Climate Hazards and Extremes – Taranaki Region

High winds and tornadoes

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Executive Summary

This report has been prepared for the New Plymouth District Council and the Taranaki Regional Council. It is the fifth in a series of reports that analyse and discuss the climate hazards, extremes and variability that are likely to impact on the New Plymouth district in the current climate and during the 21st century. This report focuses on documentation of risks that high winds and tornadoes pose for the region, records events and impacts from these storms, and assesses how variability and change affect their risk. The scope of this study has been extended to include the entire Taranaki region.

High winds occur over Taranaki when vigorous fronts, troughs, deep depressions or cyclones cause strong northerly to westerly airflows, or southeasterly 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 downslope leeward winds from the central North Island can be very strong causing substantial damage.

Taranaki is dominated a large mountain and the region is often influenced by wind effects related to flows over and around Mt Taranaki. These are termed orographic winds. The recording station closest to the summit of Mt Taranaki, East Egmont, shows very high wind speeds from the southwest, west and northwest. New Plymouth has its strongest winds from the southeast direction. Modelling of orographic winds under strong southeasterly conditions shows a marked increase of speed at the coast with the strongest winds over Mt Taranaki on the southwestern side of the mountain. New Plymouth city lies within an area of relatively high wind speeds. There is a large low wind zone east and north of the mountain.

Results from the Regional Atmospheric Modelling System (RAMS) model with uniform winds from eight directional quadrants showed that low wind zones generally occurred in the 90 degree quadrant upwind of Mt Taranaki, and also immediately downwind of the mountain. Marked increases in wind speed occurred on the slopes of Mt Taranaki usually at right angles to the main flow direction, and these were strongest under southerly and south easterly directions. Easterly flow produced marked increases off the South Taranaki coast.

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 30 m/s. However, the highest gusts at New Plymouth came from the southeast where the 50 year return period is in excess of 40 m/s. Thus the very rare extreme winds are far above the commonly occurring wind speeds.

The number of wind recording stations in Taranaki is sufficient to account for the spatial variation. Across the Taranaki stations analysed, the highest extreme speeds are influenced by the channelling effects of Mt Taranaki and the coast. Highest values occurred at East Egmont on the slopes of Mt Taranaki. For northerly winds, Omata, Cape Egmont and Hawera have high speeds. In easterly winds,

the Maui Platform has extremely high gusts due to channelling along the coast and around the mountain. Southeasterlies give high speeds at New Plymouth and Omata, and southerlies New Plymouth, Cape Egmont Maui and Hawera. East Egmont has its highest gust speeds from the westerly quarter. At other stations, these were generally more uniform across the region.

Daily records of extreme winds have been analysed for the one station in the region with records spanning several decades: New Plymouth Airport. The daily records were combined to produce long data series of daily maximum wind gusts for the period 1972-2006. The daily data were analysed for trends and cycles for very extreme wind gusts (i.e. the 95^{th} and 99^{th} percentile values in any one year). The two statistics derived for daily maximum wind gust extremes – extreme intensity and extreme frequency – show decreases over the entire period. The 95^{th} percentile annual gust speed decreased from 82 km/h to 76 km/h with the number of days exceeding the 1972-2006 average (79 km/h) declined from 24 to 16 days.

The influence of the El Niño/Southern Oscillation (ENSO) on extreme wind frequency at New Plymouth appears to be weak – although there is a slight tendency to higher frequencies for El Niño events. An examination of the extreme intensity and frequency of extreme winds at New Plymouth during two recent phases of the Interdecadal Pacific Oscillation (IPO) showed tentatively that both gust speeds, and number of days above particular thresholds in any one year were higher during the negative phase. However, the data period from the negative phase was too short to derive definitive relationships.

Tornadoes, a violently rotating column of air called a vortex from the base of a cumulonimbus cloud, or thunderstorm, do occur in the Taranaki region. The cases examined illustrate the synoptic mechanism behind tornado episodes and the importance of these in the distribution over the region.

From 1951 to 2006 (56 years) 57 tornado producing events were reported with 81% reported as damaging events and 21% producing major structure damage. On average about one tornado will occur somewhere in the Taranaki region, with the frequency of severe cases about once in four years. The majority had maximum wind speeds in the 116 – 180 km/h range, with ten percent attaining wind speeds in excess of 180 km/h. Typical weather conditions indicate the presence of low pressure and associated frontal activity over or west of Taranaki with winds from the north and west. These often track from the coast inland. 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).

A large proportion (70%) of tornadic occurrences in Taranaki was reported in the New Plymouth district especially in or near New Plymouth city. To ascertain the risk of tornadoes across Taranaki, the Enhanced Helicity Index (EHI) was analysed for high risk days. This analysis shows that the highest risk of tornado development occurs over the sea surrounding the region. The many reports of Taranaki tornadoes suggest many of these spawn as waterspouts over the sea and come in across the north Taranaki coast from the northwest. It appears that Mt Taranaki has little effect on the spatial distribution, and that proximity to the northwest coast was more important. Compared with other regions in New Zealand the Taranaki region has a high rate, accounting for 12% or more of the national occurrences, making it a relatively high-risk area, especially New Plymouth city.

The case studies of two very severe tornadoes show these originate offshore as waterspouts travelling towards the south or southeast. In both cases very strong cyclonic northwest airflow prevailed over Taranaki producing strong northerly quarter winds. These both caused damage to much property, and one caused loss of life. To investigate the mechanisms further, the Waitara tornado was simulated by the RAMS weather forecast model. This showed the development of a mesoscale circulation that could spawn a tornado ahead of the passage of a cold front in northwest flow. The simulation shared many, but not all, of the characteristics that would likely spawn the tornado. The model wind fields show that there was little influence of Mt Taranaki on the flow over the sea area northwest of New Plymouth. Thus Mt Taranaki had little influence on the development of the Waitara tornado.

Seasonally the most tornadoes occur in August, double the frequency of any other month, and the least in November, with none ever being reported in January. The most severe occurrences occurred during August. Although it was not possible to make conclusions on diurnal activity, the EHI analysis suggests higher occurrences at 1200 and 1800 hours NZST.

There was no clear relationship between phases of the El Niño-Southern Oscillation (El Niño/La Niña) and tornado frequency. However, there is a probably a higher frequency of tornadoes in Taranaki during the negative phase of the IPO. From 1951 to 2006 the annual mean occurrence is close to one day annually, although average frequencies were higher in the 1951-75 period compared with 1976-2006, which is consistent with the IPO climate shifts.

This study shows that the New Plymouth district is more at risk than other parts of Taranaki, especially New Plymouth city, because of its exposure to thunderstorms and unstable northwest air masses from the Tasman Sea. The majority have occurred in this district with the worst causing major structural damage and some loss of life. However, damaging tornadoes have also occurred in many other towns and rural areas throughout the Taranaki region.

The broad pattern of expected changes out to 2100 for New Zealand includes increases in westerly winds. Global climate models suggest that for mid-range temperature change projections, the mean westerly wind component across New Zealand will increase by approximately 10% of its current value by 2050. As a result, for mid-range temperature change scenarios, the highest wind speed expected to occur once per year could increase by about 3% by 2080. 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 21st century.

1. Introduction

The New Plymouth district and Taranaki region are susceptible to significant adverse effects from natural hazards. Natural hazards and disasters can result in heavy losses of property and a threat to lives, forcing communities to "learn to live" with these hazards. While it is not possible to reduce the incidence of natural hazards, steps can be taken to reduce the vulnerability of the community to their impacts. Landslides, floods, cyclones, high winds, storm surges, tornadoes and such other natural calamities have affected many livelihoods, and over the past decade caused many million dollars of damage in the area. Lessening the impact of natural hazards may save lives, reduce damage and disruption and enable faster recovery.

The objectives of this study are:

To examine and assess the risks that weather 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.

The report comprises the second module on assessing hazards and extremes – those of high winds and tornadoes. The focus of the module has been extended to cover the entire Taranaki region. This module evaluates the risks these pose for the Taranaki region. The area is open to the prevailing winds off the Tasman Sea from the west. Extreme winds throughout the district can cause damage to infrastructure. Especially damaging were the extreme easterly winds produced by Cyclone Bola in the lee of Mt. Taranaki. Other damaging wind events in the district have occurred ing strong southerlies, strong westerlies and in tornadoes.

This work determines average recurrence intervals of strong wind events from the east, south and west, and documents the worst wind events in the historical record and their impacts. Through the Regional Atmospheric Modelling System (RAMS), directional analysis of wind fields over the Taranaki are made so as to determine favoured areas of channelling and funnelling. Tornado occurrences are documented from various historical sources to determine the spatial and temporal distribution of these throughout the district and the year, to determine their likely risk. Relevant aspects of climate variability are assessed. RAMS has been used to model the Waitara 2004 tornado.

2. Background

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 country lies in a large area of ocean within the prevailing westerlies of the mid-latitude Southern Hemisphere. The travelling anticyclones, depressions, and fronts within this 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.

2.1 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 here range from gale force, when speeds reach or exceed 62 km/h (Appendix 1), 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 (probably at about 1000 m 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 southeasterlies predominate for a quarter of the time because of the deflection of southerly quarter winds by Mt Taranaki, and a southeasterly drainage of cold air off the slopes. Strong and high winds over the region are generally most frequent from either the southerly or northwesterly 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. Thus 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 over 100 km/h at Paritutu, and a gust of 98 km/h at New Plymouth Airport This 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) the New Plymouth district was severely affected by damaging winds, and along the coast by high seas. A large pressure gradient developed over the North Island (between the southward moving cyclone and the 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 southeasterly 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.

2.2 Tornadoes

A tornado is a violently rotating column of air called a vortex (Williams, 2006), extending from the base of a cumulonimbus (or thunderstorm) cloud to the ground (American Meteorological Society, 2007), 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 spinning 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. Within a thunderstorm cell a strong persistent updraft of warm moist air is maintained as air enters the forward right flank at low altitude. As the air ascends it is forced to turn due to the variation of wind speed with height (known as vertical wind shear) and due to its proximity to a downdraft of drier cold air. By this means, the buoyant warm updraft acquires rotation in an anticlockwise sense as it undergoes local stretching in the vertical. The spinning, spiralling effect gradually extends along the length of the updraft, and the speed of rotation or 'twisting' increases as the effective column diameter diminishes.

Eventually, given enough time and a high-enough rate of spin and stretching, the tornado's funnel lengthens to the ground, and with it come the high-speed potentially-damaging winds. By contrast, winds in the limited area at the middle of a tornado funnel are light, if not approaching calm at the epicentre, as with the eye of a tropical storm or hurricane.

Tornadoes of North America and Europe have been studied the most, especially since 1970. In the USA and Europe two tornado wind-speed scales have come into use. There is the international decimal T-Scale which ranges from 0 to 9 and is a simple development of the 200-year old Beaufort wind speed scale, and there is the American F-Scale and now EF-Scale with its shorter span from 0 to 5 (Appendix 2). In the severest tornadoes wind speeds have been known to approach 130 metres per second or 480 km/h. The strongest known tornadoes for the USA and for Europe are T10 or EF5 on these scales. Tornado tracks commonly range from a few dozen to a few hundred metres in diameter but can be up to 5 or more kilometres wide. Lengths of tornado tracks exceeding a hundred kilometres are known, especially for the USA.

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).

