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WATER & ATMOSPHERE

NIWA
Taihoro Nukurangi

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Cover

NIWA's research vessel *Tangaroa* sailing between Possession Island and the Antarctic mainland during a suveying mission in February and March 2001. The photograph was taken from Possession Island while a team of four were ashore running a 25-hour tidal station. For more details see the article on page 4 of this issue.

(Photo: John Mitchell)

Produced by Wickliffe Design

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WATER & ATMOSPHERE

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A surprisingly strong seaweed

Masses of the giant kelp Durvillaea antarctica *growing on an exposed, rocky shoreline.*

In other parts of the world, seaweeds found in such places tend to be small and low-growing – adaptations that help the plants survive in stormy conditions. Recent experiments have shown how this huge native seaweed can withstand violent wave action.

Refer to pages 8–9 for details.

(Photo: Craig Stevens)

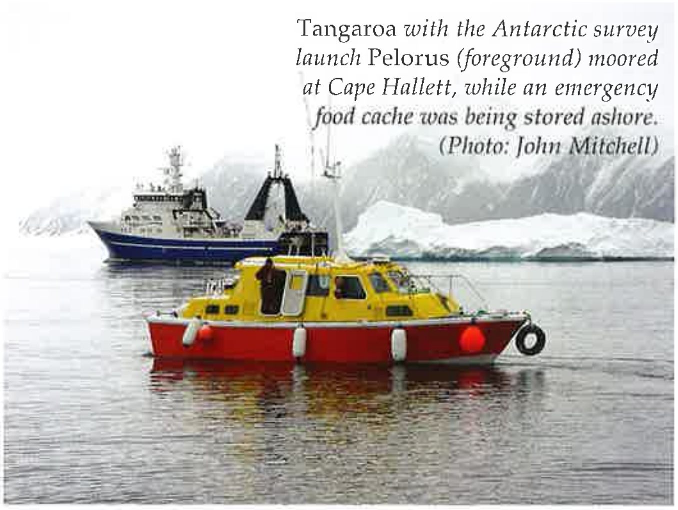
NIWA NEWS FORUM

Tangaroa explores the Antarctic

NIWA's 70-m-long research vessel *Tangaroa* set sail from New Zealand on 4 February 2001 for a 40-day voyage to the Antarctic. With air temperatures of –2.9°C, and a thin barrier of ice slowing down the vessel, *Tangaroa* arrived off Cape Adare on 11 February. The crew then negotiated their way around numerous large icebergs while sailing between Cape Adare and Possession Island.

After eight days at sea, a survey team was landed at Possession Island to install a tidal station. The team of four spent two days working in bleak surroundings to find the best location for the station. Meanwhile, the rest of the crew continued surveying the Possession Island–Cape Hallett area. Large amounts of multibeam data were collected, in some places showing scouring of the seabed by icebergs.

While those at home were celebrating Valentine's Day, the crew on board *Tangaroa* were busy preparing for their arrival at Cape Hallett. Using NIWA's 10.5-m-long Antarctic survey launch *Pelorus*, the survey team went ashore to re-establish existing survey marks and to establish new ones (if required). Two Dobie tide gauges were deployed, and an emergency food cache – 320 days of food and 60 litres of kerosene – was stored on land in one of the existing food storage huts.



Tangaroa *with the Antarctic survey launch* Pelorus *(foreground) moored at Cape Hallett, while an emergency food cache was being stored ashore. (Photo: John Mitchell)*

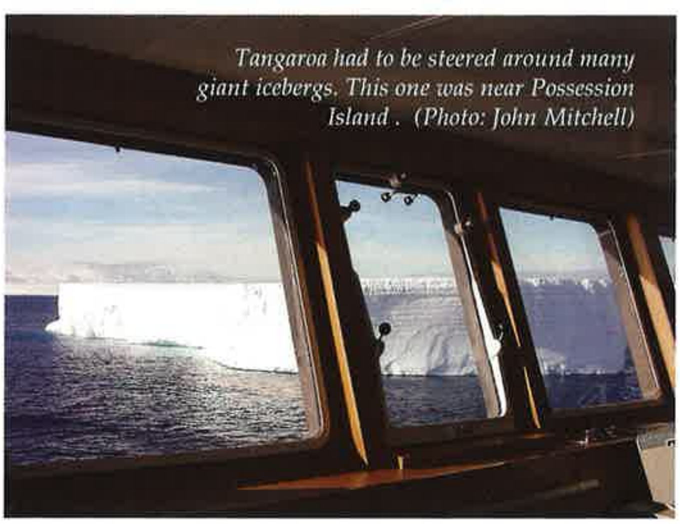
Pelorus was also used to study biodiversity around the Cape Hallett area, using a trawl from *Tangaroa* and a special "Splash" video camera. Many of the crew had the opportunity to go ashore and mingle with some photogenic Adelie penguins and a large female elephant seal.

Deteriorating ice conditions on 22 February led to a decision to pull out of the Ross Sea survey area. Although there was still plenty of ice-free water visible, an increasing amount of pack-ice was moving into the Cape Hallett–Cape Adare area, held back by icebergs, some as large as 70 km wide and 180 km long. Poor visibility overnight slowed progress, but by morning the bad weather had cleared, and several minke whales, penguins and seals arrived to escort *Tangaroa* and its crew out of the area. The ship then headed for the inhospitable Balleny Islands to continue hydrographic surveying.

On the last day, the crew was mustered for a team photograph. Getting everyone outside in 50-knot winds was not easy – nor was taking a photo!

On the way back to Wellington, the scientific team spent most of their time analysing data and writing reports. *Tangaroa* arrived back in Wellington on 17 March, bringing to an end a very successful survey.

This survey was carried out under contract to Land Information New Zealand (LINZ), the New Zealand government department responsible for hydrographic charting. The main purpose of the voyage was to collect hydrographic data for determining safe passages and anchorages for the tourist cruise liners frequenting Cape Adare, Cape Hallett and Possession Island. A secondary aim was to collect fisheries, aquatic biodiversity, oceanographic, and other marine science data.

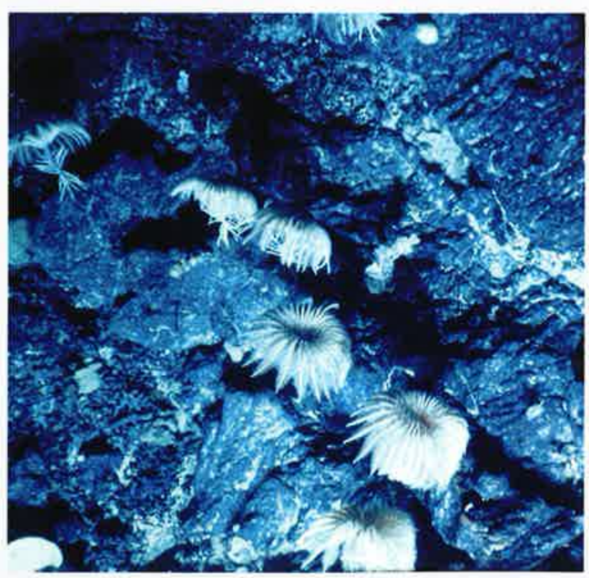


Tangaroa had to be steered around many giant icebergs. This one was near Possession Island . (Photo: John Mitchell)

ERRATUM

Sea lilies and feather stars – the exquisite crinoids of the New Zealand region. *Water & Atmosphere 8*(4): 6.

The lower photograph on page 6 was incorrect. The correct illustration is reproduced below, along with its caption.

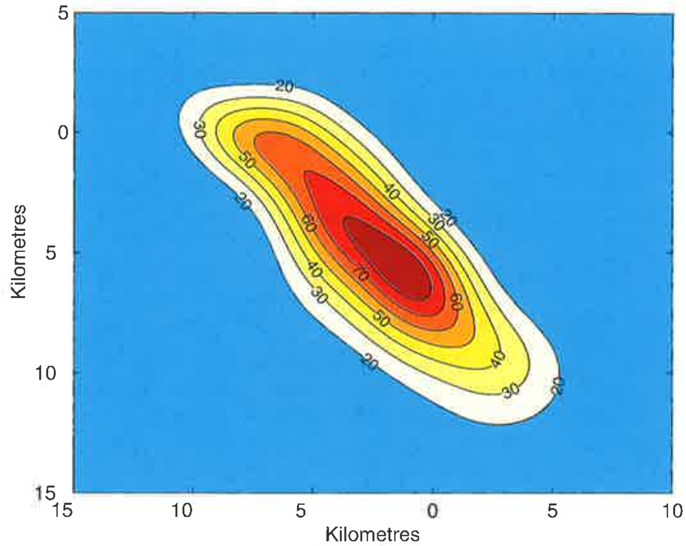


Stalked crinoids (Metacrinus wyvillei) *of the family Pentacrinitidae on Clark Seamount at about 900 metres depth, photographed during* Sonne *cruise SO-153 in 1998. (Photo: Ian Wright)*

Tracking water at sea

Dr CLIFF LAW, from the Plymouth Marine Laboratory (UK), visited NIWA during January and February 2001. Cliff and his team have developed world-leading techniques for following the dispersal of patches of water at sea. A gas known as sulphur hexafluoride, or SF6, is dissolved in the water. This gas is biologically inert and is measurable at very small concentrations. Specialised equipment is used to measure the concentration in the seawater collected from a moving ship, and this enables the patch of water to be mapped as it is spread by the ocean currents.

Cliff's involvement was central to the recent iron-release experiment carried out by NIWA staff in the Southern Ocean (known as the Southern Ocean Iron Release Experiment or SOIREE). This experiment stimulated an algal bloom by fertilizing a patch of sea-water with dissolved iron. The UK group provided the technology needed for tracking the patch, enabling the bloom to be followed for a fortnight as it developed.



A map of a patch of water which was labelled with the dissolved gas SF6, eleven days after the experiment began. The data are from the Southern Ocean Iron Release Experiment and were obtained by Cliff and his team. The contours show the concentration of SF6 dissolved in the seawater in units of femtomol (10^{-15} mol) of SF6 per litre of seawater. Data like this provide valuable information on dispersal in the surface ocean.

Cliff has recently been working with Dr Edward Abraham, of NIWA in Wellington, analysing the results of SOIREE and developing plans for future SF6 experiments. It is hoped to use the technology to follow the development of naturally occurring algal blooms and so gain insights into their ecology.

Award: Joe Aberle

JOE (JOCHEN) ABERLE, currently working under a NIWA post-doctoral award in the Freshwater Hydrodynamics Group in Christchurch, has been awarded the "Ehrensenator-Huber-Preis 2001" of the Faculty of Civil Engineering, Karlsruhe University, Germany. He has received the award (worth DM7000, or around NZ$7700) for his PhD thesis about mountain torrents, which he prepared and defended at the Institute of Water Resources Management, Hydraulic and Rural Engineering at Karlsruhe University. The official ceremony will be held in May in Germany, but unfortunately without Joe's attendance.

Artificial intelligence and river biomonitoring

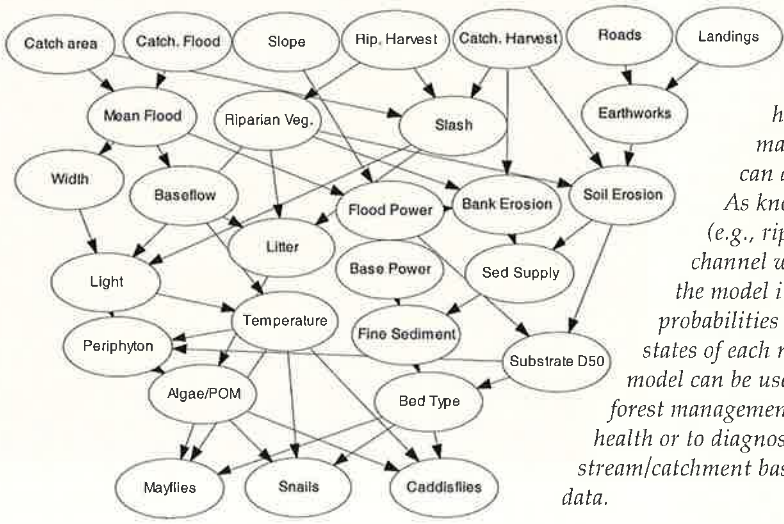
THE USE OF PREDICTIVE models for bioassessment of water quality in rivers is a hot topic internationally, and debate is still raging about what, if any, models will be useful in the New Zealand context. A recent visitor to NIWA Hamilton added fuel to this debate. Professor Bill Walley is head of the Centre for Intelligent Environmental Systems at Staffordshire University, UK. He is a world leader in the application of artificial intelligence (AI) techniques to environmental science.

Bill has approached the issue of biomonitoring in rivers by trying to model how expert stream ecologists assess stream health. In general, experts use two complementary mental processes when diagnosing or predicting problems in their domain of expertise. These are:

(a) plausible ("probabilistic") reasoning based upon their scientific knowledge;

(b) pattern recognition based upon their experience of previous cases.

Bill has recently developed river health models for the British Environment Agency using probabilistic reasoning based on Bayesian methods and pattern recognition based on neural networks.



Example of BBN developed to provide a model of how forestry management practices can affect stream health. As knowledge about a site (e.g., riparian management, channel width) is entered into the model it updates the probabilities associated with states of each related node. The model can be used either to predict forest management effects on stream health or to diagnose problems in a stream/catchment based on biological data.

