Climate Trends, Hazards and Extremes – Taranaki

Synthesis Report

NIWA Client Report: AKL-2008-080
October 2008

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Climate Trends, Hazards and Extremes – Taranaki

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Prepared for

New Plymouth District Council, the Taranaki Regional Council and South Taranaki District Council

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Executive Summary

This report has been prepared for the New Plymouth District Council, the Taranaki Regional Council and South Taranaki District Council. This synthesis report integrates the climate hazardscape across the Taranaki region for the current climate, and identifies climate trends, hazards and extremes that are likely to impact on the region as a result of climate warming during the 21st century. Some of the results regarding present climate come from several other reports prepared for the New Plymouth District Council and Taranaki Regional Council prepared between 2006 and 2008. New results are presented for an analysis of the drought hazard, and showing the climate changes predicted for the Taranaki region in the 21st century based on scenarios discussed by the Intergovernmental Panel on Climate Change (IPCC) in their fourth assessment report (AR4).

The Taranaki region has a temperate climate. Situated on the western side of the North Island, it is exposed to all weather systems moving from the west. Being surrounded by ocean, annual mean land temperature varies between about 11 to 14°C in lowland parts of the region. Average annual rainfall totals in the region vary, with a narrow coastal strip receiving in the order of 1400 - 1600 mm. Most of the area has rainfall in excess of 1800 mm and reaching in excess of 5000 mm on the slopes of Mt Taranaki.

Current Climate

1. Extreme rainfall – Daily rainfall extremes – extreme intensity and extreme frequency – show decadal maxima during the 1960s and decadal minima during the 1990s, corresponding to the opposite phases of the Interdecadal Pacific Oscillation (IPO). Most of the region shows an increasing trend in both extreme intensity and extreme frequency since the late 1990s.

2. Strong winds – High winds occur over Taranaki when vigorous fronts, troughs, deep depressions or cyclones cause strong northerly to westerly airflows, or south easterly airflows over the region. In the former cases the region is exposed to these airflows coming in from the Tasman Sea. In the latter case down-slope leeward winds from the central North Island can be very strong, causing substantial damage. At New Plymouth over a third of the years have their annual maximum gusts from the west, with this direction dominating at low return periods up to 5 years, with gusts just below 110km/hr. However, the highest gusts at New Plymouth came from the southeast where the 50 year return period is in excess of 145 km/hr.

3. Tornadoes – On average about one tornado will occur somewhere in the Taranaki region each year, with the frequency of severe cases about once in four years. The majority had estimated maximum wind speeds in the 116 – 180 km/h range, with ten percent or more attaining wind speeds in excess of 180 km/h. Typical weather conditions indicate the presence of low pressure and associated frontal activity to the west or over Taranaki with winds from the north

and west. These often track inland from the coast. Track or damage widths averaged 100 m (range 15 to 500 m) with a mean track length of 5 km (range 1.5 to 16 km).

4. Ex-tropical cyclones – The ex-tropical cyclones that affect New Plymouth generally develop in the Coral Sea and near Vanuatu, later tracking south-southeast towards New Zealand. On average the probability of one or more cyclones of tropical origin passing within 550 km (1 degree of latitude) of New Plymouth in any year is close to 0.6, i.e. we would expect to see one or more ex-tropical cyclones in three out of five years.

5. Lightning – Lightning records show a high seasonal to interannual pattern of variability. Diurnally there is an early morning and afternoon peak in stroke counts from AWS data: the former a result of storms arriving from the Tasman Sea from the west, and the latter owing to afternoon convective heating.

6. Drought – Dry conditions and drought in the Taranaki region occur during episodes of easterly flow with anticyclones occurring east of the South Island. The northern part of the region experiences some deficit, but the southern coast is drier. The long term annual average potential evapotranspiration deficit (PED)(mm) for Taranaki calculated over the period 1971-2008 shows that all the area around Mt Taranaki is the wettest, while the northern part of the region experiences some deficit, with New Plymouth at the centre of the driest area (lowest values of PED: less than 100 mm). The southern coast is drier with values around 125 mm and a peak of 175 mm along the southern coast. The time series for Taranaki from 1972-2008 show that the 1977/78 and 2007/2008 years were the driest on record.

Natural Variability

New Zealand climate varies with two key natural cycles that operate over timescales of years (El Niño-Southern Oscillation, ENSO) and decades (Interdecadal Pacific Oscillation, IPO). The El Niño/Southern Oscillation (ENSO) is a natural feature of the global climate system. El Niño events occur irregularly, about 3 to 7 years apart, typically becoming established around April or May and persisting for about a year thereafter. The circulation is modulated between El Niño and La Niña. Extremes of high intensity rainfalls in La Niña years are on the whole slightly greater than in El Niño years. Extremes in La Niña years are on the whole slightly greater than in El Niño years. With extreme wind frequency at New Plymouth ENSO influences appears to be weak. ENSO causes the number of cyclones reaching the district to vary. Cyclone occurrences near the Taranaki region are 20 percent less likely during El Niño events than during neutral or La Niña conditions. With drought, the difference between El Niño and La Niña events are small.

The Interdecadal Pacific Oscillation, or IPO, is a Pacific-wide natural fluctuation in the climate, which causes abrupt "shifts" in Pacific circulation patterns that persist for decades. There are two phases, positive and negative. The positive phase produces more westerly quarter winds over the country and in the negative phase more easterlies and north easterlies occur over northern New Zealand, with increased tropical disturbances.

An examination of the high intensity rainfall at New Plymouth during two recent phases of the IPO showed that there were non significant changes in rainfall across all durations, although for some duration's the rainfall amounts in the negative phase of the IPO were higher than in the opposite phase. The intensity and frequency of extreme winds at New Plymouth show tentatively that both gust speeds, and number of days above particular thresholds in any one year were higher during the negative phase. The occurrence of cyclones near New Plymouth is higher during strongly positive IPO seasons combined with neutral ENSO conditions.

Climate Change Trends

Likely future changes in climate are assessed through scenarios of temperature increase, as generated by a suite of global climate models forced by scenarios from the Intergovernmental Panel on Climate Change (IPCC, 2007a) of increasing greenhouse gas concentration. The mid-point warming (average over the 12 global models examined by NIWA) works out at: +0.93°C for 50-year change to 2040, and +2.07°C for 100-year change to 2090.

Precipitation projections show much more spatial variation than the temperature projections, and can also be quite different for different climate models. The general pattern is for decreases in precipitation in the Taranaki region in summer, and increases in winter, with the other seasons showing intermediate trends. There is likely to be an increase in extreme rainfalls in Taranaki region through the 21^{st} century as the temperature increases. What is an extreme rainfall in the current climate might occur about twice as often by the end of the 21^{st} century under a mid-range temperature change scenario, and up to 4 times as often under a high temperature change scenario.

Over the sea or flat land the annual frequency of occurrence of winds of 30 m/s or above might increase by about 40% by 2030 and 100% by 2080. Gale and storm force winds from the west are likely to increase in Taranaki during the 21^{st} century.

The change in the frequency of occurrence of tropical cyclones is uncertain but there is good evidence that tropical cyclones will increase in intensity for the strongest cyclones in the tropics, with stronger winds and more intense rainfall. How these cyclones will affect New Zealand after they undergo their transition to an ex-tropical cyclone remains an open question, although it is likely that there will be some higher intensity ex-tropical cyclones producing larger storm impacts as the 21^{st} century progresses.

Changes in drought risk for Taranaki region indicate a slight increase in the annual accumulated PED (in mm), with a higher increase in the southern coast of the region. Under the 'low-medium' scenario (25% scaling) both the CSIRO and Hadley Centre models show no large change in the frequency of severe episodes. Under the ‘medium-high’ scenario (75% scaling, Hadley model) severe droughts are projected to at least double by the 2080s under this scenario in the central and southern part of Taranaki. For this same scenario, CSIRO model show a similar increase in frequency, but for a smaller part of the region.

1. Introduction

The Taranaki Region is susceptible to significant adverse effects from natural hazards. Reducing the impact of natural hazards on the community is a major function of the territorial local authorities in the Taranaki region, and is required by statute pursuant to the Civil Defence and Emergency Management Act (CDEM) 2002. Improved information on such hazards enables lessening the impact to communities in the region, reduce damage and disruption and enable faster recovery.

In 2005 the New Plymouth District Council commissioned the research project "Climate Hazards and Extremes – New Plymouth District" whose objective is:

> To examine and assess the risks that water and climate related extreme events pose to communities and infrastructure in the New Plymouth District, and to assess the potential changes to those hazards due to natural climate variability and human induced climate change.

This study gathered together and assessed current information on natural hazards and climate change and risks posed to the New Plymouth District, and one for the Taranaki region for the following hazards:

1. Storms and high intensity rainfall leading to slope failure in New Plymouth.
2. High winds and tornadoes for Taranaki.
3. Lightning.
4. Cyclone risk.
5. Tsunami and storm surge risk.
6. The impact of climate variability and change on the risk of these hazards.

Storms and high frequency rainfall are covered in Thompson et al. (2006), high winds and tornadoes in Burgess et al. (2007) and Salinger et al.(2007), lightning by Gray and Salinger (2006), cyclone risk in Burgess et al. (2006), and tsunami and storm surge risk by Bell et al. (2008). The impact of climate variability and change, and drought is new work presented in this report.

The goals of this final report, The Synthesis Report are:

- *To provide a synthesis and integration of the material contained in the previous modules, with an overview of policy relevant information arising from the hazardscape for the Taranaki Region;*

- *To provide a context of the risks associated with natural climate variability together with global warming during the 21st century which is expected to lead to increased rainfall and decreased ARI for high intensity rainfall, and changes in other climate extremes and hazards.*

The Synthesis Report integrates all the climate hazards, but not the others that have been considered – tsunami and storm surge, and the landslide hazard.

From November 2007 to near the end of March 2008, climatic conditions produced an extended dry period and severe soil moisture deficits throughout Taranaki, and other western areas of the North Island. This resulted in the agricultural feed situation becoming very low over 70 percent of the region, with the remainder of the area having just adequate feed. Drought was declared in South Taranaki District and eastern parts of the Stratford District. The estimated loss of farm gate income of this drought event for the entire North Island was estimated at $1.24 billion in March 2008.

This Synthesis Report also includes a new assessment of the drought hazard in Taranaki by:

- Drawing together the main features of the drought hazardscape of the Taranaki Region and Districts;

- Assessing the importance of climate variability and climate change for drought. The Synthesis Report will be policy relevant, but not policy prescriptive so as to assist the Regional and District Council's to fulfil their statutory and other obligations. A summary of knowledge gaps and areas for further investigation and study and overall summary provided.

The level of risk from drought hazards is compared to other natural and meteorological hazards faced by the Councils, and an attempt will be made to prioritise the hazards. A summary of knowledge gaps and areas for further investigation and study and overall summary are provided.

2. Present Climate

2.1 Taranaki regional environment

The Taranaki region is on the North Island's west coast, and extends into the Tasman Sea and is half way between Auckland and Wellington (Figure 1). New Zealand's climate is influenced by the subtropical belt of travelling anticyclones to the north, and westerly wind flow to the south, with the Taranaki region being directly exposed to disturbed weather systems from the Tasman Sea, and therefore often quite windy, but with few climate extremes. The region's climate is usually sunny and windy, with mild conditions and regular rainfall throughout the year. The most settled weather occurs during summer and early autumn. Summers are warm. The region's topography has a marked influence on climate, especially precipitation amounts and patterns. The highest point in the area, Mt Taranaki, is an almost symmetrical volcanic cone that dominates the whole region, reaching a height of 2518 metres.

Figure 1. Map of the Taranaki region

2.2 Climate of Taranaki region

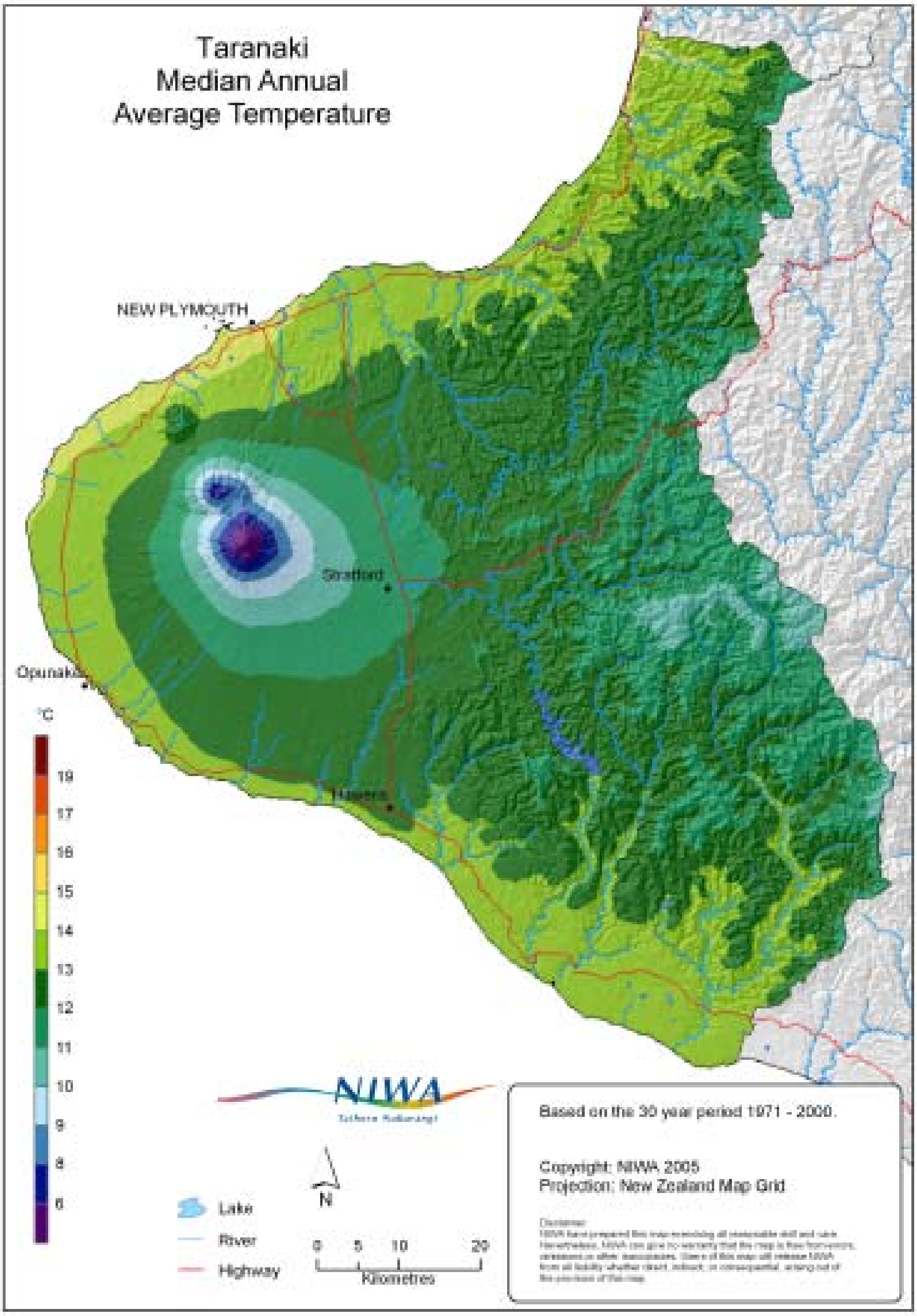

Figure 2. Median annual average temperature (°C) 1971-2000 for Taranaki. © NIWA.

The Taranaki region has a temperate climate. Situated on the western side of the North Island, it is exposed to all weather systems moving from the west. Being surrounded by ocean, land temperature varies between about 11 to 14°C (Figure 2), except for the summit of Mt Taranaki where the mean temperature is below 0°C. Typical summer daytime maximum air temperatures range from 19°C to 24°C, and seldom exceed 30°C.

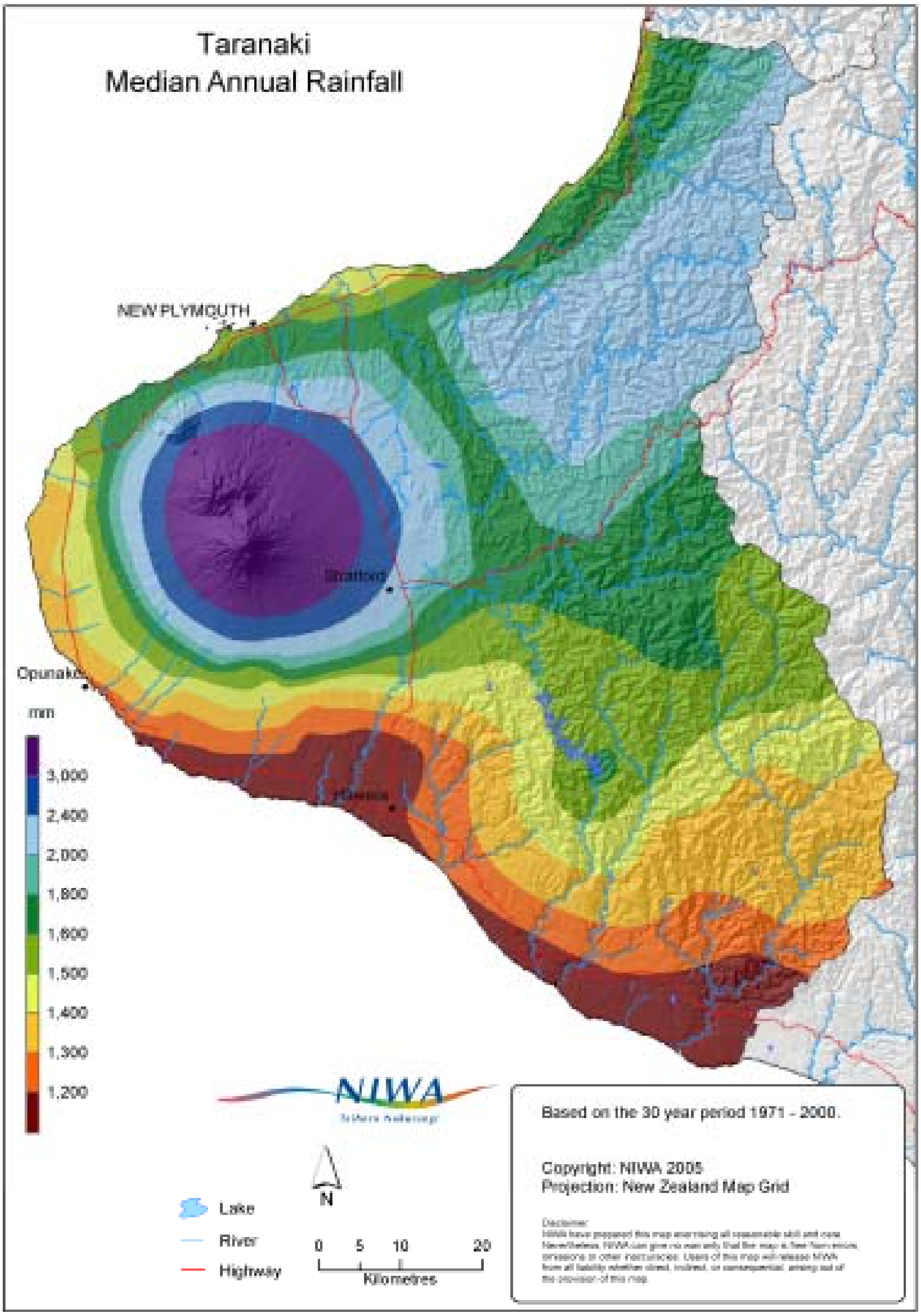

Figure 3. Median Annual Rainfall (mm) 1971-2000 for Taranaki. © NIWA.

Winters are relatively mild with daytime maximum air temperatures ranging from 10°C to 14°C. Frost occurs inland during clear calm conditions in winter.

Median annual rainfall totals in the region vary, with a narrow coastal strip receiving in the order of 1400 - 1600 mm. Most of the area has rainfall in excess of 1800 mm and reaching in excess of 5000 mm's on the slopes of Mt Taranaki. Median annual rainfall is shown in Figure 3 for the Taranaki region which shows the strong spatial variation.

Heavy rainfall is meteorologically defined to be "when greater than 100 mm of rain falls within 24 hours, or a pro rata amount" (Thompson et al. 2006). The regions heaviest rainfall occurs when warm moist northerly airflow flow from the tropics flows onto the district. These conditions can persist when fronts lying north/south near Taranaki become slow moving or depressions move across the region.

Annual sunshine hours average about 2000 hours. North westerly airflows prevail and sea breezes occasionally occur along the coast during summer in weak wind situations.

2.3 Storms and high intensity rainfall

2.3.1 Methods

Daily rainfall extremes

Thompson et al. (2006), in their assessment of observed trends in daily rainfall intensity during the 20th century, produced a long-term rainfall series for the New Plymouth district by combining records from a number of sites, and adjusting these to the modern site. These series have been carefully homogenised using standard techniques.

Rainfall observations have been made in the New Plymouth district since 1862. The stations used for data and analyses (see Figure 4) were selected because of the following preferred qualities:

i. they are representative of their surroundings,

ii. have adequate long (multi-decadal) data series, and

iii. are of high quality (as accurate and as continuous as possible)

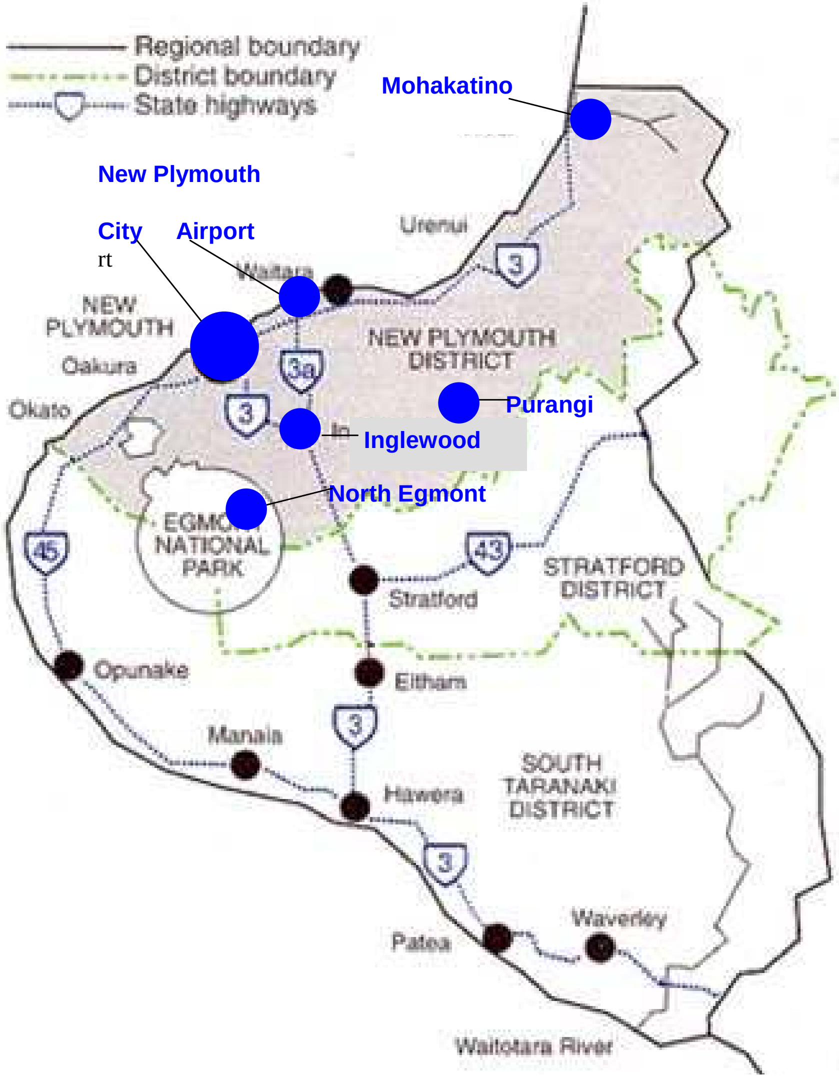

Figure 4. Location of New Plymouth District daily rainfall sites (in blue) analyzed by Thompson et al. (2006) (Map courtesy of the New Plymouth District Council)

Annual trends and daily extremes

For rainfall extremes, the following annual indices were calculated for the selected sites over their period of record:

- 95th percentile of daily rainfall (mm) *(extreme intensity)*
- Frequency of daily rainfall exceeding the 1961-1990 mean 95th percentile (*extreme frequency)*

In New Zealand, a 'rain-day' is said to have occurred when the total amount of rainfall accumulated in the 24 hours to 9.00 a.m. is at least 0.1 mm.

In a single year, 95 percent of rain-days will have had less than or equal to the 95th percentile rainfall value, or top 5 percent of rain-days exceeds the 95th percentile value. For example, if a particular year has 200 rain-days, the 95th percentile rainfall value will be that value which is left after the top 10 values (i.e. top 5 percent) have been omitted.

In this report, the 95th percentile of daily rainfall is termed the '*extreme intensity*'. The frequency of daily rainfall exceeding the 1961-1990 mean 95th percentile rainfall values is termed the '*extreme frequency*'. The *extreme intensity* index is used to identify changes in the intensity of extreme events, while the *extreme frequency* index is used to identify changes in the number of extreme events.

Extreme rainfall intensities are usually defined in terms of the average recurrence interval (ARI) or the annual exceedance probability (AEP). The ARI is the average, or expected, value of the periods between exceedances of a given rainfall total accumulated over a given duration, whereas the AEP is the probability that a given rainfall total accumulated over a given duration will be exceeded in any one year. ARIs of greater than 10 years are very closely approximated by the reciprocal of the AEP. Local authorities use records of extreme rainfalls in their area to calculate how frequently high intensity rainfalls of different magnitudes occur.

2.3.2 Observed trends in daily extremes

There are no common trends in the *extreme intensity* and *extreme frequency* of daily rainfall for all the sites analyzed.

A study by Salinger and Griffiths (2001) analysed rainfall (and temperature) trends over New Zealand. They used a 1 mm threshold to identify days of precipitation c.f. 0.1 mm in the present study, and analysed data over the 1951-1996 period. For New Plymouth, their study found decreases in both intensity and frequency that were not statistically significant. Thompson et al. (2006) in their study show that for the corresponding period, there is a small negative trend in the frequency plot with a 13 percent decrease over the

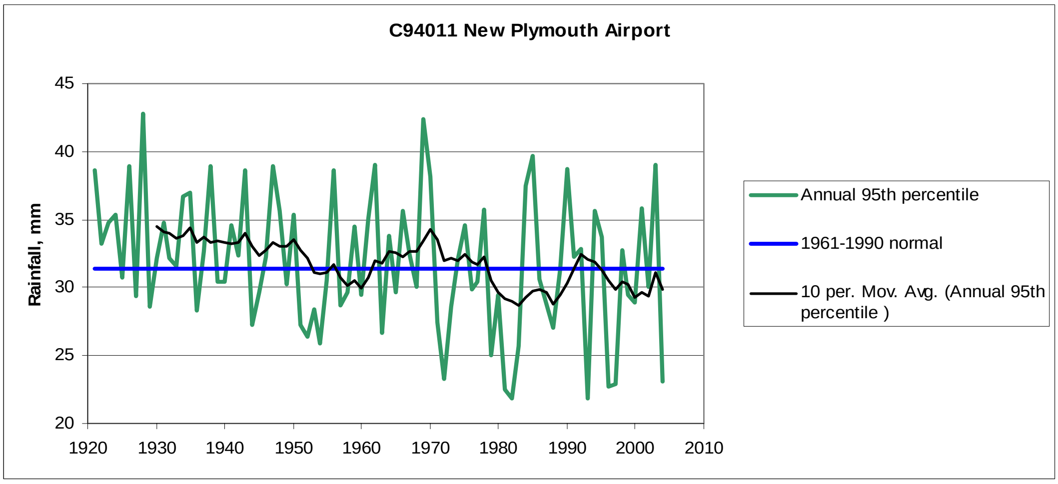

Figure 5. New Plymouth Airport: Time series of the rainfall extreme intensity. Each moving average value in the figure is derived from 10 annual 95th percentile rainfalls. © NIWA.

1920-2006 period (Figure 6), but the overall trend in the intensity plot (Figure 5) is not clear, although there is a 16 percent decrease in this statistic over the period of record from 34 to 30 mm.

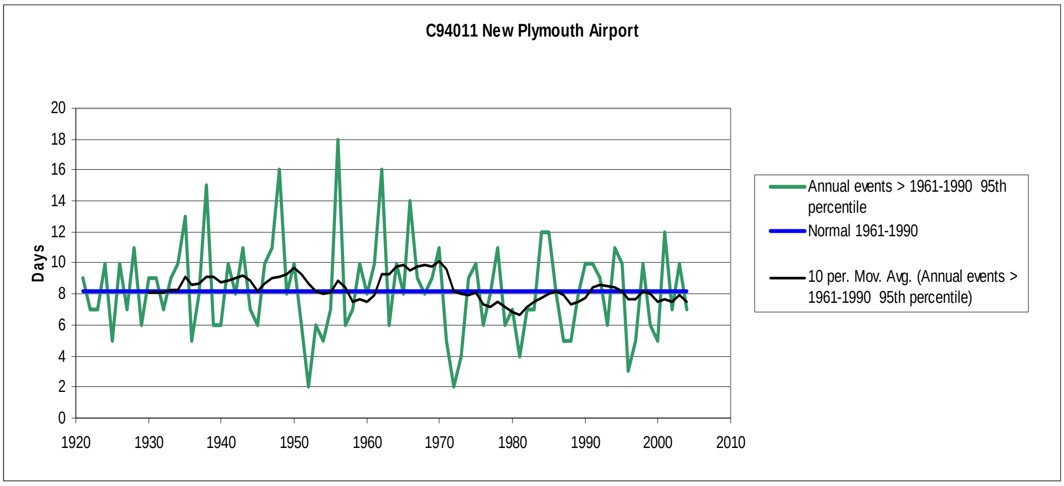

Figure 6. New Plymouth Airport: Time series of the extreme frequency. © NIWA.

For stations in the district overall, analysis of the time series of the *extreme intensity* show minima at many sites in 1993, and maxima in 2003. Significant decadal maxima occur in the 1940s and 1960s, with minima at most sites during the 1990s. All sites showed an increasing trend during or after the late 1990s.

Linear regressions over the complete historical record show net increases in the value of extreme intensities at Purangi and North Egmont (Table 1). In contrast there was a notable decrease at New Plymouth Airport, and a smaller decrease at Mokau (both northern sites), with little overall trend at the other sites.

Table 1. Percentage change with time of the extreme intensity

Location	Data period	Total % change	Mean % change per year
Mokau, Mohakatino	1932-2004	-4.9	-0.07
New Plymouth Airport	1921-2004	-15.6	-0.19
New Plymouth	1894-2004	-0.4	-0.00
Purangi	1914-2004	+6.2	+0.07
Inglewood	1910-2004	-1.7	-0.02
North Egmont	1952-2004	+7.5	+0.14

Annual frequency of the *extreme frequency* show common annual minima at many sites in 1919 and 1923, but no consistent years for annual maxima. There are significant decadal maxima at many sites in the 1960s, with minima in the 1970s and the 1990s. Common to all sites is an increasing trend during or after the late 1990s.

Linear regressions over the complete historical record show notable net increases in the value of extreme frequencies at Purangi and North Egmont, with a small increase at Inglewood (Table 2). In contrast a decrease occurred at New Plymouth Airport. There was little overall trend at the other sites.

In an analysis of New Zealand rainfall data, Griffiths (2006) show how extreme rainfalls have changed over the country since the 1930s. For New Plymouth, there have been statistically significant changes in the 95th percentile extremes and in the frequency of rainfalls greater than 25 mm over the period 1930 – 2004. However, since the 1950s the trend has been small and statistically insignificant, consistent with the results presented in Thompson et al. (2006).

Splitting the extreme intensity precipitation into periods that correspond to the phases of the Interdecadal Pacific Oscillation (i.e. 1945 – 1976; and 1977 – 2000), figures for New Plymouth, Purangi, Mokau, Inglewood all indicate the earlier period from 1945 – 1976 had larger *extreme intensities* than in the latter period. In terms of the predominant atmospheric circulations associated with each phase of the IPO, the negative phase of the IPO (1945 – 1976) typically corresponded to enhanced north easterlies or easterlies over New Zealand and an increase in tropical disturbances. In the positive phase of the IPO

(1977 – 2000), drier conditions predominated with increased showery precipitation from the west or southwest.

Table 2. Percentage change with time of the extreme frequency

Location	Data period	Total % change	Mean % change per year
Mokau, Mohakatino	1932-2004	+2.3	+0.03
New Plymouth Airport	1921-2004	-12.6	-0.15
New Plymouth	1894-2004	-3.4	-0.03
Purangi	1914-2004	+41.9	+0.46
Inglewood	1910-2004	+6.4	+0.07
North Egmont	1952-2004	+28.1	+0.53

An analysis of heavy precipitation and dry periods has been completed for two sites in South Taranaki: Inaha (Lat = 39.6°S, Lon = 174.2°E, Height = 50 m) and Riverlea (Lat = -39.4°S, Lon = 174.1°E, Height = 260 m). The time series of the index R95p, which represents the annual total precipitation when rain exceeds the 95th percentile, show, for both sites and increasing trend in the last few decades, with a clear change point at the beginning of the 1980s (see Figure 7).