A tornado will typically last for a few minutes, track across the land for 2 to 5 kilometres and will have a diameter of 20 to 100 metres. 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.

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). By comparison, the most recent fatalities caused by tornadoes in New Zealand occurred in 2004 (2, Waitara) and before that 1991 (1, Albany).

Environmental conditions in New Zealand which tornadoes occur show low values of CAPE (a measure of energy available for convection and updrafts (Appendix 2) (Figure 1). 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). In the study by Haslam it was noted that tornadic thresholds (see Appendix 6) for SRH were often exceeded in stable gradient northwest airflows cyclonically deflected by topography on the western coasts of New Zealand. The deflection means the wind is from the northeast near the surface, creating a high (vertical and horizontal) wind shear environment, a key factor for spawning most tornadoes.

Another parameter which can be used to assess the risk of tornadic 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 tornadic development mentioned previously, the potential for strong updrafts (CAPE) and the amount of spin that can put on the updrafts (SRH). Typical patterns of CAPE, SRH, and EHI over Taranaki for high risk days are presented later.

In Section 6 of this report we demonstrate that the EHI (with a lower threshold) did an excellent job in terms of "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. And therefore, EHI is used here as the main risk indicator for tornadic development in Taranaki.

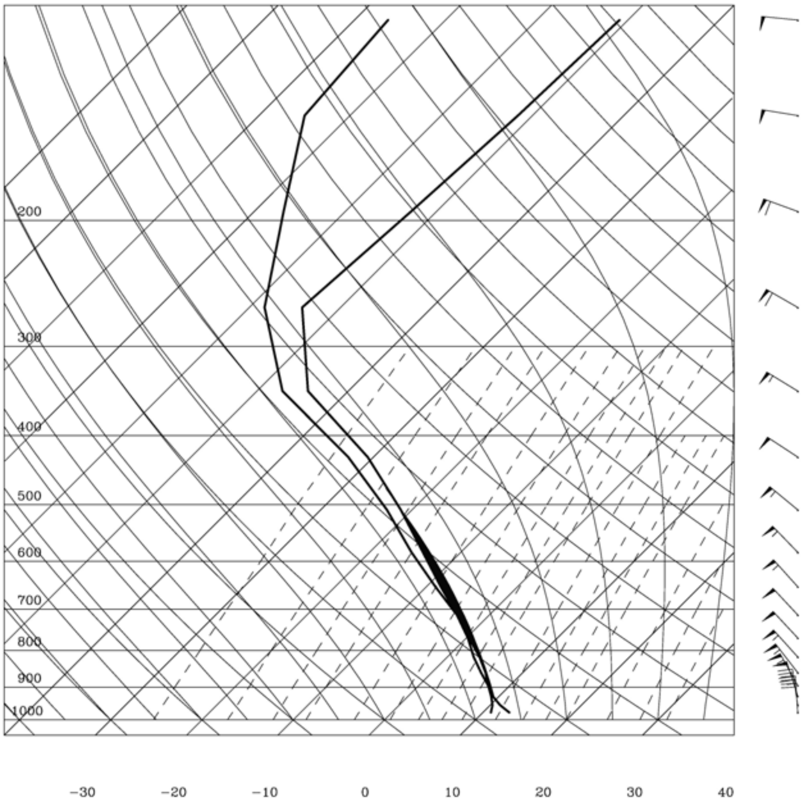


Figure 1. Skew T(emperature) –log P(ressure) plotted soundings of temperature, dew point and winds from RAMS model for New Plymouth at 0500 NZST 14 August 2004. The black shaded area between 800 and 500 hPa indicates the region of CAPE (evaluated to be approx 150 J/kg). The wind barbs are in knots (A solid filled triangle represents a wind speed of 50 knots). © NIWA.

Note it is possible that a location with a low EHI risk as indicated by Figure 12, could actually still have a relatively high risk of a tornado passing over it. This would occur when strong gradient winds (a gradient wind is any horizontal wind velocity tangent to the contour line of a constant pressure surface (or to the isobar of a geopotential surface) at the point in question) exist such that the location was downstream of a high EHI risk region. For example a tornado with a life time of just 15 minutes, if the gradient level winds were 100 km/h, could cause damage in a swath up to 25 km downwind of where it develops. Such a scenario might actually be occurring at and near New Plymouth, where EHI values on high risk days are generally much higher out to sea towards the north and west than over New Plymouth. This would be consistent with the high number of reports in the New Plymouth region of waterspouts coming from off the sea in moderate to strong north to northwest flow.

3. Methods

3.1 Orographic winds

The station nearest to the summit of Mt Taranaki, East Egmont, shows very strong effects with wind directions from the southwest, west and northwest giving extremely high speeds almost certainly due to lee wave effects. However, some wind directions give rather low speeds. Interestingly, Maui which is about 50 km from the mountain also has a very high degree of variation between direction sectors – in this case lee wave effects are not involved but channelling around the mountain and along the south Taranaki coast appear to be important.

New Plymouth has its strongest winds from the southeast direction and some mountain effects are probably involved. It is noteworthy that Stratford, on the other side of the mountain in this wind direction has remarkably low speeds in southeasterlies. The highest speeds at New Plymouth are investigated in more detail using a numerical model. The model has been used to create the field of the winds near the ground in a strong southeasterly. In this way, the relationship between New Plymouth winds and winds in other parts of Taranaki can be made clearer.

In the model, a field of strong pressure gradient is applied similar to that present in cyclone Bola. Typically, strong winds from the southeast at the surface have a more easterly orientation in the troposphere but become weaker above about 2000 m. In Cyclone Bola, the upper level winds measured at New Plymouth had a peak speed of 40 m/s at only 1000 m above ground and were less than half this value at the height of the mountain top. In the very high wind speed event on 9 April 1982, wind data for New Plymouth was unavailable but data for Ohakea showed a southeasterly speed maximum of 31 m/s at 2000 m height. The wind field in the model starts as a uniform distribution of speed equal to 34 m/s and direction from the east up to 2000 m above the ground. Above 2000m the speed decreases. Once the model starts, the surface friction modifies the speed near the ground so that speeds are much reduced at heights below 1000 m. The numerical model is stratified so that it represents a typical atmospheric structure with a generally low stability troposphere and a mid tropospheric stable layer. The results are adjusted so that the speed at New Plymouth Airport corresponds to an annual exceedance probability (AEP) of 0.05. This corresponds to a return period of 20 years.

As well, Taranaki wind fields were determined in stable flows by modelling wind speeds at 45 m above ground level by using the RAMS weather forecast model (Pielke et al 1992) using a horizontal grid spacing of 1 km for a stable atmosphere with uniform gradient level wind of 15 m/s for eight quadrants of the compass.

3.2 Extreme winds

Wind direction is an important parameter for practical applications. The direction that material is transported is important for pollution studies. Structures are affected in different ways depending on the direction in which winds reach the site of the structure. Moreover, hill shape and size tends to produce quite different effects according to the direction of flow. Here only gust data is examined because for gusts the basic data are daily maxima, the alternative mean speeds can be analysed in the same way and give useful information but they represent only 10-minute averages and even at hourly intervals the data only represent maximum winds for 17% of the daily duration.

The wind data have been analysed for their extreme values for each direction. For each year that is complete or nearly so, the maximum gust is obtained for each sector (with wind directions within 22.5 degrees of each cardinal compass point). Reid (1984) proposed a method that has been used for the New Zealand loading codes issued in 1992 and 2002 (NZS 4203 (1992) and AS/NZS 1170:2002). The method of analysis used here is similar to these and other previous analyses of directional winds.

3.2.1 Measurement sites

Although records of daily maximum wind gust are archived for several locations around Taranaki in the NIWA National Climate Database (Table 1), most of these have relatively short periods of digitally archive data, or they presently contain insufficient data to allow useful trend analysis. These sites can be used for extreme directional analysis to ascertain AEPs. The stations listed in Table 1, except Paritutu, have been analysed. The Paritutu station is not analysed because the data is only relevant to one very unusual place (on a very steep rock) and the Omata and New Plymouth stations are nearby. The New Plymouth station is the only station in Table 1 that has a dataset that meets the requirements for an extreme value analysis (10-20 years of continuous data; at other stations the record is either short in years or has substantial periods of missing data).

Network No.	Location	Lat/Lon	Height above mean sea level, (metres)	Data period
C94000	Paritutu	39.06°S 174.01°E	61	08/1966 – 12/1976
C94002	Omata	39.09°S 174.00°E	61	08/1975 – 06/1993
C94011*	New Plymouth Airport	39.01°S 174.18°E	27	01/1972 – 12/1991
C94012*	New Plymouth Airport	39.01°S 174.17°E	30	11/1991 – 03/2007
E93271	Cape Egmont	39.27°S 173.75°E	8	01/1972 – 07/1985
E93541	Maui A Platform	39.55°S 173.43°E	37	01/1979 – 06/1986
E94310	Egmont East	39.30°S 174.10°E	1045	01/1974 – 12/1982
E94334	Stratford EWS	39.33°S 174.30°W	300	06/2002 – 03/2007
E9452A	Normanby EDR	39.51°S 174.25°E	122	04/1986 – 07/2004
E94622	Hawera AWS	39.61°S 174.29°E	98	02/2004 – 03/2007

** Primary reference station used for homogenization in this report*

Table 1. Wind gust recording stations in Taranaki

In order to get enough information for spatial coverage, all years with data for over half the days have been used. For Hawera, Normanby, Maui and Stratford the records have between 3 and 5 years of data which is rather short but with overlap of stations in similar climatic zones, the results may be compared. In fact, the eight places for which data are available give a better data coverage than is available over most of New Zealand. Further, Taranaki is dominated by a single mountain and because this strongly influences the wind distribution, the station density is sufficient to make a considerable part of the spatial variation apparent using the data.

There was one location, New Plymouth Airport, which was suitable for trend analysis. It was selected because of the following preferred qualities:

i. The location is representative of its surroundings,

ii. There is an adequate long (multi-decadal) data series, and

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

New Plymouth Airport data

Maximum daily wind gusts are digitally archived from New Plymouth Airport, (Network No. C94011) from January 1972 through December 1991, and from the Automatic Weather Station (AWS, No. C94012) at the airport, from November 1991 to present.

A Munro anemometer was used at the earlier (C94011) site and a Vaisala for the AWS (C94012) – also at the airport, but in a different location. Both anemometers were located atop standard 10 m masts, with open land exposure.

There is a brief overlapping period of almost two months between the two stations to allow for inter-comparison of the data recorded by the different anemometers. The inter-comparison showed that daily maximum wind gust speeds were on average 4.3% higher at the C94011 site compared to those measured at the AWS (C94012) site. This enabled a composite New Plymouth Airport (C94011) daily wind gust series to be compiled and homogenized, for the 1972-2006 period.

For an extreme value analysis, each annual maximum is assigned a probability that is dependent on the total length of the data period and the relative magnitude of the gust speed. A Gumbel (Gumbel (1958)) plot is used in which the natural logarithm of the natural logarithm of the probability is plotted on the abscissa and the gust speed is the ordinate. The double logarithm is often called the reduced variate. The data points normally lie on or close to a straight line. However, one or two of the highest maxima sometimes lie well above the alignment of the line – these are called outliers and have been interpreted in various ways such as representing truly exceptional events or as an indication that the straight line on the Gumbel plot should really be a curve.