For further details contact John Quinn at NIWA, PO Box 11-115, Hamilton (ph: 07 856 7506; fax: 07 856 0151; email: j.quinn@niwa.co.nz)

During his visit (November–December 2000) Bill provided insights into a range of AI techniques that seem ideally suited to both the interpretation of complex ecological patterns and their presentation in a form digestible by managers and end-users. Two of the areas of particular interest were the use of Bayesian Belief Networks (BBNs), also known as Plausible Reasoning Networks, for relating stream health to environmental factors (above), and the use of unsupervised neural networks (such as Self-Organising Maps, or SOMs) for mapping patterns in environmental data (below).

As a result of Bill's visit, NIWA has developed software for the construction of models that can predict biological assemblages from habitat data (for example, predict what species should be present in a certain stream).
This software, called MOPED (MOdelling Patterns in Environmental Data), uses the SOM approach in conjunction with discriminant functions analysis.

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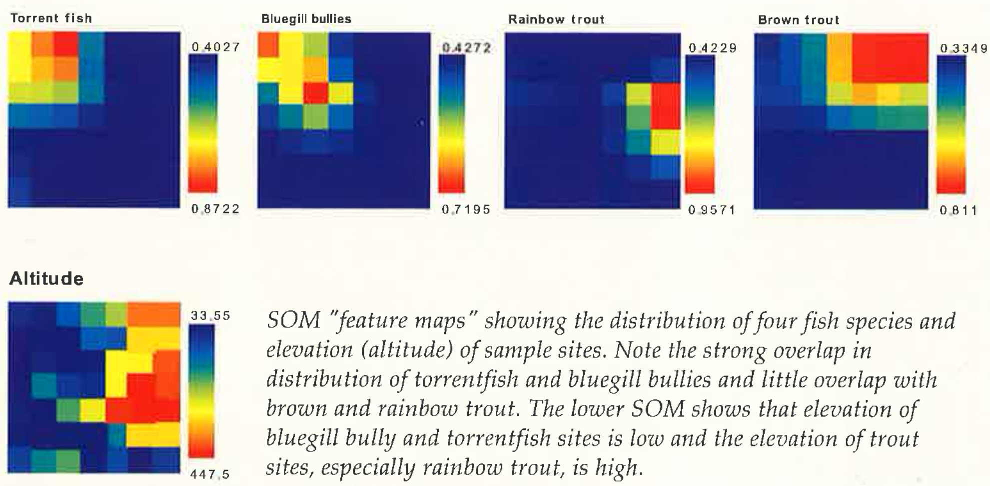

SOM "feature maps" showing the distribution of four fish species and elevation (altitude) of sample sites. Note the strong overlap in distribution of torrentfish and bluegill bullies and little overlap with brown and rainbow trout. The lower SOM shows that elevation of bluegill bully and torrentfish sites is low and the elevation of trout sites, especially rainbow trout, is high.

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Urban sustainability

THE WAY WE RUN our cities is of great concern to everyone who lives in them. We all want to maximise our enjoyment of life, without damaging the environment and without it costing us too much! However the issues with the infrastructure, the environment and the governance of large urban areas are very complex. The key current concept is "sustainability" – how do we conduct our activities without compromising the needs of future generations?

Dr Jim Salinger and Gavin Fisher of NIWA, Auckland, are part of a group from the Royal Society of New Zealand and the Auckland Branch of IPENZ that is organising a major event at the Aotea Centre, Auckland on 18–21 September 2001. The Sustainable Auckland Congress aims to bring together all the various disciplines and explore the options for making Auckland a better place to live. This includes scientists, engineers, sociologists, planners, politicians, lawyers, business people, educationalists, managers and a range of other public and private sector people. The four-day Congress will include a number of invited overseas speakers, a Mayoral debate (with four Auckland Mayors and the Chairman of the Regional Council), a youth forum, several inter-disciplinary workshops, and addresses from high-profile political leaders.

This initial Congress is focused on Auckland, where problems with transport, water supply, environmental pollution and social inequity – all associated with rapid growth – have become severe. It is hoped that by bringing various sectors together, there will be better understanding of the issues, resulting in better solutions for the city's sustainable future.

Further congresses are planned, both in Auckland and in other large New Zealand cities.

For further information (or to be included on the email list for announcements), contact Gavin Fisher or Jim Salinger at NIWA, Private Bag 109695, Auckland (ph.: 09 375 2050; fax: 09 375 2051, email: g.fisher@niwa.co.nz, j.salinger@niwa.co.nz).

25-harbour fish survey

A LARGE-SCALE estuarine fish survey is currently in progress around the northern half of the North Island, over February and March 2001. The survey covers 25 different harbours, and sites are being sampled from the upper reaches to just inside the harbour mouths. In all, more than 300 sites will be sampled for small fish (especially juveniles), using fine-meshed beach seines.

The data collected will be used to construct a fish-habitat classification scheme for estuaries. In turn this will form the basis for developing predictive models of the impacts of human disturbances on estuarine fish populations and assemblages.

A wide range of species has been sampled to date. One of the more exciting finds has been the capture of numbers of newly settled snapper – just out of their planktonic larval stage – next to seagrass beds in several harbours. Such small snapper have rarely been caught in New Zealand previously. Their possible association with seagrass beds means that the decline of these beds is even more critical, since snapper forms an important commercial fishery.

Another find has been a sizable population of the bridled goby in the upper Waitemata Harbour. This large-bodied goby is thought to have been introduced from Australia and has been recorded over the past 2–3 years.

Many other species have also been sampled as juveniles, often in high numbers.

This project will lead to a substantial improvement in our knowledge of which fish species are using our estuaries. In time, this will help us to understand the nature and magnitude of their reliance on estuarine habitats for continuing healthy and productive populations.

Contacts: Mark Morrison or Malcolm Francis, NIWA, PO Box 14-901, Kilbirnie, Wellington. (ph.: 04 386 0300; fax: 04 386 0574; email: m.morrison@niwa.co.nz, m.francis@niwa.co.nz)

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NTR97. Review of west coast North Island trawl survey time series, 1986–96. M.A. Morrison et al. 2001. 56 p. $30.00

NTR98. New Zealand glacier snowline survey, 2000. T.J. Chinn & M.J. Salinger. 2001. 78 p. $30.00

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BIOMECHANICS

Durvillaea antarctica: the strongest kelp in the world?

Craig Stevens

Catriona Hurd

Murray Smith

Deane Harder

How does a huge and unwieldy plant like the giant kelp manage to survive – and thrive – along New Zealand's rough and often stormy coastline?

THE EXPOSED COASTLINE of New Zealand is the scene of a remarkable survival story. Huge waves pound these rocky shorelines for days and weeks at a time. Despite the harsh environment, the kelp *Durvillaea* thrives, producing some of the biggest kelps in the world. The photograph shows a bed of *Durvillaea antarctica* along the Otago coast under waves that would smash a boat to pieces in minutes. We have weighed individual plants at over 70 kg with as many as 200 individual leaf-like fronds! In contrast, intertidal seaweeds found on similar wave-exposed shores of North America and Europe are small and tough. These species minimise their size and so reduce their exposure to forces and pressures imparted by breaking waves. How has the radical evolutionary alternative taken by *Durvillaea* succeeded?

Duvillaea antarctica *thrives on exposed rocky coastal areas in Otago.*

Earlier studies of plant biomechanics provide a general understanding about how intertidal seaweeds move and respond to waves and flow. But these are based on the smaller plants more typical elsewhere in the world. One of the main goals of this joint NIWA/University of Otago study is to obtain detailed observations of biomechanics at work in the wave-swept coastal region. We have been successful beyond our expectations (see panel, opposite page) – although this was at the cost of lots of broken equipment and bruised knees and elbows.

How do the plants survive?

Our measurements show the linkage between wave arrival and the forces that result at the base of the plant (the holdfast). The holdfast is the vital connection between the kelp and the rocks upon which it literally glues itself and is the most common place at which the plant breaks, leaving the kelp to be washed away. The results for two different kelp species, *Durvillaea antarctica* and *Durvillaea willana* (see panel, right) indicate some

Two solutions to the same problem

There is no straightforward answer as to why *Durvillaea* does so well. Two kelp species in the genus *Durvillaea*, *D. willana* and *D. antarctica*, have similar size but are morphologically and biomechanically different from each other. The photograph below shows how the blades of *D. antarctica* are honeycombed with air-filled pockets and so are very flexible, elastic and buoyant. *D. willana*, on the other hand, is comparatively rigid: it has no pockets and does not float. Thus *Durvillaea* has found not one but two solutions to the problem of how a large plant survives in the waves.

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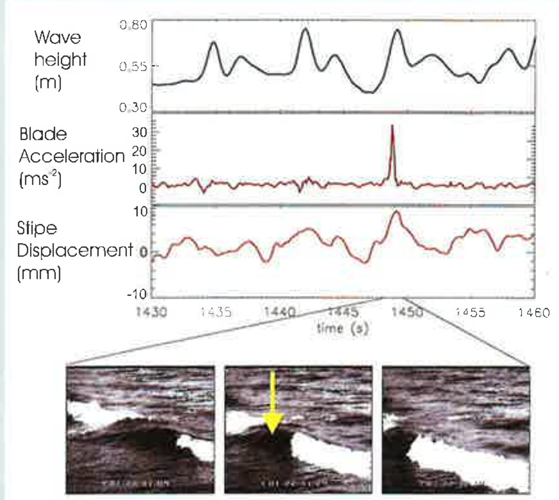
Measurement in the wave-swept rocky intertidal shore: the bionic kelp

THE UNDERWATER MEASUREMENTS required the development of some totally new techniques using electronic sensors in ways never conceived of by their manufacturers. This turns the kelp into bionic plants!

Accelerometers, often used by the automotive industry on crash-test dummies, were wired to the kelp fronds. Load and movement sensors more typically found on assembly lines were attached to the kelp stipe (the trunk or stem of the plant).

The photo (right) shows the kelp at low tide with movement sensors mounted horizontally near the base of the plant, as well as a load cell that has been spliced in-line with the plant stipe. All these devices operated under water with waves crashing all around. It was no surprise that the equipment literally took a pounding – running repairs was the name of the game for the field work. A nearby pressure sensor measured the waves. Synchronisation was key to this observational approach because we needed to know what type of wave caused each event in the measurements.

Results are shown (right) in the form of time-traces of measurement (time series). Here we plot only a few waves but we recorded results from many thousands of waves. The top trace shows the waves as indicated by a pressure sensor, the middle panel records the average acceleration from a point along a blade and the lower panel shows the sideways movement of the stipe. The interesting point here is that similar waves (top panel) do not generate similar accelerations or stipe movement. This is because only one of the waves breaks right at the kelp location. So, just like a surfer paddling out from shore, as long as the wave doesn't directly break on the kelp the extreme forces are avoided. Video is required to identify whether the wave is breaking. The illustrated sequence of images 0.6 seconds apart begins when the large acceleration starts. Although the kelp is not visible at this time, its position is marked by an arrow. The water depth is around 0.5 m.



interesting possibilities as to why these plants are so large.

The floating *D. antarctica* exposes itself to the maximum amplitudes of the passing and breaking waves. However, its internal honeycomb structure makes it stretchy as well as light. Consequently the forces experienced are smaller than if the blades were filled with water or plant material. The less buoyant *D. willana* retains something closer to neutral density so that it doesn't sit out on the water surface like *D. antarctica*, but neither does it drag backwards and forwards along the seabed.

We are also examining the importance of the close proximity of large numbers of blades. They seem to act like fibres in a bundle in the way they absorb the shock forces during a breaking wave. It appears that the force of a large wave, that might tear away any given individual, is shared amongst a number of plants.

The different mechanical structure of the two kelp species is fundamental to their success. The final stage of the project uses computer modelling to help identify the details of the kelp–wave interactions and explain these unique methods of survival. These methods of reducing the effects of the waves allow *Durvillaea* to live where competitors cannot. ■

Craig Stevens and Murray Smith are at NIWA in Wellington and Catriona Hurd and Deane Harder are in the Botany Department at the University of Otago.

Further reading

Hay, C.H. (1994). *Durvillaea* (Bory). Pp. 353–384 *in:* Akatsuka, I. (ed.). 'Biology of economic algae'. SPB Academic, The Hague, Netherlands.

Denny, M.W. (1988). 'Biology and the mechanics of the wave-swept environment'. Princeton University Press, New Jersey. 329 p.

Marsden Fund www site: www.rsnz.govt.nz/funding/marsden_fund/index.php

This work is funded by the Marsden Fund, a pool of research funding provided by the Government and administered by the Royal Society of New Zealand. This funding supports investigator-driven ideas that perhaps have no direct application but which form the building blocks of science. Ideas and techniques developed in this work are already being used in projects that have very practical applications.

LAKES

Ultraviolet light: is it harming New Zealand's lakes?

Rowena Rae

Ian Hawes

Dieter Hanelt

Clive Howard-Williams

Scientists at NIWA and the Alfred Wegener Institute in Germany have been investigating how far UV light travels into lakes, and what effects it is having on the plants that live there.

IT HAS BEEN OVER TWENTY YEARS since the so-called "ozone hole" over Antarctica was first discovered. A thin ozone layer in the atmosphere allows more ultraviolet sunlight (UV) to reach the earth. There has been a lot of scientific research into the effects of this extra UV on aquatic organisms. Most work has concentrated on the Southern Ocean and on both freshwater and marine environments in the Northern Hemisphere. (Ozone thinning also occurs over the Arctic.)

