WATER & ATMOSPHERE

November 2012

Something in the air

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Cover

NIWA Physicist Ben Liley adjusts a LIDAR (Light Detection and Ranging) device at Lauder Atmospheric Research Station, Central Otago. The LIDAR bounces laser light off aerosol (dust) particles in the atmosphere, measuring their altitude and optical properties. Aerosols come from both human activity and natural sources, and affect cloud formation, atmospheric chemistry, solar radiation and air quality. (*Dave Hansford*)

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Enquiries to:

The Editor
Water & Atmosphere
NIWA
Private Bag 14901
Kilbirnie
Wellington 6241
New Zealand

email: wa-editor@niwa.co.nz

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Water & Atmosphere team:

Editor: Dave Hansford

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NIWA
Taihoro Nukurangi

Editorial

Meeting the challenges

In July this year, the UN Environment Programme released its fifth Global Environmental Outlook, a three-yearly review of the planet's health. As report cards go, it was a D-minus: "If current patterns of production and consumption of natural resources prevail," said UNEP Executive Director Achim Steiner, "... governments will preside over unprecedented levels of damage and degradation."

Climate change, food and water shortages, overfishing, deforestation, biodiversity loss – all are chronic global maladies, but, said Steiner, the case for the cure: "a decisive and defining transition towards a low-carbon, resource-efficient, job-generating green economy ... is overwhelming".

New Zealand might seem well protected, even immune, from such global ailments, but a look through Ministry for the Environment (MfE) reports shows that we're part of the problem. Our greenhouse gas emissions, while falling overall, continue to mount over the country's farms: a consequence of continued intensification and rising nitrogen fertiliser use. Agriculture was the single largest greenhouse gas emitter in 2010, contributing 33.7 million tonnes of carbon dioxide equivalent, or 47.1 per cent of total emissions – an increase of 0.8 per cent on 2009.

In October, MfE reported that water quality was either poor or very poor at just over half of 210 monitored river swimming sites. A further 28 per cent got a "fair" grade, meaning you still risked illness by swimming there.

The Christchurch earthquakes reminded us that many of us live right beside a vast potential seismic energy: many more live beside an ocean tipped to rise by at least half a metre by century's end, and probably more. Driven by a more energetic climate, waves of change are coming our way.

So it was timely when, in early October, Science and Innovation Minister Steven Joyce boarded RV *Tangaroa* in Auckland to announce the National Science Challenges research programme.

The Challenges are a $60 million Government budget initiative to identify the paramount social and environmental problems facing New Zealand, and to secure solutions to them. The project rightly recognises that we are, above all, a ward of Nature: the country's economy stands or falls on the integrity of the environmental systems – water, energy, ecosystem services, nutrient and energy cycles – that sustain it. A more volatile climate will put still greater pressure on these systems (and on our economy – the 2007–08 drought cost around $2.8 billion in lost production), so it's vital that we strive to understand where that might lead.

As Minister Joyce said, "If we were able to talk about science more, there would be a lot more solutions coming forward, balancing science and the economy." Nowhere are they more urgently needed than in our pastures. The Government's Economic Growth Agenda calls for export revenues to earn 40 per cent of GDP by 2025. That would require the sector to treble the real value of its exports in that time.

Feeding the world is a noble cause, but if it leaves our skies loaded with greenhouse gas emissions, and our waters full of nitrogen, it will have been a lost one.

The Government has signalled, too, that it expects our territorial sea to assist the nation's economic recovery. But before we can mobilise our marine resources sustainably, we have to know what they are, what ecosystems and webs they support, how much we might wisely choose to extract.

The long-term debt of getting it wrong will cancel out any short-term economic relief: as the Minister pointed out, "It's really important to have a science-based approach.''

Which comes down to accurate information, and innovative solutions. Monitoring has always been crucial to good resource management, but now that the rate of change threatens to outstrip the capacity of natural systems to adapt, we must be sensitive to any signals they might send.

In this issue, *Something in the air* reminds us of the value of vigilance: scientists at NIWA's Lauder Atmospheric Research Station have been measuring atmospheric elements for more than four decades, and their data suddenly became pivotal with the discovery of the ozone hole in 1985.

In *Acid test*, Marieke Hilhorst reports that, as the oceans absorb more and more carbon dioxide, shell-building creatures – including, crucially, plankton – may struggle to survive in increasingly acid seawater. Just what that could mean for oceanic food webs, we don't yet know, but NIWA scientists are testing various hypotheses, because nobody wants another unpleasant surprise like the ozone hole.

John Morgan
Chief Executive

Outlook for sunshine

Solar generation is tipped to play an increasingly important part in meeting New Zealand's future electricity needs. A recent report commissioned by the Ministry for Economic Development (now the Ministry of Business, Innovation Employment) highlights the potential of underutilised renewable energy sources – like solar – to ensure a sustainable supply for the country, even as demand burgeons out to 2040.

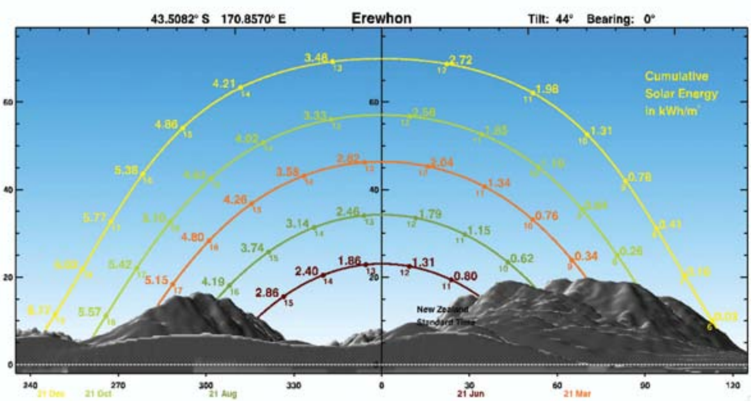
"Solar radiation is an abundant, free, non-polluting and renewable energy source," says NIWA Atmospheric Physicist Ben Liley. "In New Zealand, many homes are exposed to 20 to 30 times more energy from the sun annually than they use in electricity or gas, but little use is made of it. A well-designed home can capture the sun's heat directly, and a properly installed and controlled solar water heating system will meet 50 to 75 per cent of your hot water needs every year."

You may have considered having installing solar panels fitted to your home, but just how much solar energy is available in your region to power your life and livelihood? Will your lights stay bright through seasonal fluctuations in the strength and duration of sunlight? Are your solar panels oriented correctly? What if someone builds a high-rise next door, casting them into the shade?

NIWA's SolarView, a free online tool (http://solarview.niwa.co.nz) answers your questions in an instant. SolarView estimates the average amount of solar energy (insolation) available to power a one-square-metre solar panel at any location in New Zealand, at different times of the day and year.

Simply enter your street address, or click a location on the embedded Google Maps link, and then specify the tilt and bearing of your roof, or panel-bearing surface. SolarView takes these inputs, factors in surrounding terrain, then taps into NIWA's extensive climate database to accurately depict the sun's path from sunrise to sunset at five representative dates during the year, including summer and winter extremes. It also plots hourly measurements of cumulative insolation in kilowatt hours (kWh) per square metre on each path.

SolarView offers guidance on how to plot nearby obstructions, like buildings and trees, onto the profile, and calculate any diminishing effect of their shade on your kilowatts. Any homeowner or solar energy specialist can use this information to determine how much money solar panels or a solar water heating system might save them.



SolarView plots hourly insolation values across the sun's daily track. (*NIWA*)

The tool also helps precisely determine the optimum location for panels on any roof, given the unique surroundings and situation of each home.

SolarView is Liley's brainchild: he designed the software to help people considering installing a solar energy system. "The idea is to help users appreciate how much solar energy is available, and how it depends on various parameters," he says. "To make solar power work for them, it's important that people have good information specific to their situation. It's also important that they can make sense of that information, so we've provided guidelines on how to put SolarView's calculations into perspective."

On average, New Zealand receives about 2000 hours of bright sunshine each year. In energy terms, that corresponds to about four kWh per square metre of a horizontal surface every day. To put that into perspective, says Liley: "For an average New Zealand home, a three-kW solar photovoltaic (PV) array should generate more than half the electricity used in that house over a year. Instead of all the batteries you used to need – for when there was too little light to generate – grid-connected systems are now the norm."

Liley says SolarView is also popular with homebuyers wanting to find out how much sun their prospective new property will receive, checking sun angles at different times of year.

"The tool is a very useful guide," he says. "And if users need more detailed records – or a prediction of available solar energy – NIWA can provide this as a commercial service. We can also supply tabulated data on climate parameters, including direct irradiance, indirect irradiance, temperature and wind speed, for input into other programmes which can then analyse solar systems or a whole building's energy performance.

Contact:
Ben Liley
Atmospheric Physicist
ben.liley@niwa.co.nz

Scan this code with
your smart phone
to go to NIWA's
SolarView page.

In brief

Lake Brunner, on the West Coast. Records from 200 of the world's lakes have shown that some are beginning to warm in response to climate change. (*Hedgehog House*)

The world's lakes are warming

A global collaboration has revealed that climate change is affecting some of the world's lakes.

Recent studies have shown those lakes are warming significantly – faster than the surrounding air, in some cases – which has profound implications for the plants and animals living in them.

The Global Lake Temperature Collaboration, sponsored by the US National Science Foundation, NASA and the University of Nebraska, has been set up to better understand the dynamics of lake warming.

Thirty scientists from agencies worldwide are sharing data and expertise to develop an agreed standard for measuring lake water temperature trends at a global scale. New Zealand is represented by NIWA Freshwater Scientist Dr Piet Verburg.

The group met for the first time last June to analyse data from around 200 of the world's lakes, examining lake surface temperatures and vertical temperature profiles.

"In New Zealand, the first good continuous lake temperature records only started in the 1990s, at Lake Brunner and at Lake Taupo," says Verburg.

"In exceptionally warm years, such as 1998, we see in the records from Lake Taupo that the bottom water warms more, because there has been less mixing with cool surface water during winter," he says.

Every winter, warm and cold water layers – hitherto separate – begin to mix. So to get an accurate picture of water temperature trends, researchers need records from the entire water column.

When he compared temperature records from Lake Tutira, in Hawke's Bay, from the early 1990s with readings from the last three years, he found that the lake had warmed by around one degree. "That's significant," he says, "because it's very important to lake processes like stratification and mixing, which affect the lake ecosystem through the distribution of oxygen and nutrients."

The threat of climate impacts makes global lake temperature data – from both in situ measurements and remote satellite sensing – increasingly valuable. Verburg says it's vital to monitor our lake temperatures as thoroughly as we record air temperatures. "We have 100 years of air temperature records from some places, which is why we we can say it has warmed by around one degree in the past century. Only if you have good monitoring data can you examine long-term trends.

"This is important to our understanding of what is going on in our lakes, and how climate change is affecting them."

Contact:
Dr Piet Verburg
Freshwater Scientist
piet.verburg@niwa.co.nz
www.laketemperature.org

On subantarctic Campbell Island, Dr Paul Sagar (L) and Dr David Thompson fit geolocators to Campbell albatrosses. The lightweight devices simply record light levels and duration: because day length is different at each latitude, and the time of day is different at the longitude, scientists can later deduce the birds' wanderings. (*Henk Haazen*)

Scientists shadow ocean rovers

Remote-tracking technology has revealed the winter whereabouts of two of our largest seabirds.

NIWA scientists Dr Paul Sagar and Dr David Thompson recently tracked Campbell albatrosses to South Australia, and grey-headed albatrosses 7000 kilometres from subantarctic Campbell Island, to distant Indian Ocean waters west of Australia.

"Until we started this project we didn't know where they went in winter," says Thompson. "The data suggest that in April each year, when the Campbell albatrosses have finished breeding, they spend four months off the coast of South Australia, then return to Campbell Island." They surprised the scientists by staying relatively local. "We thought they'd go further than South Australia."

Meanwhile, the Indian Ocean, says Thompson, "appears to be an oceanic zone of importance for grey-headed albatross that we were previously unaware of."

The birds' movements were betrayed by lightweight geolocator tags, fitted to their legs back on Campbell Island. By recording information about light levels and duration, they can then be analysed to determine locations.

Thompson says the tags "will reveal information about these conspicuous marine predators and their environment – what's important to them, and why it is they go where they go."

The birds spend 90 per cent of their lives over the open sea, soaring vast distances on wings more than two metres across. Both species routinely fly to Antarctic waters on foraging trips to feed hungry chicks.

The scientists are halfway through a six-year study of the two albatross species, along with the rockhopper penguin (see: Tracking a winter wayfarer, *Water & Atmosphere*, August 2012), based at Campbell Island.

Numbers of grey-headed albatross are thought to be declining, and while the Campbell albatross previously suffered a decline, it is now thought to be stabilising at around 23,000 pairs, or increasing slightly. Both species are classified as vulnerable.

