Overview of weather and coastal hazards in the Northland region

Part I: Weather hazards

NIWA Client Report: WLG2003-57
December 2003

NIWA Project: NRC04301

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Contents

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Executive Summary

Northland is at risk from extreme weather systems, be they ex-tropical cyclones, north Tasman lows, or severe convection and thunderstorms. This report discusses these weather systems and the hazardous impacts they have in terms of the occurrence of intense rainfall, flooding, inundation, hail and lightning. While there is potential for damage from wind hazards, landslides and rural wildfire, little research has been undertaken to assess these risks. The report has also outlined the potential impacts of climate variability on Northland, both through long-period climate cycles like El Niño (2-3 year cycles) and the longer Interdecadal Pacific Oscillation (20-30 year cycles), as well as that resulting from global climate change. It is likely that the impacts of weather-related hazards experienced in Northland will increase on the back of a global warming trend, particularly with higher rainfall rates and more intense storms. We are less certain about changes in frequency of occurrence of hazardous weather events from climate change.

Of the weather-related hazards assessed in this report, those from which Northland appears to be most at risk result from ex-tropical cyclones and severe convection storms. Ex-tropical cyclones have the potential to cause damage across the entire region, both through extreme winds and heavy rain. Severe convection tends to cause localised damage, but as the events are often not well forecast, they can catch communities unaware. Recent research efforts by NIWA are outlined, such as the development of high-resolution weather models and radar nowcasting techniques for rainfall, which could provide better and more timely information for emergency managers and Northland's communities.

Introduction

As a long peninsular, the Northland region is at significant risk from both weather and coastal hazards. The long coastline and the exposure to intense weather systems, be they ex-tropical cyclones or north Tasman lows, result in a region often confronted by weather-related hazard events (Revell 2003). These events can lead to damage to property and infrastructure, disrupting transport and lifelines, impacting upon the regional economy and in extreme cases may cause injuries or death. This report documents the current level of knowledge of weather hazards, and identifies gaps where further knowledge or information is needed.

Weather systems

Ex-tropical cyclones

The exposure of Northland leaves it at risk from many sources of extreme weather. Of the larger scale systems, tropical cyclones are perhaps the most significant. Tropical cyclones change in nature as they move from the tropics into our latitudes (Brenstrum 2003). These intense but broader scale ex-tropical systems cause some of Northland's most extreme weather. Examples such as cyclones Bola, Giselle, Drena and Fergus, have resulted in damaging winds and persistent rainfall (Sinclair 1993). During ex-tropical Cyclone Bola in March 1988, a state of emergency was declared in Dargaville, and the main water supply was disrupted when the line carrying the water was washed away with a bridge (Christchurch City Libraries 2003). Figure 1 shows that Northland has, on average, around 1 ex-tropical cyclone pass near-by each year, putting it more at risk from ex-tropical storms than the rest of New Zealand (Sinclair 2002).

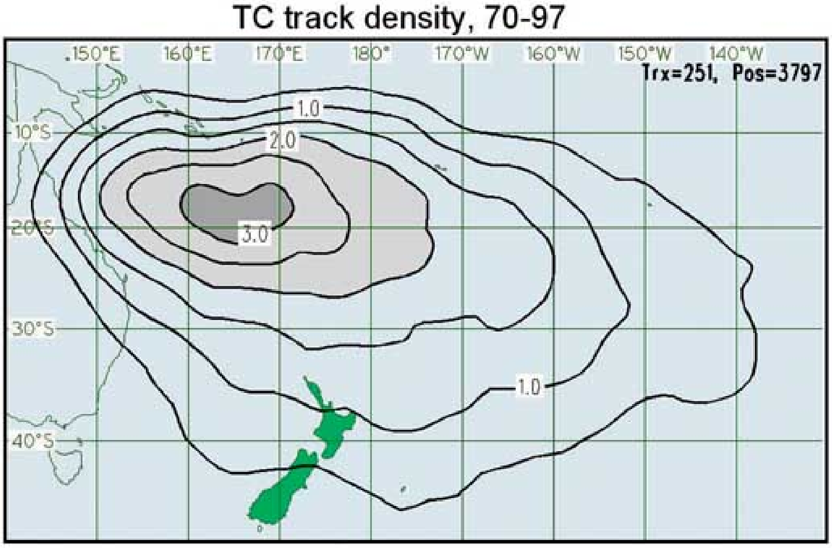

Figure 1: Distribution for all tropical cyclones during 1970–1997. Contours represent the number of tropical cyclones passing within 500 km of each point per year, drawn at intervals of 0.5; values greater than 2 and 3 per year are shaded.

North Tasman Lows

Northland is also at risk from weather systems that develop in the North Tasman Sea over the warm waters off the Queensland coast. These systems can bring persistent rain and strong winds. The "weather bomb" of 20 June 2002 was an example of such a system, with the low pressure area deepening at a rapid rate of over 24 hPa in 24 hours - hence its description as a "bomb" (Figure 2). Although this system brought widespread rain to much of the Northland region, it was the intense convective rain that led to flooding in the Coromandel (NRC 2002a, see also Figure 3 and Appendix 1).

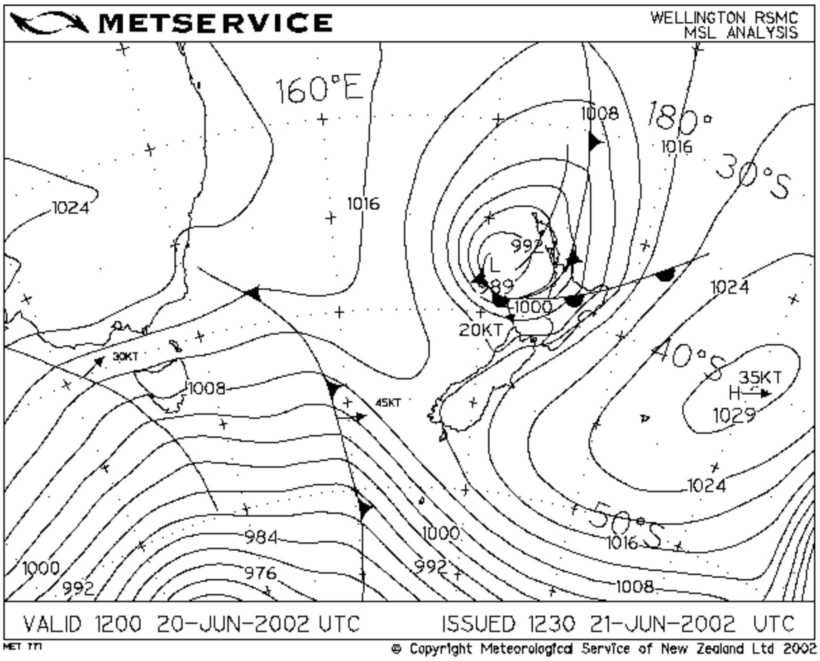

Figure 2: Mean sea level pressure analysis for midnight 20 June 2002 NZST (From http://www.metservice.co.nz/severe_weather/WINTER02_2.asp)