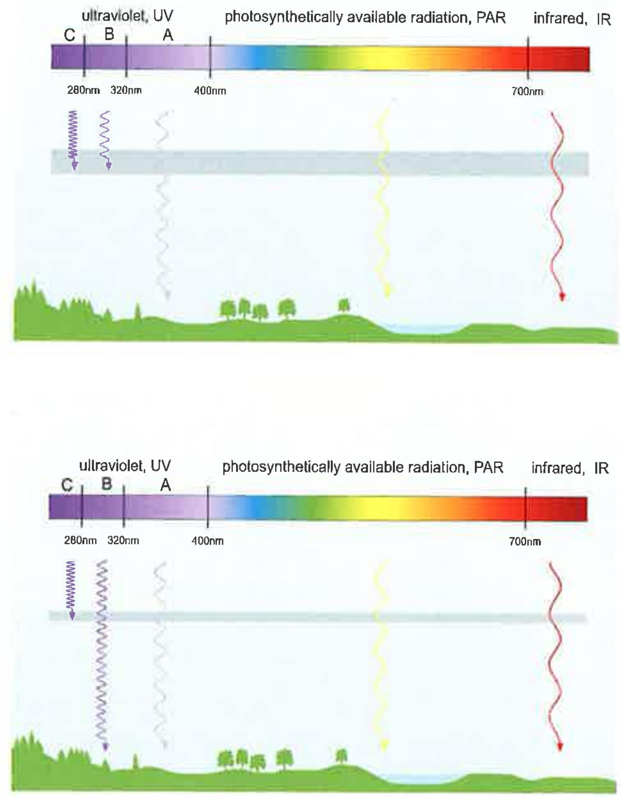
In New Zealand, UV at ground level has always been high. At certain times of the year it is almost double the amount at similar latitudes in Europe (see *Water & Atmosphere* 7(4):7–8). So there is certainly potential for UV to damage aquatic life here. However, little is known about the role of UV in New Zealand's fresh waters. Some recent studies at NIWA have started to fill the gap.

DOM: a natural sunscreen

Sunlight is made up of light energy over a range of wavelengths (see figure, right). UV light is at the short-wavelength end of the spectrum. The shorter the wavelength, the higher its energy, so light below 320 nm is usually the most damaging.

When sunlight penetrates lake water, it is absorbed in different ways by particles and natural chemicals in the water. For example, red and infrared wavelengths are absorbed by water molecules. Pigments (chlorophylls) in microscopic algae that float in the water absorb blue and red light for use in photosynthesis. And UV light is absorbed by organic material dissolved in water. So lake water with a lot of dissolved organic material (DOM) shields organisms from UV. For this reason we often refer to DOM as a "natural sunscreen" for lakes.

DOM is leached from decaying terrestrial plant material, such as leaves and twigs. High concentrations of DOM make water look brown, sometimes as dark as strong tea. Lakes in forests are often very brown. In sparsely vegetated alpine and tundra areas, lakes tend to be clearer. Clear water offers less protection from UV to organisms living in the lake.



Sunlight is classified according to the length of the different coloured waves emitted by the sun. The squiggly lines on this figure represent the energy the light has: the tighter the squiggle, the higher the energy and the greater the chances of the light harming life on Earth. Ultraviolet light (UV) has the shortest wavelengths (measured in nanometres: nm), and is subdivided into three bands: A, B and C. UV-A along with PAR (photosynthetically available radiation, also called visible light) and IR (infrared radiation) are not absorbed by the ozone layer even when it is thick and healthy. UV-B, on the other hand, is absorbed by a healthy ozone layer (upper panel) but some of it passes through when the ozone gets thin (lower panel). None of the UV-C light comes down to Earth, even with a thinning ozone layer.

UV penetration in New Zealand lakes

To find out how much UV enters New Zealand lakes we measured UV in 11 South Island lakes using special light sensors. At each lake we also collected water samples to measure how much DOM was in the water.

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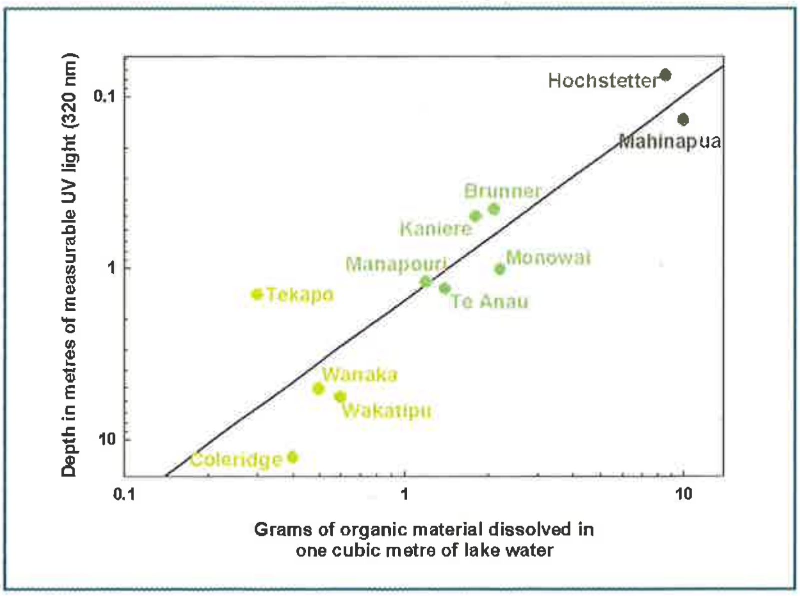
Water can be many different colours depending on what substances are in it and which colours of sunlight are being absorbed. Lake Wanaka (right, top) looks blue: water itself absorbs the red light and we see the blue – the colour least absorbed. Other water appears to be a tea-brown colour, like this river (right, below). Dissolved organic material (DOM) that comes mainly from decaying terrestrial plants absorbs a lot of the blue and violet sunlight. In these cases, the water itself is still absorbing red, and with the DOM taking out the blue and violet, a yellow-brown colour is left. The DOM is particularly effective at absorbing ultraviolet light.

We found a wide range of DOM concentrations and depths to which UV light travelled. As studies from other parts of the world have found, DOM is a very good predictor of the depth reached by UV in a lake (see graph below). Lakes with plenty of DOM (e.g., Lake Mahinapua) don't let much UV in, while those with low DOM (e.g., Lake Coleridge) are very transparent to UV.

We also calculated how much UV was absorbed by every gram of DOM in a cubic metre of lake water. We did this for each lake and compared the results with the type of vegetation growing on the land around the lake.

It turns out that one gram of DOM in forest lakes absorbs more UV than one gram of DOM in grassland lakes. This might be because the type of DOM is different in each of the lakes. Trees and grass probably break down into different types of DOM that absorb UV in different ways. From our data we don't know what type of DOM is in each lake, but determining this could be part of future research.

These differences hint to us that future changes to land use in lake catchments could alter the underwater UV environment. Such changes might arise through localised human impacts or larger-scale effects of climate change.



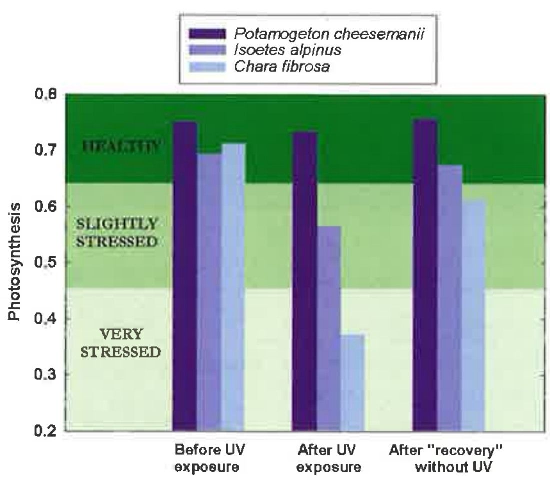
The graph (right) shows the deepest depth in each lake where we could still measure UV-B light (320 nm) compared to the amount of organic material dissolved in the lake water. The diagonal line shows the relationship between DOM and UV depth. A lot of DOM means UV is absorbed before it can travel very deep into the lake. The different colours for the symbols and lake names show what type of vegetation grows around the lake. Yellow lakes are surrounded mostly by grassland, light green lakes by about equal parts of grassland and forest, and dark green lakes mostly by forest.

UV effects on plants in New Zealand lakes

Our measurements of DOM and UV show that some New Zealand lakes have very low natural protection against UV. This means that in some lakes, organisms such as aquatic plants live with UV in their environment. How do these plants react to UV? If the UV in the lake increases, will they be harmed by it?

To find out, we did some experiments at NIWA's laboratory in Christchurch. Several common plant species from Lake Coleridge were exposed to artificial light from lamps. We tested the plants under two conditions: exposure to light without UV and to light with UV. During the experiments we measured plant photosynthesis – an indicator of whether a plant is healthy or stressed.

The plants reacted in different ways: some were very stressed by the UV and others weren't at all. For example, *Potamogeton* showed no evidence of stress when it was exposed to UV (see bar diagram below). *Isoetes* was stressed by the UV but recovered when we turned the UV lamps off. The UV particularly stressed *Chara*: even after 20 hours without UV the plants were still under stress.



This bar diagram shows the photosynthesis of three aquatic plants during experiments when they were exposed to UV light. The first group of bars shows that all three plants were healthy at the start of the experiment. The second group shows that after 5 hours of UV light one plant is still healthy but the other two are under stress. The third group shows photosynthesis after the plants were left for 20 hours with the UV lights turned off – one plant did not completely recover.

Underwater plants grow in many of New Zealand's lakes and provide important habitat for other organisms. This photo shows Myriophyllum, *a water milfoil (feathery plants), and* Isoetes, *an aquatic fern (spiky shoots). The black dots are snails* (Potamopyrgus).

Chara typically grows deeper in lakes than *Potamogeton* and *Isoetes*. It might be that *Chara* can't grow in shallower areas because it is unable to deal with or adjust to the stress of more UV.

These experiments have given us a first indication of how plants from lakes react to UV.

Key findings

Our work has demonstrated that:

- UV light can penetrate to depths where organisms live in several New Zealand lakes;
- by providing DOM, vegetation growing in the lake catchment plays a key role in how deep UV will travel in the lake;
- some aquatic plants can deal with exposure to UV, but for others UV light acts as an environmental stress, causing them to decrease their photosynthesis.

Thus, changes to the vegetation growing around a lake could alter the extent of UV effects on life in the lake. Decreased photosynthesis by the plants as a result of UV stress could ultimately have repercussions all the way through a lake food web. ■

Rowena Rae, Ian Hawes and Clive Howard-Williams are based at NIWA in Christchurch. Dieter Hanelt is at the Alfred Wegener Institute in Bremerhaven, Germany, and was a visiting scientist at NIWA in February 2000 when some of this work was done.

Acknowledgments

Our thanks to Greg Kelly for creating the figure of the various wavelengths put out by sunlight. While working at NIWA, D. Hanelt was partly funded by the International Science and Technology Linkages Fund between New Zealand and Germany. The research was funded by the New Zealand Foundation for Science, Research and Technology.

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OCEANOGRAPHY

Are there more fish in the Front?

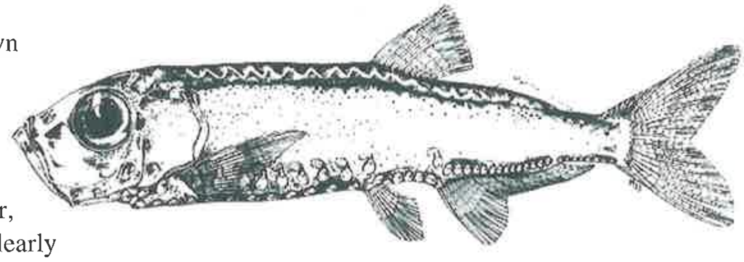
Sam McClatchie

Roger F. Coombs

Gavin Macaulay

Underwater acoustic techniques are helping to unravel part of the complex story of which creatures live where in the ocean.

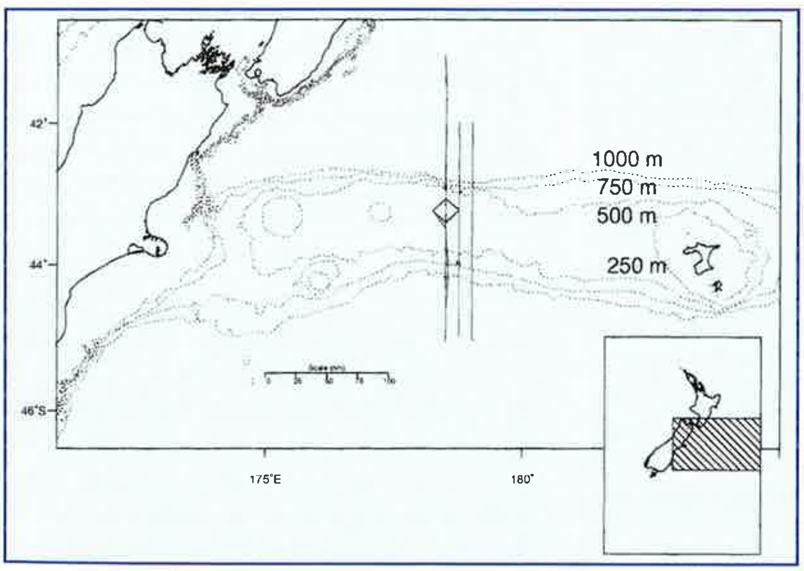
ROUGHLY TWO-THIRDS of the way down the Southern Hemisphere a major oceanographic feature – the Subtropical Front – circles the globe. This boundary separates warmer, more saline, nutrient-rich Subtropical Water from cooler, fresher, nutrient-poor Subantarctic Water. It is clearly visible in satellite images of sea-surface temperature.