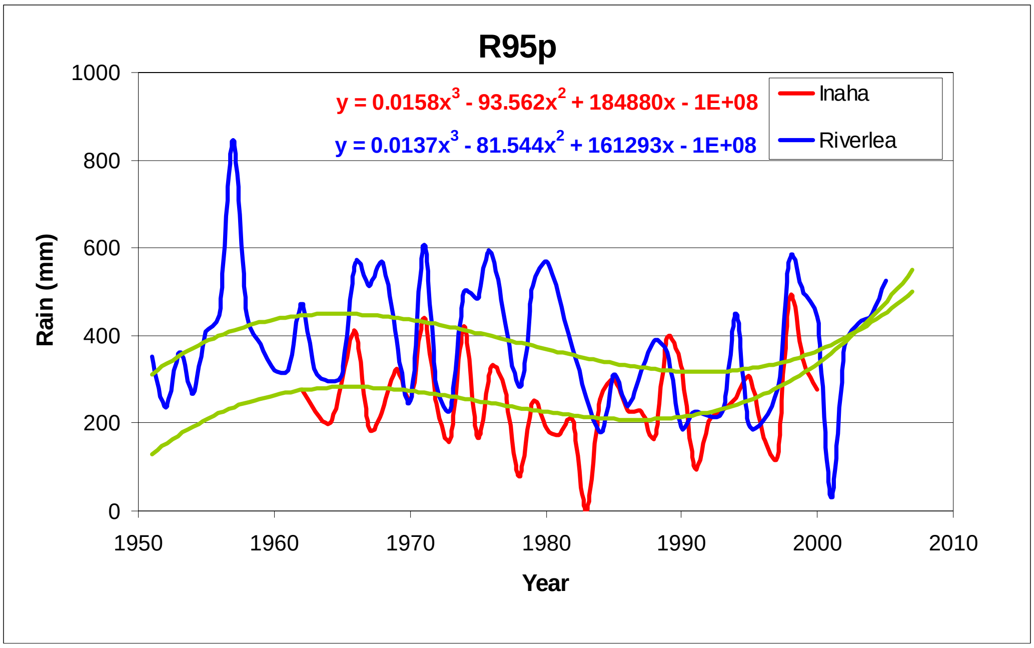

Figure 7. Time series of the R95p which represents the annual total precipitation when rain exceeds the 95th percentile for the sites of Inaha and Riverlea. © NIWA.

A decreasing trend of extreme precipitation days (days with precipitation more than 20 mm) is detected at both sites (Figure 8).

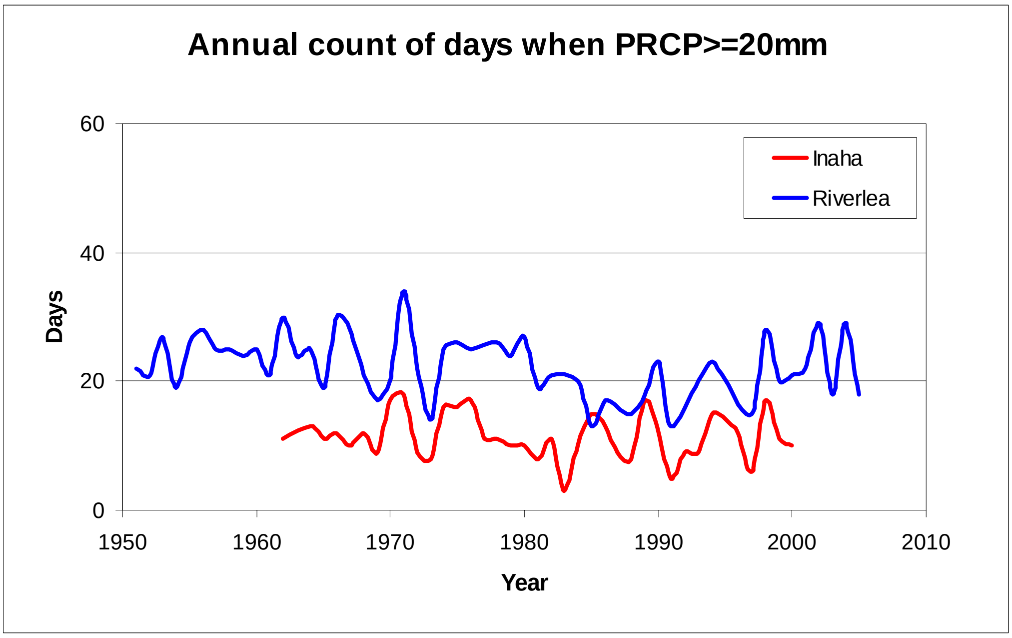

Figure 8. Annual count of days when the total precipitation is over 20 mm for the sites of Inaha and Riverlea. © NIWA.

Figure 9 shows the trend of the consecutive dry day index (CDD), which represents the number of consecutive dry days (a dry day is when the total daily precipitation is less than 1 mm). For Riverlea no trend is detected, whilst Inaha shows a slightly decreasing trend.

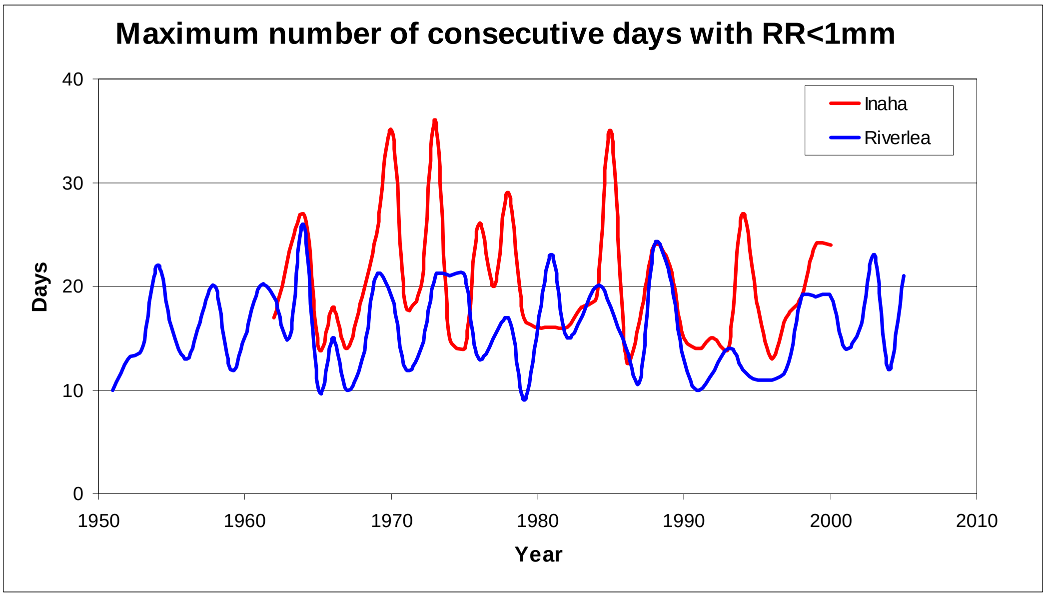

Figure 9. Time series of the number of consecutive dry days (a dry day is when the total daily precipitation is less than 1 mm). © NIWA.

Finally, the simple daily intensity index, (SDII) represents the annual total precipitation divided by the number of wet days (defined as PRCP>=1.0mm) in the year, in mm/days

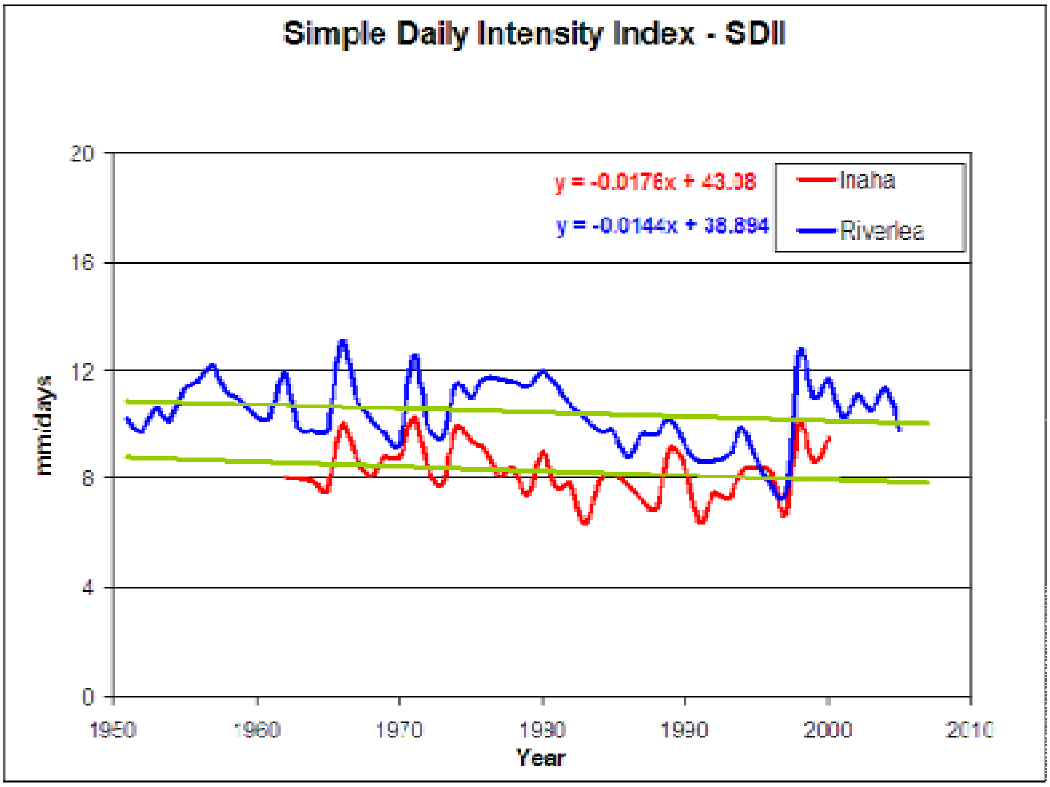

Figure 10. Time series of the simple daily intensity SDII sites in South Taranaki. © NIWA.

was examined. The SDII time series shows a weakly decreasing trend at both sites in South Taranaki (Figure 10). A clear change point is observed at both sites in the late 90s.

2.4 High winds and tornadoes

High winds and tornadoes in the Taranaki region are very much determined by its position in relation to the large scale weather patterns affecting New Zealand. The travelling anticyclones, depressions, and fronts within the westerly flow predominantly govern the progression of weather. However, weather systems that originate from within the tropics can also have an influence (Sturman and Tapper, 1996). Taranaki is thus open to all weather systems migrating over the Tasman Sea.

2.4.1 Winds

Taranaki is dominated by a large mountain, Mt Taranaki, and the region is often affected by wind effects related to flows over and around the mountain. Extreme winds are a feature of high elevation sites on the mountain and sometimes winds on the lowlands around the mountain are clearly influenced by flow over the peak. Orographic wind is a technical term for such flows.

High winds as discussed in Burgess et al. (2007) range from gale force, when speeds reach or exceed 62 km/h (see Appendix 1 in Burgess et al., 2007), and higher. Storm force winds (from 89 km/h) are particularly damaging and will uproot trees and produce structural damage. The wind direction is also important.

At the higher levels (at about 1000 metres in coastal Taranaki) the most common wind direction is westerly. Surface winds are markedly influenced by local terrain effects (Thompson, 1981), especially by Mt Taranaki, the central high country and the orientation of the coast. For example, at New Plymouth Airport south easterlies predominate for a quarter of the time because the deflection of southerly quarter winds by both Mt Taranaki, and south easterly drainage of cold air off the slopes. Strong and gale force winds over the region are generally most frequent from either the southerly or north westerly quarters. At lower elevations gusts in excess of 62 km/h generally occur on about 80 days a year, and over 94 km/h on about five days a year. At more exposed and higher elevations these figures are over 120 and 20 days respectively. In the New Zealand context strong and high winds in Taranaki are relatively common.

In a survey of tropical cyclones Burgess et al (2006) showed that those whose tracks pass close to the region produced high winds. If the cyclone centre was to the north of the district the winds were from the southeast, and if the centre was to the west, then northerly gales resulted.

Northerly airflows ahead of fronts, depressions or cyclones can produce strong to gale force winds over the Taranaki region from the northerly quarter. Locally these normally come from the north or northwest. For example, Cyclone Alison in March 1975 produced wind gusts from the north at 133 km/h at Egmont East, gusts of over 100 km/h at Paritutu, and a gust of 98 km/h at New Plymouth Airport Cyclone Alison wreaked havoc at Port Taranaki (de Lisle, 1975), with a trail of damage across the harbour.

In westerly airstreams, with high pressure to the north of the country, and migratory depressions across southern New Zealand or to the south, winds come from the northwest or west.

With a depression to the east or southeast of the North Island and anticyclones south or southeast of New Zealand winds normally come from the south or southeast. These can be particularly strong with deep depressions or strong cyclones, as the windflow is either channelled by Cook Strait up from the south, or are downslope leeward winds from the central North Island high country. For example, Cyclone Bola of March 1988 (Burgess et al. 2006) severely affected the Taranaki region with damaging winds and high seas along the coast. A large pressure gradient developed over the North Island (between the southward moving cyclone and rising pressures over the South Island), producing strong gale force winds from the southeast damaging approximately 500 houses in the New Plymouth district. It produced widespread damage to forestry over the central North Island. New Plymouth Airport recorded an extended period of gale force south easterly winds for 22 hours. Hurricane force winds, in excess of 118 km/h, from the southeast were reported on the Maui gas platform.

Finally high winds can also be produced by convective storms. Some of these can occur in thunderstorms, of which New Plymouth has, on average 15 days a year. These are higher in frequency in the New Plymouth district: other parts of the Taranaki region have occurrences of about 5 days a year in comparison.

2.4.2 Extreme winds

Burgess et al. (2007) presented a detailed analysis of extreme winds for Taranaki, and they show the gust speeds (m/s) for Taranaki stations for 4 annual exceedance probabilities (AEP). The AEP is simply the inverse of the return period so that the data are for 20, 50, 500 and 1000 year return periods. The return period is also known as the ARI.

For winds from the north, the East Egmont speeds are much higher than any other location. This is almost certainly due to the position of the site high on a spur that runs eastward from Mt Taranaki. Winds passing across the spur are affected in a manner similar to flows over a ridge. There may also be some channelling effect because of air deflection around the mountain. Another item of interest is the higher speeds at low AEPs (high return periods) at Omata, Cape Egmont and Hawera. There is fair consistency between these 3 stations. The remaining 4 stations analysed (e.g. New Plymouth AWS, Normanby EDR, Maui Platform, Stratford EWS) have consistently lower speeds. It is interesting that the Maui data belongs to this lower wind speed group for northerly directions.

Annual trends in the 95th and 99th percentile daily gust speeds or *extreme intensity* have been analyzed by Burgess et al. (2007) for New Plymouth Airport. Both the 95th and 99th percentile gust speed data over the period 1972-2006 show an overall decreasing trend in *extreme intensity* over the 1972-2006 time period. Trends in the 95th percentile are from 83 km/h to 76 km/h, and the 99th percentile 96 km/h to 91 km/h respectively.

For the 95th percentile gust speed, annual variability ranged from maxima of 89 km/h in 1972 and 1977, to minima of 73 km/h in 1993, 1998, 1999 and 2001. The decadal maximum peaked in 1981, declining to a minimum in the ten year period to 2006.

For the 99th percentile, annual variability ranged from a maximum of 111 km/h in 1982 to a minimum of 87 km/h in 1973, 1993 and 2000. Decadal maximum peaked in the period from 1985-1991, to a minimum occurring around 2002.

For the same station, both the 95th and 99th percentile gust-day data show an overall decreasing trend in this parameter over the period of record. The number of days at or exceeding the mean 95th percentile of 79 km/h shows a decrease from 24 days to 16 days. Those at, or exceeding the mean 99th percentile of 94 km/h, decreases from 5 days to just over 2 days.

For the 95th percentile gust-days, annual variability ranged from a maximum of 40 days in 1977 to a minimum of 9 days in 1986. Decadal values peaked in the years from 1981-1983, to a minimum centred on 2001.

Annual 99th percentile gust-day data ranged from a maximum of 12 days in 1972 and 1982, with no days observed in 1990. Decadal values peaked in the period centre on 1985, with minima from 2002 to 2005.

2.4.3 Tornadoes

A tornado is a rapidly-rotating vortex or narrow column of air, extending from the base of a cumulonimbus (or thunderstorm) cloud to the ground (American Meteorological Society, 2007; Houze 1994), and on a local scale is the most intense of all atmospheric circulations. Visible parts of the vortex are the condensation funnel, and the debris cloud (this is near the ground, and may consist of dust, leaves, and other airborne missiles – i.e. twigs, branches, metal, etc.).

The circulating winds of a tornado can attain extremely high speeds which provide great risk to property and life at the ground and in the air. When the humidity is high enough, the tornado funnel is made visible by the circulation of condensed water vapour in its outer sheath, but although the flow of air is inward and upward, the cloud within the low-pressure funnel actually extends downward from the cloud base.

The origin of tornadoes is often associated with well-developed thunderstorm cells on cold fronts, for example at the gust-front boundary where an advancing mass of cold air overruns and displaces pre-existing warmer humid air. Some tornadoes form out to sea as strong waterspouts which sometimes cross the coast, so a waterspout may become a tornado as the twisting funnel moves from land to sea (and vice-versa). Wind speeds are in the order of 115 to 180 km/h. At the more extreme end, some tornadoes track for over 100 kilometres, are over 1 kilometre wide and have winds up to 480 km/h – such tornadoes are extremely rare, anywhere in the world. A more detailed classification of tornadoes is reported in Wikipedia (2007a), while the complete list of tornadoes in the South Hemisphere is available in Wikipedia (2007b).

Taranaki and other New Zealand tornadoes, although not uncommon, are not as severe or destructive as those that occur over the central plains of the United States. There, each year, mainly in the spring and early summer tornadoes are responsible for many deaths (over 300 in 1974) and injuries (over 6000 in 1974) (Te Ara, 2006). New Zealand experiences, on average, about 20 damaging tornado events each year. The tornadoes are typically very narrow and have short tracks. Most are in the F0 to F2 range. These are much smaller than those occurring in USA. The most recent fatalities caused by tornadoes in New Zealand occurred in 2004 (2, Waitara) and before that 1991 (1, Albany).

Typically, a New Zealand tornado has a damage path of 10 to 30 metres wide with a length of 1 to 5 km. The distribution by month is fairly even (Seeyles, 1945; Tomlinson and Nicol, 1976), with a minimum in July compared with June and August. The daily pattern shows a maximum in the early afternoon.

Environmental conditions in New Zealand which tornadoes occur show low values of CAPE (a measure of energy available for convection and updrafts (Figure 11)). The low values of CAPE often associated with New Zealand tornadoes are well below accepted thresholds for predicting severe convection, let alone tornadoes and has motivated forecasters in New Zealand to use Storm Relative Helicity (SRH, a measure of the potential spin the atmosphere can impart to a convective updraft) as an indicator of the potential for tornadic activity (Haslam 2006), and another parameter which can be used to assess the risk of tornado activity which combines both SRH and CAPE is called the Enhanced Helicity Index (EHI). EHI is simply the multiplicative product of CAPE and SRH divided by some threshold for CAPE (160,000 is commonly used by severe weather forecasters in the USA). EHI is a good index to use because it captures the two key ingredients for possible tornado development CAPE and SRH.

Burgess et al. (2007) demonstrated that the EHI (with a lower threshold) was very useful for detecting the risk of tornadoes in Taranaki (and other parts of New Zealand) over the last five years, when analyses from the regional model with a resolution of 20 km were available. EHI is used here as the main risk indicator for tornado development in Taranaki.

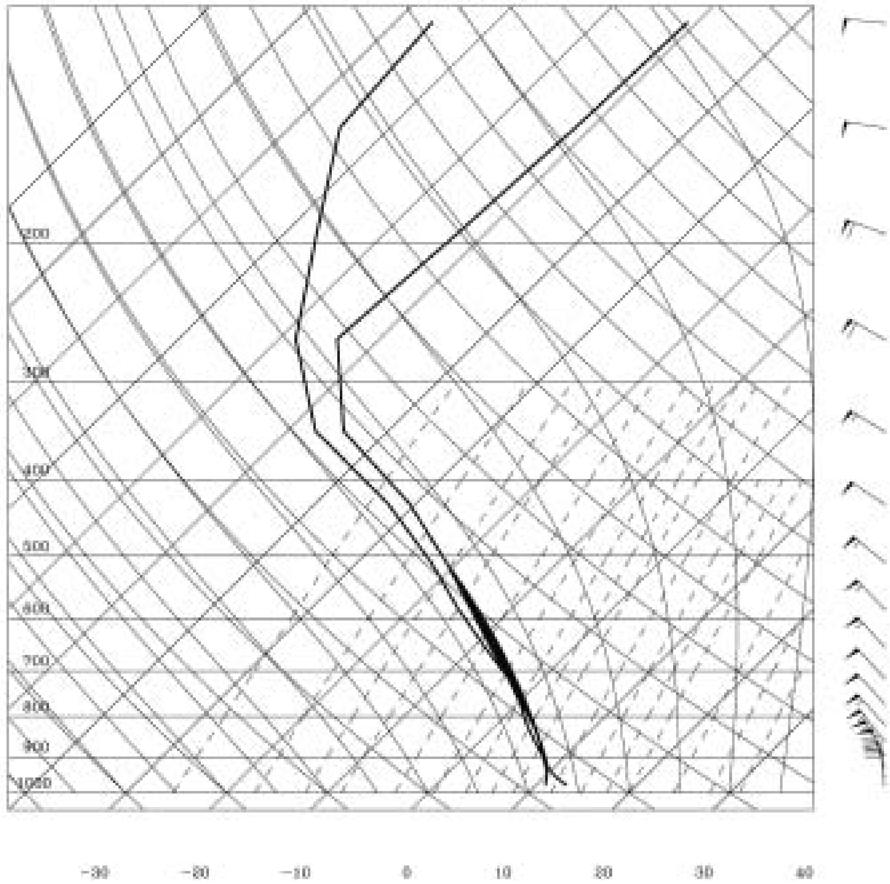

Figure 11. Skew T(emperature) – log P(ressure) plotted soundings of temperature, dew point and winds from RAMS model for New Plymouth at 0500 NZST 14 August 2004. The black shaded area between 800 and 500 hPa indicates the region of CAPE (evaluated to be approx 150 J/kg). The wind barbs are in knots (A solid filled triangle represents a wind speed of 50 knots). © NIWA.

2.4.3.1. Tornado climatology

A wide selection of sources were accessed by Burgess et al. (2007) and Salinger et al. (2007) in order to compile a workable database of past tornado events in the Taranaki region.

The tornado catalogue created for this study (Appendix 4, Burgess et al. 2007; Salinger et al. 2007) lists tornadoes (includes waterspouts) that were identified within the Taranaki or offshore region between 1 January 1951 and August 2007 (a total of 56 years). A couple of early tornadoes from the mid 1930s are also noted, but useful resources were not available for identification of other events before 1951. Most tornadoes were designated 'whirlwinds' in the early years prior to 1955. Not all of the events listed will have been true tornadoes by definition, as limited information can make it difficult to distinguish between these and squalls or sudden downbursts which also occur with thunderstorms and/or air mass boundaries, along with subsequent damage.

A total of 61 tornado producing events were identified within the Taranaki and offshore region over the period surveyed from January 1951 to August 2007 (Table 3). This includes four tornado producing events so far in 2007 (21 March, 4 July, 5 July, and 31 July). Of these 50 (82 percent) were reported as damaging events, i.e. at least minor damage occurred to property (sheds, trees, fences, etc.), of which 16 events (26 percent) were serious with major structural damage occurring to buildings. Lives were lost in two events (one fatality at Opunake on 22 April 1973 and two fatalities near Waitara on 15 August 2004), which equates to 3 percent of occurrences.

The majority of Taranaki's damaging tornadoes would be classified as F0 or F1 on the Fujita Tornado Scale, however more than 10 percent scored F2 or higher. Typical weather conditions reported at the time of Taranaki tornadoes included cumulonimbus cloud and/or associated thunderstorms, with rainfall or hail of moderate to heavy intensity, relatively low mean sea level pressure, and winds usually from between north and west, indicating the presence of a trough of low pressure and associated frontal activity over or west of Taranaki.

In Taranaki for the several (less than 10) events where a track was observed, this was often from the coast heading inland. Track or damage widths ranged from between 15 m and 500 m with a mean of 100 m, while track lengths varied from 1.5 to 16 km with a mean of 5 km. The 16 km track of the fatal Opunake tornado of 22 April 1973 was the longest documented in New Zealand.

Diurnal variation was not a feature for Taranaki tornadoes from reports, as there seemed to be no preferred time of day or night for their occurrence. On average about one tornado (often damaging) will occur somewhere in the Taranaki region per year, with a severe case reported on average about once in 4 years. Multiple tornadoes (more than one) occur in Taranaki on about 10 percent of tornado days. However, (unlike the 5 July 2007 event) it is very unusual for more than a few (2 or 3) to occur on the same day.

Table 3. Summary of Taranaki tornadoes, January 1951 - August 2007.

	New Plymouth District	Stratford District	South Taranaki District	Within Taranaki but district not specified	Taranaki Region
Observed events	43	4	10	6	61
Mean number of events per year	0.8	0.1	0.2	0.1	1.1
Events with multiple tornadoes	3 (7%)	Nil	1 (10%)	2 (33%)	6(10%)
Damaging events	38 (88%)	4 (100%)	10 (100%)	2 (40%)	50 (82%)
Events with damaged buildings	13 (30%)	1 (25%)	2 (20%)	1 (17%)	16 (26%)
Events with loss of life	1 (2%)	Nil	1 (10%)	Nil	2 (3%)
Fujita Scale, F0-F1 <116-180 km/h	32 (74%)	3 (75%)	6 (60%)	4 (80%)	43 (70%)
Fujita Scale, F2-F3 181-330 km/h	6 (14%)	Nil	2 (20%)	Nil	8 (13%)

2.4.3.2. Modelling the July 2007 tornadoes

The tornadoes of 4-5 July 2007 were unique, the first known documentation in New Zealand's history of such a high number of damaging tornadoes (at least eight or more) with widespread spatial coverage. The case studies (Salinger et al. 2007) showed that these both originated offshore and travelled southeast. The 4 July New Plymouth tornado was assessed to be F1 in strength on the Fujita scale, and tracked about 1 km to the south-southeast across New Plymouth affecting Pukekura Racecourse, after the central city. The 5 July Oakura tornado was one of the most destructive in the Taranaki record, assessed at a strength of F2-3. This also tracked in from the coast about 1 km to the south-southeast, causing extensive damage in Oakura. In both cases very strong cyclonic northwest airflow prevailed over Taranaki producing strong northerly quarter winds, and severe convection occurred in the frontal zone passing over the region.

These were modelled using the New Zealand Limited Area Model (NZLAM) weather forecasting model to give high resolution simulations of the events. This simulated clearly convection with vigorous updrafts and downdrafts (greater than 30 km/h) with some exhibiting significant rotation in horizontal winds. Although the NZLAM model does not locate these meso-cyclones precisely, these features correspond to the parent meso-cyclones that spawned the tornadoes. The mechanisms involved were not surfaced based. Precursor convection to tornado outbreaks involves the presence of very cold air in the upper troposphere in mesocyclones along the frontal zone with vigorous thunderstorms just off the north Taranaki coast, moving from northwest to southeast. Model guidance from NZLAM would allow forecasters to predict the very definite possibility of severe weather including tornadoes.

2.4.3.3. High Risk Areas

Tornadoes pose a risk in that they produce high winds, which can cause major damage, and in some cases injury and loss of life. Since they are also associated with thunderstorms, the high winds are often combined with intense rainfall, hail, and lightning strikes.

New Plymouth district may be more affected by tornadoes than other parts of Taranaki. The majority (almost 80%) of the reported tornadoes, including many of the severe cases, have occurred on the northern (New Plymouth) side of Mt Taranaki. This area is exposed to thunderstorms and unstable northwest air masses that have originated over the Tasman Sea in a region that has been identified as more prone to the development of tornadoes. Damaging tornadoes have also occurred in many towns and rural areas throughout Taranaki. The importance of terrain in deflecting low level winds in such a way as to favour the development of tornadoes appears to be greatest in the very sparsely populated area east of Stratford due to the influence of the central plateau. There is a suggestion that the Mt. Taranaki influence although slight is most important in areas to the northeast and southeast of the mountain.

2.5 Lightning

Lightning occurs from deep convective storms under circumstances that separate electrical charges. The discharges can occur as cloud-to-cloud and cloud-to-ground discharges. For the New Plymouth district three situations can lead to strong convection and thunderstorms producing lightning: cool air flows over a warmer sea with storms focussed into clusters, diurnal heating of the land surface providing convection, and the development of warm air under colder air in weather fronts.

Data on lightning is available for the district since November 1991 from a lightning strike sensor from the New Plymouth Airport automatic weather station (AWS). This sensor has an effective radius of cover of about 25 km. It records both cloud-to-cloud and cloud-to-ground lightning strokes. More complete coverage of cloud-to-ground lightning for the entire district is available from the lightning detection network (LDN) from September 2000.

The AWS record shows a high seasonal to interannual pattern of variability. Annually the total number of lightning flash counts varied from under 300 in 1998 to almost 2500 in 1994. Certainly the first six years of the record from 1991 to 1996 averaged close to 1500 strokes, with a dramatic decline to an average of under 600 strokes from 1997 onwards. Evidence suggests this could represent a decline in the disturbed westerly events that produce significant lightning strokes. Seasonally, the AWS data suggests peaks in September, followed by December, November and June, with minima in April and November. The shorter LDN data series parallels the seasonal variability to some extent.

Diurnally there is an early morning and afternoon peak in stroke counts from AWS data: the former a result of storms arriving from the Tasman Sea from the west, and the latter owing to afternoon convective heating. These maxima are less apparent in the LDN data, which reflects the shorter period of data capture.

The annual averaged lightning strike density for the district is approximately 0.5 strikes per km^2. There were some differences in the results from the two datasets. The case studies show this is probably a result of the difference in sampling: the AWS samples counts over a 25 km radius, whilst the LDN captures the entire district and Taranaki region. The localised nature of significant episodes may explain the differences. Unlike the pattern for annual rainfall, Mount Taranaki does not dominate the lightning density plot. The lightning strike density thus appears to be dominated by pre-existing storms moving in from off the sea, rather than any particular area that is more at risk.

Four case studies illustrate the most central mechanisms behind significant lightning episodes and the importance of these in giving large monthly strike counts. These occurred after the passage of the main front in cyclonic westerly and northwesterly situations and gave ground strike count occurrences with tight paths that ran northwest to southeast across the New Plymouth district. The case studies dominated the record for a particular month. This implies that the months with very high ground strike count are produced only when a relatively rare weather pattern occurs. Such lightning storms, when they pass across important infrastructure, have the potential to produce significant disruption.

2.6 Tropical cyclones

Tropical cyclones are severe low pressure systems that form in the tropics. These revolving storms gain their energy from heat that is released when water vapour evaporated from the warm ocean surface condenses into rain, releasing latent heat. The main hazard characteristics of tropical cyclones are damaging winds, high seas and heavy rainfall. Storms of this type are often called hurricanes in the North Atlantic and eastern Pacific and typhoons in South East Asia and China. They are typically called tropical cyclones in the southwest Pacific and Indian Ocean region.

As tropical cyclones move into New Zealand waters, they tend to weaken or decay as they move over cooler seas and land. However, some tropical storm systems can re-intensify in the extra-tropics to become potent mid-latitude storms ("ex-tropical cyclones") capable of inflicting loss of life and severe property damage. The worst cyclones tend to occur from December to April with at least one ex-tropical cyclone passing within 500 km of New Zealand in most years. The severity of these storms (and associated damaging winds, high seas and heavy rain) depends on their location and on the phase of the El Niño/La Niña cycle.

In the Southwest Pacific, tropical cyclones with an organized system of clouds and thunderstorms and with a defined circulation, and maximum sustained winds of 61 kph or less are called "tropical depressions". Once the tropical cyclone reaches winds of at least 63 kph they are called a "tropical storm" and assigned a name. The severity of a tropical cyclone is described in terms of categories ranging from 1 to 5 in relation to the zone of maximum winds

As these move from the equatorial region (where they form in the southwest Pacific between 5^{o}S and 20^{o}S) towards higher latitudes they transform into ex-tropical cyclones, losing the warm core typical of tropical storms and taking on the cold-core characteristics of mid-latitude storms. Such ex-tropical cyclones can affect northern New Zealand in particular.

On average, about ten or eleven tropical cyclones form in Southwest Pacific per year, although in any one season the frequency can range between approximately 2 and 16. During La Niña events, the atmospheric and oceanic conditions are more favourable for the formation of tropical cyclones in the Coral Sea, instead of further east, so the likely track may come closer to New Zealand. While the track of tropical cyclones in the tropics is affected by the El Niño-Southern Oscillation (ENSO) cycle, the chance of ex-tropical cyclone activity near northern New Zealand does not change significantly with the ENSO cycle. The average risk over a cyclone season for northern New Zealand of approximately 80 percent, i.e. one storm comes within ~500km of the New Zealand coat in 4 years out of 5, on average.

2.6.1 Occurrence in Taranaki region

The majority of ex-tropical cyclones that have eventually affected the Taranaki region originally developed within convective areas over the warm tropical waters (sea surface temperatures being at least 27 ºC) of the Coral Sea, south of the Solomon Islands in the area surrounding Vanuatu (between latitudes 10 and 15ºS, and longitudes 160-170ºE) and later tracked south-southeast, toward New Zealand. The catalogue of ex-tropical cyclones passing near or over in Taranaki during December through April periods from 1968 through 2006 is reported in Table 2 of Burgess et al. (2006).

Approximately 30 cyclones of tropical origin passed near[1] or over Taranaki between December and April during the period from 1968 to 2005. In some years more than one ex-tropical cyclone was experienced. Twenty two of the years from 1968 – 2005 had one or more ex-tropical cyclones, so the chance of one or more cyclones of tropical origin passing near Taranaki in a year is 57 percent and there is a 43 percent chance of no ex-tropical cyclones in a year. These cyclones have passed near or over Taranaki as early as 21 December, and as late as 30 April. The peak period of occurrence is during February and March due to warmer sea surface conditions in these months. Three have occurred over the observational period in December, increasing to ten in March then declining to four in April. Once in the north Tasman Sea these cyclones invariably move in a path between east and southeast putting, the regions at risk should these systems reach the north Tasman Sea between Australia and New Zealand.