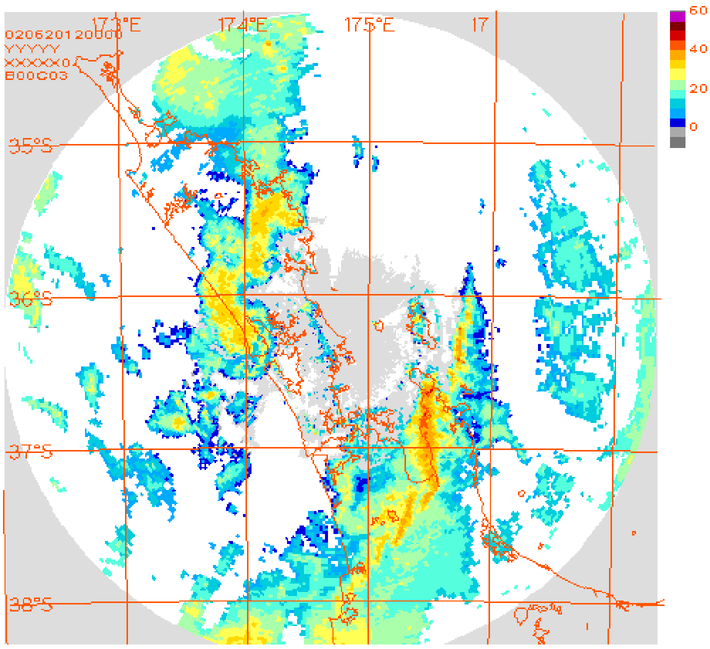

Figure 3: Weather Radar image for midnight 20 June 2002 NZST showing intense rainfall over the west of the Coromandel ranges, and also heavy rain in Northland.

Intense Convection (squall lines, thunderstorms, heavy showers)

Much of the hazardous weather Northland faces results from small-scale systems such as squall lines, thunderstorms and heavy showers. These systems are often difficult to measure and forecast, but can lead to squally winds, flash flooding, lightning and hail. For convection to occur the atmosphere needs to be unstable, and then for something to trigger that instability. There are several sources of triggering including lifting of air as it flows over hills, lifting by broad-scale ascent of the air and lifting at sea breeze fronts. Northland, with its long coastlines, often gets sea breezes. The sea breeze circulation draws air from the sea over the land, where the air rises before returning seaward. This rising air can trigger the release of the instability, and cause heavy showers. Should sea breezes meet, say one from the east and one from the west coast, the stronger uplifting can trigger more intense thunderstorms. Figure 4 shows an intense convective event that led to record rainfalls being recorded at the Marine Observatory at Leigh. The instability in this event was triggered by the broad-scale ascent due to the passage of a small low.

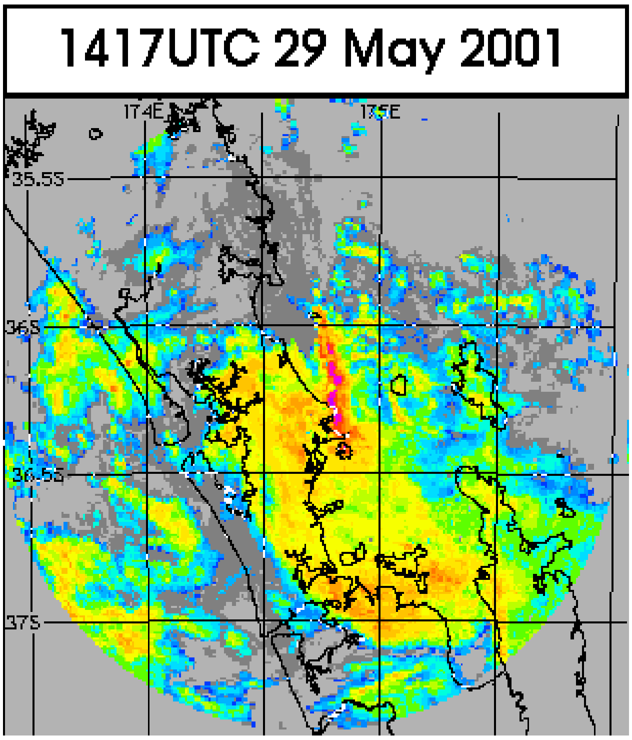

Figure 4: High-resolution radar image of the record intense rainfall at Leigh, 29 May 2001. 109.4 mm was recorded in 1 hour.

Appendix 1 contains a list of a number of heavy rainfall events, many of which were from convective storms. The convective storm tracks are shown on the map in the appendix.

Orographic enhancement

Northland's steep terrain can lead to enhancement of precipitation over the ranges. The wind flow over these hills results in lifting that can intensify rainfall from pre-existing weather systems and also trigger further rain (e.g., Gray and Austin, 1993). This can lead to the ranges being preferred locations for rainfall, with enhancements in rainfall rate of up to a factor of 5 being possible for widespread systems, and the triggering of extra showers being common place.

Climatology of hazards

Existing records of climate data can be used in the understanding of the weather hazards Northland faces. For example, Table 1 shows the extremes of climate as measured during the period 1985-2003 at the Kaitaia observatory. Data like these can often present a picture of the weather hazardscape[1], though often the extremes of weather do not occur where measurements like these are made.

[1] Hazardscape refers to the knowledge we have of the intensity, duration and the frequency of hazardous events.

Kaitaia			1985-2003 -35.135°S 173.262°E											
TYPE	Units		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Total rain	mm	MAX	286.8	252.1	226.4	248.6	244.9	261.2	358.2	309.0	222.6	209.6	194.8	184.8	1618.3
Rain days		MAX	19.0	16.0	20.0	24.0	26.0	26.0	28.0	27.0	24.0	23.0	23.0	21.0	213.0
Wet days		MAX	18.0	10.0	13.0	17.0	19.0	20.0	24.0	21.0	19.0	17.0	18.0	15.0	164.0
Max 9am-9am rain	mm	MAX	93.4	159.3	138.5	68.7	107.0	92.3	103.2	81.3	90.6	56.4	62.4	58.3	159.3
Extreme max T	°C	MAX	28.6	30.2	27.5	27.0	23.3	20.3	20.4	19.9	21.8	22.7	24.6	27.5	30.2
Extreme min T	°C	MIN	8.8	9.0	6.5	4.5	3.8	0.9	1.5	1.7	2.2	4.0	4.6	6.0	1.5
Days gust > 24kts		MAX	18.0	14.0	19.0	20.0	22.0	21.0	25.0	25.0	25.0	23.0	23.0	19.0	223.0
Days gust > 33kts		MAX	8.0	5.0	5.0	5.0	10.0	12.0	17.0	16.0	12.0	12.0	9.0	8.0	84.0
Days gust > 51kts		MAX	1.0	0.0	3.0	1.0	1.0	1.0	4.0	4.0	2.0	1.0	1.0	0.0	6.0
Max gust	m/s	MAX	26.3	25.2	33.5	38.6	30.4	30.4	32.4	32.4	28.3	30.9	27.8	25.7	38.6

Table 1: Listing of the Kaitaia 1985-2003 extremes for rain, temperature and wind.