*Pearlside (*Maurolicus mulleri*) – one of the small fish species that probably plays an important role in the ecosystem of the Subtropical Front over Chatham Rise. (Re-published from Weitzman (1974).* Bulletin of the American Museum of Natural History 153, *with author's permission.)*

The northern margin of the Chatham Rise – the shallow area to the east of New Zealand – coincides with the northern edge of the Subtropical Front. Many scientific studies have focused on the Chatham Rise and some of the work carried out by NIWA has been reported in past issues of *Water & Atmosphere*.

Ocean fronts are often areas where pelagic (open-ocean) fish and their prey are concentrated. This could mean that they are zones of high biological production, with especially rich growth of microscopic plants (phytoplankton) and animals (zooplankton). We already know that the Subtropical Front over the Chatham Rise is a region of marked biological variability. However, little is known about the distributions of zooplankton and small mid-water fish across the Front. This article summarises some recent work that investigated the question: "Are there more fish in the Front?"



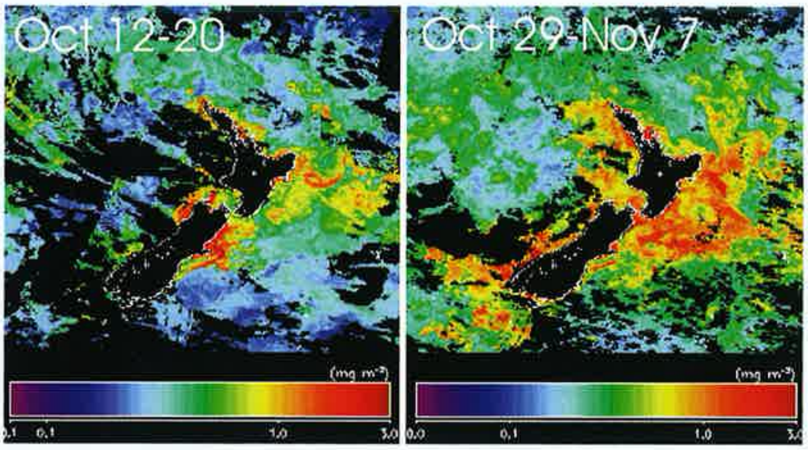
Map of the Chatham Rise underlying the Subtropical Front showing the ship transects (solid lines) analysed for acoustic backscatter during two voyages.

Echoes to measure fish

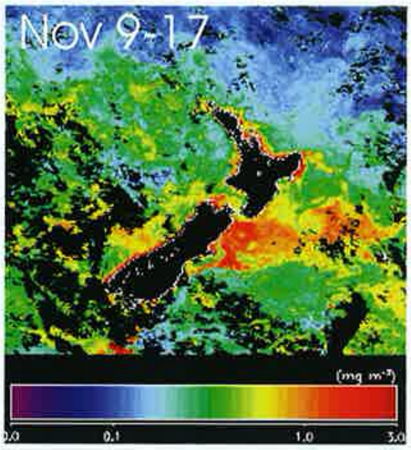
Acoustics provides a powerful tool for measuring the distributions of fish and zooplankton in the oceans. The technique involves sending out sound waves under the water. We then use the acoustic echo intensities scattered back towards a sensor (called acoustic backscatter) to deduce the biological mass of organisms in that area (see *Water & Atmosphere* 4(1):13–17).

The investigation was carried out during two research voyages during 26 September–15 October 1997 and 3–20 November1999. Data were collected along two types of transect:

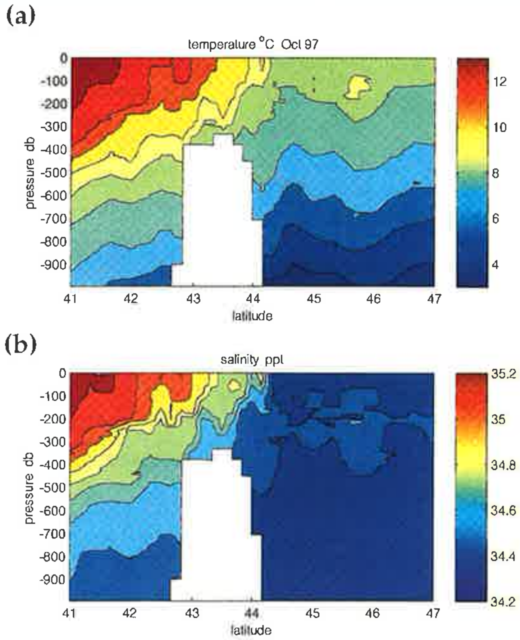
- large-scale north–south transects across the Front; these were used to define the location of the Front from conductivity–temperature–depth (CTD) sections, as well as to generate the acoustic data; surface-water chlorophyll *a* (a useful measure of phytoplankton concentrations) was also determined;
- small-scale repeated passes on a diamond-shaped area with sides 15 nautical miles long, on the crest of the Chatham Rise in the frontal zone; these allowed us to test how acoustic measurements varied over the time taken (36 hours) to complete each large transect.



above:
Eight-day composite images of ocean colour from SeaWiFS sensor for 12–20 October 1997 and 29 October – 7 November 1997, illustrating that the spring phytoplankton bloom developed only after the end of the research voyage on 15 October 1997.



above right:
Eight-day composite images of ocean colour from SeaWiFS sensor for 9–17 November 1999. Note that the spring bloom is well developed.



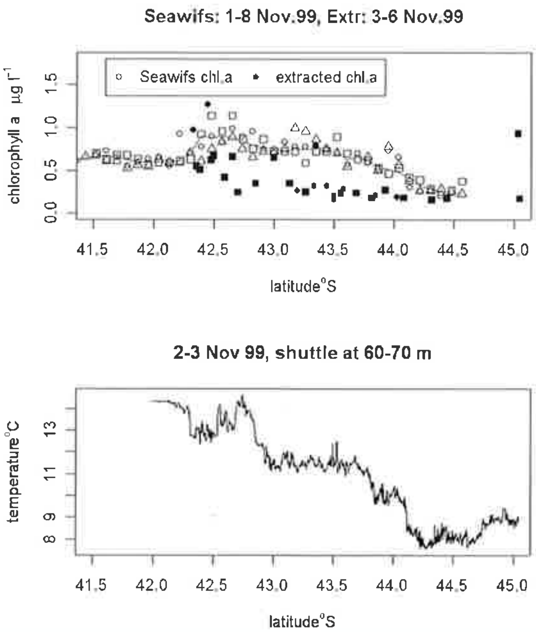
right:
CTD section across the Subtropical Front along 178° 30′E on 27–30 September 1997; (a) temperature. (b) salinity.

Satellite-generated ocean colour and sea-surface temperature (SST) images during the period of the voyages were used to place the transect data in a more regional context.

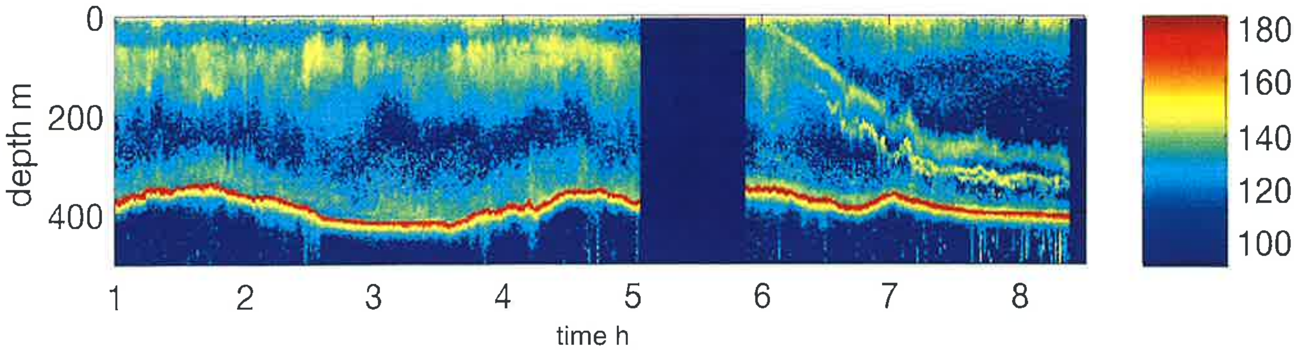
Seasonal differences

Results from the CTD sections showed – not surprisingly – that the water structure differed between the two voyages. Because the November 1999 section was taken about one month later in the season than the 1997 section, we expected, and found, evidence of seasonal surface warming in the 1999 data. The pattern of chlorophyll *a* concentration in the frontal zone also differed slightly between the two voyages.

Chlorophyll *a* can also be inferred from satellite data on ocean colour (see article on pages 17–18 of this issue). The satellite images above illustrate an important difference between the two sampling times. During the 1997 voyage, the spring bloom had not really developed until the voyage was over. The November 1999 voyage occurred when the spring bloom was well developed. (For more on the spring bloom, see *Water & Atmosphere* 8(3):11–12.) The graph (left) shows that the satellite-derived chlorophyll *a* was slightly higher than chlorophyll measured from water samples.



left:
Ocean colour data from the SeaWiFS satellite sensor provides a high-resolution transect of chlorophyll a *across the Front, showing generally higher chlorophyll to the north, with a peak on the northern margin of the Front (compare with the rapidly changing temperature signal in the bottom panel). Comparison of the SeaWiFS chlorophyll with extracted chlorophyll from water samples indicates a difference of about 0.5 mg/l.*



Acoustic backscatter at the small-scale transects on the crest of the Chatham Rise, 9 October 1997, 01:00–08:30 h. Colours represent different echo intensities with orange-to-red being strongest. Note the dawn descent of mid-water fishes. The solid blue band is a gap in the data due to rough weather.

A trend in chlorophyll *a* increasing to a maximum near the northern margin of the Front is evident in the satellite data.

Acoustic backscatter

What did our acoustic backscatter data tell us, against this background data about water structure and chlorophyll *a*?

First, the acoustic signals at both the small and large scales showed that regularly, at dawn, something descended rapidly from near the surface to around 350 m deep. The descents were too fast to be large krill. Net tows in the area collected small numbers of mid-water fishes, mainly pearlside (*Maurolicus mulleri*) and other small fish known as myctophids. We believe that these small fish caused the scattering.

For the large transects across the whole frontal zone, there were different patterns of acoustic backscattering in 1997 and 1999. In 1997 there was no obvious change in backscattering across the Front. In 1999 acoustic backscatter was much higher in Subtropical Water than in Subantarctic Water. There was no evidence in either year of more acoustic backscatter in the Front itself.

Are there more fish in the Front?

The answer seems to be "no". However, the acoustic data do indicate that there are more forage fishes and zooplankton in the Subtropical Water to the north of the Front, depending on the seasonal development of the plankton.

We find these results surprising for two reasons.

First, results from other NIWA research programmes, and from ocean colour images, have shown enhanced phytoplankton production in the Front. We might expect more zooplankton and zooplankton-eating fishes in areas where there is most zooplankton food (like phytoplankton), though many zooplankton in the Front eat microzooplankton (which are microscopic animals), not phytoplankton. However, other factors may outweigh the benefits of simply staying where the food is.

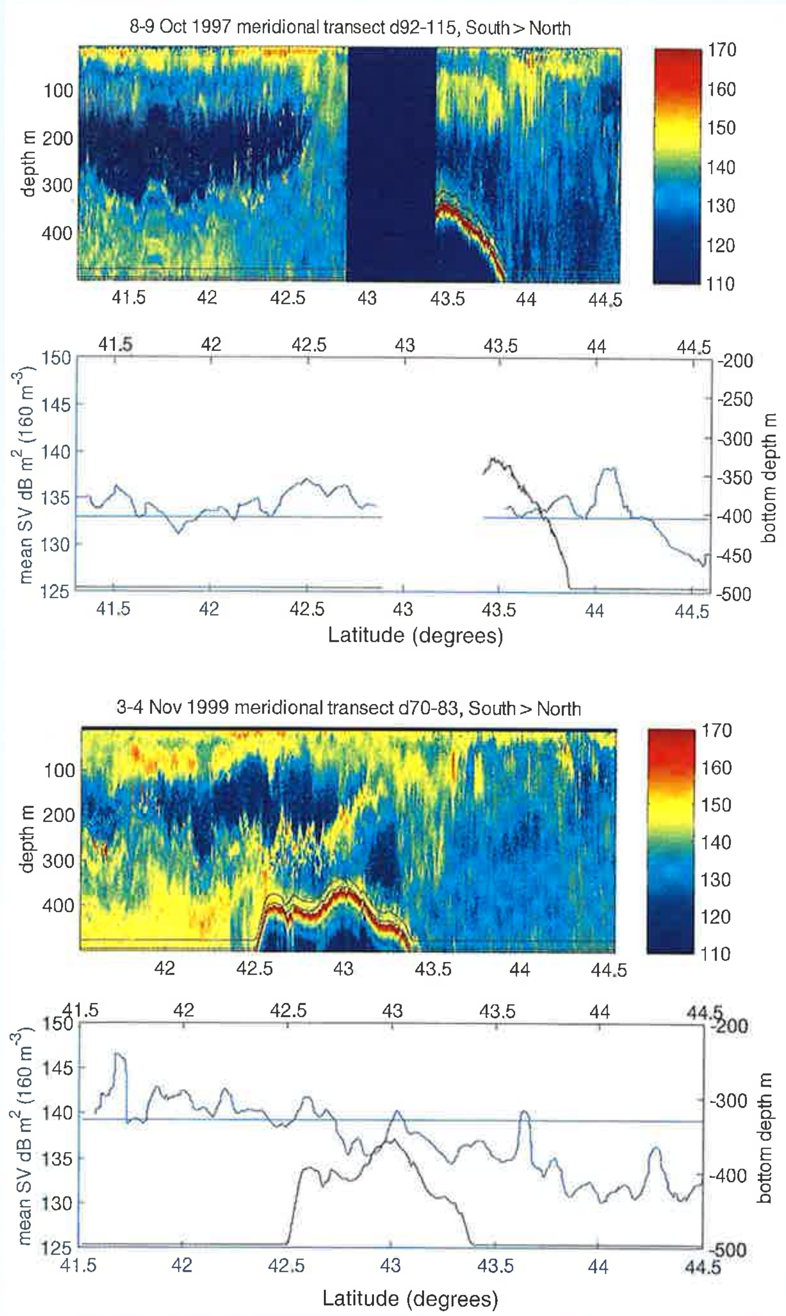
Second, other studies have demonstrated concentrations of pelagic fishes (especially tuna species) and their prey at fronts. However, these concentrations tend to be in smaller fronts, such as those on the edges of oceanic eddies. Localised water flows allow small fronts to accumulate debris and plankton, which then attract free-ranging predators like tuna. This does not seem to happen in the Subtropical Front.