"Each year since 2009," says Sagar, "we've sent a team to the island at the beginning of October through to January." The stay covers the bulk of the albatrosses' breeding season, from egg-laying through to "the guard stage, when one adult stays with a very small chick until it can defend itself."

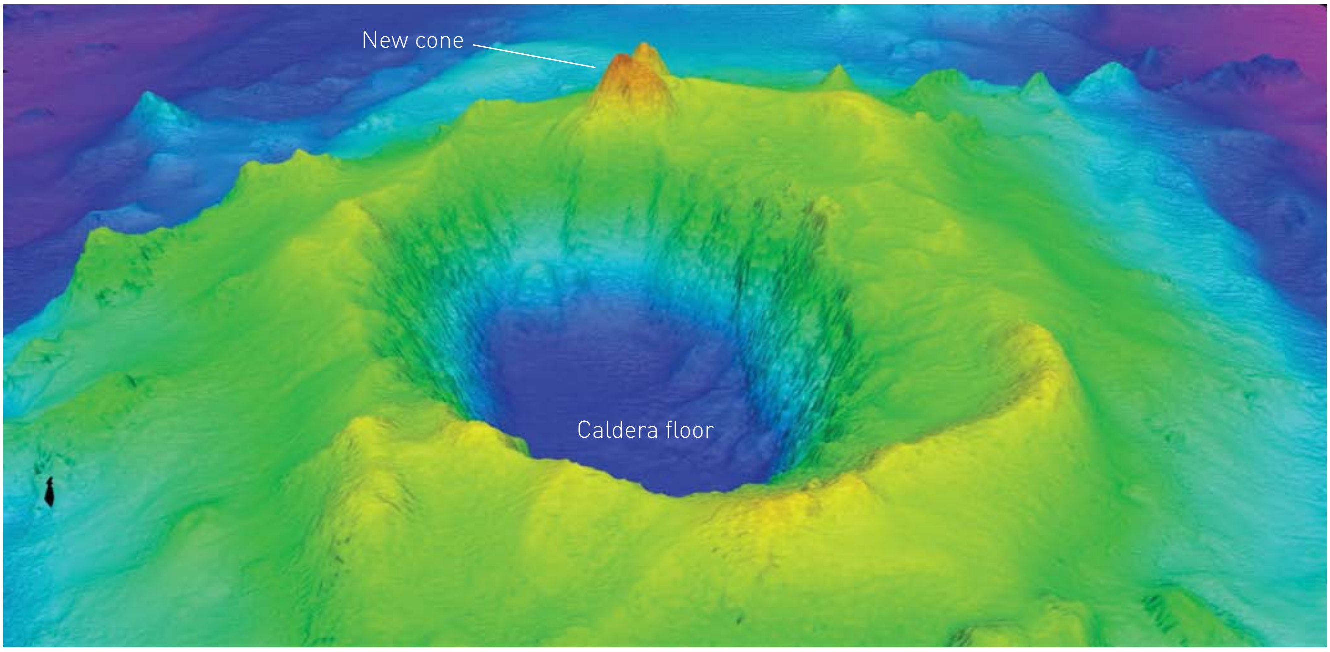
So far, the scientists have fitted tags to the legs of 70 birds. "We have over 60 tags back from the Campbell albatross, but less information for the grey-headed albatross," says Thompson.

The study is funded by the Ministry of Business, Innovation and Employment (MBIE), while the National Geographic Society part-funds the rockhopper penguin study.

Contact:
Dr David Thompson
Seabird Scientist
david.thompson@niwa.co.nz

Dr Paul Sagar
Seabird Scientist
paul.sagar@niwa.co.nz

In brief



The Havre explosion of 19 July was bigger than the 1886 Tarawera eruption, and left a new peak the size of Rangitoto atop the existing seamount. (*NIWA*)

Tangaroa records a scene of submarine havoc

A recent survey has revealed the ferocity of an underwater eruption north of New Zealand.

In October, NIWA research vessel *Tangaroa* mapped Havre, an undersea volcano 800 kilometres northeast of Tauranga, on the Kermadec chain of seamounts.

Havre erupted on 19 July this year, leaving enough pumice floating on the sea to cover an area the size of Canterbury. "We found a new volcanic cone on the edge of the volcano," says NIWA Ocean Geology Scientist Dr Joshu Mountjoy, "towering 240 metres above the crater rim. It's fantastic to be able to record the change on the seafloor following these kinds of events."

Ejecta from the Havre eruption broke the ocean surface from a depth of 1100 metres, leaving a raft of pumice over 22,000 square kilometres. Satellites recorded clouds of ash. Several cubic kilometres of new material has been added to the volcano, and Mountjoy says a blanket of freshly-ejected pumice has now raised the caldera floor by up to 10 metres.

NIWA Marine Geophysicist Dr Richard Wysoczanski led the 23-day *Tangaroa* voyage, which set out to study the Kermadec volcanic chain stretching 1000 kilometres north from Bay of Plenty. On average, there is a volcanic eruption in the region once a year.

"One of the most exciting aspects of the cruise was the chance to re-map Havre," says Wysoczanski. The seamount is a kilometre high, with a steep-walled, five-kilometre-wide caldera at its centre. Such structures are known to produce particularly spectacular eruptions.

Because NIWA had previously mapped Havre in 2002, says Wysoczanski, *Tangaroa*'s multibeam echosounder could produce "a before-and-after comparison of the volcano, to determine the size of the eruption and the change it's made to the seafloor."

Mountjoy says Havre may not be finished yet: "One side of the caldera wall is bulging in towards the volcano's centre," he says, suggesting the site of a future eruption. "Or it might lead to an undersea avalanche."

Tangaroa's crew retrieved glassy volcanic rocks from the crater wall, and pebbles of pure sulphur, which will be analysed.

The Kermadec and Colville Ridges have rifted by more than 100 kilometres, and Wysoczanski wants to know where the new material is coming from.

He suspects that the Colville Ridge is the original feature, which has provided the parent material for the younger Kermadec Ridge.

The last four days of the voyage were spent studying tectonic processes on the Hikurangi margin subduction zone, off the North Island's east coast.

The work, funded by the Ministry of Business, Innovation and Employment (MBIE), is part of an international effort to understand the behaviour of the subduction system off New Zealand's east coast.

Contact:
Dr Joshu Mountjoy
Ocean Geology Scientist
joshu.mountjoy@niwa.co.nz

Dr Richard Wysoczanski
Marine Geophysicist
richard.wysoczanski@niwa.co.nz

At some 3500 floats, the global Argo deployment is now complete, but a further 800 new ones must be placed each year as older floats fail. Their data will help develop more comprehensive ocean-coupled climate models. (*NIWA*)

Kaharoa's Argo cargo

In October, NIWA research vessel *Kaharoa* set out across the South Pacific with a cargo of Argo floats.

Over two months, the crew placed 120 of the remote sensing instruments between latitudes 28 and 46 degrees South, between New Zealand and South America, adding them to some 3500 floats already recording real-time data worldwide, for use in climate, weather, oceanographic and fisheries research.

The two-metre-high robotic probes usually drift about 1000 metres down, for about nine days. Then they automatically descend to profiling pressure – often as deep as two kilometres – before rising, profiling water temperature, pressure and salinity as they go.

The data are transmitted via satellite every ten days to scientists ashore, and the satellites determine how far each float has drifted, before the process begins again. Around 800 new Argos are deployed each year globally, and their data is freely available to all.

One of the programme leaders, Dr Dean Roemmich of the US Scripps Institution of Oceanography, says Japanese and US scientists are now testing Argos capable of descending to four, or even six kilometres. "Argo data are invaluable for informing governments, science and the community on inter-annual variability such as El Niño, as well as decadal and multi-decadal changes in the global ocean."

During this, *Kaharoa*'s 13th Argo voyage, floats were placed on behalf of Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), Scripps and the University of Washington. A further two were deployed for NIWA.

On its return, the vessel will have deployed a total of 1100 floats since the programme's inception back in 1999, more than any other vessel. Twenty-seven countries are involved in the project.

Contact:
Dr Philip Sutton
Marine Physicist
philip.sutton@niwa.co.nz

In brief

A new, four-year NIWA/Landcare Research study will help us better prepare for the ecological, social and economic impacts of climate change. (*Dave Hansford*)

New climate study to map our future

A new $7.2 million research project is about to look into New Zealand's future in a changing climate.

Led by NIWA and Landcare Research, the four-year study will model the impacts of climate change on ecosystems, environments, land and water use, our economy and society out to the turn of next century.

Co-leaders Dr Andrew Tait, of NIWA, and Dr Daniel Rutledge, of Landcare Research, say the influence of greenhouse gases on broad climate trends is now well understood, but there is still much to learn about regional and local climate variability and trends in New Zealand. "Our oceanic setting and complex topography – along with modes of natural climatic variability, such as the Southern Annular Mode (SAM), the Interdecadal Pacific Oscillation (IPO), and the El Niño-Southern Oscillation (ENSO) – complicate the climate response."

They point out, for example, that although New Zealand has warmed by about 0.9°C over the last century, a trend towards more southerly flows since about 1960 has slowed the rate of warming.

"So taking account of how these atmospheric circulation changes – and their associated influences on local rainfall patterns, flood and drought frequency and climatic extremes – affect ecosystems and natural resources is vital for improving our understanding of potential climate change impacts on the environment and the associated implications for the economy and society."

The study's findings will help guide New Zealand's climate change policy response and decision-making.

Complementary research projects will:

- update and improve regional-scale projections of climate trends and variability across New Zealand out to 2100, based on the latest global projections
- assess likely impacts, environmental pressure points and potential policy and management implications for five important environments: alpine and high-elevation native forest ecosystems; high- and hill-country; lowlands; coastal and estuarine ecosystems and oceanic food webs
- identify interactions between climate change and other key drivers, and their cumulative impacts, by integrating projections from climate, biophysical, economic, demographic, land-use change, freshwater and stakeholder models
- develop new ways to generate, translate, share and apply climate change knowledge with stakeholders.

The project will also involve researchers from AgResearch, Victoria University, Bodeker Scientific, Motu Economic Research, Plant & Food Research, Scion and the University of Waikato.

Tait and Rutledge say it's an exciting project that will, for the first time in New Zealand, examine potential climate change impacts on New Zealand's economy, environment and society in an integrated and coordinated way.

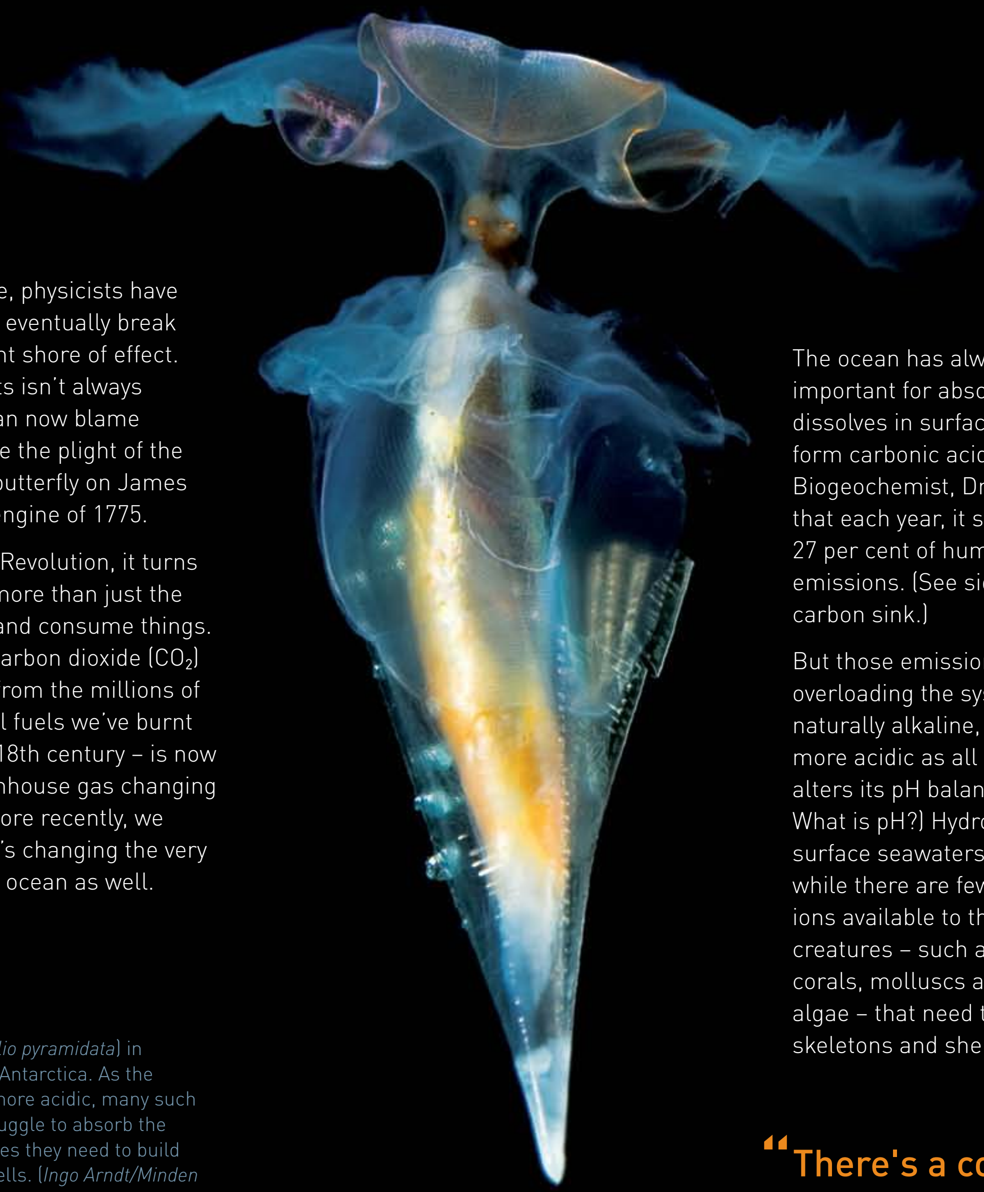
"We've assembled what we feel is a 'New Zealand best' research team," they say.

