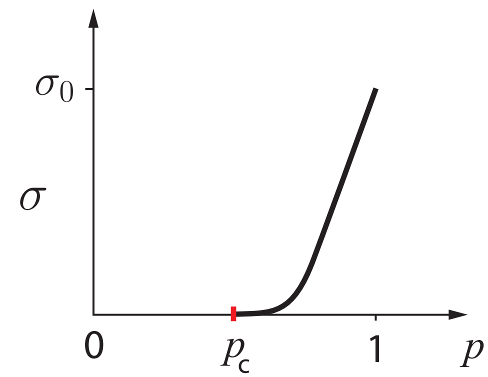
probability the origin
belongs to infinte cluster



$$P_\infty(p) \sim (p - p_c)^\beta$$

$$p \to p_c^+$$

effective conductivity or fluid permeability



$$\sigma(p) \sim \sigma_0 \, (p - p_c)^t$$

$$p \to p_c^+$$

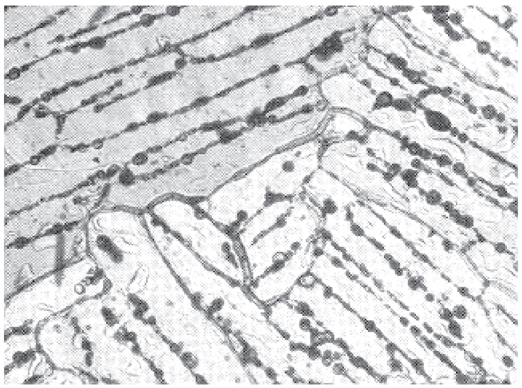
UNIVERSAL critical exponents for lattices -- depend only on dimension

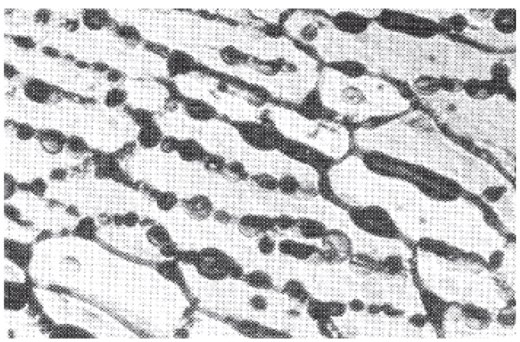
(**1 ≤ *t* ≤ 2,** Golden, *Phys. Rev. Lett.* 1990 **;** *Comm. Math. Phys.* 1992)

non-universal behavior in continuum

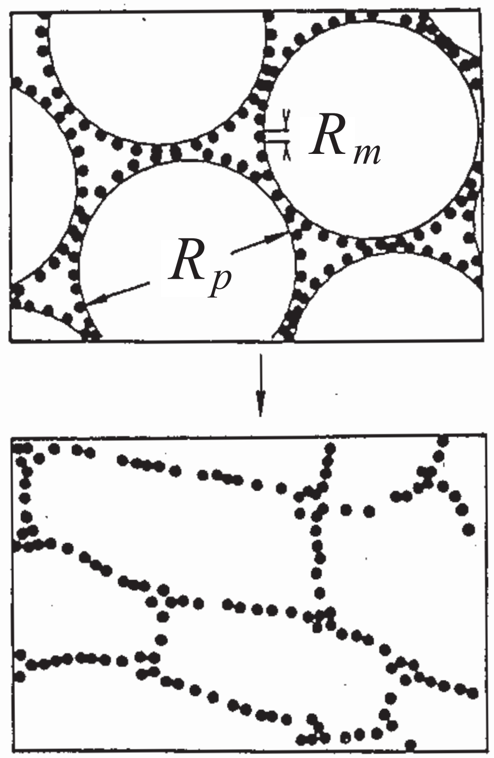
Continuum percolation model for *stealthy* materials applied to sea ice microstructure explains **Rule of Fives** and Antarctic data on ice production and algal growth

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

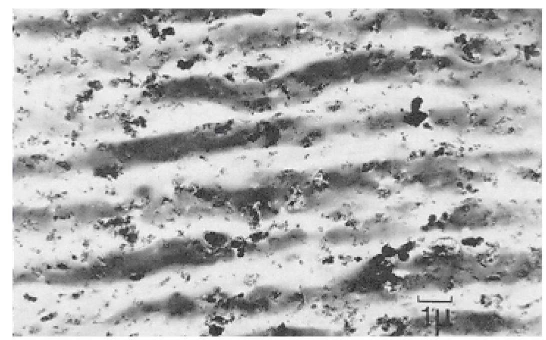




sea ice



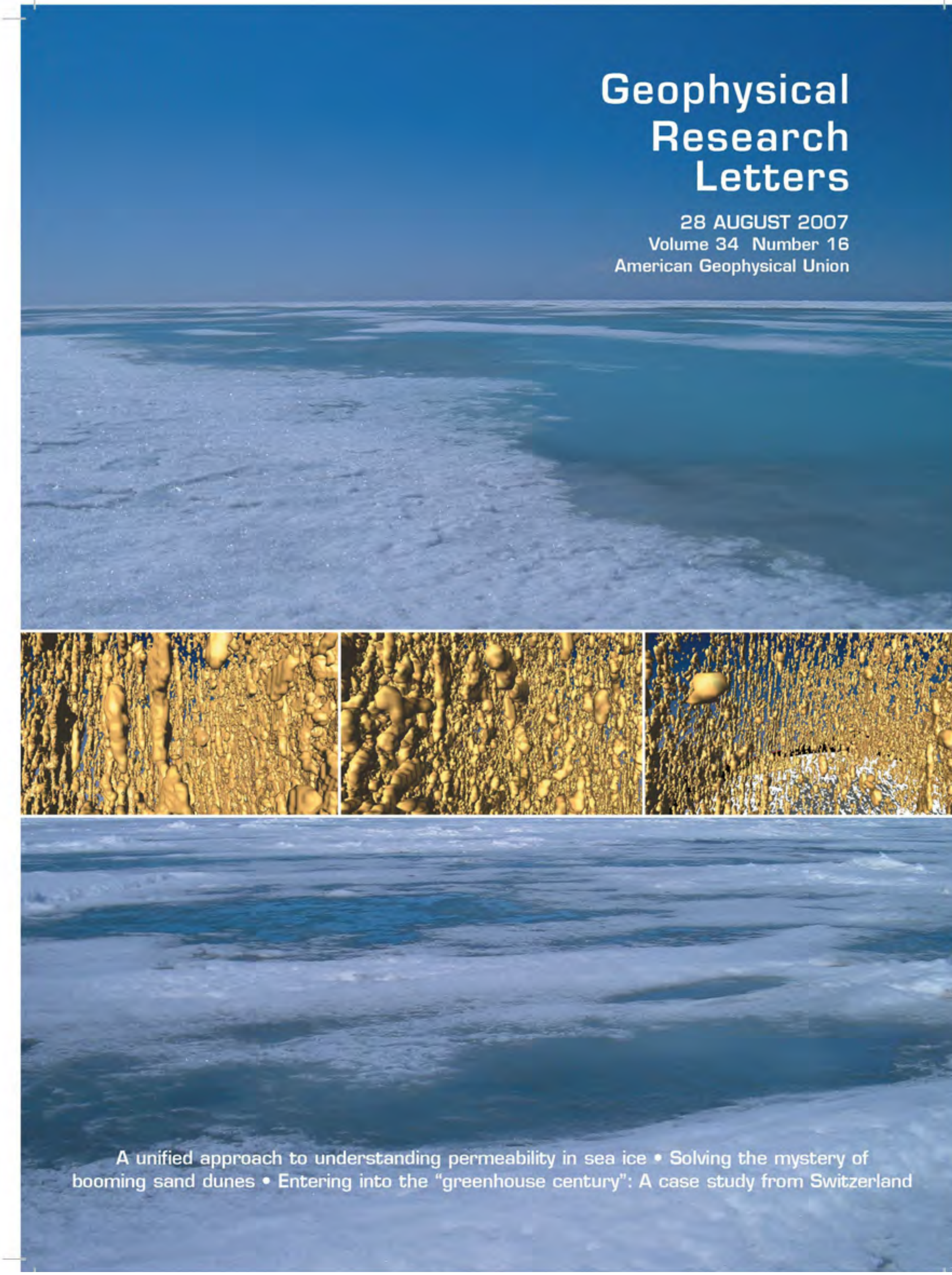
compressed powder



radar absorbing composite

sea ice is radar absorbing

Thermal evolution of permeability and microstructure in sea ice **Golden, Eicken, Heaton, Miner, Pringle, Zhu**



rigorous bounds
percolation theory
hierarchical model
network model

field data

micro-scale

controls

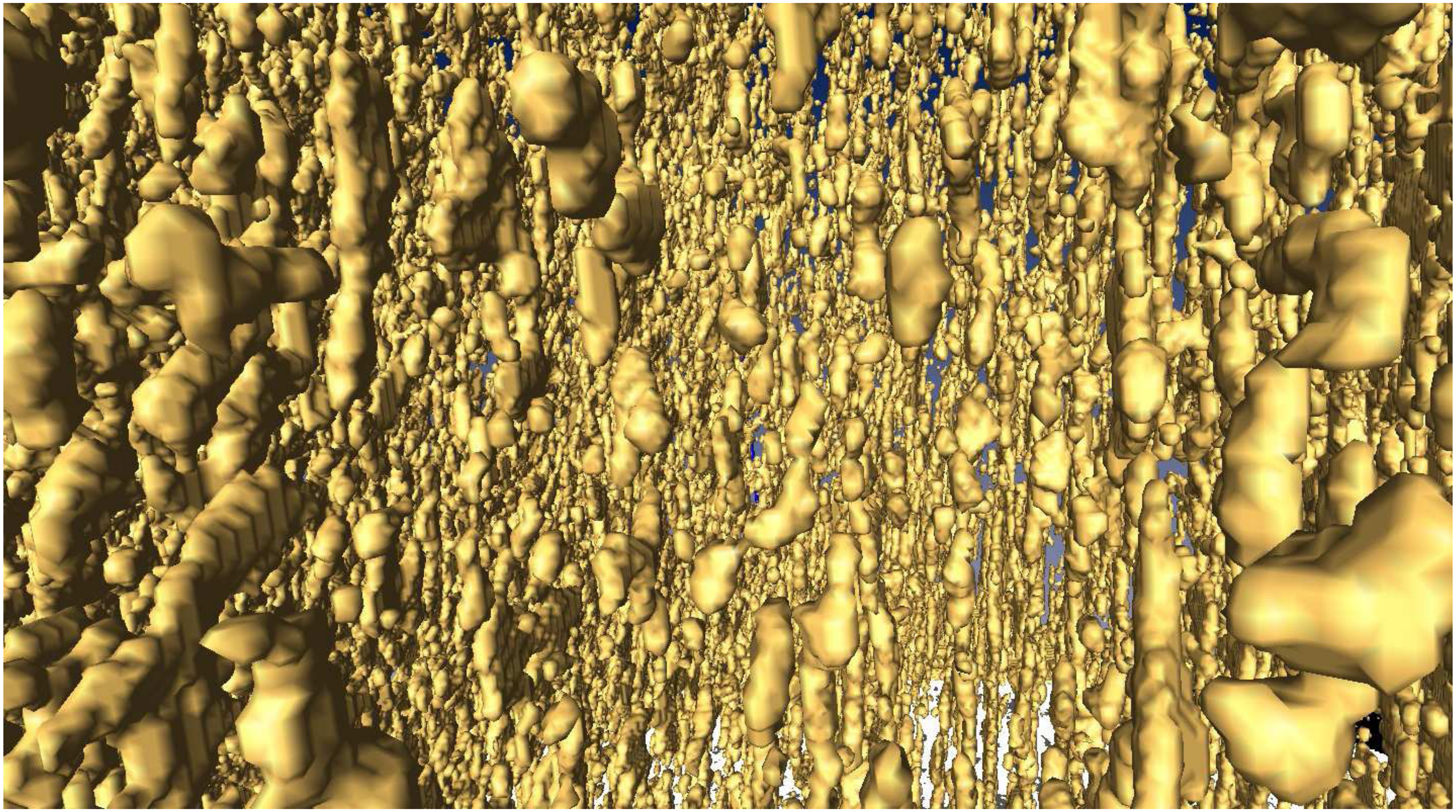
macro-scale processes

X-ray tomography for brine inclusions

unprecedented look at thermal evolution of brine phase and its connectivity

X-ray computed tomography of brine inclusions in sea ice

~ 1 cm across

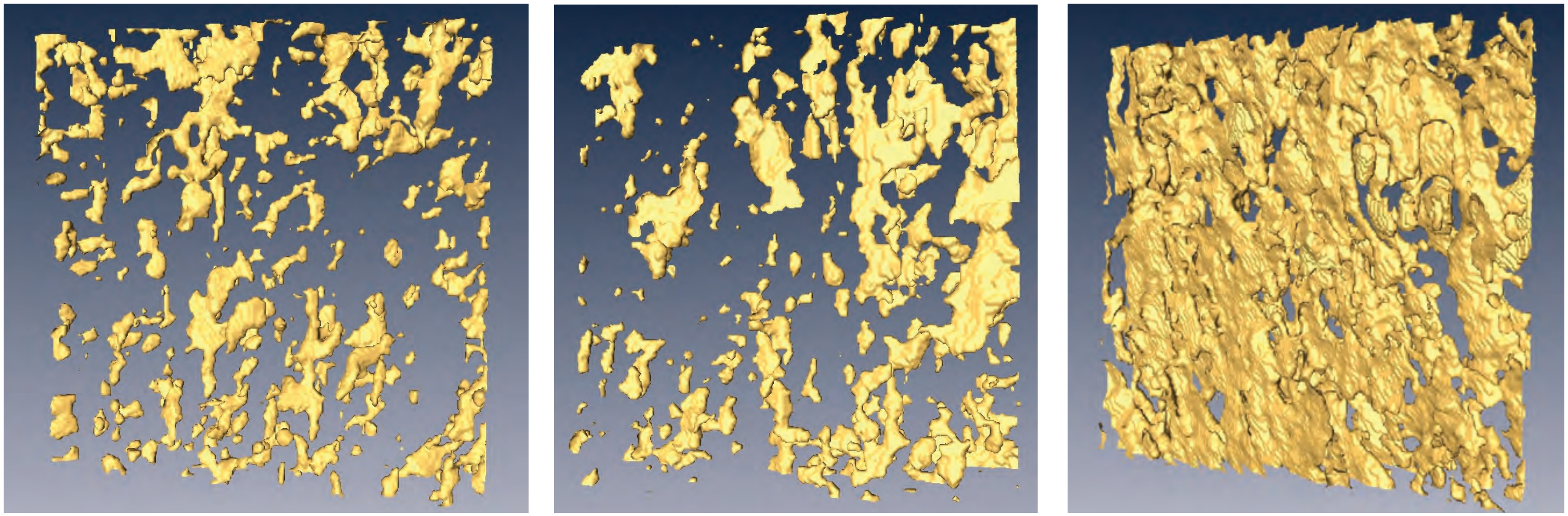


brine volume fraction $\phi = 5.7\ \%$ $T = -\,8^{\circ}C$

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

brine connectivity (over cm scale)

