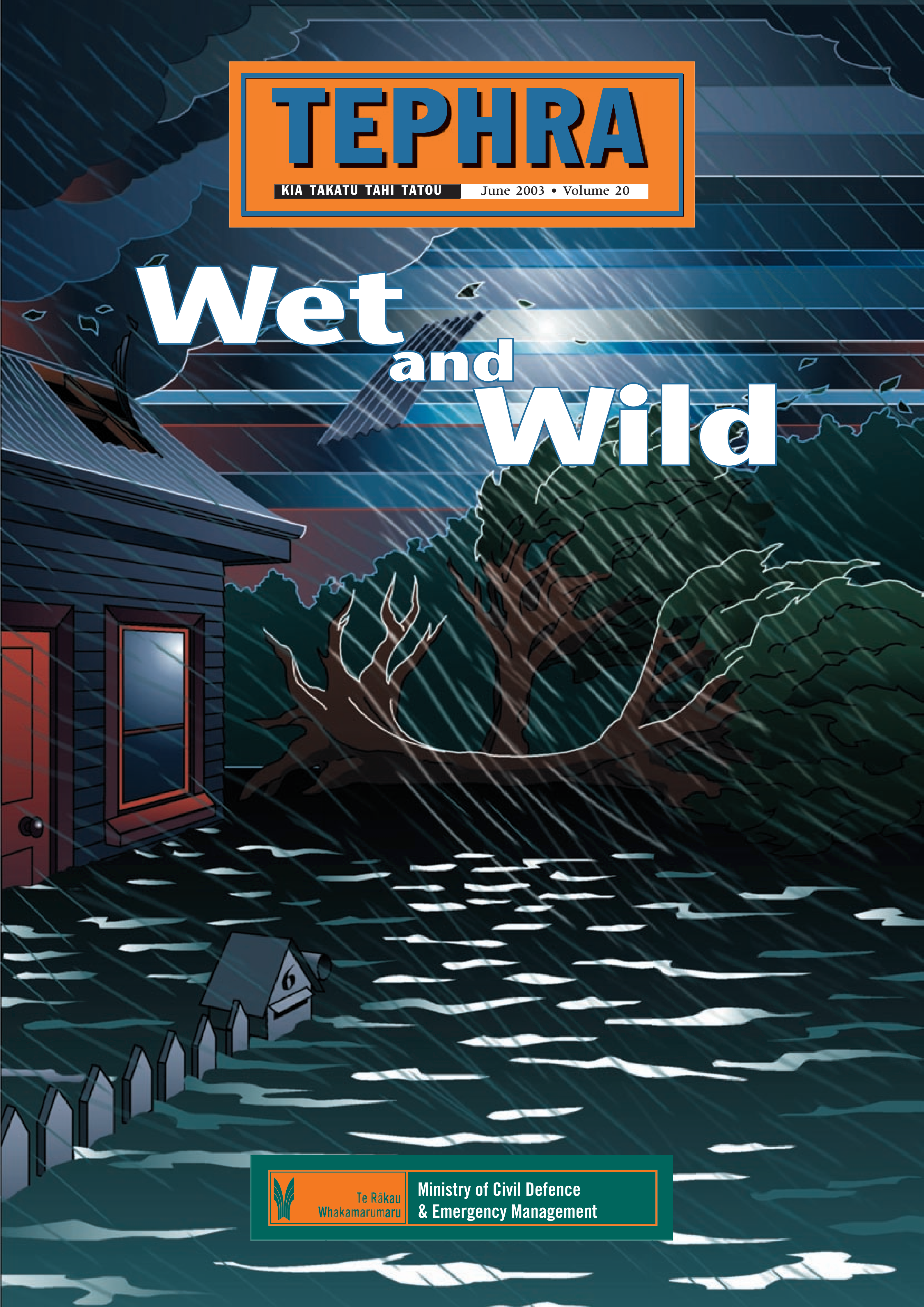
TEPHRA

KIA TAKATU TAHI TATOU

June 2003 • Volume 20

Wet and Wild



Te Rākau Whakamarumaru
Ministry of Civil Defence
& Emergency Management

From the Editor

WET AND WILD

New Zealand lies in the middle latitude of the southern hemisphere surrounded by vast oceans, making us vulnerable to a range of weather related events throughout the year.

Over the last 40 years several cyclones have hit New Zealand with varying impacts. One of the best known of these because of the impact it had is the Wahine Storm of 1968. It led to the sinking of the inter-island ferry at the entrance to Wellington Harbour, with the deaths of 51 passengers and crew.

In March 1988 Cyclone Bola wreaked havoc in the East Coast/Gisborne region with damage to farms and horticultural land.

In 1996/97 Cyclone Fergus and Cyclone Drena caused flooding and wind damage over the northern areas of the country.

Flooding is the most frequent and damaging hazard in New Zealand and the number one cause of declared civil defence emergencies. In 1999, the Southland and Otago regions experienced their worst floods in over 100 years. In October 2000 a southerly storm destroyed the Lytlleton marina and reportedly caused the worst flooding in 50 years to northern Wairarapa.

In June 2002, the weatherbomb which hit the eastern and central North Island from Northland to Taupo produced gale force winds and devastating record cloudbursts.

Over the last few issues, Tephra has sought to provide relevant scientific and educational information to help us better understand the hazards that we face. The journal aims to bring together relevant information on the leading edge work that is being done by scientists and researchers in New Zealand, and illustrate how that knowledge is applied.

This issue of Tephra takes a look at some of the extreme events of nature that lead to wet and wild conditions in New Zealand. What causes these events? Where and when are they most likely to occur? Can we predict them? With reference to specific events, the articles in this issue attempt to answer these questions and describe the relevant research that is currently being done in New Zealand.

The case studies from local authority emergency managers on how they have dealt with particular events, and the work that is being done to plan for and reduce the potential impact of these hazards in their communities, are aimed at providing practical information for those involved in the civil defence emergency management sector.

Tephra is a non-profit publication that is distributed widely within New Zealand to central and local government, commercial organisations, libraries and educational institutions. It is also distributed internationally to agencies with an interest in emergency management. The Ministry gratefully acknowledges the contributions of the various authors, in particular from the National Institute of Water and Atmospheric Research (NIWA) and the MetService, for providing the articles and technical advice for this publication.

Chandrika Kumaran

Te Rākau Whakamarumaru
Ministry of Civil Defence
& Emergency Management

WET AND WILD
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TEPHRA n . fragmented rock, ash etc ejected by a volcanic eruption [from the Greek word for ash].

Cover illustration: An artist's impression of wet and wild weather by Stephen Crowe.
Outside Back Cover: Waves crashing over the reef at Castlepoint on the Wairarapa Coast, 10 June 2002. Peak waves likely to have been close to 10 metres.

Wet and Wild

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TEPHRA
June 2003

WEATHER SYSTEMS
THAT PRODUCE FLOODS AND GALES

– *Understanding the processes that drive them*

by Mike Revell
Atmospheric Scientist, NIWA

What are the weather systems that produce floods and gale force winds over New Zealand?

Although any storm that produces heavy rain or strong winds can be devastating for those experiencing it, for identification purposes meteorologists divide them into two main groups: tropical cyclones and mid-latitude cyclones. While the terminology reflects their region of occurrence the two classes have very different energy sources, structure, formation mechanisms, and problems associated with their prediction.

ENERGY SOURCES

The ultimate source of energy for all weather systems is the sun. If it heated the atmosphere equally everywhere then the temperature would be the same everywhere and there would be no air motion and no weather. But it doesn't.

Firstly, the earth's atmosphere is almost transparent to incoming solar radiation so most of this radiation is directly absorbed at the earth's surface, thereby heating it more than the upper atmosphere. Secondly, because of the shape of the earth, with the equatorial region nearly perpendicular to the sun's rays (the sun appears higher in the sky) while the poles are nearly parallel to the sun's rays, more heat per unit area is received from the sun at low latitudes than at high latitudes.

In contrast, the heat that the earth and atmosphere radiate to space is fairly uniformly distributed and balances the total heat received from the sun. The result of these two effects is that there is a net heating at the earth's surface and a net cooling in the upper atmosphere, plus a net heating of the atmosphere at low latitudes and net cooling at high latitudes.

The former effect dominates in the tropics (and is the source of energy for tropical cyclones) and the latter in mid-latitudes (and is the source of energy for mid-latitude cyclones). If the air did not transport heat polewards and upwards then the atmosphere would get hotter and hotter at the surface and in the tropics, and colder and colder at upper levels and in the polar regions. The occurrence of tropical and mid-latitude cyclones is evidence that the atmosphere is performing its essential function of making good this heating imbalance. Exactly how these cyclones perform this role is a fascinating example of nature organising itself in a quite elegant and most efficient way.

STRUCTURE AND FORMATION MECHANISM

Tropical cyclones, usually referred to as hurricanes if they occur in the west Atlantic, notably in the Caribbean, typhoons in the west Pacific, and cyclones in the Indian Ocean, are intense cyclonic storms of tropical origin. They are possibly the most spectacular weather events on the planet and the damage they can cause is enormous. Surface winds can reach over 200km/h, and almost as if to accentuate this violence, their central region or eye, of 20 to 50 km width, is calm and often completely clear.

Thus, as a tropical cyclone passes a particular spot, a period of extreme winds from one direction is followed by an hour or two of complete calm, then equally ferocious winds from the opposite direction. When viewed by satellite from space a tropical cyclone is easily identified by its spiralling cloud bands that extend out to a radius of several hundred kilometers from its clear central eye.

Air converges at low levels (anticlockwise in the Northern Hemisphere, clockwise in the Southern Hemisphere) spinning faster and faster (in order to conserve angular momentum) as it approaches to within about 30 km of the low pressure center. At this point the air is rotating so fast that centrifugal forces (the same ones that keep water in a bucket

Otago Floods 1999. Sue Robinson keeps an eye on the rising waters of Lake Wakatipu from her Frankton home on 17 November. Photo: Otago Daily Times

swung around your head) dominate and the air turns sharply upwards, climbing to heights of 15 km, before spiraling outwards at upper levels. The heavy rain and extreme winds associated with tropical cyclones are confined to this fairly narrow region of upward motion 10 to 20 km wide known as the eye wall.

The kinetic energy of hurricanes is maintained in the presence of surface friction by conversion of latent heat energy acquired from the underlying ocean. This conversion of potential to kinetic energy is carried out by meridional circulation. Observations show that evaporation of water from the sea surface into the inward flowing air in the boundary layer causes a large increase in the entropy (heat input divided by temperature) of the air as it approaches the eye wall. This is augmented by the fact that the air is flowing towards lower pressure so should expand and cool.

However the close proximity to the warm sea and the intense winds enable rapid heat exchange to occur and the air maintains its temperature. This means that in the eye wall the air is neutrally or positively buoyant and can ascend up to 15km without external forcing. The energetics of a hurricane can thus be viewed as a Carnot cycle heat engine in which heat is absorbed (as both sensible heat and water vapour) from the ocean at the water temperature of about 300°K and expelled by radiative cooling to space from the tops of the outflowing cirrus clouds at about 200°K. These numbers give an efficiency for the heat engine of about 1/3, which is fairly high.

ORIGIN OF TROPICAL CYCLONES

The origin of tropical cyclones is still a matter of debate. It is not clear under what circumstances a tropical disturbance is transformed into a tropical cyclone. Although there are many tropical disturbances every year, only a few develop into hurricanes.

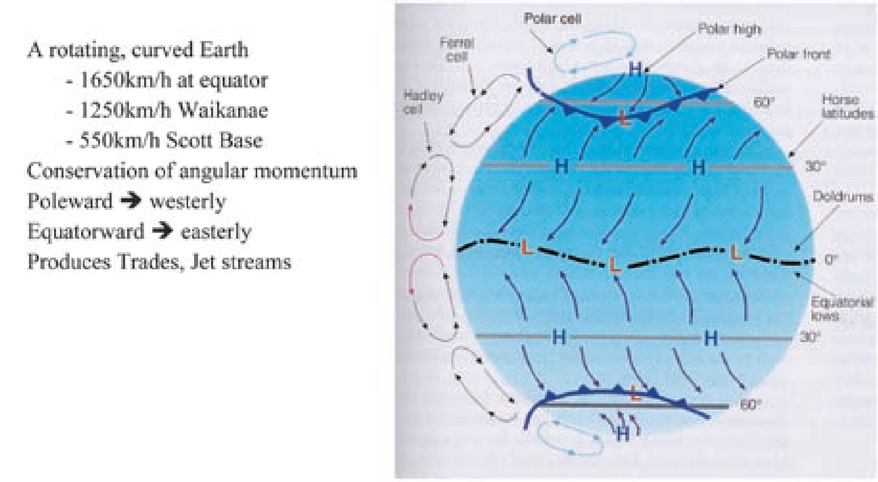
It seems a finite amplitude jolt is required to provide the winds needed for strong evaporation and to initiate the cycle above. Sea temperatures need to be above about 26°C for enough heat to enter the system in the boundary layer to sustain the intense circulation needed to maintain the hurricane. If the tropical cyclone moves too far poleward and encounters a region of strong vertical shear in the wind (typical of mid-latitudes), then the hurricane will be torn apart. In fact there is no evidence of a tropical cyclone ever having reached the latitude of New Zealand.

The drop in sea temperature, or the increasing background wind shear, destroys the hurricane maintenance cycle and it undergoes a transition into a mid-latitude cyclone. It is worth noting, however, that the residual circulation and very moist air left over from the tropical cyclone mean that these ex-tropical cyclones can become some of the most devastating mid-latitude storms. Examples are tropical Cyclone Gisele which became the April 1968 Wahine storm and Cyclone Bola which washed away large amounts of topsoil in March 1988 in the Gisborne area.

MID-LATITUDE CYCLONES

Mid-latitude cyclones (sometimes referred to as depressions or lows) usually form within the belt of westerly winds encircling the globe between 30° and 70° S. They generally move from west to east, bringing a period of unsettled weather, with wind, cloud and precipitation, most noticeably at fronts.

Mid-latitude cyclones feed on the potential energy contained in horizontal temperature contrasts brought about by solar heating imbalance. Consider a container with cold water on one side and warm (less dense) water on the other. The colder water will tend to slide under the warm water converting potential energy to kinetic energy. If the earth was stationary



A rotating, curved Earth
- 1650km/h at equator
- 1250km/h Waikanae
- 550km/h Scott Base

Conservation of angular momentum
Poleward ➔ westerly
Equatorward ➔ easterly
Produces Trades, Jet streams

Figure 1. Windflows produced by latitudinal movement of air on a rotating earth

and the sun revolved around it once per day, mid-latitude weather would consist of this simple overturning motion.

However, because the horizontal movement covers several thousand kilometers, it is very much affected by the earth's rotation. For instance, if air moves from Fiji southward to Invercargill in New Zealand, it moves considerably closer to the earth's axis. In the absence of an east-west pressure gradient it would tend to move eastward much more rapidly at Invercargill than it did at Fiji. This effect is analogous to the way a skater generates spin by starting slowly with arms outstretched then bringing them close to his sides. The approach of his arms to his body produces the same dynamical effect as is produced on the air as it moves closer to the earth's axis of rotation. This principle is known as the conservation of angular momentum. What we have just described explains the low level southeasterly trades and the upper level subtropical westerly jets in what is known as the Hadley circulation that extends from the equator to about 30°S shown in Figure 1.

If the Hadley circulation were to continue any further poleward than this, the westerly jet and implied north-south temperature gradients would become so strong that they would become unstable to small perturbations. This means that any small wavelike disturbance introduced into the jet would tend to get larger, drawing on the energy of the jet as it grows. Most mid-latitude cyclones appear to develop as a result of the instability (called baroclinic instability) of the jet stream flow. As these cyclones develop, the regions of thermal contrast are organized into cold and warm fronts, giving the mature cyclone a very asymmetric structure. The warm air flows southward and upward ahead of (east of) the low, and the cold air flows northward and downward behind (west of) the cyclone as illustrated in Figure 2. In addition most of the cloud and precipitation occurs in this rising warm air ahead of the cyclone, in contrast to the annular symmetric rainband of the tropical cyclone. Although moisture is not essential to the formation and growth of mid-latitude cyclones, latent heat release in the cloudy region ahead of the cyclone can help intensify the system. Thus, extratropical cyclones that have a low-level inflow of moist subtropical air can develop very quickly and on smaller scales, generating storm force winds and torrential rain. The terms explosive cyclogenesis or bomb are used to describe the rapid way these storms evolve and the intense weather that develops.

Much of our research effort over the last couple of years has gone into trying to better understand these latter types of storm. They are the source of some of the heaviest rain and strongest winds that northern New Zealand gets and they tend to be misforecast by the numerical weather prediction models more often than the more polar storms. A good example of this was the Queen's Birthday storm of 1994 when several yachts travelling from New Zealand to Tonga for the sailing season were sunk. Over a period of 24 hours between noon on 3 June to noon on 4 June, a surface low deepened from 1001 hPa to 986 hPa, generating winds of 25 metres per second near the centre. This evolution was not well picked up by the global forecast models at the time.

We think the reason for this was the lack of detail at analysis time in the upper level trough,

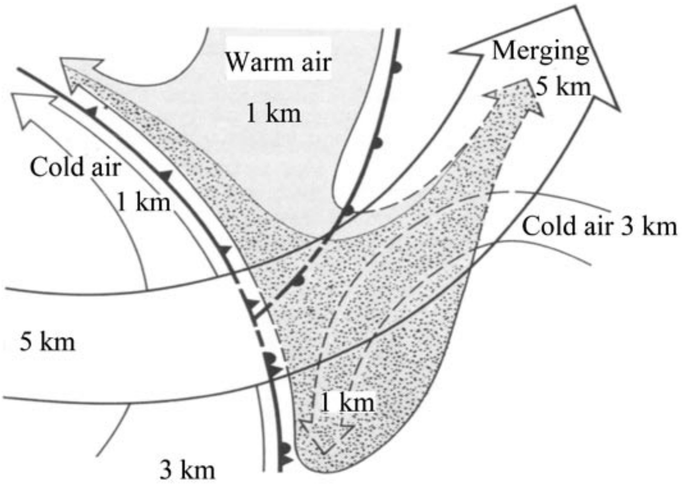
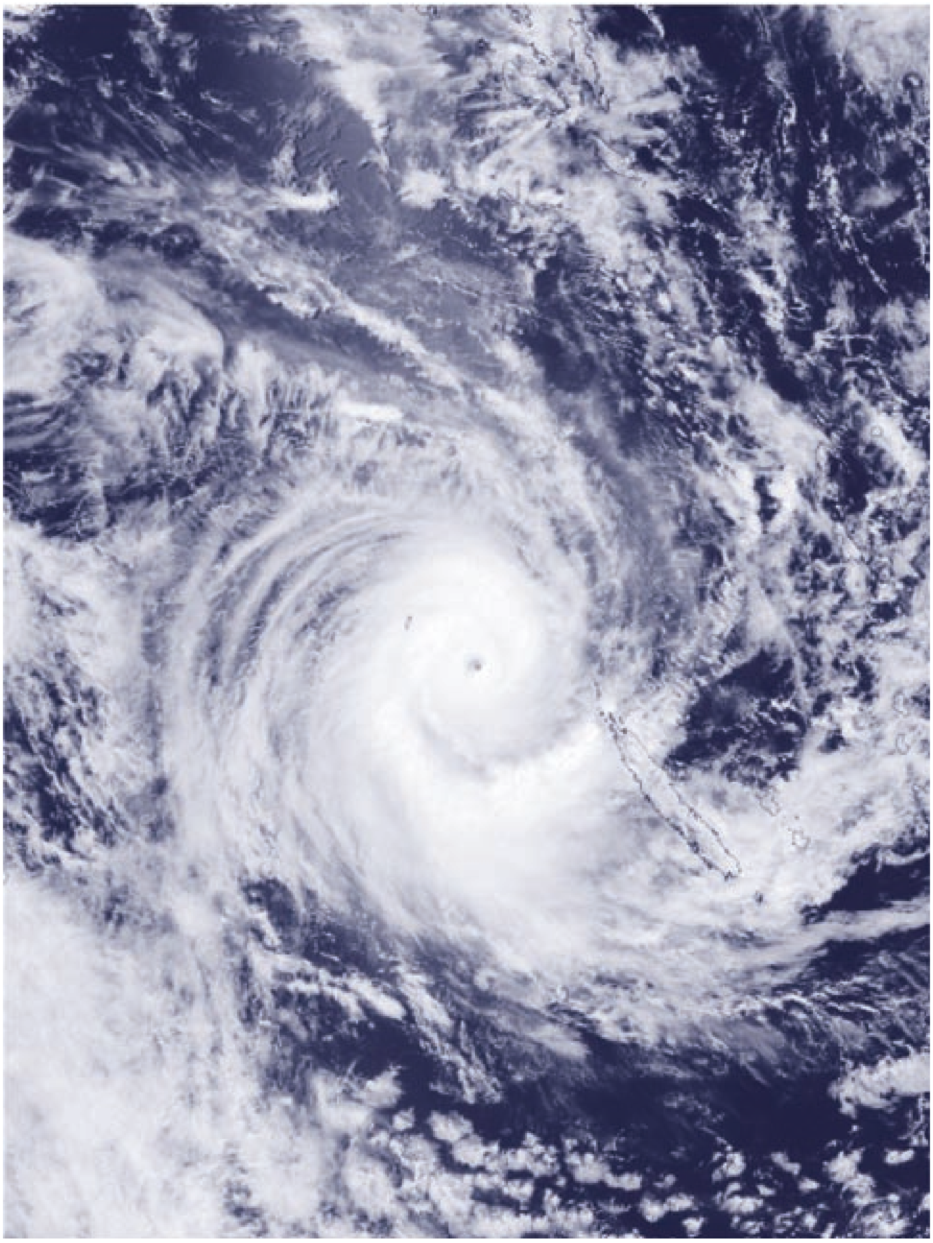


Figure 2. Currents in an active midlatitude cyclone as seen from above by an observer moving with the centre (heavier stippling denotes cloud)

associated with this development, located in the data sparse region east of Australia. It is important to remember weather is a three-dimensional phenomenon. What happens at the surface is driven very largely by what is happening aloft. The movement of highs and lows is not like the movement of pieces on a chessboard although it may seem so for short periods of a few hours. There is a continual two-way interaction between what is happening at the jetstream level (about 8km above the surface) and what is happening at the surface.



Tropical Cyclone Erica passed over New Caledonia on 14 March 2003, with winds reported up to 250km/h and air pressure as low as 910 hPA. One person was killed and 15 injured.

In complete contrast, the weather bomb, which affected the Auckland region in February 2002 and which developed at a similar rate, was forecast very well three days ahead. A key difference between the two storms was that the associated upper level trough was quite intense and located over the relatively data-rich area of eastern Australia three days before the rapid deepening. These two cases highlight the need for good initial data to make a good forecast. Increasing the resolution of the numerical weather prediction models and making better use of information observed from satellites on sea state, cloud movements and temperature and moisture through the depth of the atmosphere, is continuing to improve the situation. At NIWA, we have a programme to assimilate weather information (particularly satellite data) at 12km resolution over the area between 15° and 60° S and 150° and 190° E.

PRECIPITATION, FLOODING AND STRONG WINDS

Precipitation (usually rain, but snow, if temperatures are cold enough) forms when air parcels cool to below their dew point. The usual way this happens is when a parcel of air rises, the pressure drops (since pressure decreases with height) and the air cools (since temperature is proportional to pressure). So the most vigorous rain occurs in the regions of strongest upward motion – the eye wall of a tropical cyclone or ahead of a front in a mid-latitude cyclone. In New Zealand, particularly, another source of upward motion occurs when air flows perpendicular to a mountain range and is forced to rise. Some of our heaviest rain events occur when moist air flows very quickly across our mountain ranges – even the relatively small ones.