Contact:
Dr Andrew Tait
Climate Scientist
andrew.tait@niwa.co.nz

Dr Daniel Rutledge
Landcare Research
rutledged@landcareresearch.co.nz

Acid test

By absorbing carbon dioxide from the atmosphere, oceans ease the impacts of climate change. But it turns out there's a downside: seawater is becoming more acidic, making it increasingly hostile to some of the creatures that have to live in it, finds **Marieke Hilhorst**.



A sea butterfly (*Clio pyramidata*) in the Weddell Sea, Antarctica. As the oceans become more acidic, many such creatures will struggle to absorb the calcium carbonates they need to build skeletons and shells. (*Ingo Arndt/Minden Pictures*)

Waves of cause, physicists have always known, eventually break on some distant shore of effect. Joining the dots isn't always easy, but we can now blame with confidence the plight of the Antarctic sea butterfly on James Watt's steam engine of 1775.

The Industrial Revolution, it turns out, changed more than just the way we make and consume things. All that extra carbon dioxide (CO_2) – the exhaust from the millions of tonnes of fossil fuels we've burnt since the late 18th century – is now the main greenhouse gas changing our climate. More recently, we realised that it's changing the very essence of the ocean as well.

The ocean has always been important for absorbing CO_2, which dissolves in surface seawater to form carbonic acid. NIWA Marine Biogeochemist, Dr Cliff Law, says that each year, it soaks up some 27 per cent of human-induced CO_2 emissions. (See sidebar: The ocean carbon sink.)

But those emissions are now overloading the system. The ocean, naturally alkaline, is becoming more acidic as all that extra CO_2 alters its pH balance. (See sidebar: What is pH?) Hydrogen ions in surface seawaters are increasing, while there are fewer carbonate ions available to the many sea creatures – such as plankton, corals, molluscs and coralline algae – that need them to build skeletons and shells.

> “There's a consistent story there, and it's not a good one.”
>
> NIWA Marine Biogeochemist, Dr Cliff Law


NIWA's Dr Cliff Law: phytoplankton, he says, "are the grass of the ocean … we need to know what's going on." (*NIWA*)

Weaker building standards

Calcium carbonates come in three main forms: aragonite, low-magnesium calcite and high-magnesium calcite. Aragonite is very strong, but requires a lot of energy to use. It's very soluble in acidic water, dissolving 50 per cent faster than low-magnesium calcite, while high-magnesium calcite can be more soluble still.

For coralline red algae, that's bad news. Made of high-magnesium calcites, these ubiquitous organisms are a fundament of New Zealand's coastal ecosystems, says NIWA Principal Scientist and seaweed expert, Dr Wendy Nelson. "If you lift up seaweeds in the intertidal and subtidal zones, the pink crust covering the rocks underneath – that's coralline red algae. They occupy a huge amount of habitat." Not only do they provide habitat for other species, says Nelson, they release compounds that trigger invertebrates, such as paua, to settle. "Without those compounds, paua would not move from their free-swimming larval stage to settling down and growing a shell."

But rising temperatures and changes in seawater chemistry leave coralline red algae highly vulnerable to dissolution. Already, NIWA has found significant negative impacts on two species, although, says Nelson: "Some species are going to be more vulnerable to dissolving than others, and we don't really understand these species-specific differences yet. There may be some winners out of this – some may be tougher than others and able to withstand the changes, so you may get shifts in species composition."

Broader effects on ocean processes are also still largely unknown. "New Zealand spans so many degrees of latitude," says Nelson. "What may happen in Northland or at the Kermadec Islands may not be the same story that's happening in the Antarctic."

Because CO_2 is more soluble in cold water, acidification is expected to make life particularly difficult for polar creatures, says NIWA Marine Benthic Ecologist, Dr Vonda Cummings.

The ocean carbon sink

CO_2 circulation in the world's oceans is the concerted product of two natural 'pumps'. The solubility pump operates in those parts of the ocean – particularly polar regions – where cold, dense water sinks, carrying dissolved CO_2 down with it.

The biological pump is driven by phytoplankton, which fix carbon during photosynthesis. When the tiny animals die, their cells sink, carrying some of that carbon into the deep ocean.

By carrying carbon away from the surface, both pumps lock CO_2 away from the atmosphere for hundreds, sometimes thousands, of years.

> “No one knows if they will be able to adapt quickly enough.”
>
> NIWA Marine Benthic Ecologist, Dr Vonda Cummings

She’s focussed her microscope on two subantarctic sediment-dwelling bivalves: Antarctic geoduc (*Laternula elliptica*) and Antarctic scallops (*Adamussium colbecki*). The geoduc’s shell is aragonite, while the Antarctic scallop’s shell is mostly low-magnesium calcite.

As it is, the creatures are hard put to make and maintain thin, fragile shells in the frigid Ross Sea waters. To find out what a more acidic future might mean for them, Cummings studied live specimens at NIWA’s aquaculture facility in Wellington.

She manipulated the pH concentration in their cold-water tanks over four months, to mimic the low-aragonite conditions predicted for 2100, and noted significant changes in the animals’ shells and physiology. Respiration rates and stress protein levels both increased. “We didn’t get any mortality, which was promising,” she says, “but four months is just a snapshot in the lifetime of those long-lived animals.”

An Antarctic scallop: “It’s already a tough world down there, and it might be difficult for them to adapt to such an environmental change,” says NIWA ecologist Vonda Cummings. (*Rod Budd*)

Cummings is unsure they can sustain the increased energy they’ll need to survive in lower pH conditions, or what any knock-on effects might be for the animals that eat them. “They’re all intricately entwined in their bigger ecosystem,” she says. “Essentially, we just don’t know what the impacts will be.”

Since Cummings’ experiments, estimates of when aragonite concentrations might cross some critical low threshold in Antarctic waters have leapt forward, from 2100 to the winter of 2030. Because both geoducs and Antarctic scallops are long-lived, Cummings says those changes will happen within the lifetimes of animals alive today. “No one knows if they will be able to adapt quickly enough, or how long they can survive the effects on their metabolism.”

What is pH?

pH is the standard measure of how acidic or alkaline a solution is. A pH of 7 is ‘neutral’ on a scale from 1 to 14. A pH greater than 7 is ‘alkaline’. A pH of less than 7 is ‘acidic’. An example of an alkaline solution is oven cleaner (pH13). On the acidic side of the scale, black coffee is pH5, while vinegar is pH2.

The oceans have a natural pH of about 8.2, making them mildly alkaline. Since the industrial revolution, it’s thought that the pH of oceans has decreased by about 0.1 units, because of increased absorption of CO_2. So while the ocean is still alkaline, it’s more acidic than it was.

House of carbs

Last year, Law co-authored – with Dr Phil Boyd – *An Ocean Climate Change Atlas for New Zealand Waters*, in which they outlined a “basket of different factors that will cause change in the oceans.” Multiple stressors, they warned, could particularly affect surface waters: warming will impact the nutrient supply and the underwater light field, while changes in weather patterns will affect nutrient deposition.

The atlas also signals disruptions to the staples of the ocean’s food chain – phytoplankton and zooplankton. “My area is the microbial side of the food chain,” says Law, “the plankton.” Carbonate is a vanishing commodity in an acidifying ocean, he says, but some plankton rely on it to make shells, “so we want to know what may happen to these organisms.”

Phytoplankton are especially important. Not only do they take up carbon out of the atmosphere and produce 50 per cent of the oxygen we breathe, they’re also the bedrock of the ocean’s food chain. “They’re the grass of the ocean,” says Law. “As they’re grazed upon, the carbon they fix gets transferred up the food chain and eventually into the fish. That means plankton ultimately underpin fish stocks, so we need to know what’s going on.”

Like Nelson, he believes acidification might create winners and losers. More CO_2 might increase phytoplankton and macroalgae biomass, which could benefit the food chain. However, he says, we still understand little about phytoplankton’s place in that chain. To better identify trends and changes, NIWA is gathering baseline information about New Zealand plankton species and their abundance, using floating particle traps. Data suggest that one zooplankton group, the pteropods or sea butterflies, may be already declining in subantarctic waters.

“The problem for the sea butterflies is that their shell is made of the highly soluble aragonite, and as surface waters

Principal Technician Neill Barr checks on Antarctic cockles at NIWA's aquaculture facility in Wellington, where the shellfish are being raised under different pH levels at temperatures typical of McMurdo Sound. (*Dave Allen*)

become under-saturated, they will be under increased pressure to maintain their shell. The concern is that they won't survive."

The data need statistical analysis, says Law, "but the different results hang together: the pH decline we're seeing in subantarctic water, the experiments that show pteropods have problems below a certain pH, and their declining numbers in the particle trap record. There's a consistent story there, and it's not a good one."

Delving deeper

NIWA scientists Di Tracey (biodiversity and fisheries) and Dr Helen Bostock (marine geology) are examining the prospects for New Zealand deepwater corals that build sprawling structures serving as habitat for many other creatures. Variously, these corals employ both aragonite and calcite. "There's work internationally that shows strong associations between commercial fish aggregations and coral habitats," says Tracey.

As it is, deepwater corals already have a tough time extracting the minerals they need from the cold depths. The issue for aragonitic stony corals, Bostock says, is whether they will be able to come up with strategies to counter their increased solubility in lower pH waters.

Some corals build from both aragonite and calcite, she says. "Can they change which mineral they're going to produce if the water becomes under-saturated in aragonite? Can they start producing calcite instead to help them survive?"

She and Tracey are testing deepwater chemistry, looking for different 'saturation horizons' – critical thresholds below which minerals begin to dissolve. The saturation horizon for aragonite could be particularly important – overseas research suggests it controls the depth at which most habitat-forming stony corals are found. The expectation is that acidifying oceans will force deep sea corals into shallower, more carbonate-rich waters. If habitat-forming corals are indeed important to commercial fisheries, the implications for New Zealand's deepwater sector become obvious, says Tracey. (See sidebar: It's worse than we thought).

Meanwhile, the pair are monitoring live corals at NIWA's Mahanga Bay facility, where the many variables can be more easily manipulated and measured. It's pioneering stuff, and the challenge for now is simply to keep the corals alive long enough to test the hypothesis.

> **"There may be some winners out of this."**
>
> NIWA Principal Scientist, Dr Wendy Nelson

It's worse than we thought

By linking global climate models with biogeochemical ocean models, scientists can forecast changes in ocean acidification, and the news isn't good. The 'saturation horizon' for aragonite is rapidly foreshortening.

A 2005 model showed that, by 2100, the aragonite saturation horizon in New Zealand waters would rise from between 1000 and 1300 metres to just 500 metres.

However, Dr Helen Bostock says the original simple models didn't incorporate critical variables such as temperature increases.

An international study released in early July 2012, based on actual measurements, shows the saturation horizon in the New Zealand region is changing much more rapidly – by a couple of metres each year.

Distress signals

Backing all these lines of enquiry is Dr Kim Currie, a chemist with NIWA's Dunedin-based Centre of Physical and Chemical Oceanography. She analyses seawater samples for bicarbonate and carbonate.

For the last 14 years, in collaboration with the University of Otago's Chemistry Department, Currie has run a time series, tracking acidification. Every two months, she collects water samples along a 65-kilometre line from the tip of Otago Harbour out into subantarctic waters.

The series is invaluable because it covers the subtropical Southland Current and subantarctic water masses in a one-day trip: the only place in the world where this is possible.