8 x 8 x 2 mm



-15 °C, $\phi = 0.033$ -6 °C, $\phi = 0.075$ -3 °C, $\phi = 0.143$

X-ray tomography confirms percolation threshold

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

analyze graph connectivity as function of temperature and sample size

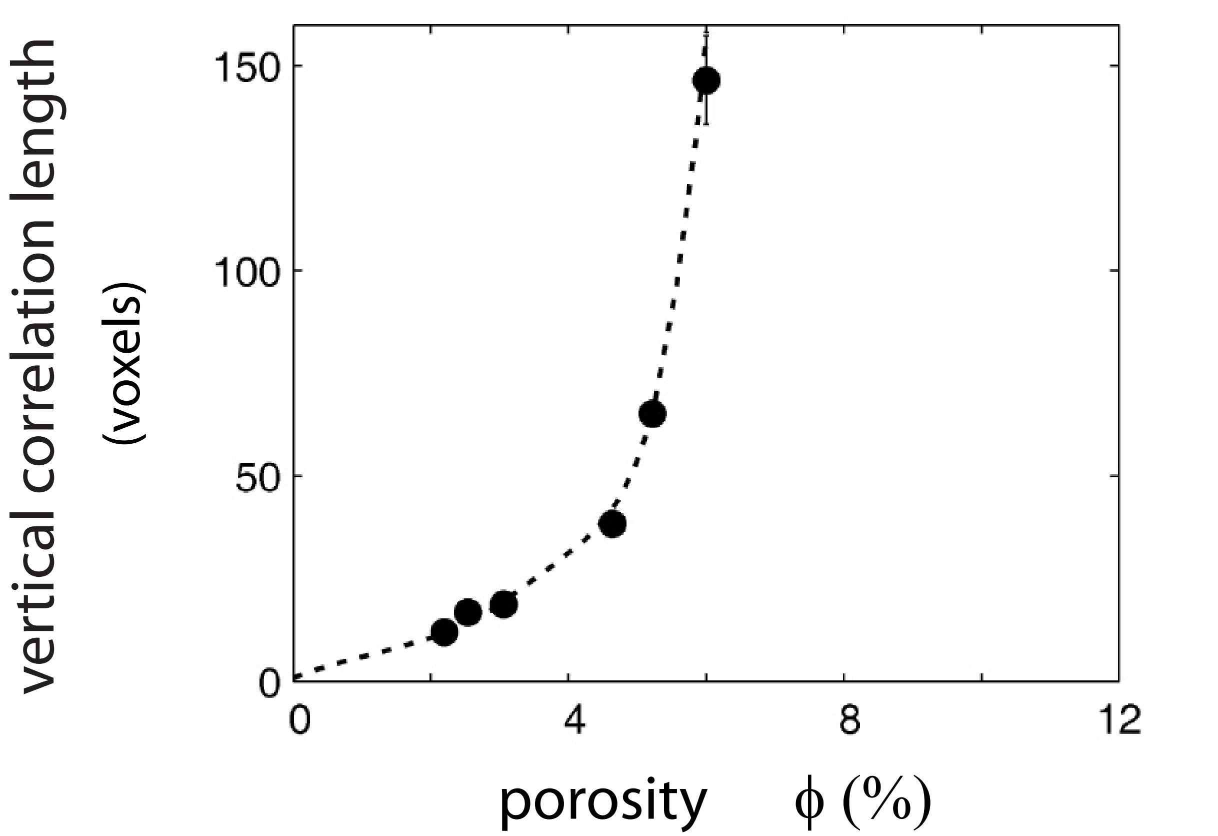
- ***use finite size scaling techniques to confirm rule of fives***
- ***order parameter data from a natural material***

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

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 and estimated anisotropic percolation thresholds.

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



divergence of correlation length for single crystal data

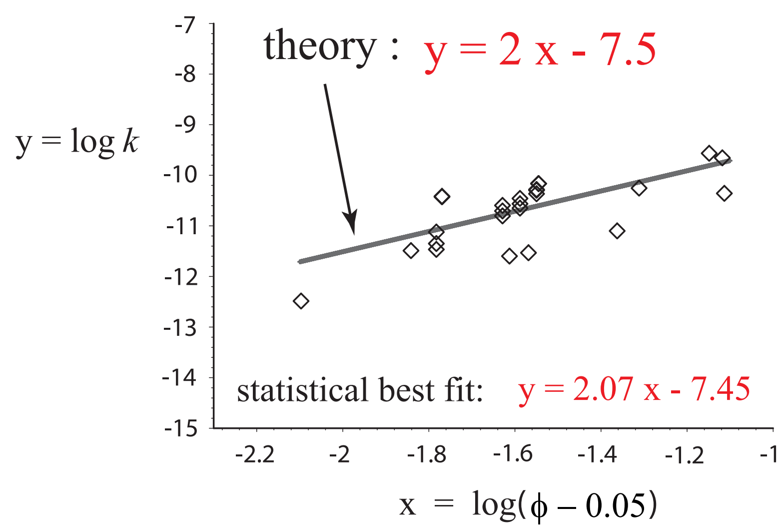
lattice and continuum percolation theories yield:

$$k(\phi) = k_0 (\phi - 0.05)^2$$

critical exponent t

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

- exponent is UNIVERSAL lattice value $t \approx 2.0$
- sedimentary rocks like sandstones also exhibit universality
- critical path analysis -- developed for electronic hopping conduction -- yields scaling factor k_0



Remote sensing of sea ice

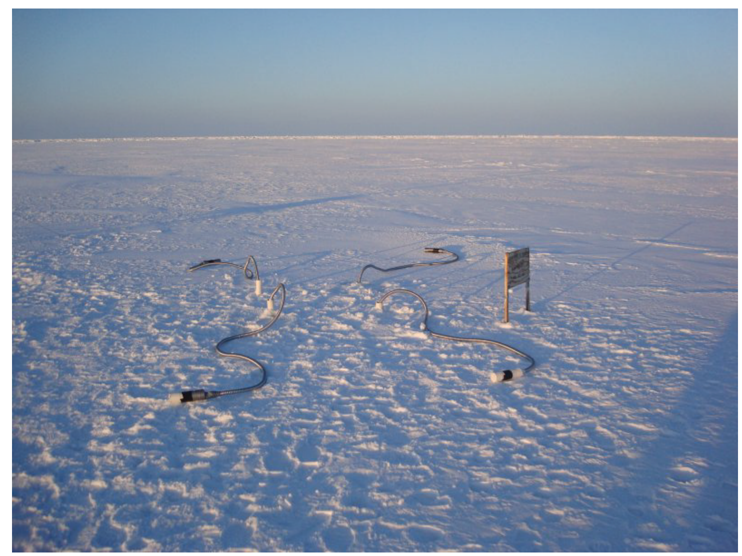
sea ice thickness
ice concentration

INVERSE PROBLEM

Recover sea ice properties from electromagnetic (EM) data

ε^*

effective complex permittivity
(dielectric constant, conductivity)



brine volume fraction
brine inclusion connectivity

Theory of Effective Electromagnetic Behavior of Composites

analytic continuation method

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

composite geometry
(spectral measure μ) ⟶ ε^*

integral representations, rigorous bounds, approximations, etc.

Inverse Homogenization Cherkaev and Golden (1998), Day and Thorpe (1999), Cherkaev (2001)
(McPhedran, McKenzie, and Milton, 1982)

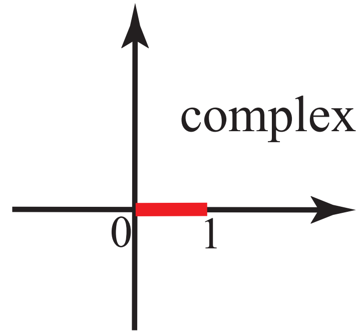
ε^* ⟶ ***composite geometry***
(spectral measure μ)

recover brine volume fraction, connectivity, etc.

Stieltjes integral representation

separation of geometry from parameters

$$s = \frac{1}{1 - \epsilon_1 / \epsilon_2}$$



$$F(s) = 1 - \frac{\epsilon^*}{\epsilon_2} = \int_0^1 \frac{d\mu(z)}{s - z}$$

μ —
- spectral measure of self adjoint operator $\Gamma\chi$
- mass $= p_1$
- higher moments depend on n-point correlations

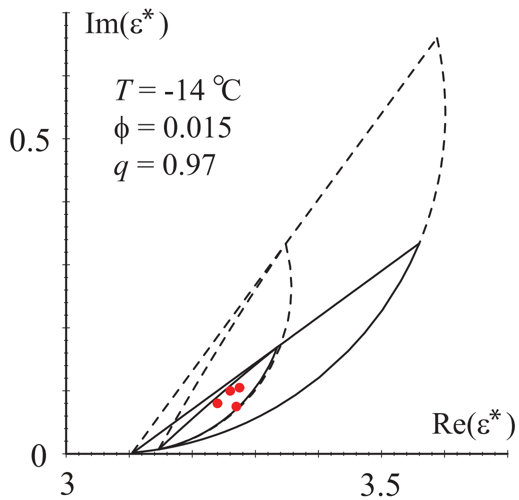
$$\Gamma = \nabla(-\Delta)^{-1}\nabla\cdot$$

$\chi =$ characteristic function of the brine phase

Golden and Papanicolaou, Comm. Math. Phys. 1983

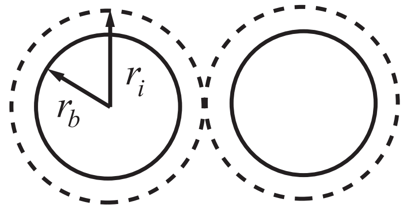
forward and inverse bounds for sea ice

forward bounds



4.75 GHz data

matrix particle

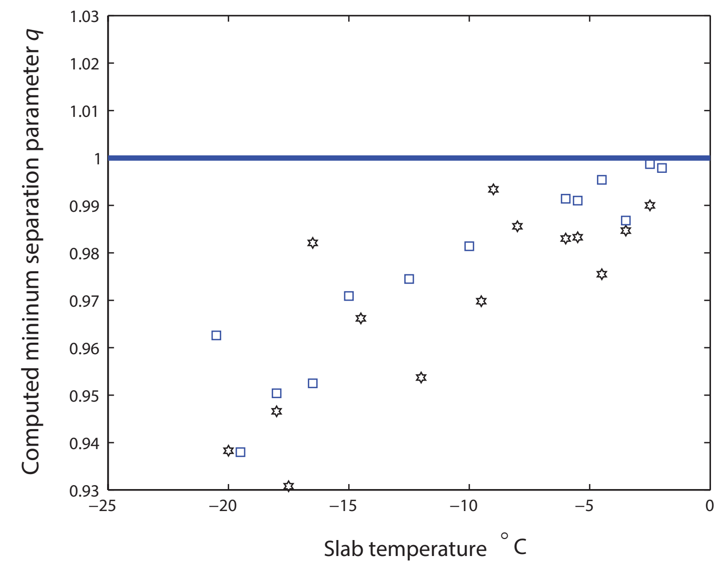


$$q = r_b / r_i$$

$$0 < q < 1$$

Golden 1995, 1997

inverse bounds



inverse bounds and recovery of brine porosity

Gully, Backstrom, Eicken, Golden
Physica B, 2007

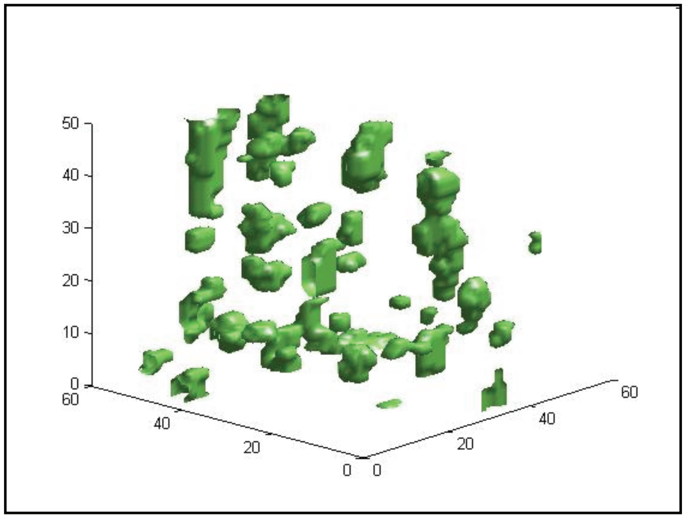
polycrystalline bounds

Gully, Lin, Cherkaev, Golden, 2013

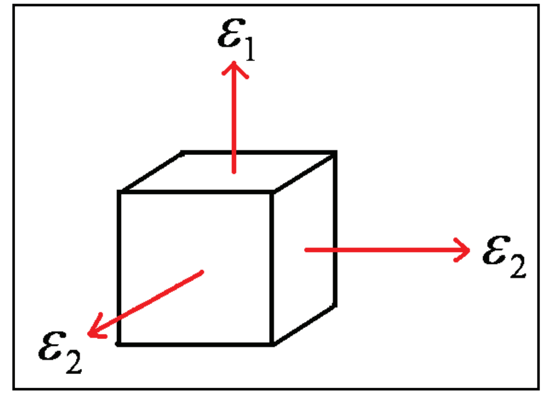
inversion for brine inclusion separations in sea ice from measurements of effective complex permittivity ε^*

Orum, Cherkaev, Golden
Proc. Roy. Soc. A, 2012

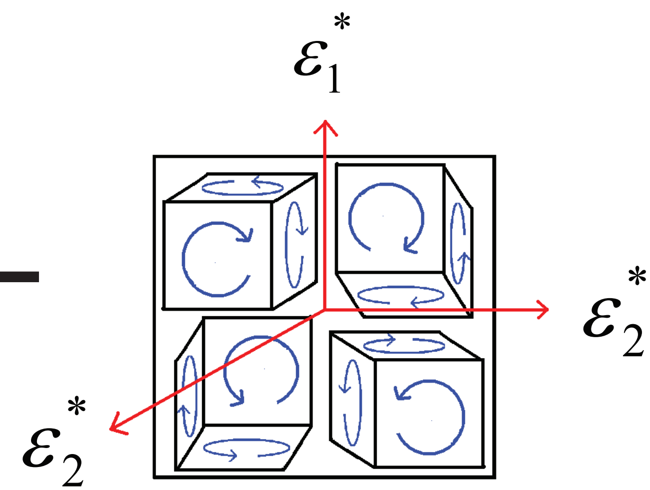
two scale homogenization for polycrystalline sea ice



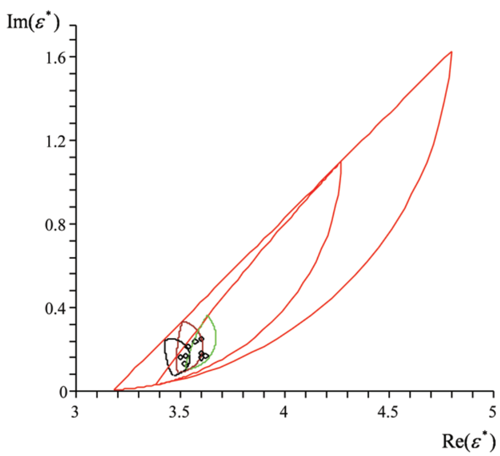
numerical homogenization for single crystal