Other studies

Our results – higher biomass in Subtropical Water to the north of the Front – agree with earlier work by NIWA. However, Russian researchers working east of the Chatham Islands concluded that biomass was higher in Subantarctic Water, to the south of the Front.

Why the interest in where fish live?

APART FROM the commercial fishing aspect, we are concerned about where fish and other marine organisms live because growth of animals (and plants) in the ocean consumes carbon, which ultimately comes from atmospheric carbon dioxide. Zones of higher production in the ocean can be sinks for carbon dioxide. The rate of transfer of carbon between different parts of the atmosphere and oceans affects the climate system.
Consequently, our research on how and where the production of the ocean varies is directly related to understanding the forces of climate change.



Acoustic backscatter along a large-scale north-south transect across the frontal zone overlying the Chatham Rise on (a) 8–9 October 1997 and (b) 3–4 November 1999. The top graphs are the raw "echograms", with the sea bed indicated by the thick red line. The lower graphs represent the average backscattering calculated from the echogram. Note how the 1999 backscattering falls going from north to south.

The work described in this article is part of the "Ocean Ecosystems" programme funded by the Foundation for Research, Science & Technology.

The conflicting conclusions could be a result of seasonal differences. The NIWA studies took place in spring and the Russian work was done in summer. In addition, the ecosystem structure east of the Chatham Islands may differ from that to the west, where the Front overlies shallower water. Australian studies showed no increased biomass of mid-water fish or zooplankton in the frontal zone, which supports our findings.

Maintaining biodiversity?

Earlier work has shown that the greatest number of hotspots in the biodiversity of semi-demersal (near-bottom) fishes was found on the northern margin of the Chatham Rise, to the north of the location of the frontal zone in this study. The coincidence of higher biodiversity of near-bottom fishes with higher biomass in the pelagic (open water) zone suggests that higher pelagic production on the northern margin of the Chatham Rise could be helping to maintain a diverse community of commercially valuable fish species in the bottom waters.

The vertical migration of midwater fishes so evident in our acoustic records is likely to be an important mechanism for transfer of energy and carbon between pelagic forage fishes and near-bottom predators. ■

Sam McClatchie, Roger Coombs and Gavin Macaulay are all based at NIWA in Wellington.

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OCEANOGRAPHY

Ocean colour offers new insights into New Zealand's upper-ocean ecosystem

Matt Pinkerton

Ken Richardson

Philip Boyd

Images of New Zealand's oceans from NASA's satellite show the beautiful – and complex – patterns of phytoplankton in the upper ocean.

REMEMBER sitting on the beach as a child and wondering why the sea was that gorgeous shade of blue? Well, thanks to the remarkable images produced by NASA's SeaWiFS (Sea-viewing Wide Field-of-view Sensor) satellite, we now know much more about ocean colour and how it relates to the ecosystem.

Anyone who has travelled by ship or aircraft, or walked along the coast, will know that the sea is a constantly changing pattern of blues and greens. Sometimes this is due to clouds moving over the sea surface, or sandbanks beneath the water. However, when the sea is deep and the sky is clear, the blue-green colour is related to the abundance of microscopic marine plants, called phytoplankton, in the water. Phytoplankton, like most plants, contains green pigments that absorb solar energy. Pure seawater is blue, and a mixture of the two is turquoise (although the exact colour depends on the concentration of phytoplankton).

The SeaWiFS satellite measures the intensity of different colours of light emerging from kilometre-sized squares of the sea. The ratio of green light to blue light tells us how concentrated the phytoplankton are in the first few metres of the ocean's surface. Images of the seas around New Zealand are collected every day, while an image of the entire earth's surface is built up every two days. Because satellites cannot see through clouds, many images over several days must be superimposed to give a single composite image in cloudy areas.

How much phytoplankton is out there?

Phytoplankton is the basis of the marine food web. These tiny plants use the sun's energy to convert atmospheric carbon dioxide into particulate organic carbon. Measuring the abundance of phytoplankton at both regional and global scales is vital if we are to understand the ocean–atmosphere carbon budget, marine ecosystem functioning, and global climate change. But how can remote sensing of ocean colour help?

The key point is that remote sensing allows us to gather unprecedented amounts of data in a very short time.

In one experiment, it took a survey ship six days to sample phytoplankton concentrations in an area of 30,000 square kilometres. An ocean-colour satellite instrument could measure the same thing in 20 minutes – and in more detail. A single SeaWiFS image contains more measurements of chlorophyll *a* concentration (the main pigment used by phytoplankton to absorb the sun's energy for growth) than previously collected throughout the history of oceanographic research.

The ability to map phytoplankton distribution over large areas is unique to remote sensing and complements traditional research methods. Images of chlorophyll *a* concentrations will help in the management of New Zealand's fisheries and, for those interested in climate change, will show how much carbon is held in the ocean as phytoplankton. The images can also be used to guide research ships to areas of interest and allow scientists to compare their measurements with the overall pattern of phytoplankton abundance.

Since 1 June 2000, NIWA has been receiving daily, full-resolution (1.1 km) SeaWiFS data around New

Past, present and future ocean colour sensors

The Coastal Zone Color Scanner (CZCS) was the first sensor to measure ocean colour from space. Its remarkable images of phytoplankton concentrations in the world's oceans between October 1978 and June 1986 led to some fundamental insights into marine ecosystems, such as how, in spring, phytoplankton forms enormous blooms in the North Atlantic. The new generation of satellite sensors, including SeaWiFS, estimates chlorophyll *a* concentration much more accurately than CZCS but may still have errors of ±50%. In addition to chlorophyll *a* concentration, SeaWiFS estimates the total concentration of pigments in the plankton and the rate at which light is absorbed in the ocean.

Other ocean-colour sensors include: a Japanese Space Agency instrument, which operated for almost one year during 1996–97; a sophisticated NASA sensor called MODIS (Moderate Resolution Imaging Spectroradiometer) that began operation in May 2000; and MERIS, the European Space Agency's instrument scheduled for launch in July 2001.

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Zealand using a satellite dish in Wellington that tracks the satellite as it passes overhead. NIWA will provide researchers with the appropriate tools to interpret and analyse the data beyond just pretty pictures. NASA allows only registered users to use the data, however, registration is straightforward – contact the authors of this article for help.

NIWA scientists have also been investigating ways to improve the quality of information from satellites. How can we measure ocean colour from space more accurately? What information can we gather from this about the components of sea water?

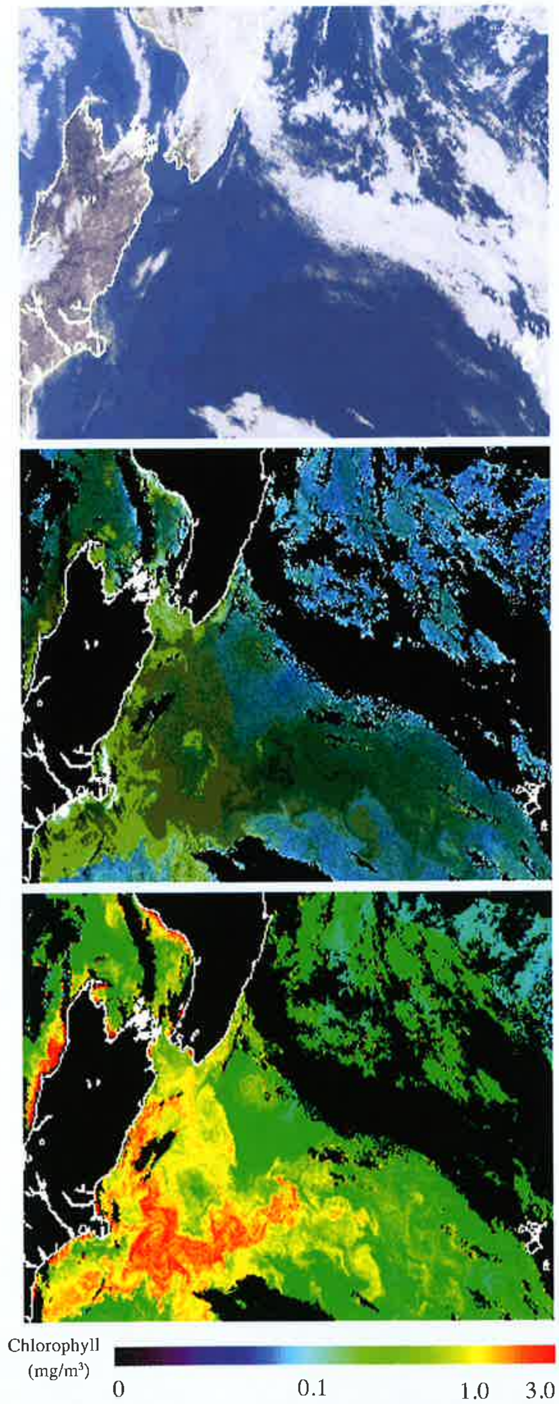
Atmospheric correction

On a sunny day the sky appears blue when you look up because light is scattered by the atmosphere. For a satellite looking down from space, a dusty haze obscures the sea. This means about 90% of the light seen by the satellite comes from the atmosphere and not the ocean, so getting the correction right is vital. Microscopic particles suspended in the air – soot, dust, tiny salt crystals from sea spray, or clusters of molecules released from the sea – are called aerosols and they have a big impact on the scattering of light in the atmosphere. Estimating their scattering effect is not easy! Even though SeaWiFS uses advanced techniques to correct satellite pictures for atmospheric scattering, the measurement of ocean colour is still not exact.

Using ocean colour data

Once we have corrected the measurement of ocean colour for atmospheric scattering, the next step is to relate the colour of the sea to the concentration of chlorophyll *a* using a set of mathematical calculations – a bio-optical algorithm. SeaWiFS uses the same chlorophyll *a* algorithm all over the world, even though the relationship between chlorophyll and ocean colour changes with location and season. Researchers at NIWA are working on modifying the SeaWiFS bio-optical algorithm so that it works better in New Zealand waters. They have been measuring ocean colour together with chlorophyll *a* concentration on various research voyages since 1997 to develop local algorithms.

Special algorithms need to be developed for situations where phytoplankton alone does not determine the colour of the water. For example, suspended sediment near the coast can make the water look brown, and some phytoplankton species, such as coccolithophores, have tiny, white calcium plates that turn the water milky.



High-resolution (1.1 km) SeaWiFS data received by the NIWA satellite-receiving station on 31 March 2000 showing an enormous phytoplankton bloom over the Chatham Rise.

top:
The view from the top of the atmosphere.

middle:
The colour of the sea after removing light which was scattered by the atmosphere.

bottom:
Surface chlorophyll a *concentration (in mg/m^3) estimated using a bio-optical algorithm.*

(Data used courtesy of the SeaWiFS Project, NASA/ Goddard Space Flight Center and Orbimage)

NIWA scientists are also working on new algorithms to interpret ocean colour data by determining how underwater light is absorbed and scattered at different wavelengths. The concentrations of material in the water can then be calculated using mathematical models specific to different oceanographic regions around New Zealand. This opens up exciting new research possibilities. Ocean-colour remote sensing may soon be able to accurately measure the growth rate of phytoplankton, spot harmful algal blooms before they affect fisheries, and estimate how much carbon dioxide is transferred between the atmosphere and the ocean. ■

Further information

SeaWiFS home page: http://seawifs.gsfc.nasa.gov/SEAWIFS.html

MODIS home page: http://modarch.gsfc.nasa.gov/MODIS/modis_front.html

Matt Pinkerton and Ken Richardson are based at NIWA, Wellington. Philip Boyd is based at NIWA, Dunedin.

COASTAL PROCESSES

Shifting sands: using image analysis and laser technology to study coastal sand dispersal

Andrew Swales

Terry Hume

John Hawken

Rick Liefting

Mark Cullingford

Rapid and detailed analysis of sand particles using image analysis and laser technology is providing new insights into our knowledge of sand dispersal along the black sand beaches of the North Island's west coast.

