Permeability of growing sea ice: Observations, modelling and some implications for thinning Arctic sea ice

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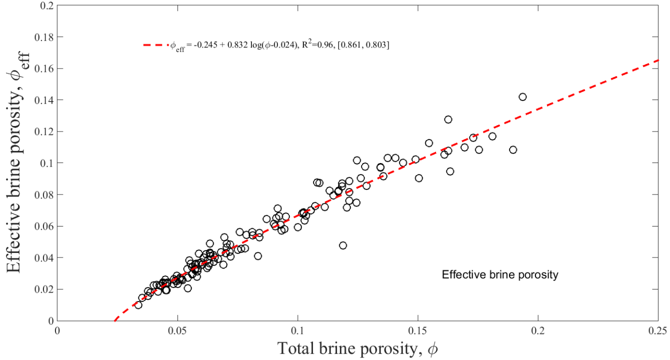
CR6.2 Rapid changes in sea ice: processes and implications

Overview

- Motivation
  - Sparse observational basis of sea ice permeability
  - Understand/ model the dependence of permeability on porosity
- Methods
  - Centrifuge study of sea ice
  - X-ray micro-tomography (μCT): 3-d sea ice microstructure
  - CFD simulations to obtain permeability from μCT images
- Key results
  - Relationship between effective and total poposity
  - Revised permeability threshold (2-3% vs widely assumed 5%)
  - Relationship between permeability and porosity

Key Result 1: Effective versus total brine porosity

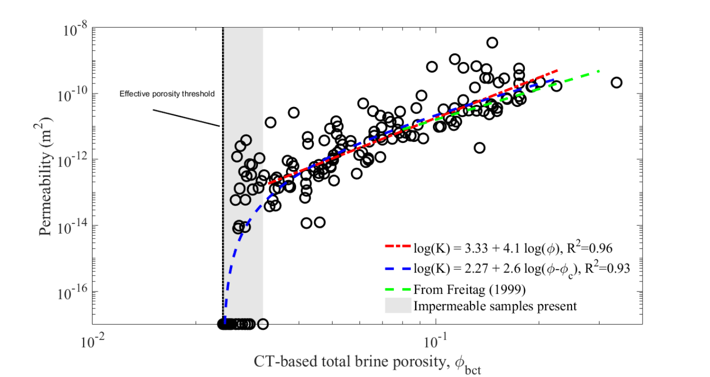


Centrifuging sea ice core segments yields a relationship between effective and total porosity of the form $\phi_{eff} = const.(\phi - \phi_c)^\beta$.

$\phi_c = 2.4 \pm 0.3\%$ is smaller than the widely assumed 5%.

$\beta = 0.83 \pm 0.03$ is consistent with the critical exponent epected for 3-D directed percolation (0.81).

Key Result 2: Permeability versus brine porosity

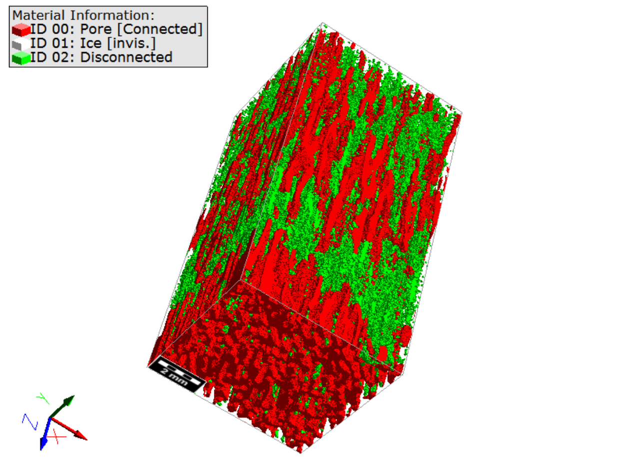


In a log-log robust fit we exclude the shaded transition regime, where both permeable and impermeable samples are present.

We obtain a relationship $K \sim \phi^{4.1}$, with larger exponent than 3.1 reported by Freitag (1999).

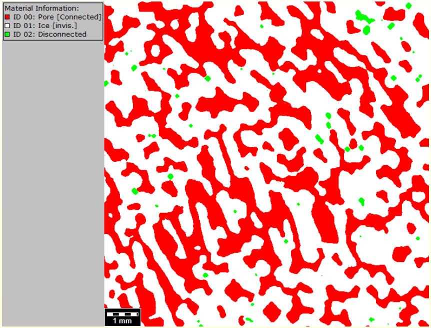
The best percolation fit gives $K \sim (\phi - \phi_c)^{2.6}$ with $\phi_c = 2.4\%$.

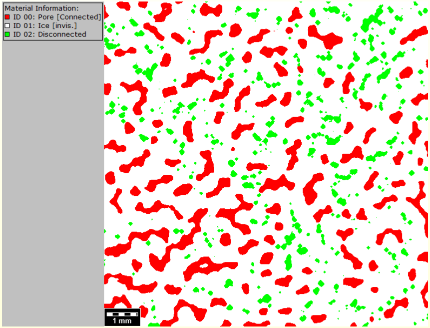
Connected versus disconnected porosity: 3-D XRT image



XRT image 2 cm from the ice-ocean inteface, highlighting connected brine versus disconnected brine (ice invisible)

Connected versus disconnected porosity: 2-D XRT slices





Most connected brine

More disconnected brine

XRT imagery based on centrifuged samples reveals disconnected and connected pores and their transition.