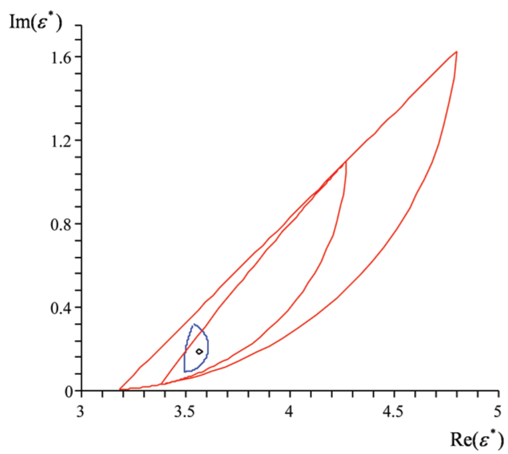


analytic continuation for polycrystals



bounds



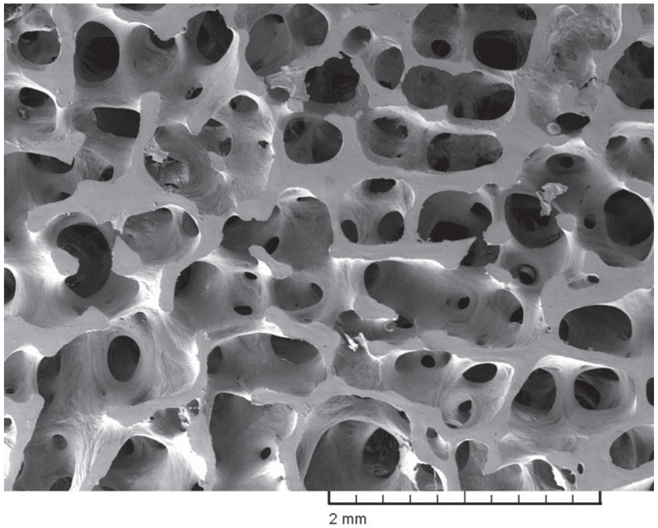


Gully, Lin, Cherkaev, Golden 2013

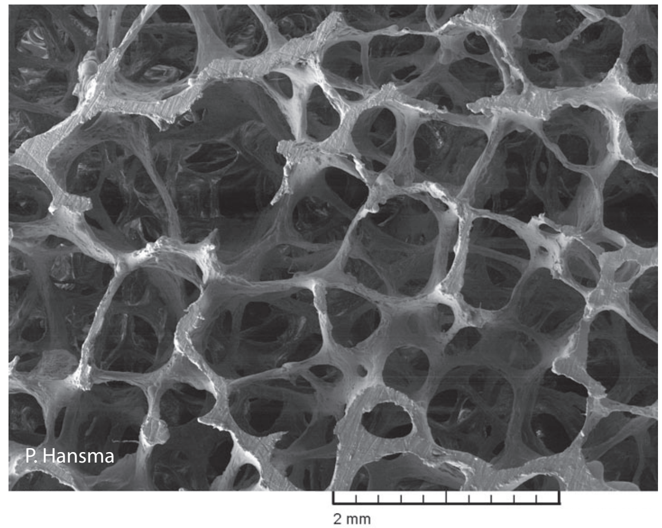
spectral characterization of porous microstructures in bone

Golden, Murphy, Cherkaev, J. Biomechanics 2011

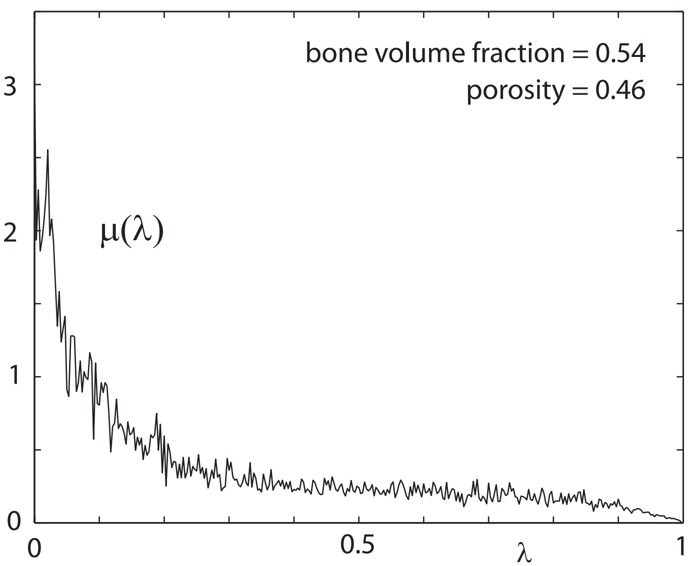
(a) young healthy trabecular bone



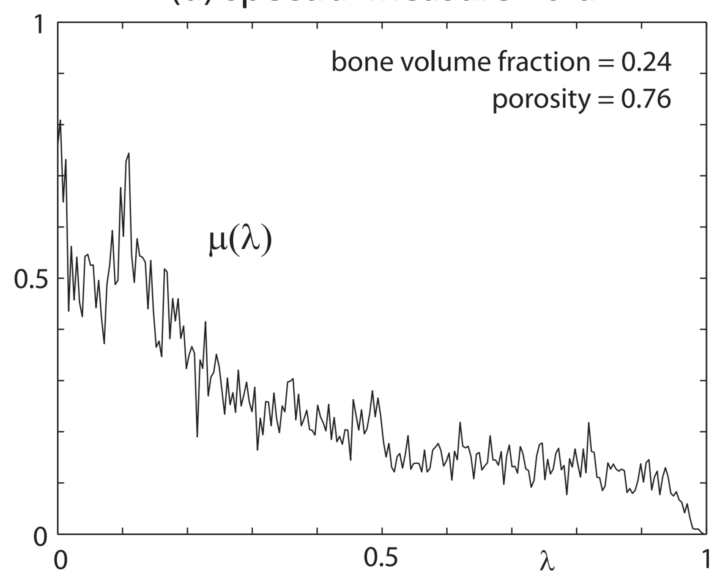
(b) old osteoporotic trabecular bone



(c) spectral measure - young



(d) spectral measure - old



+

reconstruction of spectral measures from complex permittivity data

using regularized inversion scheme

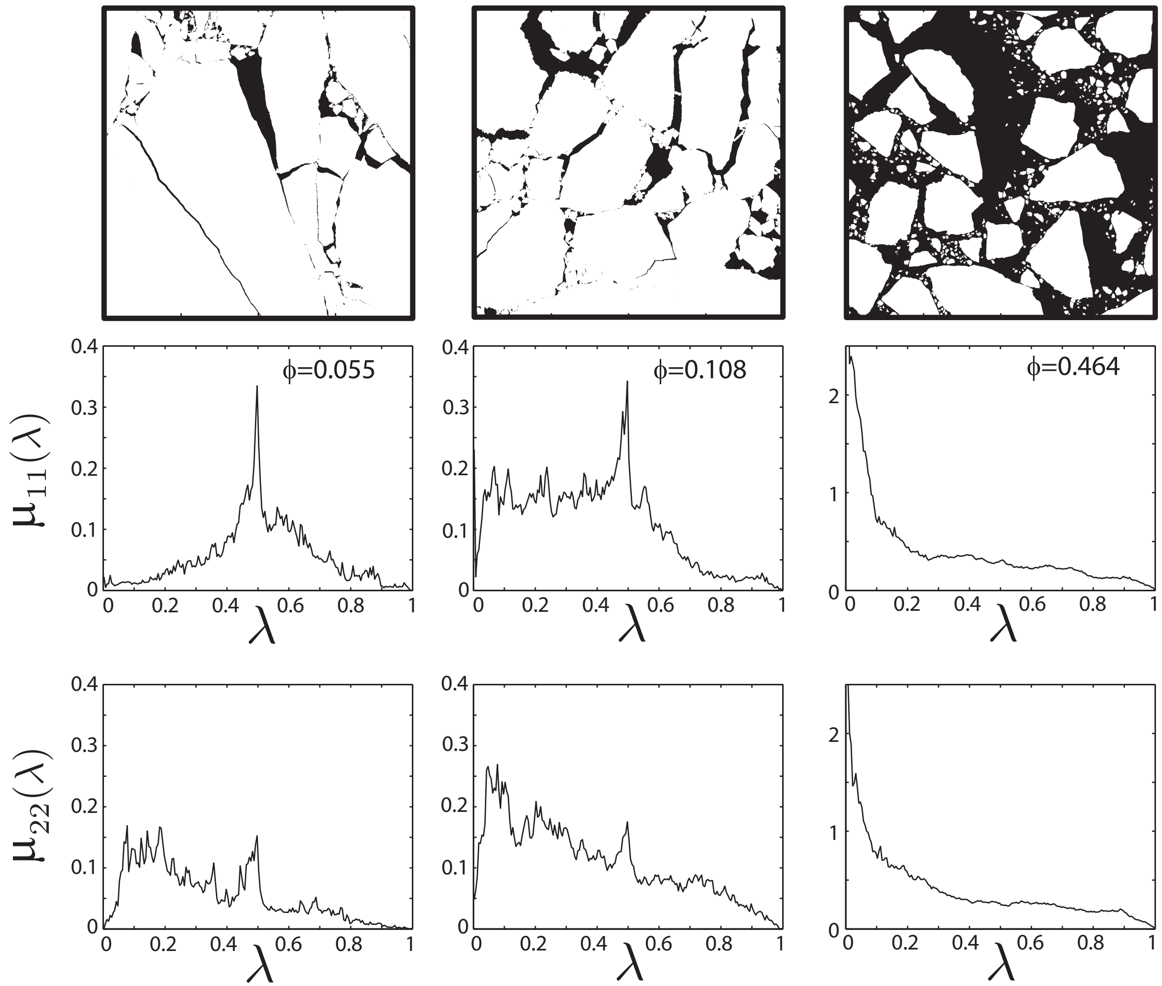
EM monitoring of osteoporosis

loss of bone connectivity

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

spectral measures provide a path toward rigorously incorporating "composite microstructure" into calculations of effective behavior on larger scales

spectral measures for the Arctic sea ice pack



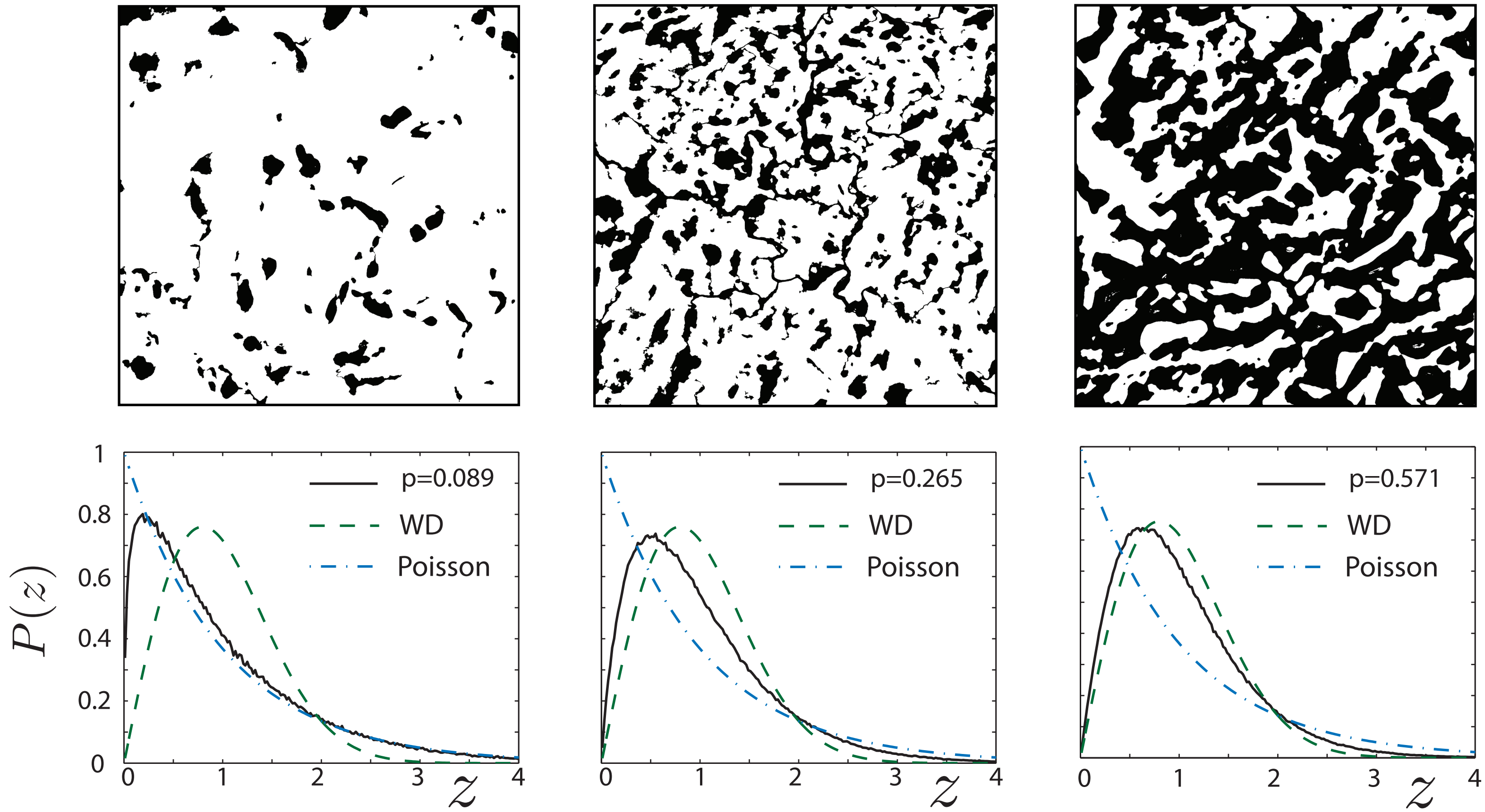
area under curve = φ = open water fraction

spectral gap closes as ocean phase becomes connected

N. B. Murphy, C. Hohenegger, C. S. Sampson, D. K. Perovich, H. Eicken, E. Cherkaev, B. Alali, and K. M. Golden, 2013 *random matrix characterization of connectedness transition -- discretization of* $\chi\Gamma\chi$

Unfolded Eigenvalue Spacing Distribution

ARCTIC MELT PONDS



eigenvalue statistics for transport tend toward the UNIVERSAL Wigner-Dyson distribution as the "conducting" phase becomes connected over large scales

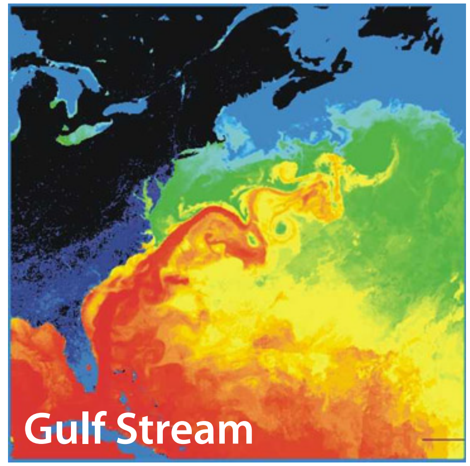
uncorrelated → *"level repulsion"*

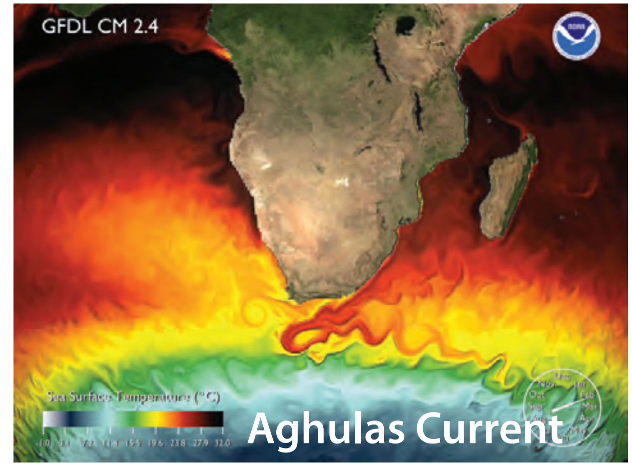
N. B. Murphy, K. M. Golden 2013

advection enhanced diffusion

effective diffusivity

tracers, buoys diffusing in ocean eddies
diffusion of pollutants in atmosphere
salt and heat transport in ocean





advection diffusion equation with a velocity field $\vec{u}$

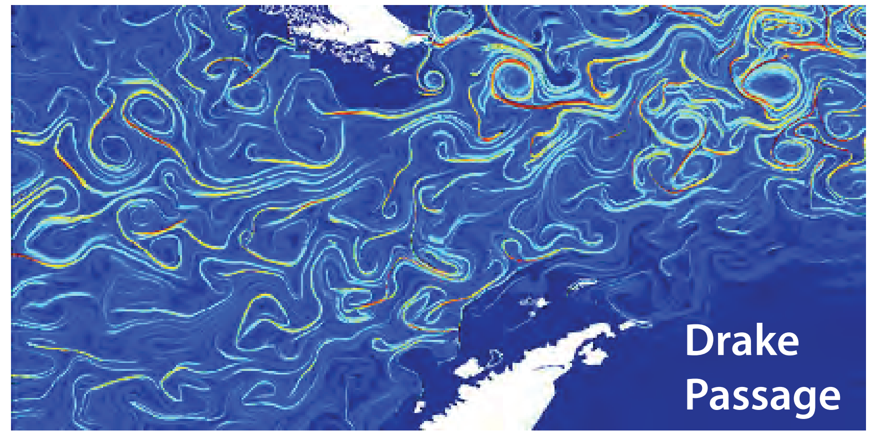
$$\frac{\partial T}{\partial t} + \vec{u} \cdot \vec{\nabla} T = \kappa_0 \Delta T$$

$$\vec{\nabla} \cdot \vec{u} = 0$$

homogenize

$$\frac{\partial \overline{T}}{\partial t} = \kappa^* \Delta \overline{T}$$

κ^* ***effective diffusivity***



Stieltjes integral for κ^* with spectral measure

composites

Golden and Papanicolaou, CMP 1983

$$\frac{\epsilon^*}{\epsilon_2} = 1 - \int_0^1 \frac{d\mu(\lambda)}{s-\lambda}$$

$$s = \frac{1}{1 - \epsilon_1 / \epsilon_2}$$

advection diffusion

Avellaneda and Majda, PRL 89, CMP 91

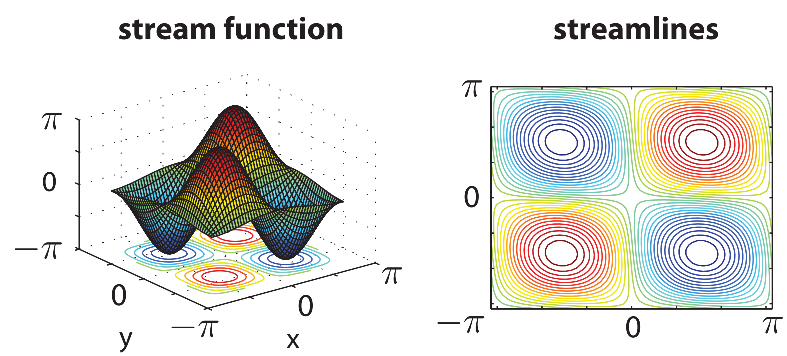
$$\frac{\kappa^*}{\kappa_0} = 1 - \int_0^\infty \frac{d\rho(z)}{t-z}$$