3.2.2 Data homogenisation

To create the longest possible daily wind-gust series for the designated location data was homogenised. This involved combining data from the two sites, with an adjustment of the secondary (C94012) data to that of the primary (C94011) site.

In general, the following processes were involved:

i. searching for and extracting all daily gust data for both the designated sites,

ii. checking for missing and erroneous data, and fill all gaps where possible,

iii. calculating and applying an adjustment factor to the AWS station series, based on the inter-comparison of the overlapping data period with the primary C94012 site; then extend the primary C94012 series.

3.2.3 Annual trends and daily extremes

For wind gust extremes, the following annual indices were calculated for the homogenized New Plymouth Airport site data over the period of record:

- 95th and 99th percentiles of daily maximum wind gust speed *(extreme intensity)*

- Frequency of daily maximum wind gust exceeding the 1972-2006 mean 95th and 99th percentiles (*extreme frequency)*

In New Zealand, the daily maximum wind gust speed is the highest recorded gust speed during the4 24 hour period from 0000-2359 NZST.

In a single year, 95 (99) percent of gust-days with have had less than or equal to the 95th percentile daily maximum gust speed value, or top 5 percent of gust-days exceeds the 95th (99th) percentile value. For example, in a 365-day year, the 95th (99th) percentile value will be that value which is left after the top 18 (3) values (i.e. top 5 (1) percent) have been omitted. The usage of the 95th (99th) percentile statistic means that the most extreme values (which may sometimes include outliers) are discarded.

The data were sorted into arrays for each individual year, and then ranked from the highest to lowest values. After discarding the highest 5 (1) percent of the ranked values for each year the next highest values for each year are the 95th (99th) percentiles

In this report the 95th (99th) percentiles of daily maximum gust speed will be called the '*extreme intensity*'. The frequency of daily maximum gust speed exceeding the 1972-2006 mean 95th percentile rainfall values will be called 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.

3.2.4 Annual variability, the El Niño/Southern Oscillation (ENSO) and Interdecadal Pacific Oscillation (IPO)

Variability on seasonal to interannual time scales in climate phenomena can be caused by the El Niño/Southern Oscillation (ENSO). Background on ENSO is given in Appendix 3, and contained in an earlier report (Thompson et al., 2006). Daily gust speed data were stratified on the basis of El Niño and La Niña events. For this purpose the Southern Oscillation Index (SOI) was used as the indicator of ENSO. Negative phases of the SOI are usually associated with El Niño events and an increase in the frequency of southwest airflows over New Zealand. A reversal of this pattern occurs during the positive (often La Niña) phase.

The two indicators are used in this analysis, being the magnitude and frequency of the annual 95th percentile daily maximum gust speed. This is usually the level of gust speed that can be expected to occur on average about once every 3 weeks, and there are enough observations available to detect any useful correlation with the SOI. The other indicator is the days per year with gusts to at least 60 km/h. These gusts are normally associated with windy-days, having at least strong winds (i.e. mean speeds of 40 km/h or more). Again, there are many observations available for this parameter to distinguish any connection with the SOI.

The Interdecadal Pacific Oscillation (IPO) provides information on longer-term climate variability (Appendix 3). For this gust data for the New Plymouth record must be separated into the negative (1948 - 1977) and positive (1978 - 1997) phases of the IPO. This gives six years of data for the negative phase compared with 27 years of data for the positive phase.

3.3 Tornadoes

3.3.1 Documenting past tornadoes in Taranaki

A wide selection of sources were accessed in order to compile a workable database of past tornado events in the Taranaki region. Amongst these, the main sources of information were:

i. New Zealand Meteorological Service, monthly and annual climate summaries

ii. New Zealand Meteorological Service, Scientific and Technical reports

iii. NIWA, monthly and annual climate summaries

iv. Meteorological Service of New Zealand, Notable weather events archive

v. Meteorological Society of New Zealand Inc, Quarterly newsletters

vi. Media articles, i.e., Newspaper reports

The tornado database (or catalogue) created for this study is provided in Appendix 4. This lists tornadoes (includes waterspouts) that were identified within the Taranaki or offshore region between 1 January 1951 and 31 December 2006 (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. Note that 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 mix of tornado information was available, ranging from the most simple statements, such as 'small tornado observed yesterday near Bell Block', to more detailed descriptions including the time of occurrence, the direction from which the tornado came, descriptions of any damage or fatalities incurred, its width and track, and associated weather conditions. Additional information, such as the presence of thunderstorms, the intensity of precipitation, wind direction and speed, and the classification of the event based on the Fujita Tornado Scale, along with El Nino/Southern Oscillation (ENSO) and Interdecadal Pacific Oscillation (IPO) phases, are also included.

An event can consist of multiple tornadoes observed at the same location at the same time. Risks from tornadoes in the Taranaki region have been identified, together with areas of particularly high risk where tornadoes can threaten the communities in the region and lifeline infrastructures. How long-term variability and climate change might affect tornado risk is also discussed qualitatively.

3.3.2 2004 Waitara Tornado

One particular event studied in greater detail using high resolution computer modelling was the 2004 Waitara tornado. In this section details of the modelling methodology are given; the results are presented in Section 6. The simulations of this event were performed with the RAMS weather forecast model (Pielke et al 1992) using a horizontal grid spacing of 1 km. (Currently, typical operational regional forecast models have horizontal grid spacing's as fine as about 10 km). The important configuration settings for the RAMS model are given in Table 2. The purpose of this simulation was to (i) better understand the meteorological environment in which the tornado formed (ii) test to see if the influence of Mount Taranaki on the flow might have favoured the formation of the tornado as suggested by Haslam (2006) (see background discussion above), and (iii) see if any rotating mesoscale feature that might spawn a tornado is forecast.

Parameter Description	Value	Comment
Forecast Start Time+Length	2004081400+24	
Grid 1 NX/NY/ΔX/DT	100/100/4 km/12 s	
Grid 2 NX/NY/ΔX/DT	98/98/1 km/3 s	
Vertical Grid NZ/(DZ)	62/(variable, 100 m at surface, to a maximum of 400 m above 2200 m)	Logarithmic increase from surface to 2200 m altitude. Terrain following σ_z
Location of SW corner of Grid 2	(41,41)	Grid 1 – coordinate
Orography	From 500 m NZ dataset.	Filtered to remove 2 Δx forcing
Sea Surface Temperatures	From weekly NCEP global SST analysis.	Interpolated to Grids 1 and 2.
Initial & Lateral BC's	Nudging to RAMS 20 km NZ regional forecast applied hourly.	RAMS 20 km NZ region forecast nudged to 6 hourly 0.625º forecasts from The Metoffice's™ global Unified Model
Convective parameterization scheme Grid 1/Grid 2	On/Off	Modified Kuo, updated every hour (Tremback 1990).
Radiation scheme	Longwave and Shortwave schemes both on	Chen and Cotton 1983 and 1987. Updated every hour.

Table 2. Important parameter settings for the RAMS high resolution 24 forecast for the Taranaki region starting at 1200 NZST August 14, 2004

Finally, in order to refine our knowledge about the geographic pattern of tornado risk in Taranaki, for this report we calculated typical patterns over Taranaki of CAPE, SRH, and EHI on days for the possible tornado development occurred in the region. To do this we calculated values of CAPE, SRH, and EHI on a 20 km grid over a 160x200 km^2 region centred on Taranaki every 6 hours from Jan 1 2002 to April 30, 2007. The 'data' used in calculating these indices came from an archive of daily 20 km New Zealand region +12, +18, +24, +30, and +36 hour forecast soundings produced by the RAMS weather model (Pielke et al 1992) The resultant patterns from this analysis are presented in section 6.

4. Orographic winds

The pattern of orographic winds from the numerical model under strong southeasterly conditions is shown in Figure 2. The patterns of wind show a marked increase of speed at the

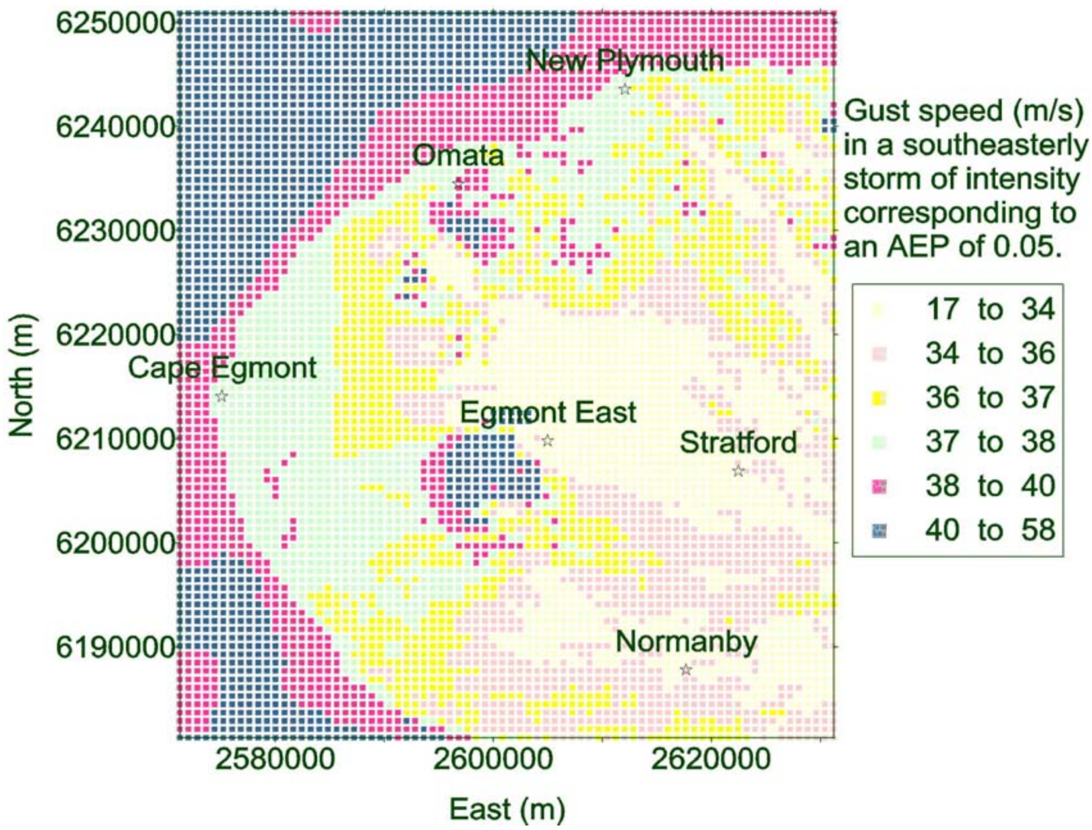


Figure 2. Maximum gust speed (m/s) at 10 m above ground determined by a numerical model run on a grid spacing of 800 m and extending to 7000 m above the ground. Mt Taranaki is in the lower central part of the grid. © NIWA

coast, as expected. The highest winds over Mt Taranaki are on the southwestern side of the mountain and East Egmont is within the lowest wind speed zone. The low wind zone extends over quite a large area east and north of the mountain. The Cape Egmont area is quite windy and a wind speed maximum occurs near Omata. New Plymouth city extends from near

Omata towards New Plymouth airport and lies within an area of relatively high winds without a marked wind increase at the coast.

The distribution of winds over the model domain in Figure 2 is similar to the variation of winds between stations in Table 3 of section 5. Although the surface wind direction at New Plymouth is from the southeast, at other parts of the domain the wind direction may be from the east and the low winds at East Egmont, Stratford, and Normanby may be associated with an easterly wind regime.