Burgess et al. (2006) document a ex-tropical cyclone event that produced major impacts on the region. All known cyclones of tropical origin that have influenced Taranaki have also been categorized. Tropical cyclone Bola originated on 26 February 1988, about 200 km northeast of New Caledonia. Bola impacted much of the North Island from 5-9 March. Intense flood-producing rainfall occurred in northern and eastern regions of the North Island. Damaging southeast winds affected several parts of the North Island, especially Taranaki.

2.6.2 Trends in Cyclones

The average number of cyclones of tropical origin passing within about 550 km of New Plymouth each year is 0.8 (Figure 12). However, 40 percent of seasons have no occurrences, so there is a 0.6 probability of one or more cyclones of tropical origin in any given season. A smaller proportion of seasons (20 percent) have more than one occurrence. For, example, there were four ex-tropical cyclones (Fergus, Drena, Harold, and Gavin) in the December 1996 to April 1997 season.

[1] within approximately 550 km

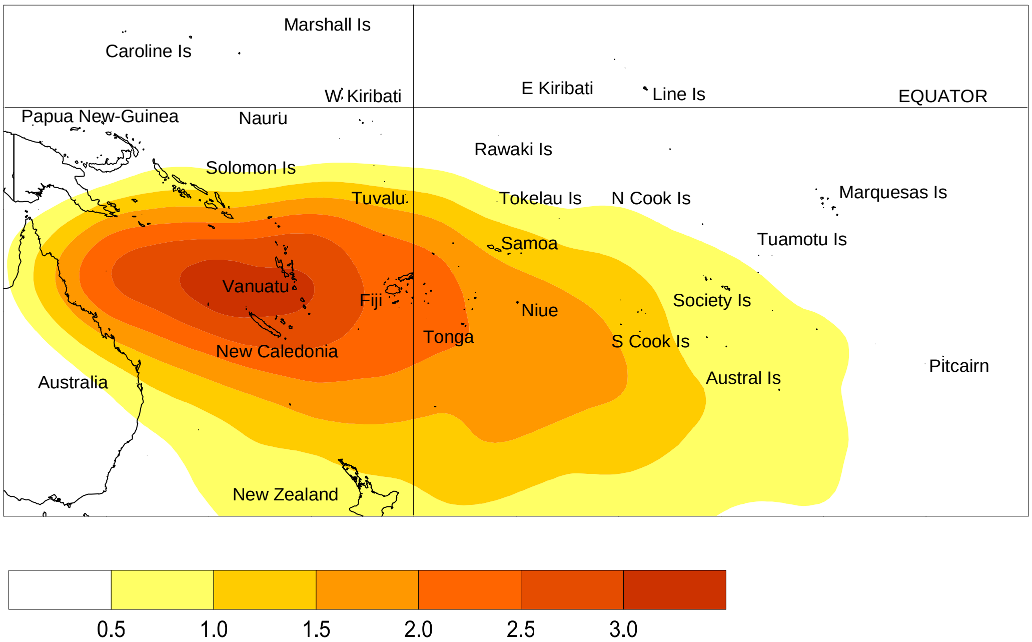

Figure 12. Mean annual tropical cyclone occurrence (Nov-May periods), from 1970/71. ©NIWA.

Trends over time (Figure 13) show that these were more frequent than normal (0.8 per year) during the mid 1970s through to the early 1980s, and again from the late 1980s to the late 1990s. Periods with little activity occurred in the mid 1980s and early 2000s. The record here is too short to ascribe any long-term trends.

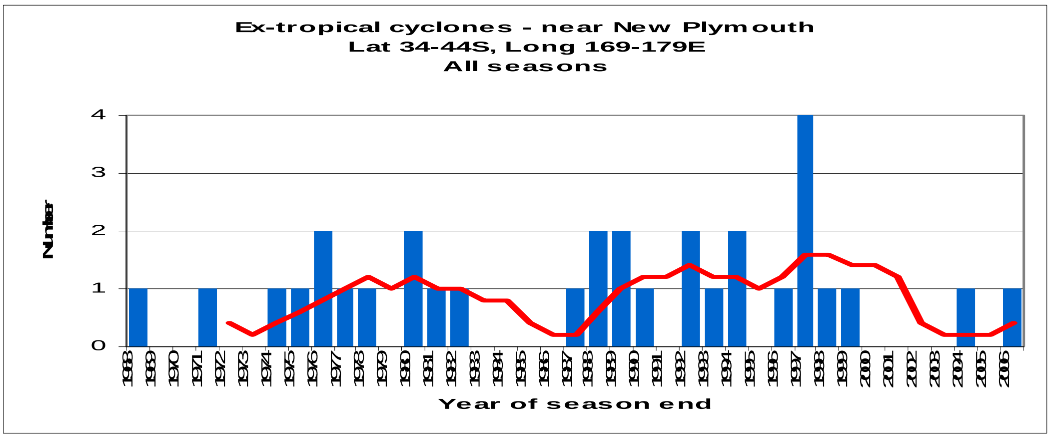

Figure 13. Frequency of ex-tropical cyclones passing near or over New Plymouth. Blue bars represent individual seasons. The red line shows the 5-year running mean. ©NIWA.

2.6.3 High risk areas

Ex-tropical cyclones pose a risk in that they bring both intense rainfall and high winds, which as detailed in this report, can cause major damage. Far from being confined to wind damage, flooding, and landslides, there is also the potential for storm surges and waves to exacerbate the situation along the New Plymouth district coastline. Coastal erosion may be a potential hazard where an ex-tropical cyclone is well offshore in the west.

A flood event brought about by heavy rain during an ex-tropical cyclone will cause greater damage in low-lying coastal areas if a storm surge or high waves develop and prevent rivers draining to the sea. A severe flood therefore has the potential to cover a greater area and more infrastructure and property would be exposed to failure.

2.6.4 A 100-year tropical cyclone event

The risk from such an ex-tropical cyclone lies in the combined hazards of wind and high rainfall. A 100-year average recurrence interval (ARI) event is likely to have rainfall totals in excess of 250 mm in the New Plymouth district, with still higher totals on Mt Taranaki (see, e.g., Cyclone Hilda in March 1990). Average wind speeds are likely to exceed storm force (> 88 km/h) for many hours, and gusts could exceed 140 km/h at times. The cyclone track will determine the wind direction; whilst the centre is to the north of the district storm force south easterlies are likely.

These hazards would lead to extensive flooding, particularly from rivers and streams, with the flooding being exacerbated by slip and wind created debris blocking river courses and culverts. Sewerage may enter the flood waters, particularly around urban streets and streams. Storm surges and high waves will prevent flood waters draining to the sea and at the same time lead to enhanced erosion along the coast line.

The wind would cause power lines and possibly pylons to be blown down, trees to be uprooted, roofs to be damaged. Many roads will be blocked with slips and fallen trees or be otherwise impassable, and such inclement weather is likely to lead to road accidents.

The combination of these impacts is likely to mean that power and telecommunications are expected to be disrupted over much of the region. Water supplies may be cut to some areas, for example, as pipelines near rivers are undermined. Some communities would be isolated. The normal time taken to repair faults would be extended, as places may be hard to access. Details as to where the worst impacts are happening may be hard to obtain, as communication with outlying regions may be broken. The storm is likely to lead to a regionally-wide response, with a regional "declaration". Additionally a storm of this magnitude is likely to affect neighbouring regions. This will mean that the district may need to cope without outside help for a significant period of time. The 1 in 100-year cyclone is likely to produce dramatic impacts to property and infrastructure. Such a storm produces both high intensity rainfall and hurricane force winds leading to extensive flooding. High winds would damage infrastructure (especially power supply and telecommunications), forests (uprooted trees), as well as cause coastal impacts from storm surges.

2.7 Drought

Drought is a normal, recurrent feature of climate[2]. This hazard occurs almost everywhere though its features vary from region to region. Defining drought is difficult as it depends on need, physical differences in regions, and varying disciplinary perspectives. In the most general sense, drought originates from a deficiency of precipitation over an extended period of time, usually a season or more[3], resulting in a water shortage for some activity, group, or environmental sector.

In contrast to natural hazards, such as floods and earthquakes, the onset of a drought can be slow and unspectacular[4]. Nevertheless, its effects can be severe as has been seen over the last decade on urban water supply, energy generation and the pastoral industry. Droughts tend to break when there is substantial rainfall to recharge the moisture levels in the rivers, lakes and soils.

Mullan et al. (2005) in their study developed a quantitative indicator of drought, the ‘potential evapotranspiration deficit’ (PED) and applied it to the recorded climate from recent decades to assess how variable and severe droughts can be under the ‘current’ climate in New Zealand. PED is not the only index that can be used to measure drought, but is the one used in New Zealand. In a second phase of their study they applied the drought risk indicator to a number of climate change scenarios to show a plausible range of effects that climate change may have on drought risk around the country.

The ‘potential evapotranspiration deficit’ (PED) can be used as a measure of drought and is a useful means of ranking the severity of dry periods from a meteorological viewpoint, but based on a water balance application that takes soil moisture deficiency into account. The choice of whether a dry period takes on the more sinister term of ‘drought’ might then be made on how often a given level of dryness (as defined by PED) might occur or be exceeded. As drought is a response to several factors, this measure incorporates several of the climatic factors. Accumulated PED is the amount of water that would need to be added to a crop over a period, (for example a year), to prevent loss of production due to water shortage. For pastures not receiving irrigation, an increase in accumulated PED of 30 mm corresponds to approximately one additional week of pasture moisture deficit (reduced grass growth). In New Zealand, the accumulated PED is typically

[2] Many people erroneously consider it a rare and random event.
[3] Drought is a temporary aberration; it differs from aridity, which is restricted to low rainfall regions and is a permanent feature of climate.
[4] Droughts tend to be prolonged events in comparison to other extreme events which may cause a similar magnitude of havoc yet be over within a few hours or days.

calculated over a July to June 'growing year', from daily information stored in NIWA's climate database, although comparisons of drought severity can also made on sub-annual (e.g. spring) or multi-annual time scales.

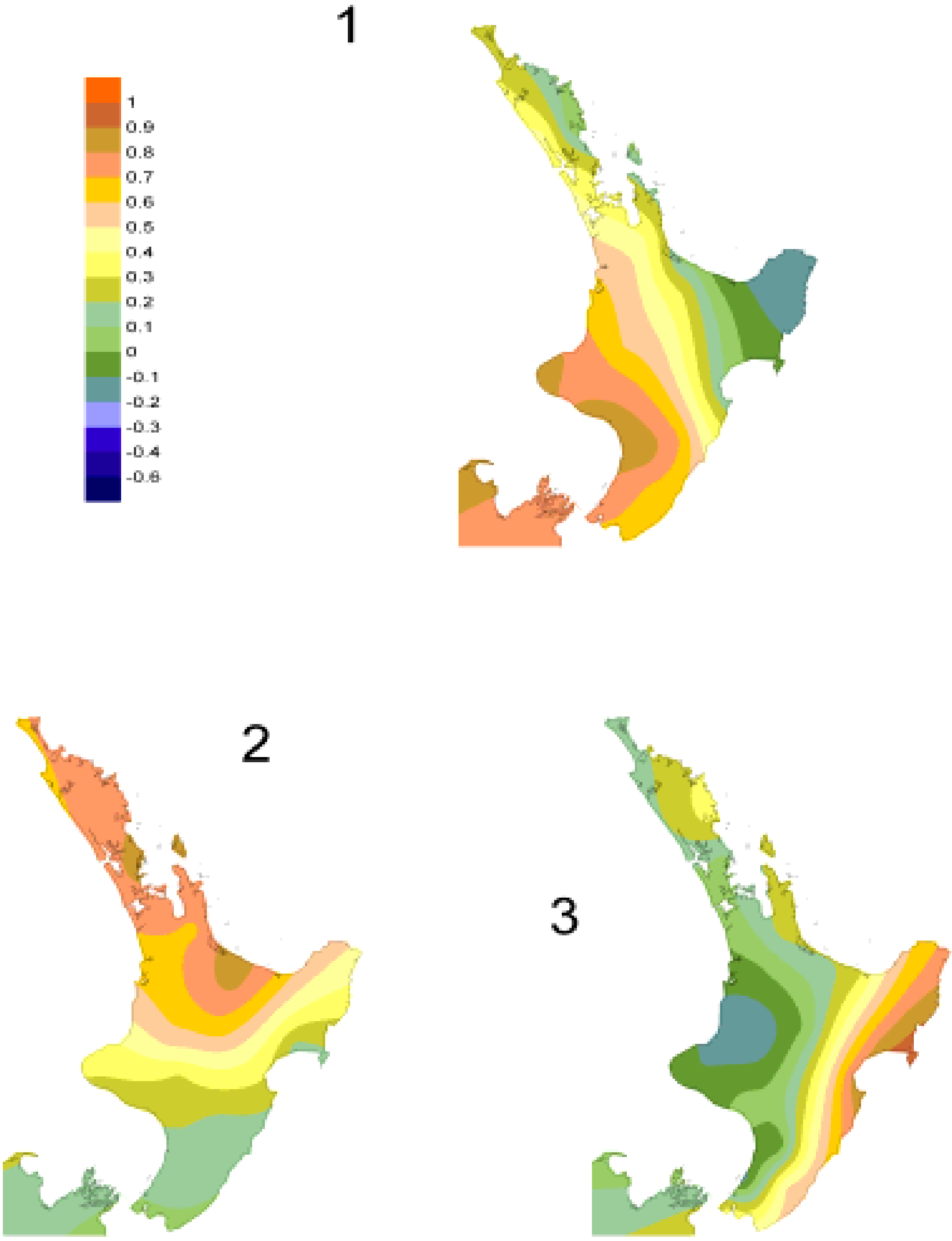

Figure 14. North Island patterns of drought.These account for 29% (1) , 30% (2) and 13% (3) of the total variability in PED over the the North Island respectively.

Droughts are typically produced by persistence in circulation or increased frequency of a particular weather type interacting with New Zealand's topography. Increased frequencies of anticyclones are a common thread for higher than normal PED; wetter seasons typically occur when more troughs than usual occur. Drought over extensive areas is evidence of seasonal persistence of atmospheric circulation and anticyclonic weather types (Salinger and Porteous, 2006). The two regionally significant impacts produced by drought and dry periods are on agricultural and water supply storage.

In the North Island three patterns of drought have been identified and associated with different weather patterns (Figure 14) (Salinger et al., 2006). Dry conditions in the west of the North Island (panel 1 above) including the Taranaki region, occur during episodes of easterly flow with anticyclones occurring east of the South Island.

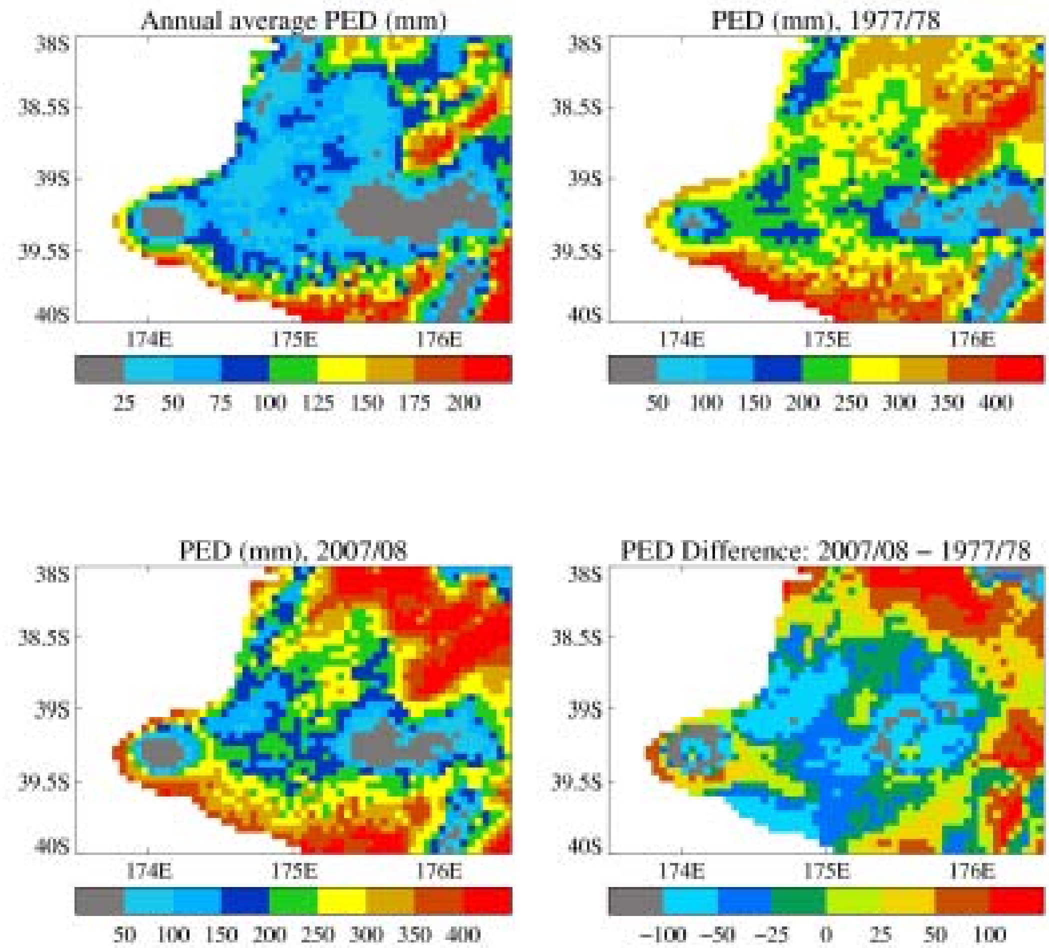

Figure 15. Potential evapo-transpiration deficit (mm) for Taranaki region: long term annual average (1972/3-2007/8), annual mean for 1977/78 (July to June) and for 2007/2008, difference between the two driest years. Note the different contour intervals used in the various plots. © NIWA.

NIWA's gridded PED data used in Mullan et al. (2005) have been updated, and Figure 15 shows examples of accumulated annual PED (July-June year) for the Taranaki region and its surrounds. The long term annual potential evapotranspiration deficit for Taranaki, averaged over thirty years 1972/73 to 2001/02, shows quite small moisture deficits except for a narrow coastal strip, especially to the south of Mt Taranaki. This pattern closely follows that of annual rainfall (Figure 3). Annual deficits range from 25-75mm immediately east of Mt Taranaki to as much as 200mm along parts of the southern coast.

Figure 15 also compares the two driest years (highest PED) for Taranaki in the record available from the gridded data (starting 1972): the El Niño year of 1977/78 and the La Niña year of 2007/08. The accumulated deficits in these years are much larger than the long-term average (note change in contour interval), although Mt Taranak and the areas immediately to the eat are still the wettest part of the region (lowest deficits). The final panel of Figure 15 shows the difference between these two driest years. There is a ring around Mt Taranaki which was drier (larger deficit) in 2007/08, but for much of inland Taranaki the 1977/78 drought had accumulated deficits 25-100mm greater than in 2007/08.

Averaging the gridded PEDs over the entire Taranaki Regional Council area (Figure 16) shows that overall 1977/78 was slightly drier than 2007/08. Analyses at individual climate sites (Figure 17) support the claim that these two years were particularly dry, but also highlights regional variations.

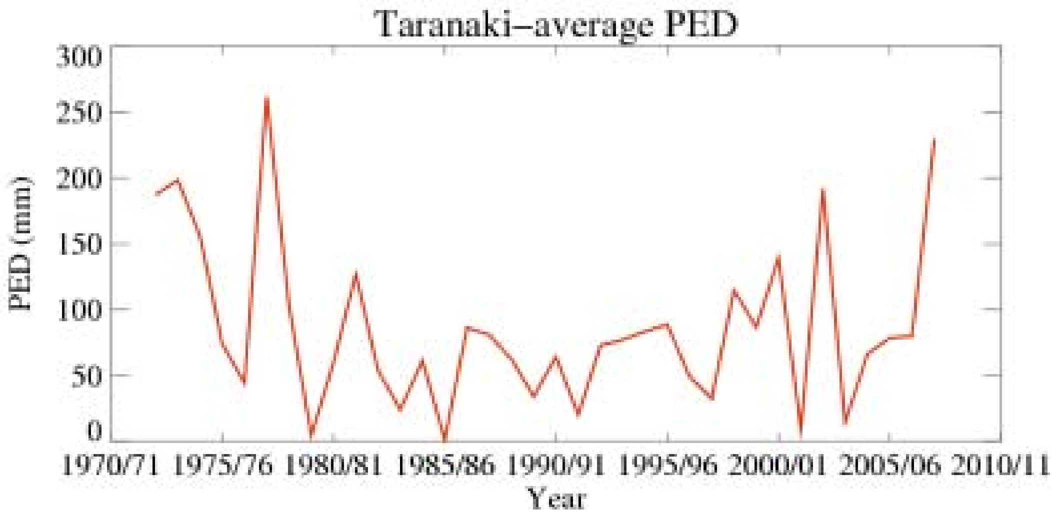

Figure 16. Time series of annual accumulated PED (in mm), averaged over all grid boxes of the Taranaki region for the July to June growing seasons from 1970/71 to 2007/08.

The single site analysis over the period 1951-2008 shows demonstrates the differences at local scale. The time series represents the annual potential evapo-transpiration deficit, *PED*, expressed in mm, over July 1st – June 30th years. The PED is approximately equivalent to the amount of water that is required to be added by rainfall or irrigation to keep pasture growing at its daily potential rate. Time series of New Plymouth, Stratford

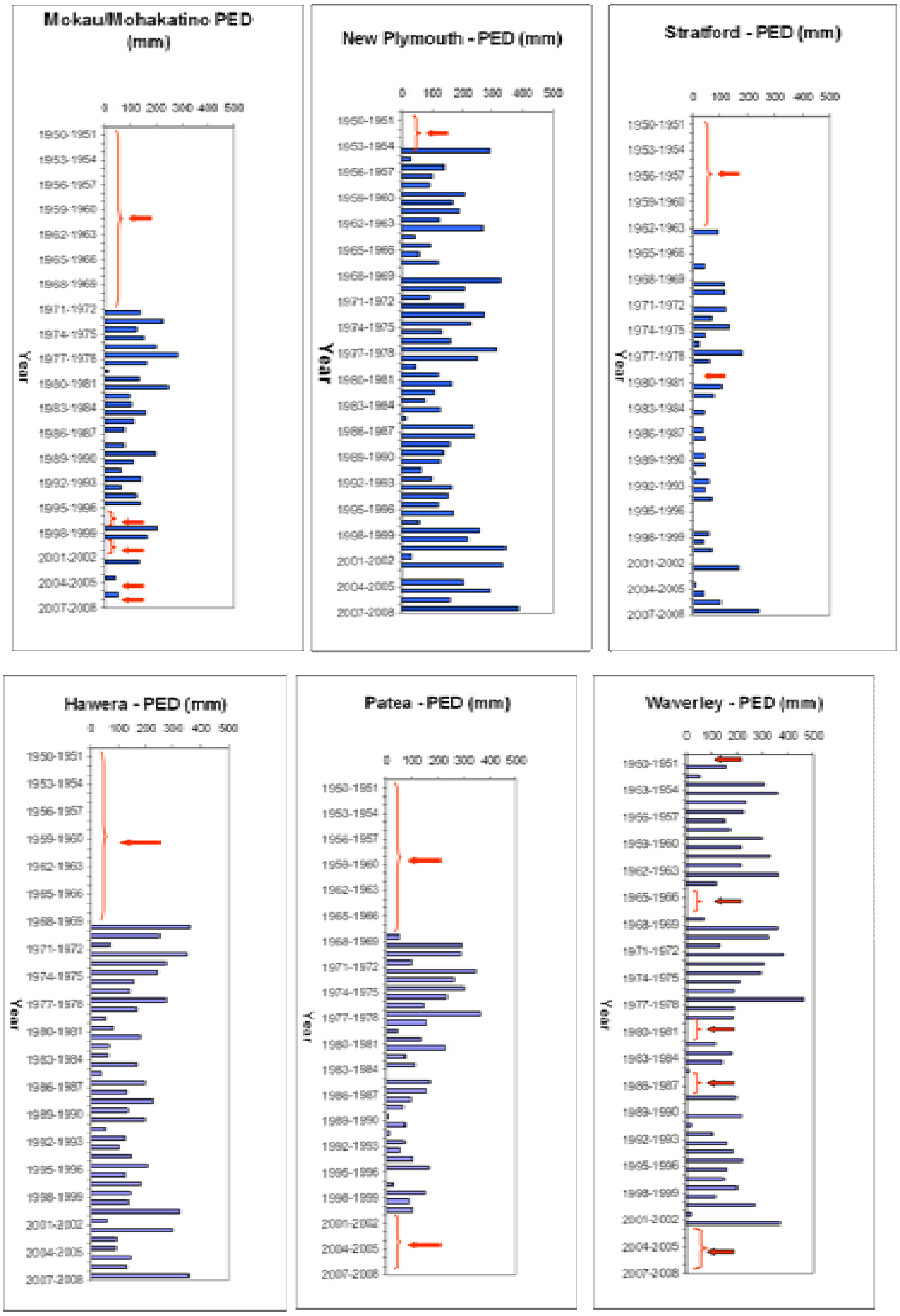

Figure 17. Potential evapo-transpiration deficit (mm) for sites in the Taranaki region: Mokau-Mohakatino, New Plymout, Stratford, Hawera, Patea, Waverley. The red arrows indicate missing values © NIWA.

and Hawera show that the 1977/78 and 2007/2008 years (Figure 17) were the driest on record.

3. Climate variability

3.1 Climate change and variability

Climate trends in Taranaki are subject to variations of the global climate system. The climate in any place over a particular time period is determined by processes within the Earth-Atmosphere system, as well as external components. Those usually regarded as *external* to the system are solar radiation (which includes the effects of Sun-Earth geometry, and the Earth's slowly changing orbit around the Sun), volcanic eruptions and the atmospheric concentration of greenhouse gases. These features determine the mean climate, which may also vary due to natural (*internal*) causes within the climate system. The Earth absorbs radiation from the Sun, mainly at the surface. This energy is then redistributed by the circulation of the atmosphere and ocean and radiated to space at longer wavelengths. On average, for the entire globe, a stable climate requires that the incoming solar energy be balanced by outgoing terrestrial (infra-red) radiation. Any factor that alters the quantity of radiation received from the Sun or lost to space, or alters the redistribution of energy within the Earth-Atmosphere system, can effect climate. Human activity has been altering this radiation balance, with greenhouse gas increases trapping more heat within the climate system. The Intergovernmental Panel on Climate Change (IPCC, 2001; IPCC, 2007a) has concluded that increases in the greenhouse gases have probably been the most important cause of global climate change over the past half-century.

Long-term trends in Taranaki climate will depend on future anthropogenic emissions of greenhouse gases. Consequences can be assessed through the use of global climate models (see section 4). Climate also fluctuates on timescales of decades and shorter due to natural variability. The two main factors for New Zealand climate are El Niño-Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO). ENSO and the IPO are natural cycles that operate over timescales of years and decades, respectively. These natural phenomena are confined largely to the Pacific Ocean, and there is evidence that sea temperature conditions elsewhere, such as in the Indian Ocean, can also affect New Zealand climate at certain times of year. The future climate of Taranaki will arise as a combination of anthropogenic forcing (and possibly other external changes such as long-term variations in solar radiation which we are unable to predict) and these natural variations.

3.2 The El Niño-Southern Oscillation (ENSO)

El Niño-Southern Oscillation is a natural feature that redistributes energy within the climate system. El Niño removes heat from the tropical Pacific Ocean, and moves it into higher oceanic latitudes and into the global atmosphere. The term El Niño was originally used by fishermen for the occasional warming of waters along the Peruvian coast which they observed, as it became strongest around Christmas in some years. The warming extends out along the Equator from the South American coast to the central Pacific. It is accompanied by large changes in the tropical atmosphere, lowering pressures in the east and raising them in the west, in what is known as the "Southern Oscillation". In the late 1960s and early 1970s, scientists realised that El Niño and the Southern Oscillation were linked, with one component in the ocean and the other in the atmosphere. This became known as ENSO. A convenient way of measuring ENSO is in terms of the east-west pressure difference, the Southern Oscillation Index, or SOI, which is a scaled form of the difference in mean sea-level pressure between Tahiti and Darwin. A graph of the SOI is shown in Figure 18.

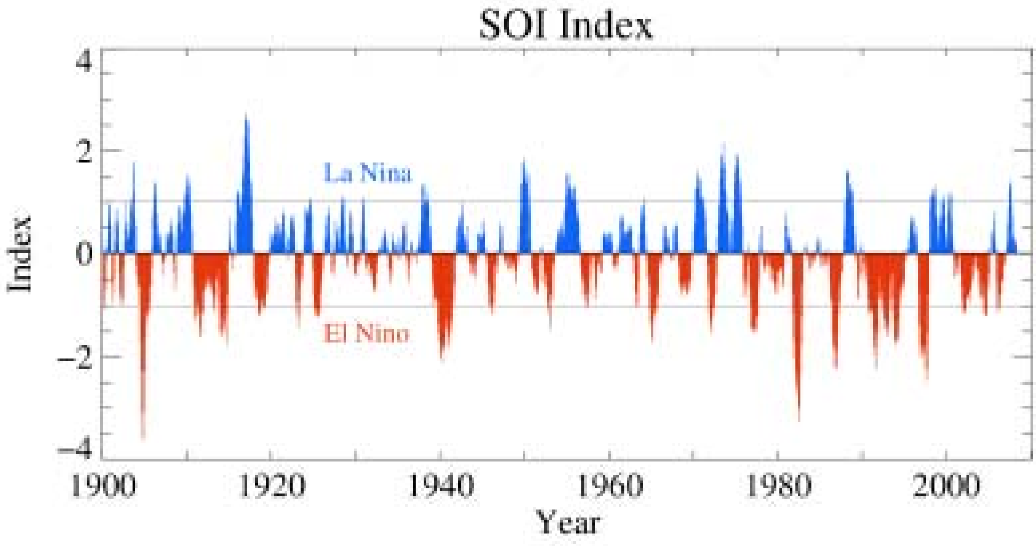

Figure 18. The Southern Oscillation Index (SOI) over the period 1900 - 2007. Negative excursions (red) indicate El Niño events, and positive excursions (blue) indicate La Niña events. The irregular nature of ENSO events is evident in the time sequence. © NIWA.

ENSO may be thought in terms of a slopping back and forth of warm surface water across the equatorial Pacific Ocean. The trade winds, blowing from the east towards the west, normally help to draw up cool water in the east and to keep the warmest water in the western Pacific. This encourages low air pressures in the west and high pressures in the east. An El Niño event is when the warm water "spills out" eastwards across the Pacific, the trade winds weaken, pressures rise in the west and fall in the east. Eventually, the warm water retreats to the west again and "normality" is restored. The movements of water can also swing too far the other way and waters become unusually cool near South America, resulting in what is termed a "La Niña", where the trade winds are unusually strong while pressures are unusually low over northern Australia.

El Niño events occur irregularly, about 3 to 7 years apart, typically becoming established around April or May and persisting for about a year thereafter. The ENSO cycle is an example of a positive feedback system, where a small change in the trade winds can change equatorial sea temperatures to encourage a larger change in the trade winds that changes sea temperatures even more, and so on, into a full-blown El Niño or La Niña.

New Zealand does not lie directly in any of the high-impact regions in the Pacific, but its climate is significantly affected by changes in the atmospheric circulation (winds). In general, El Niño conditions, indicated by persistently negative values for the SOI, give more westerly and south-westerly wind than usual over the country. Annual mean sea levels around the North Island are generally depressed below normal. Conversely, La Niña conditions, indicated by persistently positive SOI values, typically give more north-easterly wind than usual over the country. Annual mean sea levels around the North Island are generally increased above normal (up to 0.1–0.12 m in larger La Niña events). In the centre of the country the climate effects are muted for most seasons and no clear ENSO influence is identifiable against the random variations in climate.

In El Niño years, Taranaki tends to experience stronger and/or more frequent west to southwest winds, bringing relatively cool conditions, with below average land and sea surface temperatures. On a seasonal basis, increased southerlies and south westerlies lead to lower rainfall (Figure 19 and Figure 20, and see also Gordon 1985, Kidson and Renwick, 2002a, b).