$t = -1/\xi^2$, ξ = Péclet number

- computations of spectral measures and effective diffusivity for model flows

iΓHΓ $\qquad \vec{u} = \kappa_0 \, \xi \, \vec{\nabla} \cdot \mathbf{H}$

Murphy, Zhu, Golden 2013



- rigorous bounds and computations on convection enhanced thermal conductivity of sea ice

Wang, Zhu, Golden 2013

Arctic and Antarctic field experiments

develop electromagnetic methods of monitoring fluid transport and microstructural transitions

extensive measurements of fluid and electrical transport properties of sea ice:

2007	*Antarctic*	*SIPEX*
2010	*Antarctic*	*McMurdo Sound*
2011	*Arctic*	*Barrow AK*
2012	*Arctic*	*Barrow AK*
2012	*Antarctic*	*SIPEX II*
2013	*Arctic*	*Barrow AK*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of the American Mathematical Society

May 2009 Volume 56, Number 5

Climate Change and the Mathematics of Transport in Sea Ice

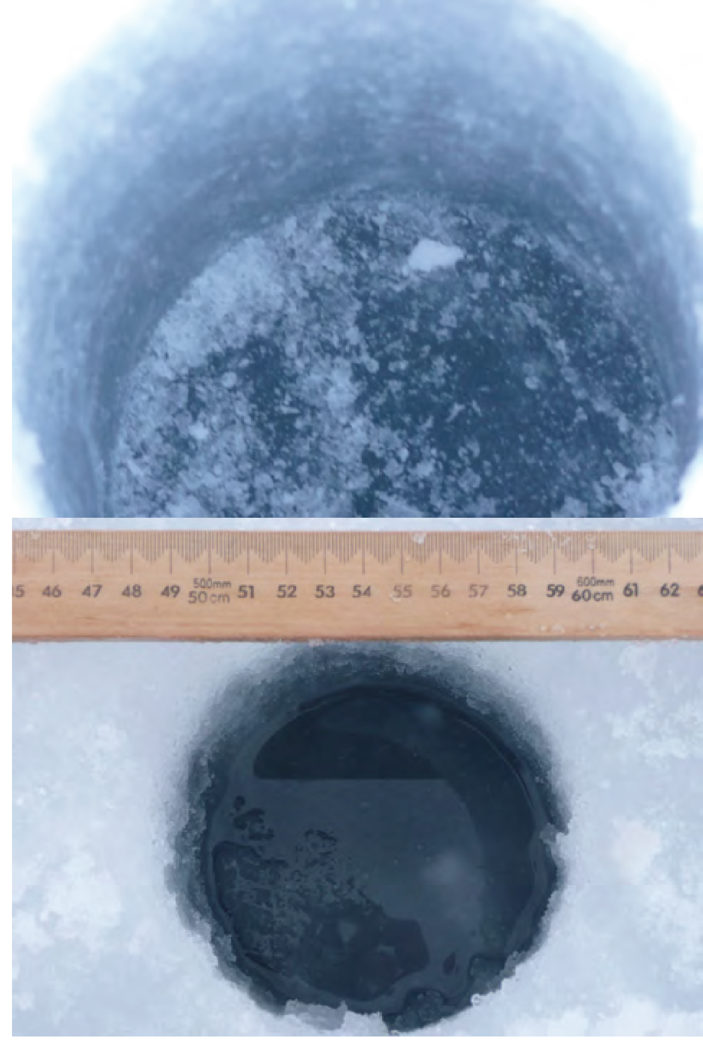
page 562

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

page 586

Real analysis in polar coordinates (see page 613)

photo by Jan Lieser

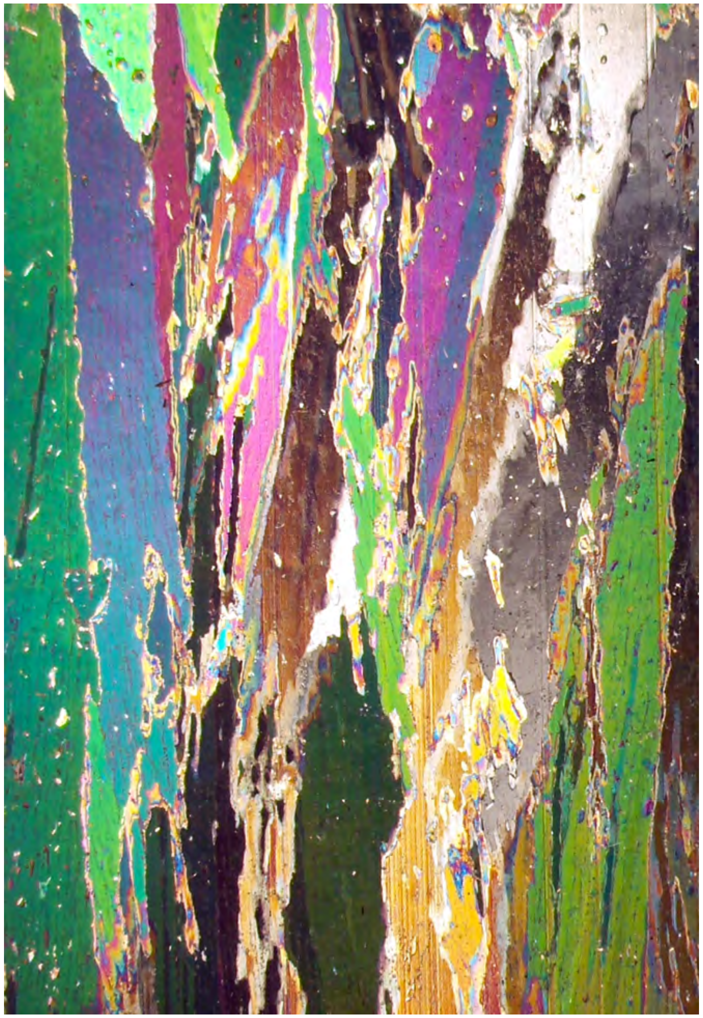


measuring
fluid permeability
of Antarctic sea ice

SIPEX 2007

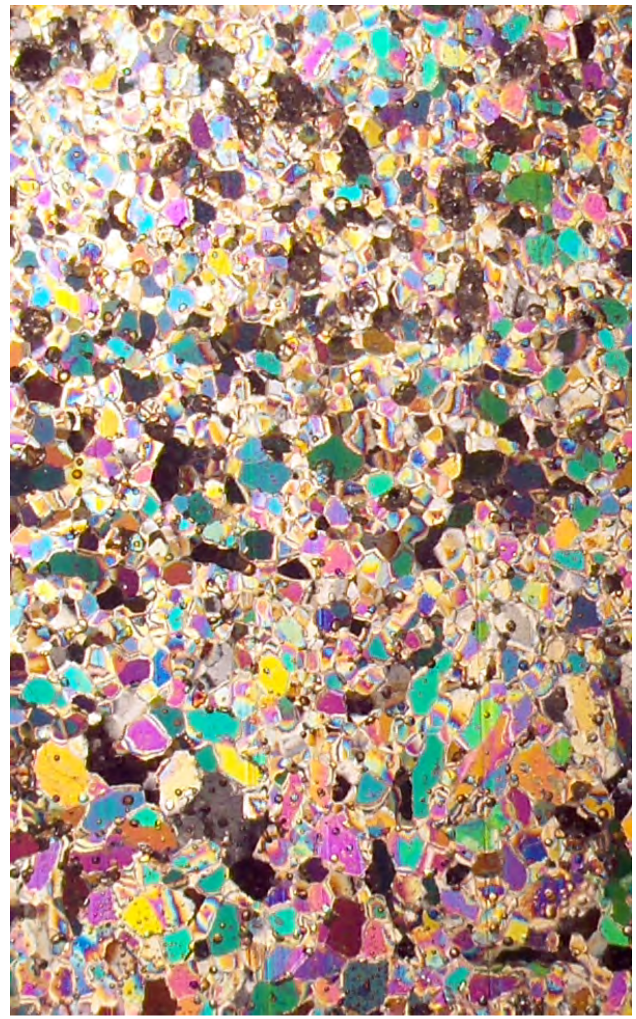
higher threshold for fluid flow in Antarctic granular sea ice

