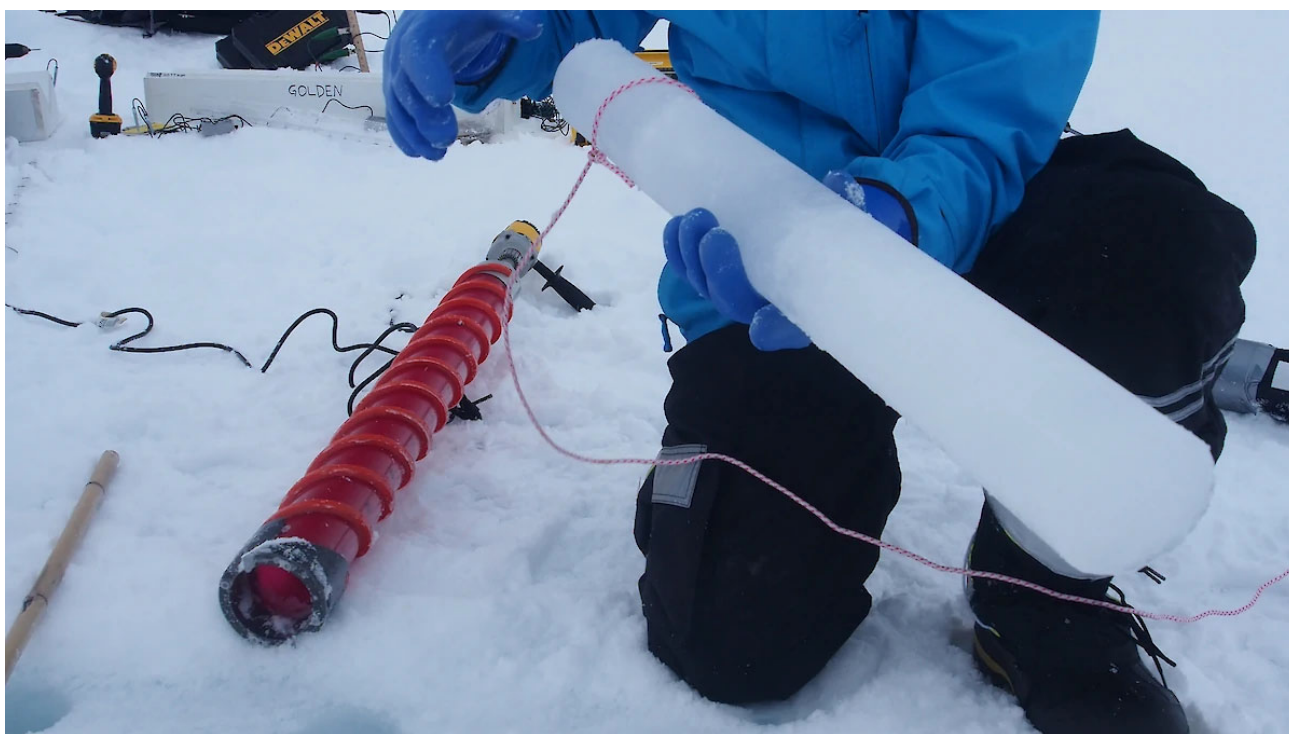


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The Golden rule of sea ice permeability



Ken uses a lasso to help remove another perfect ice core. Photo: Wendy Pyper

During the second Australian-led Sea Ice Physics and Ecosystem Experiment (SIPEX-II) to the sea ice zone off East Antarctica, between September and November 2012, mathematicians investigated a new ‘rule’ of sea ice permeability. Their work will provide clues to how climate change will affect sea ice formation and longevity and how changes in sea ice permeability will affect biological productivity in Antarctica.

University of Utah mathematics professor, Ken Golden, vividly remembers the moment in 1994 when all the threads of his academic career came together in a pivotal realisation.

‘I was out on the ice at midnight in the eastern Weddell Sea in a raging storm and I saw seawater suddenly percolate up and flood the surface,’ he says.

‘I’d just spent years of my life proving rigorous theorems about percolation models and I knew enough about the structure of brine inclusions in sea ice to realise that what I was seeing was a percolation threshold – a “tipping point” in the connectedness of these inclusions.’

In that one moment Ken realised that when sea ice reaches a critical temperature, the pockets of brine connect up to form brine channels, shifting the ice from an impermeable state to a permeable one. When this happens, seawater underneath the ice can percolate upwards and flood the ice surface, where it combines with snow to form snow ice.

As sea ice warms, the volume of brine in the ice (the 'brine volume fraction') increases. Through analysis of the data from their 1994 expedition and previous work on brine drainage, Ken was able to deduce that the tipping point occurred at a brine volume fraction of about 5%. By coincidence, the threshold from impermeable to permeable ice occurs when the temperature is -5°C , for a typical bulk salinity of the ice of 5 parts per thousand. Ken went on to prove this hypothesis and coined the term the 'rule of fives'.