Intense Rainfall

Flood reports show the event-by-event occurrence of hazardous weather, and capture the information available at the time. Events on 29 May 2001 and 1 June 2002 show that often the systems that cause flooding in Northland are small-scale intense convective rain storms, though events on 27 March 2003 and 20 June 2002 show that widespread regional flooding can also occur as a result of larger-scale weather systems.

River flows

Much of Northland can be characterized as having steep hills (often heights exceed 600 m, with slopes greater than 1:10) and sluggish rivers (NRC 2002). This can lead to rain being converted to riverflow with little delay. The flat terrain around the ranges means that the rivers become slow flowing, and hence floodwaters recede slowly. The many harbours and estuaries that lie at the mouth of these rivers mean that at high tide river waters can be further held back.

It is well known that many of the communities in the Northland region are flood prone (NRC 2002) and flood mitigation measures have been applied to several rivers (for example, the Whangarei City Flood Control Scheme and the Kaitaia Flood scheme).

Added to the river-flood hazard is the large amount of silt and debris that often accompanies flooding. This is again a result of the steep topography, and soils that are prone to slipping in the upper catchments of Northland's rivers.

Rain gauge observations

Often the primary source of information to assess weather hazards is rain gauge data. Table 2 shows the maximum rainfall totals observed at the Kaitaia observatory over an 18-year period. These totals will have been exceeded at times by rain gauges at other points, and even higher totals will have been experienced in areas not currently gauged. Such is the nature of rainfall measurements.

Duration	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
10 min	12.2	14.7	12.1	13.6	11.0	11.4	10.6	12.5	11.7	9.1	10.4	11.3	14.7
20 min	15.8	25.9	20.0	20.4	13.9	19.0	17.0	15.1	14.4	10.8	16.8	17.6	25.9
30 min	18.1	29.5	27.5	26.4	18.9	24.2	24.2	17.4	21.2	12.2	21.2	23.2	29.5
60 min	20.1	46.7	32.5	40.5	24.3	31.6	45.7	23.4	29.6	23.2	27.2	29.2	46.7
2 hr	37.8	66.4	51.7	47.5	38.6	41.3	65.2	28.0	36.8	25.7	41.3	35.9	66.4
6 hr	74.5	146.0	61.9	56.9	71.5	72.5	94.9	44.1	67.8	51.9	66.6	47.3	146.0
12 hr	92.6	158.4	76.6	60.8	79.9	109.3	102.3	60.8	87.2	55.1	80.0	53.2	158.4
24 hr	121.9	159.4	100.7	71.2	107.2	140.7	103.9	102.9	90.6	62.7	87.0	84.5	159.4
48 hr	122.1	159.4	111.5	81.5	125.6	152.8	119.7	145.8	109.4	76.0	109.9	106.4	159.4
72 hr	122.8	159.5	134.1	85.9	131.9	156.6	122.6	168.5	125.3	106.4	116.0	110.4	168.5

Table 2: Maximum rainfall totals (mm) as observed over the given durations at the Kaitaia observatory between 1985 and 2003.

High Intensity Rainfall Design System

One technique that has been developed to interpolate between raingauge observations is the High-Intensity Rainfall Design System (HIRDS) (Thompson 2003). HIRDS produces estimates of rainfall depth for pairs of duration and return period for any specified point around the district. HIRDS also produces an estimate of the standard error of the depths (not shown here). Table 3 shows an example of the output from HIRDS for Kaitaia.

Kaitaia		10’	20’	30’	60’	2 h	6 h	12 h	24 h	48 h	72 h
Annual Recurrence interval (Years)	2	10.2	15.0	18.7	27.5	35.4	52.8	67.9	87.4	101.7	111.2
	10	14.4	21.3	26.8	39.8	50.7	74.2	94.5	120.2	141.8	156.3
	20	16.6	24.6	31.1	46.3	58.7	85.4	108.2	137.0	162.6	179.7
	50	20.1	30.0	38.0	57.0	71.7	103.3	130.0	163.7	195.7	217.2
	80	22.2	33.3	42.3	63.5	79.7	114.2	143.3	179.8	215.8	240.2
	100	23.3	35.0	44.5	67.0	83.9	119.9	150.2	188.1	226.3	252.1
	150	25.5	38.4	48.9	73.8	92.2	131.1	163.8	204.6	247.0	275.7

Table 3: Data from HIRDS, showing the rainfall depth (mm) for pairs of duration (minutes or hours) and return period (years) for Kaitaia.

Weather Radar

While raingauges provide estimates of rainfall at a point, radar can provide rainfall estimates over an entire district. Metservice (NZ) operates three weather radars, of which the one located near Warkworth covers much of the Northland region. Figure 5 shows an example of weather radar data from the event that caused flooding in Taupo Bay. The black circle shows the range out to which radar data are regarded as being quantitative (120 km). Beyond this range the data can be used to show the presence of rainfall, but has little quantitative value (Austin, 1987).

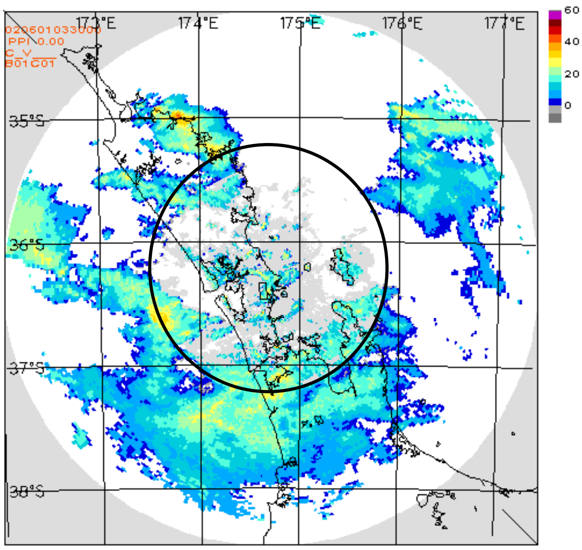

Figure 5: An example of an image from the weather radar that covers the Northland region. This example is from the 1 June 2002 event at 0330 UTC. This

event brought heavy rain to Taupo bay. The black circle shows the 120 km radius ring, within which radar data are regarded as being quantitative.