The majority of insurance claims in New Zealand due to natural hazards arise from flooding. Flooding is dependent on catchment properties as well as rainfall intensity and occurs when rain falls in a given location at a rate faster than the local drainage system can cope with. Severe thunderstorms, located within fronts or in the cold air behind, can give short lived but very intense rain rate bursts of 100 mm/hr. Alternatively a front may become stationary over a particular location and lesser rain rates of 10 mm/hr

Containers blown over at Ferguson Wharf, Auckland in February 2002. © New Zealand Herald.

but lasting for more than a day will also lead to flooding.

Strong winds usually occur in association with the same features of tropical and mid-latitude cyclones that produce heavy rain – namely the eye wall and associated fronts. In New Zealand, as well as enhancing precipitation, the mountain ranges can also speed up the wind by funnelling it through gaps (like Cook Strait or the Manawatu gorge). Downslope windstorms can occur on the downwind side of mountain ranges as air sinking from upper levels upstream of the mountains, under favourable conditions, continues to cross the mountain and accelerate down the lee slope. This effect is probably responsible for some of the very strong northwesterly winds in western Canterbury.

Although not as dramatic as in the Midwest of the United States, tornadoes do occur in New Zealand. These are associated with the cold downdrafts (produced by evaporation of rain) from severe thunderstorms producing very intense horizontal vortices at the gust front that are then tilted and stretched into the vertical.

PROBLEMS WITH PREDICTION

One thing our research has shown is that numerical weather prediction models are getting better at forecasting the pressure, wind and temperature fields associated with weather systems. Three-day forecasts are about as skilful now as one-day forecasts were 20 years ago. Forecasts of rainfall have also improved but the increased skill is smaller mainly because of the localised nature of rainfall.

At present, the resolution of all global weather models that are used to make daily forecasts is too coarse to resolve the fine scale detail of what goes on in the eye wall of a tropical cyclone. Also, exactly what initiates a tropical cyclone is still uncertain. Small perturbations in the tropics tend to lead to the growth of cumulus clouds. It appears a finite amplitude kick is needed to start a tropical cyclone. So, if a numerical model is to forecast the initiation of a tropical cyclone it must also forecast the initial perturbation. Again the existing models do not have the required resolution.

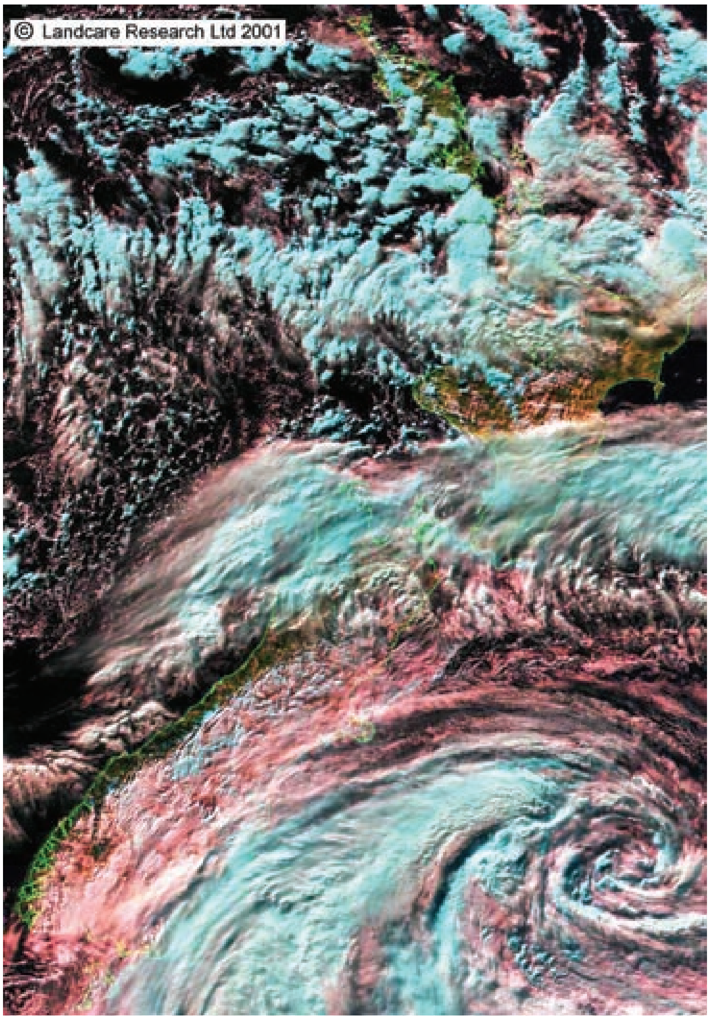
Mid-latitude cyclones, however, are largely driven by the vorticity dynamics of the wind flow at the jetstream level, which occurs on a larger scale and is better resolved by the current observational network. In general, these systems are well forecast out to three days and still show reasonable skill out to five and seven days – particularly in the northern hemisphere where the observation network is denser. Most of the larger forecast errors in the New Zealand region occur when moist processes play an important role. The area to the north of New Zealand does not have a dense observational network and the details of the low level moisture fields there are to a large extent determined by the boundary layer processes in the prediction models themselves, namely surface fluxes and mixing due to convection. Work is still going on to get these processes represented more accurately in weather prediction models. ■

SEVERE WEATHER FORECASTING

By Rod Stainer

Chief Forecaster, MetService

New Zealand lies in the middle latitudes of the southern hemisphere surrounded by vast expanses of oceans. This location makes it vulnerable to weather systems that either move out of the tropics or develop in the westerlies that circumnavigate the globe south of about latitude 25 south. The seas and oceans that surround New Zealand provide a plentiful supply of water vapour to fuel and energise these weather systems. The atmosphere is a very efficient engine and can suck vast quantities of water vapour out of the oceans and convert it into deep cloud systems that can hold millions of tonnes of liquid water and ice. Eventually this material precipitates out of the clouds, potentially leading to devastating floods and paralysing snowstorms.



In the last week of December 2002, Cyclone Zoe became the most intense tropical cyclone ever recorded in the tropics north of New Zealand. Zoe devastated the remote islands of Anuta and Tikopai, but miraculously no deaths were reported.

As far as natural hazards go, earthquakes and volcanic eruptions arguably have the most catastrophic effects but fortunately really severe events do not occur very often. On the other hand, weather frequently impacts upon us to a greater or lesser degree. Rarely does a month go by when some part of New Zealand has not been affected by a storm.

How bad can the weather get and how much devastation can it cause? On 22 October 1998 a tropical cyclone named “Mitch” formed in the Caribean Sea east of Honduras and went on to become one of the strongest Atlantic cyclones ever, causing one of the western hemisphere’s greatest natural disasters of the twentieth century. In a 34-hour period, Mitch deepened by almost 60 hPa and eventually bottomed out at 905 hPa. The winds reached a sustained maximum of almost 300 km/h which lasted for 15 hours – a 200 km/h wind is enough to lift an average sized person into the air. The east coast of Honduras was buffeted by waves of up to 16 metres in height and torrential rain fell over the interior of both Honduras and Nicaragua. Total rainfalls ranged from 1200 to 1800 mm (that is more than either Auckland or Wellington expects in a normal year) and there was a report of 600 mm falling in a six hour period (almost as much as Christchurch gets in a whole year). Over 11,000 deaths were thought to have occurred with countless missing. In Nicaragua, total damage was estimated at US$1.36 billion or 67% of GDP.

In the South Pacific, storms are generally smaller and less intense than Mitch. However, in the last week of December 2002 Cyclone Zoe became the most intense tropical cyclone ever recorded in the tropics north of New Zealand. Maximum winds were estimated to have exceeded 240 km/h with a minimum pressure at the centre of the cyclone of 890 hPa. Zoe devastated the remote islands of Anuta and Tikopai, but miraculously no deaths were reported.

Over the last 40 years or so several cyclones of tropical origin have hit New Zealand with varying impacts. The best known of these is the "Wahine Storm" which on 10 April 1968 sunk the inter-island ferry "Wahine" at the entrance to Wellington Harbour resulting in the deaths of over 50 passengers and crew. In March 1988 Cyclone Bola brought widespread flooding to the Gisborne region resulting in large tracts of farm and horticultural land being submerged under thick layers of mud. In the summer of 1996/97 two cyclones, Fergus and Drena emerged from the tropics in quick succession resulting in flooding and wind damage over northern areas of the country. The impacts of these two cyclones were exacerbated by the fact that they hit some of the country's most popular holiday resorts during the peak of the holiday season.

It is important to note, though, that tropical cyclones are the exception and not the rule as far as weather systems that lead to damage and disruption in New Zealand. Storms that are born and grow in the belt of middle latitude westerly winds often create havoc the length and breadth of the country at any time of year and present meteorologists with some of their greatest weather forecasting challenges. Examples of these types of events include:

- Canterbury windstorms in August 1975
- Wellington and Hutt Valley floods of December 1976
- Southland floods of 1978, 1980 and 1984
- Explosive deepening of a Tasman Sea depression that contributed to the deaths of seven soldiers on Mt Ruapehu in August 1990
- Canterbury snow storms of July and August 1992 which led to huge stock losses
- Central Otago and Southland floods in November 1999, reported to be the worst in 120 years
- Southerly storm of October 2000 that destroyed the Lyttleton Marina and reportedly brought the worst flooding in 50 years to northern Wairarapa
- Central North Island snow storm of August 2001 that caused the closure of all roads over the central plateau and blocked the main railway line.

Clearly it is vital that these types of events are accurately forecast.

The Meteorological Service of New Zealand, or MetService as it is popularly known, is New Zealand's only official source for warnings of severe weather as authorised by the Minister of Transport in accordance with the Meteorological Services Act. The meteorological warnings service that MetService provides is funded through a contract with the Minister of Transport.

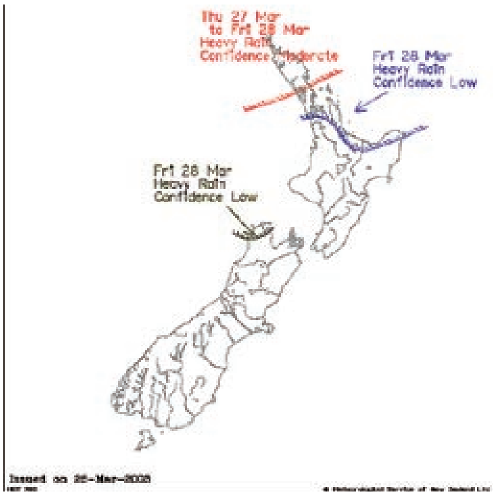


Figure 1. Severe Weather Outlook graphic.

What do we mean by severe weather? An obvious answer is: weather which causes damage and disruption. However, MetService's severe weather forecasters, who are based in Wellington, are not in a position to make such value judgements on the weather – similar weather conditions may have quite different impacts in various parts of the country. Therefore, severe weather for the purposes of issuing meteorological warnings has been quantified as follows:

- **Heavy Rainfall -** whenever more than 50 mm of rain is expected to fall in six hours or less, or greater than 100 mm within 24 hours over an area of at least 1000 square kilometres (km2).
- **Heavy Snow -** whenever widespread snowfall (over an area greater than 1000 km2) occurs below 1000 metres on the North Island and below 500 metres on the South Island with a snow depth to at least 10 cm within six hours or 25 cm within 24 hours.
- **Severe Gales -** whenever the sustained wind speed is likely to exceed 90 km/h, or frequent gusts greater than 110 km/h are likely to be experienced, over a land area of 1000 km2 or more.

A major goal of MetService is to ensure there are "no weather surprises" to the community through a structured system of severe weather advice. Ideally, the aim is to provide an Outlook of the likelihood of severe weather several days away, followed by a Watch as the time shortens, and eventually a Warning is issued when severe weather is expected to strike within a day.

SEVERE WEATHER OUTLOOK

Severe Weather Outlooks have been designed to provide a "heads-up" assessment of the likelihood of severe weather, as defined above, occurring three to six days away. These Outlooks are issued by MetService every afternoon and are freely available on the MetService web site: www.metservice.co.nz.

They consist of some text describing the possibility of potentially severe weather and a graphic, highlighting those areas where there is a risk of severe weather.

In order to give users an idea of the likelihood of severe weather occurring several days out, a measure of the confidence is included in the forecast:

- Low confidence indicates a 20% likelihood (or 1 chance in 5) that the event will actually happen.
- Moderate confidence indicates a 40% likelihood (or 2 chances in 5) that the event will actually happen.
- Good confidence indicates a 60% likelihood (or 3 chances in 5) that the event will actually happen.

METSERVICE

SEVERE WEATHER WATCH

FOR COASTAL WAIRARAPA, SOUTH COAST WELLINGTON

ALSO OUTER SOUNDS AND KAIKOURA COAST

ISSUED BY METSERVICE AT 1211HRS 09-JUN-2003

SOUTHERLY GALES EXPECTED OVER CENTRAL NEW ZEALAND TONIGHT - GUSTS

COULD REACH 120KPH IN EXPOSED COASTAL PLACES

A low will move over northern New Zealand from the Tasman Sea tonight but a new low centre is developing east of Napier and MetService expects it to drift southwards today.

Southeast winds over central New Zealand are starting to strengthen ahead of this new low, and will reach gale force in many areas as they turn southerly this evening.

In coastal Wairarapa from Castle Point southwards, near the south coast of Wellington also outer Marlborough Sounds and possibly the Kaikoura Coast from about Clarence northwards, gusts will probably pick up to 100kph from about dusk and may nudge 120kph for a time overnight if the new low comes close enough. Winds should start easing on Tuesday morning.

Residents in these areas should be prepared for rising winds and skippers of coastal vessels keep up to date with warnings.

This Watch will be reviewed by 5pm Monday 9 June Forecast prepared by: Ian Miller

These measures of confidence are based on ensemble weather model data made available by the United States National Weather Service. There are a number of sophisticated computer weather models that are being run by various large forecasting centres around the world. These models require very powerful computing resources since they produce forecasts for the entire globe for the next 14 days or so. However, the accuracy of these models diminishes markedly after the first four or five days and by the 14th day the value of the forecast is extremely speculative.

One of the larger sources of forecast error is the uncertainty concerning the initial analysis of the data, and ensemble forecasting recognises this uncertainty by asking the question: "What range of forecasts are possible?" To answer this question a model can be run many times with differing initial analyses to see how the forecasts vary – this is referred to as ensemble forecasting.

As lead-time increases, so the various forecasts in the ensemble diverge. A measure of the spread in the various forecasts then tells us how reliable our prediction of severe weather is likely to be. More often than not the further ahead, the bigger the spread, and hence the less confident we can be in making our forecasts. It is this information that MetService forecasters utilise to provide an expression of the likelihood of an event occurring several days ahead.

SEVERE WEATHER WATCH

A Severe Weather Watch is the next step in the severe weather advice process. An Outlook of a particular event may be upgraded to a Watch or it may be dropped if the confidence has remained poor during the Outlook phase. Remember that a “Low” confidence implies that there is only a 20% chance that the event will come to pass so, 80% of “Low” confidence forecasts are not likely to occur, and therefore many Outlooks will never move into the Watch phase.

Severe Weather Watches are issued whenever there is an expectation that conditions will deteriorate to the thresholds quantified earlier for severe weather in the period following the next 24 hours but within 48 hours. A Watch may stay in force for part of the immediate 24 hour period if there is a high level of uncertainty regarding the event.

All severe weather watches are posted on the MetService web site.

SEVERE WEATHER WARNING

The Severe Weather Warning is the final phase of the process. Warnings are issued for severe weather events (ie. heavy rain, heavy snow, severe gales) that are likely to occur within the next 24 hours.

Two people try to prevent further damage to a 7.6-metre yacht after it washed up on rocks in Wellington. Photo: DomPost. 11 June 2002.

Once the Warning has been prepared it is sent by fax or email to regional and district council offices, the Ministry of Civil Defence & Emergency Management, the Police, and the news media. The forecaster then follows up the issue of the first Warning of an event with a telephone call to ensure that primary users have received the Warning. Warnings are updated at regular intervals during the event until a final message is sent out advising that the weather has improved and the Warning is lifted.

Some warning messages are very complex with many regions being involved and for more than one type of event – eg. heavy rain and severe gales. In order to avoid any confusion, all warnings of severe weather are included in a single message.

The Severe Weather Warning message contains:

- The time issued by MetService;
- Advice that the warning should not be used by the media after a certain time;
- A headline and accompanying text in non-technical language for use by the news media and general public;
- MetService web site link to the latest weather analysis and forecast charts;
- More detailed regional information for technical users – this section will provide more precise information on timing, rainfall accumulations and peak intensities;
- Advice on the time of the next issue of the warning; The name of the issuing forecaster so that users know whom to contact in order to obtain clarification or further advice.

SEVERE WEATHER ADVISORY

There are occasions when the forecaster does not expect the weather to deteriorate to the extent that meets the criteria for issuing a Severe Weather Warning, yet this weather may cause some disruption, inconvenience or concern to the general public. For example, an unseasonably cold wet southerly outbreak is of concern to farmers and growers at certain times of the year. Whilst a Severe Weather Warning may not be warranted in these situations, clearly some particular advice is needed over and above the routine forecasts in order to draw attention to adverse conditions which may have an impact. To meet this need, MetService will issue a Special Weather Advisory with a wide distribution to the news media and farming groups. MetService may also issue Special Weather Advisories to assist with "clean up" operations in the wake of a particularly severe weather event. Those involved in such clean up operations are often very sensitive to weather conditions immediately following a major event, such as flooding.

Another severe weather product that MetService supplies as part of its contract with the Minister of Transport is the Road Snowfall Warning. This is issued for some of the main high country passes whenever snow is expected to settle and accumulate on the road. Formal Severe Weather Warnings for heavy snow are not entirely appropriate since several important South Island road links rise above the 500 metre altitude threshold for heavy snow warnings, and snow accumulation less than 10 cm is often enough to cause major disruptions on some of the roads. Currently, roads that receive warnings include the Desert Road, Rimutaka Hill Road, Porter's Pass, Lindis Pass and the Milford Road.

All the latest Severe Weather Warnings, Watches, Outlooks, Special Weather Advisories and Road Snowfall Warnings are available on the MetService web site at: www.metservice.co.nz. The weather information on this site is updated immediately after the forecasters have issued it. Users can also subscribe to an email warning service, a free service that was introduced a couple of years ago in support of the Government's "e-government" strategy.

HOW GOOD ARE THE FORECASTS?

MetService continually monitors its performance in order to gauge quality and accuracy. In particular, Severe Weather Warnings of heavy rain, heavy snow and severe gales are rigorously verified. Weather data for all events is carefully checked and additional information, if required, is obtained from a variety of sources including regional councils and media reports.

The two principal measures of performance obtained through this verification process are the Probability of Detection (POD) and the False Alarm Ratio (FAR). The POD is a measure of the percentage of events that have been successfully forecast and the FAR indicates the percentage of forecast events that did not occur. MetService targets maintaining the POD above 75% and the FAR below 40%.

During the period from February 2002 to February 2003, the PODs have generally fluctuated between 85% and 90% and the FARs between 25% and 35% which are well within target.

In addition to carrying out quantitative verifications, MetService formally seeks comment from regional councils and the Ministry of Civil Defence & Emergency Management to gauge satisfaction on the quality of services provided. Returns from annual surveys over recent years have been very positive with respondents indicating that MetService is neither missing too many events nor issuing too many false alarms.

Society continues to push the limits on its activities and where it builds settlements, and there are consequent demands for more accurate and precise weather forecasts and warnings. MetService is meeting this challenge through the development of high-resolution weather models and maximising the use of data from lightning detectors, high-resolution satellite imagery and weather radar. Getting the information out to people is paramount and new cell phone technologies will undoubtedly provide great opportunities for delivering detailed weather information, in both text and graphical forms. As well as utilising technological developments, MetService will continue to develop the skills of its forecasters and carry out appropriate research to meet the ever-increasing demands of the community for accurate warnings of severe weather. ■

Waves crashing over the reef at Castlepoint on the Wairarapa Coast, 10 June 2002. Peak waves likely to have been close to 10 metres.

WEATHER BOMB-
The Coromandel Experience

By Ron White
Thames Coromandel District Council

The civil defence emergency, now commonly referred to as the June 2002 Weather Bomb, started as a normal 'Severe Weather Warning'. The first heavy rainfall and wind warning was issued on Wednesday 19 June 2002 at 0820 hours. Northeast wind gusts up to 120 km/h and rainfall accumulations up to 150mm, with likely intensities of 15-20mm per hour, were predicted for the 18 hours from noon on Thursday 20 June to 0600 on Friday 21 June. A total of six weather warnings were issued for the region but essentially the predicted rainfall and timings remained constant.

On 20 June, the term 'Weather Bomb' was used in a severe weather warning. The terminology is now part of Coromandel history. The predicted rainfall totals and intensities were unremarkable. In the words of Chief Executive Steve Ruru, "another heavy rain warning – so what?"

The 19 June warning was disseminated in the usual way with emergency services, utilities, councils and communities of interest advised by early afternoon. There was no urgency at this stage as the prediction was effective from noon the following day.

Thursday morning dawned as a rather unpleasant day. Northeast wind gusts of 120 km/h were recorded at 0730 hours in the Tararu catchment and at the Firth of Thames wind and tide gauge. Minor flooding and moderate wind damage was reported by 0830 hours with some disruption at Kennedy Bay and the Kauaeranga Valley. The day continued with moderate rain and high winds. Concern about the high winds and consistent rain became more evident as the day wore on but by 1700 hours there were no reports of significant damage.

There was an uneasy feel about the weather at the end of business on Thursday. Rainfall totals


Flood and wind damage from the weather bomb on 21 June 2002 in the Coromandel.

In 1985, there was a fatality in Waiomu when Ivy Salter was swept out to sea after her house was undermined by severe flooding.

were not that high but the wind factor, with almost horizontal rain, added a sobering dimension. [For emergency managers – Technical reports on the event are available from MetService, and I recommend the 'Final Technical Report' prepared by Adam Munro from Environment Waikato.]

From here on, the rest of the article is about my personal recollection of the event compiled from my notes, observations and records on file.

I remained in and around the office for most of Thursday evening in a support and monitoring role. The electricity network failed at around 2100 hours and remained off until late Friday 21 June. The Emergency Planning Unit premises have auxiliary power and double as the Thames Valley 'Emergency Operating Centre'. The final Severe Weather Warning, applicable to this event, was issued by the MetService at 2017 hours on 20 June 2002.

Rainfall accumulations of a further 100 mm in some high parts of the ranges, with intensities of 15-20 mm/hour, were predicted for the 9 hours from 2000hrs on 20 June to 0500hrs on 21 June. Continuing east or northeast winds gusting 120km/h were predicted from 2000 hrs on 20 June to 0300 hrs on 21 June. For the Coromandel, this was manageable.

The conditions were such that river watch precautions were initiated on the Te Puru and Tapu Streams. I kept a close watch on the Karaka and Tararu Streams. At 2350 hours on 20 June 2002 there was ample freeboard in all streams. I spoke with the civil defence personnel at Te Puru and Tapu and we agreed there was no apparent imminent danger of flooding. On this basis we decided to call it a night and keep a watch as necessary.

The event unravelled at such speed that it was difficult to accurately record everything as it occurred.

The Thames Valley 'Weather Bomb Emergency" was all over by 0045 hours on 21 june 2002. Not in 34 years of emergency management experience in the Coromandel have I witnessed rainfall intensities such as those occurring in the 45 minutes from midnight on 20 June.