The rule of fives applies to columnar ice (long, downward-growing ice crystals formed under calm conditions), which comprises most of the ice in the Arctic and a significant proportion in the Antarctic. In the Arctic the permeability of sea ice is important in the formation and longevity of dark melt-water ponds on the surface of the ice, which absorb sunlight (and heat) and affect the 'albedo', or light reflecting properties, of the region.

'Sea ice albedo is one of the least understood parameters in the climate system in terms of modelling, and a significant source of uncertainty in climate projections,' Ken says.

'Whether these Arctic melt ponds drain in a day or pool up and cover more of the ice is largely controlled by the rule of fives. So the brine microstructure of the ice and its fluid flow properties control larger scale processes that are critical for climate modelling.'

The rule of fives also affects the availability of nutrients for sea ice algae which, in Antarctica, provide an important food source for krill. Once the tipping point for changing permeable ice into impermeable ice reaches an algae layer, the algae are stuck with the nutrients they have and there can be a dramatic decrease in their growth rate.

'So biological activity often turns on and off according to the rule of fives,' Ken says.

Since his light-bulb moment, Ken has conducted numerous studies in the Arctic and Antarctic, including the first Sea Ice Physics and Ecosystem eXperiment (SIPEX) in 2007, gathering data on the permeability of different ice types.

As well as columnar ice, Antarctic ice is comprised of about two thirds granular ice, which is finer grained than columnar ice. It forms in turbulent weather and sea conditions, and as snow ice. Back in 1998 Ken predicted that the more randomly distributed brine pockets in granular ice would exhibit a percolation threshold at a higher critical brine volume fraction than in columnar ice, making it harder for fluid to flow through the ice. In other words, the rule of fives would not apply. But perhaps another rule would.

He saw hints of this on the first SIPEX. So on SIPEX-II (between September and November 2012), Ken and his PhD student Christian Sampson and electrical engineering graduate student David Lubbers, applied all their experience, observations, theory, and technology to begin investigating the difference in permeability between columnar and granular ice.

To do this the team extracted an ice core and measured temperatures along its length — the bottom of ice is warmer (and more permeable) than the top, because it's close to the ocean. They then measured the electrical conductivity of the core (in the vertical direction), which relates to permeability. The higher the conductivity — the ability to move electrons from one end of the core to the other — the higher its permeability.

'It makes sense that conductivity and permeability are linked because to have electricity flow through the core you need a path for the electrons to flow,' David says.

'The electrons will move through brine, which is salty and electrically conductive. But if the brine channels are isolated from each other, fluid can't move through them and, similarly, the electrons can't move through them because there's solid ice in the way.'

The team then examined the core's crystal structure and measured its salinity to obtain the brine volume fraction. They also drilled several 'partial permeability holes' of different depths, near where their core was taken, to look at how quickly sea water percolated up through the bottom of the ice.

'Then we deployed pressure sensors into the holes to see how, over time, the water level changed,' Ken says.

'If the ice is permeable then a lot of water moves in quickly; if not, then the water takes a long time.'

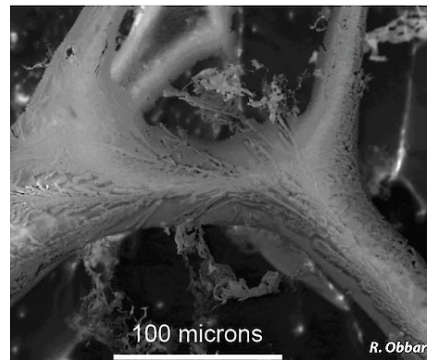
Finally, the team took microwave measurements through a thin section of ice to see how the electromagnetic properties of the ice altered the returning microwave signal and whether it correlated with the rule of fives. These measurements will be combined with experiments by their colleagues from New Zealand and Alaska using 'cross-borehole tomography'. Here, electrode strings are frozen vertically into the ice and the effective electromagnetic properties of the ice between the electrodes are reconstructed mathematically. If it works, it could be scaled up to collect information about the ice type, fluid movement and temperature, from buoys deployed on the ice, or from satellites.

‘Then we could electrically classify ice as impermeable enough to allow melt ponds in the Arctic to grow, or highly permeable ice that allows for carbon dioxide pumping and the build-up of sea ice algae,’ Ken says.

For now though, Ken and his team are continuing to analyse and model their new data. They have found strong evidence that the percolation threshold for fluid flow in Antarctic granular ice is quite a bit higher than in columnar ice. As these preliminary findings are examined and made more precise, they will impact models of transport processes in Antarctic sea ice, and ultimately, our projections of climate change and the response of Antarctic ecosystems to this change.

Wendy Pyper
Australian Antarctic Division

PHOTO GALLERY



This content was last updated 11 years ago on 18 June 2013.