columnar



5%

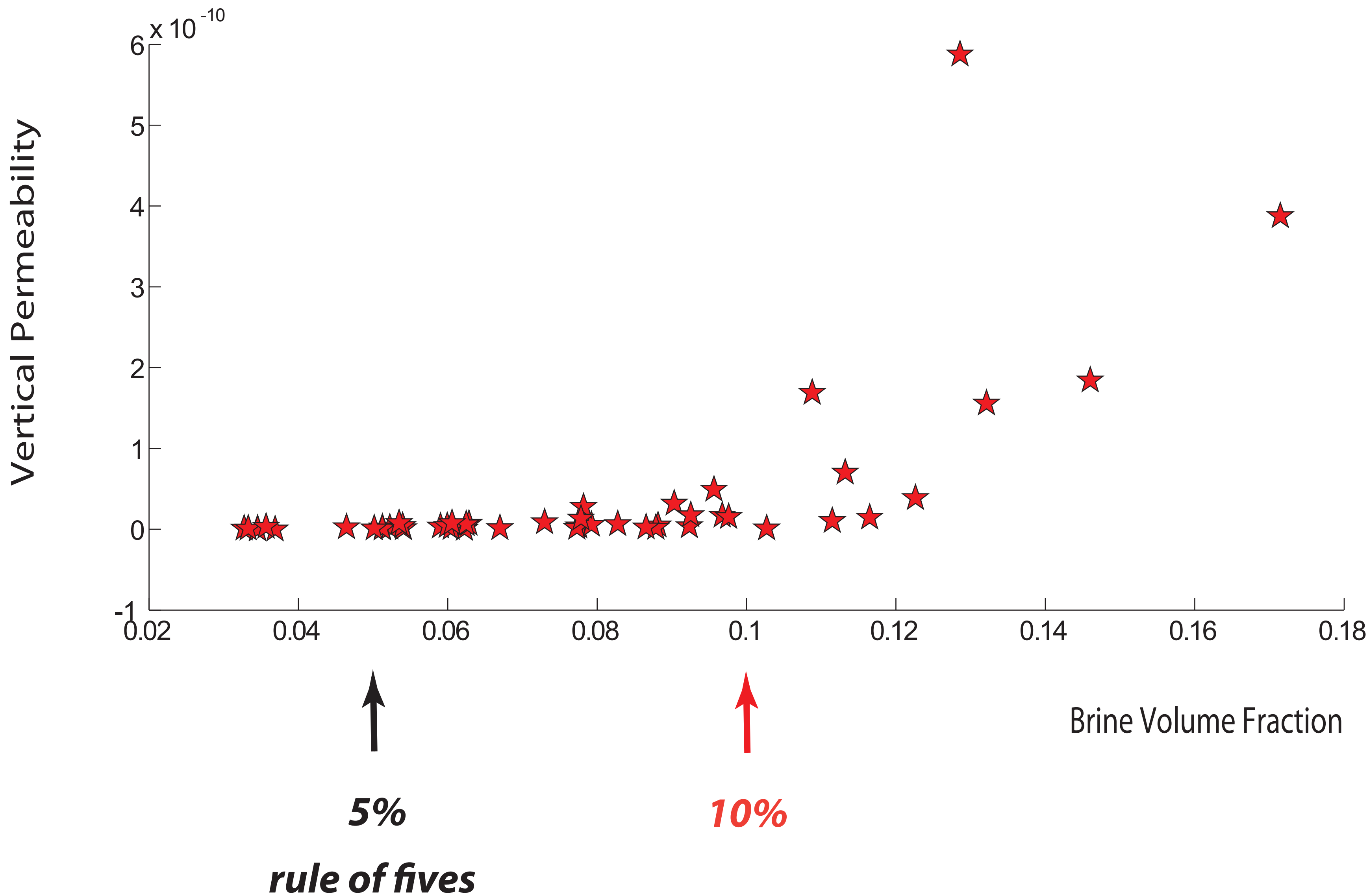
granular



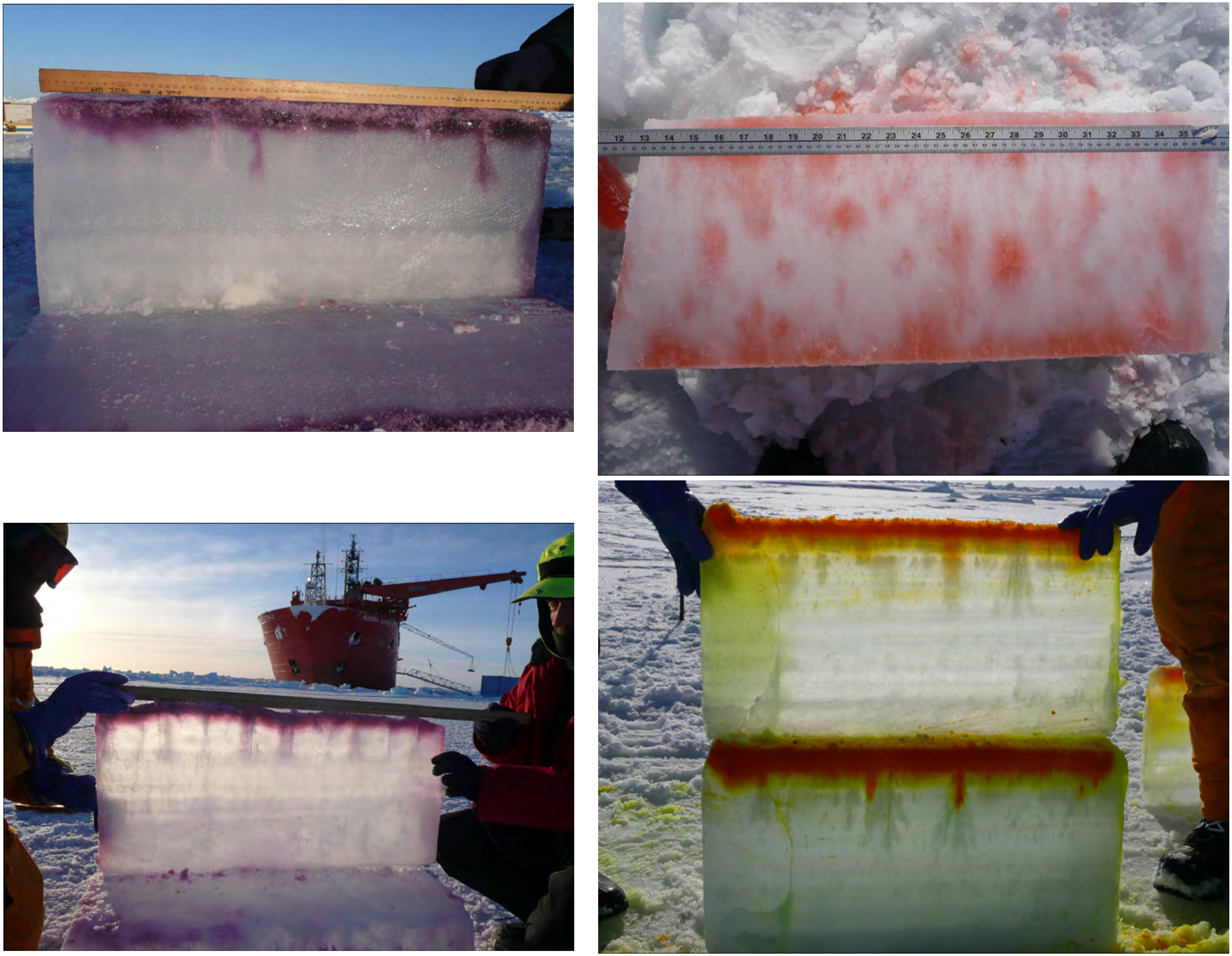
10%

Golden, Gully, Lubbers, Sampson, Tison 2013

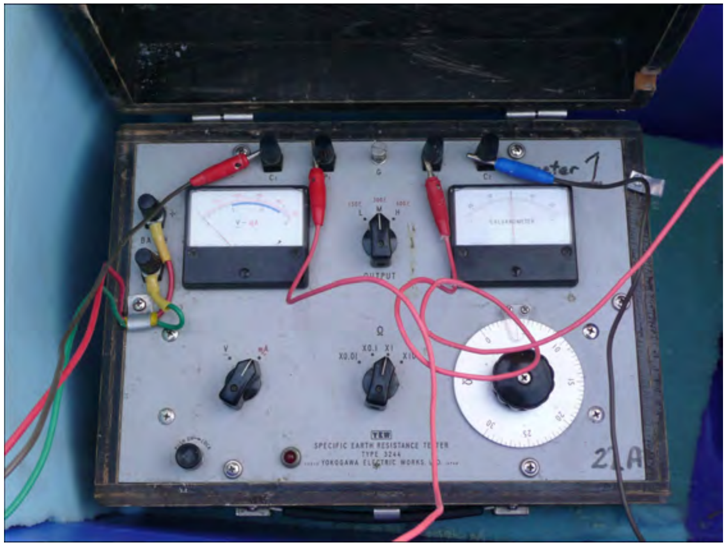
SIPEX II ***preliminary vertical fluid permeability data*** ***September - November 2012***



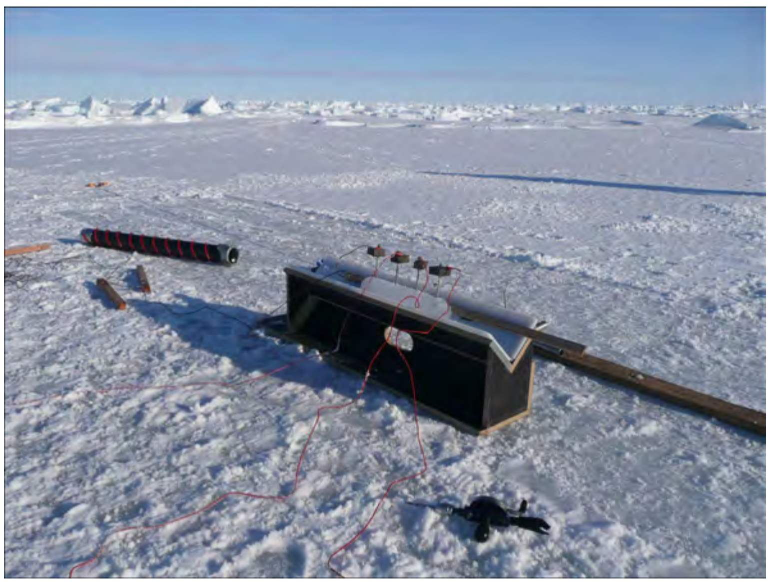
tracers flowing through inverted sea ice blocks

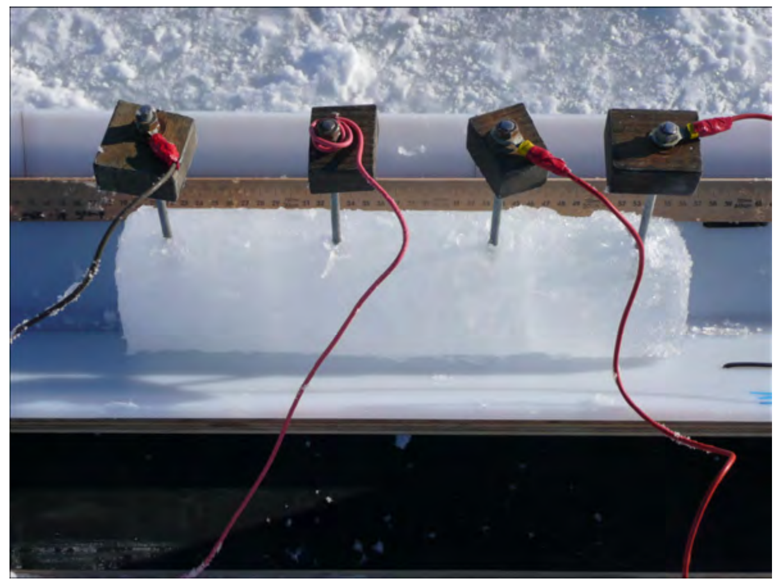


electrical measurements



Wenner array





vertical conductivity

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

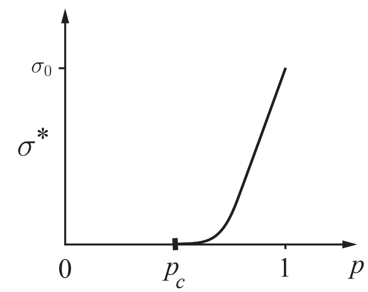
Sampson, Golden, Gully, Worby ***Deep Sea Research*** 2011

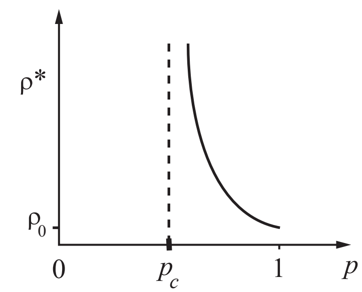
critical behavior of electrical transport in sea ice

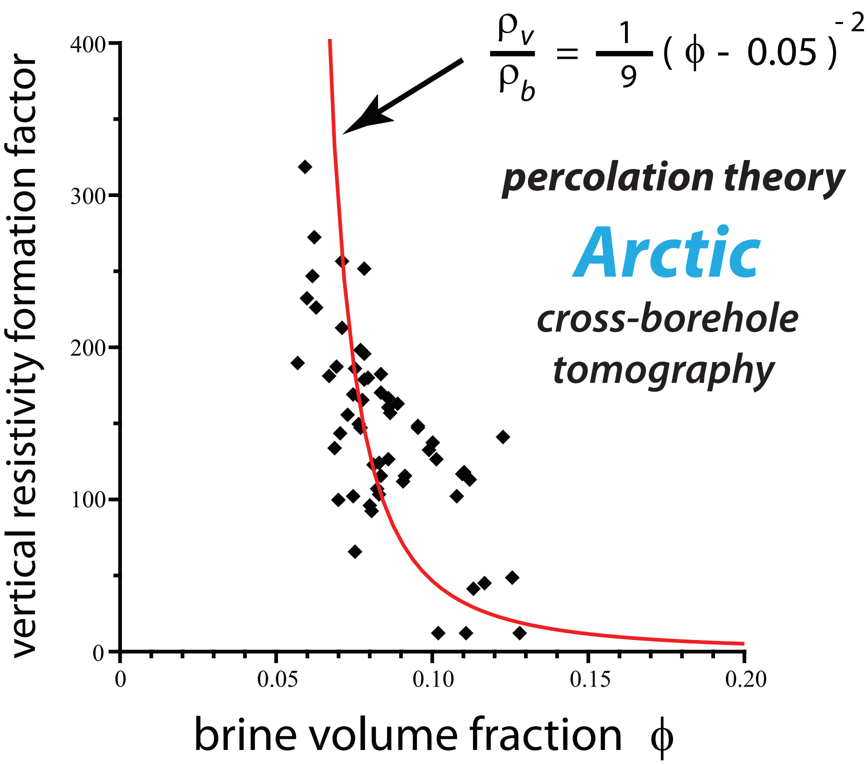
electrical signature of the on-off switch for fluid flow

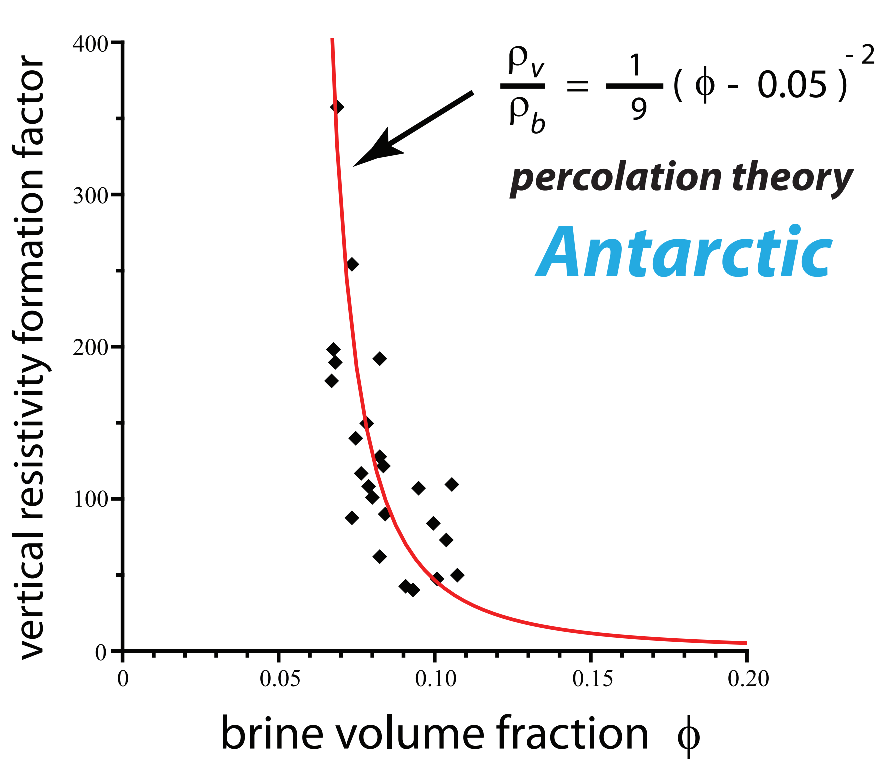
same universal critical exponent as for fluid permeability

studied for over 50 years but no previous observations or theory of critical behavior



