Article

K131 Antarctic sea ice science:
A case study of infrastructure, strategies, and skills

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Introduction

If you are fortunate enough to have access to a port-side window when flying into McMurdo Sound, Antarctica, you'll see a long, slender glacier that spills off the south-western flank of Mount Erebus and then floats out into the waters of the Sound. This is the Erebus Glacier tongue, as big as any glacier in New Zealand, but tiny in Antarctic terms. It is also uncommonly narrow relative to its length, and edged by substantial undulations. It has been the focus of research ever since Scott's last expedition, with geologist Griffith Taylor documenting its structure (Taylor 1922). Remarkably, given the decades-long interval between occurrences, the last few kilometres of the glacier broke off during their time there (Stevens *et al.* 2013). The abnormal structure, history of research, and ease of access mean it has been scientifically pored over for decades. It was also the starting point for the development of some Antarctic infrastructure that has been a mainstay of New Zealand sea ice research for more than thirty years.

Ernest Rutherford is supposed to have said 'we don't have much money so we have to think' (da C. Andrade 1964). In the era of ~10% success rates for funding applications, this could be augmented to additionally say 'and be flexible and be prepared to take one's time'. Big science is about big missions, large teams focused on a fundable goal, with its end-points well defined. Certainly, within this envelope, research takes its meanders and, science being science, advances are often found in the side-meanders. What about a different kind of mission? What if the mission is built upon meanders? What if we could go from listening to a glacier through to predicting the impacts of a changing climate?

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K131 genesis

New Zealand's Antarctic science is organised into 'Events', each given a 'K' (for Kiwi) designation. The formative work for one of the better known, and longer-lived Events, K131, took place in the 1980s. Timothy Haskell, then a scientist at the Physics and Engineering Laboratory (part of the Department of Scientific and Industrial Research), along with Bill Robinson and Arnold Heine, developed methods to gauge the Erebus Glacier tongue's inner mechanical workings and how, and why, the tip would periodically calve. This calving phenomenon only occurs every three or so decades (Stevens *et al*. 2013) – hence the point about the good fortune that Scott's party were there to see it happen.

Craig Stevens graduated in civil engineering at the University of Adelaide, and obtained his PhD at the University of Western Australia, subsequently working as a postdoctoral fellow at the University of British Columbia studying environmental fluid mechanics. Dr Stevens is now a physical oceanographer at the National Institute of Water and Atmospheric Research (NIWA) while also being an Associate Professor at the University of Auckland.

Dr Stevens is currently co-President of New Zealand Association of Scientists.

Natalie Robinson obtained her PhD at the University of Otago, specialising in chemical and physical oceanography. She now works as a physical oceanographer at the National Institute for Water and Atmospheric Research (NIWA), where her principle work involves field collection and analysis of data in the Antarctic on a range of ice–ocean processes relating to both sea ice and ice shelf regimes.

Pat Langhorne is an Antarctic sea ice researcher and Professor in the physics department at the University of Otago. She graduated from the University of Aberdeen and obtained her PhD at the University of Cambridge with studies on crystal alignment in sea ice. Dr Langhorne now leads the sea ice observation component of one of New Zealand's National Science Challenges – the Deep South.

Figure 1. A 'ditch-witch' cutting sea ice beams, with the Transantarctic Mountains in the background, 1992.
(Image: T. Haskell)

In the late 1980s, the trio of Robinson, Heine and Haskell spent several field seasons measuring the mechanical response of the glacier to various drivers. It was only a matter of weeks *following* retrieval of their instruments in 1990 that the long-awaited calving event occurred (Robinson & Haskell 1990). Haskell has been recorded as suggesting that, as the strain-meters they were using comprised long wires, the meters may have been holding the glacier tongue together and when removed the glacier fell apart. Here we trace the evolution of the team and infrastructure that evolved from this early Antarctic ice–ocean work. Indeed, Haskell was still involved, two decades later, in work with the team that documented the next, and somewhat earlier than expected, calving of the glacier in 2013 and was acknowledged in a paper on the event (Stevens *et al*. 2013).