The distribution of wind speeds is likely to depend on quite precise details of the atmospheric structure. With changing stability and upper wind structure the relative magnitudes of gust speeds between stations will change somewhat. Nevertheless, over all weather events that have affected the Taranaki wind-measuring stations, the spatial patterns are very marked and we could expect a repetition of many of the major features of the flow patterns.

Figure 3 shows orographic wind speeds under stable atmospheric conditions with a uniform gradient level wind of 15 m/s for various wind directions. Under northerly conditions (Figure 3a) there are small increases on the southwest and southeast flanks of Mt Taranaki. The low wind zone extends over quite a large area to the north, and in a zone immediately south of the mountain. With northeast winds (Figure 3b) increases occur in narrow zones to the northwest and southeast of Mt Taranaki, with a large area of reduced wind speeds to the northeast. The low wind zone extends to the southwest of Mt Taranaki. The most marked increases in wind speeds occurred under easterly conditions speeds (Figure 3c). The highest winds occur along the coast of the South Taranaki Bight and offshore to the south and southwest. Low wind zones occurred in a large area immediately upwind of Mt Taranaki to the east, and also the northwest. Under southeast gradient flow (Figure 3d) there were considerable increases over Mt Taranaki and to the area northeast, with a large zone of reduced winds to the area immediately upwind of Mt Taranaki and also downwind to the west.

The RAMS model output for southerly gradient flow (Figure 3e) shows areas of wind speed increases on the northwest flank of Mt Taranaki, and to the northwest offshore in the North Taranaki Bight, with increases also on the northeast flows to Waitara. A large area of low wind occurs upwind to the south and in a narrow zone downwind to the north over New Plymouth. Southwest flow (Figure 3f) gives some increases on the northwest and southeast flanks of Mt Taranaki, with reductions upwind to the southwest, and downwind to the northeast, and westerly gradient flow (Figure 3g) increases are on the northern and southern flanks of Mt Taranaki, with reductions upwind to the west, and in a narrower zone

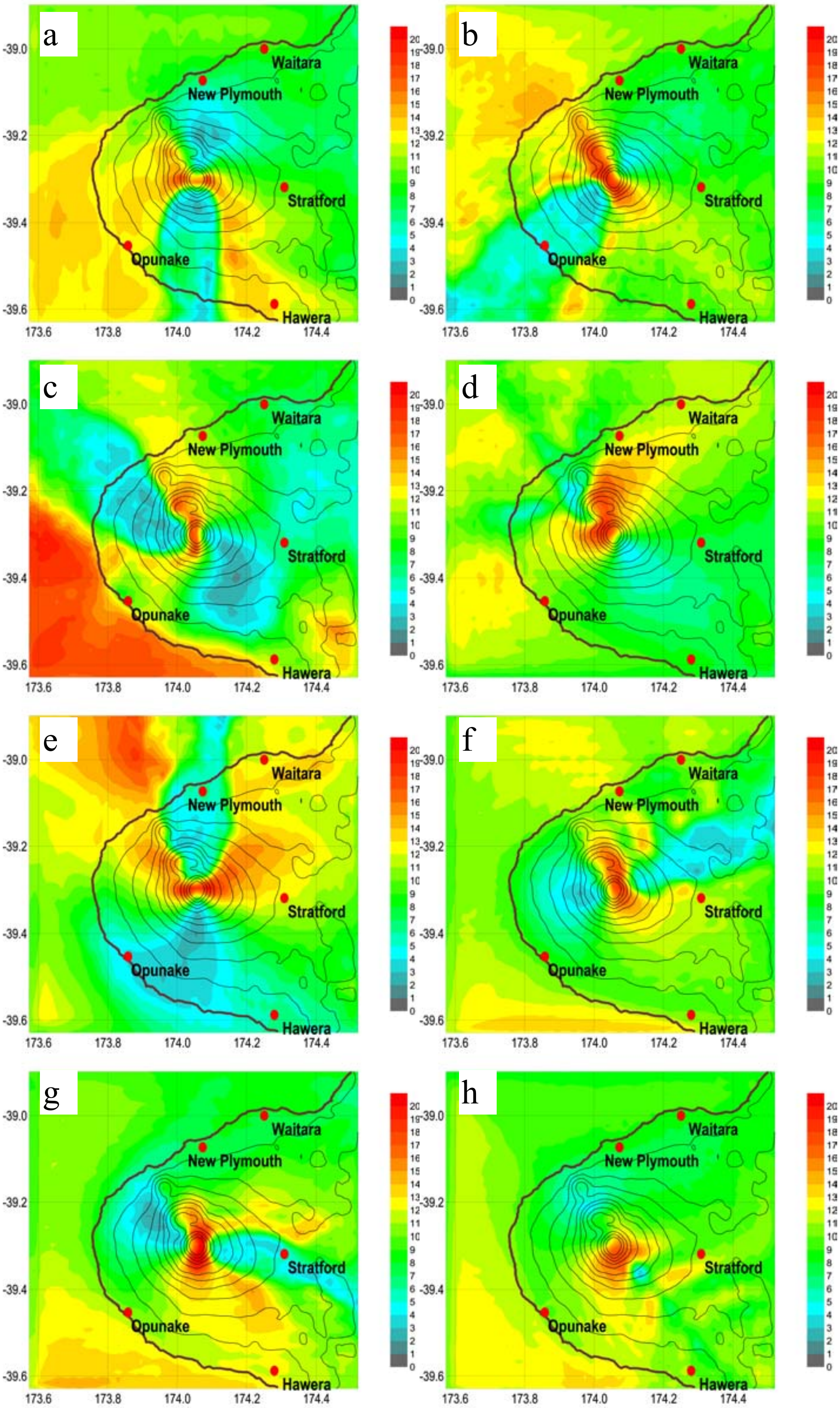


Figure 3. **Wind speeds at 45 m above ground level as simulated by RAMS model on a 1 km grid for stable atmosphere with uniform gradient level wind of 15 m/s from the a) N, b)NE, c) E, d)SE, e) S, f)SW, g) W, and h) NW. © NIWA**

downwind to the east including Stratford. There are increases offshore off the south Taranaki cost. Finally with northwest gradient flow (Figure 3h) small increases occur on the south eastern slopes of Mt Taranaki.

5. Extreme winds

5.1 Directional analysis

5.1.1 New Plymouth

The high peaks in annual maximum gust speeds at New Plymouth (Figure 4) do appear as outliers in a conventional Gumbel plot. However, if the gust speed data is arranged by direction, the reason for the outlying points becomes clearer. Over a third of the years have their maximum gust from the west. However, the highest gusts at New Plymouth have been from the southeast. The west direction dominates at low return periods up to about 5 years. However, beyond this point the southeast gust dominates and the overall relation between

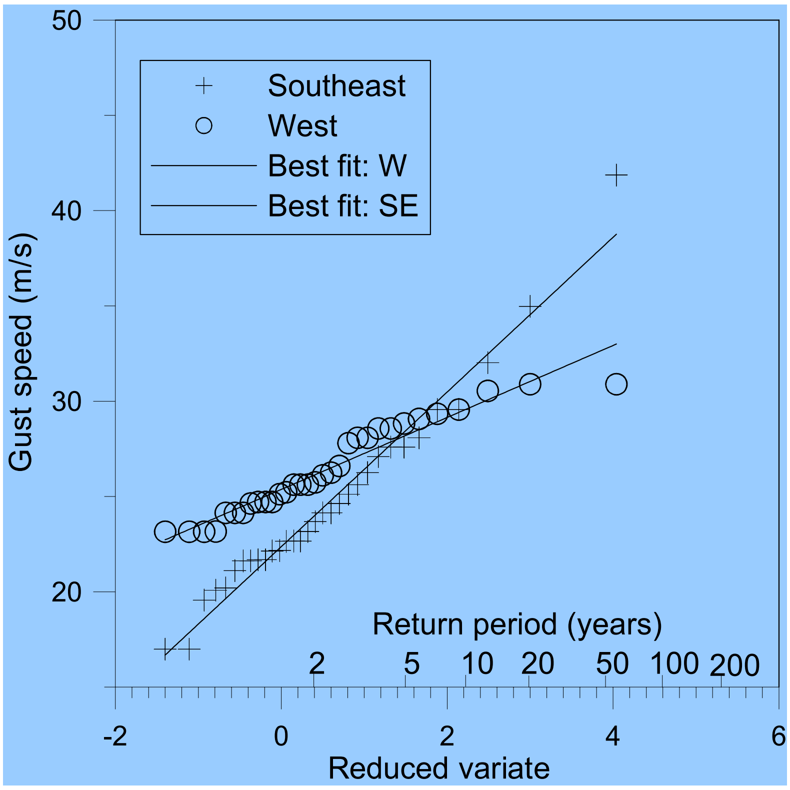


Figure 4. Gumbel plots of the annual maximum gust speeds at New Plymouth from the west and southeast directions. © NIWA

gust speed and reduced variate appears to be curved. This has important consequences for the susceptibility of New Plymouth to extreme winds because the very rare extreme winds are likely to be far above the commonly occurring speeds.

5.1.2 Taranaki

The station density is sufficient to make a considerable part of the spatial variation apparent using the data. For winds from the north (Table 3), the East Egmont speeds are much higher than any other data set. 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 deflected 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 but it is not clear why they should behave similarly. The remaining 4 stations have consistently lower speeds. It is interesting that the Maui data belongs to this lower wind speed group for northerly directions.

Station	New Plymouth AWS	Cape Egmont	Egmont East	Omata	Normanby EDR	Maui A Platform	Stratford EWS	Hawera AWS
AEP	North							
0.05	28	35	50	29	28	31	29	33
0.02	30	38	52	33	30	32	31	36
0.002	34	45	58	42	34	36	35	43
0.001	35	47	60	45	35	37	37	45
	Northeast							
0.05	28	31	20	29	24	31	26	27
0.02	30	33	23	32	26	32	29	31
0.002	36	37	30	41	30	36	36	40
0.001	37	39	33	44	32	37	38	43
	East							
0.05	23	28	20	29	17	42	19	25
0.02	26	31	23	33	20	48	22	29
0.002	33	39	30	43	27	64	29	38
0.001	36	41	33	46	29	69	31	41
	Southeast							
0.05	37	36	34	37	31	44	21	31
0.02	41	38	38	41	34	48	23	33
0.002	51	44	48	52	42	56	29	39
0.001	54	45	51	55	44	59	30	40

Station	New Plymouth AWS	Cape Egmont	Egmont East	Omata	Normanby EDR	Maui A Platform	Stratford EWS	Hawera AWS
AEP	South							
0.05	34	34	36	27	27	38	28	36
0.02	38	37	37	31	29	42	30	40
0.002	47	44	39	41	33	52	34	49
0.001	50	47	40	44	35	56	36	52
	Southwest							
0.05	29	34	42	32	30	31	24	25
0.02	32	36	45	36	33	33	25	26
0.002	38	41	54	45	40	38	27	28
0.001	40	43	57	48	42	39	28	29
	West							
0.05	32	36	45	32	30	37	27	25
0.02	34	39	49	35	32	40	29	26
0.002	38	46	58	42	38	46	33	28
0.001	40	49	61	45	39	48	35	29
	Northwest							
0.05	31	30	49	29	29	24	27	36
0.02	34	32	52	32	33	27	29	40
0.002	40	36	59	39	43	36	33	50
0.001	42	38	62	41	46	38	35	53

Table 3. Gust speeds (m/s) for Taranaki stations for 4 annual exceedance probabilities (AEP). The AEP is the reciprocal of the return period so that the data are for 20, 50, 500 and 1000 year return periods.

