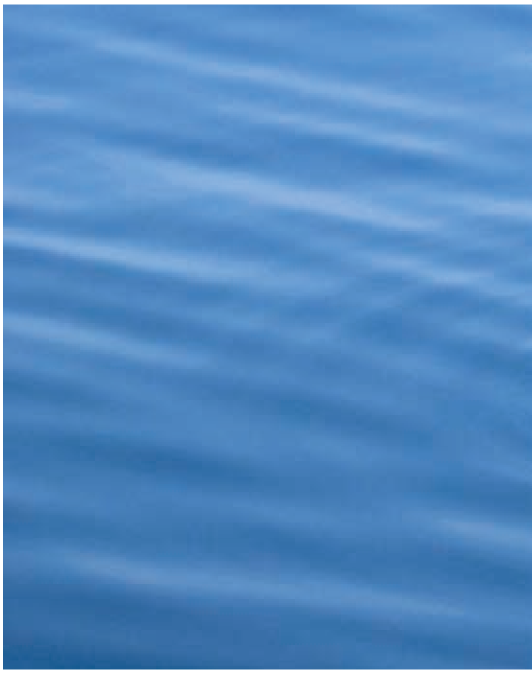
# Afloat on a sea of noise



Global geophysicists map the Earth's interior using seismic waves. But until recently the oceans have been largely off-limits. Frederik Simons describes creating a floating instrument that he hopes will change that.

Back in 2002, when I was a freshly minted PhD en route from MIT to Princeton for post-doctoral work, I received a brown envelope in the mail, marked 'confidential'. It was Guust Nolet letting me in on a pet project and long-time dream of his – to build a versatile earthquake recorder for use in the oceans. I decided making this happen was going to be my thing.

At the time, much of my research was devoted to seismic tomography – the science, and art, of making three-dimensional maps of how fast seismic waves propagate inside the Earth. Wave speeds vary according to the composition of the rocks they pass through, and also according to temperature and pressure.

So seismic 'CAT scans' can be interpreted to yield clues on the structure and evolution of the Earth's deep interior. What we know of the fate of subducting slabs (where tectonic plates sink into the mantle), the role of mantle plumes (where hot material rises up to the surface), or the detailed structure of the inner core, is partly thanks to seismic tomography.

Much of the Earth's crust, mantle and core have now been studied this way, by oil companies looking for oil and gas in the shallow subsurface using explosives, and by 'global' geophysicists looking thousands of kilometres into the planet with earthquake sources and recorders, sophisticated broadband seismometers, on much of the available land surface – including some ocean islands.

There's the rub. There just isn't enough dry land to ensure adequate coverage – it's as if the terrestrial MRI machine has had three quarters of its detectors knocked out by flooding. Putting earthquake detectors on the ocean floor is an enormously expensive undertaking. It's being tried with considerable success, but it's hard to imagine this leading to large-scale and long-term networked arrays on a par with what we have available on the continents.

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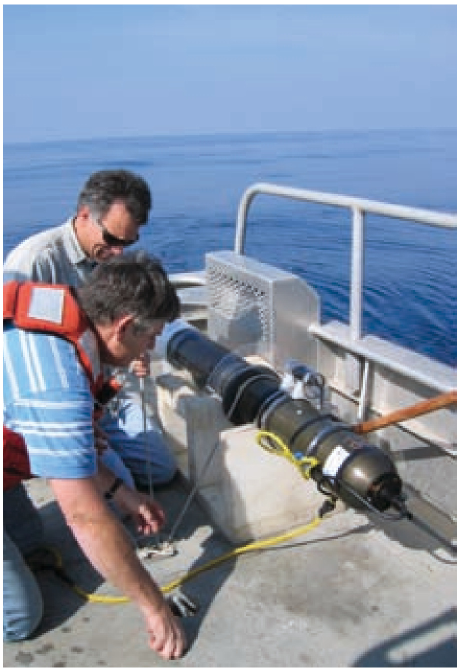
In the few years following my receipt of the brown envelope, first together at Princeton University and subsequently, for me, at University College London, Guust and I worked with scientists and engineers from the Scripps Institution of Oceanography to put together a truly novel instrument.