Infrastructure as a spine to cross-disciplinary study

The glacier tongue mechanical work naturally led to ideas around the strength of the sea ice surrounding the glacier and its role in protecting the glacier from storm events. This progressed into a project looking at the potential of ocean waves to break up sea ice. The team developed a method to detect the signatures of ocean waves that had travelled substantial distances through sea ice from the open ocean. However, to predict and generalise the effect of these waves, the basic mechanical properties of sea ice needed to be measured.

The team did this by developing techniques for producing ice beams ten metres long, cut from the sea ice during the cool of the spring evening, and then subjecting them to wave-like loading until failure (Figure 1). However, every Antarctic field season brings its own challenges. During the first attempt at measuring mechanical properties, in 1990, the importance of having good infrastructure was revealed and, despite every effort, it was a no-data season. There had to be a better way to work.

A re-thinking as to how field operations could be conducted on the McMurdo sea ice resulted in the birth of the K131 container camp. Insulated shipping containers on sled-skis were converted for various camp tasks and provided a largely weather-proof base from which to conduct work (Figure 2). The camp concept, developed by Tim Haskell and Johno Leitch and fitted out for comfort by Jane Haskell, included containers modified for sleeping, eating, laboratory space – and importantly, a generator. These are deployed by bulldozer in chains, with a single dozer sometimes towing five or six containers. It became a regular sight around McMurdo Sound in October to see the camp being deployed. A line of green boxes inching their way across the sea ice signalled the start of the summer sea ice research season (Figure 3). This first camp was the basis for the diverse variety of research that followed.

The connection between mechanical behaviour and the physics of the ice was explored by developing a team of collaborators with different perspectives on the problem. One of the key environmental factors, apparent even in Scott's time and

Figure 2. K131 in 2016, Transantarctic Mountains in the background. (Image: Natalie Robinson)

Figure 3. K131 container camp being towed to field site using a bulldozer. (Image: Natalie Robinson)

recognised as a possible influence on how the sea ice responded to moving loads, was the layer of platelet ice crystals often found beneath the sea ice. This was the research focus for Pat Langhorne (Otago), a collaborator on the moving-load experiments, who proved to be the scientific thread within the K131 weave, as the container camp proved perfect for development of her work looking at these ice crystals. In a classic example of big science building through linked serial-meandering developments, work looking at individual crystals within ice cores is now looking at ways to observe hidden layers of such crystals from space and then how to connect this with climate prediction.

Sea ice prediction is proving to be one of the leading tasks yet to be reliably resolved with the present family of climate models. However, improving these models is severely limited if the only knowledge on spatial distribution comes from driving around on skidoo and drilling holes. Remote sensing of sea ice extent and thickness is thus crucial to advancing these models. Langhorne brought in collaborators Wolfgang Rack (Canterbury) and Christian Haas (Alfred Wegener Institute, Germany) with air- and space-borne sensor technology to determine sea ice thickness with promising results confirming existing measurements and pointing the way forward for substantial mapping of the nature and condition of sea ice around Antarctica. Understanding the crystal structure *in situ* is required to understand what the satellites are seeing. A sequence of collaborators (Joe Trodahl and Malcolm Ingham from Victoria University of Wellington and Inga Smith from Otago) explored the growth of the sea ice, comparing this with electromagnetic responses, and made comparison with Arctic observations.

Beyond fast ice

Despite the container camp not being particularly designed with marginal ice zone wave studies in mind (one doesn't really want to be in a container on an ice floe moving up and down in swell), Vernon Squire's (Otago) work on waves in sea ice spawned a separate connection to K131. This work always maintained a strong analytical mathematics pathway and is being reinvigorated by Alison Kohout's (NIWA) experiments on waves in pack ice. Kohout conducted her initial tests at the 2012 K131 field camp, learning what needed to be done to substantially develop instrumentation since Squires' first measurements in the 1980s and winter deployments conducted by Haskell and others off the US icebreaker *Nathaniel B. Palmer* in 1999. This preliminary work at the K131 camp proved a basis for ultimate success in deployments from the Australian polar supply vessel, the *Aurora Australis*. The critical point here is that waves might be a pathway for understanding how sea ice will change as climate evolves, since changes to wind patterns may affect how sea ice is broken up (Kohout *et al.* 2014).

