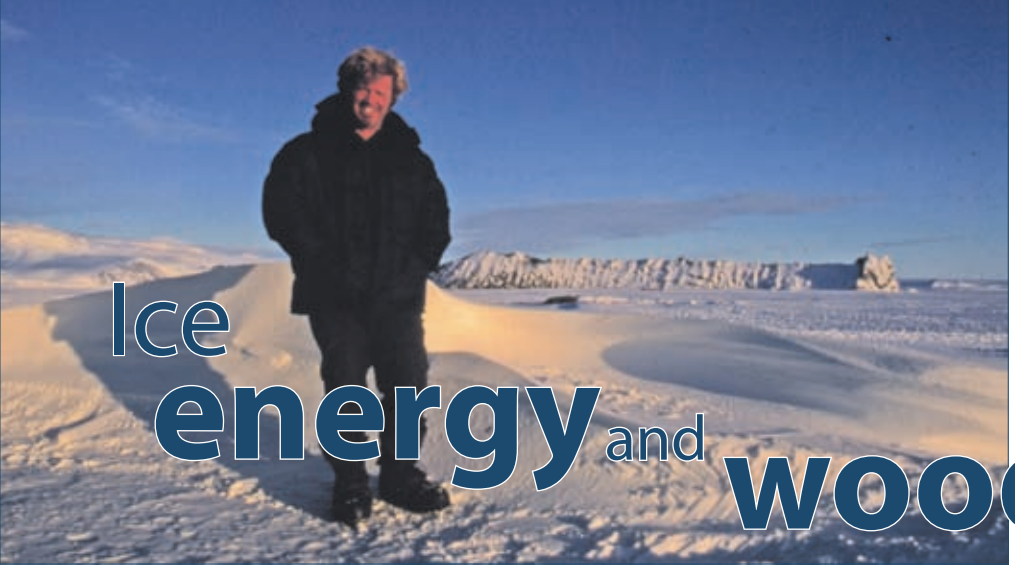

Ice energy and wood

From IMAges 7
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"The magic of mathematics is that the same methods have applications in a whole range of fields," says Colin Fox. He described some to Jenny Rankine.

"Partial differential equations (PDEs) model energy propagating through a system that varies in space and time, like sound or seismic waves, or x-rays through human tissue," says Fox (above).

"For example, the gung-ho overuse of early geothermal fields is no longer acceptable," he says, "so those fields need to be modelled for environmental management and sustainable power generation." But underground measurement involves a lot of signal noise and uncertainty.

Fox was a co-director of the NZIMA programme on Analysis, Applications, and Inverse Problems in PDEs in 2007, and with co-director Professor Mike O'Sullivan, supervised NZIMA scholarship student Tiangang Cui to compute a Markov Chain Monte Carlo method.

"But if you use basic MCMC methods, the universe wouldn't last long enough for the computer programme to finish, so we developed some algorithms around that," says Fox. "The computations then became faster than standard engineering least squares optimisation methods; it's like a big camera for looking at the geological structures."

The solution is now used for resource consent hearings and long-range planning. Auckland was one of three centres in the world where the same combination of PDEs from engineering, inversion in graduate statistics and numerical and analytical maths was taught. The notes for Physics 707 - Inverse Problems, written in 1997 by Fox with colleagues Geoff Nicholls and Sze Tan, reached the 60 most-downloaded mathematical texts online. The area became a priority for the USA National Science Foundation this year, so Fox predicts that they'll catch up soon.

The largest seasonal process in the world, the southern ice freeze and thaw, is a very mathematical system, says Fox, and was another focus for his work with PDEs for more than 12 years. In the 1990s, he was part of the New Zealand science team K131, which studied sea ice far from Scott Base.

"The sea ice freeze was the biggest effect in southern hemisphere climate models, but modellers didn't know how to include it," he said. No one had made the measurements Fox needed to describe how ocean waves affect land-fast sea ice, so for years his team tried to gauge them with sensitive tilt meters at the edge of the sea ice, "hoping it didn't break that day and float off".

When they decided to make their own waves, the team built a hydraulic jack they called the Thumper. "In the first year, I left out some terms in the residue late one night, which cost the taxpayer about $50,000 because the Thumper was about ten times too small."

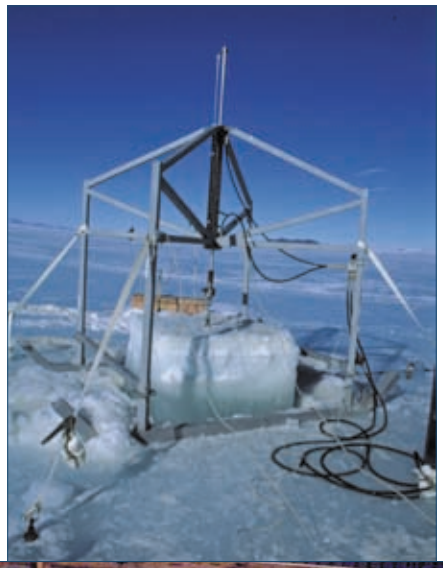
The second year he recalculated, and the 3m by 3m jack happily created waves by picking up two tonne lumps of ice and dropping them, safely away from the edge. The results led to better mathematical methods for solving those kinds of problems.

"To a mathematician, sea ice is a combination of fluids, thin elastic plates and waves. Lightweight timber construction in New Zealand is similar - plates and beams in a fluid." Fox had been interested in acoustics as a student, and directed the Acoustics Research Centre from 1998 to 2007.

"Sound insulation in houses is a complicated problem - over the years we saw hundreds of entrepreneurs with the latest idea for quiet walls." Fox supervised post-doctoral student Hyuck Chung, who wrote the codes and did the modeling to design a timber floor with better sound isolation than concrete.

"We used a version of finite element methods, a standard engineering technique for solving PDEs. We wouldn't have come to these methods without the semi-analytic methods we'd developed for sea ice." They worked with acoustics and building specialists, building a simple floor and making sure the computer model exactly matched.

"Two designs both performed better than concrete floors. They included careful placement of joists, choice of material and layering - nothing exotic. One included a novel element - a layer of mixed sand and sawdust between ply and floorboards."

"Listener tests were part of final testing. We recorded the noise of walking over the floors and replayed them in a listening room. You would swear that someone was walking on the floor above you, and we asked them to rate the noise as better or worse. That's why I enjoy acoustics - at the end the human ear is the final arbiter."

Below: The thumper.
Bottom: The sand and sawdust sound isolating floor.