From the ocean scientists we borrowed the technology known as 'SOLO' floats. Short for 'Sounding Oceanographic Lagrangian Observers', these can drift at depths of anywhere between the surface and about 1500m. Currently, well over 3000 similar instruments are floating at large, measuring conductivity, temperature and depth in a large-scale multinational effort to contribute data to study how the oceans influence and regulate our climate. Onto our own SOLO float we grafted



a hydrophone, an off-the-shelf instrument that detects sound waves underwater – effectively, a single-component 'seismometer'. In principle, our MERMAID – Mobile Earthquake Recording in Marine Areas by Independent Divers – was now born.

### Sounds of the sea

In fact, the research had just started. Turns out that seismologists are much more demanding than oceanographers. To be of use to global seismology, the water pressure variations that may contain the tiny signals due to distant earthquakes have to be logged at a rate of 20 samples per second – recorded, filtered, analysed and reported in real time. A demanding task for an instrument whose battery energy is both finite and small, due to space and weight restrictions. Moreover, if the instrument oscillates by as little as a millimetre relative to its equilibrium cruising depth, this might be falsely interpreted as a sign of earthquake activity. This could unnecessarily trigger the costly resurfacing procedure.

Ideally, MERMAID would spend as much time as possible hunting for signals, coming up only to report 'interesting' (deep and distant) earthquakes, while turning a deaf ear to the noise caused by the 'uninteresting' ones. Not to mention the sounds of storms, whales or passing ships.

Rapid, precise identification of the signal, exact timing and location accuracy, and a high signal-to-noise ratio are of vital importance for the improvement of seismic tomography. After all, we are trying to map three-dimensional seismic wave speed variations that may be only as small as one per cent of the global average.

In the meantime I had moved to University College London, and with the help of the Nuffield Foundation and a NERC New Investigator Grant I set about designing algorithms that could identify and pick out arriving seismic sounds, efficiently and reliably, from a sea of noise.

I quickly settled on a mathematical technique called wavelet analysis. Wavelets are the fundamental building blocks of time series, and thus also of noisy seismograms. What wavelets have on more traditional ways of analysing and representing information such as the Fourier transform is that they can be calculated with great speed.

Also, wavelet transforms mean only a very small number of coefficients are needed to represent the signal at hand very faithfully. Not surprisingly, the FBI in the US use wavelets to store and search through vast databases of fingerprints, and these days most cameras use them to compress and denoise digital pictures.

With these algorithms onboard, MERMAID can quickly filter through the incoming stream of sound, identify seismic arrivals that could be useful for seismic tomography, and send the results as a series of small messages to one of the many IRIDIUM satellites, which will relay them to land.

We tested the MERMAID prototype at sea on numerous occasions, and it works! Many further tests await, however, before our dream of building a fleet of such devices to collect large quantities of new seismic waveforms from previously inaccessible oceanic areas will become a reality. For one thing, we are planning tests in different and less hospitable areas than our relatively cushy spot offshore La Jolla, California. The software needs to be more fully integrated with the instrument, and the next model will have a GPS receiver and an IRIDIUM transmitter on board.

While I have moved from Europe back to Princeton, in the United States, the development of MERMAID continues on both continents, as Guust moved to the University of Nice in Sophia Antipolis, where he received a large sum from the European Research Council. As for me, I hope to keep the US National Science Foundation and any other organisations interested in funding my work.

In Bud Vincent from the University of Rhode Island I have found an additional partner to help bring seismic data acquisition to the seas. The Son-o-Mermaid, our latest brainchild, will take the concept several steps further with the addition of a green energy source based on water wave motion, a full-ocean depth fathometer, and not one but three hydrophones mounted in sequence. But that's a story for another issue.

**MORE INFORMATION**
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