The following Personal Log entries for 21 June 2002 illustrate the point:

0015	Call from Coromandel Fire – Extensive flooding
0030	CDHQ established. Auxiliary power and communications operative.
0035	Coromandel Fire report stream levels dropping
0100	Tapu Camping Ground flooded – water one metre in depth. Tararu Creek overtopped with extensive flooding through properties. A repeat performance of flooding in January 2002. Karaka Creek (Central Thames) overtopped having exceeded the flood protection design level. Te Puru settlement devastated. Worse than the 1980s floods and Cyclone Bola. Waiomu extensively flooded.
0145	Waiomu report woman missing from Motor Camp
0146	Matamata-Piako District activate at Te Aroha
0220	Further rain predicted by MetService (which did not, thankfully, eventuate)
0240	Comprehensive briefing at CDHQ. Controller Basil Morrison at HQ.
0303	Declaration of Civil Defence Emergency for Thames-Coromandel District. Declaration signed by Deputy Mayor, Philippa Barriball.
0309	First evacuees arrive at Thames Hospital. (No other suitable premises were available with auxiliary power and independent water supply.) Declaration requested by emergency services.
0310	Realisation that Thames was without water due to a major break.

By 0100 I was aware that we were at the start of a major emergency and couldn't help but think, "here we go again – history repeating itself."

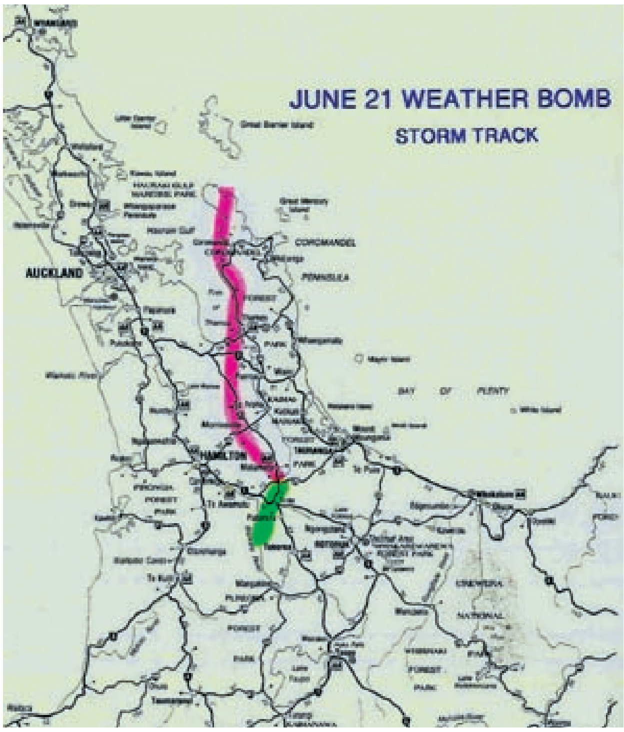
Comprehensive accumulated rainfall totals are available for the event but it is the one hour statistics that are remarkable.

- Tapu – 83mm in one hour.
- Waiomu – 31mm in 15 minutes.
- Te Aroha – 97mm in one hour. Highest on record.
- Putaruru – 120mm in two hours resulting in a declaration for the South Waikato District.

The major river systems coped well. It was the smaller peninsula streams north of Thames that bore most of the storm's sting. Many of these streams exceeded the annual mean flow of the Waikato River through Hamilton by up to 80 cumecs. It is difficult to imagine viable engineering solutions for flows of this magnitude.

The storm made landfall at Port Charles on the north east coast of the peninsula. Twenty three homes were inundated in Port Charles as the storm then crossed to the west coast of the peninsula into Colville. From there it travelled south through Kopuatauaki, Coromandel, Manaia, Waikawau, Te Mata, Tapu, Waiomu, Te Puru, Tararu, and Thames. It caused little damage in Hauraki District but left its mark in Matamata-Piako as it moved into South Waikato.

Tragically a life was lost at Waiomu and two people were seriously injured. Dorothy and Ross Newall were asleep in their caravan at the Waiomu Bay Holiday Park when they were woken by the sound of the Waiomu Stream in flood. They dressed quickly but the water had reached a height of nearly 1.5 metres against the awning ranchslider in this short time. Both were swept from the caravan. Ross was swept into a tree but Mrs Newall was swept out into the main stream. Her last words to her husband were "I love you" as the stream carried her out into the Firth of Thames. Dorothy's body was found near Thames the following day. Fortunately the emergency did not occur at a peak holiday season or the death toll could have been much higher.



This is the second death to occur in flood events at Waiomu but from a different catchment. On 17 February 1985 Ivy Souter was swept out to sea by the Pohue Stream after her house was undermined by severe flooding.

Other response issues of interest were a significant North Island power outage, due mainly to wind conditions, resulting in 125,000 customers being without power for varying periods. The insurance industry struggled to cope with the largest number of claims in New Zealand history – 14,500 as at 2 August 2002.

Central Government was quick to respond with Minister of Civil Defence the Honourable George Hawkins arriving on 21 June 2002 and returning with Prime Minister Helen Clark on Saturday 22 June to visit the devastated areas.

Civil Defence Controller Basil Morrison used his considerable knowledge and skills to keep the response on track. The event was managed well and some 34 agencies were involved at various stages.

Early attempts at impact assessment were inadequate and the Thames Search and Rescue Organisation were contracted on the Saturday to individually inspect every affected property and record it on council planning maps. This was achieved in two days for the area from Thames to the north and east to Port Charles.

More than 500 properties were affected with 356 houses inundated. For many, June 21 was a day that changed their lives for ever.

Since the event, I have spoken to countless organisations and groups on the management of the event. Perhaps the most outstanding feature of how it went is the community spirit which, for many of us, was quite humbling. The emergency services excelled and the civil defence management structure was robust. Beyond that we were dependent on hundreds of volunteers.

New Zealand Fire Service volunteers, with 20 appliances, worked 3072 manhours from Thursday through to Monday. Voluntary Rural Fire Forces also worked long hours, some in isolation. Additional volunteers had to be coordinated and this is an issue each emergency manager has to plan for. Te Puru was the area hardest hit. CEO Steve Ruru resides in Te Puru and was a victim of the flood himself, making it a difficult time with conflicting priorities

The Waiomu Motor Camp on the Thames Coast following the weather bomb. Photo: John Titmus, MCDEM. 21 June 2002.

and responsibilities. Somehow I recall seeing Steve at nearly all the major briefings and his leadership was apparent.

Although not officially endorsed by civil defence, a community centre was established at Te Puru, requesting donations on national media. The result, as you can imagine, was massive with the ultimate consequence of becoming somewhat out of control. However, the local communities drew considerable strength from the centre and the positive outcomes outweighed later inconveniences.

An ex-gratia payment of $245,000 pledged by Central Government was gratefully accepted. A Mayoral Flood Relief Fund reached an amazing total of $352,081.86. Transfund subsidy to date totals $1.6 million. The Thames-Coromandel District Council costs total $3.12 million.

Car swept away, Te Puru, Thames Coast, June 2002.

No article on the "Weather Bomb' would be complete without reference to the recovery and reduction phases of the emergency. Transition from response to recovery was seamless. Recovery was evident from early Friday 21 June and continues to date. Unfortunately the Coromandel was severely flooded again on 20 April 2003 causing a major setback. For Tararu residents it was the second major flood in six months adding an unwanted dimension. Recovery costs, without the latest Coromandel flooding, exceed $4 million.

Recovery has been further hindered by the significant rainfalls experienced since the weather bomb and its effect on stream maintenance. Many of the homes flooded are now uninsurable. In fact motor vehicles, in some cases, are not covered by flood insurance. An accurate assessment of the insurance problem is something we are currently trying to assess.

It is obvious that a reduction strategy is necessary. Before embarking on this track we need to recognise what has already been done. Without the mitigation measures currently in place we would have lost the entire Thames central business district. Completion of the Waihou River Scheme was a major benefit to the Thames Valley combined district. However there is much more that needs to be done. Obviously total flood protection is not possible in all areas. Flood Management Plans, currently in place for Te Puru, Tararu and Thames are an example of mitigation by restriction on land use and building requirements. A Flood Management Plan for Coromandel is nearing completion.

Since the June 2002 weather bomb Thames-Coromandel District Council, in partnership with Environment Waikato, has completed Hazard Mapping for the coast area from Thames to Coromandel. An independent 'Risk Assessment Report' has been commissioned over the same area. A report from a risk assessment consultancy, URS NZ Ltd, is due for public consultation by early June 2003.

Investigations to date indicate a risk assessment below that of the Waiho River at Franz Joseph. However it appears certain that mitigation measures will be recommended to reduce risks to an acceptable level.

Camping grounds will be a prime area for consideration, both relative to physical works and enhanced warning and evacuation procedures.

The risk assessment study will also assist in establishing priorities over a wider area and reduce the tendency for individual communities to be considered in isolation.

A process for effective 'Reduction' is clearly in place. A longer term approved reduction strategy will result and, in my opinion, the process is not reversible. A strategy of viable physical works, improved warning and evacuation procedures including a programme of public awareness, will reduce the risk to more acceptable levels. Ultimately those remaining in moderate hazard areas will need to accept responsibility for their personal safety and property.

LESSONS LEARNT

The most common question following a significant event like the weather bomb is, "what lessons were learned'? Each and every emergency is a steep learning curve and the list of lessons can be endless. I have taken the liberty of summing up with seven issues that are important to me:

- Be outcome focused rather than process driven.
- An effective 'Operations/Advisory Group, call it a CAG, CEG or whatever you like, is essential to good management of an emergency event. This is not just an 'Emergency Services Coordinating Committee'. It is much more representative than an ESCC.
- Intelligent use of Coodinated Incident Management Systems (CIMS).
- Recognition of trauma, for both providers and victims, beyond the traditional 'Crisis Intervention' systems currently in place.
- Greater recognition of the 'professional' volunteer agencies/groups involved.
- Leadership for the 'volunteer on the day'.

In conclusion remember that the Coromandel is really a great place to be and we can cater for all tastes and circumstances. ■

Damage caused by the Kauaeranga River in flood in the Cyclone Bola event of 1988.

STORMS FROM THE TROPICS

By Erick Brenstrum

Lead Forecaster, MetService

Tropical cyclones are revolving storms, about half the size of a mid-latitude depression of the sort commonly experienced in New Zealand, but with a pressure gradient about ten times greater. If you drew all the isobars around a tropical cyclone on the weather map, they would be so close together near the center that they would touch, leaving just a blob of black ink on the page.

When tropical cyclones move away from the tropics towards New Zealand they gradually weaken as the cooler seas provide less heat to sustain them. However, occasionally they have a second burst of development if they meet a cold front in an active trough in the westerlies near New Zealand, which transforms the tropical cyclone into an intense mid-latitude depression.

During this change the cyclone loses its eye wall and the belt of extreme winds surrounding it weakens. However, the area of gale and storm force winds becomes larger – sometimes by a factor of four. Consequently, although the strongest winds associated with the cyclone may now be weaker than before, they are often 500 km or more away from the centre of low pressure. Usually with a tropical cyclone the damaging winds are within about 100 km of the centre, and the maximum winds within about 30 km.

This is one reason these storms are not referred to as hurricanes, or even tropical cyclones, once they reach New Zealand's latitudes. In the tropics these storms are small enough for ships to be able to take evasive action and get out of their way if given sufficient warning, but in our part of the world the area of strongest winds is usually too large to be sidestepped and ships just have to ride it out, unless they can shelter in the lee of the land.

When winds of hurricane force are expected in New Zealand latitudes they are described in a storm warning, with the actual wind speed expected given in knots. Using the term hurricane carries the risk that it may be interpreted to mean that the only danger is close to the centre of lowest pressure.

The worst of these storms to affect New Zealand often occur in the second half of summer or

The Wahine founders at the entrance to Wellington Harbour off Seatoun. Photo: The Evening Post. April 1968

Cyclone Bola devastates a kiwifruit orchard in the Gisborne region. Photo: Gisborne Herald.

in autumn. This is because sea surface temperatures remain high in autumn, allowing the tropical cyclones to retain intensity for longer as they travel away from the tropics, and the chance of encountering an outbreak of cold air surging up from the Antarctic increases as autumn progresses.

After a number of relatively quiet summers in the late 90s, the visits of two decaying cyclones to the North Island in quick succession in the summer of 1996 focused attention on just how destructive cyclones can be.

Cyclone Fergus, coming between Christmas and New Year, brought torrential rain and damaging winds to parts of the North Island and triggered a major exodus from coastal camping grounds as thousands of people got out of its way. Over 300 mm of rain fell in 24 hours over the Coromandel causing flooding and landslides. Heavy rain also fell over Northland and Auckland and a large slip closed State Highway 1 in the Brynderwyn Hills. The wind was at its worst near East Cape where a house was destroyed. Fortunately, there was no loss of life, in part because of timely warnings about the ferocity of the storms.

A fortnight later, Cyclone Drena hit the North Island causing more wind damage than Fergus but bringing less rain. The combination of wind and extremely high tides caused millions of dollars of damage at Thames, where the waves came over a seawall and inundated houses on a reclamation. Easterly winds of 90km/h the day before had helped pile up water against the coast near Auckland. Without losing much of its strength, the wind swung around to the north, pushing the excess water southwards into the Firth of Thames and dangerously increasing the sea level there. The waves on top of the higher-than-normal sea did the rest.

Cyclone Drena claimed one life in Auckland, when a man was electrocuted. He had grasped a fallen power line in order to pull himself up a bank.

During the summer, the Pacific was influenced by a weak La Nina event which caused the airflow over the North Island to be from the northeast more often than normal. This helped steer Fergus and Drena over the North Island.

NEW ZEALAND'S WORST STORM

Cyclone Bola caused extensive flood and wind damage in March 1988, and Cyclone Gisele sank the Wahine in April 1968. They were both examples of decaying tropical cyclones. So too was the great storm of February 1936, which has largely fallen from popular memory, but was arguably the most damaging storm to strike New Zealand in the last 100 years.

This tropical cyclone formed south of the Solomon Islands on 28 January 1936, then moved southeast to pass between New Caledonia and Vanuatu. It met up with a cold front north of New Zealand on 31 January, and intensified and crossed the North Island on 2 February. It was not assigned a name, as the practice of naming tropical cyclones did not begin until 1963.

Heavy rain fell over the entire North Island, bringing most of the major rivers into flood. The Mangakahia River in Northland rose 19 metres at Titoki. Kaitaia's main street was flooded a metre deep and one man was drowned when a house washed away. Another man was killed in the Coromandel near Thames when his hut was carried into a flooded stream by a slip.

In Whangarei, almost 300 mm of rain fell in 24 hours and floodwaters ran through the business district, tearing up footpaths and entering buildings. At Waitangi the water rose two and a half meters in twenty minutes, forcing eight men sleeping on the floor of the Tung Oil Company cookhouse to take refuge on the roof. When the structure began to move they clambered on to a tree overhanging the cookhouse, which was later carried away by the flood.

A train was marooned by washouts near Kaikohe and a railway bridge north of Whangarei was destroyed, stopping rail traffic for days. Torrential rain fell on the slopes of Mount Pirongia between Kawhia and Te Awamutu, causing flash floods in the streams and gullies running down its flanks. A huge landslide fell across the valley floor of the Ngutunui stream, holding the floodwater up like a dam. When the increased pressure carried away the obstacle, an enormous body of water swept down the river bed with irresistible force, carrying away a large bridge and damaging four kilometres of road. Both banks of the river were swept clean of soil and vegetation.

Aerial view of a property on the Poverty Bay Flats after Cyclone Bola. Photo: Gisborne Herald.

One observer saw rimu and kahikatea trees borne along the torrent rear up when their roots or branches caught against some obstacle, and topple end over end, with a crash that could be heard a long way off. When the water subsided, he picked up 40 dead trout and counted hundreds of dead eels killed by the rushing timber and large boulders carried along by the flood.

Drowned sheep, cattle, pigs and chickens, mingled with trees, were a common sight in rivers all over the North Island.

In Hawkes Bay, the Tukituki river flooded the settlement of Clive, cutting the road and rail link between Napier and Hastings, and drowning 1500 sheep in the stockyards. The Tukituki also broke its banks at Waipukurau, forcing the evacuation of 70 houses and drowning thousands of cattle and sheep. The Esk River flooded to over a kilometre wide, and began to flow down an old channel, threatening the township there, until the river mouth, which had been closed by the high sea, was reopened.

Roads and railways were inundated by floods and undermined by washouts; bridges were destroyed, and slips came down in their thousands all over the North Island. Near Stratford, the main trunk railway line was blocked by more than a dozen slips, the biggest of which was 500 metres long. Another slip diverted a stream so that it flowed a meter deep through a tunnel, leaving it strewn with driftwood.

The Whanganui river flooded thousands of acres of farmland, entered a number of houses, and carried away two spans of the Shell Oil Company wharf. The Okehu water pipeline was cut, leaving the city with only one day's supply. The Whangaehu river rose almost two and a half metres in half an hour, drowning hundreds of sheep and flowing through the Whangaehu hotel.

In the Wairarapa, the Ruamahanga river flooded farmland, cutting off Martinborough, and the Waipoua flooded several streets in Masterton. The Waiohine river flowed over the main highway for a time, and the Rimutuka road was blocked by a large slip.

Storm surge occurred along the east coast of the North Island, causing extreme high tides topped by large waves. At Te Kaha in the Bay of Plenty, a sea higher than any in living memory washed a house into the ocean and swept away eight fishing boats. The road was washed away in some places, and in others covered by heavy logs and piles of driftwood. Near East Cape, huge seas entered the estuary of the Awatere river and smashed a portion of a factory at Te Araroa. At Castlepoint on the Wairarapa coast the sea washed away the sand hills and invaded houses a hundred metres inland.

The wind blew in windows from Kaitaia to Picton, and brought down hundreds of thousands of trees, cutting power, telephone, and telegraph lines all over the North Island.

Palmerston North was hardest hit. Houses lost roofs, chimneys were blown over, and the grandstands of the A&P Association, the Awapuni Racecourse, and the sports grounds were demolished. A man was killed when he was blown off his roof as he was trying to repair it. Hoardings, fences, and brick walls were blown over. Twenty-eight trees came down over the main power lines in a 120 metre stretch of road. The Manawatu River rose five metres and flooded the Taonui Basin, turning it into an inland sea.

A train was derailed near Makerua, just south of Palmerston North. The last two carriages and the guards van were caught by a gust of wind and thrown down a bank into the Makerua swamp. Empty railway wagons on sidings at Levin and Linton were blown over and the small railway station at Karere was destroyed. Fallen trees blocked the line between Levin and Otaki, and passengers had to cut through them with axes before trains could pass.

At Longburn, the Anglican church was demolished and scattered over the road and railway line. A horse on a nearby farm was cut in half by a flying sheet of corrugated iron. The Feilding Aero Club hanger was blown away and the two planes inside it destroyed.

Buildings were also destroyed in Taranaki. In Inglewood the badminton hall blew down and the Anglican church lost its roof. In New Plymouth the Frankleigh Park hall was destroyed, while in Waitara a number of large buildings disintegrated, and a 25 metre steel and brick chimney was blown over, as was the Harbour Board beacon tower.

The wind wrought havoc in orchards all over the North Island, destroying large portions of crops. Fields of maize, wheat, and oats were flattened from Northland to Marlborough, haystacks blew away, and in Pukekohe potato plants were sheared off at ground level.

A hunter and a tramper died of exposure in the Tararua Ranges, north of Wellington. At the height of the storm, trees were being uprooted from the ridges and thrown into the valleys, and the Waiopehu hut was blown into a gully. Trampers described whirlwinds in the gale twisting the crowns of trees around until the branches splintered off. The trunks of some of these trees are still standing today.

In Auckland 40 boats were sunk or driven ashore in the Waitemata Harbour and several more in the Manukau Harbour. In Cornwall Park, hundreds of trees were snapped off or uprooted, accompanied by sounds likened to cannon fire. Falling trees brought down power lines in all suburbs and also delayed the trams. The Auckland Gliding Club hanger disintegrated and all the gliders were destroyed.

A fishing launch in New Plymouth was lost at sea and the crew presumed drowned. Numerous small boats were wrecked in Wellington Harbour and a coastal streamer was driven ashore near the city, at Kaiwharawhara.

Disaster was only narrowly averted when the inter-island ferry Rangatira steamed into rocks near the mouth of Wellington Harbour. After twenty minutes stuck fast she was able to reverse off the rocks then turn, and back slowly up the harbour. Taking water in through the gaping holes in her bow, her propellers were half out of the water by the time she grounded next to Clyde Quay wharf, and her forward passenger decks were awash. Fortunately none of the 800 passengers and crew suffered serious injury, although many were plainly terrified by their experience.

Just as Drena followed Fergus, the great storm of February 1936 was followed by another in March 1936, which affected a smaller area of the North Island, but caused more damage in some places.

Thirty-two years later, the fate the Rangatira escaped befell the inter-island ferry Wahine, when the remains of another tropical cyclone reached New Zealand. Although warned of the possibility of southerly winds in excess of 110 km/h occurring in Cook Straight as the low pressure zone passed over the North Island, the Wahine attempted to enter Wellington Harbour in deteriorating conditions. As she crossed Cook Straight, her barometer dropped 5.6 hPa in just over an hour and the gale force wind was rapidly intensifying. The waves were rising, causing difficulty in steering the ship even when it was still in deep water 45 minutes south of the harbour. As the Wahine moved into the shallow waters of the harbour mouth she was struck by several large waves. One broke over her stern and another rolled her partly on her side and swung her sharply off course. About this time, for reasons unknown, she lost the use of her radar. She became disorientated in poor visibility and manoeuvred in the harbour mouth for almost half an hour before striking Barrett's Reef. Seven hours later she sank with the loss of 51 lives.

Although the worst of these storms from the tropics may only occur in New Zealand once or twice in a lifetime, their powers of destruction are so great, that they are remembered forever by the people who live through them. ■

COASTAL HAZARDS

By Robert G. Bell &
Richard W. Gorman

Coastal hazard scientists, NIWA

Increasing numbers of people are realising their dreams of living by the sea, or at least spending more recreational time at the beach, fuelling a buoyant real-estate market. Usually, the coast is an obliging environment to enjoy these lifestyle and recreational experiences. But occasionally, the sea can turn ugly, turning on a wet and wild front that can cause serious damage to coastal properties and infrastructure, create havoc for recreational pursuits and shipping, and at worst endanger lives.

Marine scientists and coastal engineers have learnt through bitter experience that attempting to control the ocean during its wild moods can be next to impossible. Therefore, it is important that coastal developers, resource managers, maritime and recreational users apply some precaution when planning coastal developments, protection measures or activities. Emergency management groups also need to know about areas of the coast that are vulnerable to wave impacts, coastal inundation and erosion to ensure the safe evacuation of residents.

COAST'S FUNCTION AND OUR RESPONSE

After all, the natural function of the coast is to act as a buffer as the dynamic ocean "collides" with a static landmass. To achieve this, the coast must at times absorb tremendous energy generated not only by large waves, but also severe winds, storms, and tsunami, and undertake this absorption over a very narrow buffer zone.

Mostly, the coast absorbs this energy by wave breaking in shallower water and by either flexing through the redistribution of large quantities of beach sand or gravel (potentially causing erosion) or providing a sufficiently high barrier such as a cliff or sand dune for gravity to halt the sea's onslaught. But when properties, infrastructure and people get caught up in this natural buffer zone, these ocean processes become coastal hazards that require some form of pre-planned response, whether it be houses set back sufficiently from the shore to avoid being in this buffer zone or provision of forecasting systems to warn the public, emergency management agencies and shipping of the hazards.

COASTAL HAZARDS

Coastal hazards arise from several different sources, producing coastal-hazard "drivers" (Figure 1) that cause impacts on the coast, which can be conveniently split into three categories to manage and plan for:

- coastal inundation (or flooding)
- coastal erosion
- recreational and maritime hazards.