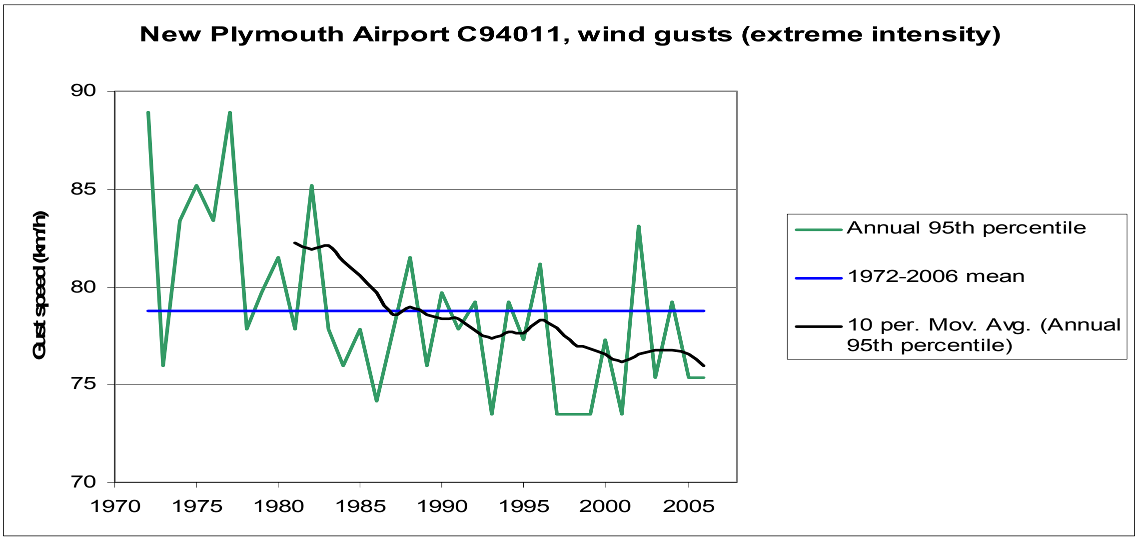
With northeast wind directions there is less variation in the data in Table 3 among the stations than with northerlies. East Egmont has anomalously low speeds but Omata and Hawera again have relatively high values at low AEPs. For east winds, Maui has extremely high gusts. This is probably associated with channelling along the coast and around the mountain. Omata, Hawera and Cape Egmont also have relatively high values and Stratford and Normanby have low values. Southeasterlies give high speeds at New Plymouth, as noted previously, and the nearby station at Omata has very similar values. Maui, Egmont East and Cape Egmont also have high values. In southerlies (Table 3), New Plymouth, Cape Egmont, Maui and Hawera have high values. The latter place has a much greater exposure to this direction than to any other direction except northwest. Stations with particularly low exposure to southerlies are Stratford and Normanby.

In southwest, west and northwest winds the station having the highest gust speeds is East Egmont. There appears to be some intensification of the winds in the lee of the mountain because speeds are uniformly high for all these directions. Hawera and Normanby have their highest 1000-year speeds with the northwest direction, some lee effect may be important.

5.2 Annual trends

5.2.1 Extreme intensity

Annual trends in the 95th and 99th percentile daily gust speeds or *extreme intensity* are shown in Figure 5, and cover the period 1972-2006.



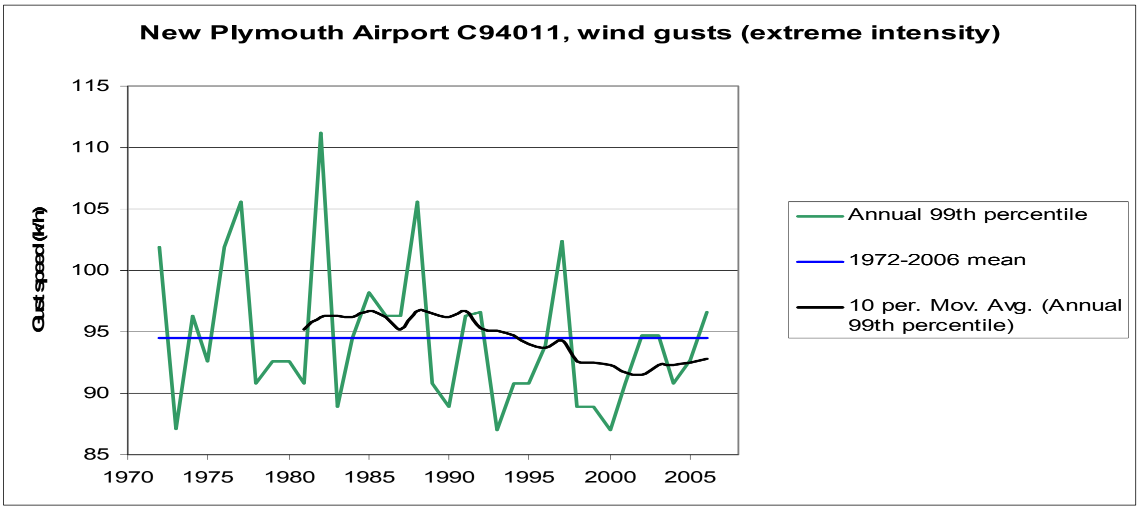


Figure 5. New Plymouth Airport: Time series of the annual 95th (upper) and 99th (lower) percentile daily maximum gust speed *(extreme intensity)*. Each moving average value in the figure is derived from 10 annual 95th (99th) percentile maximum gust speeds. © NIWA.

Both the 95th and 99th percentile gust speed data 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.

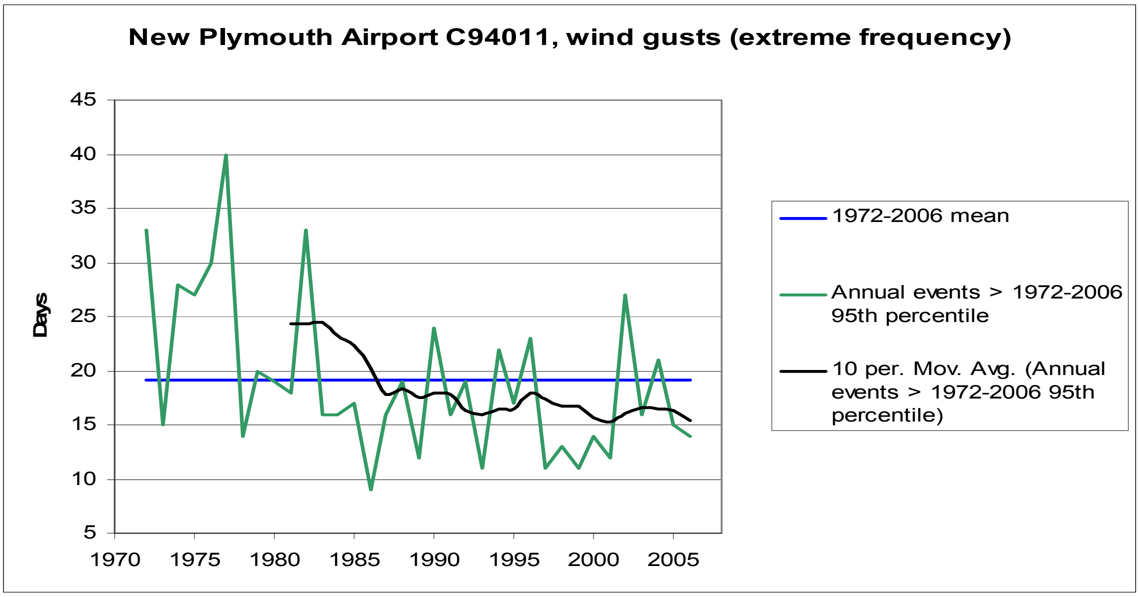
For the 99th percentile, annual variability ranged from a maximum of 111 km/h in 1982 to a minimum of 87 km/h in 1973, 1993 and 2000. Decadal maximum peaked in the period from 1985-1991, to a minimum occurring around 2002.

5.2.2 Extreme frequency

Annual trends in the 95th and 99th percentile daily gust speeds or *extreme frequency* are shown in Figure 6, and cover the period 1972-2006. 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.



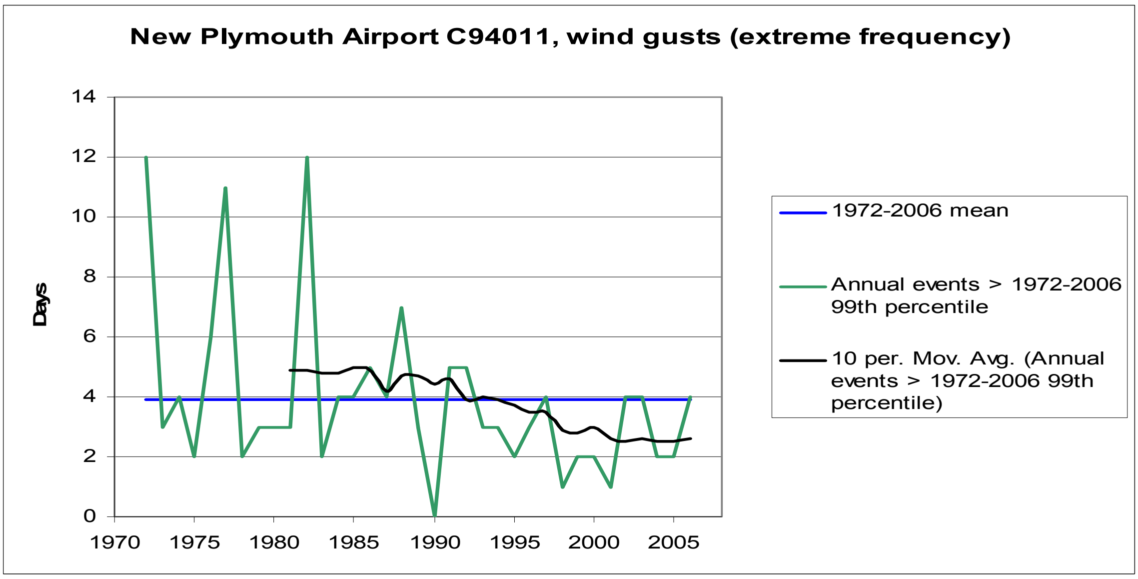
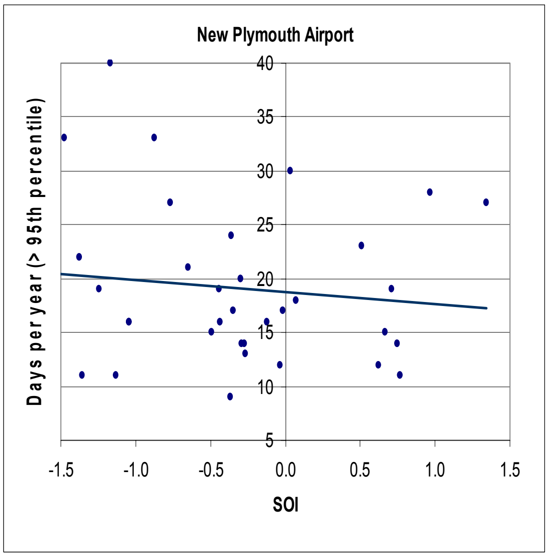


Figure 6. **New Plymouth Airport: Time series of the number of days exceeding the 1972-2006 mean 95th (upper) and 99th (lower) percentile (*extreme frequency*). Each moving average value in the figure is derived from 10 annual 95th (99th) percentile gust-days. © NIWA.**

5.3 El Niño/Southern Oscillation and Interdecadal Pacific Oscillation

The scatter plots in Figure 7 show 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. 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.