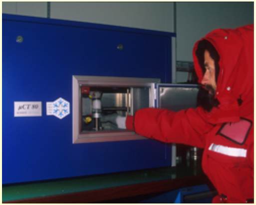
Work Flow from Field to CT Image Analysis

Present work flow:

1. Rapid sectioning of sea ice cores
2. Transport samples at *in situ* temperatures
3. Centrifugation of brine at *in situ* temperatures
4. (Cooling sequence: centrifugation at lowered temperatures)
5. Storage below eutectic temperature (-80 °C) - stable samples
6. Absorption tomography: distinguishes air, ice and solid salts
   Air: connected network ↔ salt: disconnected inclusions
7. 3-d image postprocessing (filtering, segmentation)
8. Pore space ananlysis and permeability simulation

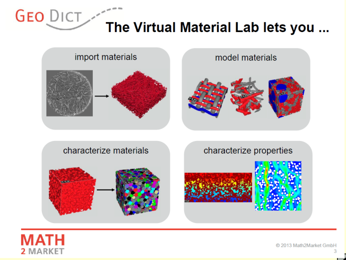
Work Flow from Field to CT Image Analysis

1. Field Sampling



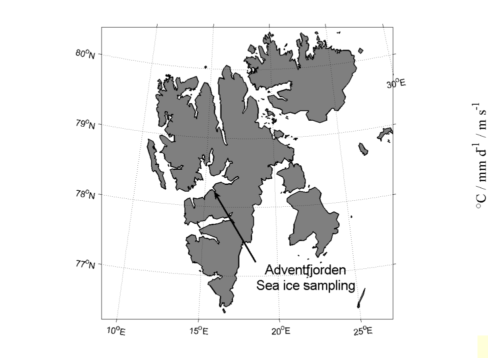
2. Computed Tomography

3. Refrigerated Centrifuge

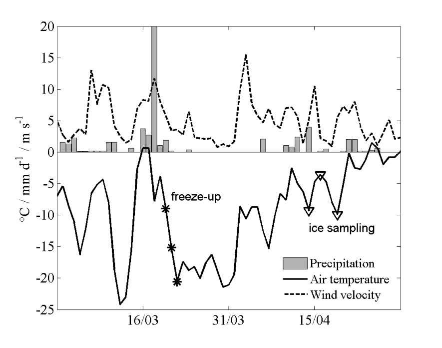


4. Analysis/simulations with GeoDICT

Field Conditions, April 2011, Longyearbyen

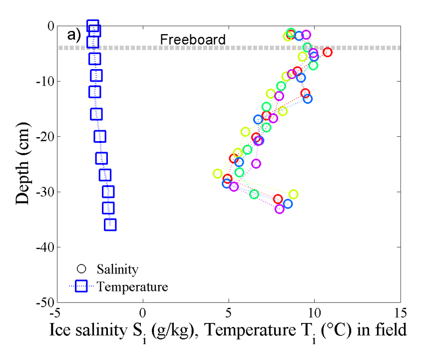


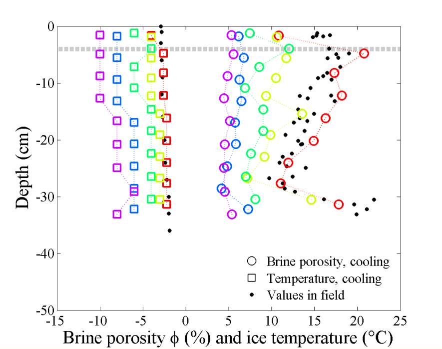
Location in Adventbay, Svalbard



Meteorological conditions at Longyearbyen airport

Temperature, Salinity, Brine Volume Fraction





In situ ice temperature and salinity
Note: $S_{water} \approx 35$ g/kg

Cooling sequence:

temperature and brine volume fraction

Computed Tomography and Permeability Simulations

Computed Tomography

- MicroCT 40 and MicroCT 80, Scanco Medical AG
- 37 mm FOV (horizontal image width), 18 μm resolution
- $\approx$ 1 hour scanning time per centimeter sample height
- $\approx$ 5 Gigabyte raw data per centimeter
- imaging at -20 °C

Simulations with GeoDICT

- X x Y x Z $\approx$ 1200 x 1200 x 1500 voxels
- 18 μm voxel size $\Rightarrow$ 2 x 2 x 2.5 cm
- Flow simulation in stacks ($\approx$ 1200 x 1200 x **300** voxels)
- Hardware: 32 GB RAM, 1cm $\approx$ 4 days on 3 Ghz Quadcore PC
- Stokes-Solver, Darcy flow (low Re): $V = \frac{K}{\mu}\frac{dP}{dz}$
- Vertical permeability K

Acknowledgements

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