Radar is also not without its problems when it comes to quantitatively estimating precipitation (Austin 1987). Despite these difficulties, for many events radar remains an important option for detecting and measuring hazardous rainfall.

Appendix 1 shows several radar maps from events where flooding and damage occurred. Of these events, many are characterised as being from small-scale intense systems, though the events of 9-10 March 2003 and 19-20 April 2003 were more widespread in character.

Climate Variability: ENSO/IPO

One of the influences on the frequency and intensity of extreme events is the El Niño/La Niña Southern Oscillation (ENSO). This climate cycle modulates the weather systems that affect NZ (NIWA 2003), and changes from "El Niño" to "La Niña" (or vice versa) on an approximately 2-3 year time scale (Wratt 2003). The El Niño phase leads to a predominance of westerlies, making regions in the west wetter, and the east drier. Research has also shown that this phase also leads to tropical cyclones being developed further east, decreasing the number that pass near NZ (Sinclair 2002a). In contrast, the La Niña phase has more north-easterlies, and a greater number of ex-tropical cyclones tend to pass closer to NZ.

More recently, a longer climate cycle has been identified in our weather and rainfall patterns. The Inter-decadal Pacific Oscillation (IPO), changes phase on an approximate 20 to 30 year time scale. The IPO has a modulating influence on the ENSO cycle e.g. in the period from 19781998, the IPO provided background climatic and oceanic conditions in the Pacific that enhanced El Niño events–both in frequency and intensity (Salinger et al. 2001, McKerchar and Henderson 2003). The recent shift in the IPO to a negative phase could lead to more predominance of La Niña events.

Global Climate Change

Although there is much variability in weather from day-to-day, year-to-year, it is the impacts of the increasing amounts of greenhouse gases in the atmosphere that occupy much of the headlines. With increasing pressure on land use, hazardous zones are being more intensively occupied. This can lead to the impression that extreme events are occurring more frequently than in the past as damage and insurance costs of weather-related events worldwide is rapidly increasing. An objective approach is needed to assess the changes in extreme events. Evidence to hand already shows that sea levels around New Zealand are rising (Bell et al. 2002), and the frequency of intense weather systems may be increasing (Sinclair 2002a). Predictions for the future suggest that the amount of energy available for our weather systems may increase. Recent global climate change models, modelling a steady increase in CO_2, suggest that the temperature difference between the pole and the equator will increase (NIWA 2003a). This difference is the main source of energy for our mid-latitude lows and fronts. As air temperatures are predicted to increase, so too will the moisture holding capacity of the air. The more moisture available, the more latent heat that can be released as cloud forms. This latent heat is another source of energy for our weather systems, particularly those in Northland. As the energy sources increase, so it is expected that the intensity of our weather systems will increase. As yet unclear is whether this increase in energy will also change the frequency of events. To help regional and territorial authorities assess the likely effects of climate change on their region, the Ministry for the Environment has commissioned two sets of guidance notes; one for coastal hazards and one for more general effects (Ray et al.. in press, Wratt et al. in press). These are due to be released in early 2004.

Forecasting river flow

One approach to mitigating the effects of a natural hazard is to forecast its occurrence so that prior actions can be taken to reduce damage done. Riverflow forecasting can be used to give people sufficient warning of flooding, and thereby time to remove property and themselves from hazardous sites. One such scheme is currently employed to give warnings for Kemp House, Kerikeri. This flood forecasting system was developed for the Historic Places Trust to enable them to move ground floor exhibits to safety before the flood arrives. The system uses telemetered raingauge data as input into a hydrological model. The model then forecasts the amount of water expected in the river over the next few hours.

Similarly, a flood forecasting scheme is being set up by NRC for the Kaitaia area. This scheme will take information from telemetered raingauges and flow gauges along the upstream river catchments, and produce forecasts to warn the emergency managers of the potential for flooding.

Hail Risk

While hail is difficult to forecast, it can be damaging, particularly to horticulture operations. Little evidence exists as to the degree at which Northland is at risk from hail, but Steiner (1989) suggests that the higher freezing level found in the north of the country makes the formation of large hail less likely than for many other regions. Steiner also found that the afternoon was the preferred time for hail formation. Table 4 shows the maximum number of hail days seen in any month for the period 1985-2003. These relatively low totals supports the hypothesis that hail is not a frequent occurrence in Northland.

Kaitaia	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Hail days	1	1	0	1	3	4	4	6	3	1	1	0	16
Thunder days	4	2	4	4	6	5	5	9	3	5	2	3	23
Lightning days	3	1	4	5	6	6	6	11	4	5	3	4	31
Gale days	0	1	3	1	1	2	4	3	2	1	2	0	7
Fog days	7	5	6	7	8	8	6	8	7	5	7	5	46

Table 4: Maximum number of days with the observed phenomena from 1985-2003, for each month, and for any year.

Lightning

While damaging hail may not be a significantly frequent hazard, the occurrence of intense convective systems suggest that thunder and lightning may be significant hazards. Indeed, almost continuous thunder and lightning was observed with the heavy rainfall event of 1971 at the Whangarei Heads. Table 4 show that while there is a winter time predominance for thunder and lightning, thunderstorms can occur at any time of the year.

A new source of data that might be considered for evaluating the risks associated with intense convection is data from the Metservice (NZ) network of lightning recorders. This network is able to pin-point any cloud-to-ground lightning strikes, anywhere over the country (http://www.metservice.com/lightning/index.htm).

Wind Hazard

Northland is at risk from wind hazards, particularly during the passage of ex-tropical cyclones. For example, Wells (1989) reported that Cyclone Bola passed over Northland during the first week in March, 1988, bringing rainfall up to 500 mm over a six-day period, and winds gusting up to 130 km/h (36 m/s). The gusting winds following rain caused "windsnap" damage and, in conjunction with saturated soils, windthrow of many of the trees commonly used in the region for farm and horticultural shelter and specimen plantings. Damage was also caused to shallow rooted trees such as citrus and tamarillos. While Northland’s general wind climate is relatively benign (on average only 7 gale days a year at Kaitaia), it is the extreme events that cause the damage. For example, the strongest gust measured at Kaitaia between 1985 and 2003 was 38.6 m/s, (140 km/h or 75 knots) (see Table 1). Tropical cyclones are not the only source of damaging winds. Reid (1995) reports that gusts from large cumulonimbus cloud systems can also produce damage from squalls, microbursts and tornadoes.