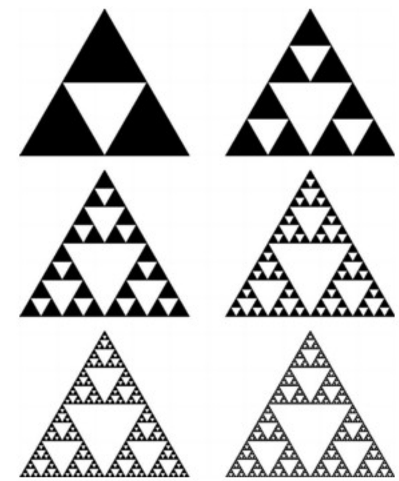




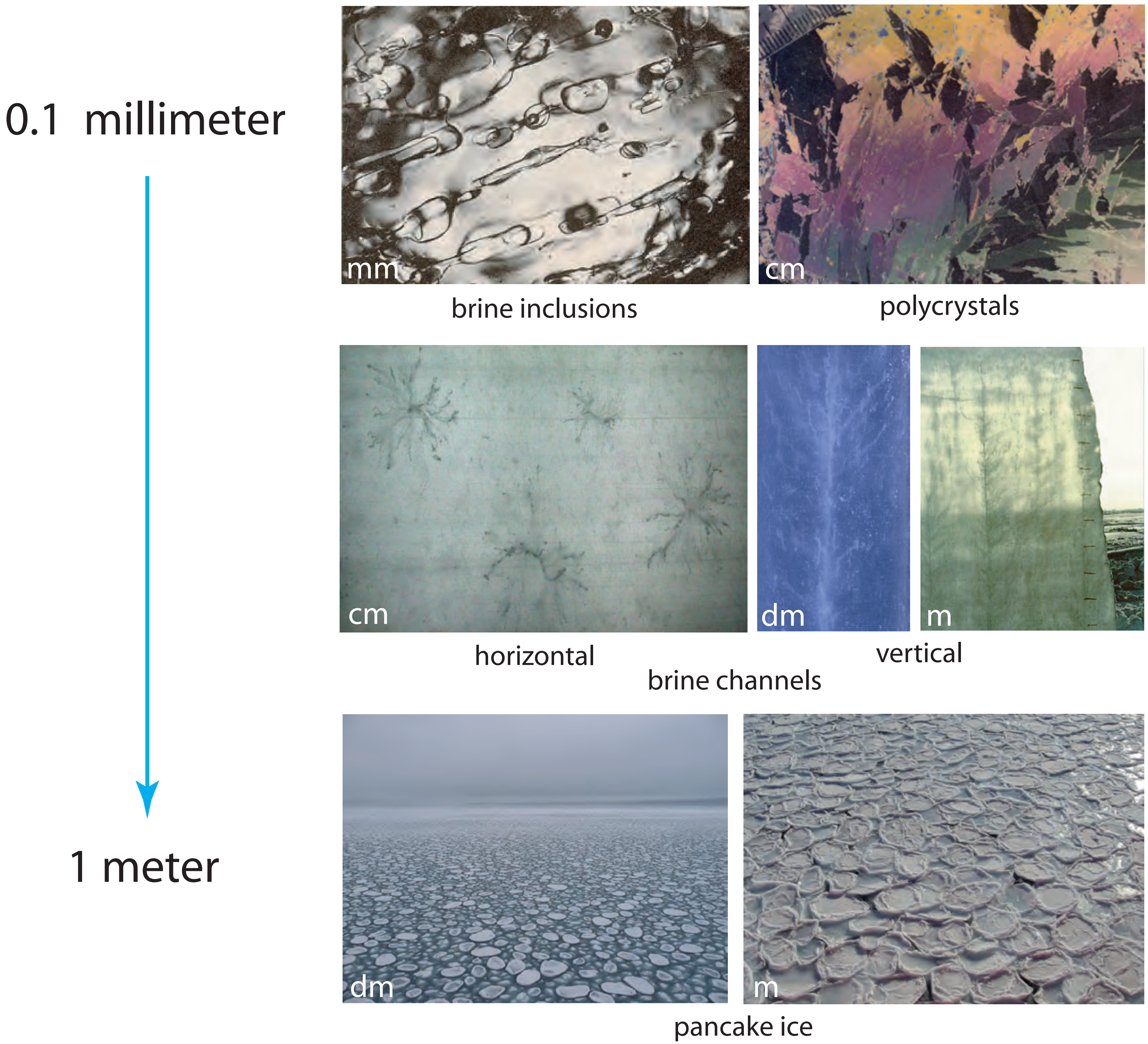


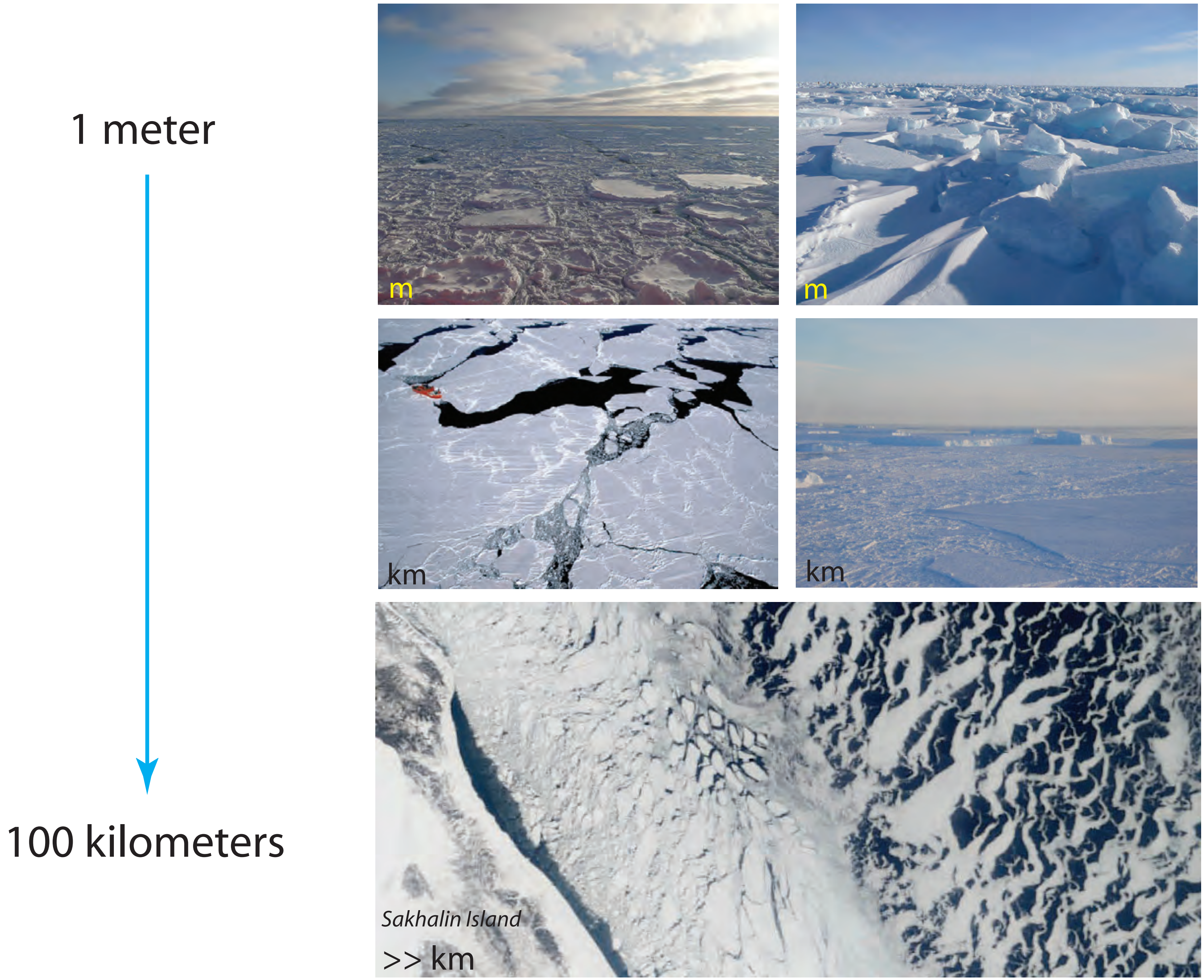
Golden, Eicken, Gully, Ingham, Jones, Lin, Reid, Sampson, Worby 2013

fractals and multiscale structure



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




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

melt ponds on the surface of Arctic sea ice

Frey

melt pond formation and albedo evolution:

- ***major drivers in polar climate***
- ***key challenge for global climate models***

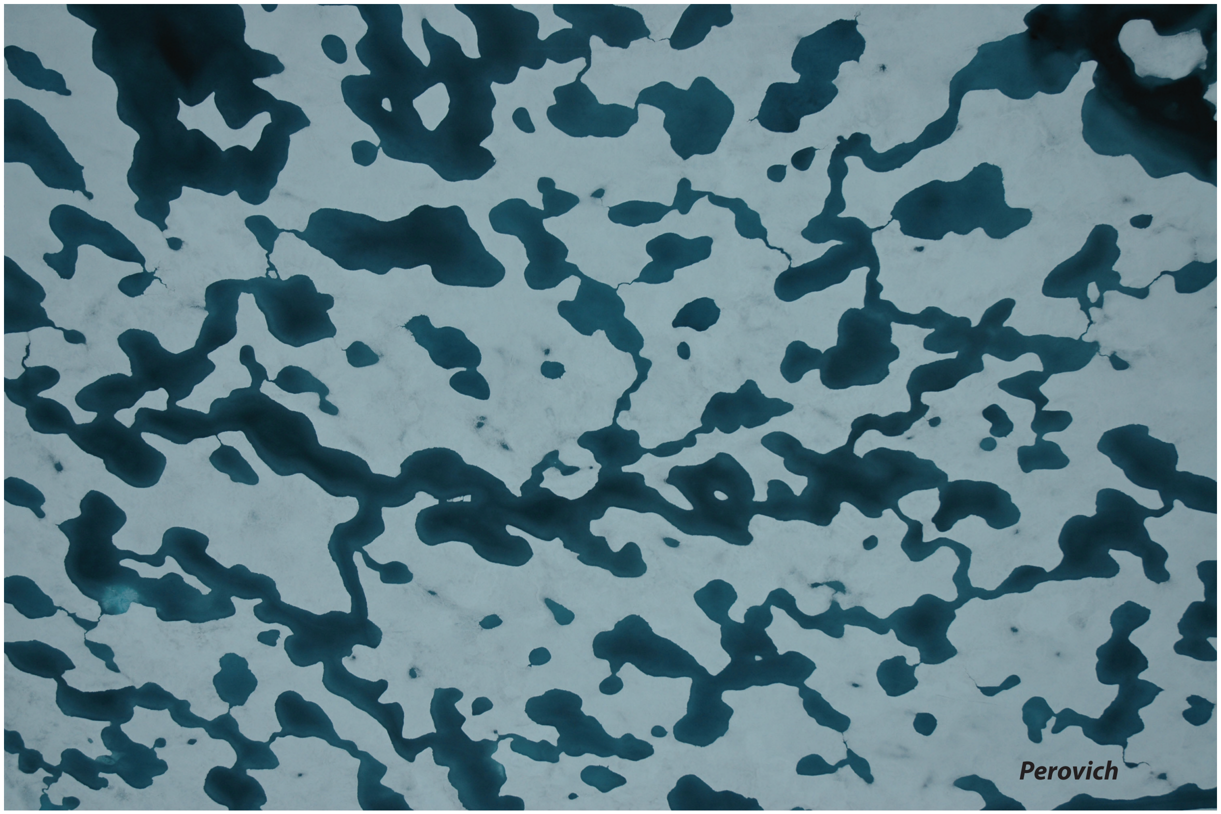
numerical models of melt pond evolution, including topography, drainage (permeability), etc.

Lüthje, Feltham, Taylor, Worster 2006

Flocco, Feltham 2007

Skyllingstad, Paulson, Perovich 2009

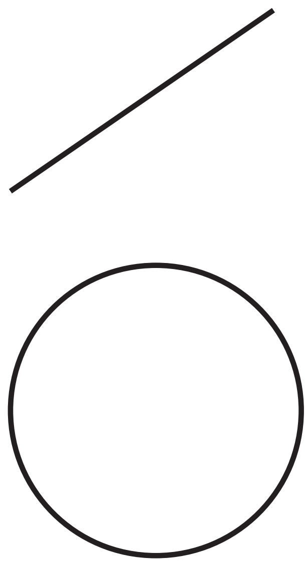
Flocco, Feltham, Hunke 2012



Are there universal features of the evolution similar to phase transitions in statistical physics?

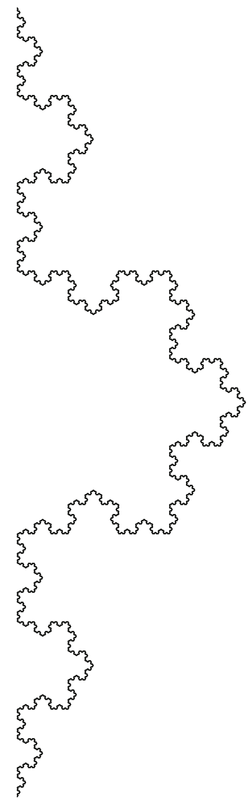
fractal curves in the plane

they wiggle so much that their dimension is >1



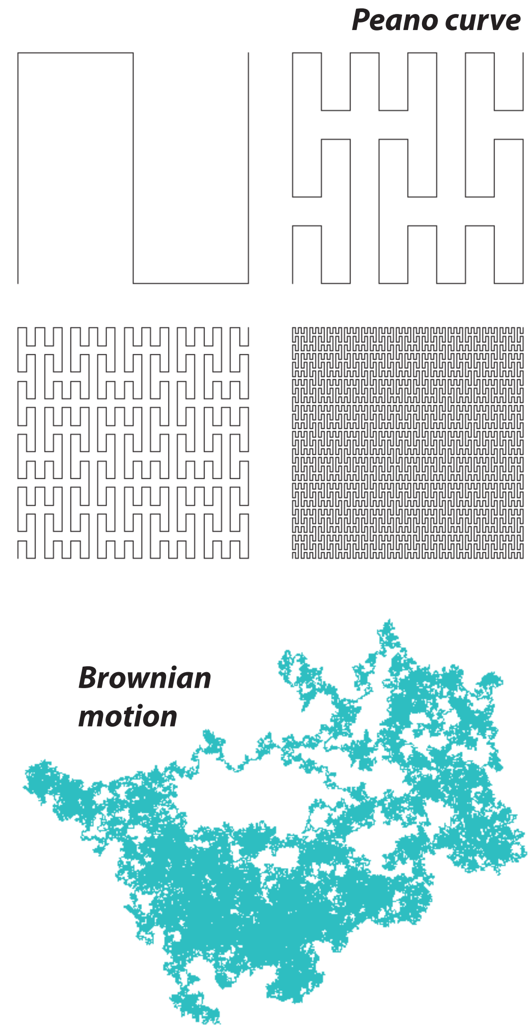
simple curves

***D* = 1**



Koch snowflake

***D* = 1.26**



space filling curves

***D* = 2**

clouds exhibit fractal behavior from 1 to 1000 km

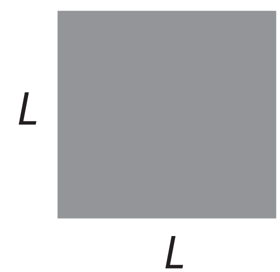
use ***perimeter-area*** data to find that cloud and rain boundaries are fractals