A black-sand dune-beach system at Whatipu Beach at the north head of Manukau Harbour. View looking north towards the pocket beaches of Karekare, Piha and Te Henga.

EVERY DAY, waves and currents shift thousands of tonnes of sand back and forth along the west coast of the North Island. This sand, either eroded from the land or swept from the seabed, has been sorted and transported during the past 6000 years or so since the sea reached its present level to form the coastal landforms that we see today.

The size and shape of individual grains of sand provide important clues about the physical changes that transform these particles and the way they are dispersed along the coast. A current NIWA research project is using state-of-the-art technology to determine large-scale patterns of sand dispersal on the North Island's west coast.

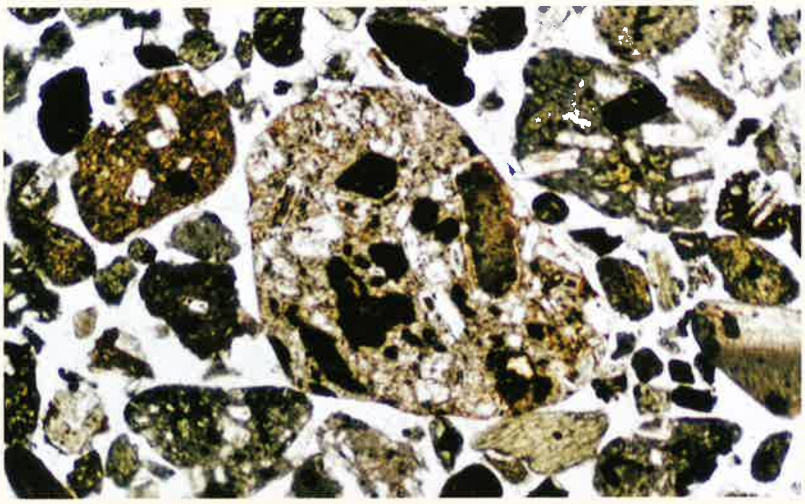
Map of North Island west coast showing locations where cores of sand were taken from the beaches, and analysed for shape characteristics.

Sands on the west coast

The 750-km of shoreline between Taranaki and Cape Reinga on the west coast of New Zealand's North Island is well known for its black-sand beaches and rugged, varied coastal landforms. In some places there are long straight beaches like Ninety Mile Beach in the north. Elsewhere, small pocket beaches like Piha are tucked between headlands. Large banks of sand accumulate as deltas at the mouths of harbours.

The sands vary in colour from black in the south to lighter colours farther north. Black sand – or ironsand – comes mostly from Mount Taranaki, which is an andesitic (explosive) volcanic centre. Its black colour is due to small grains of titanomagnetite which is a magnetic iron ore. Lighter-coloured sand comes from sources such as the Waikato River. This sand derives from the rhyolitic (lava producing) Taupo volcanic centre and is rich in lighter-coloured minerals such as quartz and feldspar. It also contains some black mineral grains such as hornblende and augite. Different mineral types each have their own characteristic hardness, density and crystal structure, and abrade at different rates.

Physical abrasion of sand particles alters their size and shape characteristics as they are dispersed along the shore. In general, particles become smaller and more rounded during transport. Quartz, for instance, is very hard and the grains



left top: *Thin-section micro-photo of sand particles from a Taranaki beach, composed of rock fragments and individual crystals. Note the black octahedral titanomagnetite crystals in the large rock fragment which is typical of the grains close to their Mt Taranaki source (photo centre).*

left below: *Thin-section micro-photo of sand particles collected at Mokau. Farther away from the Mt Taranaki source the soft titanomagnetite particles are rounded while the harder augite particles (olive-green) retain their original elongate crystal shape. (photos: Jason Laurent, University of Waikato)*

stay angular even after travelling long distances. Magnetite is soft and the grains get smaller and rounded after travelling short distances. By measuring differences in particle size and shape of different minerals and mapping these, we can learn more about the processes of sand dispersal and storage along the coast.

The problem measuring differences in particle size and shape is that sand particles are so tiny. To measure the size and shape characteristics of large numbers of individual sand particles by hand would be a daunting task. This is where the new image analysis and laser technology of the Galai comes to our aid.

Galai instrument system

The Galai is a sophisticated instrument system that uses laser-based measurements to determine particle size and image analysis to determine particle shape.

Particle size (diameter) is taken as proportional to the time for individual particles to transmit a narrow beam of laser light. The laser system counts large numbers of particles, as many as 1 million in 10 minutes. The system can distinguish measurements of single particles from several particles clumped together. Particle size distribution can be resolved into as many as 600 size classes and over a broad size range (0.5–3600 μm).

Shape analysis is carried out by measuring large numbers of particles in many different orientations to build up a picture of the three-dimensional variability in particle shape. The system includes a high-resolution digital video camera, microscopic lenses and powerful software. The software can be customised, for example, to ignore smaller silt particles. Once processed, each particle can be described using a wide range of parameters, such as diameter, perimeter, surface area, aspect ratio (relative lengths of sides), sphericity and shape factor (particle surface smoothness). These statistics are used to distinguish various types of particles from each other.

Beach sand census

We used the Galai to analyse 150 sand samples collected from beaches on the coast between the Patea River mouth and Cape Reinga.

If you dig a hole in a west coast beach you'll often see layers of dark and light sand. The layers are made by wave action sorting sand particles according to size and density, so that the heavier ironsand separates from lighter quartz particles. So, to get a composite picture of the sand composition on each beach, we collected short cores of sand that intersect these different layers. All the samples were collected from the mid-tide level on the beaches where the sand is moved daily by the wind and sea.

Some samples had to be sorted by hand, to confirm our idea that sand particles of different minerals really do have distinctive size and shape characteristics. To do this, sand samples collected at eight sites between Waitara (Taranaki) and

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Bayleys Beach (near Dargaville) were split into their main mineral components before being analysed using the Galai. This calibration comprised preparing 100% pure mineral splits of particles using magnetic separation and finally a laborious hand-picking of some 1000–5000 grains of each mineral under a microscope.

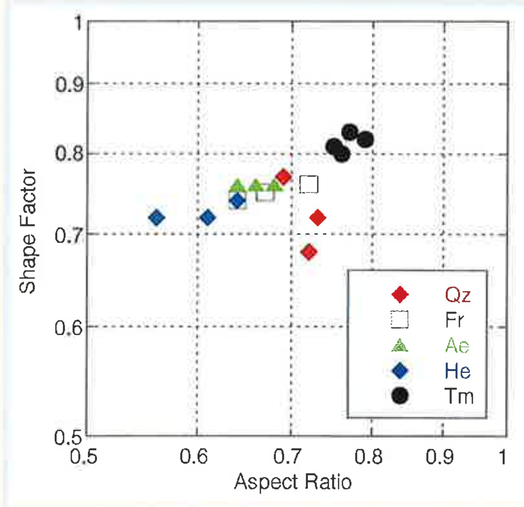
Promising results from Galai analyses

Initial results from Galai analyses of west coast sands show clear distinctions in the size and shape characteristics of different mineral sands from different parts of the west coast. For example, the ironsand particles in the sands from Bayleys Beach are characteristically much smaller (less than 200 μm diameter) than quartz (200–400 μm). Also, the ironsand particles are more spherical than quartz.

Using various shape factors it is possible to identify and measure the differences in shape of different mineral types. Hornblende particles, for example, are elongated in shape compared to magnetite particles, which are spherical. Feldspar and augite particles are intermediate in shape between ironsand and hornblende, but can be distinguished by their size.

The results confirm that the Galai instrument system can rapidly measure differences in the particle size and shape characteristics of different minerals that make up the west coast sand beaches. In other words, we now have a relatively easy way of measuring the size and shape signature of individual sand particles and of counting very large numbers of very small particles. This gives us robust statistics on the sand properties of different beach types. The size and shape signatures reflect both mineral type and rock source, and their history of abrasion and dispersal along the coast. We can use the Galai to track the changes in the shape of ironsand particles from their octrahedral form, which they have close to their Mount Taranaki source, to their distinctive spherical shape farther north as they are abraded during transport.

The Galai has already been used to map the distribution of different sand sizes along the west coast. Now that we have successfully developed a methodology to measure and calibrate particle shape, we will map the way different types of minerals abrade as they are dispersed along the black sand beaches of the west coast. ■



Aspect ratio and shape factor characteristics of common beach-forming minerals found on the west coast. Key: quartz (Qz), feldspar (Fr), augite (Ae), hornblende (He) and titanomagnetite (Tm). Note how the "aspect ratio" clearly separates the rod-shaped crystals of hornblende from the spherical grains of magnetite, while the "shape factor" separates angular crystals of quartz from rounded magnetite.

This research is being undertaken as part of NIWA's FRST-funded programme "Natural Physical Hazards Affecting Coastal Margins and the Continental Shelf" (C01X0015). You can see associated web pages at www.niwa.co.nz/pgsf/COSMOS/ and www.niwa.co.nz/pgsf/CASHCANZ/

Galai instrument system for particle size and shape analysis.

Andrew Swales, Terry Hume, John Hawken and Rick Liefting are based at NIWA in Hamilton; Mark Cullingford is an Earth Sciences student at the University of Waikato.

ATMOSPHERIC RESEARCH

Antarctic ice: the world's air museum

Dave Lowe

David Etheridge

Air bubbles trapped in ice hundreds or even thousands of years ago are providing vital information about past levels of greenhouse gases in the Earth's atmosphere.

IT'S A FACT: the chemical composition of the atmosphere is changing rapidly, worldwide. Since the pre-industrial era, the concentrations of important greenhouse gases (see panel) have all increased significantly. NIWA maintains the longest continuous measurements of atmospheric carbon dioxide (CO_2) in the Southern Hemisphere at Baring Head (see *Water & Atmosphere* 8(1):14–16). In the 30 years since measurements began there, atmospheric CO_2 has increased by about 15%.

But even the longest available dataset for atmospheric CO_2 goes back less than 50 years. So how do we know how CO_2 concentrations were changing before this? And what were the levels of greenhouse gases in the atmosphere before emissions from modern industry and agriculture started to change things?

Drilling for ice

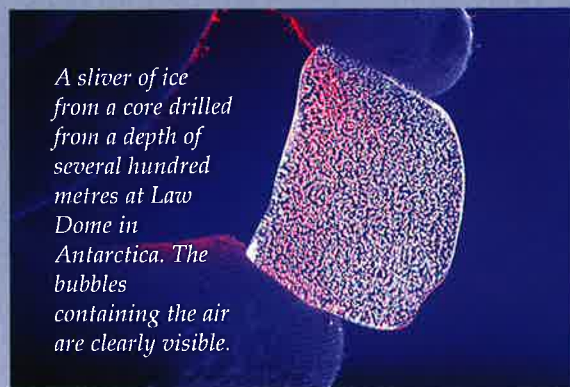
Fortunately, over 20 years ago, scientists made an important discovery. Near the surface of ice sheets, snowfall eventually turns into ice containing air trapped in tiny bubbles (above, right). This ice provides a remarkable museum of the chemical state of the atmosphere.

The most successful investigations so far have been at the polar ice caps. Here, snow traps air in the firn, a permeable surface layer about 40–100 m thick. As more snow falls, the firn is buried deeper and deeper until it is compressed into solid ice, with the trapped air enclosed in bubbles. Layer after layer of ice is built up, burying in the ice cap a history of past atmospheric composition. Because the ice is both impermeable and inert, it is a remarkably good storage container for many of the important gases in air.

To retrieve this atmospheric information, researchers drill into the ice cap and remove cores of ice. The cores are kept frozen until the air trapped in them can be analysed.

Methane increases over 1000 years

Australian researchers have been particularly successful with cores extracted from Law Dome, an ice cap 200 km across and up to 1200 m thick

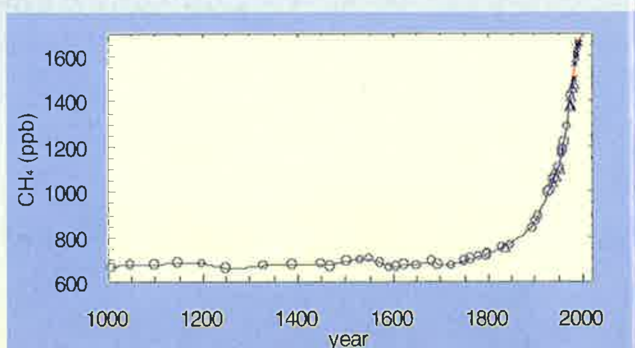


A sliver of ice from a core drilled from a depth of several hundred metres at Law Dome in Antarctica. The bubbles containing the air are clearly visible.

near the coast of the Australian Antarctic Territory. This area was especially suitable because of its rapid ice formation and very cold temperatures, averaging –20°C. Fast ice formation means that trapped air bubbles cover a shorter time span. Changes over as little as 10 years can be detected. Also, the most recent air available is quite young, allowing comparison with modern atmospheric measurements.

The ice cores on Law Dome extended right down to the bedrock. At this depth the trapped air is over 1000 years old.

Analysis of the methane (CH_4) content of the trapped air (below) shows small variations in atmospheric methane since 1000 AD. However, from 1800 to the present atmospheric methane has



Atmospheric methane over the last 1000 years. The plot shows small variations in atmospheric methane during the natural climatic events: the medieval warm period (1000–1300 AD) and Little Ice Age (1550–1800 AD). These contrast with the dramatic increase in methane over the last 200 years. The blue symbols are measurements from ice; the red line at the end of the record is from recent atmospheric measurements from Cape Grim, Tasmania. (Adapted from Etheridge et al. *1998.* Journal of Geophysical Research *103(D13): 15,979–15,993.)*

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more than doubled. This dramatic rise has been caused by increased emissions associated with human activity.