Coastal hazard "drivers" are sourced from storms, winds and geological ruptures of the seabed (which can create tsunami waves). Storms and cyclones are the most common cause of coastal hazards, creating waves and storm surge that ride on top of the tide. As a result, storms can cause havoc in coastal communities (through coastal flooding, wave overtopping and damage, and coastal erosion), to recreational activities (fishing, boating, swimming) and maritime operations (eg. the grounding of the Jody F Millennium off Gisborne during a storm on Waitangi

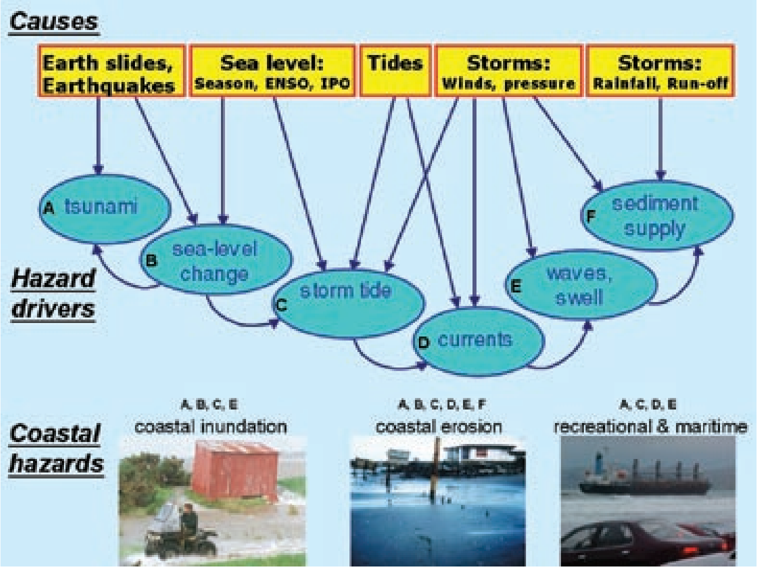


Figure. 1: Coastal hazards: causes, "drivers" and impacts. Photos: The Southland Times, T. Hume (NIWA); R. Saxby (Gisborne)

Coastal inundation of the road and beach front motels at Whitianga along the Esplanade at the southern end of Buffalo Beach. The sandbagging prevented any real damage. This 23 August 1989 event was smaller in terms of previous coastal flooding experienced at this site in 1936/1968/1972/1978. Photo: Environment Waikato.

Day, 2002). The main focus of this article is on waves and elevated storm tides and their impacts.

WAVES

The waves that reach the New Zealand coast have often travelled a long way to get here. They are born somewhere in the wide expansive ocean where wind is blowing across the surface. As you can observe when a puff of wind first starts to blow on a calm lake, the first waves to form are small, closely spaced ripples travelling in the wind direction. Once a wave crest is formed, if the wind continues to blow across it, the air speeds up over the curved crests of the waves. Much like the force on an aeroplane wing, the Bernoulli effect of reduced air pressure exerts a lift force to make the wave grow further in height.

However, waves do not grow indefinitely. If they become too steep they will break, dissipating their energy. For short lengths between crests (the wavelength), this happens quite early in the growth stage, resulting in a dynamic equilibrium between energy gained from the wind and energy dissipated by breaking, while longer waves can keep growing. There is another limit to wave growth in the open ocean. The longer the wavelength, the faster the waves travel. As the wave speed approaches the wind speed, the relative wind speed over the crest decreases, reducing the force acting to increase the wave height. The end result is that under a steady or constant wind speed, the sea state will eventually tend towards an equilibrium mixture of different wavelengths and a limit on the wave height. For low wind speeds, this mixture is dominated by small, short-crested waves, while for stronger winds during a storm, the waves become both taller and longer. So while a persistent 15 knot trade wind in the tropics will produce waves of about 3m height and 100m wavelength, in the Southern Ocean, where persistently strong winds circle the globe, wave heights of 10m and wavelengths of 200m are not uncommon.

As a rule, though, winds over the ocean are highly variable. Calm periods are interspersed with the passage of storms and other weather systems of various shapes and sizes. The sea state produced by the storm will depend not just on the wind speed, but also on the physical size and structure of the storm, and on how long the storm takes to pass. A weather map showing a very slow-moving system of long, straight, tightly spaced isobars indicates a region of strong winds that have plenty of time and distance to build up a well-developed sea state. A compact, fast moving weather system, on the other hand, can result in a less developed, more confused mixture of wavelengths and directions, as "young" waves soon lose the wind speeds and directions favourable to their ongoing development.

What can happen though, is that groups of waves travelling at close to the same speed and direction with which the whole storm system is moving can continue to grow as the storm travels along with them. For an observer anchored in a boat at a fixed location, this can mean that the sea state can increase very rapidly as the storm arrives, bringing along with it already well-developed big waves. This phenomenon is

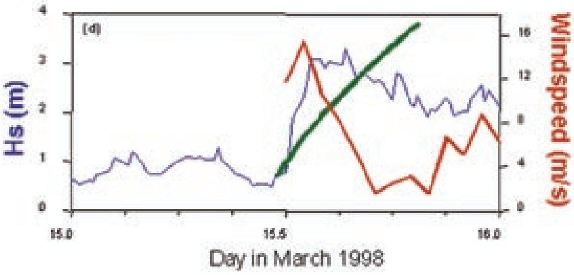


Figure 2. Actual wave growth measured by the Baring Head wave buoy (blue line) and wind speed recorded at Wellington Airport (red). The rate of duration-limited growth in waves expected for winds of this speed blowing over the ocean is shown in green.

Wave inundation at Haumoana during the Easter Storm (3–4 April 2002). Photo: Hawkes's Bay Regional Council.

often observed in wave measurements off Wellington (and by the Cook Strait ferry pilots) in which wave heights associated with the onset of southerly winds rise much faster than would be expected for local duration-limited wave growth from the observed wind speeds. NIWA has used wave and wind model simulations with moving storm systems to reproduce results of this type. See Figure 2.

Once generated by winds in a localised weather system, the waves can keep on travelling away from the generation area. Longer waves (swell) in particular lose very little energy as they travel, and can cross thousands of kilometres. Groups of waves have been tracked from waters south of New Zealand right across into the North Pacific. An enterprising surfer with an airline ticket could even manage to surf the same wave in Hawaii and California. Even on a windless sunny day, a section of coast can experience waves arriving as a long swell from distant parts of the ocean, which can catch coastal communities unawares, particularly during high tides, as happened along the South Wellington coastline during Waitangi Day in 2002.

Because of the high prevalence of strong winds (predominantly westerlies) in the Southern Ocean, New Zealand's south and west coasts can generally rely on receiving some swell from this sector. But storms in the Tasman Sea will frequently contribute as well. The northeast coast, from East Cape to Cape Reinga, is exposed instead to the Pacific Ocean, which for most of the time has less energetic wave conditions. However occasional very intense extra-tropical cyclones, can produce intense wave conditions here, as witnessed by Cyclone Giselle (Wahine storm) and more recently by Cyclone Fergus and Drena in 1996/97.

The long-term average wave height in the waters around New Zealand (See Figure 3) reflects the influence of these generation sources. Mean wave heights of 3-4m are found off the southwest tip of the country, with waves predominantly arriving from the SW quadrant. The presence of landmasses such as the South and North Islands blocks waves from some directions reaching nearshore waters, resulting in a shadow effect and a decreasing trend in wave height in a north-easterly direction. There is also a seasonal cycle in mean wave height, with the highest monthly means in late autumn or winter around one metre higher than the lower summer average height.

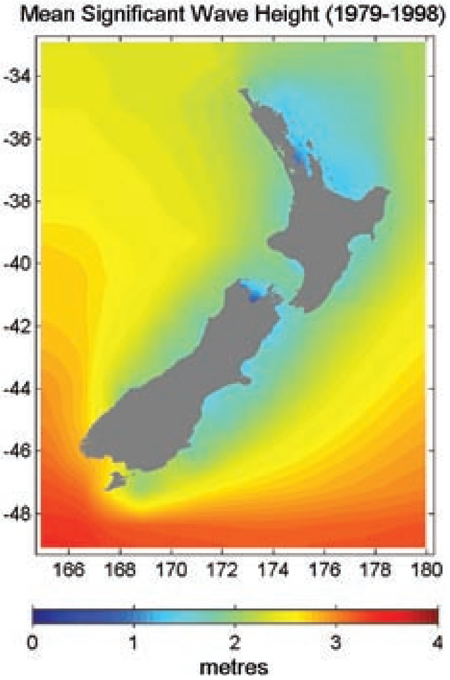


Figure 3. Significant wave height derived from the NIWA WAM model hindcast of wave conditions in the New Zealand region, averaged over the full 20 years (1979-1998) of the hindcast.

NIWA used the WAM wave generation model to simulate wave conditions in the New Zealand region over the 20 years from 1979 to 1998. Why was this approach adopted? How can we use this and other means to characterise the wave climate, to help us understand how damaging wave events occur at the coast, and how to predict and mitigate their effect?

The traditional way of gathering wave information was visual observation. Experienced observers such as ships' officers, lighthouse keepers and harbourmasters have contributed a

An averaged video composite of numerous 1-second images of waves at Tairua Beach. The whitest areas indicate areas where wave breaking is dominant, and darker areas indicate surf rips, that channel water back out to sea.

considerable and longstanding record of sea conditions. The advent of instruments with automatic recording capability, such as accelerometer-based wave buoys, has allowed for more detailed in situ records, particularly for nearshore waters. More recently, satellite-based radar altimeter and synthetic-aperture radar instruments have allowed regular sampling over the vast ocean surface, but don't cover coastal waters due to interference by the adjacent land mass.

All of these methods still have limitations in terms of the spatial and temporal coverage they can provide, and numerical modelling can help to fill some of those gaps, as well as providing a forecasting capacity. Models such as WAM and Wavewatch are designed to simulate wave generation and transformation at oceanic scales. They work by considering the transfer of wave energy associated with a sea state subject to all the processes described above, ie. energy input from the winds (which can be forecast ahead of time), propagation across the ocean, energy transfer between different wavelengths and wave directions, dissipation through breaking, and interactions with the land. The models are heavily dependent on high quality inputs in the form of wind fields over the oceans, usually taken from global atmospheric models and/or meteorological data assimilation systems, which are now routinely used by weather forecasters. Now, armed with a much better knowledge base of the "wave climate" around New Zealand, coastal resource managers have a better base to plan coastal subdivisions from wave impacts on coastal erosion or flooding and ship operators can plan voyages more safely.

SURF RIPS

Surf beaches are very popular places of recreation in the New Zealand summer, but contain dangers both in the sheer energy of the breaking waves, and the less obvious form of rip currents that can sweep swimmers out to sea. A rip is formed because breaking waves tend to pile up extra water between the outer surf breaks and the beach ("wave set-up"). If, for some reason, one part of the beach has bigger waves breaking, and hence more set-up than an adjacent section of beach, a mismatch in water level along the shore is created that drives the excess seawater parallel with the shore from the high set-up zone to the lower set-up zone, which then escapes out to sea as a rip current. This tends to be a self-reinforcing process, as the offshore-directed rip current then acts to further inhibit wave breaking near the shore, sustaining the wave-set-up gradient. Surf rips can be spotted by looking for areas of relatively little wave breaking—indeed a trap for the unwary who might think that the apparently calmer water would be a safer place to swim. But sometimes rips are not particularly obvious at a quick glance. Furthermore, they can be quite dynamic features that move around considerably from day to day and with the tide, so they can still present problems even for people aware that they may be present at a particular spot along the beach.

Video imaging provides one useful tool for identifying and studying surf rips and related features of the beach and surfzone, and is also useful for education. Mounted on a high vantage point, a video camera can capture images of a large area of beach, and can be set to record automatically on a regular schedule. This has some big advantages in frequency of measurement and spatial coverage over traditional surveying methods, as well as not requiring people or equipment to enter the very difficult working environment of the surf zone.

An example is the video system at Tairua Beach, on the Coromandel Peninsula (www.niwa.co.nz/services/cam-era). The camera is mounted at 70.5m elevation on Paku Hill, overlooking the beach from the south. The camera is activated hourly, taking a burst of images every second over a 940 second recording period during daylight hours. The captured images can be used in various ways. Individual waves can be identified, and tracked through a video sequence to estimate wave speed across the varying water depth, for example. For tasks such as identifying surf rips though, individual images are not immediately useful. Waves occur at somewhat random times and with considerable variability in height and breaking position along the beach. So where a single wave happens to be breaking when an image is taken this does not necessarily give a good indication of the location of rips or sandbars. But with digital recording it is possible to average over a sequence of images long enough to include a large number of passing waves (eg. the whole 940 seconds), largely removing this inherent variability. The resulting averaged images are brightest in the regions where waves mostly break, corresponding to sandbars, and are darkest in the surf rips and other areas of less frequent wave breaking. This provides a valuable tool by providing a clear and direct map of potentially dangerous surf rips and can be used in educating swimmers. The mass of data provided by a long record of averaged images (the Tairua camera has been running since September 1997) is also invaluable in studying the dynamics of moving sandbars and rips. Both rapid movements through storms and longer-term variations through the year can be tracked.

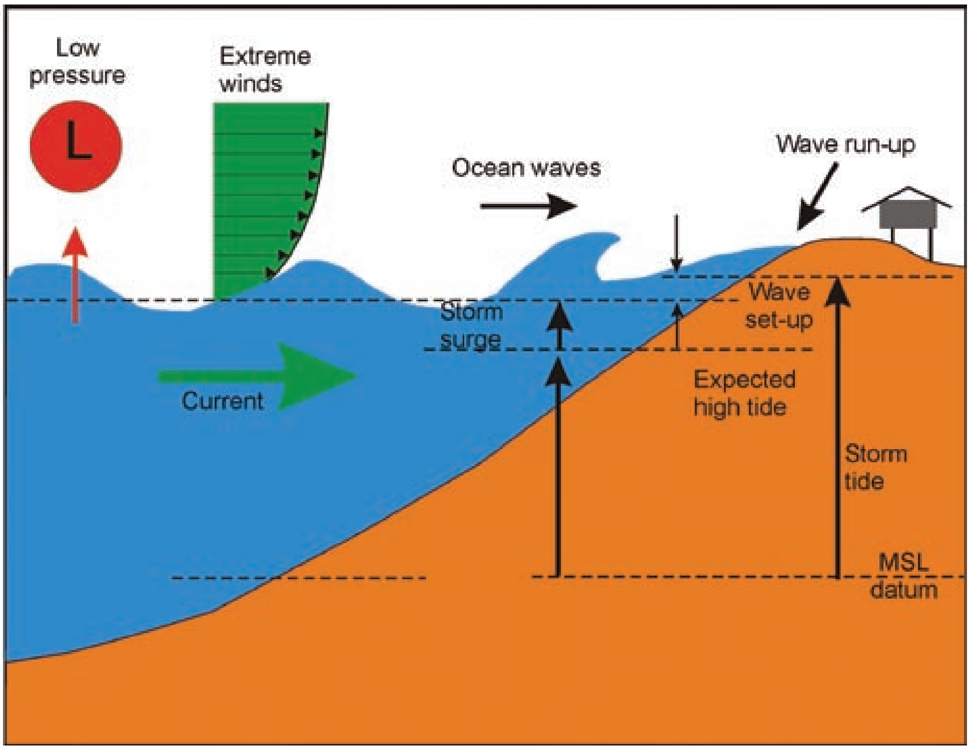


Figure 4. Schematic of the various vertical height components that contribute to a storm-tide elevation above a MSL datum, at the shoreline, which is added to the wave run-up.

STORM TIDES

When waves and winds whipped up by storms combine with high tides, it becomes a recipe for coastal inundation or sea flooding of low-lying coastal land. Extensive sea flooding or wave damage has impacted Thames (1995, 1997), Haumoana/Te Awanga south of Napier (1974, 2002), Invercargill and Colac Bay (1999), and South Canterbury (2001). The most extensive coastal inundation event occurred in March 1936, when a low depression system causing significant storm surge on the back of the highest spring tides last century flooded much of the Hauraki Plains. In many other cases, storm surge and/or high tides have exacerbated river flooding impacts by holding up flood waters causing extensive inundation of lowland areas.

Storm surge is the term used to describe the temporary elevation in sea level that arises during adverse storm conditions (See Figure 4). There are two contributing factors (low barometric pressure and winds), which when combined can produce storm surge heights of up to one metre above the predicted tide around New Zealand. First, low atmospheric pressure causes a "vacuum effect" over the ocean underneath the moving low system, where the sea level is raised to compensate for the drop in air pressure– theoretically a 1cm rise for every fall of 1 hPa in barometric pressure below the mean atmospheric pressure (called inverted barometer). For example, the barometric pressure in the eye of Cyclone Giselle (Wahine storm) as it passed Tauranga on 9 April 1968 reached 964 hPa. That is 50 hPa lower than the mean annual pressure of 1014 hPa, which would have raised the sea level locally by around 0.5m due to the inverted barometer effect alone.

The second contributor to storm surge comes from adverse winds that pile up water against the coast, either by strong winds blowing directly onshore or by marine winds that blow parallel with the coastline, provided the wind has the shoreline on its left. This is caused by the Coriolis force of the spinning Earth that deflects the sea movement to the left of a wind stream in the Southern Hemisphere. For instance, in the Bay of Plenty situation again, Cyclone Giselle initially caused strong north-easterly onshore winds but as the storm moved further south, winds became more south-easterly (shore parallel) with the coast on the left, continuing to pin ocean water up against the coast (whereas a norwester on that coast causes the sea to be deflected left way from the coast). Total storm surge (inverted barometer and winds) at Tauranga

Waves up to six metres high crash into the backyards of Richmond Street properties. Photo: The Timaru Herald, 20 July 2003.

during Cyclone Giselle reached around 0.9m above the predicted tide for that day.

For resource and emergency managers, what is important is not necessarily the storm surge, but what the storm tide level will reach above a local datum, before assessing the risk of coastal inundation.

Wave set-up occurs when waves pile up extra water between the outer surf breaks and the beach. For a typical dissipative (gently-sloping) beach, wave set-up is usually around 15% of the offshore wave height beyond the breaker zone, which say for 4m waves can add another 0.6m onto the storm surge height at the shoreline. Finally, the vertical height reached by wave run-up across the beach or up over coastal barriers needs to be added to the storm-tide level. Wave run-up is governed very much by local shoreline topography, the slope of the beach and the type of coastal barrier, whether it is a sand dune, gravel barrier or seawall. Run-up can add a few metres vertical reach above the storm tide level, particularly when a big sea is running during high tides, causing damage to coastal properties, infrastructure (lifelines, roads) and coastal inundation of properties or agricultural land.

A recent example is the damage done by the Easter storm on 3–4 April 2002, that caused coastal property damage by waves overtopping the gravel barrier at Haumoana and Te Awanga in the Hawkes Bay, and also closed the Kaikoura stretch of SH1 and the South Wellington roads. In this case a moderate storm tide due to high perigean-spring tides but little in the way of storm surge, combined with wave set-up and wave run-up from heavy southerly swells generated by a deep low to the South Island.

Although coastal hazards only affect vulnerable low-lying coastal margins, nevertheless the risk of damage and potential loss of life increase markedly each year as the value of coastal properties continues to boom and infrastructure and roads are installed to service this growth. Large coastal storms affect some part of the New Zealand coast at least once per year, and occasionally severe storms that produce high waves and storm surge coincide with high spring tides to create havoc for vulnerable low-lying communities. Furthermore, looming on the horizon is the projected acceleration in sea-level rise and possible increases in the intensity of storms. The risks from coastal hazards to people living and enjoying recreational activities by the sea are likely to continue increasing. Better public awareness of the vagaries of the sea and appreciation of the crucial role the coastal buffer plays in absorbing the sea's energy will be needed to assist implementation of prudent measures to minimize future impacts of coastal hazards.

Acknowledgement: This article is based on work funded by the NZ Foundation for Research, Science & Technology. ■

Swells on
NEW ZEALAND COASTS

By Mads Naeraa

Marine Forecaster, MetService

As an island nation, New Zealand is continuously faced with coastal gales and storms, and huge swells that batter our coastline several times a year. A danger to all beach users, including boaties and fishermen, these swells sometimes reach a size when even buildings, roads and railway lines suffer structural damage, coastal farmland is flooded and livestock perish. While most prevalent in autumn and winter, big swells can hit at any time of the year. The Waitangi Day storm of 6 February 2002 is a prime example of an extreme weather and swell event that occurred in the middle of summer.

Although the entire New Zealand coastline is exposed to open ocean swells, the swell climate differs greatly from coast to coast. The majority of the swells that hit our coasts are generated by depressions in the Roaring Forties and Screaming Fifties, and these are more intense in winter.

All waves start out as little ripples called capillary waves. With increasing wind, these grow into larger waves known as sea, and upon leaving the area where they are generated, or when the wind ceases to blow, these waves become swell. Following great circle lines – straight lines on a sphere – swells travel large distances across the oceans, becoming organised into groups of larger waves known as sets, the distance between crests growing and the individual waves becoming flatter.

Some swells that hit New Zealand are generated close to the country, such as in the Tasman Sea, while others come from distant storms in the eastern or northern Pacific, or even from the Indian Ocean. Once swell waves approach the coast and shallower water, they slow down due to friction and become steeper, eventually breaking as surf.

REGIONAL EXPOSURE

THE WEST COAST

Situated in the path of the mid-latitude westerlies, the west coast of both islands of New

The Suilven battling huge waves off the Wellington Coast in February 2002. Photo: Trevor McGavin.

Zealand sees constant swell action. Flat days are very rare and most days see swells of around two metres, with bigger swells a common occurrence. Therefore, structural damage is rare on this well prepared coastline, and perhaps the biggest threat is to recreational users such as boaties, swimmers and fishermen.

The **Kapiti-Horowhenua coast** stands out because of its sheltered location in the lee of the South Island. However, when a deep low develops in the Tasman Sea, or a strong westerly flow covers New Zealand, big swells and rough sea will impact on this low lying coast, potentially causing serious damage to the many seaside homes.

Facing northeast, the **east coast of the North Island from Cape Reinga to Cape Runaway** is sheltered from the prevailing southwest swells, and consequently sees less swell action, but at times very big swells in excess of four metres will hit this area, especially from tropical cyclones.

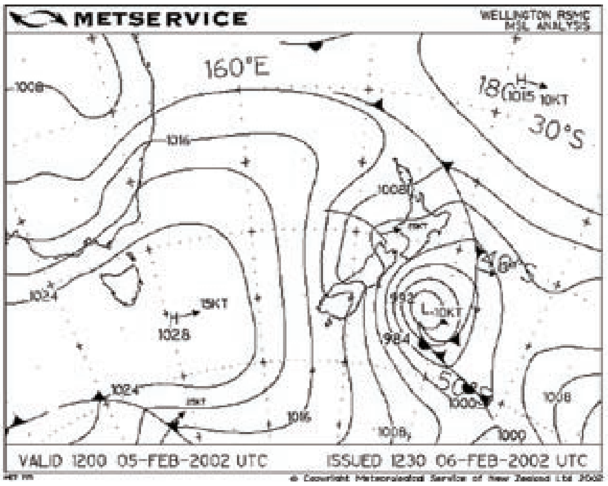
Tropical cyclones are much smaller than the mid-latitude lows characteristic of New Zealand weather, but potentially very destructive. Extreme winds, often up to 150 knots, blow clockwise in a small area around the cyclone. When the system moves south to our latitudes, and begins its transformation to a mid-latitude storm, the maximum winds decrease significantly but spread out over a much larger area. If the cyclone moves only slowly southward a very big swell will be generated, hitting the coast a day or two later. Should the "cyclone" itself reach the coast, big swells combined with gale or storm force onshore winds and driving rain, can cause flooding, wind damage and possible slips.

Furthermore, the storm surge caused by onshore winds and low atmospheric pressure can cause flooding, even in areas not exposed to heavy wave action.