$$D \approx 1.35$$

S. Lovejoy, Science, 1982

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

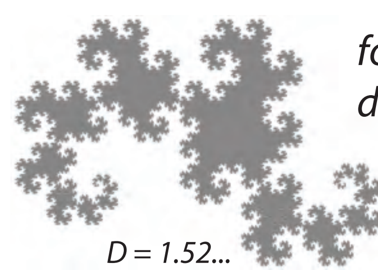
simple shapes



$A = L^2$

$P = 4L = 4\sqrt{A}$

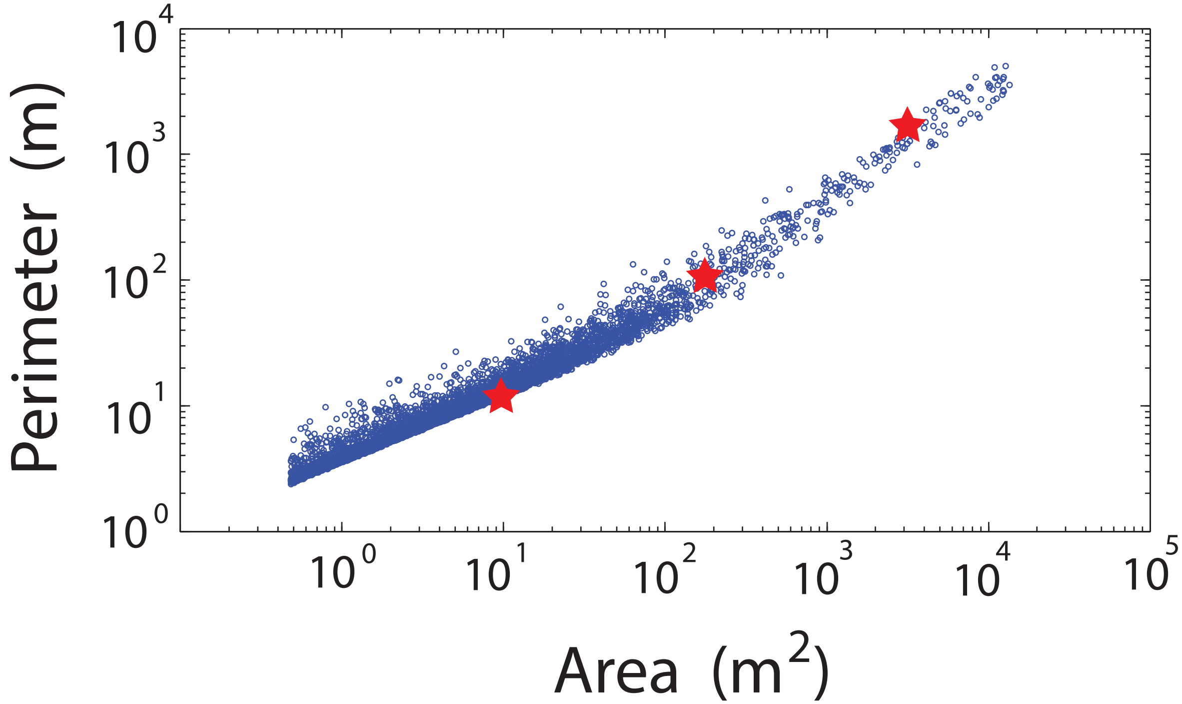
$$P \sim \sqrt{A}^{\,D}$$



for fractals with dimension D

Transition in the fractal geometry of Arctic melt ponds *The Cryosphere, 2012*

Christel Hohenegger, Bacim Alali, Kyle Steffen, Don Perovich, Ken Golden

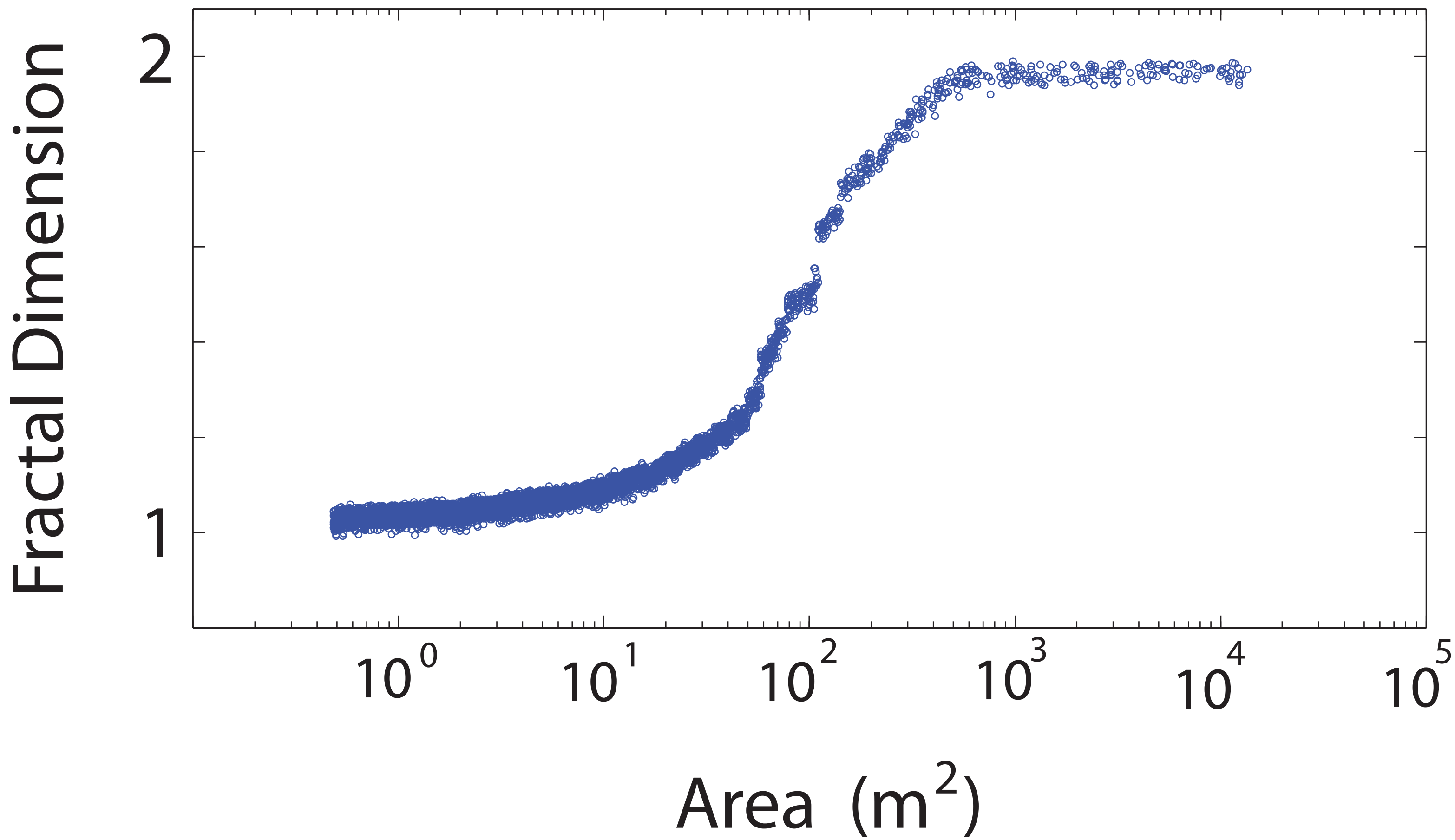


data from
5269 Arctic
melt ponds

simple pond ***transitional pond*** ***complex pond***

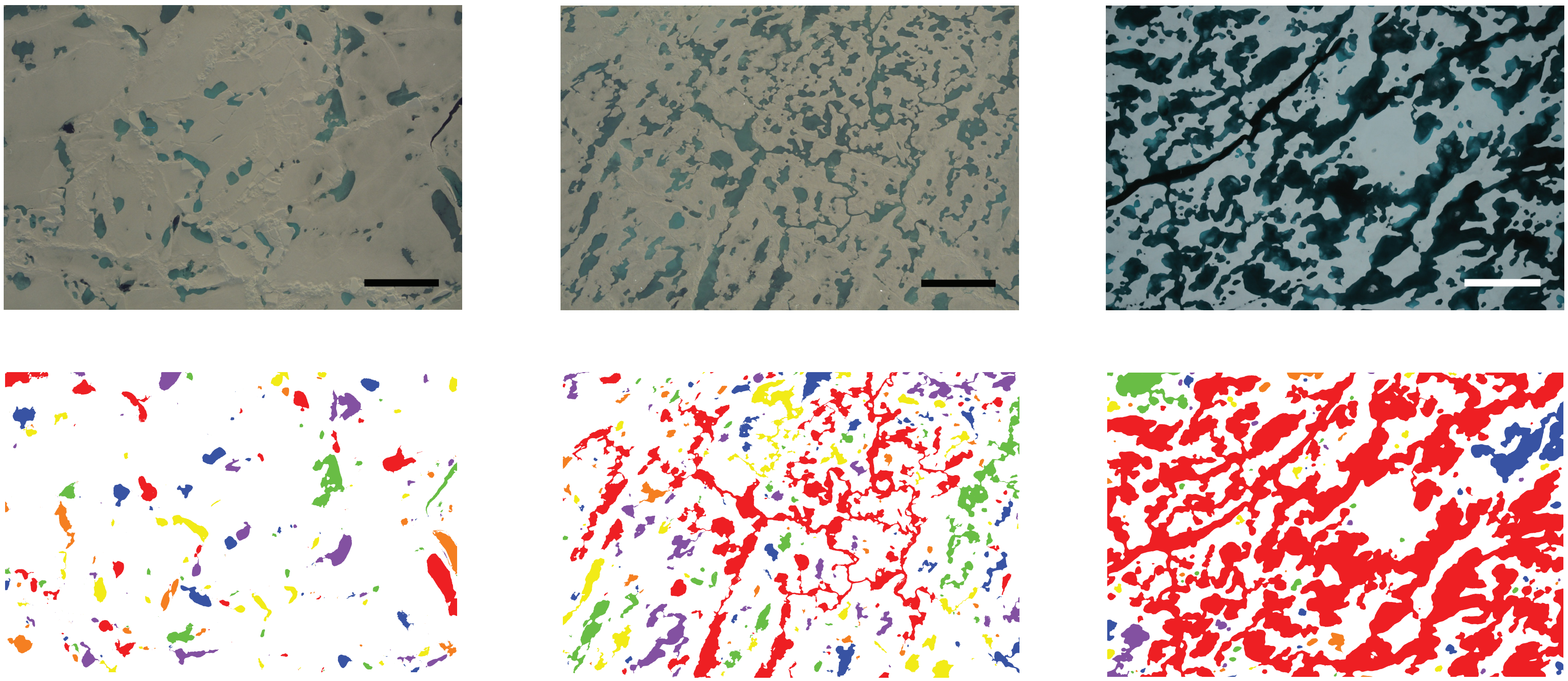
transition in the fractal dimension

complexity grows with length scale



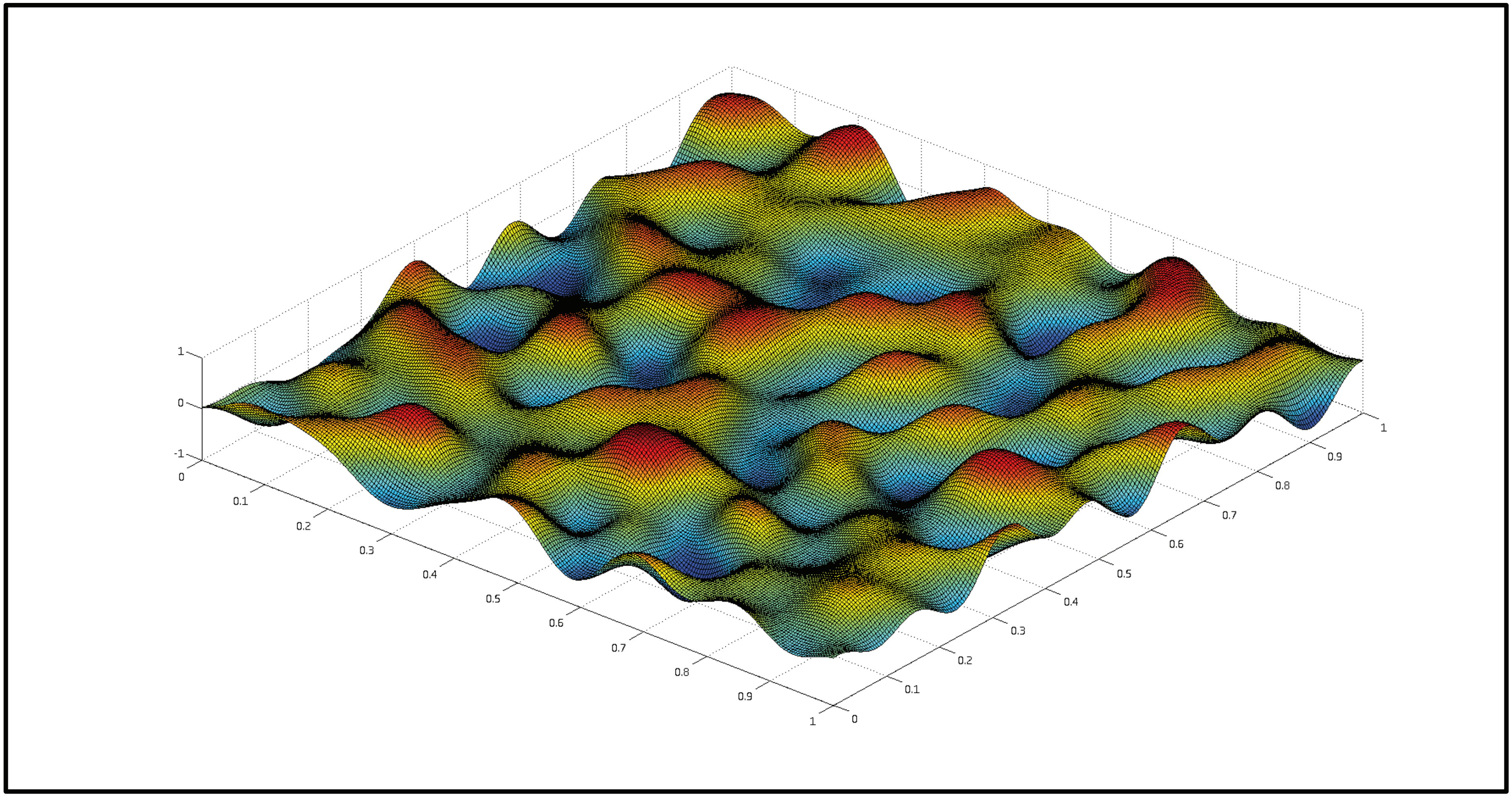
compute “derivative” of area - perimeter data

small simple ponds coalesce to form large connected structures with complex boundaries



melt pond percolation

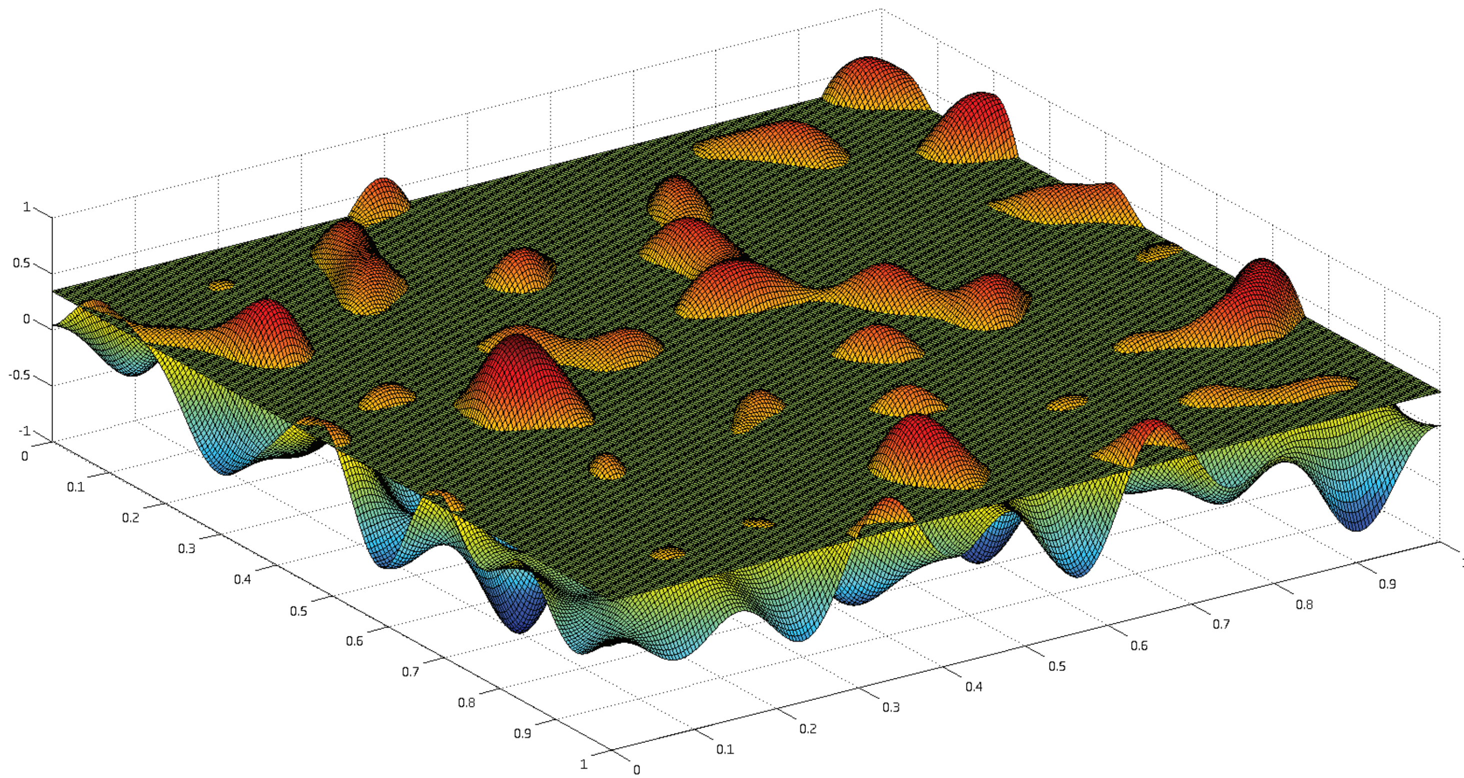
Continuum percolation model for melt pond evolution



random Fourier surface

Brady Bowen and Ken Golden

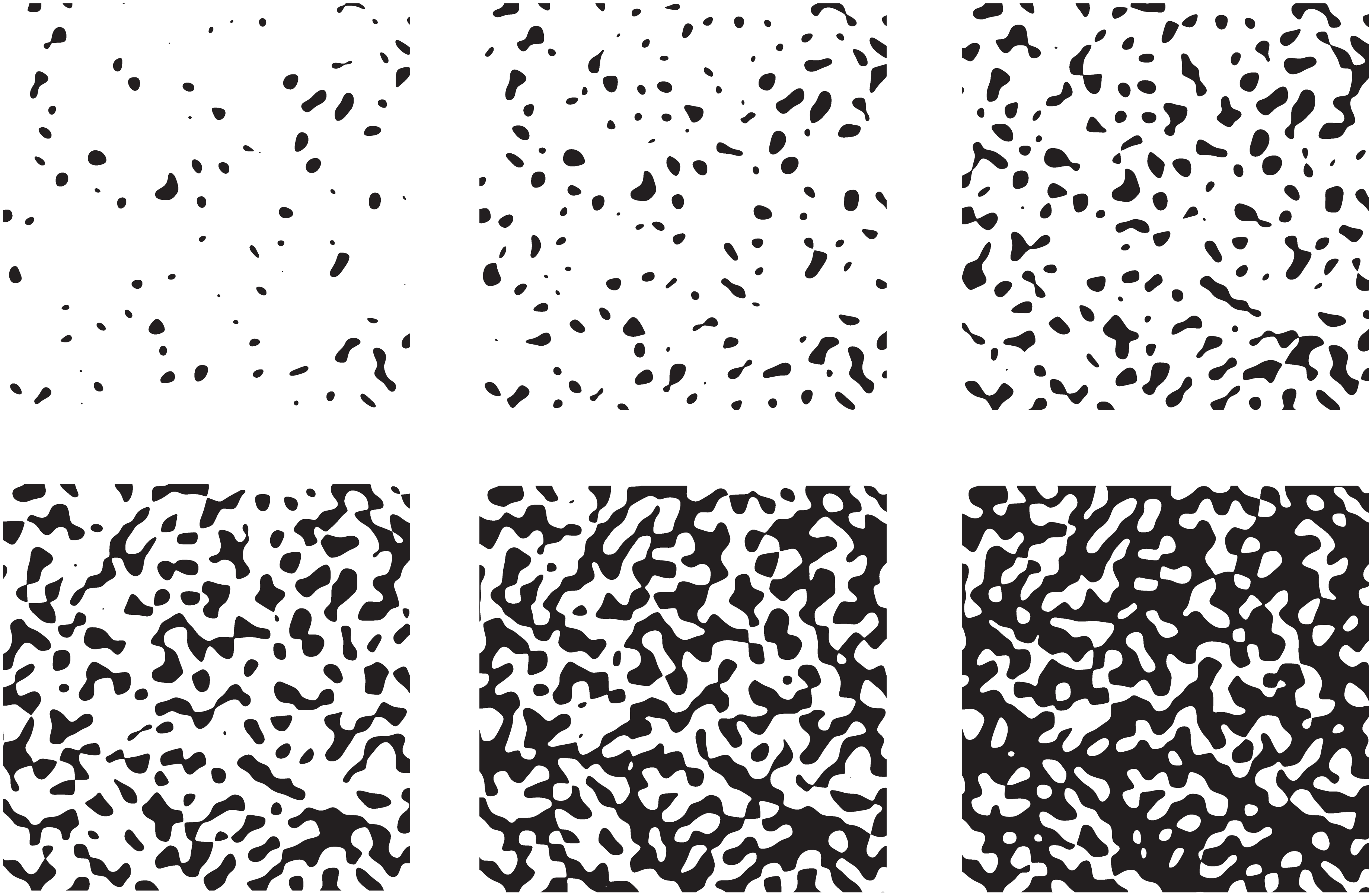
intersections of a plane with the surface define melt ponds