Along the line, Otago University scientists measure the pH, while Currie measures the other three parameters – alkalinity, total dissolved inorganic carbon and partial pressure of CO_2. The data help model changes in different water masses at different times. For example, pH is linked to temperature, so varies between summer and winter, and from year to year.

After 14 years, says Currie, the data are starting to reveal trends. "It seems like there's a change, and we think it's probably due to atmospheric CO_2, but ... I'd be reluctant to say that for definite."

Maybe not, but her observations match those from other places around the globe. "When we start putting it together, then it really is pointing to the pH decrease being human-induced."

Contact:
Dr Cliff Law
Marine Biogeochemist
cliff.law@niwa.co.nz

Dr Wendy Nelson
Principal Scientist
wendy.nelson@niwa.co.nz

Dr Vonda Cummings
Marine Benthic Ecologist
vonda.cummings@niwa.co.nz

Di Tracey
Fisheries Scientist
di.tracey@niwa.co.nz

Dr Helen Bostock
Marine Geologist
helen.bostock@niwa.co.nz

Scan this code with your smart phone to hear Cliff Law talk more about ocean acidification.

The ocean's great recyclers

NIWA Marine Biogeochemist, Dr Cliff Law, calls bacteria "the refuse men of the ocean," vital to life on Earth because they break particulate material down to its small constituent compounds.

However, bacteria can only internally handle molecules up to a certain size. Beyond that, they release enzymes into the water to break things down instead. "But, once in the water, those enzymes are no longer influenced by the pH of the bacteria's cell," says Law, "they're influenced by the pH of the water, and that's where it gets interesting.

"Enzyme activity is very sensitive to both temperature and to pH, and both are going to change in future oceans that are warmer and more acidic. So the question is: are these enzymes going to change their activity? And what's that going to mean for the rate that material gets broken down in the oceans?"

So far, the answers aren't reassuring. Early work suggests some enzymes become more active under a lower pH. "The faster the material is broken down," says Law, "the quicker it gets converted back to CO_2, which goes back to the atmosphere.

"One outcome of this is that the pathway of locking the carbon away in the deep ocean is being short-circuited. It's a kind of positive feedback effect with negative consequences."

Cold case

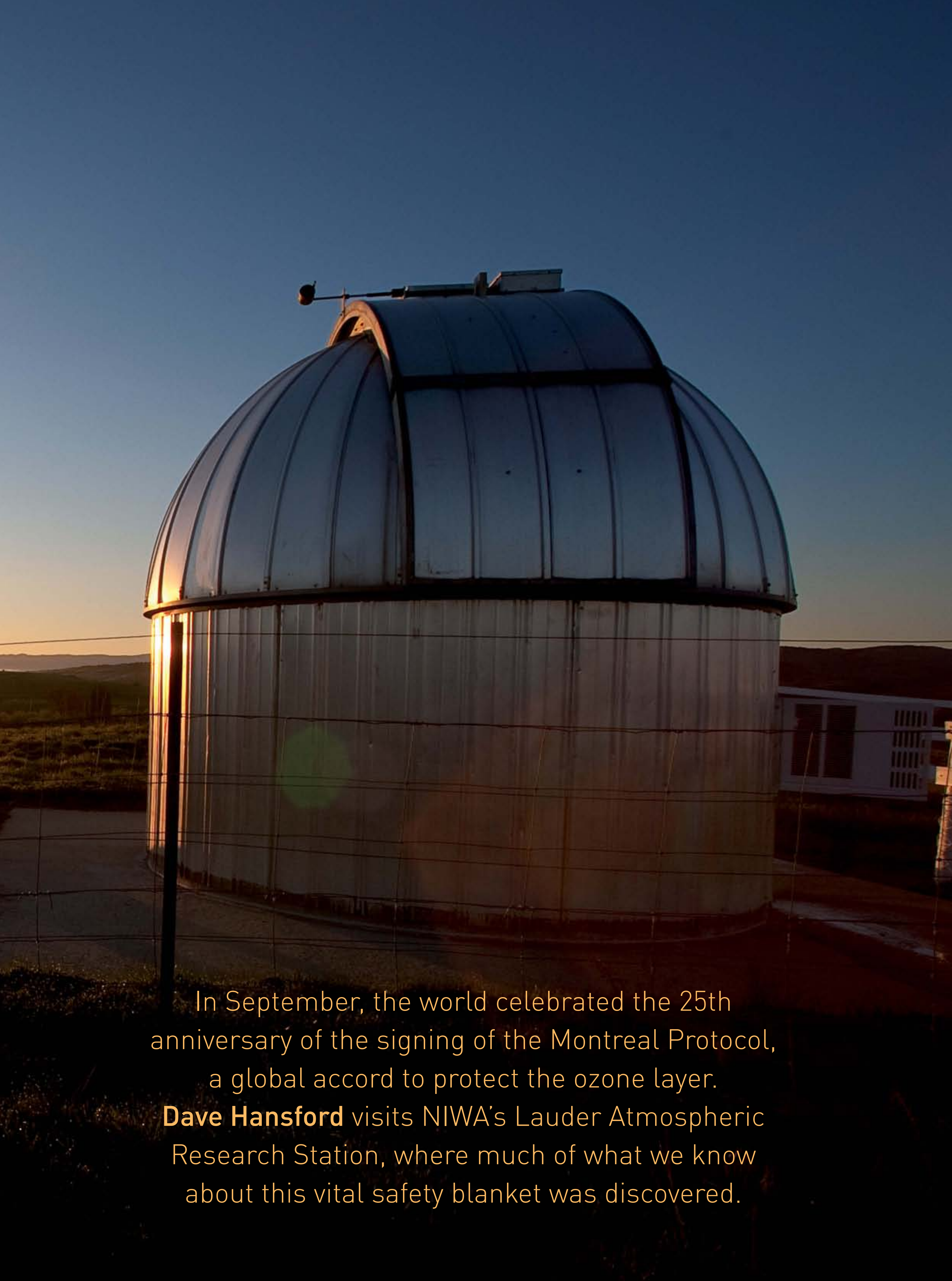
NIWA's Marine Benthic Ecologist, Dr Vonda Cummings, has been leading research on how ocean acidification is likely to affect Antarctic shellfish.

At NIWA's aquaculture facilites in Wellington, two refrigeration systems separately control air and seawater temperatures in the laboratory, holding seawater just above freezing.

Once cooled, the water flows into mixing tanks, where CO_2 is bubbled through to create various pH levels that mirror predicted changes in polar ocean acidity. Water samples are automatically drawn from each tank and assessed by a purpose-built, highly accurate spectrometer.

The system is also being used to study paua, Bluff oyster and deepsea coral species.

Something in the air



In September, the world celebrated the 25th anniversary of the signing of the Montreal Protocol, a global accord to protect the ozone layer. **Dave Hansford** visits NIWA's Lauder Atmospheric Research Station, where much of what we know about this vital safety blanket was discovered.

Dr Richard McKenzie has one hell of an office. It's maybe 30 kilometres of placid verdure to the north wall, where the Hawkdun Mountains rise, glinting white, then glide gently west, melding seamlessly, it appears, into the St Bathans Range.

From there, a quarter-turn introduces the clean lines of the Dunstans – a crane of the neck to see all the way down the Manuherikia Valley, back towards Alexandra. And above it all, a classic, crystalline Otago sky – so big you have to look to find the sun.

After 30 years, you might think McKenzie would have stopped noticing it all, but that vast firmament is why he's here, at NIWA's Atmospheric Research Station near Lauder.
I look up and see blue: the Atmospheric Scientist Emeritus sees the physical essence of the heavens – cocktails of gases – nitrogen, oxygen, argon, neon, helium. Molecules in endless pas-de-deux. Boundaries – hard yet diaphanous – set by subtleties like temperature, pressure, density. He knows that seeming blue serenity is just a trick of the light. It's a maelstrom up there: shrieking stratospheric winds, withering radiation, extreme chemistry.

But mostly, he's focussed on a sparse scattering of molecules some 20 or 30 kilometres above our heads. When ultraviolet (UV) light strikes an oxygen molecule (O_2), it can cleave the two oxygen atoms apart. These estranged atoms float alone until they encounter another intact oxygen molecule. When they bind to that molecule, they create ozone (O_3).

But the union is fleeting. When struck by UV, the ozone molecule splits once more, back into an O_2 molecule, and an atom of atomic oxygen. This eternal seesaw of fusion and nihilism maintains the ozone layer, and you should be very glad it does. Around the immensity of the earth's atmosphere, the ozone layer is but a sheet of glad wrap – stratospheric ozone concentrations comprise around 10 parts per million – but without it, those lethal UV rays would kill pretty much everything.

> **"People really want to know how their world is going to change."**
>
> Programme Leader, New Zealand Regional Atmosphere Programme, Dr Olaf Morgenstern

The elephant in the atmosphere

It might have stretched over 1.1 million square kilometres at the time, but the ozone hole proved difficult to spot in the early eighties. We'd have known about it much sooner, had scientists just believed their own eyes. NASA satellites had been measuring atmospheric ozone since 1979, faithfully reporting incremental losses. However, the data came in faster than the scientists could analyse it, so they set up a processing programme which filtered out any measurements above – or, crucially, below – what they considered instruments could accurately process.

Says Dr Richard McKenzie, the satellites recorded losses so large, NASA's algorithms rejected them as bad data. "We all do this," he points out. "We all have rejection criteria in our data. They felt there must be something wrong, so they chucked out what they considered to be bogus data. It was very embarrassing for them."

Then, he says, the very first mention of the discovery may well have been lost in translation. "It was actually first reported at a conference in 1984 in Greece," he recalls. McKenzie missed the presentation in which Dr Shigeru Chubachi, of Japan's Meteorological Research Institute, reported low ozone measurements over Syowa, Antarctica. But he says that Chubachi's heavily-accented English may have obscured the true significance of what he had witnessed. "So no one picked it up at the time, but you've got to be very careful to acknowledge that Japanese work."

Meanwhile, British Antarctic Survey scientist Joseph Farman had been collecting atmospheric data from Halley Bay, near the South Pole, since 1957. In 1982, his ozone readings dipped dramatically, by some 40 per cent. Like NASA, he figured the data must be dubious, and blamed his aging, temperamental spectrophotometer. Besides, he reasoned, if ozone levels had dipped that much, surely NASA's satellites would have detected the trend? Nevertheless, he ordered a new instrument. Next season, he and his colleagues found that ozone levels had fallen still further.

When they went back through old data, they realised that the slump had begun back in 1977. To make sure it wasn't a purely local phenomenon, they shifted the spectrophotometer the next year to a new site, 1000 kilometres from Halley Bay, where they recorded the same persistent trend. They decided to publish.

In May 1985, Farman and his colleagues Brian Gardiner and Jonathan Shanklin described their observations in *Nature*. They went on to point out the connection to increasing atmospheric CFC levels. NASA went back through their deleted satellite data, which soon corroborated the British observations. Farman et al.'s paper ranks among the most cited articles of all time.

The ozone hole was official.

NIWA Atmospheric Scientist Emeritus, Dr Richard McKenzie, with an all-sky camera at the Lauder Atmospheric Research Station in Central Otago. The device, owned by the University of Hannover in Germany, takes a high-resolution picture of the full sky every minute, building the long-term record of cloud cover essential to our understanding of UV radiation. (*Dave Hansford*)

Scant protection

McKenzie only has to glance at his computer to confirm that this mid-September day, above Lauder, the ozone layer is exactly 370 Dobson Units thick. It's a good solid shield – the global average is 300, which, if you brought all those ozone molecules down to ground level, at standard pressure and temperature, represents just three thin millimetres of armour between you and blistering harm.

But in just a few weeks, that shield will thin over Antarctica to less than 100 Dobson Units, as the ozone layer approaches its annual minimum.

Most of us know that the ozone hole yawns wide over Antarctica each spring, torn open by chlorinated fluorocarbons (CFCs) emitted from our (and our parents') refrigerators, spray cans, air conditioners, foaming agents and other chemical conveniences. We might recall that politicians got together back in the eighties and signed some agreement to ban the CFCs, and that now the hole is slowly healing again.

What we don't generally appreciate is that McKenzie and his colleagues – taking meticulous measurements every day for thirty years, launching balloons, firing lasers, crunching numbers, analysing spectrograms, writing reports and papers, making presentations – have helped save hundreds of thousands of lives. One of them might have been yours.

Lauder scientists contributed to one study which concluded that, by 2030, the Montreal Protocol will prevent two million new cases of skin cancer worldwide each year.

> "We can't rely on other people solving this problem for us."
>
> Atmospheric Scientist Emeritus, Dr Richard McKenzie

The Protocol not only got chlorines and other ozone-killing substances banned, but it's done a good job of enforcing compliance, so that global skin cancer rates are now projected to peak around the middle of this century, then decline.