Development of the east coast, especially close to Auckland, with new houses being built ever closer to the sea, will undoubtedly lead to increased damage from future big swells.

THE EAST COAST – EAST CAPE TO BLUFF

The east coast from East Cape to Bluff receives swells from several sources, mostly mid-latitude lows that track east, south of us, and from lows that develop southeast of the country. Normal swells on this stretch of coast are between half a metre and two metres from the south-southwest through northeast. However, big swells over four metres are not rare, and every now and then swells of over six metres will hit this coast.



Surface analysis at midnight 5 February 2002, showing the storm low just west of the Chatham Islands.

HEAVY SWELL EVENTS IN 2002

THE WAITANGI DAY SWELL

On the evening of 5 February 2002 a low developed rapidly east of the South Island and during the night, southerly winds west of this low reached storm force with sustained winds of more than 47 knots. This storm sunk five boats in Lyttelton Marina and generated a huge swell that travelled up the east coast.

On the morning of Waitangi Day, it was uncommonly calm on the south coast of Wellington, but giant waves were crashing on deep outside reefs far offshore, and whitewater washed across roads, leaving gardens full of rocks and kelp. The Baring Head wave rider buoy, moored southeast of Wellington Harbour, measured astounding 13 metre waves.

Wellington surfers, who normally complain about the lack of swell, were scouring the coast looking for rideable waves, finding them only at sheltered spots inside the harbour, places that barely see a ripple on normal days.

Around midday, a southerly gale hit the area, adding a confused sea to the swell and the tide peaked. Roads along the coast were closed, as they were full of debris and there was a real danger of cars being washed into the sea. The tide started dropping in the afternoon, and the Wellington City Council could start the long process of clearing roads and repairing sea walls. The cost of the damage ran to several hundred thousand dollars.

Ferry sailings across Cook Strait were cancelled, but one freight ship, the Suilven, braved the elements. She was seen on national TV news the same evening, struggling to make it out of Wellington Harbour in waves that dwarfed her.

High winds and rough seas are by no means a rare occurrence on the Wellington coast, but for the thousands of people who witnessed this spectacle, there was no doubt that this was something out of the ordinary. On beaches and headlands, people watched in awe as enormous waves crashed in a deafening roar and salt spray covered everything and everyone.

In Gisborne, the log carrier Jody F Millennium was being battered against the wharf by big waves and was forced to leave port. It ran aground on a sandbar outside the harbour and for the next two weeks, authorities struggled to free the vessel, while pumping off the oil in order to avert an environmental disaster. On 14 February huge waves again pounded the coast, thwarting attempts to refloat her.

Only on 24 February did three tugs finally succeed in refloating the Jody F Millennium, the rescue operation costing an estimated $1.5million.

Waves on Waitangi Day reached heights probably not seen since 1968, when on 10 April, Cyclone Giselle, better known as the Wahine Storm, sank the inter-island ferry off the coast of Wellington, killing 51. Amazingly two more very big swells hit the east coast during the late summer and early spring of 2002.

EAST COAST OF THE NORTH ISLAND

On 13 February 2002, a low that had crossed the upper North Island from the northwest deepened rapidly off the east coast. The following day, a mere week after Waitangi Day, a swell with waves over six metres again hit the east coast to the frustration of those trying to float the Jody F Millennium, but causing little damage otherwise. MetService marine forecasters, in Kelburn as well as onsite in Gisborne, worked closely with the Maritime Safety Authority and salvage operators in Gisborne, issuing special forecasts for the operation.

The swell was forecast several days before the low that was to generate it had even developed, and authorities were briefed on new developments several times daily.

Top: Lyttleton Marina 6 February 2002, Anders Gillies, right, lashes a line to secure a yacht that jammed beneath a walkway during a storm that sank boats in the Lyttleton Marina. This yacht sank soon after. Photo: The Press

Below: A man struggles to keep his balance on the floating pontoons of the Lyttleton marina in the gale. Several boats were battered, some sank, and others were scuttled to minimise damage. Photo: The Press.

SOUTH CANTERBURY

In early April 2002, after a very stormy Easter that saw thunder and hail over the South Island, southwest gales on the Hauraki Gulf and large waves pounding the Kapiti Coast, yet another heavy swell hit. From 1-2 April a low deepened rapidly southeast of the Chatham Islands, and storm force winds generated a southeast swell. This swell coincided overnight 3-4 April with a king tide on the east coast of the South Island, causing severe damage. In South Canterbury, farmland was inundated and a few alpacas drowned. On the Kaikoura Coast, State Highway 1 closed, and kelp and huge boulders were washed across the railway tracks.

Roads were once again closed on the Wellington coast and ferries cancelled, leaving large numbers of frustrated holidaymakers stranded. In Hawke's Bay several houses were destroyed by the massive waves around Haumoana and Te Awanga.

Three swells of this magnitude in such a short space of time are a very rare occurrence, especially in summer.

SWELL FORECASTING AND WARNINGS

Swells may be very big and destructive and forecasting these events is of vital importance. MetService marine forecasters work closely with the Ministry of Civil Defence & Emergency Management and civil defence staff in regional and district councils, providing alerts of heavy swells for east coast areas from South Canterbury to Gisborne, and on the Kapiti Coast, of potentially hazardous swells.

These areas have different thresholds over which swells become hazardous and each is sensitive to swells of different angles. The flat farmland of the Canterbury Coast from the Waitaki River to the Waipara River floods easily, and southeast swells over three metres are dangerous, while swells five metres or more pose a threat to State Highway 1 on the Marlborough Coast.

Storms that are likely to produce swells over three metres are monitored closely, and 'heads up' calls may go out several days in advance. Twenty-four hours before wave height is forecast to reach warning criteria, an official swell warning is issued, followed by a telephone call to the relevant duty manager.

In addition to swell warnings, MetService issues advisories on abnormally high water for the enclosed bays from Bay of Islands to Opotiki. Spring tides, low atmospheric pressure and strong onshore winds, especially in the case of a tropical cyclone northeast of the North Island, can raise the sea level by several metres.

MetService forecasters and civil defence emergency management staff at national, regional and district levels will continuously be cooperating in an effort to ensure public safety and to reduce damage.

FORECASTING TOOLS

Forecasting these potentially destructive swells is a very important job for marine forecasters, and many different tools are used in the process. Moored wave rider buoys continuously relay information on swell height, direction and period, and ships report wind, sea and swell every six hours.

Scatterometers on polar orbiting satellites use a microwave radar to measure the roughness of the sea surface – a rough sea surface will reflect a stronger signal than a smooth surface – giving forecasters direct information on winds over the ocean. This is

Stuck fast in the sand – the Jody F Millennium which ran aground at Gisborne's Waikanae Beach is pounded by the southerly swell.
Photo: Gisborne Herald, February 2002.

an invaluable tool since observations from ships and islands are very scarce over the data sparse South Pacific.

In order to forecast swell a number of parameters must be known. The forecaster must define a fetch – the area over which the wave-generating wind blows – its length, width, the strength of the wind and the duration for which it blows. Armed with this knowledge we can use empirical tables called nomograms to determine when a new swell will arrive, how big it will be, how long it will last and what its period will be (the time between the passing of two successive wave crests). This process is rarely straightforward, since fetches are often of irregular shape and are constantly moving.

Computer weather models predict wind fields over the oceans, but these also depend on observations for their ‘first guess’, and are therefore inherently less precise over ocean areas where few observations exist.

The duration for which the wind blows over a fetch of a certain length determines the height and period of a swell. Because the speed with which a swell travels is proportional to its period, the time of arrival can be determined. A swell with a period of 10 seconds travels at a speed of approximately 16 knots or 30 km/h, while a larger swell with a period of 15 seconds will travel at a speed of 23 knots or 43 km/h.

Once a fetch has been defined, the next problem is to determine the strength of the wind. On land, there are many automatic weather stations (AWS), but very few observations are available over the oceans, apart from a few ship reports, which tend to be less accurate. Scatterometry data provide a good picture of winds over the oceans, but the data is contaminated in the presence of precipitation, and only comes in twice a day.

Having a large number of moored buoys relaying swell data, some close to shore, others further offshore, as well as more drifting buoys over the oceans feeding more data into weather models would obviously increase the accuracy of swell forecasts. But to buy and maintain high-tech equipment in a rough marine environment is unfortunately very costly.

The marine forecaster must thus sort the wheat from the chaff, relying on extensive experience not only to produce the swell forecast, but also deciding which data to use. Local knowledge of the bathymetry of an area – its underwater topography – is also essential. Continental shelves, typically at a depth of 200-300 metres, and gently sloping beaches will significantly cut down the size and energy of a swell, while deep water offshore and underwater canyons can focus swell energy at certain beaches.

Computer swell models, coupled to global weather models, do provide instant swell forecasts for up to six days ahead. It is however dangerous to accept their output at face value, as the same lack of good input data that the weather models suffer from simply cascades down to the swell models. Model output must be thoroughly checked against current observations and satellite data to ensure its consistency.

The strength of these models lies in their ability to give the forecaster an overview of what is happening, providing a ‘heads up’ on possible important developments during the following days, which can then be studied in greater detail.

Is there a real
TSUNAMI THREAT
TO OUR COASTS?

By Russ Martin
Environment Bay of Plenty
Bronwen Gibberd
Environment Waikato

On any map of the south-western Pacific, New Zealand appears as a lonely, small group of islands surrounded by a vast expanse of ocean. Gaze over the horizon from any New Zealand beach on a sunny summer's day and who could possibly believe that the sea that girdles us could ever become treacherous. But logic decrees otherwise.

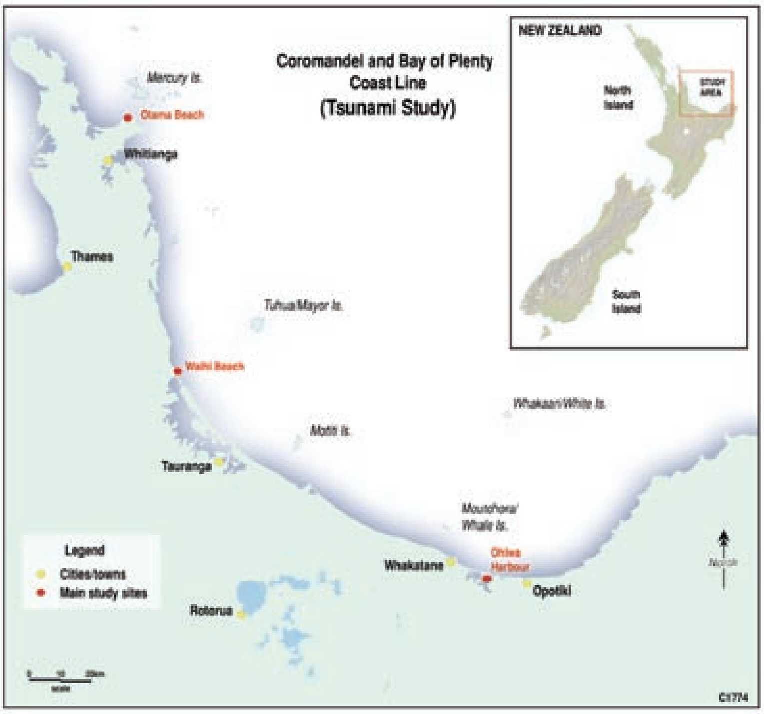
Although our short history indicates that we seem to have little to worry about, there must have been major tsunami impacts on these islands at some, perhaps many, times in the distant past. Our written records will not tell us much of that story. But, with increasing assets now directly on our coastline, we need to seek it out. Do we have a real tsunami threat to our coasts?

With this as our major question in mind, midway through 2002, Environment Bay of Plenty and Environment Waikato reached an agreement to conduct a jointly funded tsunami research study, covering the coastlines of the eastern Coromandel and the Bay of Plenty.

The project managers sought a wide input to the study by inviting the Institute of Geological and Nuclear Sciences (GNS), the National Institute of Water and Atmosphere Research (NIWA), and GeoEnvironmental Consultants to join forces and blend their respective skills in a phased 2-3 year research programme.

The desired eventual outcomes of the study will provide statements on the overall vulnerability of the coastline to tsunami hazards (compared to other natural coastal hazards faced by the regions), identification of vulnerable localities, and priorities for

Ohope Beach with Ohiwa Harbour in the background. Photo: Environment Bay of Plenty future investigations and action.



Map of Bay of Plenty/Coromandel study area. Based on a map by James Goff, GeoEnvironmental Consultants

For the two regional councils concerned, the principal areas of interest are the developed and potentially developable areas of the coastline of the Bay of Plenty region and the eastern coastline of the Coromandel Peninsula. In the Bay of Plenty, the major urban areas of Tauranga, Whakatane, Opotiki and the beach resorts are all potentially at risk from tsunami. In both regions, beach areas such as Ohope, Pukehina, Whitianga, Whangamata and Mt Maunganui/Papamoa are among many that are developing rapidly in capital values and numbers of permanent residents. A greater knowledge of the tsunami risk to these areas seems essential if informed and adequate land use and emergency response planning is to occur.

The specific objectives of the study are to:

- Define the tsunami and tsunami-related events that have occurred in the Bay of Plenty and Coromandel region over the last 5000-6000 years
- Identify potential source regions and generating mechanisms for tsunami that could impact the Bay of Plenty and eastern Coromandel regions. Potential sources should include both remote and local sources. Where possible, a preliminary assessment should be made of the potential magnitude (height or run-up) and likelihood of each type or source of tsunami hazard
- Identify the most likely tsunami impact types and describe their likely effects on the coastal margins, islands, harbours, estuaries, rivers and waterways of the Bay of Plenty and eastern Coromandel regions
- Identify and rank areas that are vulnerable to tsunami hazards generated from both local and remote sources
- Summarise current research relevant to tsunami hazards in both regions
- Qualitatively assess the uncertainties of the known information on tsunami hazards in both regions
- Identify gaps in the available historical, palaeo and scientific records relating to tsunami hazards in both regions and recommend priorities for the work needed to fill these knowledge gaps
- Identify mitigation, awareness or education measures that Environment Bay of Plenty and Environment Waikato could initially undertake to reduce the risks from tsunami-related hazards.

The project managers felt that these objectives would best be achieved in two or three phases.

Whakatane Harbour and entrance. Photo: Environment Bay of Plenty

The partner councils saw this research as best conducted over a period of 2-3 years, (depending on the findings of Phase 1) in order to spread costs and to allow detailed consideration of the findings of each phase before moving on to the next.

PHASE ONE

Coordinated by Environment Bay of Plenty, the first phase of the study by James Goff of GeoEnvironmental Consultants commenced late in 2002. This part of the research is intended to target pre-historic impacts of major tsunami events on the coastline of the study area. Given the known limitations of palaeo-tsunami research techniques we expect to see evidence of mainly large tsunami impacts, around 5 metres or more above mean sea level. Smaller pre-historic tsunami will probably not be detected, but some assumptions of frequency or effect may be possible if the work to detect the larger events is successful. The report on this phase has now been received and is under study by the clients and the partner consulting scientists.

The Crown Research Institutes, GNS and NIWA, will have their main involvement in the second and third stages of the project when they will define potential tsunami sources that could impact on the study area, and move on to provide the advice on how the various councils of the regions should work to mitigate or avoid the potential hazard. Once we have the problem defined, we will then set out to do something about it.

This is an exciting study for a number of reasons. It is the first systematic attempt to determine just what the palaeo-tsunami record indicates of the scale of the tsunami problem on the study coastline. It will integrate the results with known historic tsunami events and impacts of the past ~150 years. It will look at the vulnerabilities of the existing human infrastructure on our coastline and seek to find solutions to the potential threat that exists.

The results of this research will be an important early input to the new civil defence emergency management structure that central government handed to local government on 1 December 2002 with the Civil Defence Emergency Management Act 2002. It is this new Act that places increased emphasis on reduction of risk, rather than simply responding to hazard events as and when they occur. How this will be achieved with a natural hazard such as tsunami, on coasts with an ever-increasing population, will be a major challenge. ■

Whangamata township and beach resort. Photo: Environment Waikato

ENHANCING FLOOD FORECASTS

By Richard Ibbitt & Ross Woods
Hydrological scientists, NIWA

While we may all think we know what a flood forecast is, have you ever stopped to think about what makes a flood forecast valuable? As a potential victim of a flood you want to know two things: when is the water going to arrive? how deep will it be? This article deals primarily with the first topic.

If flood damage is to be reduced, people must be given sufficient advanced warning to react appropriately. The longer the notice of impending inundation, the more lives and property that can be saved. In situations where flood-warning times are short, say less than an hour, people may only be able to save their own lives. With more warning, say an interval sufficiently long to cover a period of daylight, animals, vehicles and household possessions can be moved to places of relative safety. With even longer warning times, rather than "flood fleeing", "flood fighting" can be undertaken. This is where non-movable assets, such as buildings, are protected by building temporary waterproof walls of sand bags, or installing pumps to reduce the depth of inundation.

Clearly, mitigation of flood damage requires accurate knowledge of when the floodwaters will arrive. The longer the period of warning the more that can be done, and hence, the more potentially valuable is the forecast.

The preceding description indicates what we want from a forecast – TIME. But how can this time be generated? This is the realm of the flood forecaster who uses information such as the amount of rainfall that has fallen recently and the current state of the river to estimate the likely future state of the river. Except in very large river systems, like the Murray, the Mekong or the Yangtze, where it can take many days for an upstream flood to travel to downstream populated


Volunteers shovel sand into sandbags in Helwick Street, Wanaka, as the rising Lake Wanaka floods into the central business area. Photo: Otago Daily Times. November 1999.

The extent of the damage to central Queenstown is evident from this aerial view taken at the height of the flood. Photo: Otago Daily Times. November 1999.

areas, knowledge of upstream river conditions provide only a limited amount of advance notice of when a flood will occur. This is definitely the situation for many New Zealand rivers where a flood can travel from the headwaters of the river basin to the mouth in a matter of a few hours. Under these conditions a crucial ingredient in any flood forecast is the assessment of what future rainfall will occur.

MEASURING RAINFALL

Traditionally, rainfall is measured by rain gauges, devices that are basically buckets in which the rainfall is caught and the amount periodically measured. In an automated rain gauge the frequency of measurement can be quite high and gives a picture of how quickly the rain is falling at the point where the rain gauge is located. The critical word here is the word "point" since, to estimate the total volume of water coming from a river basin, we need to know the rain at all points in the basin if we are to have an accurate picture of the spatial variation of the input to the basin. Unfortunately for New Zealand, its sparse population and large tracts of inhospitable terrain make it difficult to locate rain gauges in the places where heavy rainfall occurs. Accordingly, flood forecasters are further handicapped in their efforts to provide accurate forecasts by a dearth of rainfall data.

To summarise the flood forecaster's plight, they are required to make forecasts with only sparse information on the crucial rainfall input they need. But their problems get worse because not all the rain that falls immediately contributes to a flood. If it did our rivers would be dry or very low between rainstorms. So what happens to the rain that falls? Some of it is soaked up by the ground to emerge into the stream channel long after a flood has past. As a significant fraction of any heavy rainfall can infiltrate into the ground it becomes important for accurate flood forecasting to know just how much water will enter the stream channel and contribute to the flood flow in a river. Without this knowledge, floods could be seriously over-estimated, and there is nothing worse for the credibility of a flood forecast than "crying wolf".

Can the advance warning of a flood be increased and an accurate assessment of flood size be made? The brief answer is yes. The longer answer involves telling you how sophisticated meteorological weather forecasts are combined with computer models that mimic the processes that convert rainfall into river flows.

MESO-SCALE MODELS

The road to better flood forecasts starts far away in either the United Kingdom, the USA, or Japan. Each day these three countries make quantitative forecasts of the weather to be expected around the world in

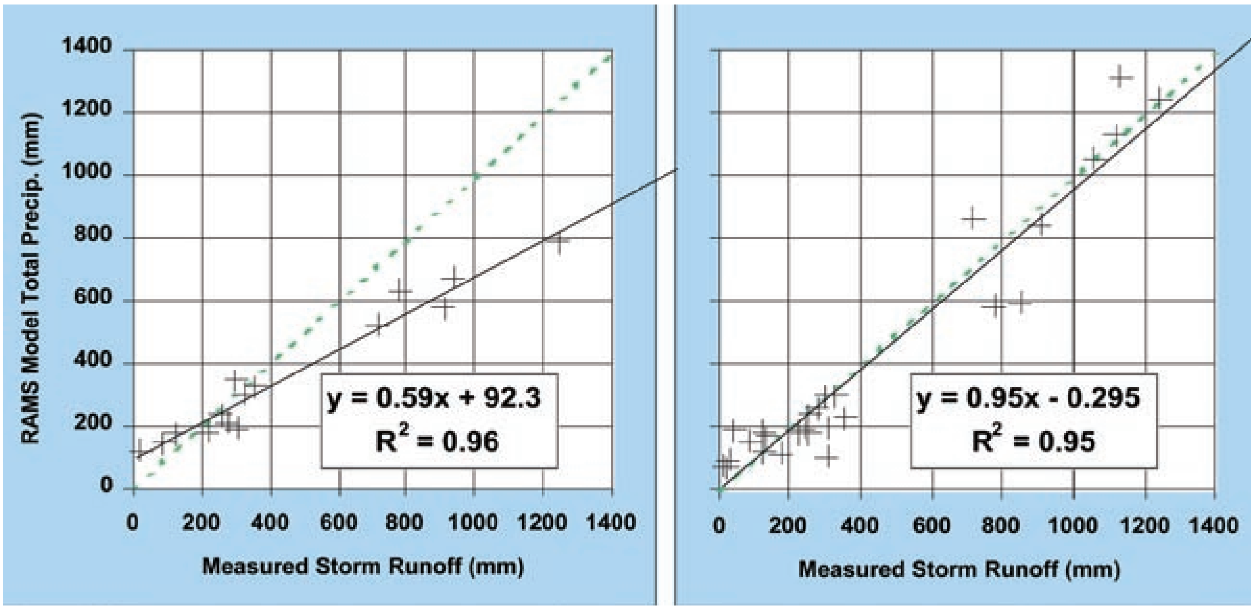


Figure 1 – The left hand plot shows a comparison between measured rainfalls and the corresponding ones calculated using a 20 x 20 km resolution meso-scale weather model. The right hand plot shows the corresponding comparison but for the 5 x 5 km meso-scale weather model.

the next 48-72 hours. The results of these forecasts are made available to countries like New Zealand under an agreement between member countries of the World Meteorological Organisation. We get access to the global forecast in exchange for providing basic data needed to set the initial conditions for the global weather models. The weather forecasts that New Zealand receives are not suited for direct use in flood forecasting because their spatial resolution is too coarse to provide accurate information over river basins that are no more than a few thousand square kilometres in size. However, New Zealand meteorologists, using what are called meso-scale weather models, can refine the global forecasts over New Zealand to smaller spatial scales that are more compatible with the size of our river basins. From the calculations of the meso-scale weather models comes information on rainfall over approximately square areas with sizes between 5 x 5 km and 20 x 20 km. Figure 1 shows a comparison between meso-scale generated rainfall at both 5 x 5 km and 20 x 20 km resolutions over river basins in the Southern Alps with corresponding estimates of the rainfall based on the flows from the same basins.

While the 5 x 5 km size is ideal for flood forecasting, it takes a long time to calculate even on NIWA's super-computer. Consequently there has to be some compromise if forecasts are to be made in "real time", ie. before the event actually occurs. At present, data over 20 x 20 km squares is being used in pilot studies of the potential of the data to improve flood forecasts over a number of river basins scattered across New Zealand. To compensate for the differences shown in Figure 1, the 20 x 20 km data can be linearly adjusted to more closely match the 5 x 5 km data.