The work evolved from ice to ice–ocean interaction through to regional oceanography, and then to climate scales, as there is a growing awareness that the ocean beneath sea ice and ice shelves is crucial to polar environments. The K131 evolution spanned one of the largest geophysical events of the last century in the McMurdo region, with the 2000 massive iceberg calving event that saw several very large icebergs ground themselves to the north of Ross Island. These bergs, amongst the largest ever observed, were originally spawned from the front of the Ross Ice Shelf, and dramatically affected McMurdo Sound regional sea ice and ocean conditions for a decade (Robinson & Williams 2012).

K131 work extended beyond the container camp and included experiments in challenging environments including the marginal ice zone and winter polar oceanography. As well as a winter (1998) voyage aboard the *Nathanial B Palmer*, Haskell, along with Langhorne, designed and supervised two winter-over sea ice campaigns in 2003 and 2009. On each occasion, a postdoc, a PhD student and a field support expert put in the commitment to winter-over (Greg Leonard, Craig Purdie and Johno Leitch in 2003; Andrew Mahoney, Alex Gough and Brian Staite in 2009) to conduct these difficult measurements (Leonard *et al*. 2005, Mahoney *et al*. 2011, Langhorne *et al*. 2015). Throughout all this work, international contributions have been commonplace, with scientists from a range of countries including USA, Canada, Belgium, and Australia all participating in events.

A series of K131 field camps commencing in the mid-2000s saw extension of the facility to include several containers with holes in their floors to enable ready access to the ocean via holes drilled, either mechanically, or with a hot water melter. This was initiated through Mike Williams' (NIWA) integration of full water column oceanography into what had previously been viewed as the boundary condition for ice (Robinson *et al*. 2015). This drove thinking relating to the connection between sea ice and ice shelf cavities. The water beneath the giant Ross Ice Shelf, for example, is around the volume of the North Sea, yet essentially un-sampled. These cavities have been largely excluded from climate models, but we know they are clearly part of the climate system (e.g. Timmermann & Hellmer 2013) and influence coastal margins like McMurdo Sound.

These threads remain in place in a weave with new research components as the K131 team are set to work on several ice–ocean research problems. The 'Deep South' National Science Challenge is a decade-long mission seeking to understand climate impacts on New Zealand with an emphasis on Antarctic drivers of change. Langhorne led sea ice work within the Challenge that connected the remote sensing work with a 2017 *Nathaniel B Palmer* winter voyage. Natalie Robinson, in a Marsden-funded experiment, continued to evolve the K131 infrastructure when she led the 2016/17 and 2017/18 K131 events in search of the fate of the meltwater exiting the Ross Ice Shelf. The 2016/17 event was a double milestone in that it was the first season without Haskell (with Brett Grant of NIWA taking responsibility for keeping infrastructure operating) and it was also the furthest west the camp had ever been deployed. The group pushed the geographic bounds wider through collaboration with Italian and Korean groups working to the north around the Drygalski Ice Tongue, and also to the south with the NZARI-funded Ross Ice Shelf Drill Project led by Christina Hulbe (Otago).