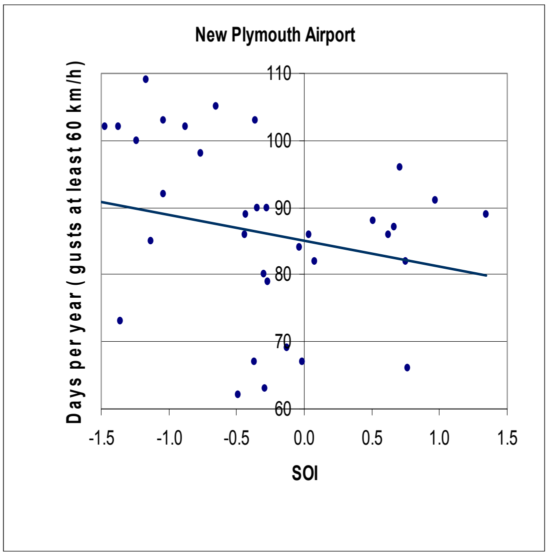


Figure 7. Scatter plots of the number of days exceeding the 1972-2006 mean 95th percentile gust speed or *extreme frequency* (left), and the number of days with gusts to at least 60 km/h at New Plymouth Airport, in relation to the mean annual value of the SOI. The solid lines represent the least squares relationships. © NIWA.

An extreme intensity indicator, the relationship between the annual 95th percentile maximum gust speed, with the SOI, is shown in Figure 8. There is no discernible relationship.

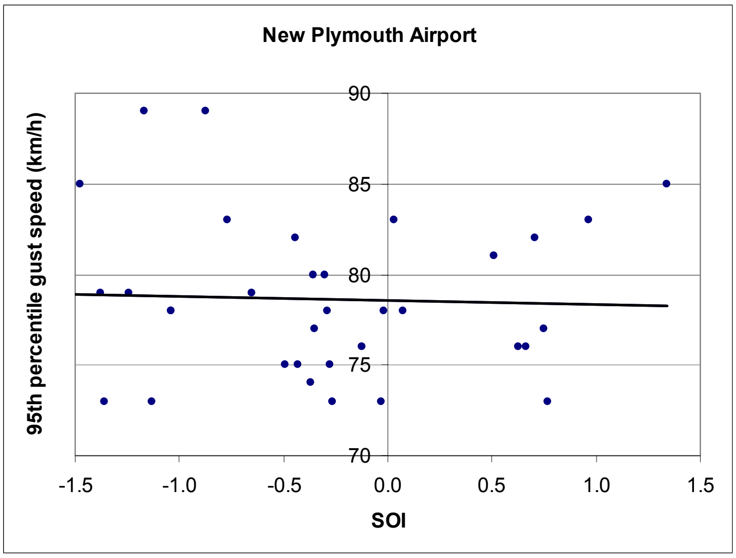


Figure 8. **Scatter plot of the annual 95th percentile daily maximum gust speed or *extreme intensity* at New Plymouth Airport over the period 1972-2005, in relation to the mean annual value of the SOI. The solid line represents the least squares relationship. © NIWA.**

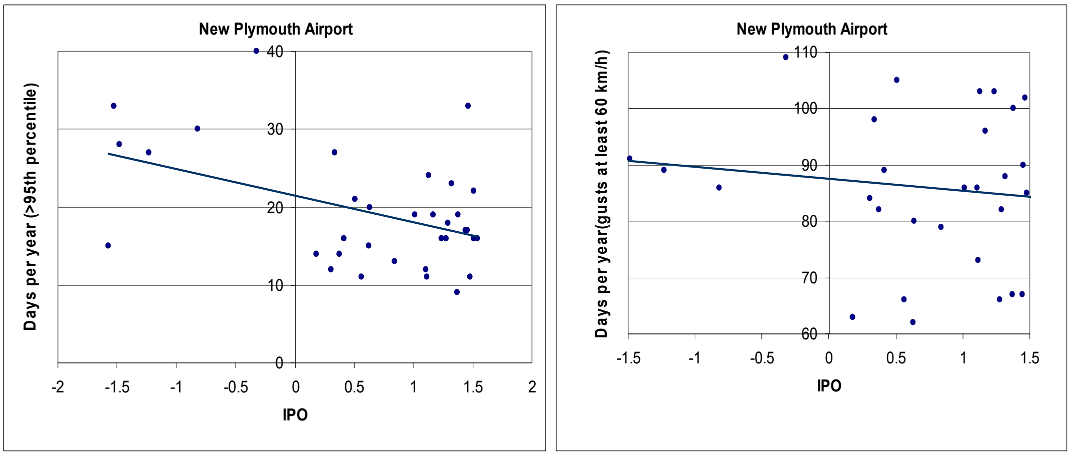


Figure 9. **Scatter plots of the number of days exceeding the 1972-2005 mean 95th percentile gust speed or *extreme frequency* (left), and the number of days with gusts to at least 60 km/h at New Plymouth Airport, in relation to the mean annual value of the IPO. The solid lines represent the least squares relationships. © NIWA.**

Interesting initial relationships emerge with the IPO analysis. The scatter plots in Figure 9 show 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 to the IPO. This data shows that both frequency indicators appear to be weakly correlated with the IPO, tending to be a lower during positive values of the IPO and higher with negative values of the IPO. However, any clear-cut relationship can not be firmly concluded from this data, as there were only 6 years between 1972 and 2005 when the IPO was in its negative phase, compared to 27 years when it was in the positive phase.

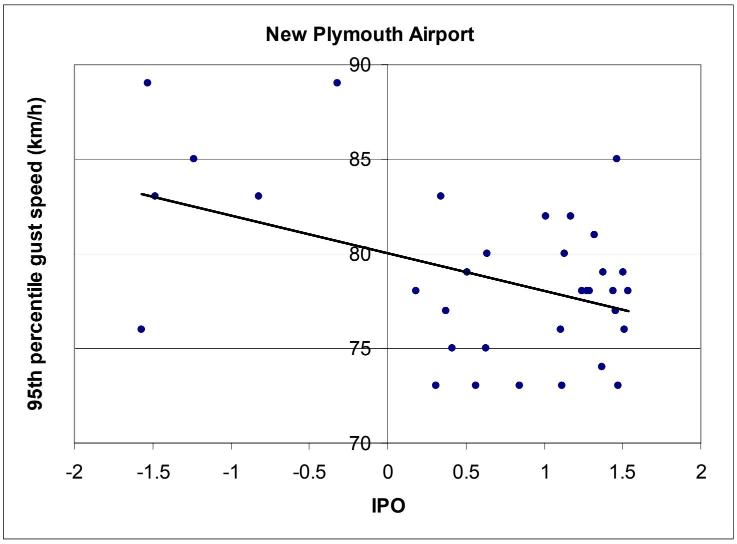


Figure 10. Scatter plot of the annual 95th percentile daily maximum gust speed or *extreme intensity* at New Plymouth Airport over the period 1972-2005, in relation to the mean annual value of the IPO. The solid line represents the least squares relationship. © NIWA.

Similar relationships emerged with the intensity indicator. The scatter plot in Figure 10 shows the relationship between the annual 95th percentile maximum gust speed and the IPO. The annual 95th percentile maximum gust speed appears to be weakly correlated with the IPO, tending to be a lower during the positive phase and higher during the negative phase. Again, any definite relationship in the intensity of high gust events can not be firmly concluded from this data, as there are relatively few years in the analysis covering the negative IPO phase, compared to when it when it was in the positive phase.

To summarize, the *extreme frequency* of high wind events in New Plymouth appears to be weakly correlated to phases of the SOI, being more frequent, as expected, during the negative (usually El Niño) phase. However, although both the *extreme intensity* and *extreme frequency* of high wind events show weak correlations to phases of both the IPO, there is not yet enough evidence to establish any clear-cut relationship.

6. Tornadoes

6.1 Summary of Taranaki tornadoes

A total of 57 tornado producing events were identified within the Taranaki or offshore region over the 56 years from 1951 through 2006 (Table 4). Of these 46 (81%) were reported as damaging events, i.e. at least minor damage occurred to property (sheds, trees, fences, etc.), of which 12 events (21%) 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 4% of occurrences. The most devastating tornado, in New Zealand, in terms of loss of life and injury, was the F2 Frankton-Hamilton tornado of 25 August 1948, which killed 3 people and caused injury to 80, along with 163 damaged buildings and 50 businesses (Wikipedia, 2007).

The majority of Taranaki's damaging tornadoes would be classified as F0 or F1 on the Fujita Tornado Scale, however more than 10% scored F2 or higher. A description of the Fujita Tornado Scale is provided in Appendix 2.

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.

Tomlinson's (1976) analyses of track information states that a typical New Zealand tornado normally has a damage path of about 10-30 m wide and about 1 to 5 km long. 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.

	New Plymouth District	Stratford District	South Taranaki District	District within Taranaki not specified	Taranaki Region
Observed events	40	2	9	6	57
Mean number of events per year	0.7	< 0.1	0.2	0.1	1.0
Events with multiple tornadoes	2 (5%)	-	-	2 (5%)	4 (7%)
Damaging events	35 (88%)	2 (100%)	9 (100%)	-	46 (81%)
Events with damaged buildings	10 (25%)	-	1 (11%)	1 (11%)	12 (21%)
Events with loss of life	1 (3%)	-	1 (11%)	-	2 (4%)
Fujita Scale, F0-F1	30 (75%)	1 (50%)	5 (56%)	4 (10%)	40 (70%)
Fujita Scale, F2-F3	5 (13%)	-	2 (22%)	-	7 (12%)

Table 4. Summary of Taranaki tornadoes, 1951-2006.

6.2 Distribution of tornadic events

A large proportion of the tornadic occurrences (70% of all the Taranaki region events) were reported within the New Plymouth district (Figure 11 and Table 5), especially in or near New Plymouth City (including Waitara and Bell Block).

It is not known how much this is related to specific topographical effects that may occur to the north of Mt Taranaki, or how much is due to the much larger population in the New Plymouth district (i.e. the chance of tornadoes being observed and hence reported is much higher, since half of the population of the Taranaki region resides in New Plymouth city, and more than 60% of the Taranaki population lives within the New Plymouth district. However, it does imply that the reporting of tornadoes in sparsely populated areas is probably far from complete (Tomlinson & Nicol, 1976).