Without the international agreement, says McKenzie, "by 2030, the incidence rates [of skin cancer] would have increased, so that instead of approximately 300 people dying each year in New Zealand, it would have been 350."

But that's only the start of the salvation, he says, "because UV levels would have really rocketed up in the latter part of the century. By 2065, at the end of our model runs, UV levels in New Zealand would have been three times higher than they are now." By then, he says, serious skin damage could have been done in the time it took you to cross the street.

Beyond that, "hundreds, or even thousands, of extra deaths per year would have followed the exposures they got in 2065."

Eye on the sky

Instead, thanks to a complicated relationship between ozone and climate change, ozone may even recover beyond its original levels – in middle and high latitudes at least. That means that, by the end of this century, skin cancer cases could drop to below 1960s rates.

NIWA's Dr Olaf Morgenstern – Programme Leader of the New Zealand Regional Atmosphere Programme. "It's not so easy when people ask: 'When is the ozone layer going to recover?' It won't recover to the state we've seen it in before, because the atmosphere has changed since then." (*Dave Hansford*)

McKenzie came here to Lauder late in 1979, to study auroras. He meant to stay three years, until his son started school. "Andrew's now 36," he grins, as he shows me around a rooftop array of technologia. Domed all-sky cameras stare at the sun, blinking as they automatically record cloud cover at timed intervals. There's a quiet whir of servos as pyranometers, pyrheliometers, pyrgeometers and sunphotometers track the sun like robotic sunflowers, measuring radiation – diffuse, direct, longwave, filtered – as part of the international Baseline Surface Radiation Network.

Not all these devices are NIWA's. Science agencies from around the world have placed instruments at Lauder, because of the unsullied clarity of the skies here. "You can see things in the stratosphere here that you don't see at other sites," brags McKenzie. "Because the troposphere (the lowest 10–15 kilometres of sky) is so clean, the light from the sun through the atmosphere carries the imprint of the stratosphere, rather than the troposphere."

If Lauder's taught us one thing, it's the value of observational data – the sheer wisdom of watchfulness. When McKenzie tired of aurora nearly three decades ago and started measuring nitrogen oxides in the atmosphere, he had no idea of the eventual value of that work.

"The atmosphere is about 80 per cent nitrogen," says McKenzie, "and 20 per cent oxygen, so nitrogen oxides are important." After the ozone hole was discovered in 1985, theories pointed fingers at various suspects, including nitrogen oxides. "Our measurements here and in Antarctica," recalls McKenzie, "showed that theory was wrong."

Crucially, that turned the spotlight instead onto chlorine and bromine – components of CFCs. "Scientists then realised that the ozone hole had been getting bigger and bigger, as the concentrations of chlorine had been getting bigger and bigger."

McKenzie immediately grasped the implications. "We already had the world's highest death rate from melanoma. If ozone does go down, UV is going to go up. That became the focus of my research."

Over the long dark of the Antarctic winter, ozone is largely inert: without light, explains McKenzie, there's no UV radiation either, so there's a temporary ceasefire. But once the sunlight returns each spring, ozone-killing chemical reactions rekindle, playing out on the ice crystals that form polar stratospheric clouds. The intense cold drives the conversion of unreactive chlorine to reactive forms at breakneck speeds, opening a hole that reaches maximum width each October. Fierce, spinning polar winds contain the hole in what is essentially a giant, closed reaction vessel.

Ordinarily, such conditions only occur over Antarctica, but in 2011 it happened over the Arctic too.

But in one perverse sense, the ozone hole actually works in our favour here in New Zealand. As long as those polar winds are whirling, they keep ozone out as effectively as they trap air in. So when ozone produced in the tropics is dragged south by atmospheric circulation, it starts piling up at higher latitudes – right over New Zealand, even as the ozone layer hangs in tatters over Antarctica (our ozone minimum occurs instead in the autumn).

CFC production ended in 1996, and scientists have watched the ozone layer respond ever since. Lauder's Programme Leader of the New Zealand Regional Atmosphere Programme, Dr Olaf Morgenstern, says levels over Antarctica are projected to heal to 1980 levels "sometime between 2050 and 2070. In the Northern Hemisphere, that return might come 20 years earlier or so." But, he says, "It won't recover to the state that we have seen it in before, because the atmosphere has changed since then."

Mathematical models, fed a 'business as usual' scenario without the Montreal Protocol, says Morgenstern, have shown that we would have "fallen off a cliff, essentially." All the extra CFCs emitted, "would rival CO_2 as the leading climate agent." Their stratospheric cooling effect, exacerbated by runaway ozone depletion, would have seen polar-stratospheric clouds billow across the tropics, causing what Morgenstern calls "precipitous loss of ozone ... sufficient to condemn us to oblivion."

Around Lauder, the UV index typically peaks at 12. Untrammelled CFC production, he says, could have seen it hit 50 by the end of this century. "Under such conditions, you couldn't move out of the house any more, and you probably couldn't grow any plants."

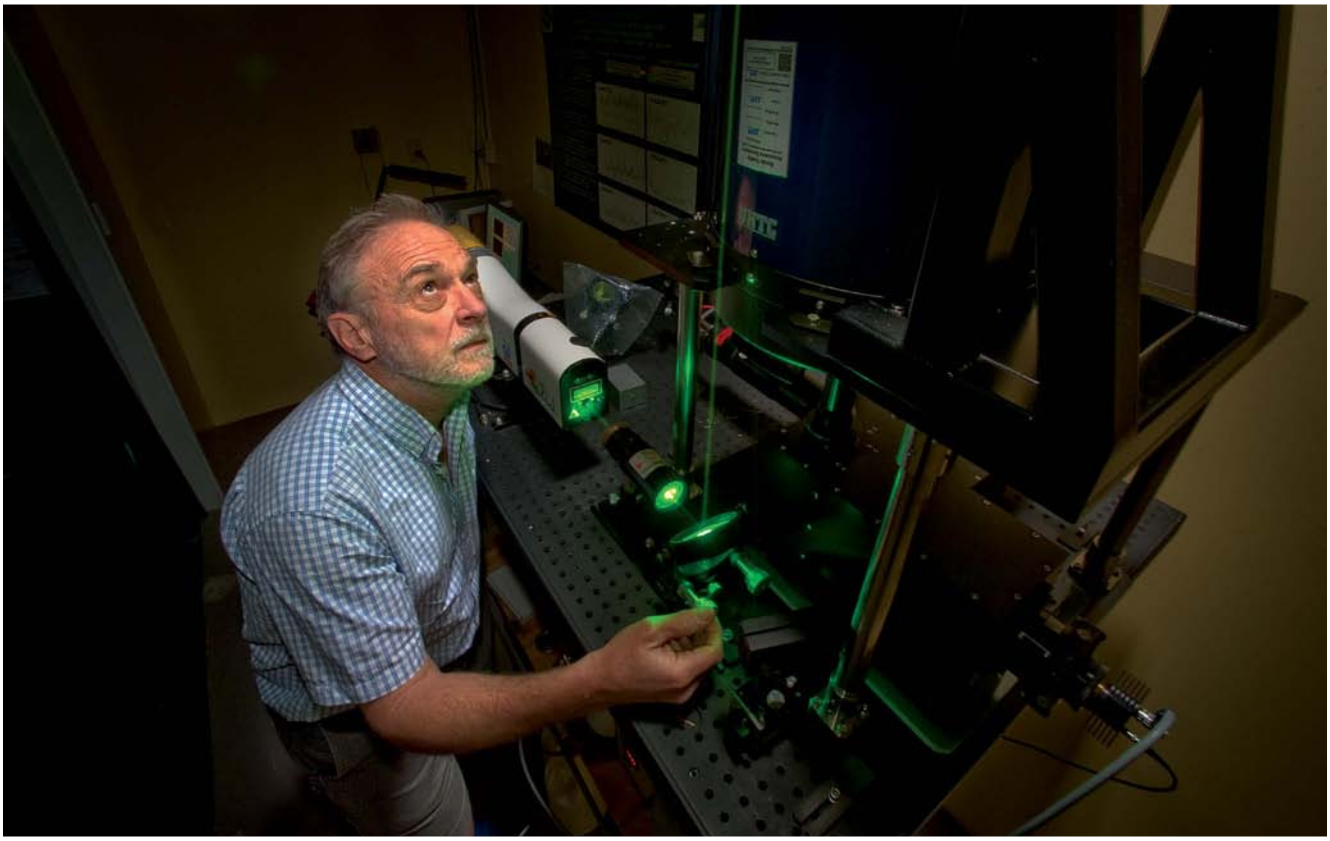
Climate of uncertainty

Morgenstern's job is to predict what ozone recovery might mean for climate change, and vice-versa, and it's far from simple. Greenhouse gases trap warmth inside the Earth's atmosphere, but prevent it escaping into the stratosphere, which is duly getting colder – scientists say temperature changes there could be twice the magnitude of those near the Earth's surface: a one-degree increase down here equals a two-degree decrease in the stratosphere. The risk, then, from global warming is that those polar-stratospheric clouds might yet extend beyond the poles, undoing some of the ozone recovery that has begun.

"Over the last 50 years or so," says Morgenstern, "we've seen some quite dramatic climate change over Antarctica. The interior has cooled, but the Antarctic Peninsula is one of the fastest-warming regions on the planet. People now think that ozone depletion is the cause of that sharp contrast." Recent papers have suggested that effect may even influence climate all the way to the Equator.

As ozone levels are restored, he says, the trends in familiar climate traits – prevailing winds, the timing of rains, etc. –

Technicians release a balloon at Lauder. Chemical sensors attached will measure the vertical ozone profile up to an altitude of around 35 kilometres before descending. (*Dave Hansford*)



NIWA Physicist Ben Liley adjusts a LIDAR (Light Detection and Ranging) device. The LIDAR bounces laser light off aerosol (dust) particles in the atmosphere, measuring their altitude and optical properties. Aerosols come from both human activity and natural sources, and affect cloud formation, atmospheric chemistry, solar radiation and air quality. (*Dave Hansford*)

could alter, or even reverse. The cooling effect could switch, and the Antarctic continent might begin melting apace, as the Arctic is already doing.

"At the same time, of course, we're releasing more and more greenhouse gases into the air. They also have an effect," but it remains to be seen, he says, which one will predominate in the next few decades.

That's perhaps because most contemporary climate models don't explicitly include ozone chemistry – which may, suggests Morgenstern, limit their power to capture the detail of regional climate change. His quest is a mathematical climate model that includes – 'understands' – atmospheric ozone chemistry. Such a model could predict changes in trace gas concentrations and how they might affect the Earth's radiation balance – and show us what that could mean for temperatures, winds and transport processes.

NIWA's Fitzroy supercomputer now gives us the means, says Morgenstern, to make that leap. "At the moment, I'm running a chemistry climate model over the 19th century. It has comprehensive chemistry and a fully coupled ocean in it."

He looks out over the array of instruments, quietly taking the pulse of the sky above, checking its vital signs. "Many people don't understand why we take all these measurements," he says, "but they're the bedrock on which we rest our knowledge.

> "The ozone hole was completely unexpected."
>
> Atmospheric Scientist Emeritus, Dr Richard McKenzie

"People really want to know how their world is going to change. What's the prospect for agriculture in this country? Is it going to get drier or wetter? Warmer or colder? They want to know about extreme weather. In order to get that, you need better models – more comprehensive physics, chemistry, higher resolution.

"But you can't verify a model if you don't have data. If you can't establish that your model is doing alright, you can't say anything about the quality of your forecasts. So we have to continue with the measurements here."

McKenzie agrees. "The world's full of surprises. The ozone hole was completely unexpected. If there hadn't been people on the ground making all those measurements, it might have been too late."

NIWA Science Technician Hamish Chisholm uses a Dobson spectrometer to measure ozone above Lauder. The spectrometer measures the total ozone column (effectively the thickness of the ozone layer as a column through the atmosphere) using either a direct sun measurement or a zenith measurement. The thickness of the ozone layer is measured in Dobson Units (DU). Values at Lauder typically range between 230 and 400 DU, with the highest values recorded in spring. (*Dave Hansford*)

There aren't many bits of land at these latitudes, he points out, so data from New Zealand is prime intelligence. "We represent a big chunk of the globe, and we can't rely on other people solving this problem for us." Meticulous monitoring might not be fashionable, he says, "but it's necessary."

Contact:
Dr Richard McKenzie
Atmospheric Scientist Emeritus
richard.mckenzie@niwa.co.nz

Dr Olaf Morgenstern
Programme Leader, New Zealand Regional Atmosphere Programme
olaf.morgenstern@niwa.co.nz

Scan this code with your smart phone to go to NIWA's real-time UV Index.