Communication and careers

It is estimated that the K131 Event has produced about 160 peer-reviewed papers in journals or conference proceedings and, at its highest, was publishing one article about every six weeks in refereed journals. Of course, there is a growing recognition that successful science needs to communicate beyond the scientific literature, to the public and other so-called stakeholders. Reasonably enough, science can't expect to tell the taxpayer to 'trust us'; instead, there are growing initiatives to explain what is being done with the resources and why. You can do this with press releases and articles in the increasingly diffuse media. Or, as K131 did, you can do it through what proved to be IRL's highest-demand publication ever. Inspired by a group from the Women's Institute in the UK, who, in support of medical research, produced a calendar combining an absence of clothes with strategically located props (Calendar Girls 2003) – K131 put their own twist on the idea. The Men of Antarctica calendar went through several versions over the late 1990s, gaining recognition in the international media including the BBC weather programme. Production ceased as that sort of activity became common-place, and the impact of slightly blue-looking naked people, with strategically placed field equipment, was lost.

Innovative communication of science for the event was elevated dramatically with the participation of the artist Gabby O'Connor in K131 sea ice camps in 2015/16 and 2016/17 (Barraclough & Findlay 2017, O'Connor & Stevens 2018). Her mission was to both contribute to the scientific data collection, and produce art and art-science crossover work that is at the forefront of STEAM (science, technology, engineering and mathematics, STEM + Art, O'Connor & Stevens 2018). This hybrid approach proved adept at documenting the science in novel ways and resulted in a number of exhibitions and media articles. This was a side-step away from the Antarctica NZ model of artists visiting Antarctica and taking on experiences from an essentially set menu; here, the artist became a protagonist. This was more in keeping with Heroic Era art and science connections – for example, Edward Wilson was a painter – where the artist was a documenter and key element of the promotion machine required to explain results and generate funding and support (Fox 2005).

While the container camp concept is locked into a limited seasonal and spatial range, needing reliable fast sea ice, it has proved a fertile springboard for new ideas and then taking them to more distant locations and seasons. This was especially true regarding the development of long-term oceanographic instrument moorings, which are made difficult by the effects of sub-surface ice growth on the lines. Techniques have evolved so that moorings have now been successfully deployed through an ice shelf, as well as an autonomous ice-tethered profiler deployed near Cape Armitage in 2010, and this dramatically increased the volume of hydrographic data recorded in the McMurdo region for the time it operated. It even became possible to see sea ice grow in real time, with the first K131 sea ice growth web page started by Greg Leonard (Otago) delivering a live feed of sea ice thickness and temperature from the middle of McMurdo Sound.

In earth system science it is often difficult to bring modellers and observationalists together. The fields are so big that individuals who work in the cross-over space are rare, as are workshops where the two approaches are given equal weighting. Instead, both approaches work in parallel and exchange ideas through the imperfect medium of the scientific literature. K131 provided an incubator, through, over the years, bringing leading climate scientists like James Renwick (then NIWA and later Victoria University of Wellington), Sam Dean (NIWA) and Cecilia Bitz (Univ. Washington, USA) to work with field observationalists to get a sense of the challenges behind the measurements and drive future questions for the observations.

Pragmatic innovation was always a specialty of the event. Perhaps in keeping with Hillary's first foray across the continent in a tractor, there has always been a thread of adapting existing technology to the high-latitude conditions. A small bulldozer with a 2m-long chainsaw enabled beams of ice to be rapidly excised (Figure 1). A space-buggy with a clear Perspex housing proved a useful transport vehicle and sun-trap. Milk-sterilising heaters have been adapted to provide water for sea ice hot-water drilling.

The facility also proved a useful incubator for early career development, with many postgraduate students, postdoctoral researchers and early-career researchers passing through the camp. Overall, it is estimated at least 26 students have been associated with the Ki3i Event. This training was critical for the winter field events which teamed a student, postdoc and field support person. With limited contact with senior team members back in New Zealand, these teams rapidly developed an ability to make decisions and operate independently.

Science v. operations

There is always a tension in Antarctic science as to how self-sufficient a science team has to be, from requiring permanent field support in order to survive, through to being entirely independent. The latter approach is more work but ultimately more flexible, and it requires only a few seasons for the science group to have had more experience on sea ice than many of the field support staff. From the outset, K131 sought to be self-sufficient, so that the camp could deploy without on-going field support. Where the operational support is invaluable is in the preparation and surveying of safe travel routes, skilful plant operations with the heavy machinery required to manoeuvre the containers, and occasionally to come and dig the camp out after some particularly deep snow accumulation.