as the plane varies in height the regions evolve like melt ponds

at a critical height h_c ponds percolate and form an infinite ocean

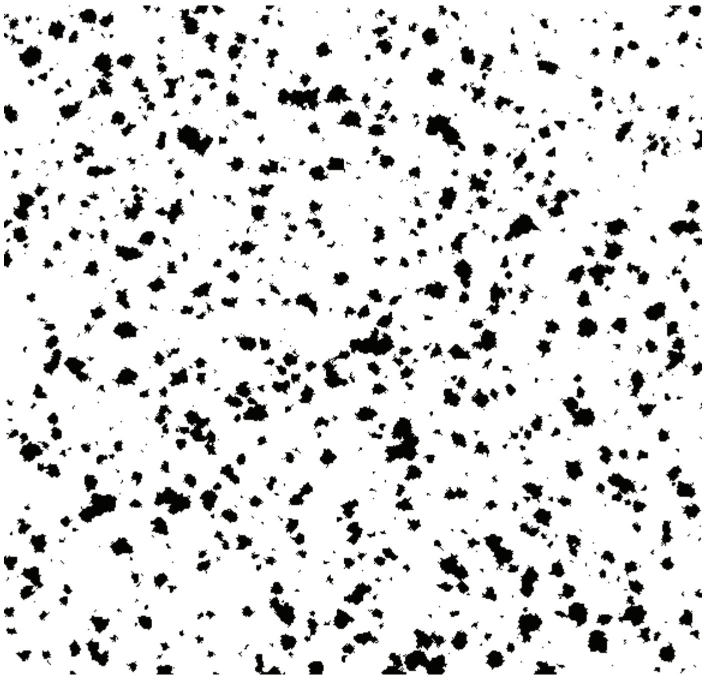
electronic transport in disordered media *diffusion in turbulent plasmas* *(Isichenko, Rev. Mod. Phys., 1992)*

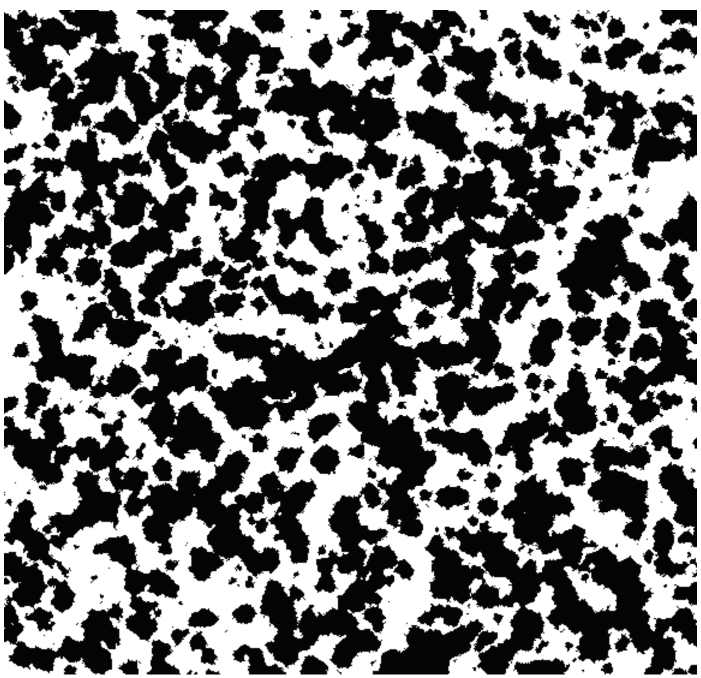


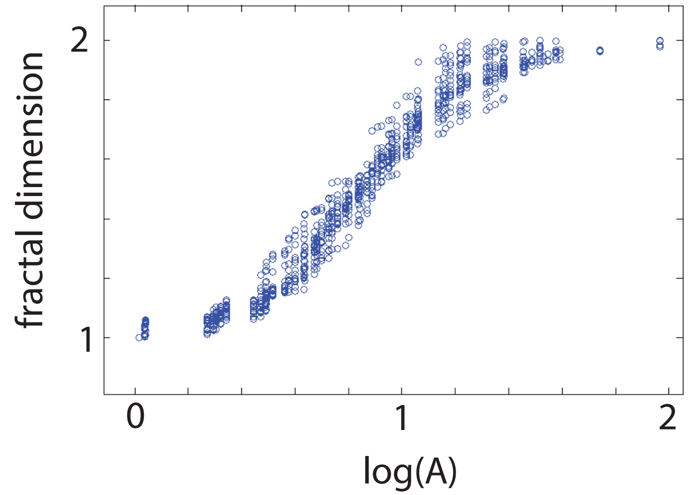
h_c

percolation threshold

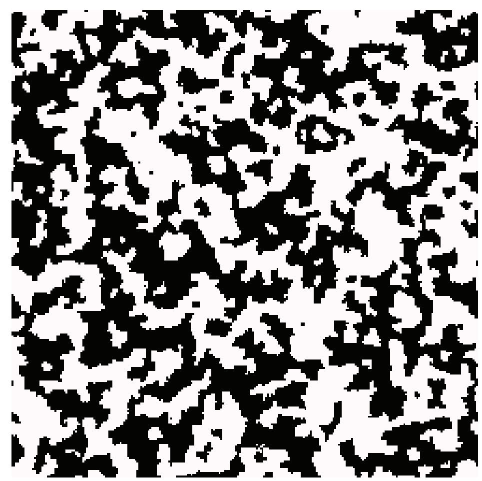
simple stochastic growth model of melt pond evolution







a square is more likely to melt if its neighbors have melted

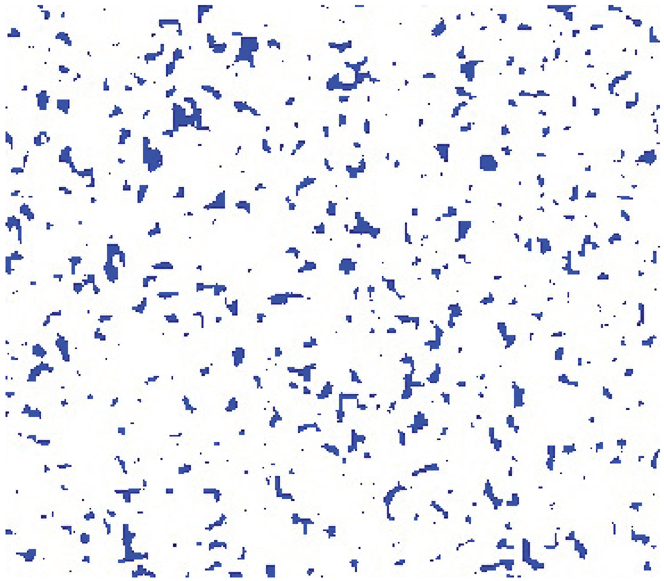


voter model

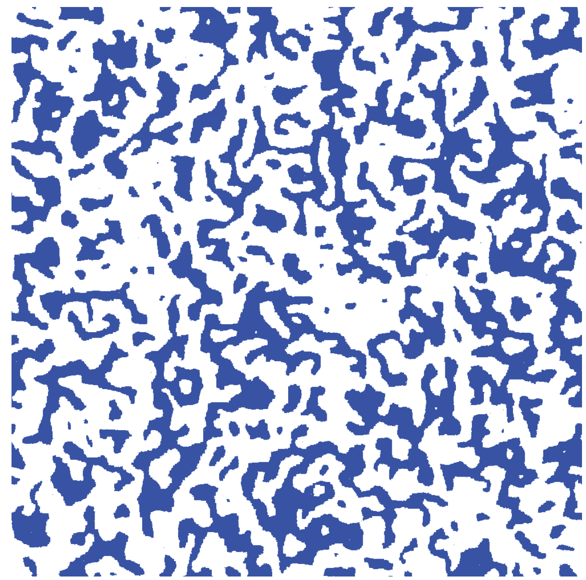
Rebecca Nickerson (high school student) and Ken Golden

Ising model for ferromagnets ⟶ Ising model for melt ponds

$$\mathcal{H}_\omega = -J \sum_{<i,j>}^{N} s_i s_j - H \sum_{i}^{N} s_i \qquad s_i = \begin{cases} \uparrow & +1 \quad \text{ice} \\ \downarrow & -1 \quad \text{water} \end{cases} \qquad M = \lim_{N\to\infty} \frac{1}{N} \left\langle \sum_j s_j \right\rangle$$



COLD



WARM

"melt ponds" are clusters of magnetic spins that align with the applied field

clusters exhibit transition in fractal dimension

Thekkedath, Alali, Sudakov, Ma, Golden

Conclusions

1. Summer Arctic sea ice is melting rapidly.

2. Fluid flow through sea ice mediates many processes of importance to understanding climate change and the response of polar ecosystems.

3. Mathematical models of composite materials and statistical physics help unravel the complexities of sea ice structure and processes, and provide a path toward rigorous representation of sea ice in climate models .

4. Field experiments are essential to developing relevant mathematics.

5. Our research will help to improve projections of climate change and the fate of the Earth sea ice packs.

THANK YOU

National Science Foundation

Division of Mathematical Sciences

Arctic Natural Sciences

Office of Polar Programs

CMG Program

(Collaboration in Mathematical Geosciences)

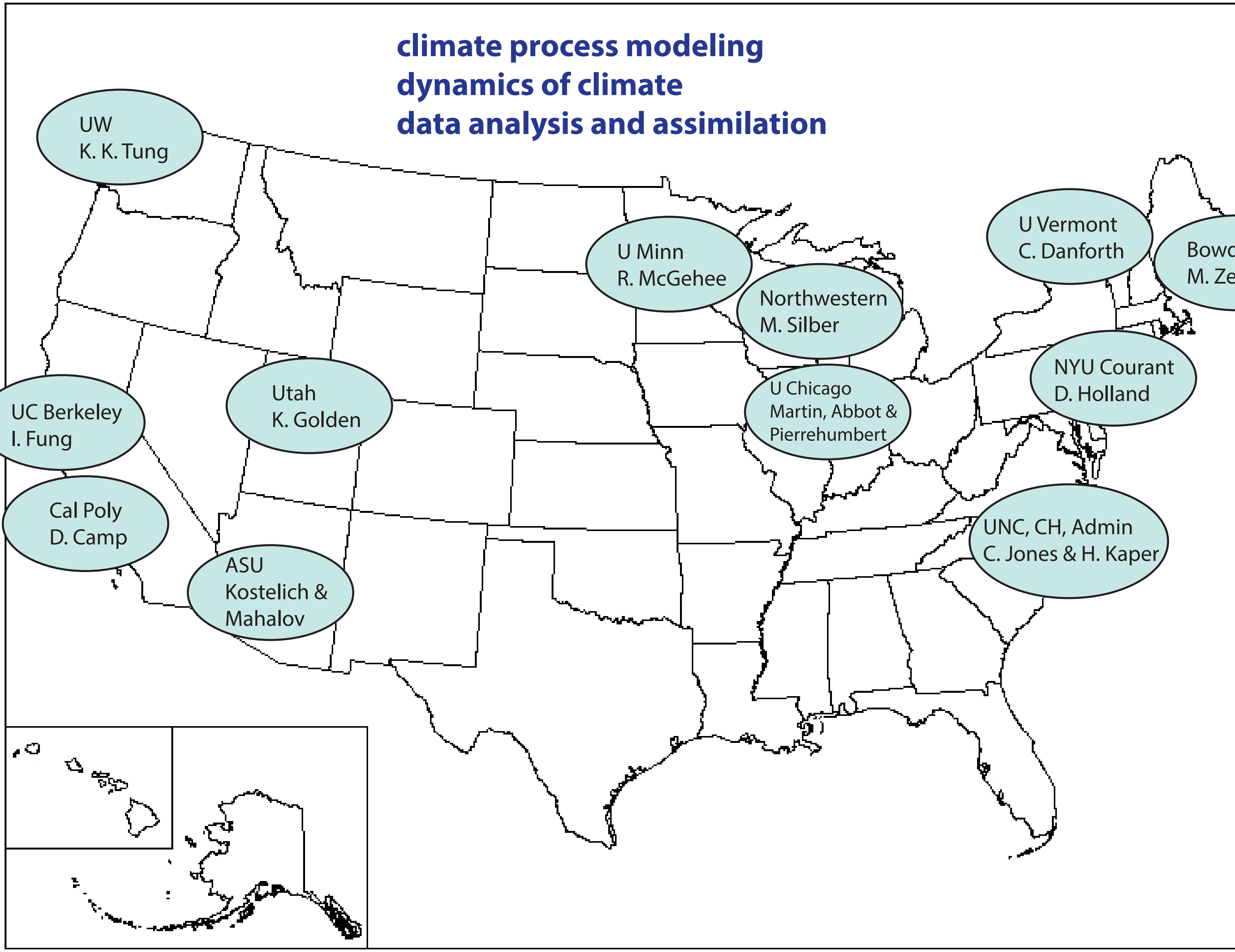
Office of Naval Research

Applied Computational Analysis Program

Arctic and Global Prediction Program

Buchanan Bay, Antarctica Mertz Glacier Polynya Experiment July 1999

Mathematics and Climate Research Network (MCRN)



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

Jones, Golden, Kaper, Zeeman

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.

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.

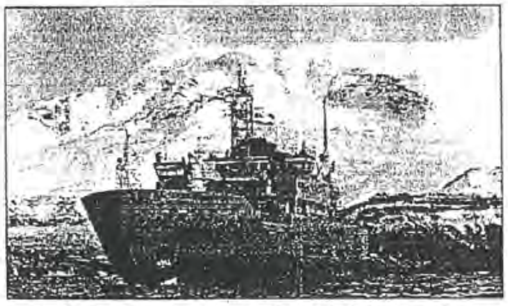
It was too early to say whether P&O would be liable for the cost of the aborted mission.

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.

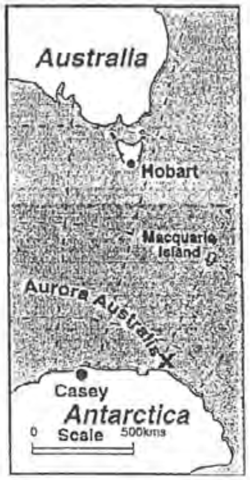
The ship was nearing the polynya when the fire broke out.

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.



A file photo of the Aurora Australis in Antarctica.



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 ...."