Technology Brief 6
Measurement of Electrical Properties of Sea Ice

Climate change is often first measured by the decrease of our polar ice caps. This sea ice is a unique and vibrant type of ice; the fresh water freezes first, leaving pockets of more and more briny (salty) water, that eventually freezes only when the temperature gets below its eutectic point around −21 °C. A combination of gravity and freeze-thaw cycles elongates these tiny brine pockets (initially sub-mm in size), and many of them start linking together to form fluidic channels (which eventually expand to become a full centimeter or more in diameter), from the top of the ice all the way through one or two meters of ice to the sea below the ice pack (**Fig. TF6-1**). In this columnar type of sea ice, which is prevalent in the Arctic, there is a critical brine volume fraction of about 5%, called the ***percolation threshold***, above which there are large-scale connected channels or pathways through which fluid can flow, and below which the sea ice is effectively impermeable. For a typical bulk sea-ice salinity of 5 parts per thousand, this brine volume fraction corresponds to a critical temperature of about −5 °C. This *on-off switch* for fluid flow is known as the ***rule of fives***. The brine channels can moderate the formation of melt ponds (**Fig. TF6-2**) by quickly draining them and returning the ice to its more reflective white coloring.

This brine percolation threshold has been quantified through measurements of the electrical resistivity of the ice, as well as X-ray computed tomography and measurements of the fluid permeability. Salty brine pockets are very conductive, and the surrounding ice is a near insulator. As the brine pockets join into channels, the overall conductivity of the ice increases substantially by providing a conducting path for current in pretty much the same way it provides a path for the water to percolate (drain) through. Conductivity, then, is highly correlated with the percolation threshold and can be used to help us study melt-pond formation.

The electrical properties of the ice are measured by drilling out a 9 cm cylindrical core of ice, measuring its resistance using a model very similar to that seen in **Fig. 2-1**. Stainless steel nails are driven into the ice core (drilling holes for them first, to avoid cracking the core) to make the electrical connection to the ice. But this method has a problem. It is very hard to get a consistent electrical connection between the nail and the ice. This contact resistance is very much a part of the circuit, and it varies with each connection. A circuit model of this resistance measurement is shown below. The total resistance is the series combination of the two (variable) contact resistances and the resistance of the

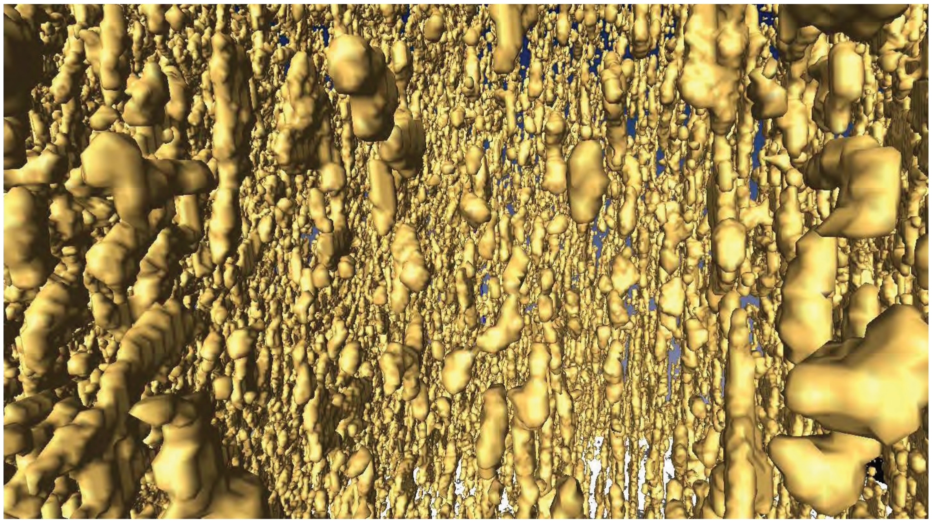
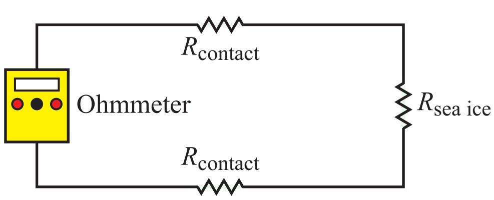


Figure TF6-1: X-ray CT images (approximately 1 cm across) of the brine microstructure of sea ice. The brine volume fraction is 5.7%, and the temperature is −8 °C. Channels are beginning to form but are not fully connected yet. (From Golden et al., *Geophys. Res. Letters*, 2007.)

Figure TF6-2: As ice melts, the liquid water collects in depressions on the surface and deepens them, forming these melt ponds in the Arctic. These fresh water ponds are separated from the salty sea below and around it, until breaks in the ice merge the two.

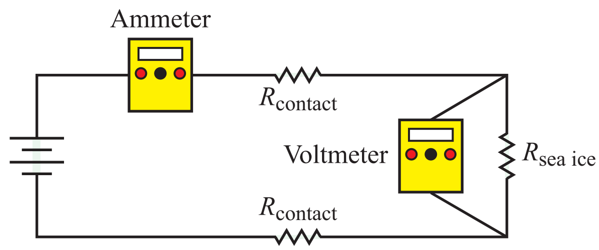
ice. Without being able to better control the contact resistance, Rsea ice cannot be accurately measured.

To solve this problem, rather than doing a simple 2-wire resistance measurement as shown in Fig. TF6-3, a 4-wire measurement system can be used as shown in Fig. TF6-4. This system employs both an ammeter and a voltmeter (which are combined into the single yellow AEMC resistance meter shown in Fig. TF6-5). Two wires are used to connect the ammeter in series with the resistances, and two are used to connect the voltmeter in parallel with $R_{\text{sea ice}}$ (hence, 4 wires). We do not need to know the driving voltage or the contact resistances in order to accurately measure Rsea ice with this method.



Ohmmeter indicates $R_{\text{contact}} + R_{\text{sea ice}} + R_{\text{contact}}$

Figure TF6-3: Simple 2-wire resistance measurement circuit.



$$R_{\text{subject}} = \frac{\text{Voltmeter indication}}{\text{Ammeter indication}}$$

Figure TF6-4: 4-wire measurement circuit.

Figure TF6-5: University of Utah mathematics Ph.D. student Christian Sampson measures the electrical conductivity of a sea-ice core during the Sea Ice Physics and Ecosystem eXperiment in 2012. Electrical clamps are attached to nails inserted along the length of the ice core. (© Wendy Pyper/Australian Antarctic Division.)