Applications, institutional transitions and funding

Describing the K131 Event as 'serial-meandering' is not a cover-up for 'no plan'. It is essential in order to work over a long period of time on sometimes unfashionable topics (keeping in mind that climate science was once unfashionable) with changing funding. The containerised sea ice camp has survived, and even thrived, through a number of institutional transitions. Initially developed as ideas at the Physics and Engineering Laboratory at DSIR, this became part of Industrial Research Ltd (IRL) with the formation of the Crown Research Institutes in the early 1990s. IRL had a mandate around industrially-relevant topics and initially it was not clear that observing the strength of sea ice, no matter how creative the proposal writing was, would fall within their mandate. However, the decision was made to continue the work, and this faith was rewarded through the K131 collaboration, with Sir Paul Callaghan's group developing portable nuclear magnetic resonance (NMR) techniques.

Callaghan, arguably New Zealand's highest-profile scientist of the early twenty first century, was a strong proponent of linking prosperity to scientific exploration (Figure 4). After an initial planning meeting between Callaghan, Mark Hunter, Bill Robinson and Tim Haskell, held in the latter's sitting room, a good deal of the portable NMR development was based at the K131 field camp. Early tests looked at brine diffusion in McMurdo Sound sea ice, taking advantage of Antarctica's low background noise, and enabled the team to build small, but highly sensitive, instruments (Hunter *et al.* 2009). From there the instruments were reduced in size so that it became possible to build small, portable NMR technology that would work in 'normal' (lower latitude, radiation-filled cities) environments making it possible to take something usually confined to a lab bench into all sorts of domains. This led to the formation of the Magritek company which developed portable instruments to provide nuclear and earth's magnetic field resonance measurements.

There were operational benefits from the science as well. Historically, large transport aircraft used by the US Antarctic Program used ice shelf regions as runways, with the hundreds of metres of ice well able to support the loads as the aircraft landed. However, the possibility of landing heavy transport aircraft on only a few metres of sea ice allows a much wider range of runway choices. A sea ice runway substantially reduces the operations required to support McMurdo Station as it bypasses the road-trip out to the ice shelf runway at Pegasus Airfield, some 40 km away by ice road. At the invitation of Bill Robinson, Vernon Squire (then at Scott Polar Research Institute) looked at how moving loads like a heavy aircraft would spawn waves in the ice, much like the waves generated by a ship moving in water. As with many wave problems, a critical condition occurs when the wave speed equals that of the forcing celerity. Experimental work followed using speeding trucks, and even Hercules aircraft, as the moving load and resulted in a *Nature* cover story based on the original publication (Squire *et al*. 1988).

Another example of the non-linear nature of how science leads to application, is that some of the concepts developed in the sea ice mechanics work led to the IRL-based team, led by Bill Robinson, successfully designing the earthquake lead–rubber base isolators for Parliament, the General Assembly Library, and Te Papa – all in Wellington. K131 outlasted IRL – the Crown Research Institute was reabsorbed into the public service as

Figure 4. Sir Paul Callaghan near Razorback Island.
(Image: T. Haskell)

Callaghan Innovation in the mid-2010s. The organisation's role was condensed around being a provider of technical support and funding for industry, somewhat at odds with the outlook of its namesake. This eventually resulted in transfer of the K131 infrastructure to NIWA, the Crown Research Institute with the greatest stake in sea ice-based research at the time, and growing work in the ice–ocean and fisheries/ecosystem themes.