A different climate

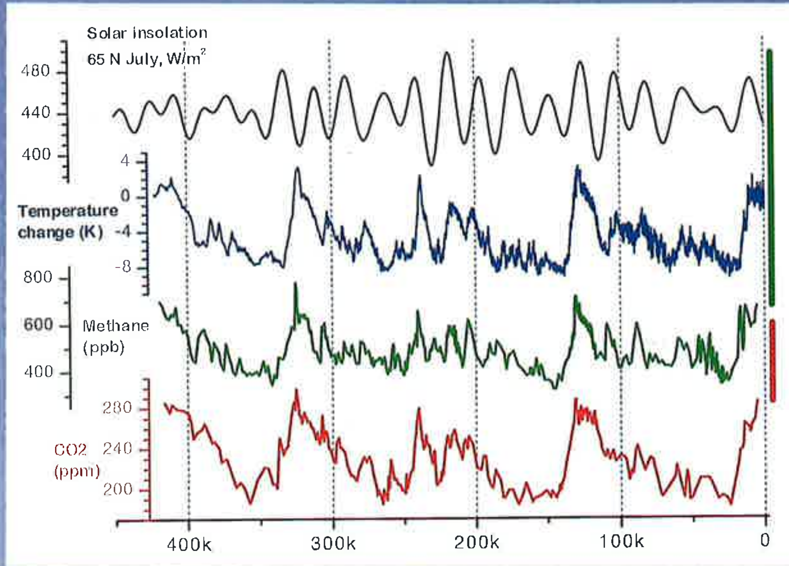
We currently live in a warm inter-glacial period known as the Holocene, which has lasted about 10,000 years. Before this, the earth was gripped in glaciation for about 100,000 years. Temperatures averaged 10–15°C cooler than today and ice sheets were much more extensive. How did the atmosphere change during these different natural climatic events?

The answer has come from an extraordinary series of ice cores drilled at Vostok, a Russian station in the remote centre of Antarctica. French, Russian and American scientists have worked together to produce a climate history from these cores, spanning over 400,000 years and covering four complete glacial and inter-glacial periods (see graph, right).

Atmospheric CO_2 and CH_4 data are clearly correlated with temperature through the record. We know that the climate changes were initially triggered by changes in the amount of solar radiation (insolation) reaching the earth due to wobbles in its orbit. The response of the greenhouse gases, however, was to feed back and amplify the temperature changes by a factor of about two. Nowhere in the over 400,000 years of record do the CO_2 or CH_4 concentrations approach today's levels. Current greenhouse gas levels, which have developed in only the last 200 years, mean that the world now faces a climate different from anything during the last 400,000 years.

Greenhouse gases and predicting climate change

Greenhouse gases – mainly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) – make up a relatively small proportion of the earth's atmosphere. However, because they absorb strongly in the infrared part of the solar spectrum and retain heat, they play a significant role in the radiation balance of the earth and hence its climate. Increases in their concentration are viewed with concern, and intense international activity is focused on predicting the consequences of changing atmospheric composition and its impact on the earth's climate. Many of these studies are based on the use of global climate models to predict, for example, the effects of doubling atmospheric CO_2. The models use measurements of greenhouse gases as input data but are restricted because data are needed over long time periods for long-lived gases like CO_2.



Simultaneous records of solar radiation or insolation, temperature, and atmospheric CH_4 and CO_2 concentrations over the last 400,000 years derived from Antarctic ice at Vostok. The parallel changes in CO_2 and CH_4 are believed to have caused about half the amplitude of the temperature changes, with the other half probably due to changes in solar insolation. Today's levels are indicated by the solid lines at the right-hand side. (Adapted from Petit et al. 1999. Nature 399: 429–436.)

Isotopes, gas measurements, models

A joint NIWA/CSIRO project is currently measuring air extracted directly from the Antarctic firn layer to look at sources of atmospheric methane over the last 100 years. NIWA has used isotopic techniques to distinguish different sources of methane (see *Water & Atmosphere* 5(2): 16–17). Levels of the naturally occurring radioactive isotope carbon 14 in methane, for example, can indicate whether the methane is derived from fossil fuels or from natural sources like swamps. Already the work has shown that 60 years ago up to 15% of atmospheric methane was derived from fossil sources.

The study of atmospheric greenhouse gas records in Antarctic ice will clearly provide a large amount of information about past climatic changes. However the data are also essential for testing how well global climate models can simulate observed climate change in the past.

The study of air bubbles trapped in Antarctic ice goes hand in hand with measurements of current greenhouse gas levels and the development of climate models to predict the future state of the atmosphere.

All three kinds of research are currently being carried out by NIWA and CSIRO. ■

Dave Lowe is based at NIWA in Wellington; David Etheridge is at CSIRO Atmospheric Research, Aspendale, Victoria, Australia.

The FRST programme funding this work is "Greenhouse Gases and Climate Change", C01X0034

ATMOSPHERIC RESEARCH

Our oceans: major players in CO_2 exchange

Mark Hadfield

Bill Allan

Martin Manning

Kim Currie

We know phytoplankton removes CO_2 from the ocean's surface, preventing the emission of CO_2 into the atmosphere. But how good are we at modelling this process, and can our models be improved?

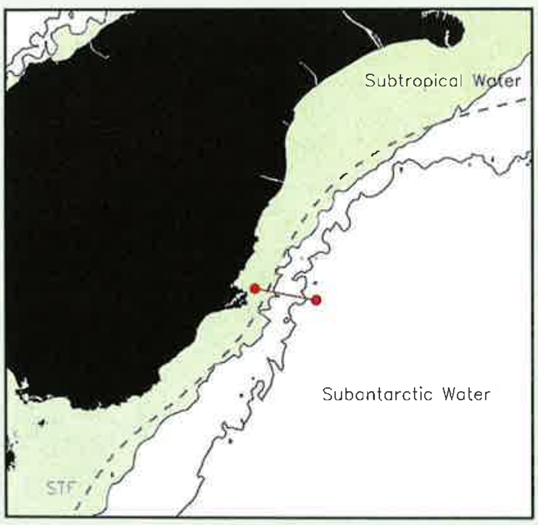
IN 1750, THE CONCENTRATION of carbon dioxide (CO_2) in the Earth's atmosphere was about 280 ppm (parts per million). Today it is more than 365 ppm – an increase of over 30% – and it is continuing to increase every year by 1.5 ppm. As a "greenhouse gas", CO_2 absorbs infrared radiation emitted by the earth, leading to increased surface temperatures. Many scientists believe this has caused, or will cause, changes in the climate.

The increase in atmospheric CO_2 is mainly due to the burning of fossil fuels like coal and oil. But not all the CO_2 generated by fossil-fuel burning stays in the atmosphere. What happens to the rest?

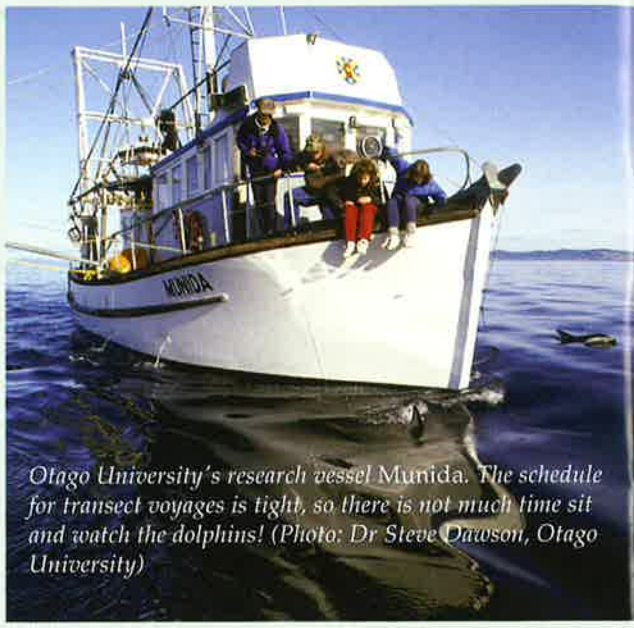
Global carbon budget is measured in PgC – or petagrammes of carbon – where 1 Pg equals 1 billion tonnes. According to current estimates, fossil-fuel burning releases 6 PgC every year. Land-use change, mainly tropical deforestation, adds another 2 PgC. Of the total of about 8 PgC, 3 PgC accumulates in the atmosphere, 2 PgC is taken up by the terrestrial biosphere, and 2 PgC is absorbed by the ocean. (The numbers do not balance exactly because they are estimates.) See *Water & Atmosphere* 8(1): 14–16 for more information on the active carbon cycle.

The ocean–atmosphere link

Clearly, the ocean plays an important part in the greenhouse gas picture. CO_2 is much more soluble in water than gases like oxygen or nitrogen, which is why CO_2 is used to make beer, soft drinks and sparkling wine fizzy. This high solubility means the total amount of CO_2 held in the ocean is huge – about 60 times that held in the atmosphere and about 20 times greater than the earth's biosphere. If people are going to continue releasing large amounts of CO_2 into the atmosphere, then we need to understand the processes controlling CO_2 exchange between the atmosphere and the ocean.



A map showing the Otago transect across the Subtropical Front. Depth contours are marked at 200 m (shaded green) and 1000 m.



Otago University's research vessel Munida. The schedule for transect voyages is tight, so there is not much time sit and watch the dolphins! (Photo: Dr Steve Dawson, Otago University)

The transfer of CO_2 through the ocean surface is driven by its "partial pressure" – that is, the pressure exerted by each element in a gas mixture. If the partial pressure of CO_2 (pCO_2) just above the ocean surface is larger than the partial pressure just below, then CO_2 is transferred from the atmosphere into the ocean (and vice versa if the partial pressure is reversed). This rate of transfer is affected by the ocean surface's resistance to gas exchange, which depends on wind speed and the state of the sea surface, particularly the presence or absence of breaking waves.

The rest of this article describes a project to measure and model atmosphere–ocean CO_2 exchange around New Zealand, concentrating on what happens near the surface. Another NIWA team is looking at the resistance of the ocean surface to CO_2 transfer (see *Water & Atmosphere* 8(3): 5).

CO_2 exchange around New Zealand

Over the last decade a lot of effort has gone into finding out the spatial and seasonal variation of pCO_2 in surface waters around the globe. New Zealand scientists can make valuable contributions in this area because of the country's position on the northern edge of the Southern Ocean, which has an important role in the global uptake of CO_2. The strong mixing between surface and deep water in the Southern Ocean means that CO_2 absorbed from the atmosphere is not available for further exchange at the ocean's surface.

For several years, scientists from the NIWA/University of Otago Centre of Excellence in Chemical and Physical Oceanography have been making regular measurements to determine the pCO_2 of seawater on a transect extending 60 km from the Otago Peninsula, across the Southland Front, and into subantarctic water. These measurements have already provided a picture of the seasonal cycle of CO_2 in seawater. Eventually we should also be able to detect year-to-year variations and trends.

A model of CO_2 exchange

NIWA scientists have also been developing and testing a model of CO_2 in the upper ocean to establish whether the observed patterns of pCO_2 variability match our understanding of the physical and biological processes influencing CO_2.

The layer immediately below the ocean surface is called the mixed layer because it is continually stirred by winds, waves and convection. The mixed layer is at its deepest in late winter, when the surface temperature is lowest. As spring progresses, the surface water warms and a new shallow mixed layer forms. This persists throughout the summer until autumn, when the surface cools, causing the mixed layer to deepen again. By the end of winter the mixed layer is at its maximum depth and the cycle is repeated.

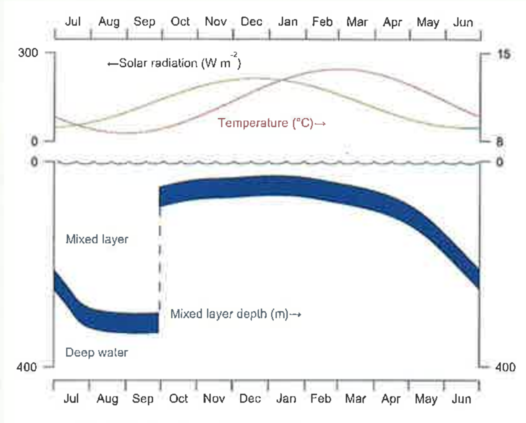
Biological processes can significantly affect this model. Like other plants, phytoplankton absorbs CO_2 to make plant tissue. When it dies, some of the carbon in its tissue is converted back to CO_2, while some sinks into deeper water. In winter, mixing brings nutrients into the mixed layer. However, because this layer is very deep, most of the phytoplankton don't have enough light. In summer, there is plenty of light, but because they are out of contact with the deeper water, the phytoplankton tend to run out of nutrients. In this model there is normally a burst of phytoplankton growth – the "spring bloom" – when the mixed layer becomes shallower in spring.

How good is the model?