Landslide

While the detailed discussion of landslide risk is beyond this report, it should be noted that land slippage is a frequent occurrence in this region, primarily a result of the step topography, the soil structure, and the intense rainfall that can occur.

Wildfire

A detailed discussion of wildfire is also beyond the scope of this study, though it is a significant hazard for many regions around the country. For example, wildfires in the Wellington region can result in the burning of large areas of bush and forest and the consumption of hundreds of thousands of dollars worth of man-hours and fire-fighting equipment usage (NIWA 2002). Wildfire could become a more serious issue as urban and semi-urban developments move into areas of scrub and bush, for example, around the Bay of Islands.

Research directions

NIWA undertakes research on a variety of weather and climate related topics. Application of aspects of this research and information to managing Northland's weather-related hazards could improve the awareness of, and resilience to weather hazards. Several are discussed below, and their relevance to Northland highlighted.

Mapping HIRDS

HIRDS has recently been redeveloped, with a significantly longer data set and a new statistical and theoretical model. The longer data set included data from much of the Northland region. There is, however, an opportunity for additional development of HIRDS, with an enhanced set of Northland data. Furthermore, there is now the capability of mapping the HIRDS rainfall onto GIS systems (see, for example, Figure 6).

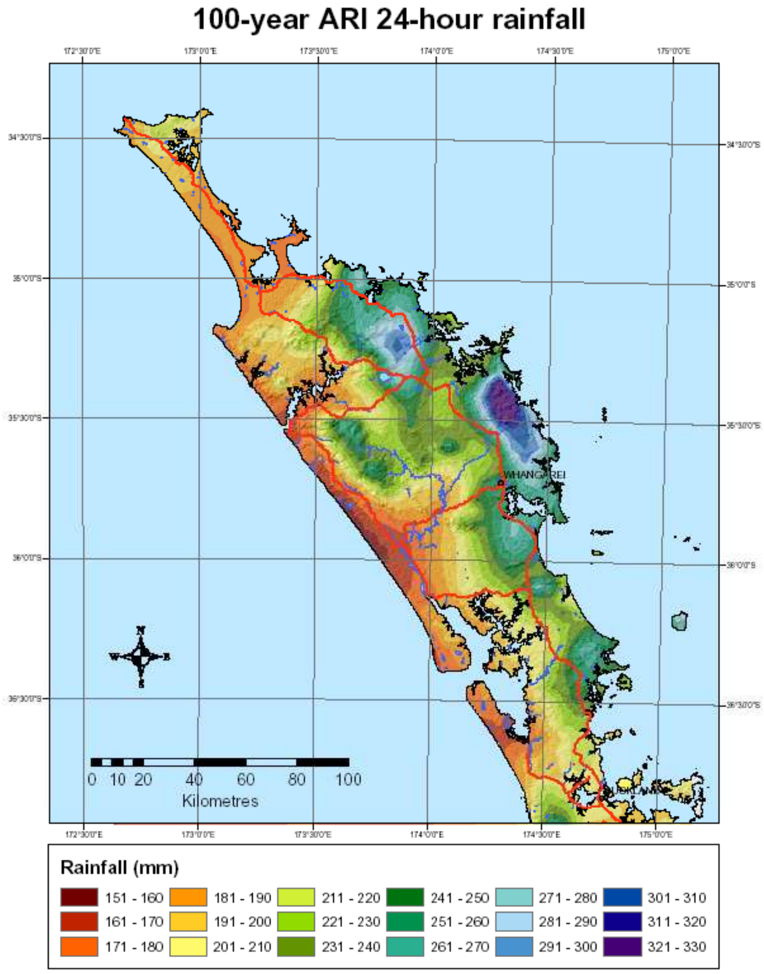

Figure 6: The total rainfall (mm) expected to fall in a 24 hour period, with a reoccurrence interval of 100 years.

Weather models and data

Recent advances in computing have led to the weather being modelled in real-time at high resolution. These models currently simulate weather at scales down to 20 km, with even higher resolution being used in special applications. At scales of 5 km, the effects of orography can be replicated, making quantitative rainfall modelling possible. NIWA is undertaking significant research in this field, particularly in the data that is used to start and maintain the model forecast simulations. Currently, Metservice (NZ) and NIWA are running weather models routinely at resolutions of 20 km. Metservice (NZ) have also run real-time applications at resolutions down to 1.25 km (namely for the Americas cup). Forecasting of the quantity and time sequence of rainfall out to 48 hours ahead for a region like Northland is now a reality.

Figure 7 shows an example of the output of the routinely run weather model from NIWA.

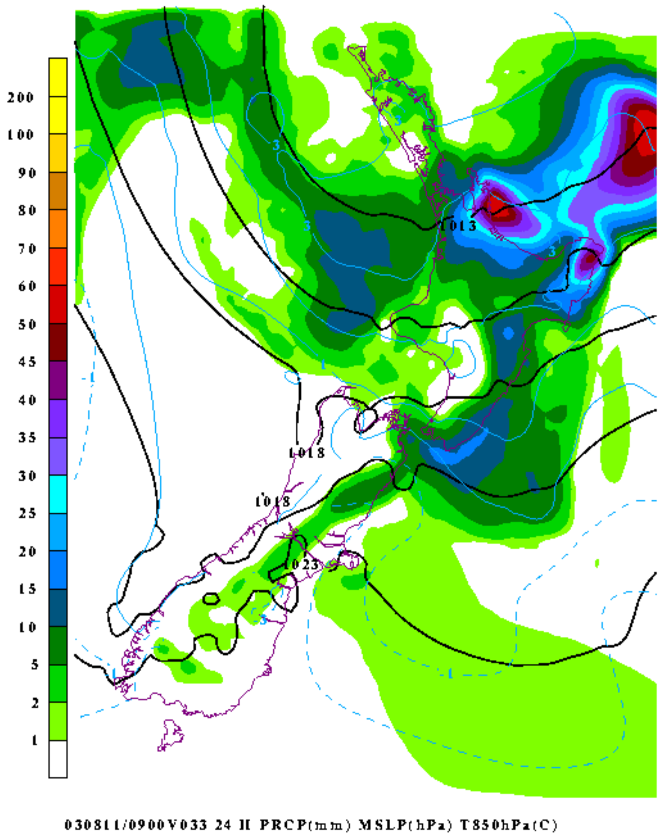

Figure 7: Weather model output showing the rainfall expected for the 24 hours up to 9 am on the 11 August 2003. Totals in excess of 50 mm were expected in the western Bay of Plenty.