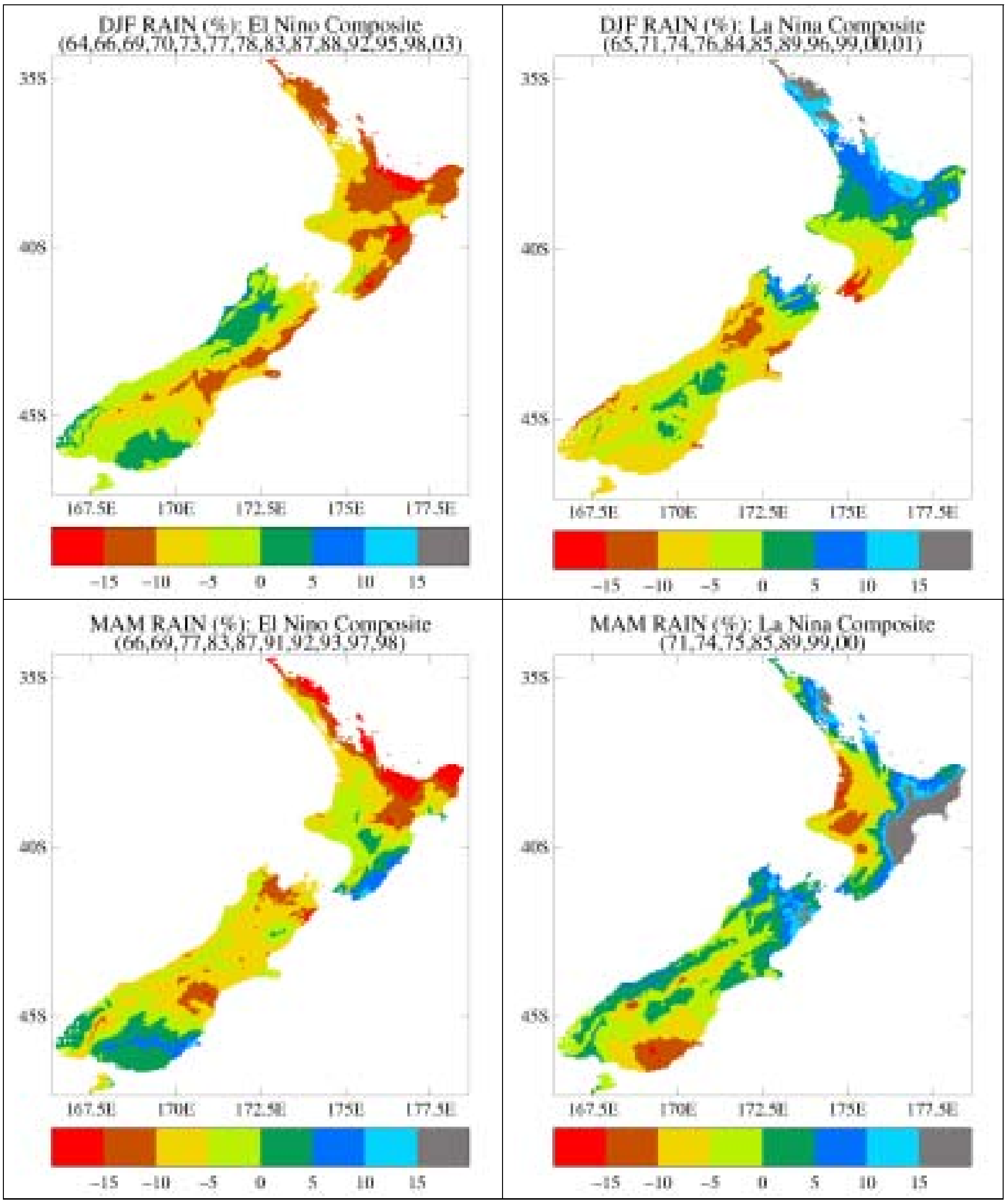

Figure 19. Average seasonal rainfall (percentage deviation from normal) for El Niño and La Niña summer (DJF, top) and autumn (MAM, bottom). Rainfall is expressed as a % difference from the 1971-2000 normals. The figure legend indicates the years entering the composite (e.g., "64" in DJF is Dec 1963-Feb 1964). © NIWA.

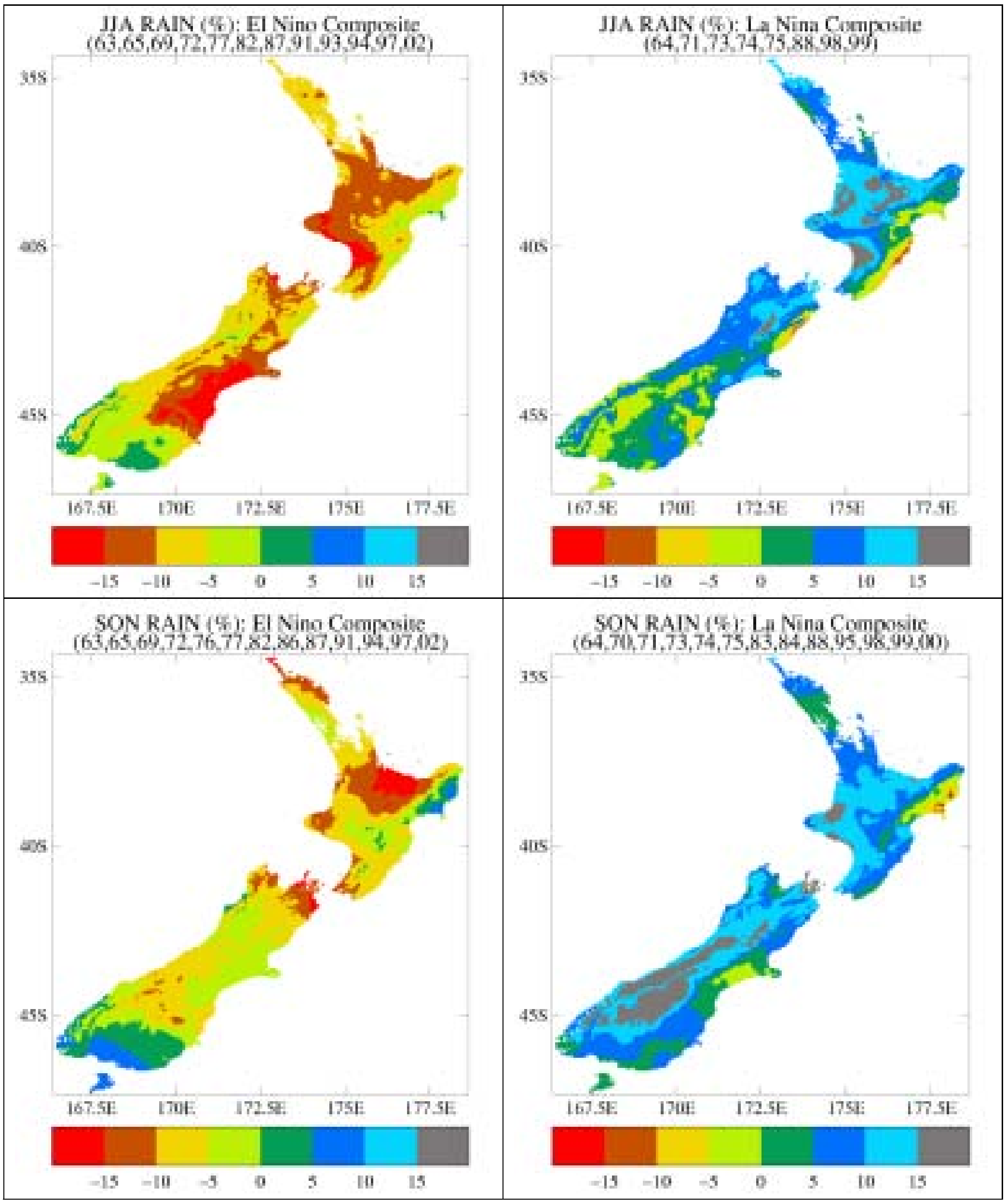

Figure 20. As Figure 19, but for winter (JJA, top) and spring (SON, bottom). © NIWA.

La Niña events bring roughly the opposite changes, with weaker westerlies in summer, and more northerly quarter winds in winter, usually associated with enhanced rainfall in the region in winter and spring (Figure 19 and Figure 20). During El Niño events, Taranaki often experiences a higher frequency of cool blustery southwest winds with occasional heavy shower events. For La Niña events Taranaki is at greater risk of heavy rainfall events, often associated with subtropical lows coming from the north Tasman.

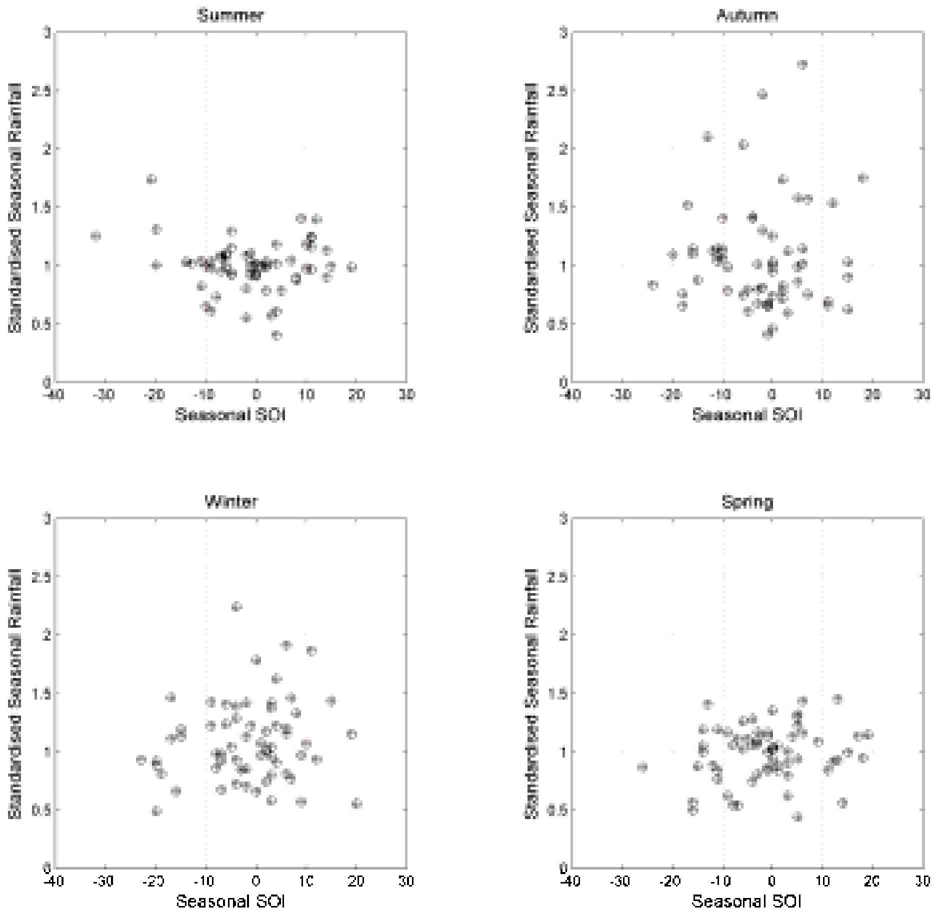

Figure 21. New Plymouth: Standardised seasonal rainfall and the Southern Oscillation Index (SOI x 10), for the period summer 1939/40 to spring 2001. El Niño events occur when the SOI is below -10 and for La Niña events the SOI is larger than +10. © NIWA.

Figure 21 shows scatter plots of standardised seasonal rainfall at New Plymouth and seasonal Southern Oscillation Index (SOI). For the four seasons, there is little discernible in New Plymouth rainfall with variation in the SOI. Note that in this plot the standard SOI has been multiplied by 10, so La Niña events are generally associated with SOI greater than 10 (as plotted) and El Niño with SOI less than -10. Each La Niña or El Niño season has its own character. While some seasonal differences are apparent at New Plymouth in the multi-year averages between El Niño and La Niña, there is a lot of year-to-year scatter between the SOI and standardised rainfall. The strongest ENSO signal in Taranaki, according to Figure 19 and Figure 20, occurs with winter El Niño events, where Figure 21 shows below average rainfall. A consistent drier pattern can be seen in the lower left panel of Figure 21.

3.3 The Inter-decadal Pacific Oscillation (IPO)

The Inter-decadal Pacific Oscillation, or IPO, is a Pacific-wide natural fluctuation in the climate, which causes abrupt "shifts" in Pacific circulation patterns that persist for decades.

The IPO also affects New Zealand's climate, with influences on temperature and rainfall averages in each phase. The IPO is strongest in the North Pacific, but sea temperatures in the eastern equatorial Pacific (the "home" of El Niño) are also influenced. Current research in Australia and New Zealand is showing that when the IPO changes phase, there are changes in the way the El Niño-Southern Oscillation affects Australasia. Thus, a "shift" can not only change the average climate, but can also mean that different forecasting relationships are needed to predict monthly and seasonal variations.

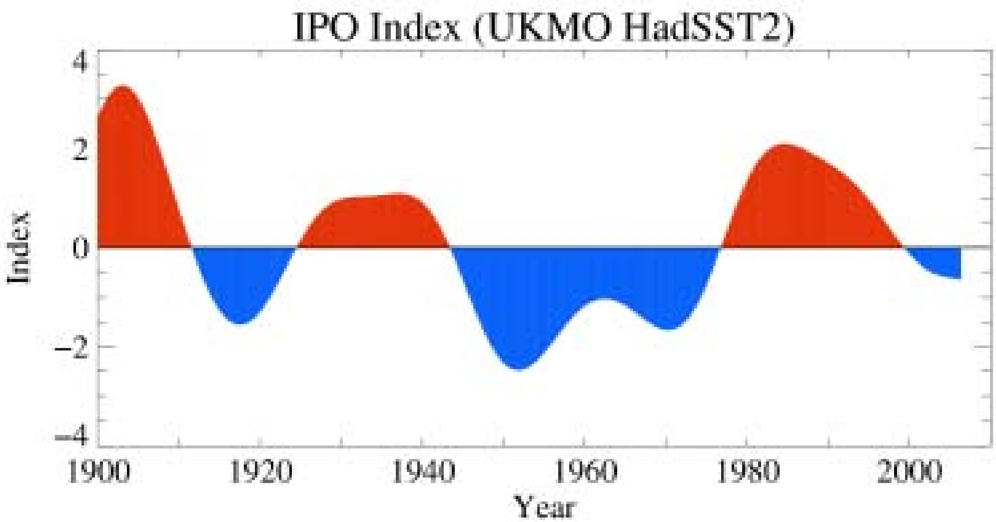

Figure 22. Phases of the Interdecadal Pacific Oscillation. Positive values indicate periods when stronger-than-normal westerlies occur over New Zealand, and more anticyclones over the northern New Zealand. Negative values indicate periods with more north-easterlies than normal to northern regions. Data courtesy of the Hadley Centre, UK Meteorological Office. © NIWA.

There are two phases, the **positive** and **negative** phase of the IPO. In the positive phase, westerly quarter winds over the country and anticyclones in the north Tasman are more prevalent, with generally drier conditions in the north and east.

Phase changes of the IPO are shown in Figure 22.The IPO exhibits phase reversals once every 20-30 years. Previous phase reversals of the IPO occurred around 1922, 1945, and 1977. The latest diagnosis of the IPO index from global sea surface temperatures (Figure 22) indicates a recent reversal in 1999/2000. This current negative phase would be expected to encourage more La Niña activity in the tropical Pacific, and a higher-than-normal frequency of north-easterlies over the country.

3.4 High intensity rainfall

3.4.1 El Niño Southern Oscillation

Thompson (2006) assessed the influence of ENSO on high intensity rainfall in a nationwide study of New Zealand. Annual maximum rainfalls were stratified on the basis of El Niño and La Niña events, and a statistical test (the Wilcoxon rank-sum test) applied to determine whether the ratio of El Niño to La Niña extremes was different from 1. Table 4 gives the results for New Plymouth for durations of 1, 12, and 24-hours. The influence of ENSO on extreme rainfalls appears to be small. The rank-sum probabilities are not statistically significant. The ratios of the two ENSO events indicates that at the 1, and 24-hour storm durations, extreme precipitation during El Niño's tends to be lighter than during La Niña's. However, at 12-hours the opposite occurs where rainfall appears to be more intense during El Niño events.

The stratification of high intensity rainfall into the two ENSO episodes includes annual maxima that have occurred in one or other phase of the IPO: some of the maxima are large, some small. This mixture influences the rank test statistic in the table by providing a relatively even distribution of high and low ranked annual maxima in each ENSO event. For the rank test to show significance, one set of test data should have a comparatively large number of either high or low ranked data, which is not the case in this analysis. Any frequency analysis to provide estimates of high intensity rainfall for New Plymouth is likely to be similar derived from data in El Niño and La Niña years.

Annual maximum rainfalls in years that are neither El Niño nor La Niña are similar to the rainfalls occurring in either an El Niño or a La Niña year. At 24-hours the median annual maximum rainfall (or a rainfall with a 2-year average recurrence interval) in a neutral phase of ENSO is 76 mm. For El Niño and La Niña years the median values are 81mm and 73 mm respectively. For 1-hour storm durations, the median values for El Niño, neutral and La Niña years are 73 mm, 76 mm and 81 mm respectively. However, considerable variability exists in the distributions of data for each ENSO episode.

Table 4. Probability levels of Wilcoxon rank-sum test of annual maximum rainfalls stratified by ENSO and, ratios of the median annual maximum rainfall during El Niño and La Niña events at New Plymouth.

	1-hour		12-hour		24-hour	
Site	Rsum Prob	Ratio	Rsum Prob	Ratio	Rsum Prob	Ratio
New Plymouth	0.44	0.84	0.64	1.23	0.81	0.90

3.4.2 Interdecadal Pacific Oscillation

This part briefly summarize results from Thompson et al. (2006) on the assessment of the extreme rainfall over a range of storm durations at New Plymouth to examine whether a change in phase of the Interdecadal Pacific Oscillation (IPO) has an influence on the extreme rainfall. Monthly maxima for 10 standard durations from 10 minutes to 72 hours were extracted from NIWA's national climate database (CLIDB) for New Plymouth Airport 39.012°S, 174.181°E), Highland Intermediate School 39.077°S, 174.09°E) and from a New Plymouth District Council site (39.071°S, 174.082°E), and the first two sites were amalgamated into a composite time-series. Estimates of the high intensity rainfall at New Plymouth for the period 1948 – 1977 during a negative phase (more northeasterly) of the IPO, and 1978 – 1997 corresponding to the positive phase (more westerly) of the IPO were made, the significance of the changes between the two IPO phases compared and whether changes in high intensity rainfall are related to seasonal mean rainfall totals.

The results are presented for New Plymouth, as the trends and cycles in the daily extreme rainfalls were consistent and spatially coherent across the New Plymouth district. Therefore it is likely the analysis of New Plymouth annual maximum rainfall data will provide insights on the extent of any differences in extremes according to the phase of the IPO, that are also applicable to other areas of the region.

Table 5 gives a table of rainfall depths and their standard errors for New Plymouth for a range of durations from 10 minutes to 72 hours and average recurrence intervals from 2 - 100 years. The annual maximum series covers the period from 1948 – 1997, which encompasses two phases of the IPO. To interpret this table, a 12-hour storm rainfall of 133 mm could be expected to recur on average once every 50 years, and the standard error associated with this estimate is ±11 mm. Further, as to be expected, high intensity rainfalls in the table increase monotonically with time and with frequency. The use of the standard error become relevant to this study when high intensity rainfalls are compared for each phase of the IPO.

When separating the New Plymouth record into the negative (1948 – 1977) and positive (1978 - 1997) phases of the IPO, two statistical tests were performed. The first was a Students t-test on the average of the annual extreme rainfalls, and the second was to perform an extreme value analysis on the stratified data sets. Depth-duration-frequency tables for the two IPO phases are given in Appendix 9.3 of Thompson et al. (2006).

Table 5. Depth (mm) – Duration (minutes or hours) – Frequency (years) analysis from an EV1 distribution for New Plymouth using annual maximum rainfalls for the period 1948 – 1997. As an example of interpreting this table, a 12-hour rainfall with an average recurrence interval of 10-years is 101.6 mm and has a standard error of 6.9 mm.

ARI	Duration									
(years)	10m	20m	30m	60m	2h	6h	12h	24h	48h	72h
2	9.4	15.0	18.9	26.5	33.5	50.1	65.8	86.1	102.2	113.1
5	12.7	20.1	25.3	35.3	43.6	64.5	87.3	119.3	140.6	154.7
10	14.8	23.4	29.5	41.2	50.3	74.1	101.6	141.2	166.0	182.3
20	16.9	26.6	33.5	46.8	56.8	83.3	115.3	162.3	190.4	208.7
30	18.1	28.4	35.9	50.1	60.5	88.5	123.2	174.4	204.5	223.9
50	19.6	30.7	38.8	54.1	65.1	95.1	133.0	189.6	222.0	242.9
60	20.1	31.6	39.8	55.6	66.7	97.5	136.5	194.9	228.3	249.7
70	20.5	32.2	40.7	56.8	68.1	99.4	139.5	199.5	233.5	255.4
80	20.9	32.8	41.4	57.8	69.3	101.1	142.0	203.4	238.1	260.3
90	21.3	33.4	42.1	58.8	70.4	102.7	144.3	206.9	242.1	264.6
100	21.6	33.8	42.7	59.6	71.3	104.0	146.3	210.0	245.7	268.5

	Standard Error (mm)									
2	0.5	0.8	1.0	1.3	1.5	2.2	3.2	5.0	5.8	6.2
5	0.8	1.2	1.5	2.1	2.5	3.5	5.2	8.0	9.3	10.1
10	1.0	1.6	2.0	2.8	3.2	4.6	6.9	10.6	12.2	13.3
20	1.3	2.0	2.5	3.5	4.0	5.7	8.5	13.1	15.2	16.5
30	1.4	2.2	2.8	3.9	4.5	6.4	9.5	14.6	16.9	18.3
50	1.6	2.5	3.2	4.4	5.0	7.2	10.7	16.5	19.1	20.7
60	1.7	2.6	3.3	4.6	5.3	7.5	11.2	17.2	19.9	21.6
70	1.7	2.7	3.4	4.8	5.4	7.7	11.5	17.8	20.6	22.3
80	1.8	2.8	3.5	4.9	5.6	7.9	11.9	18.3	21.2	22.9
90	1.8	2.8	3.6	5.0	5.7	8.1	12.2	18.7	21.7	23.5
100	1.9	2.9	3.7	5.1	5.8	8.3	12.4	19.1	22.1	24.0

The mean and variances of the high intensity rainfall for each phase of the IPO are given in Table 6. In the table it can be seen that the differences in extreme rainfalls in each phase of the IPO are not statistically significant over the complete set of storm durations. In spite of this, the table indicates that extreme rainfalls are likely to slightly heavier overall with a slightly bigger range of extreme rainfall values in the negative phase of the

IPO than in the positive phase. Overall, it appears the rainfall producing processes at New Plymouth and in the surrounding districts in North Taranaki are not being influenced to any great extent by the phase of the IPO.

Table 6. Means (mm), variances (mm^2) and significance of Students t-test of high intensity rainfall for specified durations during positive and negative phases of the IPO.

	10m	20m	30m	1h	2h	6h	12h	24h	48h	72h
Negative Phase IPO (1948 – 1977)										
Mean	9.9	16.0	20.3	29.6	37.2	54.2	71.3	95.2	111.6	122.6
Var	15	33	48	95	151	335	1179	3161	3595	3493
Positive Phase IPO (1978 – 1997)										
Mean	10.2	15.9	19.7	25.9	32.5	50.7	67.5	87.7	105.8	118.2
Var	13	30	48	82	85	243	369	1087	2249	3097
t-test	-0.23	0.07	0.27	1.31	1.42	0.68	0.44	0.53	0.35	0.26
Prob	0.82	0.94	0.79	0.20	0.16	0.50	0.66	0.60	0.72	0.80

In the analysis of Depth (mm) – Frequency (years) rainfall, at each duration, there is statistically no significant difference in the high intensity analyses between the negative or positive phases of the IPO. For durations from 1 – 24 hours, the extreme rainfalls in the negative phase are larger than those in the positive phase. There is also an indication in the 2-hour plot that the differences in high intensity rainfall in the two phases of the IPO are close to the 95 percent confidence limit. For the other durations, the extreme rainfalls are similar of the range of recurrence intervals. In a nationwide study to assess the influence of the IPO on high intensity rainfall Thompson (2006) noted there were very few locations in New Zealand for which there were significant relationships. However, at New Plymouth it was found that for 1-hour storm durations some difference existed at the 10 percent confidence level using a Wilcoxon rank-sum statistical test.

Thompson et al (2006) studied the relationships between seasonal rainfalls and seasonal extreme rainfall showing that taking seasonal averages of rainfall totals and extremes; this smooths the data and enhances any relationship between them. In the positive phase of the IPO, there is more scatter about the regression line than in the negative phase, but the all the scatter plots indicate increases in extremes with increases in seasonal rainfall. Statistically significant relationships exist between seasonal rainfall and extremes, with large F-values and zero probabilities. Any increases in mean rainfall at New Plymouth arising from climate change, will tend to indicate a corresponding increase in the extreme rainfall regime and vice versa. Salinger and Griffiths (2001) also noted the relationship between mean and extreme rainfall in their study. A note of caution however, the regression analysis shows there is a large fraction of the high intensity rainfall variation that is not attributable to the seasonal rainfall.

3.5 High winds

Burgess et al. (2007) have shown that the relationship between days per year with gust speeds above the annual 95th percentile value and days per year with gusts to at least 60 km/h with the Southern Oscillation Index (SOI). This data shows that both frequency indicators show weak relationships with the SOI, tending to be a little higher during negative values of the SOI and lower with positive values of the SOI, which is consistent with expected ENSO relationships.

An extreme intensity indicator, the relationship between the annual 95th percentile maximum gust speed, with the SOI, did not demonstrate show any discernible relationship.

3.6 Tornadoes

A simple test, to find out if there was an association between Taranaki tornadoes and ENSO was conducted by examining the ENSO conditions in individual months with tornado-days, compared to ENSO conditions in all months during the 1951-2006 period. Results from Burgess et al. (2007) show that 69% of all months between 1951 and 2006 had neutral ENSO conditions, 18% El Niño, and 13% La Niña. The proportions of months with tornadoes were all within 10% of these values for El Niño, La Niña and Neutral conditions. Proportions were also within 10% of the expected values for no relationship using the same test based on Tomlinson’s earlier collection of tornado data compiled over the 1961-1975 period. Also; no tornadoes with a Fujita intensity of at least F1 occurred during an El Niño or La Niña episode. These results, and the fact that the tornado data set may not be as complete as desired, show that there is no clear-cut relationship between ENSO and the occurrence of tornadoes in Taranaki.

As for ENSO, a test for association between Taranaki tornadoes and the IPO was conducted by examining the IPO conditions in individual month’s having tornado-days, compared to those in all months during the 1951-2006 period. The results presented in Burgess et al. (2007) show that 30% of all months between 1951 and 2006 had neutral IPO conditions, 39% positive, and 31% negative.

The proportions of months with tornadoes in Taranaki were similar to these for both neutral and positive IPO values. The occurrence of months with tornadoes during negative events was 17% higher than what would be expected if there was no relationship. These results indicate that tornado frequency may be higher during the negative phase of the IPO. During such events, more airflow from the northerly quarter is likely over Taranaki. These results show the possibility (although it may be weak) of a relationship between the IPO and the occurrence of tornadoes in Taranaki.

3.7 Tropical cyclones

3.7.1 ENSO

The majority of tropical cyclones that eventually affect the New Plymouth district develop over the warm tropical waters of the Coral Sea, south of the Solomon Islands in the area surrounding Vanuatu, and then track south-southeast toward New Zealand. A difference in points of origin in relation to ENSO events is evident (Table 7). On average tropical cyclones, which later affect New Plymouth develop nearer the equator during El Niño episodes (closer to the Solomon Islands), and further south during La Niña events (nearer Vanuatu).

Table 7. Mean location of tropical cyclone origin, during El Niño, La Niña, and neutral seasons (seasons ending in 1968-2006), eventually affecting the region near New Plymouth.

Mean location of tropical cyclone origin	El Niño	La Niña	Neutral	All
Latitude, S	12.7	15.3	13.3	13.7
Longitude, E	165.0	164.9	165.0	164.8

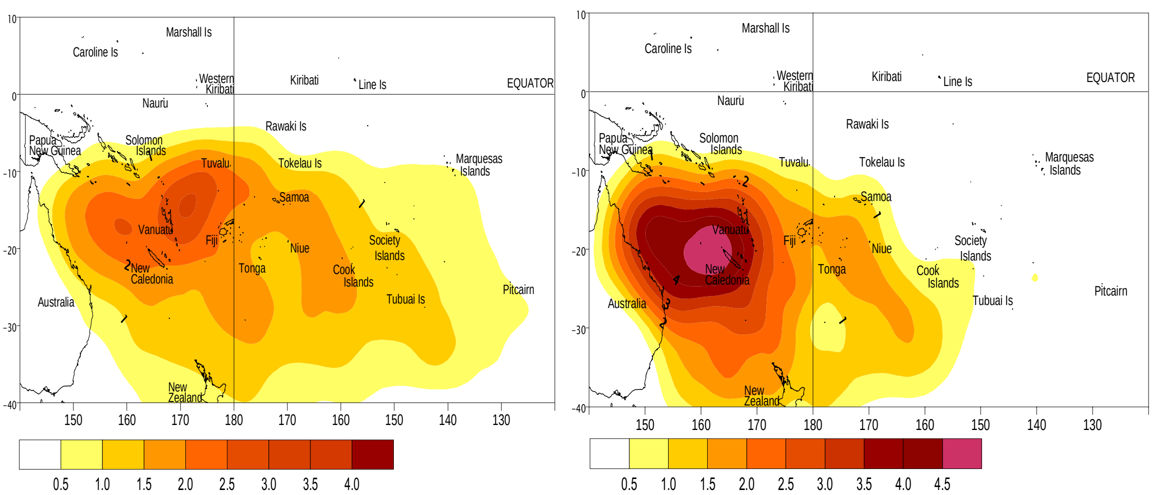

Figure 23. Mean annual tropical cyclone occurrence (Nov-May) periods during El Niño (left) and La Nina (right) episodes, from 1970/71. ©NIWA.

There is also a difference in spatial distribution related to ENSO events (Figure 23). During El Niño episodes, the warmer seas of the tropical western Pacific spread further eastward into the central Pacific, normally accompanied by enhanced convection. The opposite occurs during La Niña episodes with the warmer seas confined to the western tropical Pacific. As a result tropical cyclones are more likely to affect the South Pacific region east of the Date Line and track east of the North Island during El Niño events.

Table 8. Frequency of ex-tropical cyclones passing near or over New Plymouth, during El Niño, La Niña, and neutral seasons.

Seasons ending in 1968-2006	El Niño	La Niña	Neutral	All
Seasons with no occurrences	**55%**	33%	37%	41%
Seasons with more than one occurrence	**9%**	22%	21%	18%
Mean number of ex-tropical cyclones per season	**0.6**	0.9	0.9	0.8

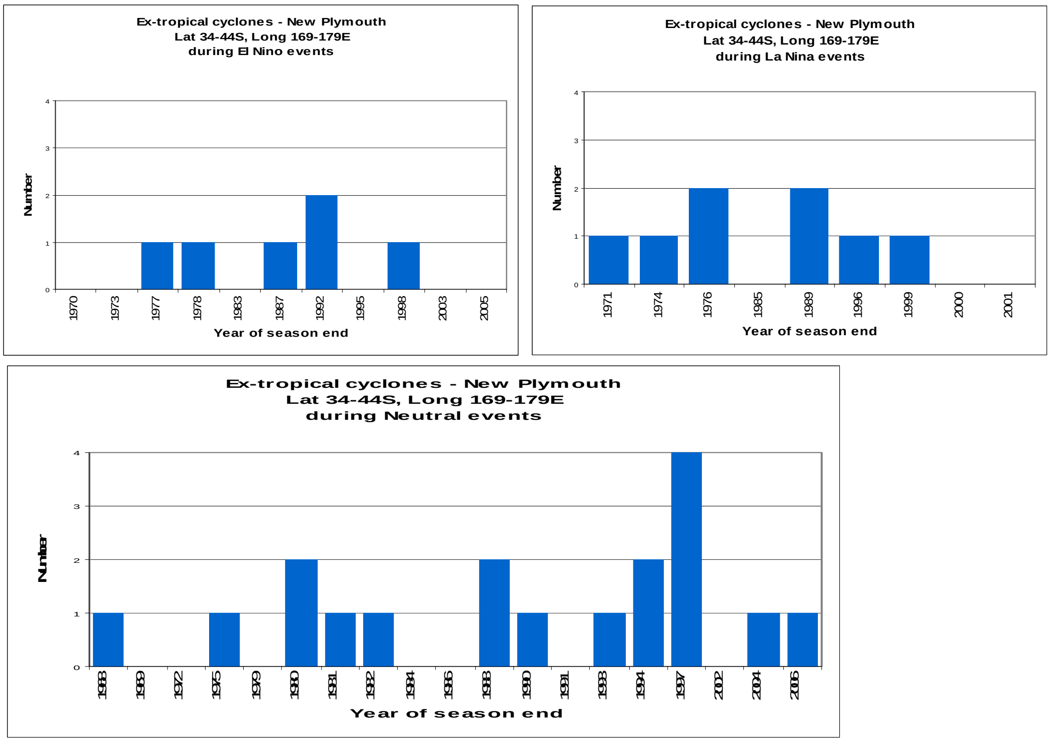

Figure 24. Frequencies of ex-tropical cyclones passing near or over New Plymouth, during El Niño (upper left), La Niña (upper right), and neutral seasons (bottom). ©NIWA.

During neutral and La Niña episodes, tropical cyclones are more likely to affect the region west of the Date Line. In these later phases, they are more likely to enter the Tasman Sea giving is a higher likelihood of affecting the Taranaki region. These assumptions are confirmed by the statistics of occurrence (Table 8). Further examination of the frequency of seasons without any cyclone occurrences over or near Taranaki shows that they are about 20 percent less likely to occur during El Niño events, than during either neutral or La Niña conditions, i.e. El Niño conditions are less favourable for cyclones of tropical origin in the Tasman Sea and western New Zealand region. Neutral and La Niña seasons are more likely to have more or multiple occurrences than El Niño seasons. The season (December 1996-April 1997) with the most occurrences was a neutral year (Figure 30). The decade 1987/88 through 1996/97 was quite active, with 14 cyclones of tropical origin tracking over or near New Plymouth. Of these, 10 occurrences were in neutral ENSO seasons, two were in La Niña's and two in El Niño's.

3.7.2 IPO

An analysis of the influence of the IPO on the frequency of cyclones of tropical origin passing near or over Taranaki (between 1968 and 2005) showed no relationship where the annual IPO index was less than +0.9. However, seasons with more than one occurrence were noticeably more frequent where the annual index of the IPO was +0.9 or higher (Figure 24).