In order to investigate these possible topographic and population effect further, we examined (i) the spatial patterns of CAPE, SRH, and EHI (these parameters are discussed earlier in the report) on days for which tornadoes occurred (in the last 5 years) and (ii) the average patterns for the top 100 “riskiest” periods for each parameter. (Note, we don’t present the averages for the days with reported tornadoes only, as this would only reinforce any population effect). The resultant average patterns and the patterns for the 2004 Waitara tornado are shown in Figure 12. These plots indicate the highest risk for tornado development based on EHI (Figure 12e) occurs over the sea surrounding the region; this is due to the higher CAPE (Figure 12a) values occurring there. Localised higher risk areas over land (due to the higher SRH values – Figure 12c) are seen in the northeast of Taranaki and this extends south along the lower elevations to the east of Mt. Taranaki to southeast Taranaki. Lower risk areas are most apparent over the high terrain of the central plateau and Mt. Taranaki. Interestingly there appears to be a low risk area that extends northwest from

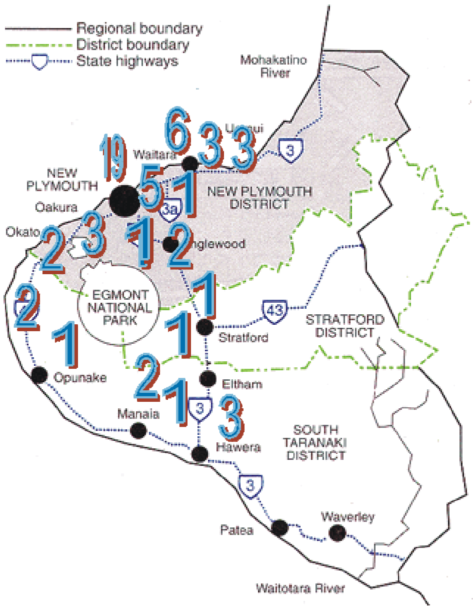


Figure 11. Taranaki locations affected by tornadoes (1951-2006). © NIWA.

Mt. Taranaki along the Kaitake range which then curves NE and runs inland paralleling the coast. New Plymouth and the Northern Taranaki coast do not appear in a region of relatively high risk (Figure 12e). At first glance this appears to be inconsistent with the reported frequencies presented in Figure 11. However, there potentially could be three reasons to explain this. The first is that the EHI maps indicate the risk of development of thunderstorms that could have the potential for spawning tornadoes, but the small scale processes through which the actual tornadoes form, which are not fully understood, are not accounted for by the EHI. This does seem unlikely however, given the locations of local maxima for specific events (e.g., Figure 12f).

The second reason is that the parent thunderstorms which spawn the tornadoes may in fact develop more often in the high risk regions over the sea and that during their lifetimes the storms may move onshore. This does seem to be supported by the many reports of Taranaki tornadoes originating as waterspouts over the sea. Along with the fact that Taranaki tornadoes tend to occur in strong, predominantly northerly or northwesterly flow, this could explain the larger number of tornadoes reported along the northern Taranaki coast and the low number along the southwest coast. It could be that over the ocean west and southwest of Taranaki that many tornadoes have occurred but that they have likely remained over the sea and thus went unreported.

The third reason is that care should be taken when assigning risk to specific location based on the patterns in Figure 12e. This is because the calculations were done on a coarse 20 km grid and so detailed terrain features such as the peak of Mt. Taranaki and the coastlines are smoothed out and not correctly located somewhat. For example, the RAMS 20 km grid point locates the peak of Mt. Taranaki over Stratford, and New Plymouth appears to be about 20 km inland. We should interpret Figure 12e broadly as suggesting that coastal locations, including New Plymouth, have a higher relative risk than locations further inland.

As a check on the robustness of this method, similar patterns were calculated for the West Coast region (Figure 13) and these indicated areas of high risk area over the Tasman Sea northwest of Greymouth and a local maximum over Greymouth itself. This does seem to support the notion that the Greymouth area is more prone to tornadoes due to the influence of terrain features because there is a maximum over Greymouth and also a large high risk zone upstream of Greymouth. It would seem therefore that the population effect on reporting is not required to explain the higher incidence of tornadoes there.

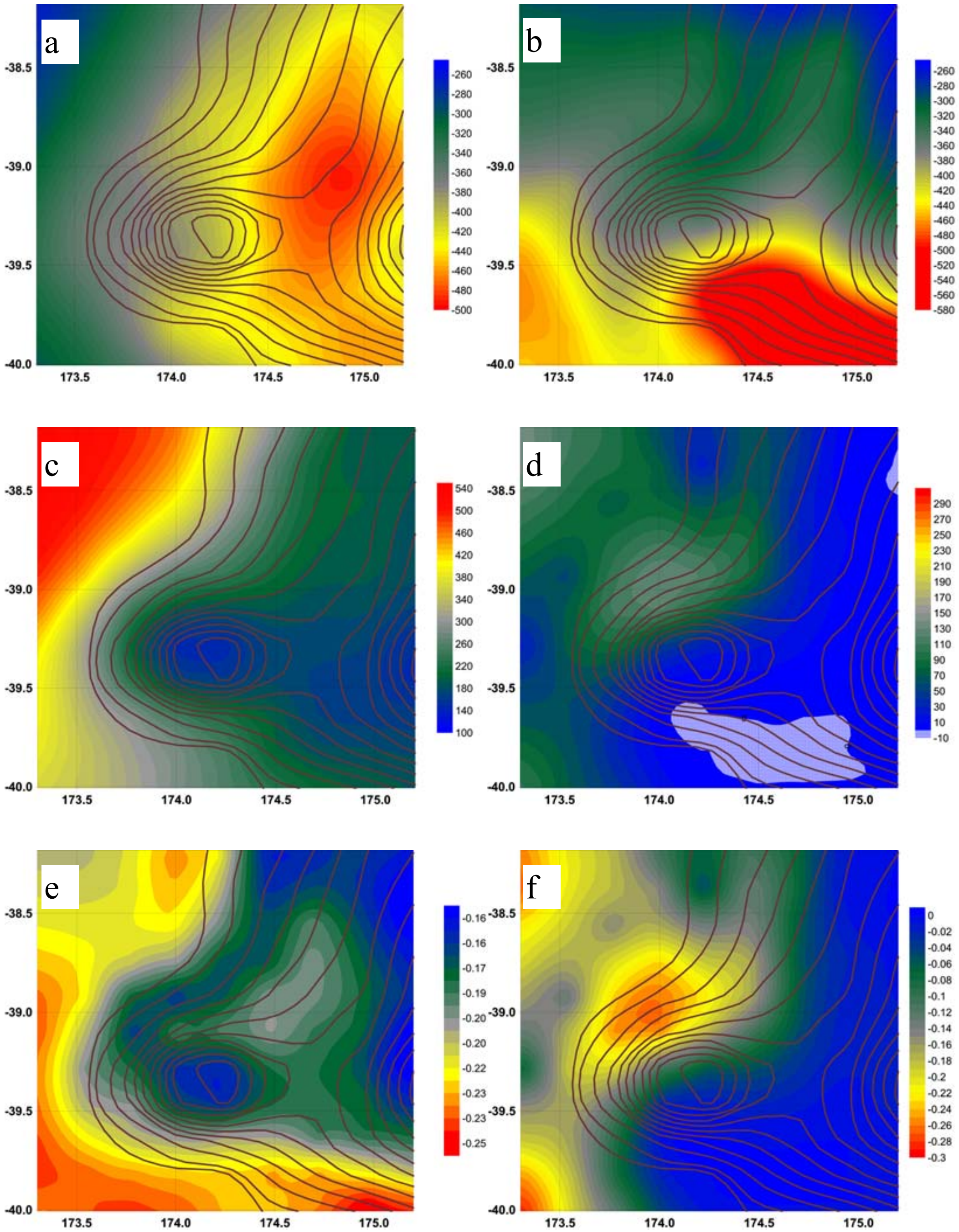


Figure 12. **The "top 100" patterns for SRH, CAPE, and EHI are shown on the left. The patterns on the right are for SRH, CAPE, and EHI at 0600 NZST 15 August, 2004 (The Waitara tornado). Note the colour scales are different for each plot, but redder colours indicate a higher relative risk of either convection (CAPE) or tornadic development. Note the southern hemisphere equivalents to the SRH and EHI threshold forecasters are negative. The black contours represent the RAMS 20 km terrain. © NIWA.**

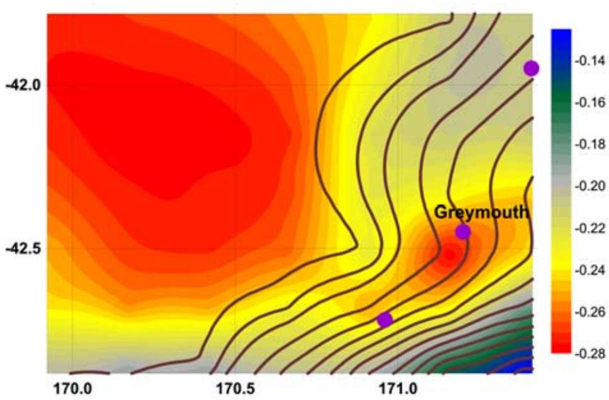


Figure 13 **Pattern of EHI for the 100 analysis periods with the highest magnitude EHI's for the Greymouth region. © NIWA.**

Location	District	Number of tornadoes 1951-2006
Urenui	New Plymouth	3
Motunui	New Plymouth	3
Waitara	New Plymouth	6
Brixton	New Plymouth	1
Bell Block	New Plymouth	5
New Plymouth City	New Plymouth	19
Oakura	New Plymouth	3
Okato	New Plymouth	2
Inglewood	New Plymouth	2
Egmont Village	New Plymouth	1
Midhurst	Stratford	1
Stratford	Stratford	1
Rahotu	South Taranaki	2
Opunake	South Taranaki	1
Kapuni	South Taranaki	2
Okaiawa	South Taranaki	1
Hawera	South Taranaki	3

Table 5 **Break-down of Taranaki locations affected by tornadoes**

A detailed study of tornadoes reported throughout New Zealand, during the period 1961-1975, was conducted by Tomlinson in 1976. That study analysed a total of 236 tornadoes (Table 6), and found that the majority of reports came from western regions from Northland to North Westland, as well as Thames-Coromandel and Bay of Plenty. The Taranaki tornadoes accounted for consisted or more than 13% of all the New Zealand occurrences, which is quite large for the size of the region. Only Auckland and Bay of Plenty incurred a similar proportion of occurrences (Table 7). Another, although less detailed and with a smaller sample, study of tornadoes from 1987-2000 (Met. Society, 2001) showed the Taranaki region as having 17% of all New Zealand occurrences, exceeded only by Auckland

(Table 6). Therefore it is concluded that the Taranaki region is a relatively high-risk area for tornadoes in respect to many other regions of New Zealand.

Tornadoes 1961-1975	**Taranaki Region**	**New Zealand**
Observed events	30 (13%)	236
Mean number of events per year	2	16
Tornadoes 1987-2000	**Taranaki Region**	**New Zealand**
Observed events	10 (17%)	58
Mean number of events per year	1	5

Table 6 Mean tornadic events: Taranaki and New Zealand

Total number of tornadoes 1961-1975	**Risk category**	**Region**
At least 30	High	Auckland, Bay of Plenty, Taranaki
15 or more	-	Northland, Thames-Coromandel, Westland
10 or more	-	Waikato-King Country, Buller
5 or more	-	Wanganui, Manawatu, Horowhenua, Wairarapa, Wellington, Canterbury, Otago, Southland
Less than 5	Low	Hawke’s Bay, Marlborough, Nelson, Fiordland

Table 7 Break-down of New Zealand regions affected by tornadoes (e.g. at least 30 tornadoes occurred in the Taranaki Region between 1961 and 1975).