The meso-scale weather model provides the flood forecaster with two pieces of information: a spatial coverage of rainfall across the river basin and estimates of how the rainfall will vary over each 20 x 20 km square during the next 48 hours.

In Figure 1, the equations in the boxes indicate that at 20 x 20 km the calculated rainfall is only 59% of that measured, whereas for the 5 x 5 km data the calculated rainfall is 95% of that measured. Given that uncertainties in the measured data are of order 5-10% the 5 x 5 km resolution data are considered to closely match what was measured.

At this point in the story the hydrologist takes over from the meteorologist. The hydrologist provides the means for converting the meso-scale rainfall estimates over a river basin into river flows. To do this the hydrologist builds a computer model of the river basin. The model has two main components: a set of many small sub-basins, and a stream network that collects together runoff from the set of small sub-basins and "routes" the flow to the basin outlet.

Each of the sub-basins is modelled using potentially the same set of process mechanisms. Thus we allow for water that is caught in the vegetation and never reaches the ground, water that infiltrates the ground to seep out into the stream channels long after the flood has past, and finally that water which runs across the ground surface to quickly add to the water already in the stream channel. Although the sub-basins are modelled using the same process mechanisms, information from topographic, land use and soil maps are used to differentiate between basins with steep slopes versus basins with milder slopes, forest versus grass cover, and sandy versus clayey soil. As a result of the analysis used to build the river basin model, each sub-basin has different runoff characteristics and so contributes different amounts of water to the stream channel at different times through the flood. For example, if a sub-basin contains a large amount of impervious ground, for instance a car park, then nearly all the rainfall will run off into the nearest stream channel. However, only a small fraction of the rainfall on a nearby ploughed field may run off owing to retention of the rainfall between furrows giving that rainfall sufficient time to soak into the soil.

Once the correct amounts of water that flow into each stream channel have been calculated, these are "routed" down the channel network to the basin outlet. The routing process uses hydraulic calculations to determine the velocity of the flow. These calculations make use of information on the slope of the channel segments and channel size as derived from analysis of the topographic map data. As every twist and turn of the channel cannot be allowed for, the computational representation of the network "straightens" out the channels so as to make the flow routing more tractable. Research and experience with the particular model being used have shown that the consequences of this virtual channel straightening are unlikely to seriously degrade the quality of the forecast.

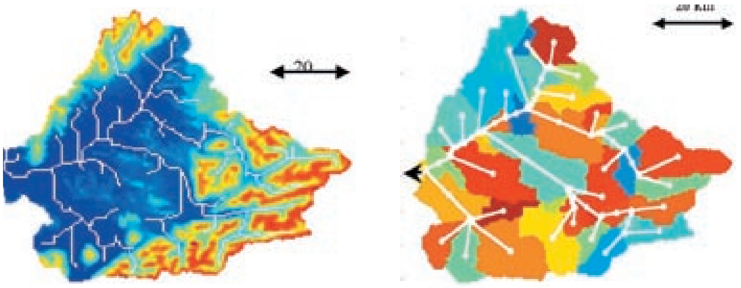


Figure 2 – The left hand panel is the topography (colour indicates elevation with blues being lower elevations) used to derive the sub-basins' sizes and locations and the stylised channel network shown in the right hand panel. In the right hand panel colour is used to distinguish the different sub-basins.

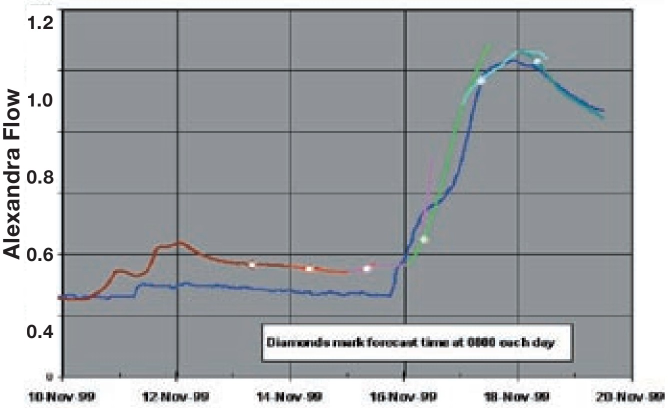


Figure 3 – Comparison of the measured flows at Alexandra (blue line) and the flows that would have been forecast at 24-hour intervals using the type of spatially distributed model shown in Figure 2, with a sequence of meso-scale weather model forecasts of rainfall.

The left hand panel of Figure 2 shows the topography and channel network for the Grey River catchment while the right hand panel shows a typical sub-division into sub-basins and the stylised network of stream channels that was derived and used for channel

Alex McGregor of Queenstown wades along Beach Street in the town's centre, as heavy rain continues falling. Photo: Otago Daily Times. November 1999.

routing. As the model is what is referred to as spatially distributed, that is, different parts of the basin are represented by sub-basins with different properties, and the channel network is also made up of separate elements, it is possible to extract from the flood forecasting procedure the flow at any point in the basin so that multiple forecasts for the basin are possible.

Pog Mahones managing director keeps his feet dry outside the Rees Street bar in Queenstown. Photo: Otago Daily Times. November 1999.

So how does all this modelling perform in practice? To test this a number of pilot flood forecasting schemes are being set up around New Zealand. The longest running trial has been on the Clutha River in Otago, and was set up in response to the disastrous flood in the upper basin in November 1999. Figure 3 shows how a sequence of five forecasts compares with the flows measured at Alexandra. The forecasts are 24 hours apart and each forecast is of 48 hours. The diamond symbols indicate the time at which each forecast becomes available. It takes 18-21 hours to make each rainfall forecast and the first 12 hours of each forecast are discarded because they are contaminated by assumptions needed to start the forecast process. The start of each coloured line segment represents the first flows calculated from each rainfall forecast. However, these early flows have already occurred because the actual time of the forecast is given by the diamond symbol. That is, to the left of each diamond symbol the model is calculating historical flows. At the diamond symbol the forecasting process has "caught up" with reality and the segment of each coloured line to the right of each diamond represents an actual forecast.

The part of each coloured line to the left of each diamond symbol represents the time "lost" in making the forecast. This loss is compensated for in the forecast scheme by having 48-hour forecasts so that there is always a 24-hour overlap between successive forecasts. As an example, consider the diamond labelled A, which is about a third of the way along the magenta segment of line. This represents the time at which the forecast, represented by the magenta line segment, became available. In due course the next forecast, the green line, began. Figure 3 shows that until the flow calculations for the green line catch up with reality, they are similar to the magenta forecast made the previous day. We can tell this because part of the magenta line is hidden by the left hand part of the green line and this gives us an idea of the accuracy of the previous forecast.

River flow forecasts are generally made by trained staff in regional or district councils. As part of the forecasting process, not only are flows generated but these are converted into water levels. Armed with information on when the flood will occur and how deep the water will be, the authorities can decide which people and what properties are at risk, and then take the appropriate action to avoid loss of life and mitigate damage. Options for reducing the effects of a flood may range from evacuating whole communities and/or moving livestock and vehicles to higher ground (flood fleeing), to sand-bagging stop banks (flood fighting).

The forecasting work in the Clutha basin has been running for three years and although there have been few significant events since the scheme was installed it has provided valuable information on system performance. As a result of the experience in the Clutha, the testing is being extended to rivers elsewhere in the country. From these new installations we hope to gain a better appreciation of how the system works in different climatic regions of New Zealand and thus be able to modify the system, if necessary, to deal with new situations. ■

Research on WEATHER SYSTEMS

By Warren Gray
Meteorologist, NIWA

New Zealand's location in the mid latitudes puts us at risk from several sources of extreme weather systems. These can include ex-tropical cyclones, strong fronts from depressions in the roaring forties, or deep lows that form in the North Tasman Sea. For many of the storms impacting on New Zealand from the north, the inclusion of warm moist air in the systems adds energy to its development through the release of latent heat.

New Zealand experiences many natural hazards but while we can't control our environment, we can mitigate the impact of hazards with forewarning and preparation. NIWA undertakes research over a wide range of natural hazards with the aim of making us better prepared for these extremes. Over 40 scientists and support staff based at three locations monitor, investigate and develop tools to improve our knowledge of these hazards, and provide information to help us prepare better for extreme events, and react faster and better when they occur.

UNDERSTANDING THE PROCESS

One aspect of NIWA's weather system research is focused on understanding the processes by which moisture is taken up from the sea and transported into the weather systems that affect us. In particular, we are looking at whether the computer models of the weather can reproduce the conveyor belts of warm moist air that we see in our North Tasman lows. Computer modelling is now an essential part of the forecasting of weather around the world. NIWA has several teams working on improving our ability to model weather systems.

One team is looking at the impact of the data used to initialise the models. Their aim is to improve the modelling by moving to high resolution (12 km, c.f. 60 km used currently) and by inserting data into the model at this high resolution. Data is needed at this high resolution if the model is to have the details right when it starts and therefore in its forecasts. This data comes not only from the conventional sources of observation (for example, balloon soundings) but also from the latest technology satellite and radar observations. The quality of this data and its impact on the skill of these models in forecasting high detailed weather out to 72 hours in advance is being assessed.

Another aspect of the modelling of the weather has been the use of computer estimates of rainfall rates as input into hydrological models for forecasting river flow. Rainfall forecasts are made out to 48 hours ahead and this lead-time can be added to the time it takes the water to flow down the river – giving more time for emergency and planning responses.

This forefront approach has been successfully trialed for the catchments around the Otago region.

Otago Floods 1999. An area now part of a pilot flood forecasting scheme since 2000. Photo: Otago Daily Times

Extreme waves from 6 Feb 2002. The Cook Strait region is targeted for future detailed wave and tide modelling. Photo: Evening Post

Indeed, since the trial was begun in 2000, there have been no significant floods – in fact the region had near-drought conditions for much of this time! More significantly, the spring of 2002 had significant rainfalls, which led the lakes to be near capacity. Forecasts from this system suggested that, although further rainfall was expected on several occasions, the lake level would remain below its banks. These forecasts verified well, reducing the occurrence of false alarms.

This pilot study is now being extended to the Rangataiki River in the eastern Bay of Plenty and the Waipaoa catchment in the Gisborne district. New computing resources have also lead to forecasts now being available out to 72 hours ahead.

WEATHER RADAR DATA

The information contained within weather radar data has long been thought of as a potential source of information from which detailed short term forecasts of rainfall could be made. However, realising this potential has been a long time coming. Recent advances in the quality control of the data, and in the sophistication of the systems used to forecast rainfall, have enabled this potential to be released.

NIWA is currently assessing the skill of a forecast system, developed in Australia, for forecasting rainfall for the areas covered by the MetService radars (Auckland, Wellington and Canterbury regions). This forecast system takes a sequence of radar images, and extrapolates the motion of the rainfall seen, but decreases the intensity of the smallest scales – the scales whose size means that they won't be predictable out to the end of the forecast period. Initial trials suggest that the system can outperform persistence by 50%, with forecasts over small catchments out to a period of 90 mins showing 80% correlation with radar-observed rainfall. Future trials are set to investigate the impact of improved radar data quality, and the use of multiple motion vectors for each sector of the radar domain.

Radar information is also being looked at as a source of information for input into hydrological models. Radar data is formed from averages over an area, making it a natural choice of input into hydrological models that assume areal averaged quantities. Assessment of the skill of the data over that of a high-density rain gauge array is being made for the Mahurangi catchment north of Auckland. Initial results suggest that once the radar data has been quality controlled, the pattern of rainfall is well measured, but work needs to be undertaken to find the scaling factors needed to reproduce the rainfall totals seen in the river flow.

HYDROLOGICAL MODELLING

Underlying much of our work is the development of our hydrological modelling capability. NIWA has been at the forefront in the use and development of the TOPNET model. This is a distributed model, in which the flow from each of the segments of a catchment is calculated independently, leading to an estimate of the flow down the river channel. This system has been implemented for a number of our significant rivers, and a model capable of covering the whole country is envisaged.

As part of our monitoring of the river levels, work on the statistics of river flow has highlighted the link between climatological weather patterns and river flows. It has been long known the 2 - 4 El Niño - La

Houses on the south coast of Wellington take a thumping from waves coming in. Photo: Evening Post. 6 Feb 2002.

Niña (ENSO) pattern affects our rivers, but more recent studies have shown the longer 20 - 30 year Interdecadal Pacific Oscillation (IPO) has an influence as well. This has implications for planning. For example, the atmosphere may recently have moved back to a phase of the IPO that would leave the southern catchments in a phase of lower inflows – perhaps similar to that of 1947 to1977. This would have implications nationally for the supply, use and pricing of electricity.

While knowing the flow within a river can be important information for emergency management, it is the water level of the river, and the level of the overflow into the adjacent flood plains that is ultimately of importance. The calculation of river and floodplain level (known as inundation) is a complex undertaking. Riverbed resistance is a factor of bed roughness and geometry, as well as the resistance imparted by obstacles such as trees and buildings. NIWA is working on two levels of computer model– one where the adjacent floodplains are flooded slowly as the river overtops its banks, and the other more complex approach where the flow of floodwaters around buildings and through breaches is dynamically simulated. The “dynamic” model is still under development, but is a promising tool for the future, particularly when applying it to coastal inundation resulting from waves, tsunami and storm tides, as well as flash floods in rivers.

Important though it may be, defining the geometry and height of a riverbed and adjacent floodplains can be arduous and expensive. Conventionally, this has been done by soundings from a boat and land-based survey techniques. Increasingly, we are turning to the skies, where aerial scanning methods such as airborne laser or aerial photogrammetry can cover much more ground in a shorter time. The advantage of laser scanning is that it gives direct physical output and can also measure building heights and penetrate non-dense vegetation to reveal the underlying ground-surface height.

WAVE MODEL

NIWA research into marine winds and waves has looked at the wave climate around NZ over the last 20 years. (see www.niwa.co.nz/rc/prog/chaz/news/waves) A 20-year record of wind patterns from a global wind model has been used to drive a wave model for the SW Pacific covering the same period from 1979 to 1998. The statistical summary of these wave results in open deep water (> 50 m depth) means we now have a consistent understanding of wave climate around New Zealand. While previous wave modelling focused on the offshore deepwater waves, new innovations in wave modelling have enabled an improved representation of waves inshore along the coast. This has come through the use of more sophisticated models capable of handling both shallow waters and modelling at high resolution to capture the changes in seabed bathymetry. The SWAN model, with a spatial grid of 750m by 750m and using a spectral approach to represent the distribution of wave heights and shapes consisting of 33 frequencies from 24 directions, is used to bring the deepwater waves ashore. Input into these models come from the offshore waves climatology and a detailed map of the sea floor contours. Initial work on the Hauraki Gulf shows good correlation with data from the inshore wave buoy that was moored off Mangawhai in the outer Gulf for three years.

The action of waves and currents on our sandy or gravel coasts is one of the major areas of research for NIWA’s coastal hazard scientists. The erosion or accumulation of sand on beaches is an important management issue for many of our coastal communities, particularly as the value of dwellings on the coast is rising rapidly, and along with that, the risk of consequential damage.

STUDY OF COASTAL SYSTEMS

NIWA is putting endeavour into each of these areas. Two types of coastal systems are being studied; one being a wide open exposed coastal system eg. the west coast of the North Island, where sediment moves large distances from its source by alongshore wave action; and the small pocket-beach systems of the Coromandel, where relatively small quantities of sand are constrained between rocky headlands.

Flooding of low-lying coastal land can occur independent of any rainfall or elevated river flows. Coastal or sea flooding is caused by the temporary elevation of sea level and/or wave heights during storms, where the storms may be some distance

A spring tide and a northwesterly wind combine to produce dramatic seas at Plimmerton Beach near Wellington, with waves crashing over sea walls and depositing debris onto front lawns. Photo: Evening Post. 20 August 2001.

offshore from the coast. Storm surge associated with storms and cyclones arises from low barometric pressure and adverse winds that cause a rise in the mean sea level at the coast of up to 0.8 to 1m in New Zealand region. The importance of tides in the overall equation for coastal flooding has inspired NIWA's research on understanding and modelling tides around the wider New Zealand region. The work has culminated in a new system for predicting tides anywhere around the coast or out at sea in the EEZ around new Zealand.

Coastal encroachment on the other hand is a chronic inundation process, where rising sea levels due to climate change gradually encroach on low-lying coastal and estuarine land. Initially, encroachment will become evident by an increasing frequency of sea flooding at high tides or during storms, but with time (if the process is not constrained by landward defences) the area will transform into a coastal marsh and eventually become a permanent part of the coastal or estuarine system. Sound planning responses to coastal hazards and global warming effects depends on sound scientific research and monitoring.

One hazard that often gets forgotten is the risk from tsunami. New Zealand has gone through a quiescent period recently, with few tsunami causing damage – the last significant ones being in the early 1960s. The worst event in historic record occurred in August 1868 when a Chilean earthquake produced waves around 3m above normal water levels at Lyttleton, and 5-10m levels at the Chatham Islands. GNS and NIWA have a combined programme of research looking at not only the risks of tsunami arising from earthquakes (both remote or local), but also from submarine landslides occurring along New Zealand's continental margin.

One way for a community to be resilient is to have its people prepared for hazardous events. Measuring the preparedness of at-risk communities can improve understanding of their resilience and signal ways to improve emergency management strategies. The assessment of hazard preparedness of at-risk communities is an area of combined research between NIWA and GNS. Currently GNS and NIWA are combining resources to survey community perceptions of coastal hazards, including inundation from tsunami and coastal erosion, at several seaside communities.

More information can be gleaned from our web site (www.niwa.co.nz/rc/hazards), or that of the National Hazards centre (www.naturalhazards.net.nz). ■

A NATIONAL WARNING SYSTEM

By David Coetzee
Emergency Managent Planner, Ministry of Civil Defence & Emergency Management

The articles in this issue explore some of the excellent work that is being done by scientists in New Zealand to improve our understanding of weather systems that can lead to severe weather events, and the exciting work that is being done by our weather forecasters to develop techniques and tools to improve our ability to provide early warning of extreme weather events.

How is this information used by the civil defence emergency management sector to ensure the safety of our communities? And what systems are in place to ensure that potential emergency events are monitored, and alerts and warnings issued effectively?

The National Civil Defence Plan outlines the responsibilities of departments, agencies and organisations in relation to emergency readiness, response and recovery. Under Part 3 of the Plan, the Director of Civil Defence & Emergency Management can issue warnings for all or part of New Zealand in respect of hazards that might lead to, or worsen a civil defence emergency. Examples of such warnings are severe weather events, the impending arrival of a tsunami, or a potential volcanic eruption. Where possible, early notification in the form of an alert may precede a warning.

Responsibility for the provision of national alerts and warnings rests with the Ministry of Civil Defence & Emergency Management. On their part, regional councils, territorial authorities, government departments and organisations are responsible for maintaining their own warning procedures. This includes measures to pass on alerts or warnings issued by the Director.

RECEIVING INFORMATION

The Ministry's main sources of information for alerts or warnings are:

- MetService
- Institute of Geological & Nuclear Sciences (GNS)
- the Pacific Tsunami Warning Centre in Hawaii
- the Centre for Critical Infrastructure Protection (CCIP)
- United Nations Disaster Assessment and Coordination (UNDAC) programme.

Standing procedures are in place with these agencies to ensure that the Ministry is notified of relevant events in a timely manner.

The Ministry also has good working arrangements in place with the research agencies, including the National Institute of Water and Atmospheric Research, and the universities who have the expertise to add value to the information as needed.

24 HOUR WARNING SYSTEM

The Ministry operates a 24-hour emergency system with calls channelled to rostered duty officers for after-hours coverage. In addition, alerts or warning messages are also received by the duty officers via fax (office and home) and email (office and cellphone). The duty officers also have Internet access both in the office and via cell phone through which they can verify information received.

DISSEMINATION OF INFORMATION

Alerts or warnings are issued direct to:

- Regional and district councils
- Government departments and agencies, news media, lifelines utilities, Crown Research Institutes and the general public as appropriate.

Messages are sent according to standard operating procedures by both fax and email to the appropriate address lists.

In the case of warnings, a copy of the message is also faxed to the Police Communications Centres who instruct Police Districts to check with local civil defence offices at the councils on whether they have received the message. Regional councils also have a similar system in place for checking that the relevant district councils have received the message. Confirmation of receipt of the messages with the Ministry's Emergency Management Advisors (EMAs) is also a part of the process. The EMAs confirm and report on the timings of receipt to the national duty officer. In the event of a warning message being sent after hours, the EMAs will alert the regions by phone that a message has been sent or is forthcoming. The regions in turn will alert the councils. In all cases regional, district and city councils also contact and warn other local agencies as appropriate.

The Ministry provides a "value added" service in that all warning related information is received, assessed and considered as to whether it needs to be

disseminated, and in what format, ie, as an alert or a warning. Different standard operating procedures and criteria exist for the actioning of information related to weather, earthquake, tsunami and volcanic events. While these procedures in some types of events such as tsunami, provide clear guidelines on what action is warranted by what type of information, the element of judgement is however always present in deciding on the appropriate response.

A balance between time (to facilitate foreknowledge), and the quality of information (verification and threat analysis to avoid false alarm and achieve maximum value) has to be struck. This underlines the importance of a basic understanding of the nature of the different type of events by the relevant Ministry staff, and the value that the Ministry puts on maintaining a close relationship with its advisors and sources involved in the respective fields of speciality.

TSUNAMI TRAVEL TIMES FROM CHILE EARTHQUAKE

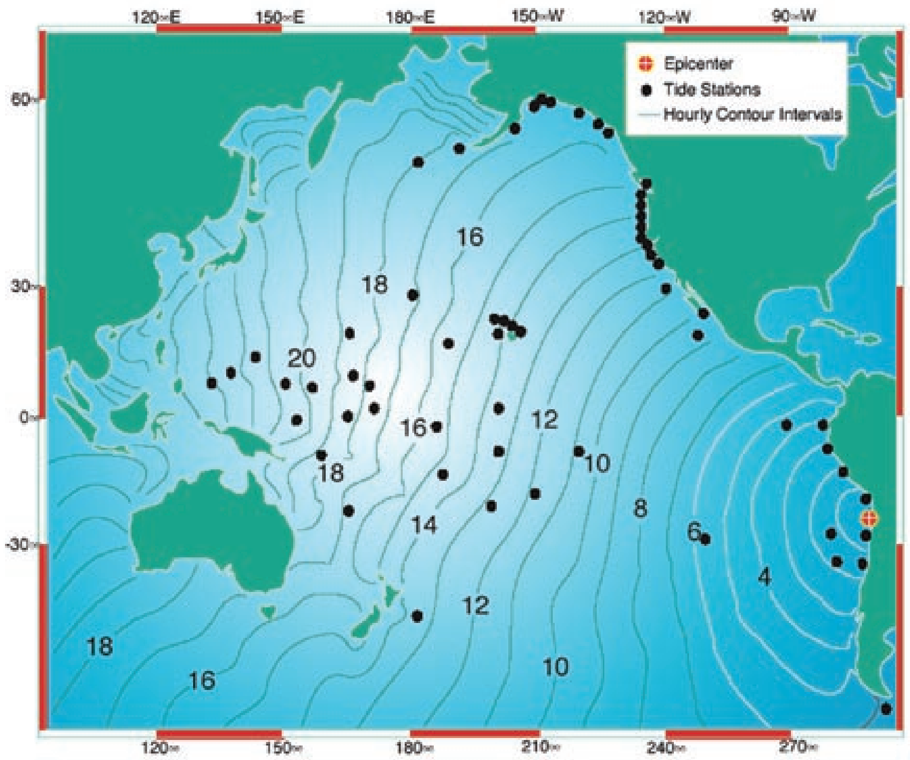


Illustration showing tsunami travel times from the 1960 Chile Earthquake. The impact of the quake was felt in Japan 17,000 kms away with a tsunami that killed 200 people. Photo: International Tsunami Information Centre.