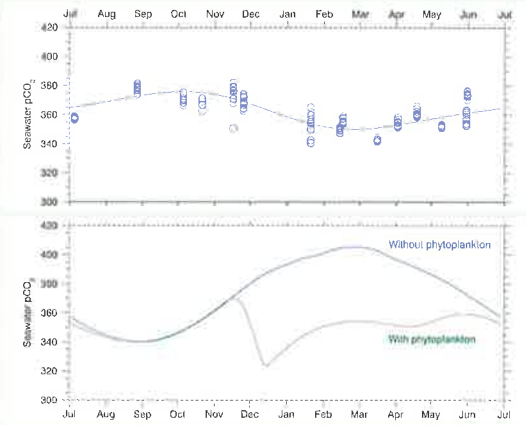
We compared the model results with measurements from the Otago Peninsula transect. On average, measured pCO_2 is highest in September and lowest in March. In the model, if we do not include the phytoplankton processes explained above, then we get the opposite result – that is, pCO_2 is lowest in late winter (October) and highest in late summer. Also, the model produces a range of pCO_2 values that is too large. If we include phytoplankton processes, then the model's seasonal variation in pCO_2 agrees better with the measurements, though pCO_2 in late winter is still too low.

To improve the model we need better measurements, and more information on the CO_2 content of the water below the mixed layer. And to improve our understanding of biological processes, we are currently expanding the range of chemical measurements made on the transect, including measuring the ratio of the stable isotopes ^{12}C and ^{13}C in the seawater CO_2. Phytoplankton growth tends to leave seawater slightly enriched in ^{13}C (see *Water & Atmosphere* 8(1): 14–16), and this factor can be incorporated into the model.

Time-series measurements in the ocean involve a lot of hard work, but the results are rewarding. The Otago Peninsula transect is already generating data to describe seasonal cycles in ocean chemistry. As this programme progresses, we will be able to describe these cycles in more detail and determine year-to-year variations. Using these measurements, and models of the processes involved, we hope to be able to relate these variations in chemistry to climatic changes. ■



The model's seasonal cycle: solar radiation peaks in mid-summer and sea surface temperature peaks a couple of months later. A shallow mixed layer forms in summer. As it deepens in the autumn and winter, it incorporates material from below. In spring a new shallow mixed layer forms.



The upper panel shows 2½ years of measurements from the Otago Peninsula transect (>50 km from shore) collapsed onto a single year. The solid line is the mean seasonal variation (estimated omitting unusual results from February 1999, shown in red). The lower panel shows modelled pCO_2 from versions of the model with and without phytoplankton.

Mark Hadfield, Bill Allan, Martin Manning and Kim Currie are all based at NIWA in Wellington.

MARINE GEOLOGY

Giant submarine avalanche: was this "Deep Impact" New Zealand style?

Keith Lewis

Jean-Yves Collot

About 170,000 years ago, a piece of seabed as big as the Coromandel Peninsula fell down a 3-km-high submarine scarp off the east coast, North Island. The giant avalanche then roared for 50 km out across the flat, abyssal ocean floor. Did it produce a giant tsunami? Could it happen again?

IN THE SOUTHERN ALPS, big landslides and rock avalanches can send hundreds of millions of cubic metres of mountainside crashing into the valley below. Huge ones may contain more than a cubic kilometre of debris. An ancient one in Fiordland involved about 26 cubic kilometres and may be the world's largest onshore landslide.

But marine geological surveys over the last decade have shown that submarine "landslides" can be much, much bigger than any on land. Lubricated by water, they can involve the catastrophic collapse of *thousands* of cubic kilometres of seabed.

New Zealand and French marine geologists recently discovered the debris of a truly awe-inspiring avalanche off the east coast near Ruatoria. The discovery posed questions, not only of "when?" and "how?", but also of "what are the risks of such events to coastal communities?".

Catastrophic events

Most people have seen slides on muddy hillsides after winter rains. The image that appeared on the French research vessel *Atalante*'s state-of-the-art "swath-mapping" monitor looked much the same, except for the scale. Instead of being a few hundred metres across, the slide off Ruatoria was 40 km wide and 100 km long. The top of the slide-scar is off the mouth of the Waiapu River near East Cape. The jumbled mass of debris at the toe extends 50 km out across the floor of the Hikurangi Trough, which is about as deep as Mt Cook is high. Within the broken rocks and mud are dozens of individual blocks larger than Mt Ngauruhoe. The largest block, which is near the front of the mass of debris, is the size of Mahia Peninsula.

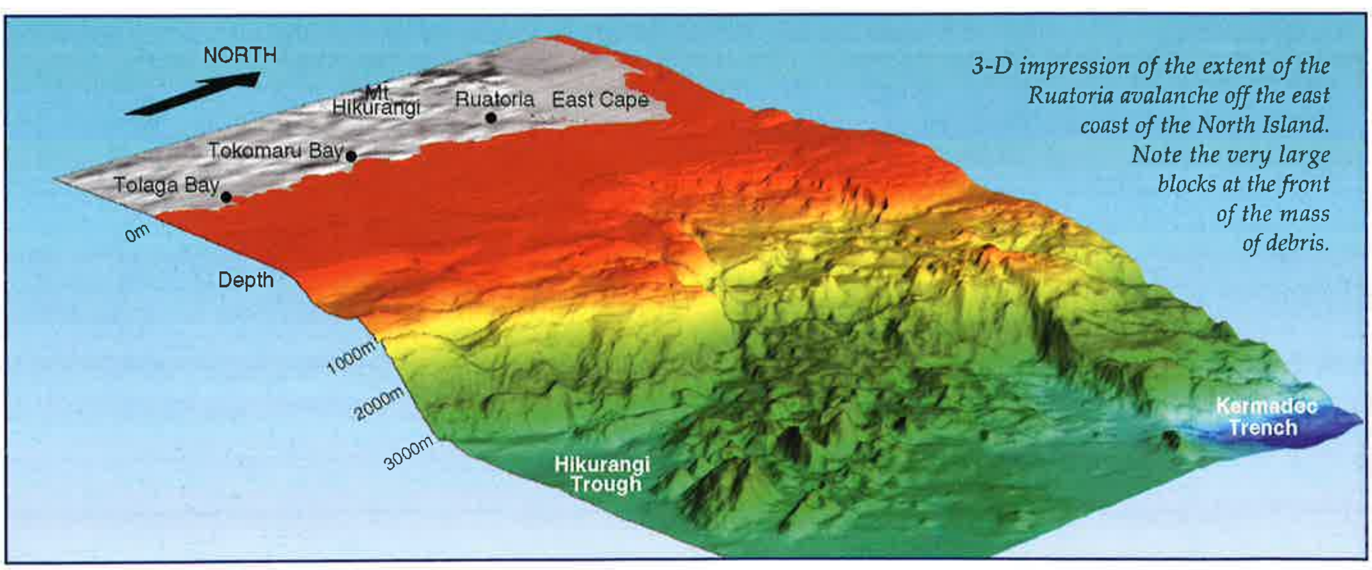
Imagine, for a moment, the Coromandel Peninsula suddenly cascading from the top of Mt Cook with sufficient velocity to carry it 50 km. You then get some idea of the enormity of the event. Even so, we know of bigger ones, including a Hawaiian slide that travelled 160 km. These were clearly catastrophic events. They were not creeping landslides: they were huge avalanches.

Tsunami?

It is a frightening thought. An even more frightening thought is what happens at the sea surface during one of these avalanches. On a miniature scale, fishermen working around Kaikoura Canyon have reported a flat, calm sea suddenly erupting into violent waves that threatened to capsize their boat. They think the cause is small pieces of the canyon-wall beneath them falling away. What would happen if a vast section collapsed? Seawater would first be sucked down with it, but then would bounce back, forming huge tsunami waves.

A relatively minor slope collapse after an earthquake off New Guinea in July 1998 produced a tsunami that appeared along the coast at dusk as a red-crested wave 10–15 m high – as high as a three-storey building. For over 2000 people, who had watched from their homes the curious withdrawal of the sea that often precedes a tsunami, it was the last thing they ever saw.

Perhaps the most dramatic evidence of a tsunami generated by a submarine landslide is from Hawaii, long before the first Polynesians arrived. The



3-D impression of the extent of the Ruatoria avalanche off the east coast of the North Island. Note the very large blocks at the front of the mass of debris.

collapse of a 5-km-high submarine volcano generated a wave that washed white coral boulders to a height of nearly 200 m up the black lava slopes of neighbouring Lanai Island and removed the thick, tropical soils to a height of over 370 m – higher than the Auckland Sky Tower.

In open water, however, the Lanai wave would have been much smaller. For example, in 1958 a landslide into an unpopulated Alaskan fjord generated a wave 60–80-m high (the height of 20-storey high-rise). As it travelled down the fjord at 180 km per hour, watched by the crew of a fishing boat in the mouth of the fjord, it washed up the side of a projecting spur, destroying pine trees to a height of 524 m. Incredibly, the fishermen survived the wild ride over the bar and out to the open ocean.

In both the Hawaiian and Alaskan examples, the tsunami was enormous because the head of the avalanche was near or above sea level.

Evidence for a Ruatoria tsunami

What of the Ruatoria avalanche? Was there a tsunami? The search for evidence has begun onshore, but searchers will need to be very lucky because most signs will have been eroded away in the 170,000 years since they formed, the rocks being softer and the avalanche older than the one off Hawaii. If, as we suspect, there was a tsunami off Ruatoria, how big was it? Frankly, we don't know. Probably smaller than the Hawaiian one because the head of the main avalanche was deeper so that the effect on the sea-surface was partly dissipated in the surrounding water.

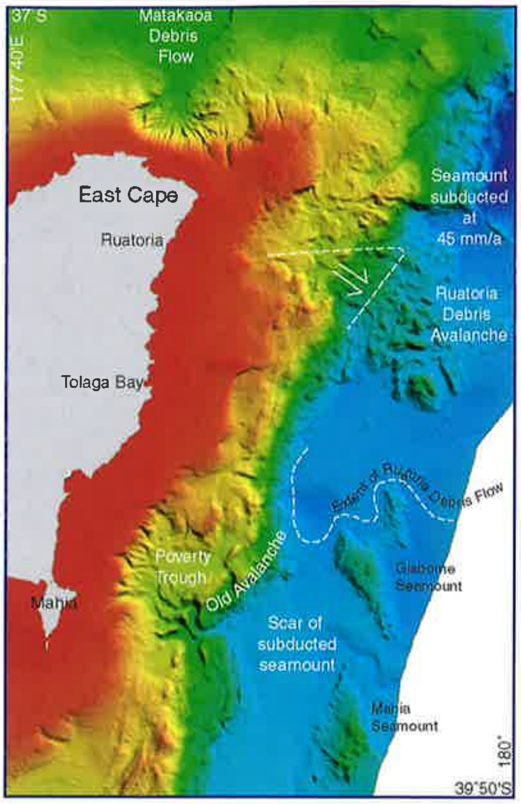
We have computer models to estimate the sizes of tsunamis generated by earthquakes and what happens to tsunami waves when they reach the adjacent coast. The waves slow down in the shallows, but drag increases their height to many times their height in open water.

Modelling tsunamis from submarine avalanches is far more complicated because the drop in the seabed moves down the slope and so does a bulge of collapsing rock debris and pressurised water. This causes a whole series of waves that interfere with one another in complex ways.

Understanding the avalanche

Are giant avalanches likely to happen again around New Zealand? If so, where? To answer these questions, it helps to understand why the Ruatoria avalanche occurred where it did.

Ruatoria lies near the boundary of two of the earth's vast crustal plates. To the east, the Pacific Plate creeps towards and dives under the edge of the North Island at about 45 mm per year. The Pacific plate is like a conveyor belt, but it is not smooth. It has many long-extinct volcanic seamounts. When these reach the steep slope off Ruatoria, they are not scraped off like conveyor-belt luggage. Instead, they plough into and then under the steep submarine slope. Each one penetrates like a slow-motion bullet, crumbling the rocks, which collapse back into the tunnel in its wake. The result is a trough that marks the passage of the seamount into and under the continental slope. These impact-troughs occur widely around the Pacific, accompanied by small avalanches. The New Zealand margin is different because the volcanic cones hit the margin obliquely, so that the troughs leave an unstable triangle of rock between themselves and the steep margin slope. It was the collapse of this badly fractured triangle that caused the huge avalanche off Ruatoria.



Map showing the origin of the Ruatoria avalanche and scars left by other, earlier avalanches (see text, left).

Earlier impacts

This was not the first time it had happened. There are ghostly scars of earlier seamount impacts, and even older avalanches, at several places along the east coast. One off Poverty Bay will be investigated on a voyage in May 2001. Dating of these features is uncertain, but we think that large impacts and their avalanches have occurred at intervals of several hundred thousand years.

So, big avalanches and their tsunamis may fascinate film-makers, but they are not something most of us will lose sleep over.

This is not to suggest that we should be complacent. The coast from Bay of Plenty to Kaikoura is close to the plate boundary, where small seabed avalanches may generate New Guinea-sized tsunamis often enough for one to be expected in a human lifetime. Also, tsunamis that have travelled vast distances from places around the Pacific rim are a constant threat, although international monitoring may give sufficient warning for evacuation. But what of homes built close to the shore? In New Guinea, a few fragments of foundation remained. There, legislation has been suggested to prevent building close to the sea in susceptible areas. Here, the catalyst for awareness and change has yet to strike. ■

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Keith Lewis is based at NIWA in Wellington; Jean-Yves Collot is from IRD (Institut de Recherche pour le Developpement), Villefranche, France.

Recent publications by NIWA staff

The following list includes papers in refereed journals, books and book chapters reported between November 2000 and January 2001. Please note that NIWA staff papers appear in a range of journals and are not published by NIWA. Your local library will be able to obtain copies through the interloan system if required.

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