Un-natural born killers – chlorine and bromine

In 1971, James Lovelock, proponent of the Gaia hypothesis, noted that the bulk of CFCs created since 1930 were still present in the atmosphere.

In 1995, Sherwood Rowland, Paul Crutzen and Mario Molina won the Nobel Prize for showing that convective air currents could carry CFCs all the way to the stratosphere, where, split by high-energy photons from sunlight, they could free their chlorine atoms.

Unleashed, chlorine – along with bromine (from the halons used in some old fire extinguishers, and from the fumigant methyl bromide, still used in New Zealand), and other accomplices like nitrous oxide destroy ozone on contact through a series of catalytic reactions. A single chlorine or bromine atom can persist for a century, destroying many thousands of ozone molecules.

Alternative wisdom

Where high-tech science sometimes struggles, Māori knowledge can offer answers, find **Tina Makereti** and **Dave Hansford**.

At the day's close, Te Arawa people like to treat their guests to a feast of traditional kai, like kōura, kākahi, or other freshwater kai gathered from Te Arawa Lakes. In this way, the tribe extends its manaakitanga, serving delicacies that will be relished and recalled long after. Each iwi has a signature dish – a culinary badge of identity and pride – but pollution is threatening that customary fare. In some places – such as Te Arawa's own harvesting grounds – some traditional kai has become scarce, suspect, or both.

That decline saw iwi and NIWA team up to track the fortunes of critical food species, and they're employing techniques that some had long forgotten. Mātauranga Māori, or Māori knowledge systems, have helped solve problems that 'conventional' science was struggling with.

Tau kōura, for instance, is an ancestral harvesting method, but it was recently resurrected as the only successful way to keep tabs on kōura populations.

Of Tūwharetoa/Te Arawa descent himself, environmental consultant Ian Kusabs has more than just a professional interest in kōura. "They're the most important customary fisheries resource up here." Canaries in the freshwater coalmine, their fortunes reflect the overall health of the entire ecosystem. To Māori, they're a taonga – the relationship goes far beyond harvest and consumption, embracing values like custodianship, pride and identity. At first, Kusabs tried all the conventional sampling methods to monitor kōura: underwater video cameras, gee-minnow and fish traps, scuba diving. None of them worked. "You run into problems with those visual methods when you get into dirty or discoloured water," he says.

Māori fishermen haul in a catch of kōura, circa 1921. (*Alexander Turnbull Library*)

Working with local customary fishers, Kusabs was reminded of a traditional method, the tau kōura. Ngāti Pikiao kaumatua Willie Emery was one of just a handful still running kōura lines. "It was a dying practice," observes Kusabs. They've been working together to revitalise it since. Bundles of bracken fern are tied to ropes, then dangled on the lake bed for a few weeks, offering prime real estate to the little crustaceans. Unlike modern traps, they snare a representative sample of the kōura population, from the very smallest to the largest, they're non-invasive and they work in winter.

Chief Executive Officer of Te Arawa Lakes Trust, Roku Mihinui, found there were two compelling results: "One: a method of catching food and providing a safe space for the kōura was internationally recognised as being a scientific tool, and two: mātauranga was finally recognised as being actual and relevant knowledge related to the environment, that could be accepted as scientific as well."

A subsequent collaboration saw tau kōura employed again, when the Trust and NIWA measured contaminants in traditional kai. The project, says Executive Officer of the Trust, Hera Smith, also became about "sharing stories about how the environment has changed, and what might have caused that change." Everyone learned from storytelling that chronicled the fate of food sources over the years.

A dynamic discipline

Mātauranga Māori had shown – or more correctly, reasserted – its value. Any description of the concept must accommodate a wealth of meanings and perspectives. It's sometimes described as Māori science, but this is misleading. Mātauranga Māori, says NIWA scientist Darren King, instead represents: "a range of different

NIWA's Erica Williams: top-down approaches to restoration won't work. (*Dave Allen*)

forms and expressions, based on different tribal histories, different geographies, different practices, different values. Mātauranga Māori incorporates both traditional and non-traditional knowledge, so it's dynamic, constantly evolving."

Nevertheless, mātauranga Māori and science can find agreement at points along parallel lines of scientific enquiry. For starters, both are informed by observation and patterns in natural systems. "Our people have always asked questions," says NIWA's Māori Development Manager, Apanui Skipper. "A lot of our knowledge is based around longitudinal observation over 1000 years or more, pondering the past and the future without the need for certainty or absolute solution." Such objective scrutiny offers science a perspective other contemporary methods lack. "Mātauranga Māori can help detect subtle changes in environments, based on detailed observations of natural phenomena over a lifetime," says King.

Conventional science field observations are based on assumptions and the development of measurement methodologies, and the same can be said for mātauranga Māori. It also uses systems to organise information, just as mainstream science does, but the principles can be very different. For example, Māori hold an extensive whakapapa of flora and fauna – an abundant, fertile family tree that connects all living things according to their relationships and functions in the natural world. In science, this whakapapa might be called taxonomy.

> **"Our knowledge is based on longitudinal observation over 1000 years or more."**
>
> NIWA Māori Development Manager, Apanui Skipper

"There are many different levels of mātauranga Māori," says King. "It can be specific, or empirical and practical, and I think that's the knowledge most people are attracted to." But, he says, "mātauranga Māori also incorporates elemental, abstract, metaphysical and instinctual knowledge and understanding. These forms of mātauranga Māori are underpinned by whakapapa and tīkanga – that is, the values that define human relationships between themselves, and with nature."

About here, mātauranga Māori becomes more esoteric, and best left in the hands of those qualified to understand the concepts from within a Māori world view. That hasn't deterred iwi and scientists, though, from working together more often, using that empirical knowledge. Wendy Henwood of Te Roopū Taiao o Utakura takes a pragmatic view: "We don't actually separate out what's western and what's Māori. We only know what we know, and we're happy to look at all knowledge and see what works for us. We don't say: 'right, today we're going to do western science, tomorrow we're going to do Māori science.' We look at blending kaitiakitanga practices with mana whenua knowledge and kaupapa Māori principles, instead of over-analysing and separating them out."

Insight restored

Lake Ōmāpere drains to the sea – eventually – first through the flailing shallows of the Utakura River, into the headwaters of the Hokianga Harbour. Like the Te Arawa Lakes, these far-northern reaches run heavy with agricultural runoff, but NIWA's been working with Te Roopū Taiao o Utakura to clear up Ōmāpere's waters. Restoring the lake's riparian strip may well help, but first the group needs a way to monitor the lake's health, to help track the success of improvements they make.

To that end, NIWA scientists Erica Williams, Wakaiti Dalton and Jacques Boubée worked with Te Roopū Taiao o Utakura to monitor tuna, another taonga and indicator species, as well as water quality assessment tools. "The relationship we've had with them has just been amazing," enthuses Henwood. "They're really willing to share knowledge and expertise with us in a way that's actually building our capacity. They'll come and show us how to do stuff, and then work alongside us to do our own thing, so they're well respected in the community."

The feeling is mutual. "Te Roopū Taiao Utakura has one of the best models," says Williams. "They can do their own monitoring programmes, and their own outreach for the local schools and wider community, teaching them how to age eels, and monitor the stream invertebrates." It would be difficult for a top-down approach to work in the long term for Lake Ōmāpere and the Utakura, she says, "because a lot of the restoration and co-management is going to have to be driven by local communities ... the guys that live and eat and breathe from these rivers and lakes over generations." For Māori, projects like Lake Ōmāpere are not only helping to restore mauri: they revive traditional practices – among young and old – around caring for the environment and learning new, science-based skills.

> "There's a depth that comes from these knowledge systems talking to each other."
>
> NIWA Chief Scientist, Māori Environmental Development, Dr Charlotte Severne

Mātauranga Māori brings many benefits to science, as does science to mātauranga Māori. But the whole, says Dr Charlotte Severne, is greater even than the sum of the parts: "It doesn't stop at complementarity – there's a depth that comes from these knowledge systems talking to each other."

Shakedown trials: Ngāti Pikiao kaumatua Willie Emery (L) and environmental consultant Ian Kusabs empty tau kōura bundles on Lake Rotoiti. (*Geoff Osborne*)

NIWA scientist Erica Williams (R) surveys fish in the Okaka Stream, in the Utakura River catchment, with members of Hokianga's Te Roopū Taiao o Utakura. As part their project, "Working for the river will lift the health of the people," the group is monitoring ecological indicators in the river, which drains Lake Ōmāpere. (*NIWA*)

"The integration of these knowledge systems adds depth and richness to observations, data and analysis."

But King says we've yet to reach the full collaborative potential: "More needs to be done in terms of realising how these two systems can complement each other." He's investigating how pūrākau, or Māori oral histories and narratives, can contribute to scientific understanding of tsunami risk. "By ignoring Māori experience and traditions, valuable insights are being missed out on." Collective memory can reinforce and confirm existing knowledge, he says, "but it also gives us an opportunity to question whether or not we've quite got it right."

Then there's protocol. Hera Smith points out the critical importance of tribal consent, and subsequent acknowledgement, "because that's where the mātauranga is derived from." Tau kōura struck early problems when a scientist presented information to an international conference. "We hadn't yet presented it back to our own people," says Mihinui, "in the first instance, for them to be happy that it had been captured appropriately, and secondly so the use of that information could be qualified. That experience ... almost put us off continuing in other areas we were discussing with NIWA at the time."

It was, according to Kusabs, a lesson widely learnt. "Basically, it was a conflict between Māori society and western science, because in western science, if you come up with something, you try and ... get it out there as quickly as possible, whereas in the Māori world, you have to take your time and bring everybody along with you, and make sure you get that mandate."

For NIWA, mātauranga Māori extends a guiding hand from out of the past, and into the future: a rekindled flame illuminating the intimate connection between the environment and humanity. Says King: "It's at society's peril that we ignore the value and insights and expertise that lie within the knowledge-practice-belief complex that is mātauranga Māori."

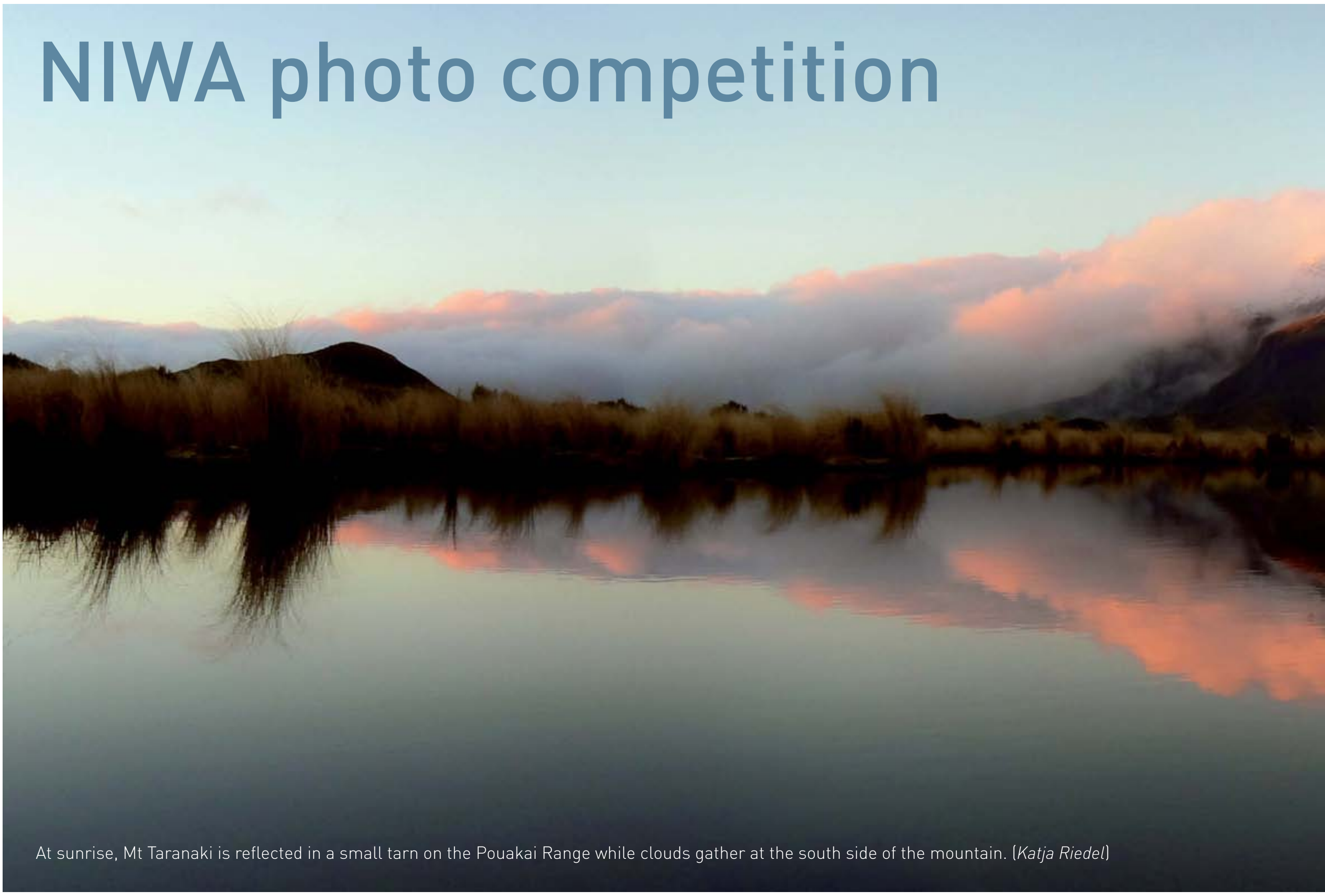
Contact:
Dr Charlotte Severne
Chief Scientist
Māori Environmental Development
charlotte.severne@niwa.co.nz