SYSTEM MAINTENANCE

The Ministry conducts quarterly tests of the national warning system. A test message is sent (unannounced) to all local authorities as well as the Police Communications Centres. The tests offer the ability to check faults on address lists, response times and any system problems that might arise. Based upon the results of these tests, "fine tuning" is continuous.

In addition, a "National Contact List for Emergencies" is maintained by the Ministry. The list is sent to all civil defence offices on a quarterly basis to be checked for changes and updates. The list contains the contact particulars of the civil defence officers, controllers and alternative controllers at all councils.

THE FUTURE

The Civil Defence Emergency Management Act 2002 requires the first National Civil Defence Emergency Management Plan to be completed within three years. The National CDEM Plan must detail a national warning system. The drafting of the new plan therefore implies scrutinising the existing Civil Defence Warning System (Part 3 of the existing National Civil Defence Plan).

As a precursor, the Ministry is in the process of establishing a working party comprising relevant sector stakeholders to help shape ideas around the improvement of the existing national warning system. It is also envisaged that the deliberations by this group will result in immediate changes to standard operating procedures in the existing system.

In addition, the investigation and employment of instruments aimed at enhancing decision-making and analysis of information related to alerts and warnings deserve constant attention. The Ministry is currently considering proposals for such instruments offered by systems capable of providing hazard information, risk analysis, modelling based upon scenarios and previous events, and formatting of alerts and warnings. Information on current developments is available on the Ministry website at: www.civildefence.govt.nz. ■

Using Radar to Diagnose Weather Systems

By John Crouch

Severe Weather Forecaster, MetService

Throughout the world, weather radar is an essential tool for analysing and predicting the weather. By transmitting and receiving short bursts of microwave energy, weather radar is able to show the location and intensity of precipitation through a wide area.

MetService currently operates three high-quality Doppler weather radars in New Zealand. These are based in Auckland (near Warkworth), Wellington and Canterbury (near Rakaia). A fourth smaller non-doppler radar is based at Invercargill.

Recent developments within MetService have allowed forecasters to make greater use of these weather radars. This article describes some of these recent developments, and shows how MetService forecasters are using new techniques to delve into and diagnose weather systems within New Zealand.

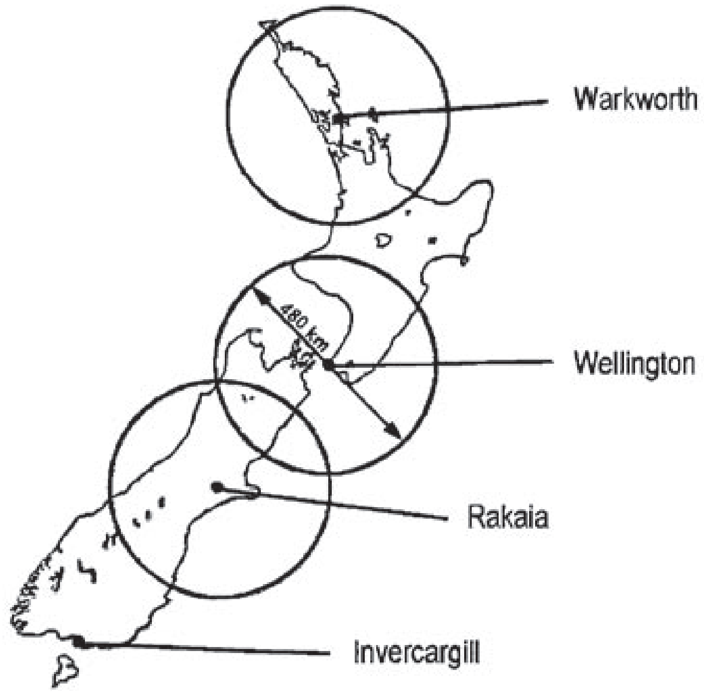


Figure 1: Location and coverage of MetService weather radar. The 3 radars are high-resolution doppler radars. A fourth smaller radar is located at Invercargill.

SCALE

Every 15 minutes, MetService weather radars perform two full 3-dimensional volume scans. The first scan covers an area out to a range of 480 kilometres, records data at 2-kilometre resolution, and measures only radar reflectivity. The second scan covers an area out to a range of 240 kilometres, records data at 1-kilometre resolution, and is able to measure velocity as well as radar reflectivity. These two scans are processed to produce high-resolution images of the precipitation over one of the three main metropolitan areas of Auckland, Wellington and Christchurch.

Figures 2 and 3 show an example of the three radar reflectivity images produced by MetService for the same time (6 am NZDT) on 10 March 2003. The images illustrate the differences in scale, and show how the high-resolution image gives much more detail on the nature and intensity of precipitation. The images show an area of rain covering the Auckland area. In the larger scale image (Figure 2) it is apparent that an area of moderate to heavy rain is affecting part of the Auckland area. In the high resolution image (Figure 3) the exact location and intensity of the rain over Auckland can be seen. The image shows a band of heavier rain affecting an area from North Shore southwards to Auckland Airport. This rain continued over the next couple of hours causing localised surface flooding and traffic problems during the morning commute.

MetService developed these high-resolution radar images in 2002 for the three metropolitan areas of Auckland, Wellington and Christchurch. Images are updated every 15 minutes. They allow forecasters and other users of the weather radar a much greater level of detail than existed previously. Team meteorologists during the 2002/3 Louis Vuitton and America's Cup regattas used the high-resolution radar imagery for Auckland to track rain showers approaching the race course. These rain showers are accompanied by significant changes in wind speed and direction. By using the MetService high-resolution radar imagery, the teams were able to predict wind shifts in addition to the onset of rain.

RAIN VERSUS SNOW

As well as scanning horizontally around a radar site, MetService radar also scans vertically. Up to 15 scan elevations ranging between 0.5° and 20° above the horizontal allow a three-dimensional radar image to be recorded. This three-dimensional data allows forecasters to look at the vertical structure of weather systems affecting New Zealand.

One of the problems forecasters have in New Zealand is determining which precipitation bands are likely to produce snow during winter, and to forecast when and where this snow is expected to fall. Fortunately, they can often solve this problem in the short term by analysing the vertical structure of precipitation bands using radar. See Figure 4.

THUNDERSTORMS

Perhaps one of the greatest benefits of weather radars is their ability to peer into the heart of thunderstorms. At MetService, weather forecasters are able to use radar to figuratively slice through thunderstorms, and to look inside them. This enables forecasters to determine the structure of the thunderstorm, and to assess its potential for severe weather (such as damaging hail or torrential rain).

Thunderstorms within New Zealand can be classified into 4 broad categories. These are single cell storms, multicell cluster storms, squall lines (or multicell line storms), and supercell storms.

Single cell thunderstorms are the smallest, and have lifetimes of 20-30 minutes. Most single cell thunderstorms are considered non-severe. However they may produce brief episodes of severe weather such as localised heavy downpours, hail, or short periods of strong winds.

Multicell cluster storms consist of a group of thunderstorm cells moving along as one unit. Each cell within the cluster lasts only 20-30 minutes, but the cluster itself may persist for several hours as new cells develop within the cluster. Multicell clusters are usually more intense than single cell storms, and can produce heavy rainfall over a wider area, moderate-sized hail (marble size or larger), severe wind gusts, and occasional weak tornadoes.

Squall lines (or multicell line storms) consist of a long line of storms, with a continuous well-developed wind gust front at the leading edge of the storm. Squall lines can last for several hours, and sometimes even a day or two. These systems are often associated with a short period of severe wind gusts, briefly heavy rain, and small hail. In New Zealand, the severest forms of squall lines tend to be associated with southerly buster events (which affect the east coast from Otago to Gisborne), or active cold fronts moving out of the Tasman Sea.

The supercell is a highly organised form of thunderstorm which, although extremely rare in New Zealand, is associated with the severest convective weather. These storms usually bring large hail (golf-ball size or larger), torrential rain, short periods of severe wind gusts, and often a tornado. Supercell thunderstorms are known to occur occasionally in Canterbury, and possibly other parts of New Zealand.

AUCKLAND SQUALL LINE

Squall Lines (or multicell line clusters) occur over a multitude of scales, and are observed in many parts of New Zealand. Occasionally squall lines are associated with passing cold fronts, and can become extremely organised and severe.

One such severe frontal squall line crossed the Auckland area during the night of 31 October - 1 November 2001. Wind gusts of up to 80 knots (150

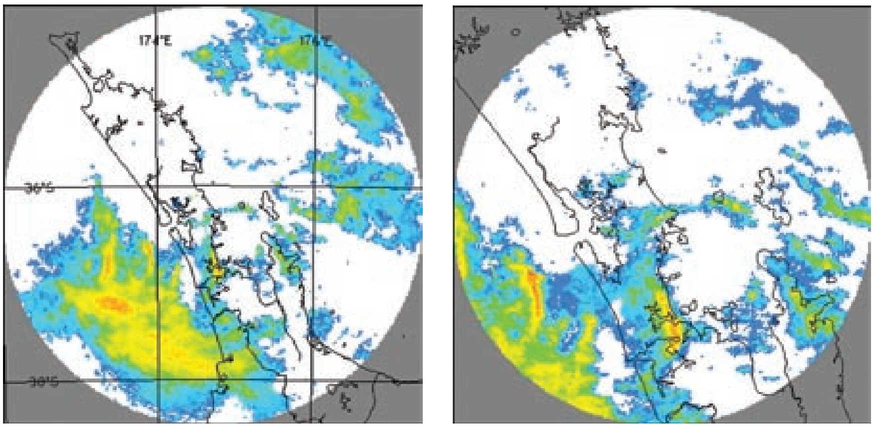


Figure 2: Radar reflectivity images from the Auckland radar at 6 am (NZDT) 10 March 2003. The rain intensity is colour coded so that blue/green is lighter rain, and yellow/orange is heavier rain. The left image is the full non-doppler scan covering an area 480x480 kilometres, with a 2-kilometre resolution. The image on the right is the full doppler scan covering an area 240x240 kilometres, and a resolution of 1-kilometre.

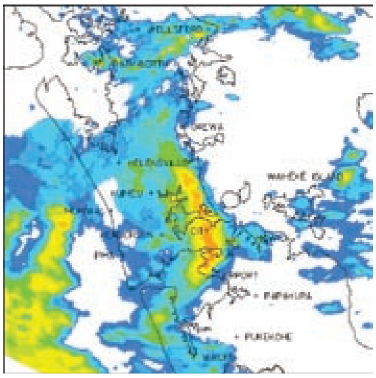


Figure 3: High-resolution radar reflectivity image over Auckland at 6 am (NZDT) 10 March 2003 The rain intensity is colour coded so that blue/green is lighter rain, and yellow/orange is heavier rain.

The Auckland weather radar is situated on Mount Tamahunga near Warkworth, at a height of 452 metres above sea level. Photo: Gordon Saggers, MetService.

km/h) were officially recorded in two locations, and significant wind damage occurred in several areas from Helensville to Mangere. Damage reports included trees being uprooted, roofs lifted, windows broken, and fences being demolished by the strength of the wind.

The Auckland weather radar captured the passage of the frontal squall line. A subsequent analysis of the images by MetService forecasters revealed many features in common with severe squall lines observed in the USA.

Good quality weather radar is important to forecasters. By recognising the radar reflectivity and velocity patterns associated with severe squall lines (or thunderstorms), forecasters are able to identify weather systems that have the potential to produce severe weather. Although MetService currently does not issue Severe Weather Warnings specifically for thunderstorms, it is hoped to move towards such a warning service in the future. Severe Weather Warnings for thunderstorms will rely on high-quality weather radar deployed around New Zealand, and a method to disseminate these warnings quickly to the public.

Weather radar has proved itself an invaluable forecasting tool at MetService. As well as showing the location and intensity of precipitation bands, the 3-dimensional radar data allows forecasters to look inside weather systems and determine their structure.

It is hoped that in the future MetService will be able to expand its radar network and provide greater coverage. This will give forecasters a much better insight into New Zealand's unique weather allowing a superior forecast and warning service to the country. ■

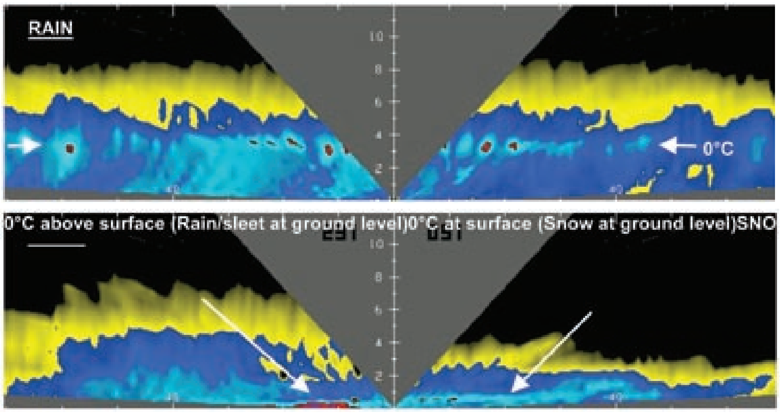


Figure 4: Vertical radar reflectivity slices through weather systems producing rain (top), and snow (bottom). Distances are kilometres from the radar. Reflective intensity is colour coded so that light blue and red represent higher reflectivities. The 0°C line is marked by a radar 'bright band'. About and above this line, the precipitation is in the form of ice and snow crystals, while below this line the precipitation is falling as rain.

SNOWSTORMS

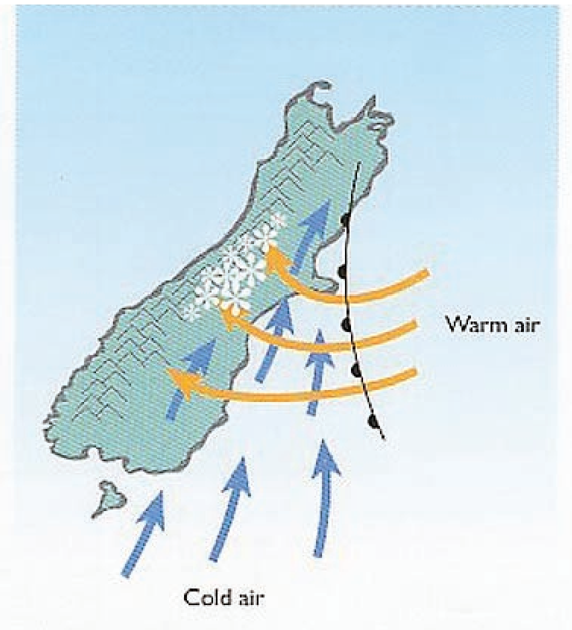
By Erick Brenstrum

Lead Forecaster, MetService

Most heavy snowfalls of recent decades in New Zealand have affected relatively restricted areas, such as half of one province or even less. This is because they have been formed by a process weather forecasters refer to as warm advection. This involves a relatively warm airstream, coming from north of New Zealand, riding up over a colder one, coming from a long way south of the country.

The key role of the warm airstream is to feed the storm with plenty of water gas - known as water vapour. Warm air is able to contain a lot more water vapour than cold air. Imagine comparing two lots of air approaching New Zealand - one from the tropics and the other from near Antarctica, both with 100% humidity. The amount of water vapour in the northerly airstream would be about three times that in the southerly airstream.

The idea of a warm airstream contributing to snow may seem strange but it is important to remember that as this airstream rises inside the storm, it is cooled considerably. By the time the air is three or four kilometres up, its temperature has fallen well



Heavy snow occurred on 8 July and 27 August 1992 when warm humid air from the north and very cold air from the south were brought together over Canterbury by a deepening depression.

Motorway mayhem, North Dunedin. Photo: Otago Daily Times. June 1986.

For the kids it was time for some fun in the snow. Photo: Otago Daily Times. June 1986.

below zero. This cooling occurs because the rising air encounters lower surrounding air pressure as it moves higher into the sky. Consequently, the air expands. Whenever air, or any gas, expands, its temperature falls. As the air cools, some of its water vapour condenses into the tiny liquid drops that clouds are made of.

Once the air has cooled some way below zero, the water vapour changes directly into ice crystals without going through the liquid water phase. As the ice crystals stick together to form snowflakes, they become heavy enough to fall. At first, as the snowflakes move through layers of air closer to the ground, they begin to melt and reach the ground as cold rain. However, the melting snowflakes take heat out of the air next to the ground until its temperature falls to near zero. Then subsequent snowflakes can fall all the way to the surface without melting.

The reason the heavy snowfall area is relatively small is because the warm airstream delivering the water vapour to the storm is only tens of kilometres wide.

Two classic examples of warm advection storms occurred over Canterbury in the winter of 1992. In the first storm, early in July, the heaviest falls were in the foothills, where snow accumulated to depths of one metre or more over several days. Roads were closed, power lines brought down and tens of thousands of cattle and sheep trapped.

The snow stayed on the ground for more than a week on hill country farms and stock rescue became a major operation involving hundreds of volunteers. Tractors and bulldozers were used to reach stock in the more accessible areas, but helicopters had to be used to fly hay and shepherds into more remote places. Sometimes the sheep had to be dragged or lifted bodily to safety, but often it was enough to make a path for the animals by walking ahead of them and stamping down the snow. This exhausting process, called “snow raking”, entailed the risk of triggering small but dangerous avalanches if attempted on the steeper slopes. Hard work in the cold conditions could also cause exposure.

Paradoxically, the snow acts as an insulator once it is on the ground. In the clear nights that followed the snowfall, temperatures dropped to minus 16 degrees Celsius at the top of the snow surface, but the ground temperature stayed near zero. Animals trapped under the snow are sheltered from the wind, and their body heat can help form small snow caves.

In mid-winter the sunlight in Canterbury is not strong enough to melt the snow, especially since most of the light is reflected away by the snow surface. Warm winds or rain are needed for a thaw. This finally came after ten days when warm northwesterly winds developed and the snow began to melt.

Disastrous floods have followed a number of heavy snowfalls in the past. In 1868, for example, the Opihi River in South Canterbury ran 11 km wide when swollen with melt water. This time there was no flood because the northwest wind in Canterbury is a very dry wind and much of the snow and water evaporated directly into the air.

Thousands of sheep and cattle died in the 1868 July storm and many more were left in poor condition. Tragically, when a second storm struck in the last week of August over a million lambs died. This storm was also caused by warm advection, but the snow was heavier in some areas, particularly parts of Banks Peninsula, where drifts of six metres were reported.

More common than these warm advection snowstorms are cold outbreaks where the air has come from the south through the whole depth of the atmosphere. These often bring snow down to sea level in the South Island and to low lying hills in the North Island, but the amounts of snow are much less than in the warm advection events, because the cold air has such a small amount of water vapour.

THE 1939 SNOWSTORM

Probably the worst storms of this kind in the last hundred years occurred during the winter of 1939 when snow fell the length and breadth of the country during frequent southerly outbreaks from June through to August.

On 31 July the lighthouse keeper at Cape Maria van Dieman, at the top of the North Island, reported snow falling at the lighthouse. A few days earlier it snowed in Dargaville and Ruapekapeka and snow lasted on the hills behind Kaikohe for several hours.

In Auckland, snow fell in many suburbs just before dawn on 27 July sticking to the clothes of people who were out and about such as milkmen and policemen. Five centimetres of snow were reported lying on the summit of Mt Eden while the Bombay Hills shone white for most of the morning. In the hills around Clevedon, just south of Auckland, snow lasted into the afternoon and numerous snowball fights took place between people who had never seen snow before.

Although snow threatened stock in some North Island hill country areas, over the low-lying areas it was largely treated with joy and amazement. In Gisborne snow fell for nearly three hours covering lawns and gardens, and those people who ventured outdoors enjoyed the novelty of being covered in snowflakes.

The road north of Taihape was blocked as was the Rimutaka Hill Road. Snow fell to sea level at Castlepoint and the road to Masterton was closed by drifts at Big Saddle on the Whakataki Hill. Snow lay 15cm deep in Masterton, where the town clock was stopped at 0220 am by the weight of snow on its hands.

Further south the snow was heavier. In Canterbury, Banks Peninsula was cut off from Christchurch. Snow lay 30 centimetres deep in Akaroa and southerly gales piled up drifts 10 metres deep in places. Sixty men in a public works camp near Duvauchelle were without food for two days until a launch arrived with supplies from Akaroa. Stock sheltering in gullies were buried in snow drifts and many perished. In other places snow covered the tops of the fences so that sheep and cattle were free to roam.

While roads on Banks Peninsula were blocked by snow, the road around the southwest of the peninsula was impassible at Kaituna where the waters of Lake Ellesmere were driven over it by the southerly gale.

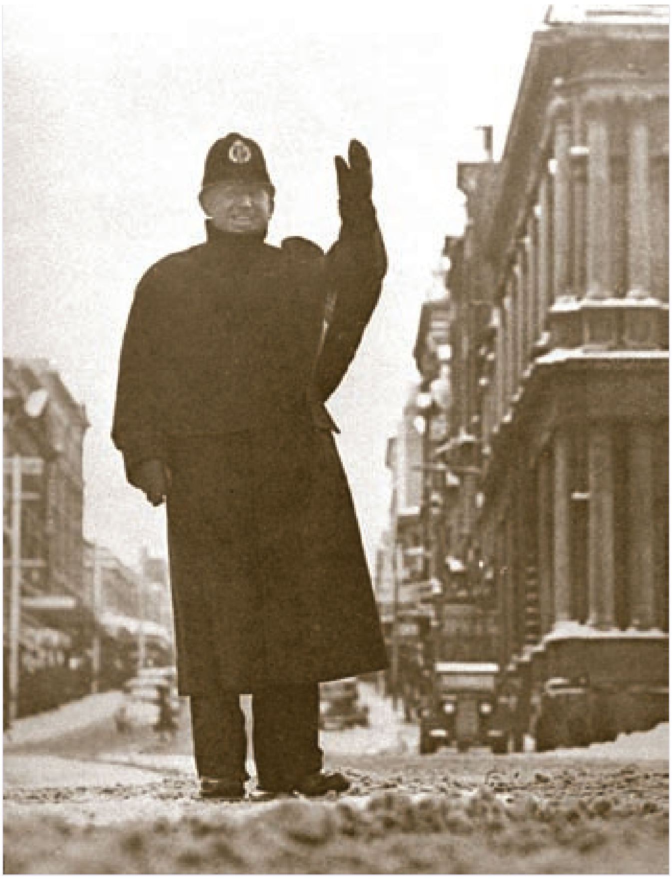
Although snow in Christchurch was only a few inches deep, frost on top of the snow caused numerous road accidents and disrupted the tram service.

Further south in Dunedin, conditions were much worse. Here snow and thunderstorms began during the evening rush hour on Monday 24 July, and by morning snow lay 15cm deep over the city. Only one bus made it out to the north over Mount Cargill, assisted by a gang of men with shovels. Electric trams did not commence running until the middle of the morning, and then only on certain lines on the flat. Buses made some progress over the snow but cars needed chains, although visibility was hampered for those whose windscreen wipers had frozen to the windscreen.

The road to the south was closed, as was the airport. Some trains got through, running silently over the snow-covered rails and only in tunnels making the usual clickety-clack noises. Schools were closed and no work was possible on the waterfront.

The snow continued falling through the Tuesday with gale force winds developing at night. The wind piled the snow into huge drifts completely filling road and rail cuttings and isolating the city from all sides. By the Wednesday morning snow was 35cm deep at St Kilda and half a metre deep at the north end of town but up to a metre deep in the higher suburbs such as Roslyn and Maori Hill. One drift on Mount Cargill was five metres deep and icicles 30cm long were reported on some houses. The weight of the snow caused some roofs and skylights to cave in.