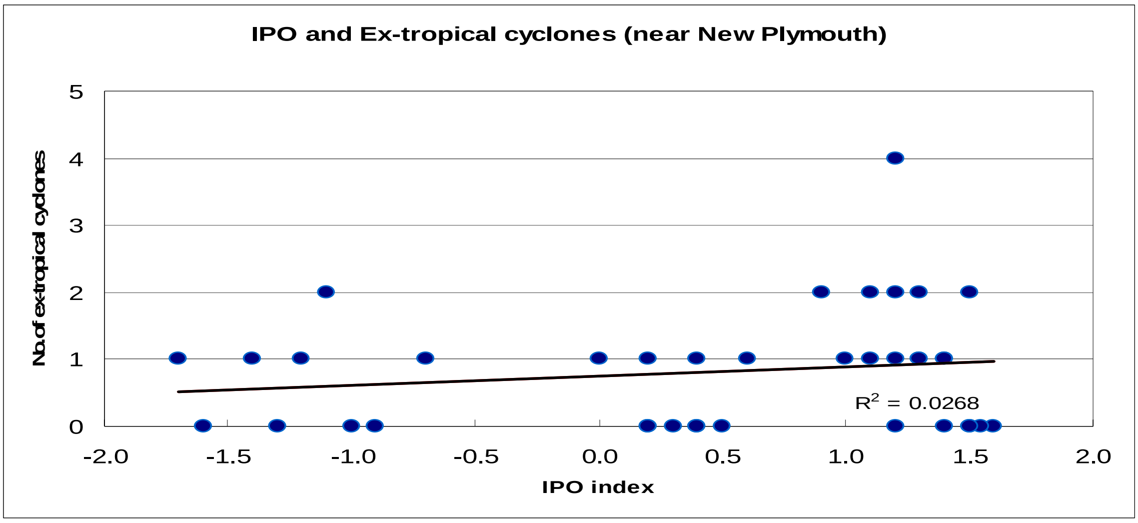

Figure 24. Frequency of ex-tropical cyclones passing near or over New Plymouth. The blue dots represent frequencies for individual seasons. The red line shows the correlation between frequencies and the IPO. ©NIWA

In these very positive IPO periods there were 4 seasons with multiple cyclone occurrences in neutral ENSO seasons, two seasons with a La Niña and one during an El Niño. Very positive IPO combined with neutral ENSO conditions may appear to favour seasons with cyclones of tropical origin affecting the New Plymouth district. However, there are only nine IPO negative years compared with 28 IPO positive years of cyclone data to assess changes with the IPO, which makes the sample period somewhat unbalanced. A longer data period is required to verify any relationships.

3.8 Drought and ENSO

Drought incidence varies from year to year, and is often associated with El Niño-Southern Oscillation (ENSO) variations. ENSO is a natural fluctuation of the tropical Pacific atmosphere and ocean. In the El Niño phase, the easterly tropical trade winds weaken and tropical sea surface temperatures can be several degrees above normal. New Zealand often experiences stronger than normal south westerly airflow, with lower temperatures across the country and drier conditions in the northeast of both Islands. The

La Niña phase results in higher pressures and more settled weather over southern New Zealand, which can also bring drought to the eastern South Island (Mullan et al., 2005).

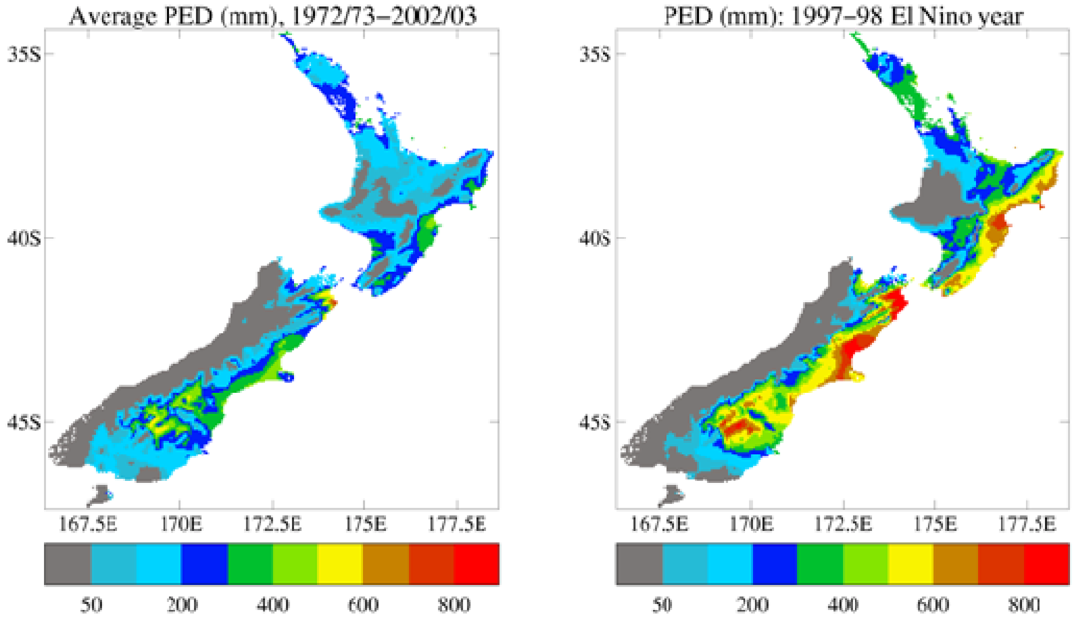

Figure 25. Accumulated July-June PED (mm) calculated from 0.05° gridded data set: average over 31-year period 1972/73 to 2002/03 (left), and PED levels in extreme drought year of 1997/98 El Niño (right). © NIWA.

Figure 25 (right panel) shows that PED exceeded 600 mm in a substantial part of eastern New Zealand in the severe drought year of 1997/98, which coincided with a strong El Niño in the tropical Pacific. Drought can affect different parts of the country in different years. During the same El Niño year only a small impact was detected in the Taranaki region, with a small increase of PED (less than 50 mm).

4. Global Climate Change

4.1 Global perspective

The Intergovernmental Panel on Climate Change (IPCC) issued updated climate change assessments during 2007 (IPCC, 2007a,b), and NIWA has used climate model data from the IPCC Fourth Assessment to update the climate change scenarios for New Zealand. These are described in a guidance manual prepared for the Ministry for the Environment (MfE, 2008a), and supersede the earlier scenarios (MfE, 2004) which were discussed in Thompson et al. (2006). The current report draws on the new scenario information.

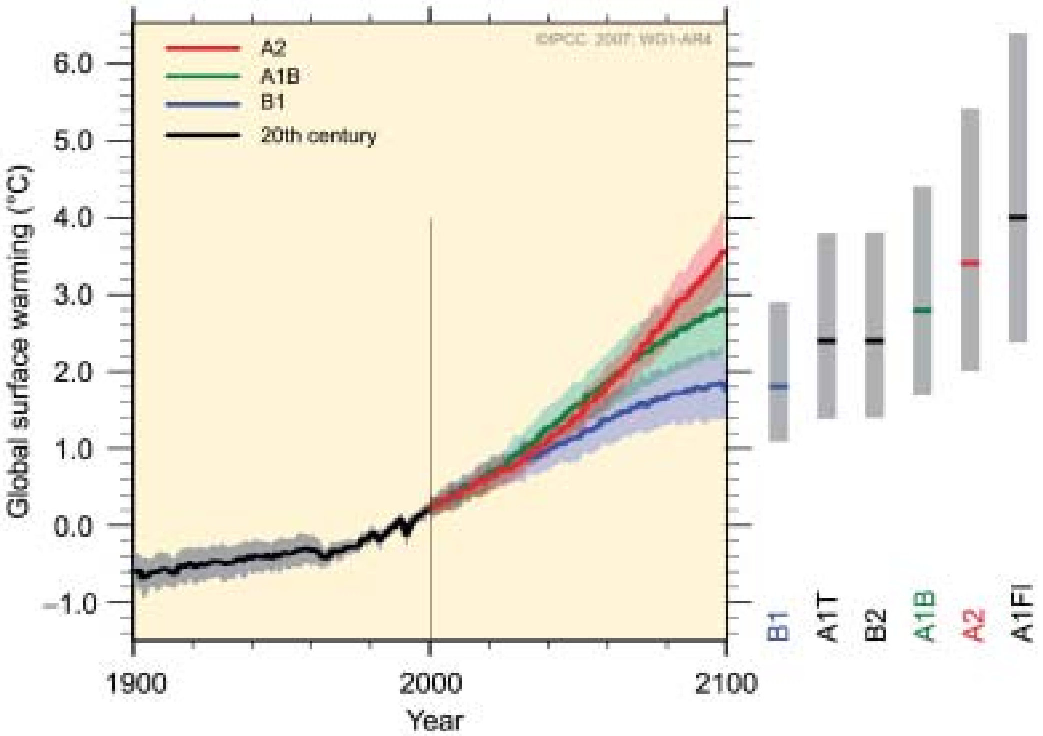

Figure 26. IPCC projections of global temperature increase. Solid coloured lines are multi-model global averages of surface warming (relative to 1980-1999) for emission scenarios B1, A1B and A2, shown as continuations of the 20th century simulations (black line). The coloured shading denotes the ±1 standard deviation range of individual model annual averages. The grey bars at right indicate the best estimate (solid horizontal line within each grey bar) and the 'likely range' across 6 scenarios that span the full range of all IPCC emission scenarios. (Adapted from Figure SPM-5, IPCC 2007).

The IPCC presented projections for 6 emissions scenarios (called "marker" scenarios) to cover a wide range of possible future economic, political and social developments during the 21st century (although it turns out that 2 of the emission scenarios produce virtually the same global warming). Figure 26 shows the IPCC projected range of global temperature increases likely out to 2100. Three of the marker scenarios are shown in the boxed figure below, and temperature increases at 2100 for all 6 to the right-hand side. There is a substantial spread in projected warming. One factor causing the spread in temperature increase is the range of plausible emissions scenarios (temperature consequence represented by separation between the coloured lines or, at 2100, between the coloured marks near the middle of the grey bars). The second factor is the variation in climate response by the models for the same emissions (represented for warming to 2100 by the height of the grey bars).

The global-average temperature increase at 2100, relative to the average over 1980-1999, varies from +1.1°C (least sensitive model combined with the lowest emission scenario B1) to +6.4°C (most sensitive model with the highest emission scenario A1FI). The multi-model average, or IPCC ‘best estimate’, of the global temperature increase for the mid-range A1B scenario is +2.8°C.

4.2 Taranaki Temperature Projections

There is a corresponding large range in projected temperature increases for New Zealand, although with a given climate model there is little spatial variation. In this report, we focus on the mid-range IPCC emissions scenario known as A1B (green curve in Figure M1). NIWA has produced downscaled scenarios for New Zealand from 12 global climate models (reported in MfE (2008a), where maps and tables of New Zealand projections are given, along with background on the downscaling methodology). The climate models are driven by the increasing greenhouse gas emissions of the A1B scenario between years 2000 and 2100, and changes in climate are compared to the model simulation of the 20th century climate to 1999 (where observed greenhouse gas increases are used in place of the scenario emissions).

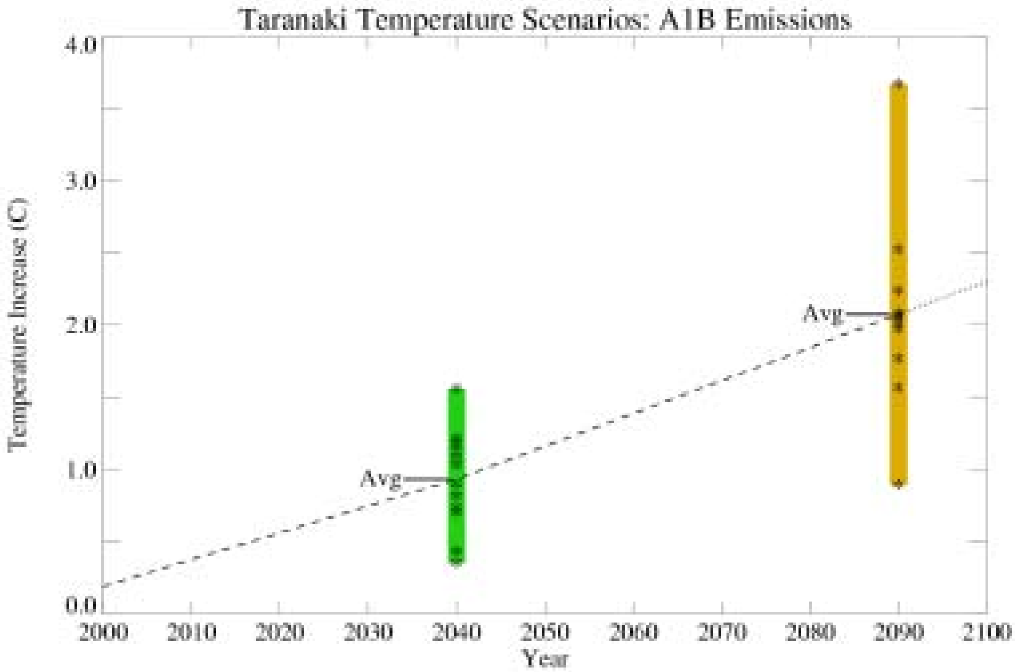

Figure 27. Projections of annual temperature increase downscaled to New Plymouth City. Vertical coloured bars show the range across 12 climate models for the mid-range A1B emissions scenario. Stars mark the individual model warmings. Short horizontal lines show the positions of the model average warming used in this report. The warming trend through time is shown by the dashed line, and by the dotted line for the extrapolation beyond 2090. © NIWA.

Figure 27 shows the projected annual warming at 2040 and 2090, averaged over the Taranaki Regional Council region. These nominal years represent the mid-points of bi-decadal periods: 2040 is the average over 2030-2049, and 2090 the average over 2080-

2099, relative to the baseline climate of 1980-1999 (denoted as 1990 for short). Note that 20-year averages are used to smooth out the large natural inter-annual variability in the observations (and models), that are caused by climatic features such as the El Niño-Southern Oscillation.

Temperature increases for other years (than the standard 2040 and 2090 shown) can be evaluated by interpolation. As with the global temperature projections Figure 27 shows a large difference between model projections for Taranaki as well. The mid-point warming (average over the 12 global models examined by NIWA) works out at: +0.93°C for 50-year change to 2040, and +2.07°C for 100-year change to 2090.

Figure 27 shows the annual warming for the A1B emissions scenario. The climate models also suggest some seasonal variation in temperature increase, with warming in the spring season being slightly less than in other seasons.

Table 9 shows the model-average warming, and model ranges, for the other IPCC marker scenarios. For example, at 2090 the model-average temperature increase is projected to range from 1.4°C for the low B1 emissions to 3.0°C for the high A1FI emissions. Thus, the high emission scenario produces twice the warming this century as the low emission scenario. Apart from any direct effect of temperature extremes (hot days and frosts), a larger temperature increase means a greater increase in extreme rainfalls.

The climate models also suggest some seasonal variation in temperature increase, with warming in the spring season being slightly less than in other seasons (Table 10).

Table 9. Projected changes in annual mean temperature (in °C) for Taranaki for 2040 and 2090, as a function of the emissions scenario. The first number is the model average, with the bracketed numbers giving the lower and upper limits.

Period	B1 Scenario	B2 or A1T Scenario	A1B Scenario	A2 Scenario	A1FI Scenario
2040	0.6 [0.2, 1.0]	0.8 [0.3, 1.4]	0.9 [0.4, 1.6]	1.1 [0.4, 1.9]	1.3 [0.5, 2.3]
2090	1.4 [0.6, 2.4]	1.8 [0.7, 3.2]	2.1 [0.9, 3.7]	2.5 [1.1, 4.5]	3.0 [1.3, 5.3]

Table 10. Projected changes in seasonal and annual mean temperature (in °C) for Taranaki for 2040 and 2090, over all 6 IPCC marker scenarios. The first number is the "best estimate", with the bracketed numbers giving the lower and upper limits.

Period	Summer	Autumn	Winter	Spring	Annual
2040	1.1 [0.2, 2.4]	1.0 [0.2, 2.6]	0.9 [0.1, 2.2]	0.8 [0.0, 2.0]	0.9 [0.2, 2.3]
2090	2.3 [0.9, 6.1]	2.2 [0.6, 5.3]	2.1 [0.5, 5.1]	1.8 [0.3, 4.9]	2.1 [0.6, 5.3]

Note: The ranges given in this table encompass all 6 IPCC marker scenarios combined, not just A1B.

4.3 Taranaki precipitation scenarios

Precipitation projections show much more spatial variation than the temperature projections, and can also be quite different for different climate models. Figure 28 and Figure 29 show the seasonal patterns of the 12-model average precipitation change over the central North Island at 2040 and 2090 for the A1B emission scenario. The general pattern is for decreases in precipitation in the Taranaki region in summer, and increases in winter, with the other seasons showing intermediate trends.

Seasonal changes in precipitation at the New Plymouth City are shown in Table 11. The first number given in each cell of the table is the A1B 12-model average, corresponding to the maps above. The numbers in square brackets show the full range possible across the 12 models, including allowing for lower and higher IPCC emissions scenarios than A1B.

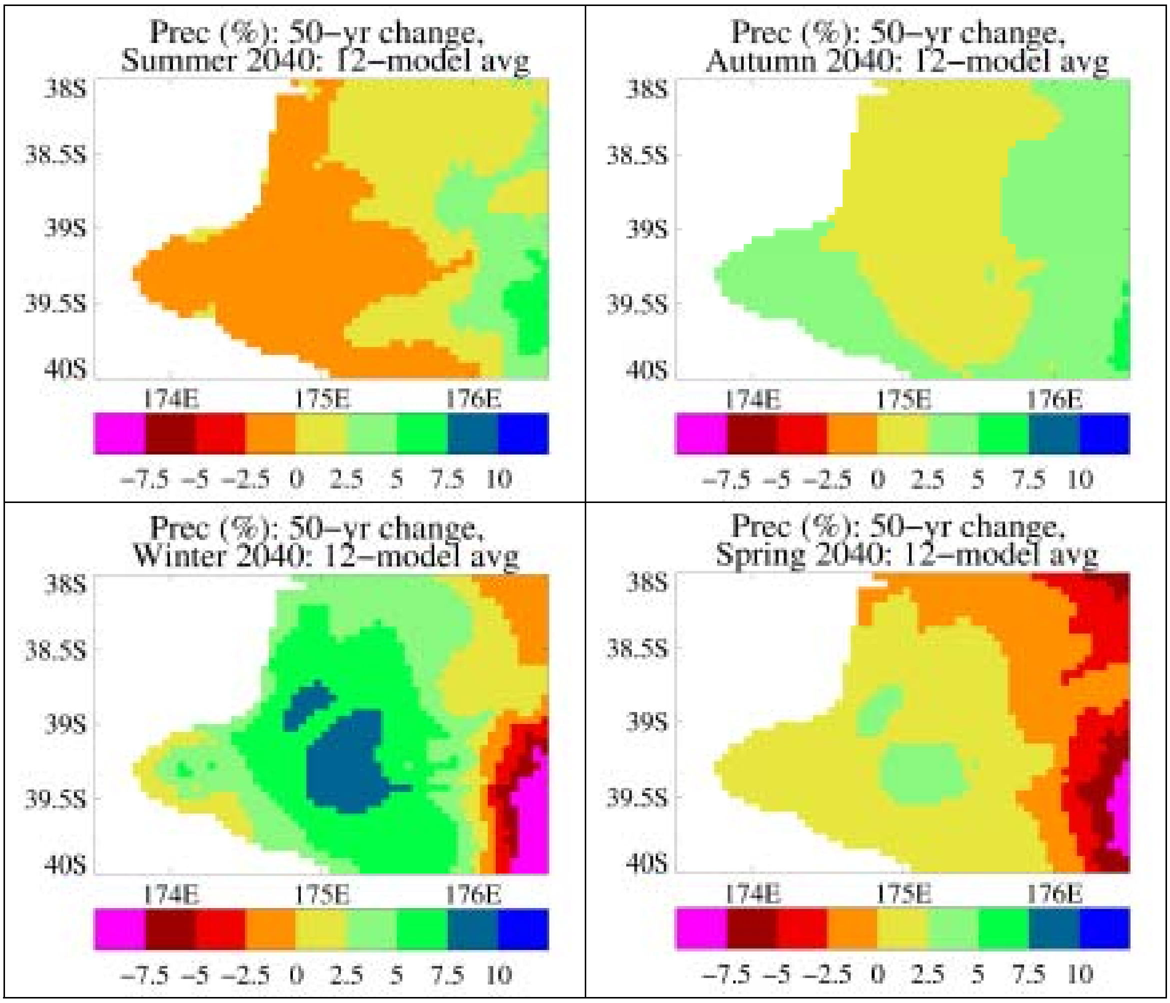

Figure 28. Projected seasonal precipitation changes (in %) at 2040 (2030-2049 average), relative to 1990 (1980-1999), for the IPCC A1B emission scenario, averaged over 12 climate models. ©NIWA

Table 11. Projected changes in seasonal and annual mean rainfall (in %) for New Plymouth City for 2040 and 2090. The first number is the "best estimate", with the bracketed numbers giving the lower and upper limits.

Period	Summer	Autumn	Winter	Spring	Annual
2040	0 [-20, 18]	3 [-8, 13]	2 [-2, 9]	0 [-8, 16]	2 [-3, 9]
2090	-2 [-38, 15]	1 [-18, 15]	6 [-6, 20]	-1 [-17, 21]	1 [-10, 11]

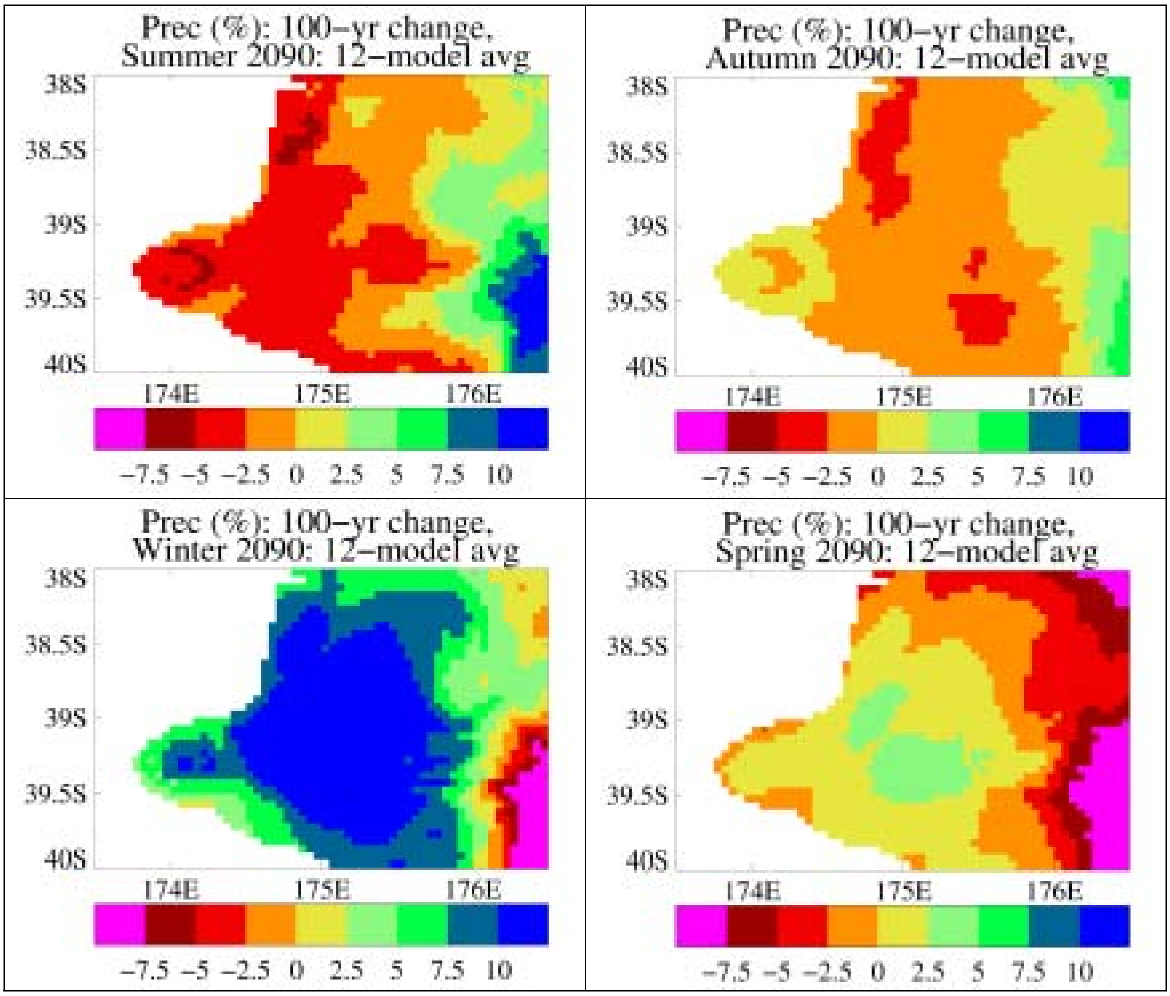

Figure 29. Projected seasonal precipitation changes (in %) at 2090 (2080-2099 average), relative to 1990 (1980-1999), for the IPCC A1B emission scenario, averaged over 12 climate models. The star in the lower right panel (Spring) marks the location of the New Plymouth grid-point. ©NIWA

The 12-model average picture can be a slightly misleading as there is a lot of disagreement between the climate models on the rainfall changes. Figure 30 shows the 2090 seasonal rainfall projections for all the models individually under an A1B emission scenario. Note that there is one very much drier model than the other 11 in summer. All but one of the 12 models indicates rainfall increases in the winter season. Hence, an increase in winter rainfall for the Taranaki region is considered very likely. The trend in rainfall for other seasons is not clear from the models surveyed.

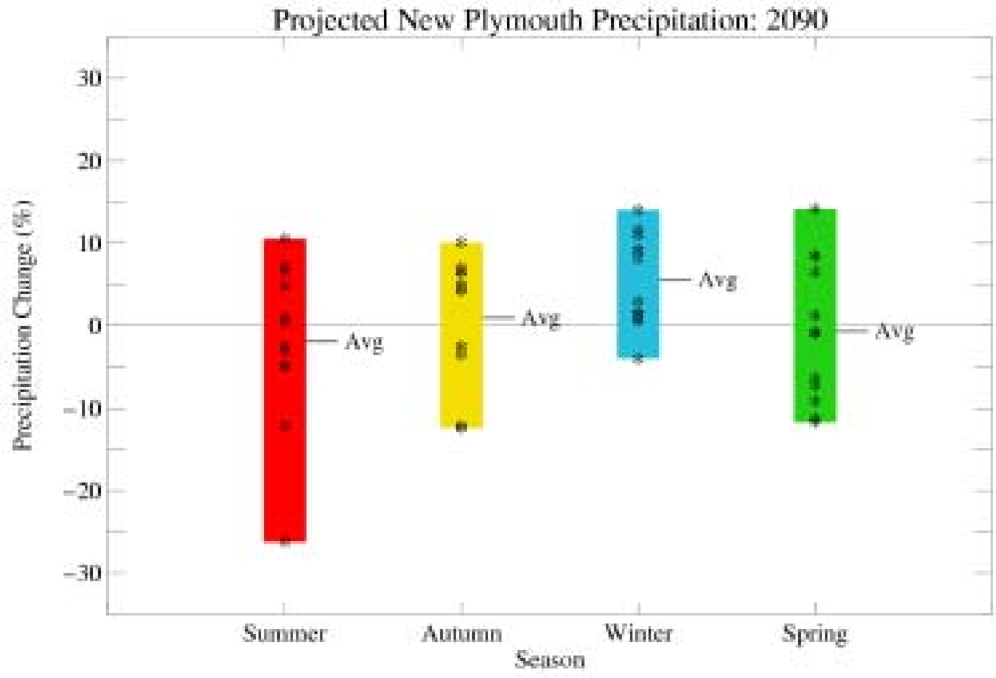

Figure 30. Projected seasonal precipitation changes by 2090 for New Plymouth City grid-point. The vertical coloured bars show the range over all 12 climate models used, and stars the changes for each model individually. The average over the 12 models is also marked on figure. ©NIWA

4.4 Changes in Rainfall Extremes

Extreme rainfall events are expected to become more frequent as the climate warms. For the current climate, extreme rainfall amounts can be calculated for a range of return periods and durations, to produce depth-duration-frequency (DDI) tables. A previous report for New Plymouth District Council (Thompson et al., 2006) discussed current DDI rainfalls and how these might alter under climate change. Thompson et al. (2006) is updated using the new annual temperature increases (Table 12), and an updated rainfall factor Table (MfE, 2008a).

The Ministry for the Environment in its 2004 publication *"Preparing for climate change: A guide for local government in New Zealand"* and the recently updated 2008 publication *"Climate change effects and impacts assessment: A guidance manual for local government in New Zealand, 2nd Edition"* provides a method showing how high intensity rainfalls can be adjusted for preliminary scenario studies. It advocates that at least two sets of calculations be undertaken for low and high temperature change scenarios. For screening assessment purposes, Table 13 provides the recommended percentage adjustments per degree Celsius of warming to apply to high intensity rainfalls for various durations and average recurrence intervals. The percentage changes in this table for durations of 24 – 72 hours are based on results from a regional climate model (MfE, 2008a). Entries for 10 minute duration are based on the theoretical increase in the amount of water held in the atmosphere for a 1°C increase in temperature. Entries between 10 minutes and 24 hours are derived from a logarithmic interpolation (in time) between the 10 minute and 24 hour periods.

Table 12 Scenarios of annual temperature increase (in °C) for New Plymouth, for three time periods centred on 2040 and 2090, and for three scenarios (coldest model under lowest B1 emissions, 12-model average under A1B emissions, hottest model under highest A1FI emissions.

Scenario/Period	2040	2090
B1 coldest model	0.22	0.58
A1B 12-model average	0.96	2.15
A1FI hottest model	2.43	5.72

Table 13. Factors (percentages/degree Celsius of warming) for use in deriving high intensity rainfall information in preliminary scenario studies. (Adapted from MfE, 2008)

ARI	AEP	5m	10m	20m	30m	60m	2h	6h	12h	24h	48h	72h
1.58	0.63	8.0	8.0	7.7	7.2	6.7	6.2	5.3	4.8	4.3	3.8	3.5
2	0.50	8.0	8.0	7.7	7.2	6.7	6.2	5.3	4.8	4.3	3.8	3.5
5	0.20	8.0	8.0	7.7	7.4	7.1	6.7	6.1	5.8	5.4	5.0	4.8
10	0.10	8.0	8.0	7.8	7.6	7.4	7.2	6.8	6.5	6.3	6.1	5.9
20	0.05	8.0	8.0	8.0	7.8	7.7	7.6	7.4	7.3	7.2	7.1	7.0
50	0.02	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
100	0.01	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0

The regional frequency analyses in this study were produced using the NIWA software package known as HIRDS (High Intensity Rainfall Design System). HIRDS is a procedure for estimating extreme rainfall frequency across New Zealand, and uses the annual maxima method (Thompson, 2002). For a given scenario, the change in high

Table 14. List of stations analyzed using the HIRDS version2

Station Name	Latitude	Longitude
Cape Egmont	39° 17' S	173° 45' E
Hawera AWS	39° 37' S	174° 18' E
Eltham	39° 26' S	174° 17' E
Inglewood	39° 09' S	174° 12' E
Mohakatino	39° 45' S	174° 38' E
New Plymouth Aero	39° 01' S	174° 11' E
New Plymouth	39° 04' S	174° 05' E
North Egmont	39° 16' S	174° 06' E
Omoana	39° 26' S	174° 34' E

Opunake	39° 27' S	173° 51' E
Patea	39° 45' S	174° 28' E
Purangi	39° 09' S	174° 00' E
Stratford EWS	39° 20' S	174° 18' E

intensity rainfall is computed by multiplicative factors (as indicated in

Table 15).

Table 15 gives these for the mid-range scenario for 2090 for the New Plymouth Airport, by way of an illustration. The same analysis has been done for the stations listed in Table 14. High intensity rainfall estimates for other locations in Taranaki region (shown in Figure 31) have been computed for each of the projected temperature scenarios, and can be found in Appendix.

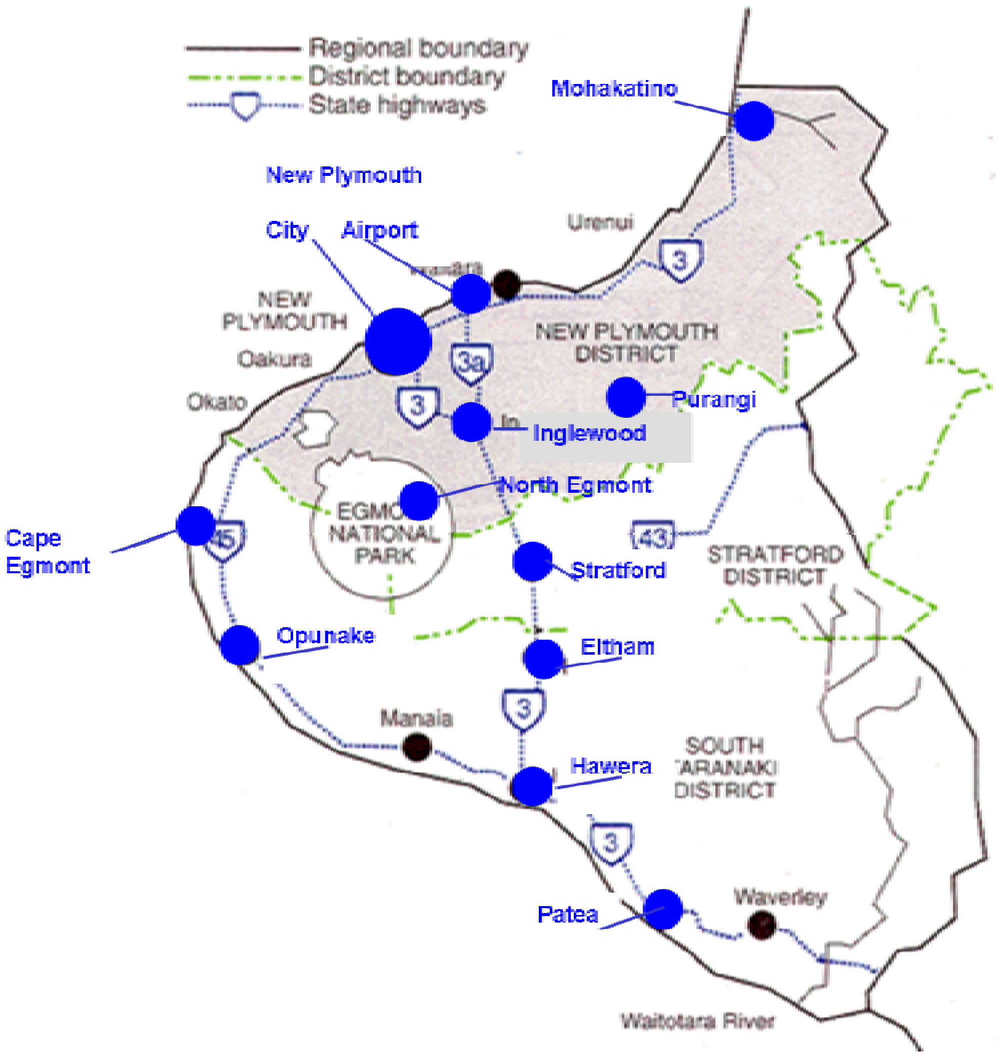

Figure 31. Location of Taranaki daily rainfall sites (in blue). (Map courtesy of the New Plymouth District Council)

Table 15. Mid-Range Temperature Scenario for 2090s: Multiplicative factors to be applied to the high intensity rainfall tables to estimate the high intensity rainfalls at Auckland City sites. As an example, to estimate a 20-year 12-hour high intensity rainfall the current rainfall is multiplied by a factor of 1.157

ARI(y)	AEP	10m	30m	60m	2h	6h	12h	24h	48h	72h
1.58	0.63	1.172	1.155	1.144	1.133	1.114	1.103	1.092	1.082	1.075
2	0.50	1.172	1.155	1.144	1.133	1.114	1.103	1.092	1.082	1.075
5	0.20	1.172	1.159	1.153	1.144	1.131	1.125	1.116	1.108	1.103
10	0.10	1.172	1.163	1.159	1.155	1.146	1.140	1.135	1.131	1.127
20	0.05	1.172	1.168	1.166	1.163	1.159	1.157	1.155	1.153	1.151
50	0.02	1.172	1.172	1.172	1.172	1.172	1.172	1.172	1.172	1.172
100	0.01	1.172	1.172	1.172	1.172	1.172	1.172	1.172	1.172	1.172

To follow is an example on computing the projected high intensity rainfalls displayed for a 20-year 12-hour rainfall New Plymouth Airport for the 2090s. From Table 16 the

Table 16. Depth – Duration – Frequency tables for New Plymouth Airport derived from HIRDS (High Intensity Rainfall System) version 2 for the current climate and for three greenhouse gas emissions scenarios for the 2040s and 2090s. Numbers in the table refer to rainfall depth in mm.