New Zealand's Antarctic research is made possible in the first instance by the Ministry of Foreign Affairs and Trade, which supports the nation's scientific presence in Antarctica, through Antarctica New Zealand. This keeps the operations and infrastructure going. With the changing institutions and evolving science priorities, support for K131 has come from many funding mechanisms. The Marsden Fund supported several K131 campaigns, including its first winter experiment, ocean-driven melting of the Erebus Glacier tongue and, more recently, work towards the western side of McMurdo Sound looking at how sea ice changes with distance from the Ross Ice Shelf. A second winter campaign was supported by dedicated funding for the International Polar Year through the short-lived Ministry of Science and Innovation. At the time of writing, along with NIWA Strategic Investment Funding, the Deep South National Science Challenge, Ministry of Primary Industry/Fisheries and the Marsden Fund are the primary supporters of the K131 legacy. Through this time, the operational support structure for Antarctica also changed. First visits to Scott Base were through New Zealand Antarctic Research Programme (NZARP); this evolved with the formation of Antarctica New Zealand and the evolution of its role in the balance between provision of logistics and assessment of which science to fund. Research funding in Antarctica recently saw the formation of NZARI (New Zealand Antarctic Research Institute), which supported several K131 events, so that philanthropic support held a controlling stake. At the time of writing, a new 'research platform' is being developed by the Ministry of Business, Innovation and Employment, which looks likely to support several sea ice and ocean research threads in the coming years.

The container camp concept has faced challenges beyond funding. Fire is one of the great dangers of Antarctic work – like a ship, shelter is everything. An unoccupied field hut mounted on the tip of the Erebus Glacier tongue was destroyed by fire after the tip broke away in 1990. One of the K131 oceanography containers was extensively damaged in a heating fire just after refurbishment, and team members witnessed the loss to fire of the Antarctica New Zealand A-Frame hut in Windless Bight during the winter of 2009.

A Strait

In 2009, the ocean passage connecting McMurdo Sound from the substantial oceanic basin beneath the Ross Ice Shelf was named Haskell Strait by the New Zealand Geographic Board Ngā Pou Taunaha o Aotearoa (Harrowfield 2017). The Strait is around 25 km wide and, in places, over 900 m deep (Figure 5). Currents of nearly half a knot have been measured, although typical flows are lower. For comparison, Haskell Strait is as wide as Cook Strait and has through-flow comparable to the Straits of Gibraltar. Although mostly covered by the ice of the McMurdo Ice Shelf and the sea ice of McMurdo Sound, on rare occasions ice breakout exposes the north-west corner of the Strait, which then becomes navigable and vessels have at times moored just off Scott Base. Until sea level rise and

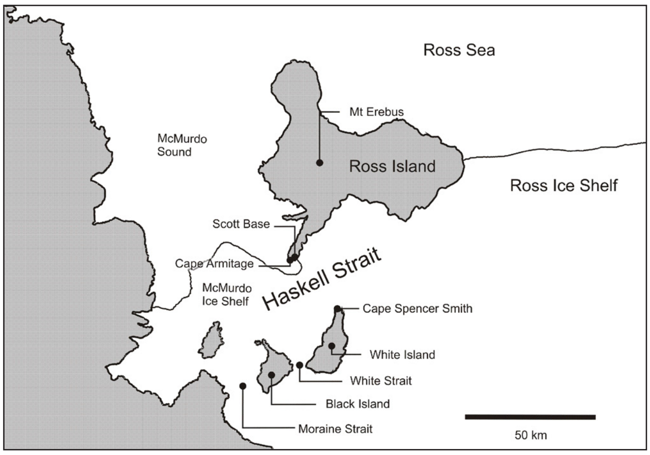

Figure 5. Map showing Haskell Strait in relation to Scott Base and Ross Island.

reduced ice coverage changes the shape of our oceans, Haskell Strait is likely the last strait of its size to be named world-wide. It was presumably previously overlooked, as it is perennially mostly ice-covered and is dominated by the ice barrier (here, the McMurdo Ice Shelf). However, it dwarfs other long-named ice-covered straits in the area – for example Moraine Strait and White Strait, which separate Minna Bluff from Black Island and White from Black Islands, respectively.