The radio masts at Highcliffs on the Peninsula had been hit by lightning and the staff there were isolated without adequate supplies of food. On Wednesday a rescue mission was launched under



Constable Joe Oswald helps restore order during the big snow in Dunedin in 1939. Photo: Otago Daily Times

the command of the director of 4YA, Mr H. Ninnis, who had been with Shackleton in the Antarctic. Four members of the Otago ski club accompanied him. To transport the supplies they borrowed one of Captain Scott's sleds from the Otago Museum. When they reached the station, one of the men coming out to receive the supplies sank up to his neck in the snow.

Supplies were also running short in many parts of town as no fresh meat, vegetables, milk or coal was coming into the city. The only fatality occurred on Thursday when a man clearing snow from a skylight at Penrose's premises in George Street fell 10 metres to the floor.

By now snowdrifts were up to the roofs of some of the houses in the hill suburbs and many roofs were damaged. Small avalanches of snow destroyed guttering and spouting and some verandahs collapsed under the weight of snow. Most businesses had three days of little or no trade except for places selling gumboots, galoshes, motorcar chains, cameras and films.

However, the abundant snow also provided ample opportunity for people to enjoy winter sports. Snowballing was rife with battles between rival groups of businesses downtown. Any moving target was fair game, including cars and buses, some of which lost windows, causing the police to intervene. Ambushes from above were common, at least while snow lasted on windowsills. Unsuspecting victims answered ringing doorbells only to have arm-fulls of snow thrust into their halls. Snowmen sprang up all over town and one school even managed to stage a paper chase with Condy's crystals used to stain the snow red to make a trail. Skiers had a grand time and eagerly assisted in rescue missions including one to a farmer whose barn had collapsed.

Tobogganing was also a popular pastime, often on strips of linoleum or tea-trays borrowed from more sedate occupations. Speeds of up to 70 km/h were reached and there were the inevitable accidents.

Inland the snow was initially lighter but increased on the Wednesday night. The train from Lumsden to Kingston was marooned at Eyre Creek when the engine charged into a drift 2 metres deep and became stuck. The two passengers and the crew of three were forced to spend the night on the train and had to raid the cargo for dinner.

Further north, many places experienced severe frosts overnight. Water pipes burst in Palmerston North and Hastings, while, at Paremata, just north of Wellington, 20 acres of the harbour froze over and seagulls were seen walking about on the ice. Tidal waters also froze at Opotiki in the Bay of Plenty where sheets of ice were left attached to wharf piles and grassy banks as the tide went out and some ice lasted until 1pm.

Flooding occurred in Southland as the thaw set in on Friday, but the situation was relieved by another cold snap with further snow. Nor was that the last event. Invercargill received a heavier snow a week later when the city was covered to a depth of 15 centimetres overnight from Friday to Saturday 12 August. A ski-party set out for Oreti Beach to try out the snow covered sand dunes and the Ranfurly Shield game between Southland and Manawatu took place regardless, with only the lines cleared. Perhaps used to the local conditions, Southland beat the North Islanders 17-3. Snow also fell to sea level along the length of the West Coast, and in New Plymouth.

Up and down the country it was seen as the worst winter for snow in living memory, although one elderly Dunedin resident avowed that inland Otago had suffered worse in 1878 when drifts of 20 metres had occurred.

Although the statistic has not been calculated, it seems likely that this snow was of the order of a once in a hundred year event. Given the warming trend in both New Zealand and global temperatures since 1939, a winter this severe may have become a once-in-500-year event or rarer, and we may never see the like again.

Numerical Weather Prediction

Norm Henry

Manager, Automated Meteorological Prediction Systems, MetService

The weather that we experience each day is governed by complex patterns of air flow in the atmosphere that continually change over time and may span tens of thousands of kilometres. Weather forecasters face the never-ending challenge of understanding how these patterns develop and change over time. Meeting this challenge begins with careful analysis of current conditions using the latest available observations. This is carried out in an on-going cycle, providing forecasters with a set of snapshots representing past and present weather conditions. By considering how the weather systems on these analyses have changed over time, it is possible to predict how they will behave in the future. However, beyond forecast periods of a few hours, this type of approach is not very accurate because it fails to take into account the complexity of the atmosphere in sufficient detail.

A more thorough treatment can be achieved by describing the atmosphere mathematically, which allows possible future weather conditions to be calculated based on what is happening right now. Due to the complexity of this problem, practical solutions require the use of computer representations of the atmosphere, referred to as Numerical Weather Prediction (NWP) models. They work by creating an abstract mathematical description of the atmosphere using a 3-dimensional grid, with each point on the grid representing a specific location. The equations describing atmospheric motion are then solved using the computer, progressing in a series of small time steps from the model's start time through to the end of the forecast period. The output from each run of an NWP model typically includes things like temperature, pressure, wind, and rainfall, which are expressed as sets of numbers on the grid for fixed points in time. These can be presented to forecasters in the form of weather maps, much like the analyses discussed above, except that they depict the weather as it might appear in the future.

The importance of NWP to weather forecasting has increased steadily in recent years, spurred on by advances in computer technology, numerical methods, and our understanding of atmospheric science. A substantial part of the modern forecaster's day-to-day effort involves critical assessment of NWP guidance, normally from several independent models. Combined with the on-going analysis of current conditions and trends, and forecaster experience, this assessment provides the basis for production and monitoring of weather forecasts and warnings.

MODELLING THE BROAD-SCALE WEATHER

Operational NWP nearly always requires a trade-off between making accurate forecasts and delivering them on time with limited computer resources. Two key issues are the spacing between model grid points, sometimes referred to as model resolution, and the size of the area covered by the model. Models in which the grid points are close together (high resolution) are able to depict fine-scale weather features. This normally improves the forecasts, since it allows a more complete representation of the atmosphere. However it requires more computer power, as does increasing the area of coverage.

A number of weather forecasting agencies operate modelling centres where supercomputers are used to run NWP models that span the entire globe. These include the National Center for Environmental Prediction (NCEP) in the United States, the United Kingdom Meteorological Office (UKMO), and the European Centre for Medium-range Weather Forecasts (ECMWF). Although costly, a global approach to NWP is essential, especially for long-range forecasting, since the weather we experience four or five days hence may depend on present weather conditions many thousands of kilometres away.

For this reason, achieving accurate forecasts requires an accurate analysis from which to get the model started. This involves a computer-based process called data assimilation, in which the most recent weather observations from around the world are combined with model forecasts to create a global analysis of current conditions. This becomes the starting point for the next run of the NWP model, and is the computer equivalent of the manual analysis cycle that forecasters carry out on an on-going basis.

Getting this right is a key aspect of NWP, because small errors in the model's initial state will eventually lead to large forecast errors as the model run progresses. This is a result of chaos, which is sometimes referred to as the butterfly effect, the idea being that a

For the duration of the America's Cup 2003, MetService provided modelling support using a version of the CHAMP forecasting tool. In the picture, NZL 82 and Alinghi battle it out on the Hauraki Gulf . © New Zealand Herald.

butterfly flapping its wings over Wellington may cause a storm in Kansas two weeks later!

Global models play a key role in modern weather forecasting, and meteorologists at MetService routinely use the NCEP, UKMO and ECMWF models to assist with day-to-day production of forecasts and weather warnings. These models give insight into the behaviour of weather systems on a large scale, without much emphasis on local detail. To illustrate, imagine a low pressure system that will develop off the east coast of Australia, then cross the Tasman Sea and intensify, bringing heavy rain to parts of New Zealand next week. Although this is a reasonably common scenario, the actual development of such a system is very complex, and depends on many factors.

The forecast track of the low, its intensity, and the approximate timing and location of the heavy rain event would be assessed using each of the global models, initially by forecasters who are focussed on the longer range (ie, 3-5 days or more ahead). At such long lead times, each of the models will typically give different results, and an important part of the forecaster's job is to decide how much emphasis to place on each model. Forecasters will also pay close attention to the differences between successive runs of the same model, which can give important clues about how reliable the model forecasts are.

ENSEMBLE FORECASTING

The use of several independent NWP models, which may offer quite different answers, is a key issue in operational forecasting. Unfortunately, forecasters often don't have enough information to tell which model is most correct, especially at long lead times. Current-generation global models typically show skill at predicting the weather out to around 5 days into the future, beyond which the errors become too large. Although this range of predictability continues to increase as models improve, it can't be extended indefinitely. This is because chaos imposes an upper limit on how far into the future the weather can be predicted, which is thought to be around two weeks.

However, the predictability of the atmosphere is not constant – it varies with both location and the weather situation. For example, during March 2003, an area of high pressure remained stationary over central New Zealand for several weeks. The Wellington region experienced an unusually long stretch of fine weather, with a high degree of predictability. Model forecasts during that period showed little variation from one modelling centre to another, and forecasters were able to predict with certainty that the fine weather would persist well into the future. Conversely, when storms from the tropics approach New Zealand, predictability is typically quite low, with independent NWP models often giving very different forecasts even at relatively short lead times. In these situations, forecasters often have to make predictions in which their confidence is low, due to the conflicting model guidance.

Therefore, the extent to which independent models differ in their solutions can provide a great deal of information about predictability, which is directly related to forecast confidence. Over the past decade, this concept has evolved into a formal technique called ensemble forecasting, in which a single model is run repeatedly for the same forecast period, using a slightly different initial state each time. Chaos ensures that the forecasts from each run will differ, with these differences growing larger as the lead time increases. The full set of solutions from all of these runs provides an estimate of the range of possible outcomes for that situation, with the level of confidence in the forecast inferred from how wide that range is.

In our hypothetical forecasting scenario, the ensemble information would be used to assess the uncertainty in the forecast track and intensity of the low, as well as the resulting rainfall distribution. This allows forecasters to go beyond simply predicting what will happen next week. They can also provide an estimate of how much confidence they have in that forecast, and can give insight into how the forecast might change or go wrong. This kind of information is especially valuable to users who need to make decisions based on an assessment of the risk imposed by weather conditions.

MODELLING THE FINE-SCALE WEATHER

Although our local weather is controlled by large-scale features, it is also affected by small-scale processes that depend on local geography (terrain height, land use patterns, coastline, sea-surface temperature, etc). These effects are said to occur on the mesoscale, and often play a key role in determining local weather conditions, particularly in a geographically diverse country like New Zealand. The resolution of current-generation global models is not sufficient to describe mesoscale features. However, in day-to-day operations, forecasters are normally interested only in a small part of the world. If the area of coverage is sufficiently small, an operational limited-area model (LAM) may be run at much higher resolution.

Since it covers only a portion of the globe, a LAM must have some way of anticipating the weather approaching from upstream. To achieve this, forecast information from a global model is supplied around the model's perimeter, which describes the synoptic-scale weather immediately outside of the model's area of coverage. LAMs may be thought of as "downscaling" the synoptic-scale weather, by adding information about how it interacts with the fine-scale characteristics of the earth's surface.

For example, during the spell of fine weather in Wellington in March 2003, forecasters would have used the global models to assess the overall behaviour of the synoptic-scale anticyclone affecting the area. However, a LAM running at much higher resolution would have been required to depict the development of daytime seabreezes in coastal areas during the same period. This is because the seabreeze depends on the fine-scale characteristics of the land and sea surfaces, which are not well represented on the relatively coarse global model grid. LAMs may be run with grid spacings

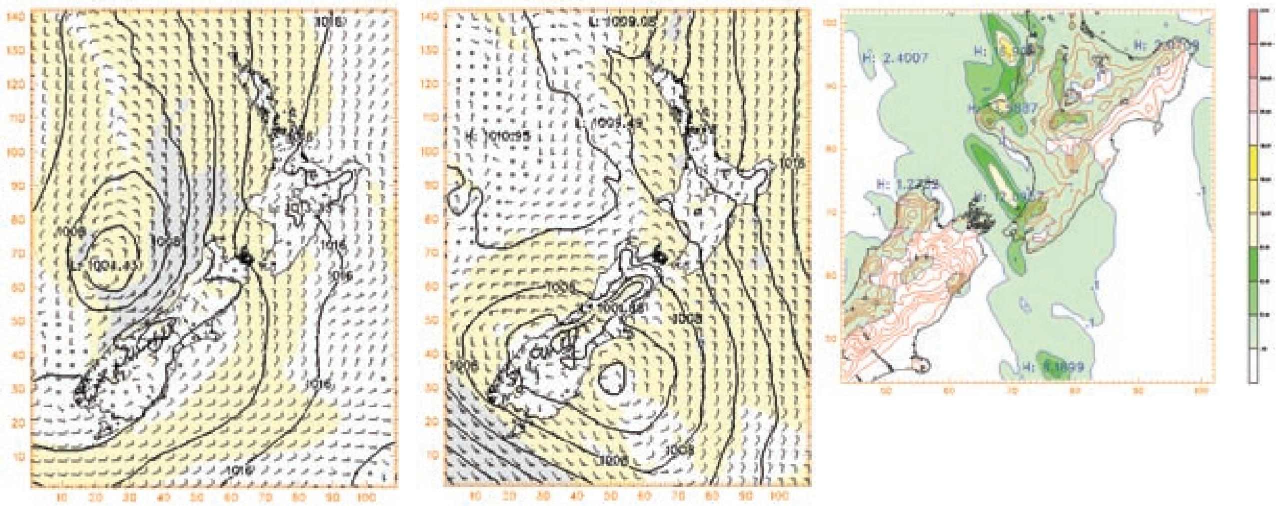


Figure 1. CHAMP New Zealand regional model forecasts. The first two images show mean sea-level pressure and the wind at 10m above the ground. The one on the left is a 9-hour forecast valid 9:00 AM NZST 5 April 2003) and the one on the right is a 27-hour forecast valid 3:00 AM NZST 6 April 2003.The image on the right is the corresponding 27-hour forecast of the 3-hour rainfall amount in mm. The wind is depicted using barbs that point in the direction the wind is blowing, with feathers that indicate the speed. Areas with wind speed of 10 knots or greater are shaded yellow; areas with 20 knots or greater are shaded grey.

MetService Meteorologist Paul Mallinson studies output from the CHAMP New Zealand regional model, along with the latest radar and satellite imagery. Expert meteorologists are responsible for issuing severe weather warnings and watches, and routinely make use of high-resolution NWP model guidance.

as small as one kilometre or less, and are often referred to as mesoscale models, in reference to the small-scale weather features they are able to depict.

MetService runs an operational mesoscale modelling system, referred to as CHAMP, that is based on the MM5 model. MM5 is an advanced mesoscale research model that was developed jointly by Pennsylvania State University and the U.S. National Center for Atmospheric Research (NCAR), and is currently maintained by NCAR. For regional forecasting in New Zealand, CHAMP is run with a horizontal grid spacing of 12 km. It uses the NCEP global model for synoptic-scale input, and is run four times per day over a forecast period of 72 hours.

The model is actually run over two separate areas at the same time. The outer domain, which has a grid spacing of 36 km, is relatively inexpensive to run and keeps the direct influence of the global model well away from New Zealand. The high-resolution inner domain is restricted to the area of immediate interest, to limit the amount of computer power required. The model is run on a Beowulf cluster, consisting of 16 dual-processor PCs connected through a high-speed network. The intensive computations required to create the model forecast are spread out amongst all of the processors in the cluster, which effectively works like a small supercomputer, without the large price tag!

As the lead time in our hypothetical weather event reduces to within one or two days, forecasters will focus increasingly on mesoscale features to fine-tune their forecasts and weather warnings. Particular attention will be paid to issues such as rainfall distribution, rain-snow boundaries, and the variation of surface wind speed and direction, all of which may be strongly affected by local geography. With its high-resolution representation of surface features and their interaction with the atmosphere, CHAMP plays a key role in helping forecasters turn their understanding of the synoptic-scale patterns into a detailed picture of local weather.

Figure shows forecasts from the CHAMP New Zealand regional model, which depict a low pressure system crossing the South Island with a trailing cold front approaching the lower North Island. Note the complex structure of the low after it has interacted with the South Island terrain. In the 27-hour forecast, the front is located over Cook Strait, extending to the west of Taranaki, as indicated by the northwest to southwest wind shift. It shows a well-defined mesoscale rainband associated with the front, affecting the Kapiti Coast and Tararua Ranges. Thunderstorms associated with this feature kept the author awake (but delighted) in the early hours of April 6.

For some forecasting applications, the 12-km grid spacing of the CHAMP regional model is too coarse to show the required detail. The wind forecasting carried out by the competing syndicates during the 2003 America's Cup is a good example. The competitors in these races are very sensitive to small changes in wind speed or direction, and the influence of the local geography around the Hauraki Gulf would have certainly affected some race outcomes. For the duration of the America's Cup, MetService provided modelling support to a number of participants using a version of CHAMP having a grid spacing of 1.67 km. It proved to be a valuable forecasting tool, providing an accurate representation of local seabreezes and other mesoscale features that affect the race area.

THE FUTURE

Numerical Weather Prediction has dramatically changed the profession of weather forecasting over the past 50 years, and will certainly continue to do so in the future. The modern weather forecaster must be an expert at the interpretation of a wide range of NWP model information, from global synoptic-scale guidance to local forecasts based on high-resolution mesoscale models. The use of ensemble methods will become increasingly important, with greater emphasis placed on objective measures of forecast confidence, and forecasters will need to take advantage of ever-increasing volumes of model-based data. MetService will endeavour to stay at the forefront of NWP through on-going development of our own modelling programme, the continued application of a range of models run at other centres, and the development of systems to make better use of model information.

A more detailed version of this article is available in the online version of Tephra at: www.civildefence.govt.nz

BE PREPARED

We can't prevent disasters. But each one of us can take some simple steps to ensure we will be better prepared to cope when they occur. Disasters can strike at any time and often without warning. Know what to do before you have to do it.

AT HOME

Develop a household emergency plan which includes:

- Where to shelter in an earthquake, flood or storm
- Who is responsible for checking essential items in your Emergency Survival Kit
- How to turn off gas, water and electricity at the mains
- How to maintain contact with each other during an emergency
- How to contact your local civil defence organisation for assistance during an emergency

Know the local Civil Defence warning system. If possible, know the location of your nearest Civil Defence or Community Emergency Centre. It is also useful to learn First Aid and how to control small fires, and escape from a fire.

IN YOUR STREET

Join or form a neighbourhood support group. You and your neighbours will have skills and resources that can be vital in an emergency. Start discussing today what you can do to assist each other. Contact the Police for advice.

Become a civil defence volunteer. Ask your local civil defence organisation how you can help.

EMERGENCY SURVIVAL KIT

If you prefer to keep your Emergency Survival Kit items in the house for everyday use, make sure you know where to find them when an emergency occurs.

FOOD AND WATER – ENOUGH FOR 3 DAYS

- Canned or dried food
- A can opener
- A primus or BBQ to cook on
- Bottled water (3 litres per person per day)

Check and renew the food and water every 12 months.

EMERGENCY ITEMS

- First Aid Kit and essential medicines
- Spare toilet paper and plastic rubbish bags for your emergency toilet
- Pet supplies
- Waterproof torches and spare batteries
- Radio and spare batteries

Check the batteries every three months.

SUPPLIES FOR BABIES AND SMALL CHILDREN

- Food and drink/clothing/favourite toy

SPECIAL SUPPLIES FOR THOSE WITH DISABILITIES

- Hearing aids/Mobility aids/Glasses

EMERGENCY CLOTHING

- Wind proof and rainproof
- Sun hats
- Blankets or sleeping bags
- Strong shoes for outdoors

Put all items, especially blankets and clothing, into leak-proof plastic bags.

Download your household emergency checklist from: www.civildefence.govt.nz

YOUR GETAWAY KIT

Everyone should have a small bag for a Getaway Kit, ready for evacuation. Most of the items are part of your Emergency Survival Kit. Other items include:

FAMILY DOCUMENTS

- Birth/marriage certificates
- Drivers licences/passports
- Family photos
- Insurance policies

PERSONAL HYGIENE ITEMS

- Towels/soaps & toothbrushes
- A change of clothes

PEOPLE WITH DISABILITIES

If you have a disability, make arrangements with a family member, friend, or neighbour to help you in an emergency.

- People with hearing impairment may not be well served by radio. Make arrangements to be sure you are informed by somebody.
- People with sight impairment may have difficulties if their home is disrupted – perhaps in an earthquake – and may have extra difficulties in an unfamiliar Civil Defence Centre. You should arrange some form of "buddy" system.
- People with asthma and other respiratory disorders may be especially qaffected by stress, dust or volcanic ash. Have plenty of medicines and face masks in your Emergency Survival Kit.
- If you have special food needs, be sure to include as much as you can in your Emergency Survival Kit.

www.civildefence.govt.nz

STORMS

Damaging wind is caused by deep depressions or by tornadoes. A strong wind warning is issued by the MetService when winds of more than 87km/h are expected over land. You can be better prepared to cope with an emergency if a plan is in place for your home.

WHEN A STRONG WIND WARNING IS ISSUED

- Listen to your radio for information.
- Bring pets inside and move stock to shelter.
- Secure outdoor furniture and lightweight garages.
- Put tape across large windows to prevent them from shattering.

DURING THE STORM

- Open a window on the side of the building away from the wind – this will relieve pressure on the roof.
- Close the curtains to slow down flying glass or other loose objects.
- Stay away from doors and windows. If the wind becomes destructive, shelter further inside the house. Use a mattress for added protection.
- Stay away from metal and electrical fixtures.
- Contact your local council if your house or building is severely damaged.
- Don't walk around outside, and don't go driving unless absolutely necessary.

AFTER THE STORM

- Avoid dangling and broken power lines. Report these to the nearest electrical authority.
- Contact your local council for advice about cleaning up debris.

FLOODS

Disastrous floods have struck most parts of New Zealand. Floods are the most common cause of a civil defence emergency.

Assume that you will have to cope with a flood. Several so-called '100-year' floods can happen in quick succession. To reduce the impact on you and your loved ones, there are measures you can take.

BEFORE A FLOOD STRIKES

- Find out about the worst flood in your locality and how high it rose. Calculate where such a flood would reach in your home.
- Know how to reach the nearest high ground.
- Keep your valuables and some food and clothing above what you judge to be the high-water mark.
- Store weedkillers, insecticides and other chemicals above your estimated high-water mark.
- Consider building some form of storage above your ceiling.
- Find out about present and future plans for building flood protection schemes in your locality.
- Keep your insurance cover up-to-date.

WHEN A FLOOD OCCURS

- Listen to your radio for information. Follow Civil Defence advice and instructions.
- Disconnect electrical appliances and move valuables, clothing, food, medicines and chemicals above the likely reach of floodwater.
- Take your Getaway Kit with you if you have to leave your home. Turn electricity and gas off at the mains.
- Take your pets with you if you can.
- Don't go into floodwaters alone.
- Don't go sightseeing through flooded areas.
- Don't drink floodwater. It could be contaminated.

TSUNAMI

A tsunami is a series of sea waves generated by underwater earthquakes or large landslides. Many New Zealanders live in coastal communities. A major earthquake, landslide or volcanic eruption can create massive tidal waves that could be disastrous for these communities.

TSUNAMI WARNING

The Ministry of Civil Defence and Emergency Management issues national warnings to civil defence organisations, and through radio and television broadcasts.

NEAR SOURCE TSUNAMI

A "near source" tsunami is one that is generated close to our coastline by a strong earthquake. New Zealand has experienced a few of these. The water level may fall very quickly past the normal low tide mark, then return just as quickly. If this happens there won't be enough time to issue a warning.

WHEN A TSUNAMI THREATENS

- Turn on your radio and follow all instructions.
- Take your Getaway Kit with you if you are told to evacuate.
- Leave the area immediately if you are on the beach or near a river when a strong earthquake occurs.
- Go at least one kilometre inland or 35 metres above sea level.
- Don't go to a river or beach to watch the waves come in.

For further information on what you should do to prepare for an emergency, contact your local council or visit www.civildefence.govt.nz.

Find out what hazards your community is at risk from and take steps to be prepared.

www.civildefence.govt.nz