Erica Williams
Scientist
erica.williams@niwa.co.nz

Darren King
Scientist
darren.king@niwa.co.nz

Apanui Skipper
Māori Development Manager
apanui.skipper@niwa.co.nz

NIWA photo competition



At sunrise, Mt Taranaki is reflected in a small tarn on the Pouakai Range while clouds gather at the south side of the mountain. (*Katja Riedel*)

The view from Mt Olympus, Canterbury, to where the Avoca River flows towards the Harper. (*Katja Riedel*)

NIWA photo competition

A leather jacket (*Parika scaber*) feasting on a jellyfish during an algal bloom at the Poor Knights Marine Reserve. (*Crispin Middleton*)

War against weeds:
NIWA Principal Scientist John Clayton uses a spray gun to control invasive weed in Lake Okataina, Rotorua. (*Tracey Edwards*)

Dave Hogan from NIWA Vessels fabricates steel pipes at the Greta Point workshop. NIWA's own technicians build, repair and maintain much of the institute's specialised equipment. (*Matt Evans*)

Current projections

Sediment-laden river or swirling ocean current, water can carry creatures and contaminants vast distances. NIWA's hydrodynamic models, finds **Veronika Meduna**, are helping planners better understand nature's conveyor belts.

When the causeway on State Highway 16, between Auckland's Te Atatu Peninsula and Point Chevalier, was built on reclaimed land in the 1950s, few predicted the Herculean demands that would eventually be placed on it. Traffic volume has burgeoned over the years, says the New Zealand Transport Agency's (NZTA) Principal Environmental Specialist, David Greig, "and the capacity of that causeway is no longer adequate."

Six decades later, it's part of NZTA's biggest, most challenging and most expensive roading project. But this time, it's being built with an eye on the future.

The Waterview Connection project will integrate motorways through – and beneath – Auckland's western suburbs to complete the Western Ring Route as an alternative to State Highway 1. To keep pace, however, the ageing causeway must not only be widened, but raised after it subsided into the soft estuary sediment. Greig says it's also suffered regular inundation during storms and high tidal surges.

Because the causeway bisects the Motu Manawa Marine Reserve, flanked by the Waterview Estuary to the west, and Waitemata Harbour to the east, the resource consent called for an assessment of any effects on the coastal environment. The NZTA hired experts to assess future environmental effects, based on historic impacts. Then, to crosscheck and augment their conclusions, it asked NIWA and Tonkin & Taylor to model the effects of sediment and stormwater discharges during construction. NIWA also used its hydrodynamic models to predict the long-term effects that additional piers and a wider channel might have on current flow patterns. "We need to keep check on the sediment load into a sensitive environment," says Greig, "and we need to know the level of contaminants going into the harbour."

Sediment from the Eglinton River eddies in Lake Te Anau. (*Jordy Hendrikx*)

NIWA's Dr Rob Bell: models "essentially describe the physics of the flow of water, and that's a fundamental part of all transport processes, whether that's sediment, larvae or pollutants." (*Dave Allen*)

Modelling behaviour

Dr Rob Bell has modelled the impacts of many coastal and estuarine projects, as well as the effects of coastal climate change. The NIWA Principal Scientist says hydrodynamic models can simulate anything from the turbulence around a sand grain to the current patterns in the global ocean. "They essentially describe the physics of the flow of water, and that's a fundamental part of all transport processes, whether that's sediment, larvae or pollutants."

Generally, says Bell, the first step when developing a hydrodynamic flow model is to get good current and water-level data, because they drive all other coastal and marine processes. These basic inputs can be measured with current meters to track speed, GPS-equipped floats to measure drift patterns, and water-level gauges. "These models can be used for applications such as understanding flow patterns around reclamations, as in the SH16 motorway project, or the effects of sea-level rise, simulating coastal inundation from storm-tides and flood levels."

Then 'downstream' models, tailored to the nature of the project, are added on. Possible applications range from assessing water quality – for example, by predicting pollutant dispersion from outfalls and stormwater systems – to simulating sediment transport, or even modelling an entire ecosystem and its response to environmental changes.

When Watercare retired its Auckland oxidation ponds and replaced them with comprehensive sewage treatment, it also shifted the discharge outfall into Manukau Harbour. NIWA models were used to predict the effects, but Bell says they had to account for more than just current flows and dispersal patterns. "The main issues with outfalls are pathogens and viruses, so you have to know how well they survive in seawater, and where the treated discharge will be carried to, in order to protect recreational uses and kaimoana. Which model is being used depends on what problem is being modelled, and its space and time scales." They can range from a simple equation, he says, "to complex code running a supercomputer, but always designed to be fit for the purpose." He says models are often the only way

> "A model is a schematisation of reality."
>
> NIWA Principal Scientist, Dr Rob Bell

NZTA Principal Environmental Specialist, David Greig, monitors sediment transport beside the northwestern motorway reconstruction, in west Auckland. "We need to keep check on the sediment load into a sensitive environment." (*Geoff Osborne*)

to predict future effects, but cautions that any numbers they produce have to be checked against reality.

In 2009, Environment Canterbury asked NIWA to model flooding along parts of the Canterbury coast, following a hypothetical tsunami from a South American earthquake. Such a scenario is considered the greatest, and most likely, threat to that stretch of shore. NIWA based its model on the 1868 Peru tsunami, which reached much of coastal Canterbury.

In 2010, a tsunami triggered by a magnitude 8.8 earthquake off the coast of Chile drove strong currents into harbours and river mouths and flooded small areas of coast.

After last year's February earthquake, Christchurch regional and local authorities decided to remodel the scenario for the coast north of the city, and to extend it south to Taylors Mistake, to see if coastal evacuation plans needed adjusting, taking land subsidence into account.

Bell says good information about terrestrial and marine topography is critical to coastal models. "A model is a schematisation of reality." Researchers begin by creating a simulation of the environment they want to represent, over which they place a grid – each cell might, for instance, represent 30 square metres of the real environment.

Calculations derive averaged values for each cell, and the model is then tuned until results give the best match with real measurements. "If you don't get a good calibration of the model," says Bell, "it's often because the schematised grid is not quite representative of reality, so we go away and modify it until it is."

The next step, says Bell, is verification, where the model is run for a different period, or under different circumstances. "This time you don't touch the tuning knobs, and check it still performs well – then it's ready for predicting various scenarios or designs."

But NIWA Biosecurity Programme Leader, Dr Graeme Inglis, has reversed this process, for good reason. The Ministry for Primary Industries contracts NIWA to run a National Surveillance Programme to ensure the best chances of detecting any alien marine invaders as early as possible. "In designing this programme," says Inglis, "if we'd just allocated all our samples around the harbours, we wouldn't stand much of a chance of detecting those species, because it's just such a large area of available habitat. So we've been using the hydrodynamic modelling and habitat suitability models to try and identify the sites where species are most likely to turn up first. Those areas provide a focus for high risk of early incursion."

For the purposes of biosecurity, hydrodynamic models are applied on different scales. New Zealand-wide, Inglis says two key areas are ballast water exchange and the placement of structures on the coastal shelf. "New Zealand has an Import Health Standard for ballast water, which is one of the most frequent ways invasive species reach our shores. This standard means that ships aren't allowed to discharge ballast water in New Zealand's territorial waters, unless they

> “(Models) force you to think more rigorously.”
>
> NIWA Modeller, Dr Niall Broekhuizen

can demonstrate that they’ve exchanged it for mid-ocean water en route … or that they have treated the ballast water to a degree that’s acceptable.”

However, the standard allows exceptions: in rough weather, for instance, when a ship has to come close to shore to exchange ballast water. Models help to find stretches of the coastline where this poses the least risk.

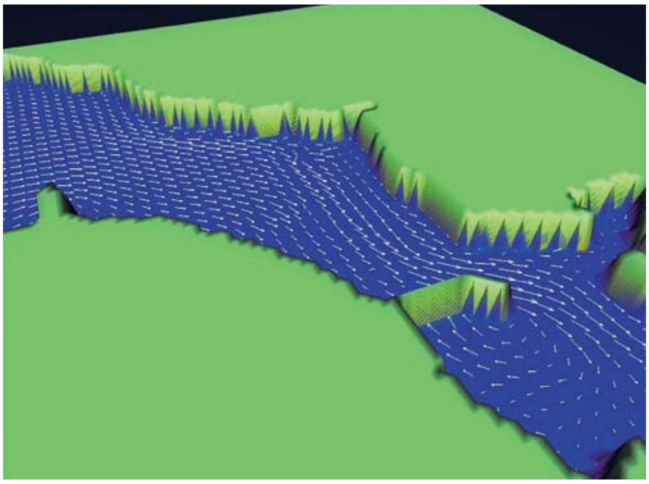
More than 170 non-native species have already established in our coastal waters. When a new one is detected, biosecurity officers use models to estimate the maximum distances any larvae could have travelled since the incursion. “During the Mediterranean fan worm incursion in Lyttelton in 2008,” says Inglis, “we used the outputs of the model that we’ve developed in designing the surveillance work to delimit the population. And we managed to remove it from the harbour.”

Where to from here?

Dr Niall Broekhuizen, at NIWA in Hamilton, is modelling impacts on entire ecosystems, assessing the effects of fish and mussel farms in the Hauraki Gulf, the Firth of Thames and Golden Bay. While filter-feeding mussels get all the nutrients they need from surrounding water, caged fish must be fed, adding organic matter to the environment that can enrich the water.

Before he can model any impacts, Broekhuizen says he first needs to know how much nitrogen and carbon is coming out of a farm, and how much oxygen the fish will consume. “The model then predicts the fate of that material.” If too much decomposing matter settles on the seabed, he says, it can create hypoxic (low-oxygen) – or even anoxic (no-oxygen) – conditions, which can cause “dramatic changes in abundance and composition of the seabed fauna in that small region.”

In the water column above, the effects are more subtle. New Zealand coastal waters are generally nitrogen-limited, and any extra nitrogen excreted by the fish may trigger phytoplankton growth. If a hydrodynamic model is to predict the effects of that, it must ‘know’ about the stratification of the water column – essentially, how it’s layered, depending on differences in salinity and temperature, which in turn cause changes in density. Less dense water ordinarily sits atop more dense layers. “The strength of stratification and the depth of the layers are important factors,” says Broekhuizen. “Any changes can have a big impact on algal growth, because phytoplankton need light to grow and will essentially starve at depth.”



Hydrodynamic modelling of the Okura Estuary, on Auckland’s North Shore, tracks the flood tide in a fine-scale schematisation. An eddy is projected to flow around the lee of the thin sandspit. (*NIWA*)

Mostly, he needs to know how far any nitrogen will travel, and how much it will boost phytoplankton biomass. “We need to know whether these changes are larger than [natural] seasonal and inter-annual changes. Circumstantial evidence suggests that any changes at the base of the food web trickle down and can transfer to the zooplankton and affect larval survival.”

But perhaps the greatest value of models, says Broekhuizen, is that they “force you to think more rigorously, and identify knowledge gaps. They’re certainly not a cheap alternative to fieldwork.”

Dr Rob Bell
Principal Scientist
rob.bell@niwa.co.nz

Dr Graeme Inglis
Biosecurity Programme Leader
graeme.inglis@niwa.co.nz

Dr Niall Broekhuizen
Modeller
niall.broekhuizen@niwa.co.nz

Cause and effect

John Morgan came to NIWA as Chief Executive in 2007, after stints at the helms of AgriQuality and Orica New Zealand, and Chairman of New Zealand Pharmaceuticals. So what drives the guy in the suit? **Dave Hansford** finds out …

John Morgan grew up in the Akatarawa hills, north of Upper Hutt, "where, every summer's day, we'd swim in the rivers next to our home. If we were thirsty, we'd just lean over the side of the kayak and have a drink." Fascinated by the forces of nature, he'd rush to the bridge over the river after each big rain, "to see how the riverbank, swimming hole and rapids had changed."