The Strait was the scene of great drama during the Heroic Era. Cherry-Garrard's description of the Scott parties' attempts to get themselves and their ponies off disintegrating sea ice, past patrolling orca, and onto The Barrier (the ice shelf) makes for harrowing reading (Cherry-Garrard 1922). While that account sits in the back of the mind of anyone who works in the region, our improving ability to understand and predict sea ice and ocean behaviour makes it ever less likely to happen again.

The strait naming was one of a number of honours bestowed upon Haskell (Figure 6). He has received the New Zealand Antarctic Medal, the Royal Society Hector Medal, the NZ Association of Scientists Marsden Medal and the Royal Society Science and Technology Medal. From the perspective of the polar work, it is rather interesting to read his citation for his 2006 NZAS Marsden Medal. The Antarctic work is barely mentioned. It says:

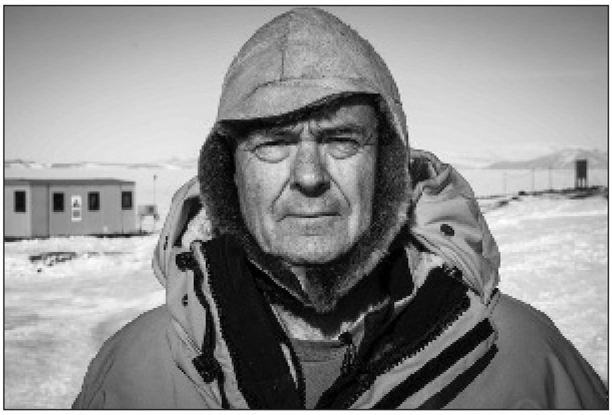

Figure 6. Tim Haskell in 2013. (Image: courtesy Air New Zealand)

The recipient of this medal for 2006 was Dr Tim Haskell of Industrial Research Limited, Wellington. Dr Tim Haskell has conceptualised, initiated and led a number of novel research programmes over a 35 year period and is an outstanding advocate for science in New Zealand. Dr Haskell's scientific interests have covered a broad range of areas from solar heating, to IT, novel optical devices and Antarctic sea ice formation and decay. He developed the test procedures and equipment for the testing of the base isolators installed in Te Papa – one of the largest commercial contracts undertaken by IRL. His outstanding leadership and work with the Antarctic Research Programme has spanned nearly 30 years, during which time he has kept together a team of researchers from the universities of Auckland and Otago, Victoria University of Wellington, IRL, and NIWA, as well as a number of overseas institutions. One of Tim's most significant leadership roles integrated signal processing, communications, optics and synthetic organic chemistry into an applied research programme. This work arises from collaboration between IRL, the universities of Auckland and Otago, as well as interactions with a number of commercial companies. The team is developing 'all-optical' infrastructure components such as routers, switches, laser sources and amplifiers, for optical networks. Without his initiative, this integration of diverse skills would not have happened. Hitherto unknown materials and techniques have been discovered which it is expected will eventually lead to new industries for New Zealand. In the mid '70s he was instrumental in developing hardware for the DSIR computer communications network. This has led to the creation of one of New Zealand's most successful communications research and development companies. He was awarded a Royal Society Science and Technology Medal in 1996 and has chaired the Environmental Assessment and Review Panel advising the Minister of Foreign Affairs and Trade on Antarctic environmental matters. He has also served on the Marsden Fund Physical Sciences Panel and provides advice to the US National Science Foundation on logistics matters relating to sea ice in McMurdo Sound. In education he has been directly involved with around 20 post graduate students in both optics and Antarctic research, as well as a number of undergraduate projects. He is an author on approximately 100 publications as well as numerous industry reports.

Over the past 30 years, K131 science has developed not only an understanding of the physical processes of how the components of an ice-covered ocean work, but also evolved robust operational methods for experimentation on ice–ocean interaction. The approach has brought together physicists of many flavours, engineers, mathematicians, oceanographers, biologists, biogeochemists, modellers and artists. It is a demonstration of how to do big science in serial-meandering mode.

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