Weather Radar

Weather radar can be used for more than just showing where an event occurred. The information can be used quantitatively, to show how much rain fell over an area, and also used to forecast rainfall in the short term over the following few hours (called nowcasting). Care must be taken in using radar in a quantitative fashion, as there are many sources of error that can lead the radar estimates to be inaccurate – often by a factor of 2. Recent research within NIWA has shown that useful estimates of rainfall can be made using radar, provided the distance away from the radar is less than 120 km. For the Northland region, areas south of Whangarei are well covered by radar and risk analysts and emergency managers may benefit from such quantitative rainfall estimates and nowcasts.

Hydrological modelling

Hydrology has developed over the last decade to the point where distributed hydrological modelling in real time is now a reality. Northland Regional Council is applying such technology to predict the flow of the river through Kaitaia. In this case, the input for the hydrological model is river flow and rain gauge data. Distributed hydrological models can also be fed with data from radar and weather models. NIWA is currently undertaking pilot studies to assess the usefulness of river flow forecasts made with weather model input into distributed hydrological models for catchments in Otago, Bay of Plenty and Gisborne. These forecasts can give lead-times up to 48 hours in advance. Flood prone communities in Northland could find value in such forecasts. Research is also underway as to the usefulness of forecasts from weather radar, with lead times out to 3 hours, and used as input into a hydrological model of the Mahurangi catchment near Warkworth.

Global Climate Change

Much of the work in assessing global warming impacts have been on understanding the changes in the average conditions, over the NZ region. New approaches are being considered, in which the frequency and intensity of extreme events for future climates are being assessed. One approach is to take a past extreme event and use a weather model to replicate the storm, but with changes made to simulate the prevailing atmospheric conditions in say 2050 e.g. warmer air temperatures, stronger winds etc. The changes in the rainfall and winds will give an indication in the likely intensity of such events in the future, and the global climate change models can tell us the likely change in frequency of events of this nature. These combined aspects can then be used, for example, to assess flooding risk over the next 100 years.

Wind modelling and mapping

Improved understanding and modelling of wind flow has enabled the regional mapping of the wind “climate”. While such information is often used to assess the wind energy potential of various sites, similar information would be useful in re-evaluating the risk from extreme wind speeds and gusts in Northland.

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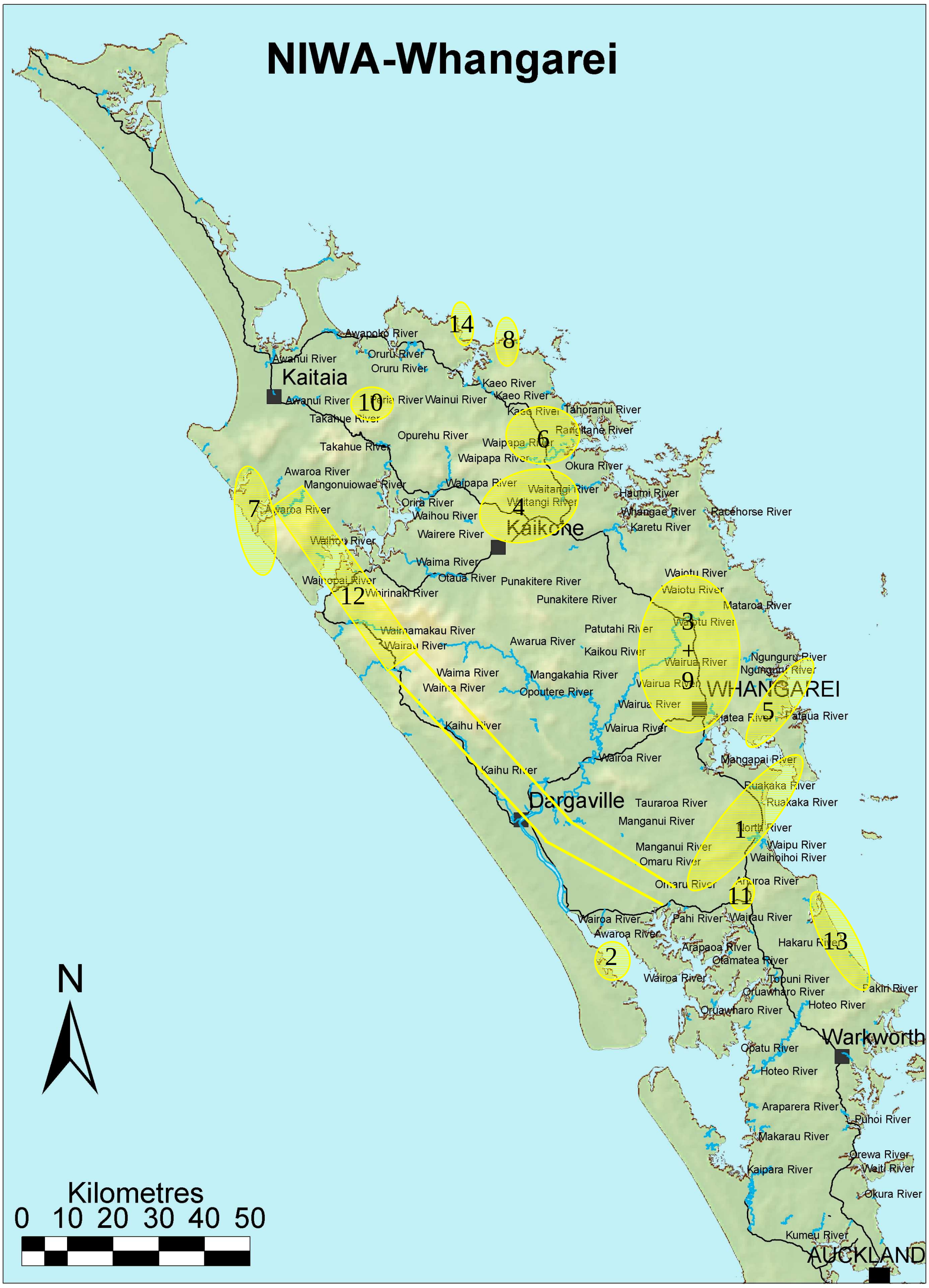
Appendix 1: Intense convective rain events.