And so began a lifetime's musing on the concept of cause and effect.

"Science captivated me right from my early days at school", he recalls. "It doesn't matter what aspect of life you look at – the environment, society, commerce – there's always cause and effect." He also came to love rugby, and remembers riding his bike as a youngster from Akatarawa to Maidstone Park to play halfback for the Upper Hutt Bantams. "I found rugby fascinating: that cause and effect again, I suppose. I used to listen to overseas rugby tests on the radio in the middle of the night, without my parents knowing of course, and could visualise clearly what was going on on the field."

He left Akatarawa to travel the world, or at least: "all the usual destinations for Kiwis of my vintage." He spent 13 years in the UK, Europe and the United States. "I played a bit of rugby – very badly – in the UK for Doncaster Rugby Club," where he learnt some more about cause and effect: typically for a halfback, he says, he "started lots of fights on the field, and never won any of them."

After returning to New Zealand, he settled on Auckland's North Shore, and has lived there ever since. "I'm a water baby at heart – so living in the East Coast Bays near the sea was an obvious choice." Inevitably, he signed up with the local rugby club (as, in time, did some of his kids), and played into his mid-forties, when age and attrition blew the final whistle.

Morgan's universe revolves around his wife and six children, and it recently expanded to embrace the arrival of his first grandchild. "The ability of humans to multiply their love never ceases to amaze me. When you have one child, you think: 'I couldn't possibly love another child as much as this', and then you have another child, and you do. I've seen that happen six times in my life, and you think: 'my life must be complete'. Then a grandchild comes along, and a whole lot of new love comes out of nowhere. The fact is, you never run out of love, you just grow some more."

Morgan's love of rugby just kept growing too. He's now a Director of the Auckland Blues and Chairman of North Harbour Rugby. But most winter weekends, he loses the suit and pulls on a referee's uniform. "Even though I can't play any more, I'm still addicted to the smell of a footy field, and there's nothing like seeing a kid's face when they score a try, or catch a high ball, or make a try-saving tackle – you see what it does for them. And to see mum and dad on the

John Morgan at home: "Probably the one thing I guard jealously is my family," he says. "They're everything to me." (*both photos Geoff Osborne*)

sideline cheering and screaming and hugging their kids afterwards – that's truly priceless."

Human triumphs – great and small – are the stuff of Morgan's inspiration. "The ingenuity of humankind to develop new knowledge, the rate of discovery in the electronic world, the medical world, and what we know now about our environment – it's just phenomenal." All of it done, he says, despite institutional hindrance: "... false ceilings above us. If we can find a way of taking those away and letting people go – that's when the great discoveries happen."

And the need is pressing, he says. "We can see now that, around the world, things have gone to hell in a handcart in many respects. Lawyers and accountants can't fix the world's problems any more. It's time for the scientists to step in with new knowledge and innovation."

Problems that once plagued the developing world, says Morgan, have now gone truly global. "Health issues, water, food and energy security, environmental sustainability, the increasing prevalence of extreme weather hazards – you don't pick up a newspaper without reading about another major event.

"It doesn't matter where you look, it's now science that's going to find the answers, and I find that exhilarating."

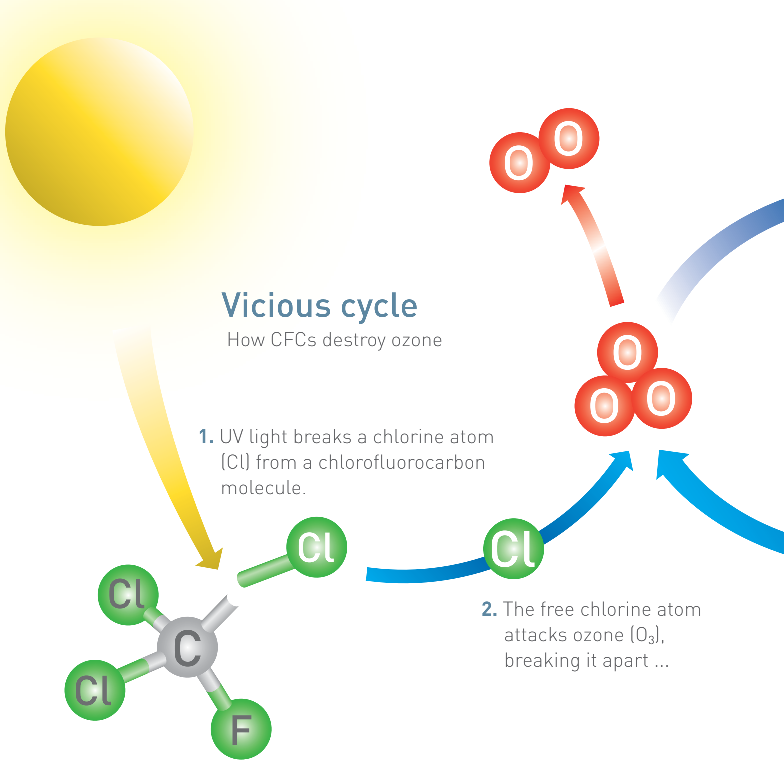
And it offers the opportunity, he says, to rethink our approach to problem solving: "When you start doing things on a grand scale, you get ecosystem impacts. We're still a long, long way from understanding full ecosystem approaches to managing our pastoral economy, our marine environment, our freshwater environment.

"There are tremendous opportunities with those natural resources, but we're going to have to do a lot of good science – acquire a lot of knowledge – to know how we can realise them sensibly and sustainably. If you look back through history, there have been some absolutely horrific unintended consequences – usually because we didn't take a holistic view."

Cause and effect once again. "I want the world to start thinking about science holistically. In our area of science, that means an ecosystem approach. The health sector is already starting to think like that, which is pretty exciting. We need to do the same with our natural resources."

Q&A

Montreal and the fall and rise of stratospheric ozone



Vicious cycle

How CFCs destroy ozone

1. UV light breaks a chlorine atom (Cl) from a chlorofluorocarbon molecule.

2. The free chlorine atom attacks ozone (O_3), breaking it apart ...

What is ozone, and where is it found?

Ozone (O_3) is a naturally occurring, colourless, pungent gas composed of three oxygen atoms. It is sparsely scattered throughout the atmosphere, but the greatest concentrations lie in a thin layer (the 'ozone layer') within the stratosphere, 20–30 kilometres above the Earth's surface.

Why is ozone significant?

In the lower atmosphere, ozone is a highly-corrosive pollutant that can cause respiratory harm. The chemical ingredients to make ozone come from vehicle and factory emissions, which means local concentrations are quite variable.

In the stratosphere, however, ozone is a lifesaver. The ozone layer absorbs much of the sun's UVB ultraviolet radiation – a catalyst for skin cancer and a range of other health problems.

Without stratospheric ozone, then, little could survive on Earth. That's why scientists were alarmed to discover in 1985 that a gaping hole was appearing in the ozone layer above Antarctica each spring.

What causes depletion of the ozone layer?

During the 1970s, University of California scientists made the connection between ozone depletion and the presence of chlorinated fluorocarbons (CFCs) and halons in the stratosphere. They also recognised the serious implications of ozone depletion for UVB levels at Earth's surface.

CFCs and halons are stable, manmade compounds invented in the 1930s for use as 'safe' refrigerants, propellants, foaming agents and cleaning solvents. CFCs comprise chorine, fluorine and carbon. Halons are similar, but also contain bromine or iodine.

CFCs and halons are very stable, so are not destroyed in the lower atmosphere but, over decades, waft slowly upwards to the stratosphere, where only harsh UV radiation finally breaks them down, releasing their chlorine and/or bromine atoms. Each unleashed atom can destroy more than 100,000 ozone molecules, much faster than they are naturally created.

What is the Montreal Protocol?

The gravity of these discoveries was not lost on the wider scientific world, nor on policymakers. In 1985, 20 nations – including most major CFC producers – signed the Vienna Convention, which established a framework for negotiating international regulations on ozone-depleting substances. After the discovery of the Antarctic ozone hole later in the same year, it took just 18 months to reach a binding agreement in Montreal.

That agreement – the Montreal Protocol on Substances that Deplete the Ozone Layer – sets binding targets for phasing out, and eventually eliminating, the production and use of CFCs and other ozone-depleting substances. It was opened for signature on 16 September 1987, and came into force on 1 January 1989.

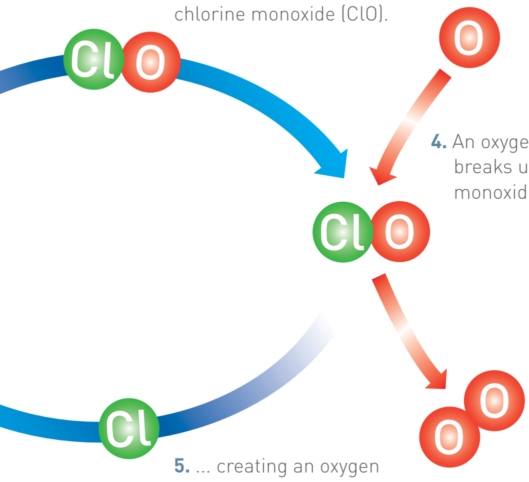
Is New Zealand playing its part?

New Zealand was present at negotiations, and an early signatory. Our obligations under the Protocol are articulated in the Ozone Layer Protection Act, 1996.

The import of all ozone-depleting substances into New Zealand is being phased out in accordance with – or in some cases ahead of – the Protocol's timetable.

Are we out of the woods yet?

Since the Montreal Protocol came into effect, concentrations of the most significant CFCs and related chlorinated hydrocarbons have either leveled off or decreased. Halon concentrations have continued to increase, as they are released from storage in equipment such as fire extinguishers. But their rate of increase has slowed.



3. … forming an oxygen molecule (O_2) and chlorine monoxide (ClO).

4. An oxygen atom then breaks up chlorine monoxide …

5. … creating an oxygen molecule and leaving the chlorine free.

Vicious cycle: stratospheric ozone is created and destroyed in an entirely natural cycle, but manmade CFCs cause still greater attrition. After being split off CFC molecules by UV radiation, chlorine atoms go about the stratosphere shattering the chemical bond that holds ozone molecules together. The chorine atoms survive the collision unscathed, to go on wreaking havoc in the ozone layer: a single chlorine atom is estimated to destroy some 100,000 ozone molecules. (*Mark Tucker*)

If all 197 signatories continue to meet their obligations under the Protocol, it is expected that stratospheric ozone (and hence surface UVB) will return to pre-1980 levels by about 2050. There are already signs of a slow restoration.

However, there is still much work to be done. CFCs have a very long lifespan in the stratosphere, so ozone-depleting chlorine levels will decrease only very slowly. Other ozone-depleting substances, such as nitrous oxide, are not covered by the Protocol, and continue to proliferate. Roughly a third of nitrous oxide emissions are man-made, with agriculture by far the largest source. Though less destructive than CFCs, they nevertheless comprise the greatest ozone-depleting emission for at least the rest of this century.

There are other influences on stratospheric ozone. Volcanic eruptions, such as Mt Pinatubo in 1991, can alter atmospheric chemistry, depleting ozone locally. In addition, greenhouse gases warm the lower atmosphere, leading to cooling of the stratosphere, increasing the probability that stratospheric clouds will form – an accelerator of ozone depletion.

Researchers from NIWA are monitoring changes to ozone and UV radiation to predict how these might change in the coming years.

Contact:
Dr Olaf Morgenstern
Chemistry-climate Modeller
olaf.morgenstern@niwa.co.nz

NIWA
enhancing the value of New Zealand's natural resources

NIWA (the National Institute of Water & Atmospheric Research) was established as a Crown Research Institute in 1992. It operates as a stand-alone company with its own Board of Directors, and is wholly owned by the New Zealand Government.

NIWA's expertise is in:

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- Atmosphere
- Biodiversity and biosecurity
- Climate
- Coasts
- Renewable energy
- Fisheries
- Freshwater
- Māori development
- Natural hazards
- Environmental information
- Oceans
- Pacific rim

NIWA employs approximately 650 scientists, technicians, and support staff. Our people are our greatest asset.

NIWA also owns and operates nationally significant scientific infrastructure, including a fleet of research vessels, a high-performance computing facility, and unique environmental monitoring networks, databases and collections.

Back cover:

Gannets (*Sula serrator*) greet with a mutual bowing display at a breeding colony at Cape Kidnappers in Hawke's Bay. At last count, there were 6600 breeding pairs of gannets here, making Cape Kidnappers the birds' largest mainland stronghold. Captain James Cook, an assiduous chronicler who named the promontory, made no mention of this colony, so it is assumed it was established sometime between 1850 and 1870. (*Dave Hansford*)

NIWA
Taihoro Nukurangi