HIRDSV2 - High Intensity Rainfall Design System

New Plymouth Aero: Latitude 39°1' S, Longitude 1 74°11' E

Duration

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	9.7	18.3	27.4	34.8	50.8	64.4	81.8	97.5	108.1
10	13.8	25	36.5	46.8	69.4	89.1	114.3	134.9	148.7
20	16.2	28.9	41.6	53.6	80.2	103.4	133.3	156.7	172.2
30	18	31.6	45.1	58.4	87.7	113.4	146.7	171.9	188.7
50	20.6	35.6	50.3	65.4	98.9	128.5	166.8	194.7	213.2
100	25.1	42.5	59.2	77.3	118.1	154.2	201.5	233.9	255.3

2040 LOW

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.17	19.09	28.50	36.09	52.42	66.25	83.91	99.72	110.37
10	14.46	26.14	38.12	48.82	72.23	92.57	118.62	139.84	153.96
20	16.98	30.25	43.52	56.04	83.76	107.93	139.06	163.38	179.43
30	18.86	33.12	47.26	61.20	91.91	118.84	153.74	179.94	197.42
50	21.59	37.31	52.71	68.54	103.65	134.67	174.81	204.05	223.43
100	26.30	44.54	62.04	81.01	123.77	161.60	211.17	245.13	267.55

2040 MID

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.40	19.49	29.05	36.74	53.22	67.18	84.97	100.83	111.51
10	14.79	26.71	38.93	49.83	73.65	94.31	120.78	142.31	156.60
20	17.37	30.93	44.48	57.27	85.54	110.19	141.94	166.71	183.05
30	19.30	33.88	48.35	62.60	94.01	121.56	157.26	183.97	201.78

50	22.08	38.16	53.92	70.11	106.02	137.75	178.81	208.72	228.55
100	26.91	45.56	63.46	82.87	126.60	165.30	216.01	250.74	273.68

2040	**HIGH**								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.71	20.01	29.79	37.60	54.30	68.42	86.37	102.32	113.02
10	15.24	27.47	40.01	51.18	75.53	96.63	123.66	145.60	160.11
20	17.88	31.83	45.76	58.90	87.92	113.21	145.78	171.16	187.87
30	19.87	34.89	49.79	64.47	96.82	125.19	161.96	189.33	207.59
50	22.74	39.30	55.53	72.20	109.19	141.86	184.15	214.95	235.37
100	27.71	46.92	65.36	85.34	130.38	170.24	222.46	258.23	281.85

historical 12-hour 20-year rainfall is 103 mm, and the projected adjustment for global warming is a 7.3 percent per degree Celsius warming. For the mid-range temperature scenario for the 2090s, the value in Table 12 is 2.15 ºC. This leads to an increase in high intensity rainfall of 15.7 percent (i.e. 2.15 ºC times 7.3 percent). This corresponds to a value of 1.157 (see

Table 15), and gives an estimated rainfall depth of 114 mm for the scenario for the 2090s (Table 16).

2090	**LOW**								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.79	20.14	29.97	37.82	54.57	68.73	86.72	102.69	113.40
10	15.35	27.66	40.28	51.52	76.01	97.21	124.38	146.42	160.98
20	18.01	32.06	46.08	59.30	88.51	113.97	146.74	172.28	189.08
30	20.02	35.14	50.15	64.94	97.52	126.10	163.13	190.67	209.04
50	22.91	39.59	55.93	72.72	109.98	142.89	185.48	216.51	237.08
100	27.91	47.26	65.83	85.96	131.33	171.47	224.07	260.10	283.89

2090	**MID**								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	11.33	21.07	31.26	39.33	56.45	70.89	89.19	105.28	116.05
10	16.12	28.99	42.17	53.88	79.31	101.26	129.42	152.18	167.12
20	18.92	33.63	48.33	62.15	92.66	119.25	153.45	180.06	197.51
30	21.02	36.91	52.68	68.21	102.43	132.45	171.35	200.06	219.21
50	24.06	41.58	58.75	76.39	115.52	150.09	194.82	227.41	249.02
100	29.32	49.64	69.15	90.29	137.94	180.11	235.35	273.20	298.19

2090	**HIGH**								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	12.03	22.25	32.91	41.27	58.88	73.67	92.35	108.62	119.45
10	17.11	30.70	44.60	56.91	83.56	106.47	135.90	159.59	175.02
20	20.09	35.66	51.21	65.82	98.00	126.04	162.09	190.08	208.36
30	22.32	39.18	55.92	72.42	108.75	140.62	181.91	212.12	232.29
50	25.54	44.14	62.37	81.10	122.64	159.34	206.83	241.43	264.37
100	31.12	52.70	73.41	95.85	146.44	191.21	249.86	290.04	316.57

4.4.1 Implications of changes in rainfall extremes

The changes in extreme rainfalls for the 2040s and 2090s, when compared to the current climate, appear to be relatively modest, but in all cases there is an increase with time and temperature. One way to interpret the tables is to ask how extreme rainfall events might change in the future. For a mid-range temperature scenario given above, a 12-hour 20-year event at New Plymouth Airport of 103 mm is expected to have a recurrence interval of just above 10 years by the 2090s for low and medium scenarios and under 10 years for high scenario. In other words what is an extreme rainfall in the current climate is projected to occur more frequently by the end of the 21st century. Another way of looking at this table is: what is currently a 12-hour 20-year event is expected to become a 6-hour storm with an expectation of once every 50 years, or a 48-hour storm event with a recurrence interval of about once every two years.

The climate change rainfall adjustment factors in Table 16 are best-estimates from the current state of science. However, these factors are still quite uncertain, and research is continuing on quantifying the likely effects of climate change on extreme rainfalls in New Zealand.

This information on high intensity rainfall has important implications for the planning of major infrastructure and developments that will need to cope with climatic conditions later in the 21st century. Storm water drainage systems, development of low-lying land already subject to flood risk, roads and bridges are examples of infrastructure where the increase in both intensity and frequency of high intensity rainfall, for example the reduction of a 24-hour 100-year storm event down to a 50-year storm event, will have significant potential impacts. Thus serious consideration of these likely impacts by councils and communities is recommended. The IPCC (2007b) has noted that adaptation will be necessary to address impacts resulting from the warming which is already unavoidable due to past emissions, and that a portfolio of adaptation and mitigation is required to reduce the risks of climate change. Because the future course of climate warming is uncertain, and greenhouse gas concentrations in the atmosphere are likely to increase for several decades yet, disaster management and risk prevention strategies should adopt a precautionary framework. It is recommended that the mid-range and high climate change scenarios are used in council guidelines with serious consideration by council and communities of their likely impacts.

4.5 Changes in Winds

The IPCC Fourth Assessment climate models project increases in westerly winds over the Southern Oceans, and a poleward shift in the sub-tropical belt of high pressures that sits to the north of New Zealand. These broad-scale regional circulation changes result in increasing westerly winds over New Zealand in the winter and spring seasons, but less westerly in the summer.

Figure 32 shows the annual cycle in what is known as the Z1 Index, which measures the pressure difference between Auckland and Christchurch and is directly related to the strength of the westerly winds in between. The 12 climate models analysed for New Zealand have a tendency to simulate westerlies over the country slightly stronger than observed, although they faithfully capture the double maxima (in autumn and spring) of the observed annual cycle. The future projections for 2090 indicate strengthening westerlies in winter (July-September) and weaker westerlies in late summer (February-March). Note that these results apply to long-term average pressure gradients, and the winter increase could arise in several ways. For example, fewer days of easterly but no increase in maximum westerly is one possibility. Essentially, an increase in the frequency of westerly weather patterns affecting Taranaki is likely in the winter, along with the projected rainfall increases in that season (Figure 30).

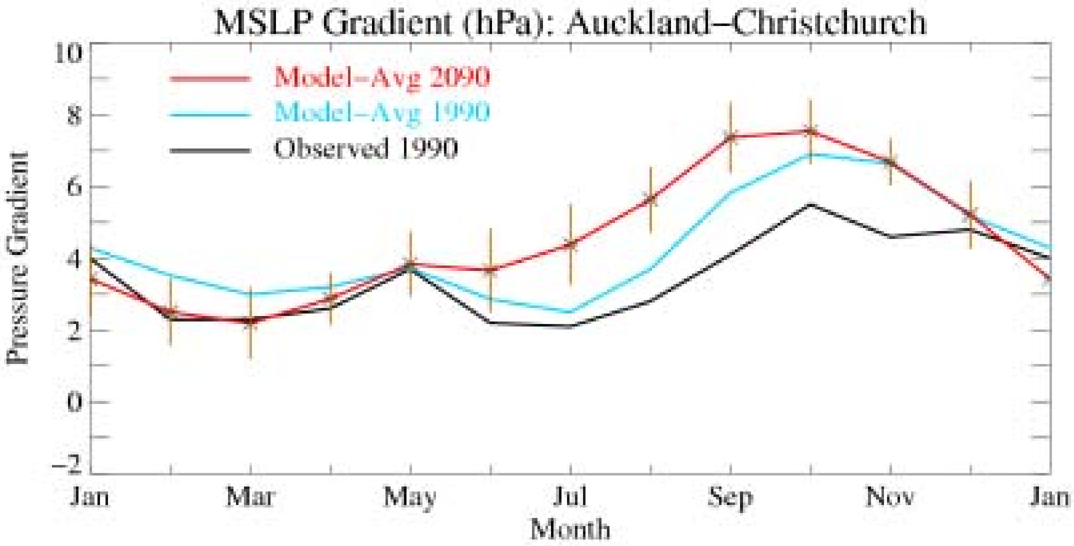

Figure 32. Long-term monthly values of the Auckland-Christchurch pressure difference (in hPa): station observations 1971-2000 (black), average over 12 global climate models 1970-1999 (blue) and 2070-=2099 (red). Stars mark the average monthly Z1 values for 2070-2099, and the short vertical orange line the ±1 standard deviation on the model changes from 1970-1999. ©NIWA

There is no simple relationship between strong winds and the average pressure gradient. NIWA has run a Regional Climate Model (RCM) over New Zealand for two of the IPCC emission scenarios (B2, A2), and from these runs we can examine winds at high temporal resolution (MfE, 2008a). Figure 33 is an example from one simulation showing changes in the top 1% of daily wind speeds. This is only a single model run, and in this case the strongest daily wind speeds show very little change around Taranaki.

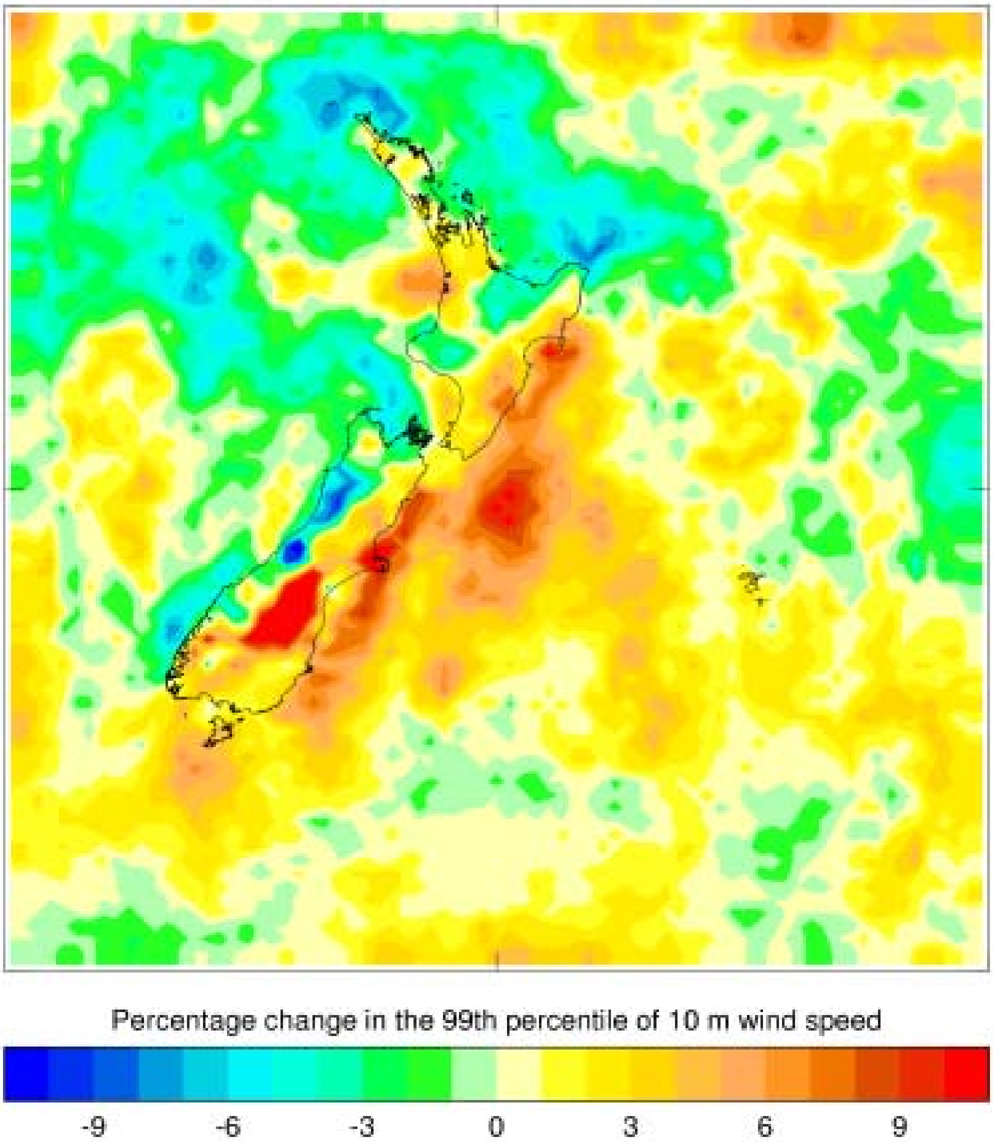

Figure 33. Change (%) in the 99th percentile daily-average surface wind speed in the winter season between a control run (1980-1999) and a future simulation (2080-2099) under the A2 emission scenario. [Reproduction of Figure 2.11 in MfE, 2008a].

Global climate models suggest that for mid-range temperature change projections, the mean westerly wind component across New Zealand will increase by approximately 10 percent of its current value in the next 50 years (Mullan et al, 2001; Table 17).

Table 17 provides projected changes in the seasonal and annual average westerly and southerly components of the flow across New Zealand downscaled from the full range of IPCC SRES scenarios. The future scenarios lean strongly towards increasing westerly flow, particularly in winter and spring. The mid-range projection for 2090 is approximately a 60% increase in the winter mean westerly component of the flow, and a

10% increase in the annual mean. Projected changes in the north-south wind component are less clear, although there is a suggestion of increased northerly in the summer season.

Table 17. Projected changes in seasonal and annual westerly and southerly wind components (in m/sec) (MfE, 2008a).

	Summer	Autumn	Winter	Spring	Annual
Westerly Wind Speed Component					
1970-1999 climate	2.9	2.2	2.1	4.2	2.9
Change by 2040: Mean	-0.3	-0.1	+0.9	+0.5	+0.3
Range	[-1.6, +1.3]	[-2.1, +1.3]	[+0.2, +2.4]	[-0.6, +1.4]	[-0.5, +1.2]
Change by 2090: Mean	-0.6	-0.4	+1.4	+0.8	+0.3
Range	[-2.5, +1.4]	[-2.3, +1.0]	[+0.0, +3.6]	[-0.7, +2.0]	[-0.6, +1.5]
Southerly Wind Speed Component					
1970-1999 climate	-0.3	0.6	0.9	0.2	0.4
Change by 2040: Mean	-0.3	-0.1	+0.0	+0.1	-0.0
Range	[-0.8, +0.5]	[-0.6, +0.3]	[-0.7, +0.5]	[-0.4, +0.6]	[-0.5, +0.4]
Change by 2090: Mean	-0.3	-0.3	-0.2	+0.0	-0.2
Range	[-1.2, +0.6]	[-0.6, +0.2]	[-1.3, +0.5]	[-0.6, +0.6]	[-0.9, -0.0]

Thus, the latest scenarios suggest an increase over the century in the westerly weather patterns affecting Taranaki, but no indication at this point of any significant changes in extreme winds.

4.6 Tropical cyclones

Future changes in tropical cyclone behaviour remain uncertain. However, there are indications that tropical cyclones may intensify on average in a warmer climate while their overall number may decrease globally. Locally, a larger number of intense ex-tropical cyclones could impact on the Auckland region in terms of torrential rain, strong winds and storm surges.

4.7 Drought

4.7.1 Climate change scenarios

Mullan et al. (2005) considered four scenarios in their analysis of how New Zealand drought occurrence might change under global warming. These scenarios combine two different projections for future global-average temperatures with two different regional patterns of change as projected by two global climate models. The projections of future global temperatures used in the study were approximately 25 percent and 75 percent of the way between the lowest and the highest temperature projections developed by the Intergovernmental Panel on Climate Change for their 2001 Climate Change Assessment, and in their report, they refer to the lower projection as "25% scaling" and the higher projection as "75% scaling". The global models predict broad climate patterns across the Pacific, which were "downscaled" to produce more locally-detailed New Zealand projections, using a statistical technique that accounts for the effect on climate of New Zealand's topography. The two global climate models chosen by Mullan et al. (2005) are widely used. One was developed by the CSIRO, Australia, and other by the UK MetOffice Hadley Centre. When downscaled, the Hadley model predicts a larger change in the ratio of western to eastern rainfall in New Zealand (compared to present conditions) than the CSIRO model. The four scenarios used in their report represent a range from a "low-medium" scenario (25% IPCC scaling, CSIRO model) to a "medium-high" scenario (75 percent IPCC scaling, Hadley model), and they applied the four scenarios to two time periods: the "2030s" (2020-2049) and the "2080s" (2070-2099), summarized in Table 18.

Table 18. Four scenarios of future climate change examined in this study.

Model	Global temperature projection	
	25% IPCC	75% IPCC
CSIRO	2030s, 2080s 'low-medium'	2030s, 2080s
Hadley	2030s, 2080s	2030s, 2080s 'medium-high'

4.7.2 Change in Average Potential Evapotranspiration Deficit

The key result of Mullan et al. (2005) is that average annual PED increases across virtually the entire country, except on the South Island west coast, under all scenarios. As expected, the drying tendency increases with time, so is greater in the 2080s than the 2030s, and is larger under the scenarios which assume higher global temperatures (i.e., for 75 percent scaling than for 25 percent scaling). The drying tendency is also more extreme for the Hadley model than for the CSIRO projections, as expected from the much greater rainfall reductions in the east in the Hadley model (Figure 34). There are, of course, seasonal and regional differences, and quite large intensity differences, between the simulated drought occurrences of the CSIRO and Hadley models.

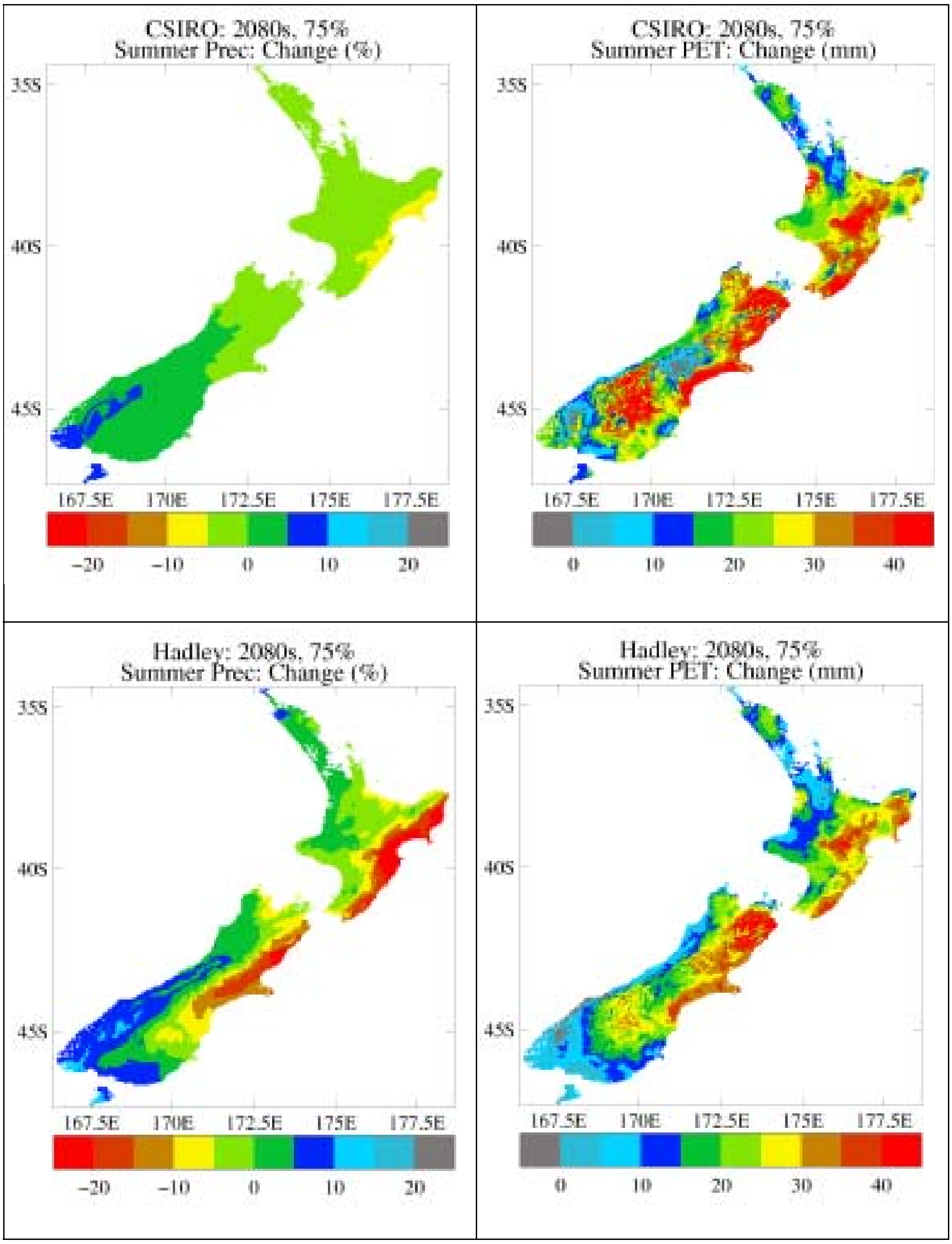

Figure 34. Climate change scenarios for the 2080s, with 75% IPCC scaling, for summer precipitation (%) and summer total potential evapotranspiration (mm), from downscaling the CSIRO and Hadley model output. © NIWA.

However, the integrated effect of both precipitation and PET changes on drought occurrence is relatively uniform, which gives confidence in the findings. In the Taranaki region both models show for 2080s a decrease in the summer precipitation (%), with some differences between the two models and with little change in central-northern Taranaki and higher values of PET as for the Hadley model results.

Figure 35 shows the most extreme result for the two models (ie, 2080s, 75 percent scaling). The Hadley model suggests the drying effect is stronger in the North Island, which is consistent with the model's larger reduction in precipitation at lower latitudes (Figure 34). In the Taranaki region the changes predicted by both models are for a slight increase in the annual accumulated PED (in mm), with a higher increase in the southern coast of the region.

Moreover, at national scale, along with the increase in average PED, there is a corresponding increase in the risk of drought (or extreme PED) in most eastern parts of the country (Mullan et al., 2005). Results from the Hadley model show more extreme changes in time (the Hadley change at the 2030s is comparable to the CSIRO change by the 2080s) and a more extreme North Island change than South Island one.

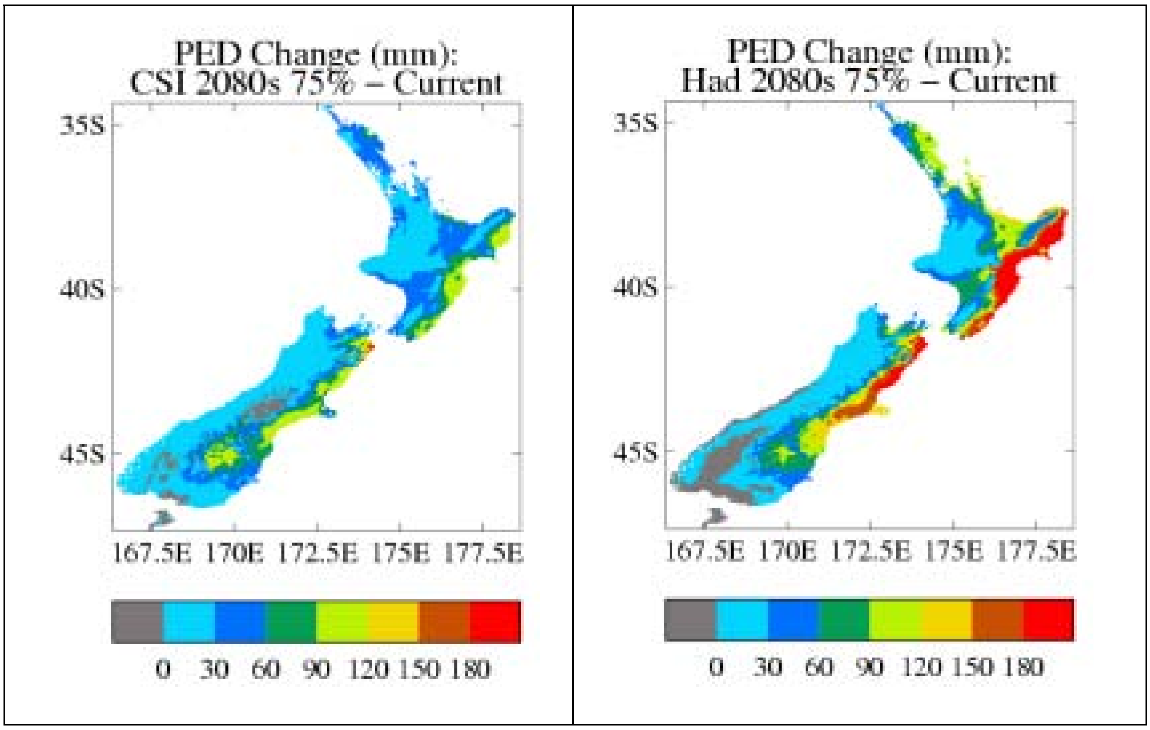

Figure 35. Average change in annual accumulated *PED* (in mm) between the current climatology and projected climatology for the 2080s according to the CSIRO (left) and Hadley (right) models, scaled to the IPCC 75% global warming. The contour intervals, every 30mm, correspond approximately to one week of pasture evapotranspiration deficit in summer. © NIWA.

4.7.3 Change in Return Period

An alternative way of describing the changes in drought risk is to calculate what the future return period is for a PED value that currently occurs with a 1-in-20 year return period. That is, if we consider this level (1 in 20 years) to be a significant anomaly over the growing season (and it will certainly be a severe drought in the east), how much more common will it become?

The results are shown in Figure 36 for the four scenarios of the 2080s, where the current 1-in-20 year drought becomes more common everywhere that is not shaded grey. At the boundary between dark blue and yellow, the future return period is 10 years; here, a current 1-in-20 year dry event becomes twice as likely in the future scenario. At the yellow-brown boundary, the event becomes four times as likely (every 5 years on average, instead of every 20).

In Taranaki region the two models show slight differences in the occurrence of severe drought for both the scenarios, by 2080. Under the ‘low-medium’ scenario (25% scaling) both the models show no big change in the frequency of severe episodes, though the Hadley model shows a little increase along a portion of the southern coast. Under the ‘medium-high’ scenario (75% scaling, Hadley model) severe droughts are projected to at least double by the 2080s under this scenario in the central and southern part of Taranaki. For this same scenario, CSIRO model show a similar increase in frequency, but for a smaller part of the region.

It also needs to be recognised that natural variations in climate on the decadal time-scale can also affect drought incidence. The importance of natural variations, relative to those caused by anthropogenic change, decreases the further ahead in time one goes.

Under future warming an increased accumulation throughout the year is likely, and it can be inferred that drought periods will tend to ‘expand’ into the spring and autumn months more often than in current climate. In their report Mullan et al. (2005) have shown that the average drying tendency (PED increment) during the spring and early summer will tend to occur about one month earlier by the 2080s under the worst scenario (ie, the current ‘dryness’ at the end of November would in future occur at the end of October under this scenario).

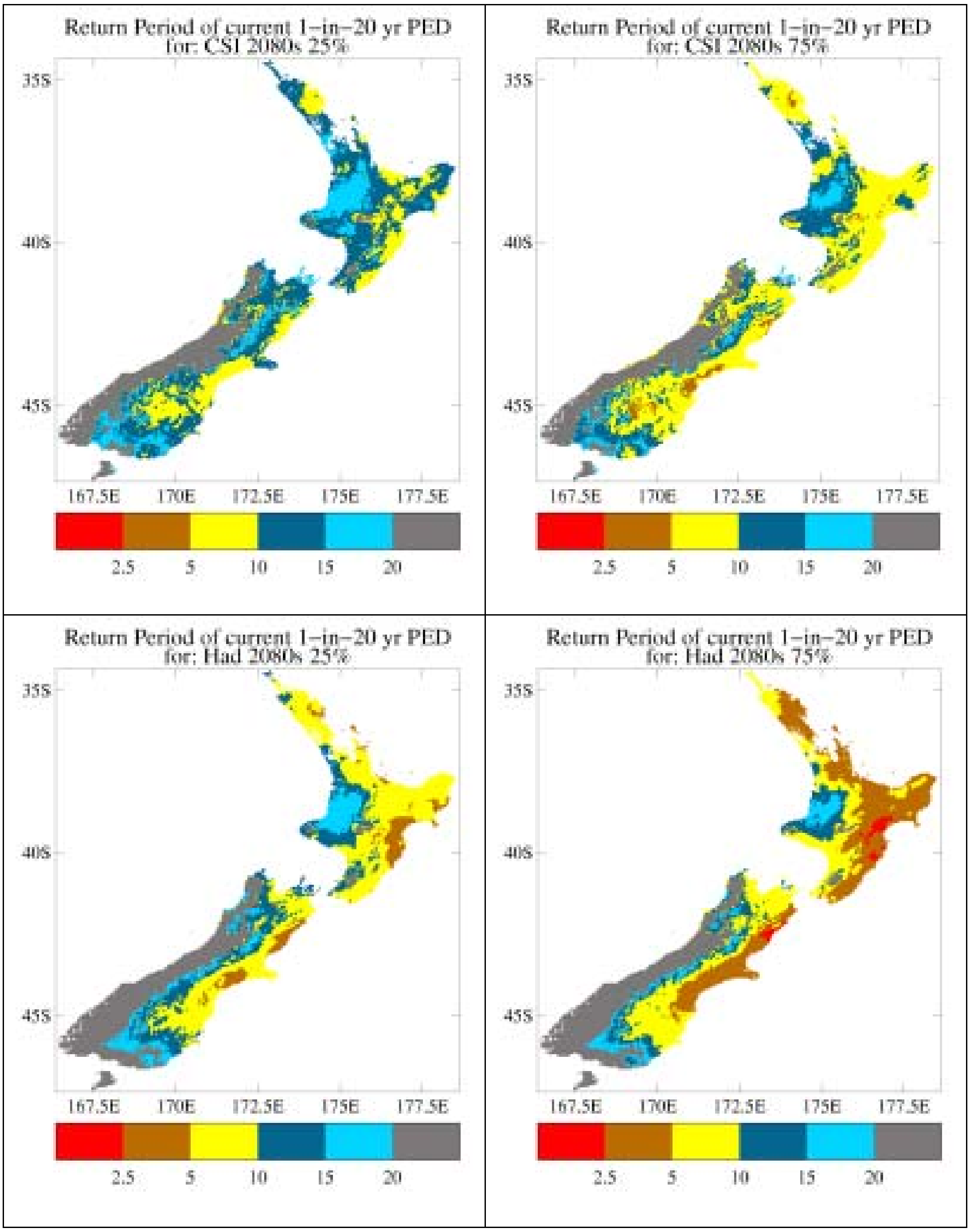

Figure 36. Future return periods (years) of current climate 1-in-20 year *PED* events, for four scenarios: CSIRO 2080s 25% and 75% scaling (upper panels) and Hadley 2080s 25% and 75% scaling (lower panels). Grey areas indicate regions of very low drought risk (where return period can't be estimated) and/or regions where drought risk decreases. © NIWA.