Event	Source	Where	How much	Date
1	M*	Whangarei heads		April 18/19 1971
2	M	Mosquito Gully		Mid 1970's and 1985
3	M*	Whangarei - Hikurangi		July 16 1973
4	M*	Kaeo – Okaihau		February 23 1974
5	M*	Onerahi to Sandy Bay		May 30 1975
6	M*	Kerikeri		March 19/20 1981
7	M*, R	Whangape – Pawarenga		January 4/5 1986
8	M, R	Tauranga Bay		April 25 1995
9	M*, R	Whangarei – Whakapara		March 29 1995
10	M, R	Fairburns – Peria		May 31/June 1 and June 30 1997
11	M*, R	Waipu – Mangaturoto		June30 1997
12	M*, R	Pawarenga – Panguru - Whirinaki		January 20 1999
13	M, RC	Mangawai to Snell's beach	Leigh 109.4 mm in 1 hour	May 30 2001
14	M*, RC	Taupo Bay		June 1 2002
15	N, RC			October 31 2002
16	N, RC	Kerikeri	178 mm	March 9-10 2003
17	N, RC	Kerikeri Kaitaia Kaikohe	116 mm 151 mm 126 mm	March 27 2003
18	N	Widespread	>100 mm	April 19-20 2003

M = Mapped, N=not mapped, *=some documentation available, R=radar available, RC = radar case analysed

http://www.metservice.co.nz/severe_weather/AUTUMN03_MAIN.asp

http://www.metservice.co.nz/severe_weather/AUTUMN03_1.asp ' a stormy easter'


NIWA-Whangarei
Kaitaia
Kaikohe
Dargaville
WHANGAREI
Warkworth
AUCKLAND
Awanui River
Awapoko River
Oruru River
Kaeo River
Takahue River
Opurehu River
Wainui River
Waipapa River
Tahoranui River
Rangitane River
Okura River
Awaroa River
Mangonuiowae River
Waitangi River
Haumi River
Whangae River
Racehorse River
Karetu River
Orira River
Waihou River
Wairere River
Waima River
Otaua River
Punakitere River
Waipoua River
Waiotu River
Mataroa River
Waimamaku River
Patutahi River
Awarua River
Kaikou River
Ngunguru River
Mangakahia River
Opouteri River
Wairua River
Hatea River
Kaihu River
Wairoa River
Mangapai River
Ruakaka River
Tauraroa River
Manganui River
Waipu River
Waihoihoi River
Omaru River
Pahi River
Hakaru River
Arapaoa River
Otamatea River
Topuni River
Oruawharo River
Hoteo River
Pakiri River
Opatu River
Araparera River
Puhoi River
Makarau River
Orewa River
Waiwera River
Kaipara River
Okura River
Kumeu River
1
2
3
4
5
6
7
8
9
10
11
12
13
14
N
Kilometres
0 10 20 30 40 50

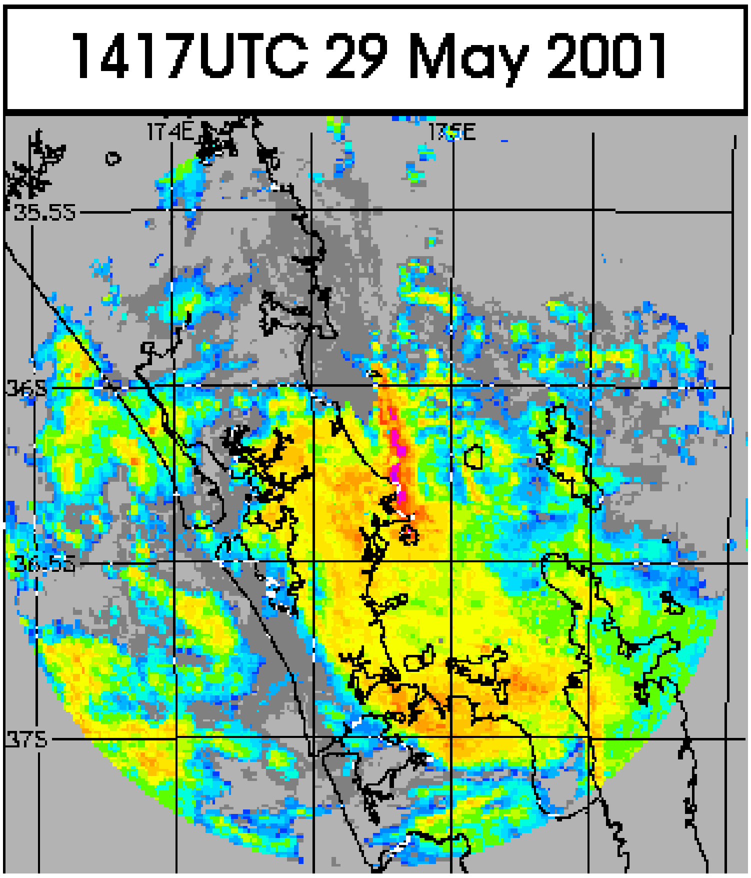


Figure 8: Radar image of the convective storm of 29 May 2001

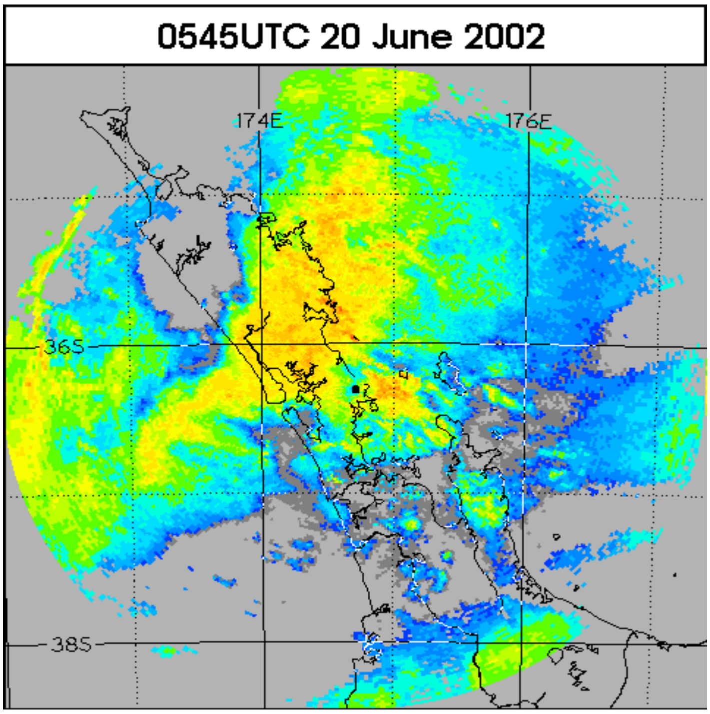


Figure 9: Radar image of the widespread rain affecting Northland during the "weather Bomb" 20 June 2002.

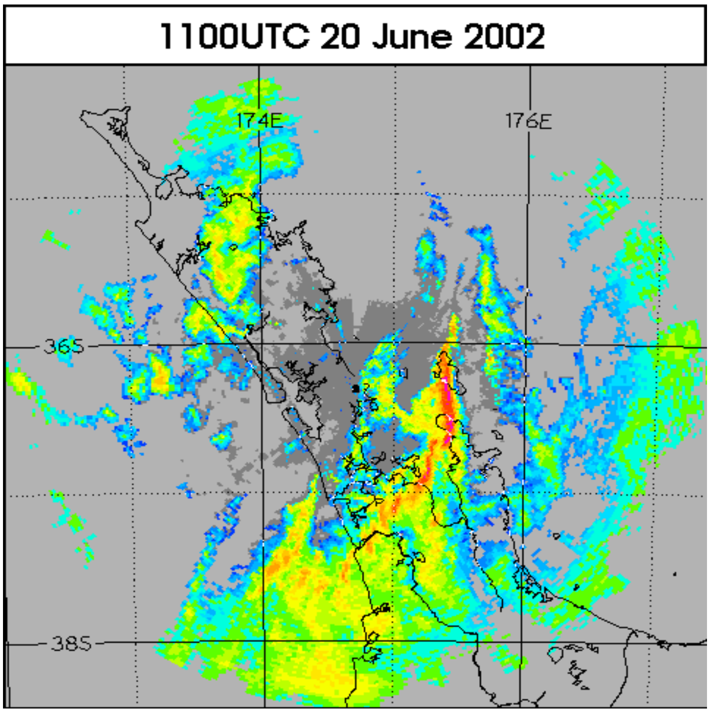


Figure 10: Radar image of the intense convective rain affecting Coromandel during the "weather Bomb" 20 June 2002.

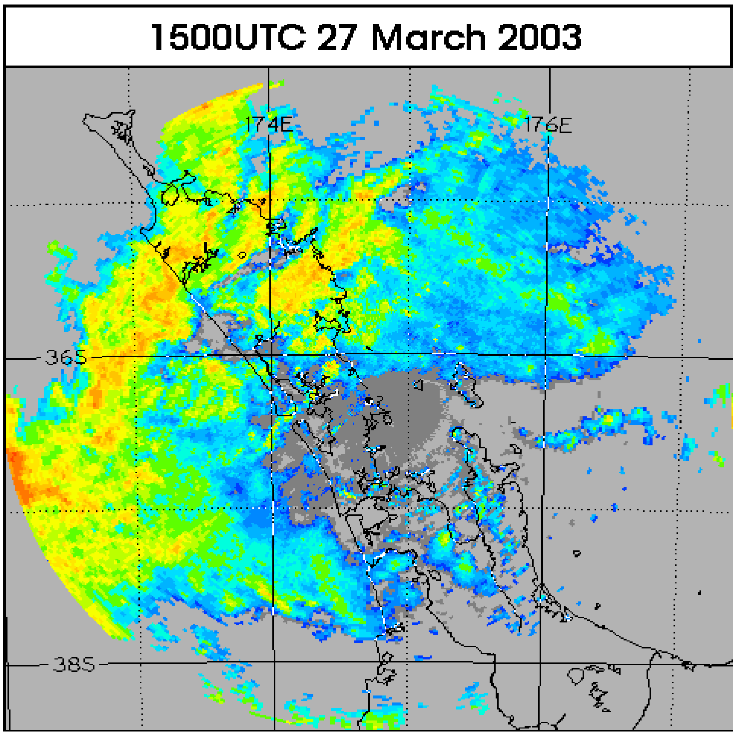


Figure 11: Radar image of the widespread rain on the 27 March 2003.

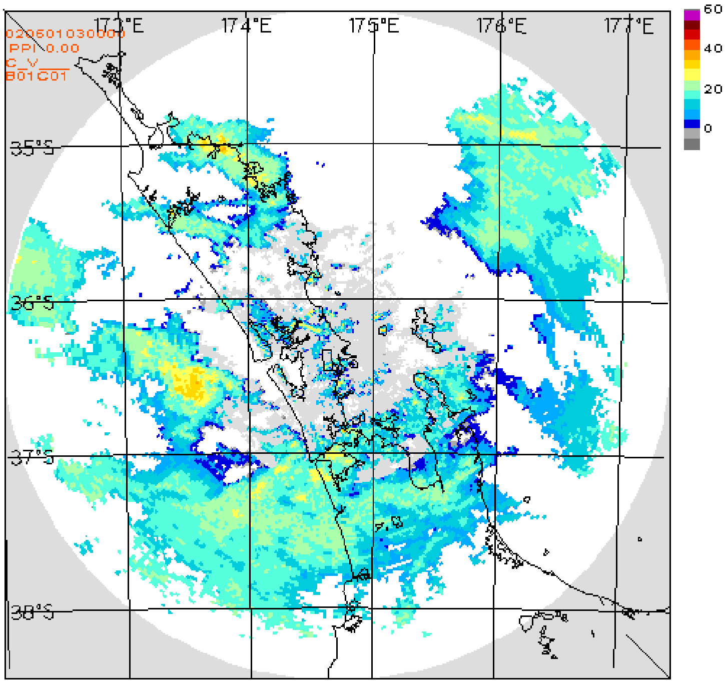


Figure 12: Radar image of the small-scale rainfall affecting the KeriKeri area on 1 June 2002.

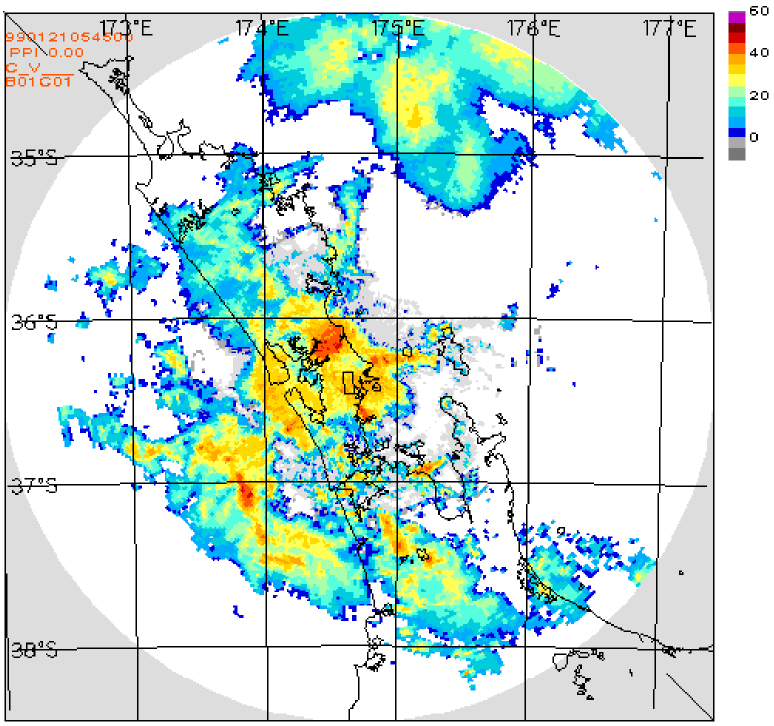


Figure 13: Radar image of the heavy convection over Northland on 21 January 1999.