5. Impacts of climate change and drought in Taranaki

5.1 Impacts

5.1.1 Temperature

Extremely high and low temperatures are associated to health problems, which impact especially in the sick, elderly, or poor part of the population. Effects are related to temperature levels, but also to the duration of episodes and to level of preparedness of the population, which varies with geographical and cultural factors. This geographical diversity needs to be accounted when assessing extremes values. Moreover both warm and cold extremes produce high energy demands, because of increase heating and air conditioning. Extreme temperatures are mainly associated to persistent large scale synoptic patterns, producing anomalous advection or regional persistence of air masses. This is not expected to be significant in the Taranaki region.

5.1.2 Precipitation

A wide class of hazards is associated with either excess or scarcity of precipitation. Intense rain can result in floods and are a major concern. Sources of precipitation are mainly large-scale weather systems, but during summer strong localised convective storms play a fundamental role. At the same time irregular and scarce precipitation is a problem already present over large areas of New Zealand. Such irregularity and the duration and frequency of dry spell events are not necessarily consistent with those of mean precipitation and they need to be assessed separately.

5.1.3 Flooding

The increased flood risk from the increases in high intensity rainfall has important implications for planning of major infrastructure and developments that will need to cope with climatic conditions later in the 21st century. Storm water drainage systems, development of low-lying land already subject to flood risk, roading and bridges are examples of infrastructure where the increase in both intensity and frequency of high intensity rainfall, for example the reduction of a 24-hour 100-year storm event down to a 50-year storm event, will have significant potential impacts. Thus serious consideration is required by councils and communities of these likely impacts.

5.1.4 Drought

The Taranaki region in the south is likely to become drier on average, in terms of the moisture availability for pasture growth. This can produce a significant impact on south Taranaki's agricultural industries, in particular, with more frequent droughts.

5.1.5 Wildfire

Results from the information reviewed here indicate that under future fire climate Taranaki may experience more severe fire weather and fire danger (Pearce et al., 2005). As suggested overseas, this will result in increased fire risk including:

- longer fire seasons and increased drought frequency, and associated increases in fuel drying;
- easier ignition, and therefore a greater number of fires;
- drier and windier conditions, resulting in faster fire spread, greater areas burned, and increased fire suppression costs and damages;
- greater fuel availability and increased fire intensities, increased resource requirements and more difficult fire suppression.

6. Knowledge Gaps

Assessment of impacts is hampered because of the uncertainly in climate change projections at the regional level, and the difficulty in communicating the consequences to end users. The mid-point warming (average over the 12 global models examined by NIWA) works out at: +0.93°C for 50-year change to 2040, and +2.07°C for 100-year change to 2090, and the range varies from 0.2 to 2.3°C (2040) and 0.6 to 4.5°C (2090), with an even wider range of precipitation scenarios. Further regional modelling will not necessarily narrow this range (some of which is inherent in the uncertainty of future greenhouse gas emissions), but may allow a better assessment of the most likely changes.

A range of climate impacts studies are required to assess the vulnerability for critical systems in Taranaki. These include:

- Water – impacts and optimum adaptation strategies for projected changes in droughts and floods, and for water security within the Taranaki region;
- Natural ecosystems – identification of thresholds including rates at which autonomous adaptation is possible;
- Agriculture – impacts and adaptation strategies for the complete range of farming systems in Taranaki, including both costs and benefits for rural livelihoods;

- Coastal communities – comprehensive assessments of vulnerability and adaptation options to provide improved guidance for planning and hazard management;

- Climate extremes and infrastructure – risks to building, water and communications infrastructure and insurance protection from an increase in extreme weather events. A re-evaluation is required of design flood impacts on dams, bridges, river protection and major urban infrastructure.

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8. Appendices

8.1 Analysis of Extreme Rainfalls and HIRDSV2

Analysis of extreme rainfall events and estimation of their frequency are required in hydro-meteorological practice. Procedures for the analysis of extremes are well established: there are two methods commonly used. The first uses annual maximum data, and selects the highest recorded value in any given year. The second uses the partial duration series (or peaks-over-threshold) method, where all data above a threshold are selected without regard to the number of events within any given time period.

This report uses the annual maximum method. In applying extreme value theory, the probability of annual maximum rainfall exceeding some threshold is known as the annual exceedance probability (AEP). The annual recurrence interval (ARI, or alternatively T_A) is simply 1/AEP, and is the average interval in years containing at least one rainfall exceeding a specified magnitude.

Statistics of annual maximum rainfalls can be estimated from a Generalised Extreme Value (GEV) distribution, a special case of which is the EV1 or Gumbel distribution. For small amounts of data (less than about 30 years) it is known that the full 3-parameter GEV often leads to unreliable quantile estimates (Martins and Stedinger, 1995; Rosbjerg and Madsen, 1995). More robust (precise) and reliable shape parameters can be obtained from a regional frequency analysis, in which data are combined from a number of sites within some defined region (Hosking and Wallis, 1997).

The regional frequency analyses in this study were produced using the NIWA software package known as HIRDS (High Intensity Rainfall Design System). HIRDS is a procedure for estimating extreme rainfall frequency across New Zealand, and uses the annual maxima method (Thompson, 2002). HIRDS estimates distribution parameters by combining sites across a region rather than a single-site estimate. Regional frequency analysis uses data from sites within a suitably defined “region” to estimate the design variable (e.g. river flows or rainfall) at each site. Pooling data usually leads to a reduction in uncertainty (i.e., lower standard error in the estimates) and hence more reliable estimates of design rainfalls.

8.2 DDF tables, Historical and Future, derived from HIRDS

In this appendix are reported the Depth–Duration–Frequency tables for sites in Taranaki Region, for present climate and for the three greenhouse gas emissions scenarios, Low, Mid and High, for the 2040, and 2090 derived from HIRDSV2.

Table 19. Depth–Duration–Frequency tables for sites in Taranaki Region, derived from HIRDS (High Intensity Rainfall System) version 2 for the current climate based on regional frequency analysis:

HIRDSV2 - High Intensity Rainfall Design System
Cape Egmont: Latitude 39° 17' S, Longitude 173° 45' E

Duration

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	9.7	16.1	22.2	29.3	45.6	60.3	79.7	92.9	101.6
10	13.4	21.8	29.5	39.6	62.9	84.3	113	130.2	141.3
20	15.5	24.9	33.5	45.2	72.6	98	132.1	151.3	163.8
30	17	27	36.3	49.1	79.4	107.5	145.5	166.1	179.4
50	19.1	30.2	40.2	54.8	89.2	121.4	165.2	187.8	202.3
100	22.7	35.4	46.8	64.1	105.8	145	198.8	224.5	241

Standard errors (mm)

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	0.8	1.3	1.7	2.3	3.4	4.4	5.4	6.2	6.7
10	1.3	2	2.6	3.4	5.1	6.7	8.6	9.9	10.5
20	1.5	2.3	2.9	3.8	5.8	7.7	10.2	11.8	12.3
30	1.6	2.5	3.1	4.1	6.3	8.4	11.3	13	13.5
50	1.8	2.7	3.4	4.5	7	9.3	12.8	14.7	15.2
100	2	3.1	3.9	5.1	8	10.8	15.4	17.6	17.9

HIRDSV2 - High Intensity Rainfall Design System
Hawera AWS: Latitude 39° 37' S, Longitude 174° 18' E

Duration

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	9.2	15.4	21.3	27.2	40.1	51.3	65.5	77.9	86.3
10	13.3	21.3	28.7	37	55.4	71.4	92	107.9	118.5
20	15.6	24.6	32.9	42.5	64	82.8	107.2	124.9	136.5
30	17.3	27	35.7	46.3	70	90.8	117.7	136.6	149
50	19.8	30.4	39.8	51.8	78.7	102.5	133.3	153.9	167.4
100	24	36.1	46.7	61.1	93.4	122.2	159.8	183	198.1

Standard errors (mm)

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	0.8	1.3	1.7	2.2	3.5	3.7	4.5	5.4	5.8
10	1.3	2	2.6	3.2	5.3	5.5	7.1	8.5	9
20	1.5	2.4	3	3.6	6.1	6.3	8.4	10	10.5
30	1.7	2.6	3.2	3.9	6.6	6.8	9.3	11	11.5
50	1.9	2.9	3.6	4.3	7.3	7.5	10.5	12.4	12.8
100	2.3	3.4	4	4.8	8.3	8.6	12.4	14.5	14.9

HIRDSV2 - High Intensity Rainfall Design System
Eltham: Latitude 39° 26' S, Longitude 174° 17' E

Duration

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	9.6	16.5	23.3	30.9	48.4	64.3	85.3	105.4	119.2
10	13.7	22.7	31.3	41.9	66.7	89.3	119.7	145.8	163.6
20	16.1	26.3	35.8	48.2	77.1	103.8	139.8	169.2	189.1
30	17.8	28.8	38.9	52.5	84.5	114.1	154	185.6	207
50	20.4	32.5	43.5	59	95.4	129.3	175.1	210	233.5
100	24.9	38.8	51.3	69.9	114.1	155.4	211.7	251.8	278.7

Standard errors (mm)

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	0.8	1.4	1.8	2.5	4	4.7	5.8	7	7.8
10	1.3	2.2	2.8	3.6	5.9	7	9.2	11.1	12.2
20	1.5	2.6	3.2	4.1	6.7	8.1	11	13.1	14.3
30	1.7	2.8	3.4	4.4	7.2	8.7	12.1	14.4	15.6
50	1.9	3.1	3.8	4.8	7.8	9.6	13.7	16.3	17.5
100	2.3	3.7	4.3	5.5	8.8	11	16.4	19.4	20.6

HIRDSV2 - High Intensity Rainfall Design System
Inglewood: Latitude 39° 9' S, Longitude 174° 12' E

Duration

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.2	18.6	27.3	37	59.7	80.8	109.4	136.1	154.7
10	14.5	25.4	36.3	49.6	81.7	111.9	153.2	188.6	213
20	17.1	29.4	41.3	56.9	94.4	129.9	178.8	219	246.7
30	18.9	32.1	44.8	61.9	103.2	142.6	196.9	240.5	270.3
50	21.7	36.1	50	69.3	116.4	161.5	224	272.5	305.6
100	26.4	43.1	58.7	81.9	139	194	270.9	327.5	366

Standard errors (mm)

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	0.9	1.6	2.1	2.9	4.7	5.7	7.2	9.1	9.8
10	1.5	2.5	3.2	4.2	7	8.7	11.5	14.5	15.4
20	1.7	2.9	3.6	4.8	7.9	10.1	13.6	17.2	18.1
30	1.9	3.2	3.9	5.2	8.5	11	15	18.9	19.9
50	2.2	3.6	4.3	5.6	9.3	12.2	17.1	21.4	22.4
100	2.6	4.2	4.9	6.3	10.4	14.1	20.5	25.4	26.5

HIRDSV2 - High Intensity Rainfall Design System
Mohakatino: Latitude 39° 45' S, Longitude 174° 38' E

Duration

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	8.5	14.4	20.2	26	38.7	49.8	64	78.1	87.7
10	12.2	20.3	27.9	36	53.8	69.4	89.5	106.5	117.9
20	14.3	23.5	32.1	41.5	62.2	80.3	103.7	122	134.2
30	15.8	25.7	35	45.2	67.9	87.8	113.4	132.6	145.3
50	18	29	39.2	50.7	76.3	98.7	127.7	147.9	161.2
100	21.6	34.4	46.2	59.8	90.2	116.8	151.4	173.2	187.4

Standard errors (mm)

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	0.7	1.3	1.6	2.1	3.2	3.6	4.5	5.4	5.9
10	1.1	2	2.5	3.1	4.9	5.2	7.1	8.4	8.9
20	1.3	2.4	2.9	3.6	5.6	5.9	8.3	9.7	10.2
30	1.5	2.6	3.1	3.9	6	6.4	9.1	10.6	11.1
50	1.7	2.9	3.5	4.3	6.6	6.9	10.1	11.7	12.2
100	2	3.4	4	4.9	7.5	7.8	11.9	13.5	13.8

HIRDSV2 - High Intensity Rainfall Design System
New Plymouth Aero: Latitude 39° 1' S, Longitude 174° 11' E

Duration

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	9.7	18.3	27.4	34.8	50.8	64.4	81.8	97.5	108.1
10	13.8	25	36.5	46.8	69.4	89.1	114.3	134.9	148.7
20	16.2	28.9	41.6	53.6	80.2	103.4	133.3	156.7	172.2
30	18	31.6	45.1	58.4	87.7	113.4	146.7	171.9	188.7
50	20.6	35.6	50.3	65.4	98.9	128.5	166.8	194.7	213.2
100	25.1	42.5	59.2	77.3	118.1	154.2	201.5	233.9	255.3

Standard errors (mm)

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	0.8	1.6	2.1	2.5	3.7	4.6	5.6	6.6	7.1
10	1.3	2.5	3.2	3.6	5.5	6.9	8.9	10.5	11.1
20	1.5	2.9	3.6	4.1	6.3	8	10.5	12.4	13.1
30	1.7	3.2	3.9	4.4	6.8	8.6	11.6	13.7	14.3
50	1.9	3.6	4.3	4.8	7.5	9.5	13.1	15.5	16.1
100	2.3	4.1	4.9	5.4	8.6	11	15.7	18.4	19

HIRDSV2 - High Intensity Rainfall Design System
New Plymouth: Latitude 39° 4' S, Longitude 174° 5' E

Duration

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	9.7	18	26.6	34.4	51.8	67	86.7	101.4	111.2
10	13.8	24.6	35.5	46.4	71	92.8	121.3	140.6	153.3
20	16.3	28.5	40.6	53.3	82.1	107.8	141.6	163.4	177.6
30	18	31.2	44.1	58.1	89.9	118.4	156	179.4	194.7
50	20.6	35.2	49.3	65.1	101.4	134.2	177.4	203.3	220.2
100	25.2	42	58	77.1	121.2	161.3	214.5	244.5	263.9

Standard errors (mm)

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	0.8	1.5	2	2.7	4.3	4.7	5.9	6.7	7.3
10	1.3	2.3	3	3.9	6.5	7.2	9.4	10.7	11.5
20	1.5	2.7	3.5	4.5	7.6	8.3	11.1	12.7	13.5
30	1.7	3	3.8	4.8	8.2	9	12.3	13.9	14.8
50	1.9	3.4	4.2	5.2	9	10	13.9	15.8	16.7
100	2.3	3.9	4.8	5.9	10.3	11.6	16.7	18.8	19.7

HIRDSV2 - High Intensity Rainfall Design System
North Egmont: Latitude 39° 16' S, Longitude 174° 6' E

Duration

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.2	20.4	31.7	48.1	93	141.1	214	271	311.2
10	14.5	27.9	42.2	64.7	127.3	195.2	299.2	374.8	427.6
20	17.1	32.2	48.1	74.2	147.1	226.6	349	435	494.8
30	18.9	35.3	52.3	80.8	160.9	248.7	384.2	477.4	542
50	21.7	39.7	58.3	90.5	181.5	281.6	436.9	540.5	612.1
100	26.5	47.4	68.5	107	216.6	338.1	527.8	648.9	732.3

Standard errors (mm)

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	0.9	1.6	2.4	3.7	7.3	9.6	13.2	15.8	18.4
10	1.5	2.5	3.6	5.4	10.7	14.5	21	25.2	28.8
20	1.7	2.9	4.2	6.1	12.3	16.7	24.9	29.8	33.9
30	1.9	3.2	4.5	6.6	13.2	18.1	27.5	32.9	37.3
50	2.2	3.6	5	7.2	14.5	20.1	31.4	37.4	42
100	2.6	4.2	5.7	8.1	16.6	23.3	37.8	44.9	49.9

HIRDSV2 - High Intensity Rainfall Design System
Omoana: Latitude 39° 26' S, Longitude 174° 34' E

Duration

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	9.4	16.5	23.5	31	48	63.3	83.5	106	121.8
10	13.5	22.8	31.7	42.2	66.1	87.7	116.5	146.2	166.9
20	15.9	26.4	36.5	48.6	76.5	101.9	135.8	169.5	192.9
30	17.6	29	39.7	53	83.8	111.9	149.4	185.8	211.1
50	20.2	32.8	44.6	59.7	94.7	126.8	169.7	210.2	238.2
100	24.8	39.4	52.8	71	113.4	152.4	204.8	252	284.5

Standard errors (mm)

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	0.8	1.4	1.8	2.4	3.8	4.6	5.7	7.2	7.9
10	1.3	2.2	2.8	3.5	5.7	6.8	9	11.4	12.3
20	1.6	2.6	3.2	4	6.5	7.7	10.7	13.4	14.4
30	1.7	2.9	3.5	4.3	7	8.2	11.8	14.8	15.8
50	2	3.2	3.9	4.7	7.6	9	13.3	16.6	17.7
100	2.4	3.8	4.5	5.3	8.6	10.2	15.9	19.8	20.9

HIRDSV2 - High Intensity Rainfall Design System
Opunake: Latitude 39° 27' S, Longitude 173° 51' E

Duration

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	9.6	15.9	21.8	28.2	42.6	55.2	71.5	86.4	96.5
10	13.5	21.5	28.9	38	58.5	76.9	101	120.5	133.6
20	15.7	24.7	32.9	43.5	67.6	89.4	118.1	140.1	154.9
30	17.3	27	35.6	47.3	74	98.2	130.2	153.9	169.8
50	19.7	30.2	39.6	52.9	83.4	111.2	148.3	174.5	191.9
100	23.7	35.8	46.3	62.2	99.4	133.5	179.3	209.6	229.5

Standard errors (mm)

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	0.8	1.4	1.7	2.4	3.6	3.9	4.9	6	6.4
10	1.3	2.2	2.6	3.5	5.5	5.9	7.9	9.6	10.1
20	1.5	2.5	2.9	4	6.3	6.8	9.3	11.4	11.8
30	1.7	2.8	3.2	4.3	6.8	7.4	10.3	12.6	13
50	1.9	3.1	3.5	4.7	7.5	8.2	11.7	14.2	14.6
100	2.2	3.5	3.9	5.3	8.5	9.5	14.1	17	17.3

HIRDSV2 - High Intensity Rainfall Design System
Patea: Latitude 39° 45' S, Longitude 174° 28' E

Duration

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	8.7	14.7	20.4	26.5	40.1	52.1	67.6	81	90
10	12.5	20.5	27.9	36.4	55.6	72.6	94.8	110.6	121
20	14.7	23.7	32	41.9	64.2	84	109.9	126.7	137.7
30	16.2	25.9	34.8	45.6	70	91.8	120.3	137.7	149
50	18.4	29	38.8	51	78.5	103.1	135.5	153.6	165.3
100	22.1	34.3	45.4	59.9	92.6	122	160.7	179.7	191.9

Standard errors (mm)

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	0.7	1.3	1.6	2.2	3.4	3.7	4.7	5.6	6.1
10	1.1	2	2.5	3.2	5.1	5.5	7.4	8.7	9.2
20	1.3	2.4	2.8	3.7	5.9	6.2	8.7	10.1	10.6
30	1.5	2.6	3.1	4	6.3	6.7	9.5	11	11.4
50	1.7	2.9	3.4	4.4	6.9	7.3	10.6	12.2	12.6
100	2	3.4	3.9	5	7.9	8.2	12.5	14.1	14.2

HIRDSV2 - High Intensity Rainfall Design System
Purangi: Latitude 39° 9' S, Longitude 174° 30' E

Duration

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.3	18.4	26.5	35	54.3	71.7	94.6	121	139.8
10	14.7	25.2	35.5	47.2	74.4	99.1	132.1	167.2	192
20	17.3	29.1	40.5	54.2	86	115.1	154	194	222.1
30	19.1	31.9	44.1	59.1	94.1	126.3	169.4	212.8	243.2
50	21.9	36	49.3	66.3	106.2	143	192.5	240.9	274.7
100	26.7	43	58.1	78.6	126.9	171.8	232.4	289.1	328.5

Standard errors (mm)

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	0.9	1.5	2	2.6	4	5.1	6.3	8	9
10	1.5	2.3	3.1	3.8	5.9	7.5	10	12.7	14.1
20	1.7	2.7	3.5	4.3	6.7	8.6	11.8	15	16.5
30	1.9	3	3.8	4.6	7.3	9.2	13	16.5	18.1
50	2.2	3.4	4.2	5	7.9	10.1	14.8	18.7	20.3
100	2.6	3.9	4.8	5.6	8.9	11.4	17.7	22.3	24

HIRDSV2 - High Intensity Rainfall Design System
Stratford EWS: Latitude 39° 20' S, Longitude 174° 18' E

Duration

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	9.7	17.1	24.5	33.6	55.4	75.9	104.1	131.9	151.4
10	13.8	23.4	32.7	45.3	76	105.3	145.9	182.3	207.7
20	16.3	27.1	37.4	52	87.9	122.3	170.3	211.5	240
30	18	29.6	40.6	56.7	96.2	134.3	187.5	231.9	262.6
50	20.6	33.4	45.3	63.5	108.5	152.1	213.2	262.4	296.2
100	25.1	39.8	53.3	75.1	129.5	182.7	257.6	314.6	353.6

Standard errors (mm)

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	0.8	1.4	1.9	2.6	4.3	5.7	6.9	8.6	9.7
10	1.3	2.2	2.9	3.8	6.3	8.5	11	13.6	15.1
20	1.5	2.6	3.3	4.3	7.2	9.8	13	16.1	17.7
30	1.7	2.8	3.6	4.6	7.7	10.6	14.4	17.7	19.4
50	1.9	3.2	4	5	8.5	11.7	16.3	20	21.8
100	2.3	3.7	4.5	5.6	9.6	13.4	19.6	23.7	25.7

Table 20. Depth–Duration–Frequency tables for sites in Taranaki Region, derived from HIRDS (High Intensity Rainfall System) version 2 for the low, medium, and high greenhouse gas emissions scenarios, for the 2040 and 2090 derived from HIRDSV2

Cape Egmont: Latitude 39° 17' S, Longitude 173° 45' E

Duration

2040 LOW

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.17	16.80	23.09	30.39	47.05	62.04	81.76	95.02	103.73
10	14.04	22.79	30.81	41.31	65.47	87.59	117.27	134.97	146.30
20	16.24	26.07	35.05	47.26	75.82	102.29	137.81	157.75	170.68
30	17.82	28.30	38.04	51.46	83.21	112.66	152.48	173.87	187.69
50	20.02	31.65	42.13	57.43	93.48	127.23	173.13	196.81	212.01
100	23.79	37.10	49.05	67.18	110.88	151.96	208.34	235.28	252.57

2040 MID

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.40	17.14	23.54	30.93	47.78	62.90	82.78	96.08	104.80
10	14.36	23.29	31.46	42.17	66.75	89.23	119.41	137.35	148.80
20	16.62	26.65	35.82	48.29	77.44	104.44	140.66	160.97	174.12
30	18.22	28.94	38.91	52.64	85.12	115.24	155.98	177.76	191.83
50	20.48	32.37	43.09	58.75	95.62	130.14	177.09	201.32	216.87
100	24.33	37.95	50.17	68.72	113.42	155.44	213.11	240.66	258.35

2040 HIGH

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.71	17.61	24.13	31.66	48.74	64.06	84.16	97.49	106.22
10	14.79	23.95	32.34	43.31	68.46	91.42	122.25	140.52	152.14
20	17.11	27.42	36.85	49.67	79.58	107.30	144.46	165.26	178.71
30	18.77	29.81	40.08	54.21	87.66	118.68	160.63	182.94	197.36
50	21.09	33.34	44.38	60.50	98.48	134.03	182.38	207.33	223.34
100	25.06	39.08	51.67	70.77	116.80	160.08	219.48	247.85	266.06

2090 LOW

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.79	17.72	24.28	31.84	48.98	64.35	84.50	97.84	106.58
10	14.90	24.12	32.56	43.59	68.89	91.97	122.97	141.32	152.97
20	17.24	27.62	37.11	50.01	80.12	108.02	145.42	166.34	179.85
30	18.90	30.02	40.37	54.60	88.29	119.54	161.80	184.24	198.74
50	21.24	33.58	44.70	60.94	99.19	135.00	183.70	208.83	224.96
100	25.24	39.36	52.04	71.28	117.65	161.24	221.07	249.64	267.99

2090	MID								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	11.33	18.53	25.32	33.11	50.68	66.38	86.90	100.31	109.07
10	15.65	25.28	34.08	45.59	71.88	95.81	127.95	146.88	158.81
20	18.10	28.98	38.92	52.41	83.88	113.02	152.07	173.86	187.88
30	19.86	31.54	42.40	57.35	92.74	125.56	169.94	193.31	208.41
50	22.31	35.27	46.95	64.01	104.19	141.80	192.95	219.35	236.29
100	26.51	41.35	54.66	74.87	123.57	169.36	232.20	262.22	281.49

2090	HIGH								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	12.03	19.58	26.66	34.75	52.85	68.98	89.98	103.49	112.27
10	16.62	26.77	36.05	48.15	75.73	100.74	134.36	154.03	166.31
20	19.22	30.73	41.24	55.51	88.72	119.46	160.63	183.53	198.20
30	21.08	33.48	45.01	60.88	98.46	133.30	180.42	204.97	220.84
50	23.68	37.45	49.85	67.95	110.61	150.54	204.85	232.87	250.85
100	28.15	43.90	58.03	79.48	131.19	179.80	246.51	278.38	298.84

Hawera AWS: Latitude 39° 37' S, Longitude 174° 18' E

Duration

2040	LOW								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	9.64	16.07	22.16	28.21	41.38	52.78	67.19	79.68	88.11
10	13.94	22.27	29.97	38.60	57.66	74.18	95.48	111.85	122.69
20	16.35	25.75	34.42	44.44	66.84	86.43	111.83	130.22	142.23
30	18.13	28.30	37.41	48.52	73.36	95.16	123.35	142.99	155.88
50	20.75	31.86	41.71	54.29	82.48	107.42	139.70	161.29	175.44
100	25.15	37.83	48.94	64.03	97.88	128.07	167.47	191.78	207.61

2040	MID								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	9.86	16.40	22.58	28.72	42.01	53.52	68.03	80.56	89.02
10	14.26	22.76	30.61	39.40	58.79	75.58	97.22	113.82	124.79
20	16.72	26.33	35.18	45.41	68.26	88.24	114.15	132.88	145.10
30	18.55	28.94	38.27	49.63	75.04	97.34	126.17	146.19	159.33
50	21.23	32.59	42.67	55.53	84.37	109.88	142.90	164.98	179.45
100	25.73	38.70	50.06	65.50	100.12	131.00	171.31	196.18	212.36

2040	HIGH								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.16	16.84	23.16	29.39	42.86	54.50	69.16	81.75	90.23
10	14.68	23.40	31.46	40.46	60.30	77.43	99.53	116.46	127.59
20	17.22	27.09	36.19	46.70	70.16	90.66	117.23	136.43	148.92
30	19.10	29.81	39.41	51.12	77.28	100.24	129.94	150.45	163.91
50	21.86	33.56	43.94	57.19	86.88	113.16	147.16	169.91	184.81
100	26.50	39.85	51.56	67.45	103.11	134.91	176.42	202.03	218.70

2090	LOW								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.23	16.95	23.30	29.56	43.08	54.75	69.44	82.04	90.53
10	14.79	23.57	31.67	40.73	60.67	77.90	100.11	117.11	128.29
20	17.35	27.29	36.45	47.02	70.63	91.26	118.01	137.32	149.88
30	19.24	30.02	39.70	51.49	77.84	100.97	130.88	151.52	165.06
50	22.02	33.80	44.26	57.60	87.51	113.98	148.23	171.14	186.15
100	26.69	40.14	51.93	67.94	103.86	135.89	177.70	203.50	220.29

2090	MID								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.75	17.73	24.30	30.74	44.56	56.47	71.41	84.12	92.64
10	15.53	24.70	33.16	42.59	63.31	81.15	104.17	121.72	133.18
20	18.22	28.63	38.22	49.28	73.95	95.49	123.41	143.52	156.57
30	20.21	31.54	41.70	54.08	81.76	106.05	137.47	158.98	173.09
50	23.13	35.51	46.49	60.50	91.92	119.72	155.69	179.76	195.52
100	28.03	42.16	54.55	71.36	109.09	142.73	186.65	213.74	231.38

2090	HIGH								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	11.41	18.73	25.58	32.26	46.48	58.69	73.95	86.78	95.36
10	16.49	26.16	35.07	44.99	66.70	85.32	109.39	127.65	139.47
20	19.34	30.36	40.50	52.19	78.21	100.93	130.36	151.50	165.17
30	21.45	33.48	44.27	57.41	86.80	112.59	145.95	168.56	183.42
50	24.55	37.70	49.35	64.23	97.59	127.10	165.29	190.84	207.58
100	29.76	44.76	57.91	75.76	115.82	151.53	198.15	226.92	245.64

Eltham: Latitude 39° 26' S, Longitude 174° 17' E

Duration

2040	LOW								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.06	17.21	24.24	32.05	49.94	66.15	87.50	107.80	121.70
10	14.36	23.74	32.69	43.71	69.42	92.78	124.22	151.14	169.39
20	16.87	27.53	37.45	50.40	80.52	108.35	145.84	176.41	197.04
30	18.65	30.18	40.77	55.02	88.56	119.58	161.39	194.29	216.56
50	21.38	34.06	45.59	61.83	99.98	135.51	183.50	220.08	244.71
100	26.10	40.66	53.76	73.26	119.58	162.86	221.86	263.89	292.08

2040	MID								
ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.29	17.57	24.70	32.62	50.71	67.08	88.60	109.00	122.95
10	14.69	24.25	33.38	44.62	70.78	94.52	126.49	153.80	172.29
20	17.26	28.15	38.28	51.50	82.23	110.62	148.86	180.01	201.01
30	19.08	30.87	41.70	56.28	90.58	122.32	165.09	198.63	221.35
50	21.87	34.84	46.63	63.25	102.27	138.61	187.71	225.12	250.31
100	26.69	41.59	54.99	74.93	122.32	166.59	226.94	269.93	298.77

2040	HIGH								
ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.60	18.04	25.33	33.39	51.73	68.31	90.07	110.61	124.62
10	15.12	24.94	34.31	45.82	72.60	96.85	129.50	157.36	176.15
20	17.77	28.97	39.38	52.96	84.52	113.65	152.89	184.82	206.31
30	19.65	31.80	42.95	57.96	93.29	125.97	170.02	204.42	227.72
50	22.52	35.88	48.02	65.14	105.32	142.75	193.31	231.84	257.78
100	27.49	42.84	56.64	77.17	125.97	171.56	233.72	277.99	307.68

2090	LOW								
ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.68	18.16	25.49	33.58	51.99	68.62	90.44	111.01	125.04
10	15.23	25.12	34.54	46.12	73.05	97.43	130.26	158.25	177.11
20	17.90	29.17	39.66	53.33	85.09	114.41	153.89	186.02	207.63
30	19.79	32.03	43.26	58.38	93.96	126.88	171.25	205.87	229.31
50	22.68	36.14	48.37	65.61	106.08	143.78	194.71	233.52	259.65
100	27.69	43.15	57.05	77.73	126.88	172.80	235.41	280.00	309.91

2090	MID								
ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	11.21	18.99	26.58	34.92	53.79	70.78	93.00	113.81	127.96
10	16.00	26.32	36.16	48.24	76.22	101.49	135.54	164.48	183.87
20	18.80	30.61	41.59	55.89	89.08	119.71	160.94	194.43	216.90
30	20.79	33.64	45.44	61.32	98.70	133.27	179.87	216.00	240.47
50	23.83	37.96	50.81	68.91	111.43	151.02	204.52	245.28	272.73
100	29.08	45.32	59.92	81.64	133.27	181.51	247.27	294.10	325.52

2090	HIGH								
ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	11.90	20.06	27.98	36.65	56.10	73.56	96.30	117.42	131.72
10	16.99	27.88	38.25	50.95	80.31	106.71	142.32	172.48	192.56
20	19.96	32.45	44.07	59.19	94.22	126.53	170.00	205.24	228.81
30	22.07	35.71	48.24	65.10	104.78	141.48	190.96	229.03	254.82
50	25.30	40.30	53.94	73.16	118.30	160.33	217.12	260.40	289.54
100	30.88	48.11	63.61	86.68	141.48	192.70	262.51	312.23	345.59

Inglewood: Latitude 39° 9' S, Longitude 174° 12' E

Duration

2040	LOW								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.69	19.40	28.40	38.38	61.60	83.13	112.22	139.20	157.95
10	15.20	26.56	37.91	51.74	85.03	116.26	158.99	195.50	220.54
20	17.92	30.78	43.21	59.49	98.59	135.59	186.52	228.33	257.06
30	19.81	33.64	46.95	64.87	108.15	149.44	206.35	251.76	282.79
50	22.74	37.83	52.40	72.63	121.99	169.25	234.75	285.58	320.27
100	27.67	45.17	61.52	85.83	145.67	203.31	283.90	343.22	383.57

2040	MID								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.93	19.81	28.95	39.06	62.55	84.29	113.63	140.75	159.57
10	15.54	27.14	38.72	52.81	86.70	118.45	161.89	198.95	224.31
20	18.33	31.46	44.16	60.79	100.69	138.43	190.39	232.99	262.24
30	20.26	34.41	48.03	66.36	110.63	152.87	211.08	257.38	289.03
50	23.26	38.70	53.60	74.29	124.78	173.13	240.13	292.12	327.60
100	28.30	46.20	62.93	87.80	149.01	207.97	290.40	351.08	392.35

2040	HIGH								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	11.26	20.34	29.68	39.98	63.81	85.84	115.52	142.82	161.74
10	16.01	27.91	39.79	54.24	88.92	121.36	165.75	203.56	229.34
20	18.88	32.38	45.43	62.52	103.48	142.23	195.54	239.21	269.15
30	20.87	35.44	49.46	68.34	113.93	157.43	217.38	264.89	297.36
50	23.96	39.85	55.20	76.51	128.51	178.30	247.30	300.84	337.38
100	29.15	47.58	64.80	90.42	153.46	214.18	299.07	361.56	404.06

2090	LOW								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	11.34	20.47	29.86	40.21	64.13	86.23	115.99	143.34	162.28
10	16.12	28.10	40.06	54.60	89.48	122.08	166.71	204.71	230.59
20	19.02	32.61	45.75	62.95	104.18	143.18	196.82	240.77	270.88
30	21.02	35.70	49.82	68.83	114.76	158.57	218.95	266.76	299.44
50	24.13	40.14	55.60	77.06	129.44	179.59	249.09	303.02	339.83
100	29.36	47.93	65.27	91.07	154.57	215.73	301.24	364.18	406.99

2090	MID								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	11.91	21.41	31.14	41.82	66.34	88.94	119.28	146.96	166.07
10	16.94	29.45	41.94	57.10	93.37	127.17	173.47	212.76	239.39
20	19.97	34.22	47.98	65.98	109.07	149.81	205.83	251.65	282.96
30	22.08	37.49	52.33	72.30	120.54	166.56	229.98	279.89	314.01
50	25.35	42.16	58.40	80.94	135.96	188.63	261.63	318.28	356.94
100	30.84	50.34	68.56	95.66	162.35	226.59	316.41	382.52	427.49

2090	HIGH								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	12.65	22.62	32.79	43.88	69.19	92.44	123.51	151.62	170.94
10	17.98	31.19	44.36	60.31	98.37	133.72	182.15	223.11	250.70
20	21.20	36.28	50.84	69.87	115.36	158.35	217.42	265.65	298.51
30	23.44	39.80	55.55	76.76	127.97	176.82	244.16	296.78	332.74
50	26.91	44.76	62.00	85.93	144.34	200.26	277.76	337.90	378.94
100	32.74	53.44	72.79	101.56	172.36	240.56	335.92	406.10	453.84

Mohakatino: Latitude 39° 45' S, Longitude 174° 38' E

Duration

2040	LOW								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	8.91	15.02	21.01	26.97	39.93	51.23	65.65	79.88	89.54
10	12.79	21.23	29.14	37.56	56.00	72.11	92.88	110.40	122.07
20	14.99	24.60	33.58	43.39	64.96	83.82	108.18	127.20	139.84
30	16.56	26.93	36.68	47.37	71.16	92.01	118.84	138.81	152.01
50	18.86	30.39	41.08	53.13	79.96	103.44	133.83	155.00	168.94
100	22.64	36.05	48.42	62.67	94.53	122.41	158.67	181.51	196.40

2040	MID								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	9.11	15.33	21.42	27.45	40.55	51.95	66.48	80.77	90.46
10	13.08	21.69	29.76	38.33	57.09	73.46	94.57	112.35	124.16
20	15.33	25.15	34.32	44.34	66.34	85.58	110.42	129.80	142.65
30	16.94	27.55	37.52	48.45	72.79	94.12	121.56	141.91	155.37
50	19.30	31.09	42.02	54.35	81.79	105.81	136.89	158.55	172.81
100	23.16	36.88	49.53	64.11	96.69	125.21	162.30	185.67	200.89

2040	HIGH								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	9.38	15.75	21.96	28.10	41.37	52.91	67.58	81.96	91.69
10	13.47	22.31	30.58	39.37	58.56	75.26	96.83	114.95	126.94
20	15.79	25.88	35.31	45.60	68.18	87.92	113.41	133.26	146.41
30	17.44	28.37	38.64	49.90	74.96	96.93	125.19	146.05	159.84
50	19.87	32.02	43.28	55.97	84.24	108.96	140.98	163.28	177.96
100	23.85	37.98	51.00	66.02	99.58	128.95	167.15	191.21	206.89

2090	LOW								
ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	9.45	15.85	22.09	28.26	41.57	53.15	67.85	82.25	92.00
10	13.57	22.46	30.79	39.63	58.92	75.72	97.39	115.60	127.64
20	15.90	26.07	35.56	45.92	68.64	88.51	114.15	134.13	147.35
30	17.57	28.58	38.92	50.26	75.50	97.63	126.10	147.08	160.96
50	20.02	32.25	43.59	56.38	84.85	109.75	142.00	164.46	179.25
100	24.02	38.25	51.37	66.50	100.30	129.88	168.36	192.60	208.39

2090	MID								
ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	9.93	16.58	23.04	29.39	43.01	54.82	69.78	84.33	94.15
10	14.25	23.54	32.24	41.44	61.48	78.87	101.34	120.14	132.51
20	16.70	27.35	37.29	48.12	71.87	92.61	119.38	140.19	153.93
30	18.45	30.02	40.88	52.79	79.31	102.55	132.45	154.32	168.80
50	21.02	33.87	45.79	59.22	89.12	115.28	149.15	172.75	188.28
100	25.23	40.18	53.96	69.85	105.35	136.42	176.84	202.30	218.88

2090	HIGH								
ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.54	17.51	24.26	30.84	44.85	56.97	72.26	87.00	96.91
10	15.13	24.93	34.09	43.78	64.78	82.93	106.42	125.99	138.77
20	17.73	29.00	39.52	50.96	76.01	97.89	126.10	147.99	162.38
30	19.59	31.87	43.40	56.05	84.20	108.87	140.62	163.63	178.86
50	22.32	35.96	48.61	62.87	94.61	122.39	158.35	183.40	199.89
100	26.78	42.66	57.29	74.15	111.85	144.83	187.74	214.77	232.38

New Plymouth Aero: Latitude 39° 1' S, Longitude 174° 11' E

Duration

2040	LOW								
ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.17	19.09	28.50	36.09	52.42	66.25	83.91	99.72	110.37
10	14.46	26.14	38.12	48.82	72.23	92.57	118.62	139.84	153.96
20	16.98	30.25	43.52	56.04	83.76	107.93	139.06	163.38	179.43
30	18.86	33.12	47.26	61.20	91.91	118.84	153.74	179.94	197.42
50	21.59	37.31	52.71	68.54	103.65	134.67	174.81	204.05	223.43
100	26.30	44.54	62.04	81.01	123.77	161.60	211.17	245.13	267.55

2040	MID								
ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.40	19.49	29.05	36.74	53.22	67.18	84.97	100.83	111.51
10	14.79	26.71	38.93	49.83	73.65	94.31	120.78	142.31	156.60
20	17.37	30.93	44.48	57.27	85.54	110.19	141.94	166.71	183.05
30	19.30	33.88	48.35	62.60	94.01	121.56	157.26	183.97	201.78
50	22.08	38.16	53.92	70.11	106.02	137.75	178.81	208.72	228.55
100	26.91	45.56	63.46	82.87	126.60	165.30	216.01	250.74	273.68

2040	HIGH								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.71	20.01	29.79	37.60	54.30	68.42	86.37	102.32	113.02
10	15.24	27.47	40.01	51.18	75.53	96.63	123.66	145.60	160.11
20	17.88	31.83	45.76	58.90	87.92	113.21	145.78	171.16	187.87
30	19.87	34.89	49.79	64.47	96.82	125.19	161.96	189.33	207.59
50	22.74	39.30	55.53	72.20	109.19	141.86	184.15	214.95	235.37
100	27.71	46.92	65.36	85.34	130.38	170.24	222.46	258.23	281.85

2090	LOW								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.79	20.14	29.97	37.82	54.57	68.73	86.72	102.69	113.40
10	15.35	27.66	40.28	51.52	76.01	97.21	124.38	146.42	160.98
20	18.01	32.06	46.08	59.30	88.51	113.97	146.74	172.28	189.08
30	20.02	35.14	50.15	64.94	97.52	126.10	163.13	190.67	209.04
50	22.91	39.59	55.93	72.72	109.98	142.89	185.48	216.51	237.08
100	27.91	47.26	65.83	85.96	131.33	171.47	224.07	260.10	283.89

2090	MID								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	11.33	21.07	31.26	39.33	56.45	70.89	89.19	105.28	116.05
10	16.12	28.99	42.17	53.88	79.31	101.26	129.42	152.18	167.12
20	18.92	33.63	48.33	62.15	92.66	119.25	153.45	180.06	197.51
30	21.02	36.91	52.68	68.21	102.43	132.45	171.35	200.06	219.21
50	24.06	41.58	58.75	76.39	115.52	150.09	194.82	227.41	249.02
100	29.32	49.64	69.15	90.29	137.94	180.11	235.35	273.20	298.19

2090	HIGH								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	12.03	22.25	32.91	41.27	58.88	73.67	92.35	108.62	119.45
10	17.11	30.70	44.60	56.91	83.56	106.47	135.90	159.59	175.02
20	20.09	35.66	51.21	65.82	98.00	126.04	162.09	190.08	208.36
30	22.32	39.18	55.92	72.42	108.75	140.62	181.91	212.12	232.29
50	25.54	44.14	62.37	81.10	122.64	159.34	206.83	241.43	264.37
100	31.12	52.70	73.41	95.85	146.44	191.21	249.86	290.04	316.57

New Plymouth: Latitude 39° 4' S, Longitude 174° 5' E

Duration

2040	LOW								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.17	18.78	27.67	35.68	53.45	68.93	88.94	103.71	113.54
10	14.46	25.72	37.08	48.40	73.90	96.42	125.89	145.75	158.73
20	17.08	29.83	42.48	55.73	85.75	112.52	147.72	170.36	185.06
30	18.86	32.70	46.22	60.89	94.22	124.08	163.49	187.80	203.70
50	21.59	36.89	51.67	68.22	106.27	140.64	185.92	213.06	230.77
100	26.41	44.02	60.78	80.80	127.02	169.04	224.80	256.24	276.57

2040 MID

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.40	19.17	28.20	36.32	54.27	69.89	90.06	104.87	114.70
10	14.79	26.28	37.86	49.41	75.35	98.23	128.18	148.32	161.44
20	17.47	30.50	43.41	56.95	87.57	114.88	150.78	173.84	188.79
30	19.30	33.45	47.28	62.28	96.37	126.92	167.23	191.99	208.19
50	22.08	37.73	52.85	69.79	108.70	143.86	190.17	217.94	236.05
100	27.01	45.02	62.18	82.65	129.93	172.91	229.94	262.10	282.90

2040 HIGH

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.71	19.68	28.92	37.17	55.37	71.18	91.55	106.41	116.26
10	15.24	27.03	38.92	50.74	77.28	100.64	131.23	151.75	165.06
20	18.00	31.39	44.66	58.57	90.00	118.03	154.85	178.48	193.76
30	19.87	34.44	48.69	64.14	99.25	130.71	172.22	197.59	214.19
50	22.74	38.86	54.43	71.87	111.95	148.16	195.85	224.44	243.10
100	27.82	46.37	64.03	85.12	133.80	178.08	236.81	269.93	291.35

2090 LOW

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.79	19.81	29.10	37.39	55.64	71.50	91.92	106.79	116.65
10	15.35	27.22	39.18	51.08	77.76	101.24	132.00	152.61	165.96
20	18.13	31.61	44.98	58.97	90.61	118.82	155.87	179.64	195.00
30	20.02	34.69	49.04	64.61	99.97	131.66	173.47	198.99	215.69
50	22.91	39.14	54.82	72.39	112.76	149.23	197.27	226.07	244.86
100	28.02	46.70	64.50	85.74	134.77	179.37	238.52	271.88	293.46

2090 MID

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	11.33	20.72	30.34	38.88	57.57	73.75	94.53	109.49	119.37
10	16.12	28.53	41.02	53.42	81.14	105.47	137.35	158.61	172.29
20	19.04	33.17	47.17	61.81	94.86	124.33	163.01	187.76	203.71
30	21.02	36.44	51.51	67.86	105.00	138.29	182.21	208.79	226.18
50	24.06	41.11	57.58	76.04	118.44	156.75	207.20	237.45	257.19
100	29.43	49.06	67.74	90.05	141.56	188.40	250.54	285.58	308.24

2090 HIGH

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	12.03	21.89	31.95	40.80	60.04	76.65	97.88	112.96	122.88
10	17.11	30.21	43.38	56.42	85.48	110.90	144.23	166.33	180.43
20	20.21	35.17	49.98	65.45	100.33	131.41	172.19	198.20	214.90
30	22.32	38.69	54.68	72.04	111.48	146.82	193.44	221.38	239.68
50	25.54	43.65	61.13	80.72	125.74	166.41	219.98	252.09	273.05
100	31.25	52.08	71.92	95.60	150.29	200.01	265.98	303.18	327.24

North Egmont: Latitude 39° 16' S, Longitude 174° 6' E

Duration

2040 LOW

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.69	21.28	32.97	49.89	95.96	145.16	219.52	277.18	317.74
10	15.20	29.17	44.07	67.50	132.49	202.81	310.51	388.52	442.74
20	17.92	33.71	50.32	77.58	153.63	236.53	364.08	453.53	515.58
30	19.81	36.99	54.81	84.68	168.62	260.64	402.64	499.74	567.04
50	22.74	41.61	61.10	94.84	190.21	295.12	457.87	566.44	641.48
100	27.77	49.68	71.79	112.14	227.00	354.33	553.13	680.05	767.45

2040 MID

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.93	21.72	33.61	50.78	97.44	147.20	222.28	280.27	321.00
10	15.54	29.81	45.01	68.89	135.09	206.62	316.16	395.38	450.31
20	18.33	34.46	51.43	79.28	156.90	241.49	371.62	462.80	525.97
30	20.26	37.84	56.07	86.62	172.48	266.61	411.86	510.91	579.56
50	23.26	42.56	62.50	97.02	194.57	301.88	468.36	579.42	656.17
100	28.41	50.81	73.43	114.70	232.20	362.44	565.80	695.62	785.03

2040 HIGH

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	11.26	22.31	34.46	51.98	99.41	149.90	225.96	284.39	325.36
10	16.01	30.66	46.26	70.76	138.55	211.69	323.70	404.52	460.40
20	18.88	35.47	52.91	81.53	161.25	248.10	381.67	475.15	539.83
30	20.87	38.97	57.74	89.20	177.63	274.56	424.16	525.81	596.25
50	23.96	43.83	64.36	99.91	200.38	310.89	482.34	596.71	675.76
100	29.26	52.33	75.62	118.13	239.13	373.26	582.69	716.39	808.46

2090 LOW

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	11.34	22.46	34.67	52.28	99.90	150.58	226.88	285.42	326.45
10	16.12	30.87	46.57	71.22	139.42	212.96	325.59	406.81	462.92
20	19.02	35.72	53.29	82.09	162.34	249.76	384.18	478.24	543.29
30	21.02	39.25	58.16	89.85	178.92	276.55	427.23	529.53	600.43
50	24.13	44.15	64.83	100.64	201.83	313.14	485.83	601.04	680.66
100	29.47	52.71	76.17	118.98	240.86	375.97	586.91	721.58	814.32

2090 MID

ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	11.91	23.48	36.16	54.36	103.35	155.32	233.32	292.63	334.07
10	16.94	32.35	48.76	74.48	145.48	221.84	338.78	422.81	480.58
20	19.97	37.47	55.88	86.04	169.96	261.34	401.77	499.86	567.54
30	22.08	41.23	61.09	94.37	187.93	290.48	448.75	555.60	629.64
50	25.35	46.37	68.09	105.70	211.99	328.91	510.30	631.30	714.93
100	30.95	55.36	80.01	124.98	252.99	394.90	616.47	757.92	855.33

2090	HIGH								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	12.65	24.81	38.07	57.05	107.79	161.42	241.61	301.89	343.88
10	17.98	34.26	51.57	78.68	153.27	233.26	355.75	443.39	503.29
20	21.20	39.73	59.21	91.12	179.76	276.23	424.38	527.66	598.71
30	23.44	43.77	64.85	100.19	199.52	308.39	476.41	589.11	667.20
50	26.91	49.23	72.29	112.22	225.06	349.18	541.76	670.22	759.00
100	32.86	58.78	84.94	132.68	268.58	419.24	654.47	804.64	908.05

Omoana: Latitude 39° 26' S, Longitude 174° 34' E

Duration

2040	LOW								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	9.85	17.21	24.44	32.15	49.53	65.12	85.65	108.42	124.36
10	14.15	23.84	33.11	44.02	68.80	91.12	120.90	151.55	172.81
20	16.66	27.64	38.19	50.82	79.90	106.36	141.67	176.72	201.00
30	18.44	30.39	41.61	55.54	87.82	117.27	156.57	194.50	220.85
50	21.17	34.37	46.74	62.57	99.25	132.89	177.85	220.29	249.63
100	25.99	41.29	55.33	74.41	118.84	159.72	214.63	264.10	298.16

2040	MID								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.08	17.57	24.92	32.73	50.29	66.03	86.73	109.63	125.64
10	14.47	24.36	33.81	44.93	70.15	92.83	123.11	154.23	175.76
20	17.04	28.25	39.03	51.92	81.59	108.59	144.60	180.33	205.05
30	18.87	31.09	42.56	56.82	89.83	119.96	160.16	198.84	225.73
50	21.65	35.16	47.81	64.00	101.52	135.93	181.92	225.33	255.35
100	26.59	42.24	56.60	76.11	121.56	163.37	219.55	270.14	304.98

2040	HIGH								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.38	18.04	25.55	33.50	51.31	67.25	88.17	111.24	127.34
10	14.90	25.05	34.75	46.15	71.94	95.11	126.04	157.79	179.70
20	17.55	29.08	40.15	53.40	83.86	111.57	148.51	185.14	210.45
30	19.43	32.02	43.83	58.51	92.52	123.54	164.94	204.64	232.23
50	22.30	36.21	49.24	65.91	104.55	139.99	187.35	232.06	262.97
100	27.38	43.50	58.29	78.38	125.19	168.25	226.10	278.21	314.09

2090	LOW								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.45	18.16	25.70	33.69	51.56	67.55	88.53	111.64	127.77
10	15.01	25.23	34.98	46.45	72.39	95.68	126.78	158.69	180.69
20	17.68	29.28	40.43	53.77	84.43	112.31	149.49	186.35	211.80
30	19.57	32.25	44.15	58.94	93.19	124.43	166.13	206.09	233.86
50	22.46	36.47	49.60	66.39	105.31	141.00	188.71	233.74	264.88
100	27.58	43.81	58.71	78.95	126.10	169.47	227.74	280.22	316.36

2090	MID								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.98	18.99	26.81	35.04	53.34	69.68	91.04	114.46	130.75
10	15.77	26.44	36.63	48.58	75.54	99.67	131.91	164.93	187.58
20	18.57	30.72	42.40	56.36	88.39	117.52	156.33	194.77	221.26
30	20.56	33.87	46.37	61.90	97.88	130.70	174.50	216.23	245.23
50	23.59	38.31	52.09	69.73	110.61	148.10	198.21	245.51	278.22
100	28.97	46.02	61.67	82.93	132.45	178.00	239.21	294.34	332.30

2090	HIGH								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	11.66	20.06	28.22	36.77	55.63	72.42	94.27	118.08	134.59
10	16.74	28.00	38.74	51.32	79.58	104.80	138.52	172.95	196.44
20	19.72	32.58	44.93	59.68	93.48	124.22	165.13	205.60	233.41
30	21.82	35.96	49.23	65.72	103.91	138.76	185.26	229.28	259.86
50	25.05	40.67	55.30	74.03	117.43	157.23	210.43	260.65	295.37
100	30.75	48.86	65.47	88.04	140.62	188.98	253.95	312.48	352.78

Opunake: Latitude 39° 27' S, Longitude 173° 51' E

Duration

2040	LOW								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.06	16.59	22.68	29.25	43.95	56.79	73.34	88.37	98.53
10	14.15	22.48	30.18	39.64	60.89	79.90	104.82	124.91	138.33
20	16.45	25.86	34.42	45.48	70.60	93.32	123.20	146.07	161.41
30	18.13	28.30	37.31	49.57	77.55	102.91	136.45	161.10	177.64
50	20.65	31.65	41.50	55.44	87.40	116.54	155.42	182.88	201.11
100	24.84	37.52	48.52	65.19	104.17	139.91	187.91	219.66	240.52

2040	MID								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.29	16.93	23.11	29.77	44.63	57.58	74.27	89.35	99.54
10	14.47	22.97	30.82	40.46	62.08	81.40	106.73	127.12	140.69
20	16.83	26.43	35.18	46.48	72.10	95.27	125.75	149.05	164.66
30	18.55	28.94	38.16	50.71	79.33	105.27	139.57	164.70	181.57
50	21.12	32.37	42.45	56.71	89.40	119.21	158.98	187.06	205.72
100	25.41	38.38	49.63	66.68	106.56	143.11	192.21	224.69	246.02

2040	HIGH								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.60	17.39	23.70	30.47	45.54	58.64	75.50	90.67	100.89
10	14.90	23.62	31.68	41.56	63.67	83.40	109.27	130.06	143.85
20	17.33	27.20	36.19	47.80	74.10	97.88	129.15	153.03	169.00
30	19.10	29.81	39.30	52.22	81.70	108.41	143.74	169.51	186.80
50	21.75	33.34	43.72	58.40	92.07	122.76	163.72	192.65	211.86
100	26.16	39.52	51.12	68.67	109.74	147.38	197.95	231.40	253.37

2090	LOW								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.68	17.50	23.84	30.65	45.76	58.91	75.80	91.00	101.23
10	15.01	23.79	31.89	41.83	64.07	83.90	109.91	130.79	144.64
20	17.46	27.40	36.45	48.13	74.60	98.54	130.00	154.03	170.08
30	19.24	30.02	39.59	52.60	82.29	109.20	144.78	170.71	188.10
50	21.91	33.58	44.04	58.82	92.74	123.65	164.91	194.04	213.39
100	26.35	39.81	51.49	69.17	110.53	148.45	199.38	233.08	255.20

2090	MID								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	11.21	18.30	24.87	31.87	47.34	60.76	77.96	93.29	103.59
10	15.77	24.93	33.39	43.75	66.85	87.40	114.36	135.94	150.15
20	18.34	28.75	38.22	50.44	78.11	103.11	135.96	160.99	177.67
30	20.21	31.54	41.58	55.25	86.43	114.70	152.07	179.11	197.26
50	23.01	35.27	46.25	61.79	97.41	129.88	173.21	203.82	224.14
100	27.68	41.81	54.08	72.65	116.10	155.93	209.42	244.81	268.06

2090	HIGH								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	11.90	19.33	26.18	33.45	49.37	63.15	80.72	96.25	106.63
10	16.74	26.40	35.32	46.21	70.43	91.90	120.09	142.55	157.25
20	19.47	30.48	40.50	53.42	82.61	108.98	143.61	169.94	187.43
30	21.45	33.48	44.14	58.65	91.76	121.77	161.45	189.91	209.02
50	24.43	37.45	49.10	65.60	103.42	137.89	183.89	216.38	237.96
100	29.39	44.39	57.41	77.13	123.26	165.54	222.33	259.90	284.58

Patea: Latitude 39° 45' S, Longitude 174° 28' E

Duration

2040	LOW								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	9.12	15.34	21.22	27.49	41.38	53.60	69.34	82.85	91.89
10	13.10	21.43	29.14	37.97	57.87	75.43	98.38	114.65	125.28
20	15.41	24.81	33.48	43.81	67.05	87.68	114.65	132.10	143.48
30	16.98	27.14	36.47	47.79	73.36	96.21	126.07	144.14	155.88
50	19.28	30.39	40.66	53.45	82.27	108.05	142.00	160.97	173.23
100	23.16	35.95	47.58	62.78	97.04	127.86	168.41	188.33	201.11

2040	MID								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	9.33	15.65	21.63	27.98	42.01	54.35	70.22	83.77	92.84
10	13.40	21.90	29.76	38.76	59.00	76.85	100.18	116.67	127.43
20	15.76	25.36	34.22	44.77	68.48	89.52	117.02	134.80	146.38
30	17.37	27.76	37.31	48.88	75.04	98.41	128.96	147.37	159.33
50	19.72	31.09	41.59	54.67	84.15	110.52	145.26	164.66	177.20
100	23.69	36.77	48.67	64.21	99.27	130.78	172.27	192.64	205.72

2040	HIGH								
ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	9.60	16.08	22.18	28.64	42.86	55.35	71.38	85.00	94.10
10	13.80	22.53	30.58	39.81	60.52	78.73	102.56	119.37	130.28
20	16.23	26.10	35.20	46.04	70.38	91.97	120.19	138.39	150.23
30	17.88	28.59	38.42	50.34	77.28	101.35	132.81	151.66	163.91
50	20.31	32.02	42.84	56.30	86.66	113.82	149.59	169.57	182.49
100	24.40	37.87	50.12	66.13	102.23	134.69	177.41	198.39	211.86

2090	LOW								
ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	9.67	16.18	22.31	28.80	43.08	55.60	71.67	85.31	94.41
10	13.90	22.68	30.79	40.07	60.89	79.21	103.16	120.05	130.99
20	16.35	26.29	35.45	46.36	70.85	92.58	120.98	139.29	151.19
30	18.01	28.80	38.70	50.71	77.84	102.08	133.77	152.74	165.06
50	20.46	32.25	43.15	56.71	87.29	114.65	150.68	170.80	183.81
100	24.58	38.14	50.48	66.61	102.97	135.66	178.70	199.83	213.39

2090	MID								
ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.16	16.92	23.27	29.95	44.56	57.35	73.70	87.46	96.62
10	14.60	23.77	32.24	41.90	63.54	82.51	107.34	124.77	135.99
20	17.17	27.58	37.17	48.59	74.18	96.88	126.52	145.59	157.94
30	18.92	30.25	40.65	53.26	81.76	107.22	140.51	160.26	173.09
50	21.49	33.87	45.32	59.57	91.69	120.42	158.26	179.40	193.07
100	25.81	40.06	53.03	69.96	108.16	142.50	187.70	209.89	224.14

2090	HIGH								
ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.79	17.88	24.50	31.43	46.48	59.60	76.32	90.23	99.45
10	15.50	25.17	34.09	44.26	66.94	86.76	112.72	130.84	142.42
20	18.23	29.25	39.39	51.45	78.45	102.40	133.64	153.69	166.62
30	20.09	32.12	43.15	56.54	86.80	113.83	149.17	169.92	183.42
50	22.82	35.96	48.11	63.24	97.34	127.84	168.02	190.46	204.97
100	27.40	42.53	56.30	74.28	114.82	151.28	199.27	222.83	237.96

Purangi: Latitude 39° 9' S, Longitude 174° 30' E

Duration

2040	LOW								
ARI	10m	30m	60m	2h	6h	12h	24h	48h	72h
2	10.79	19.19	27.57	36.30	56.03	73.76	97.04	123.76	142.74
10	15.41	26.35	37.08	49.24	77.44	102.96	137.09	173.32	198.80
20	18.13	30.46	42.37	56.67	89.82	120.14	160.65	202.26	231.43
30	20.02	33.43	46.22	61.94	98.62	132.36	177.53	222.76	254.44
50	22.95	37.73	51.67	69.48	111.30	149.86	201.74	252.46	287.89
100	27.98	45.06	60.89	82.37	132.99	180.05	243.56	302.98	344.27

2040	MID								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	11.04	19.59	28.10	36.95	56.89	74.80	98.26	125.14	144.20
10	15.76	26.92	37.86	50.26	78.95	104.90	139.59	176.38	202.20
20	18.55	31.14	43.31	57.91	91.73	122.66	163.98	206.40	236.09
30	20.48	34.20	47.28	63.36	100.88	135.39	181.60	227.74	260.05
50	23.48	38.59	52.85	71.07	113.85	153.30	206.36	258.24	294.48
100	28.62	46.10	62.28	84.26	136.04	184.17	249.13	309.92	352.15

2040	HIGH								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	11.37	20.12	28.81	37.82	58.04	76.17	99.89	126.98	146.16
10	16.23	27.69	38.92	51.62	80.98	107.47	142.92	180.46	206.73
20	19.10	32.05	44.55	59.55	94.27	126.02	168.41	211.91	242.31
30	21.09	35.22	48.69	65.25	103.89	139.44	187.02	234.38	267.54
50	24.18	39.74	54.43	73.20	117.24	157.87	212.52	265.95	303.27
100	29.48	47.47	64.14	86.77	140.10	189.67	256.57	319.17	362.66

2090	LOW								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	11.45	20.25	28.99	38.04	58.33	76.52	100.29	127.44	146.65
10	16.35	27.88	39.18	51.96	81.48	108.12	143.75	181.48	207.86
20	19.24	32.28	44.87	59.97	94.91	126.86	169.52	213.28	243.87
30	21.24	35.47	49.04	65.72	104.64	140.45	188.37	236.04	269.42
50	24.35	40.03	54.82	73.73	118.09	159.02	214.06	267.88	305.47
100	29.69	47.82	64.61	87.40	141.11	191.04	258.43	321.48	365.29

2090	MID								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	12.03	21.18	30.23	39.56	60.34	78.93	103.14	130.66	150.08
10	17.17	29.22	41.02	54.34	85.02	112.63	149.58	188.62	215.79
20	20.21	33.87	47.05	62.85	99.36	132.74	177.28	222.93	254.75
30	22.31	37.26	51.51	69.03	109.91	147.52	197.86	247.66	282.53
50	25.58	42.05	57.58	77.44	124.04	167.02	224.84	281.37	320.85
100	31.19	50.22	67.86	91.80	148.22	200.66	271.44	337.67	383.69

2090	HIGH								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	12.77	22.37	31.83	41.51	62.93	82.02	106.80	134.79	154.48
10	18.23	30.95	43.38	57.40	89.58	118.42	157.07	197.80	225.98
20	21.45	35.91	49.86	66.56	105.09	140.31	187.26	235.32	268.74
30	23.68	39.56	54.68	73.28	116.68	156.61	210.06	262.60	299.38
50	27.16	44.64	61.13	82.21	131.69	177.32	238.70	298.72	340.63
100	33.11	53.32	72.04	97.46	157.36	213.03	288.18	358.48	407.34

Stratford EWS: Latitude 39° 20' S, Longitude 174° 18' E

Duration

2040	**LOW**								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.17	17.84	25.48	34.85	57.16	78.09	106.79	134.91	154.58
10	14.46	24.47	34.15	47.26	79.10	109.41	151.42	188.97	215.05
20	17.08	28.37	39.13	54.37	91.80	127.66	177.66	220.51	250.08
30	18.86	31.02	42.55	59.42	100.82	140.75	196.50	242.75	274.73
50	21.59	35.00	47.47	66.55	113.71	159.40	223.43	275.00	310.42
100	26.30	41.71	55.86	78.70	135.72	191.47	269.96	329.70	370.57

2040	**MID**								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.40	18.21	25.98	35.47	58.04	79.18	108.13	136.41	156.17
10	14.79	25.00	34.88	48.24	80.65	111.46	154.17	192.31	218.73
20	17.47	29.00	39.99	55.56	93.75	130.34	181.34	225.01	255.12
30	19.30	31.73	43.52	60.78	103.13	143.97	201.00	248.18	280.80
50	22.08	35.80	48.56	68.07	116.31	163.05	228.55	281.29	317.53
100	26.91	42.67	57.14	80.51	138.82	195.85	276.15	337.25	379.06

2040	**HIGH**								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.71	18.70	26.63	36.31	59.22	80.64	109.92	138.42	158.29
10	15.24	25.71	35.85	49.54	82.72	114.20	157.85	196.76	223.63
20	18.00	29.85	41.14	57.14	96.36	133.91	186.24	231.02	261.84
30	19.87	32.68	44.82	62.60	106.20	148.27	207.00	255.41	288.89
50	22.74	36.87	50.01	70.10	119.78	167.92	235.37	289.69	327.00
100	27.71	43.94	58.84	82.91	142.97	201.70	284.39	347.32	390.37

2090	**LOW**								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.79	18.82	26.80	36.52	59.51	81.00	110.37	138.92	158.82
10	15.35	25.89	36.09	49.87	83.24	114.88	158.77	197.87	224.86
20	18.13	30.06	41.43	57.53	97.01	134.80	187.47	232.52	263.52
30	20.02	32.92	45.15	63.05	106.97	149.34	208.50	257.22	290.91
50	22.91	37.14	50.37	70.61	120.65	169.14	237.08	291.79	329.37
100	27.91	44.26	59.27	83.51	144.00	203.16	286.45	349.84	393.20

2090	**MID**								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	11.33	19.69	27.95	37.97	61.57	83.55	113.50	142.43	162.53
10	16.12	27.13	37.78	52.15	86.85	119.67	165.20	205.65	233.43
20	19.04	31.54	43.45	60.30	101.56	141.05	196.05	243.03	275.28
30	21.02	34.57	47.42	66.23	112.36	156.86	219.00	269.89	305.06
50	24.06	39.01	52.91	74.17	126.73	177.65	249.02	306.48	345.96
100	29.32	46.49	62.25	87.72	151.26	213.39	300.88	367.45	413.00

2090	HIGH								
ARI	**10m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	12.03	20.79	29.42	39.85	64.21	86.83	117.53	146.94	167.30
10	17.11	28.74	39.96	55.08	91.50	125.83	173.48	215.66	244.46
20	20.21	33.44	46.04	63.86	107.41	149.08	207.08	256.55	290.40
30	22.32	36.70	50.34	70.31	119.29	166.53	232.50	286.16	323.26
50	25.54	41.42	56.17	78.74	134.54	188.60	264.37	325.38	367.29
100	31.12	49.35	66.09	93.12	160.58	226.55	319.42	390.10	438.46