6.3 The Bell Block-Inglewood tornado, 12 August 1990

This very destructive tornado occurred during the early hours (between 3.22 and 3.32 am) of 12 August 1990, originating off shore (probably as a waterspout), travelling toward Inglewood and then further south, leaving a trail of destruction some 1.5 km long and 200 m wide.

Damage during this event was localised but severe (Figure 14). A total of 69 homes were damaged, 30 considerably, and 3 having to be completely rebuilt. Fortunately, there were no serious injuries in this event. Although Inglewood Primary School suffered extensive damage, it was able to be re-opened on 16 August. Numerous trees were damaged or uprooted. Insurance claims, of which there were 179, totalled $1.4 million ($1990). This was the most destructive tornado, in terms of the number of homes damaged, in New Zealand’s more recent history.

Figure 14 **Tornado damage in Inglewood, August 1990. (Courtesy Taranaki Newspapers Ltd)**

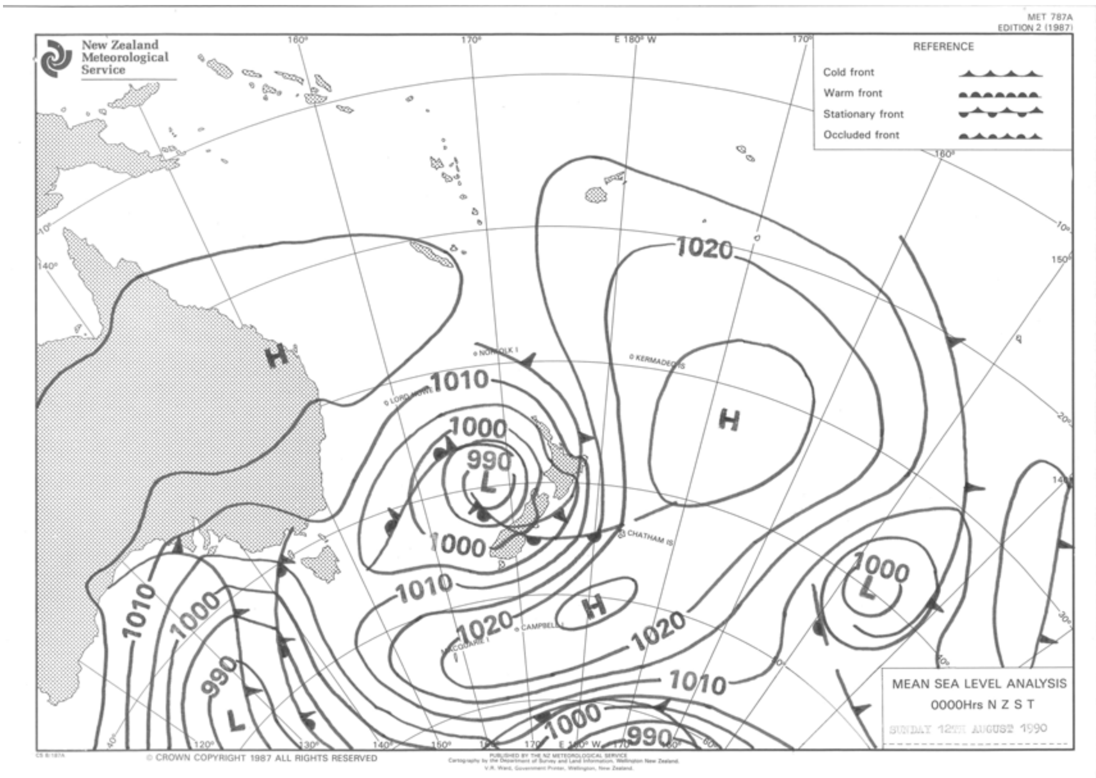


Figure 15 **Synoptic map at 0000 NZST 12 August 1990 (Courtesy Meteorological Service of New Zealand Ltd)**

The meteorological situation on 12 August a few hours before the tornado (Figure 15) shows that a depression was centred over the western South Island, with strong cyclonic curvature in its north-eastern sector extending over Taranaki. Strong northeasterlies prevailed at New Plymouth Airport with mean speeds of 50 km/h and gusts to about 75 km/h. A cold front followed later (after 5am), with surface winds at the airport backing to the north. Analyses of upper winds (at 12am) showed noticeable wind-shear in both direction and speed between the surface (040º True, 39 km/h) and 1000 metres (360 º True, 80 km/h).

The tornado was accompanied by cumulonimbus cloud (which preceded the cold front), preceded by large hailstones, and accompanied by reported wind gusts in the Inglewood area as high as 166 km/h from the northeast.

6.4 The Waitara (Tikorangi) tornado, 15 August 2004

This violent tornado occurred during the morning (between 6.00 and 7.00 am) of 15 August 2004. The tornado originated off shore (probably as a waterspout), travelling toward the Motunui area near Waitara, producing a lengthy trail of destruction, reported to be between 4 and 10 km long (MacAskill & Macbrayne, 2005) and anything from 20 to 500 m wide (MetService, 2004).

The tornado was very destructive, with a farmhouse at Tikorangi near Waitara totally demolished down to its foundations. The 4 sleeping occupants were literally tossed out of the house, two of which (a woman and child) were killed, and two were seriously injured. This was the first New Zealand tornado producing fatalities in since the Opunake event in 1991. All that was left of the house were its concrete piles. The house itself was shredded into arm length pieces and scattered up to 500m away (The New Zealand Herald, 2004). The tornado also lifted a roof off another house and sheds, and a glass house was also damaged, along with a large hole smashed through a shelterbelt, and many trees uprooted. About 70 cattle were reported to have been killed in this event (Met. Service, 2004). Four power poles were knocked down and another six lines snapped, with outages to over 6500 homes, some residents were without electricity for up to 5 hours.

This tornado was assessed as one of F3 magnitude on the Fujita Tornado Scale (Appendix 2) the most intense recorded in Taranaki, and the potential for more damage would have been high if a tornado of this magnitude had have occurred in a built-up and more populated locality. The tornado was accompanied by strong gusty northerly winds, thunderstorms and heavy rainfall, as well as hail.

The meteorological situation on 15 August near the time of the tornado (Figure 16), shows that a sharp trough of low pressure with embedded frontal bands (including cumulonimbus cloud and associated thunderstorms) was moving over New Zealand, with strong northwesterlies at gradient level ahead of a cold front lying in a north-south direction over New Plymouth. Strong northerly winds prevailed at New Plymouth Airport between 6-7am, with mean speeds as high as 50 km/h and gusts to 87 km/h. A cold front followed later (after 8am), with surface winds at the airport backing to the northwest. In the analyses of upper winds at 6am (not shown) noticeable horizontal and considerable vertical wind-shear (i.e. in direction and particularly wind speed) occurred between the surface (010º True, 52 km/h) and 900 metres (330 º True, 113 km/h), with a jet-stream maximum above the trough of 305 º True, 160 km/h at 4800 metres. Local extremes in EHI over the New Plymouth area at this time also occurred (Figure 12f).

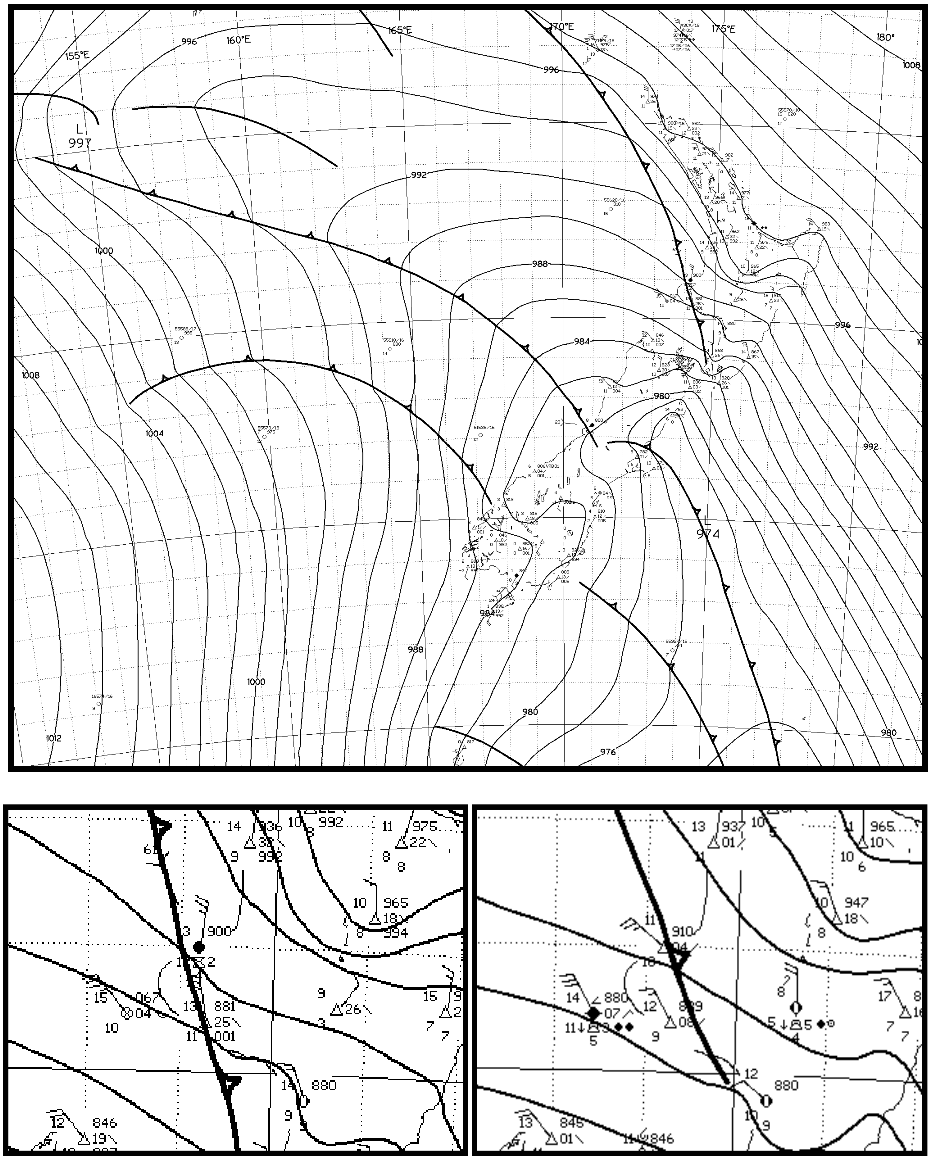


Figure 16 **Synoptic map at a) 0600 NZST 15 August 2004 showing contours of mean sea-level pressure (every 2 hPa) and the location of fronts, and zoomed in analyses over Taranaki for b) 0600 NZST and c) 0900 NZST. (Courtesy Meteorological Service of New Zealand Ltd).**

• As mentioned earlier (Section 3), a detailed computer simulation of this event was performed with the RAMS weather forecast model. The purposes of this simulation were to (i) better understand the meteorological environment in which the tornado formed (ii) test to see if the influence of Mount Taranaki on the flow might have favoured the formation of the tornado as suggested by Haslam (2006), and (iii) see if any rotating mesoscale feature that could possibly spawn a tornado is forecast. There is no intention of trying to actually simulate the tornado as even our 1 km grid spacing would be likely be insufficient to resolve the complex processes whereby tornadoes are spawned from parent storm circulations.

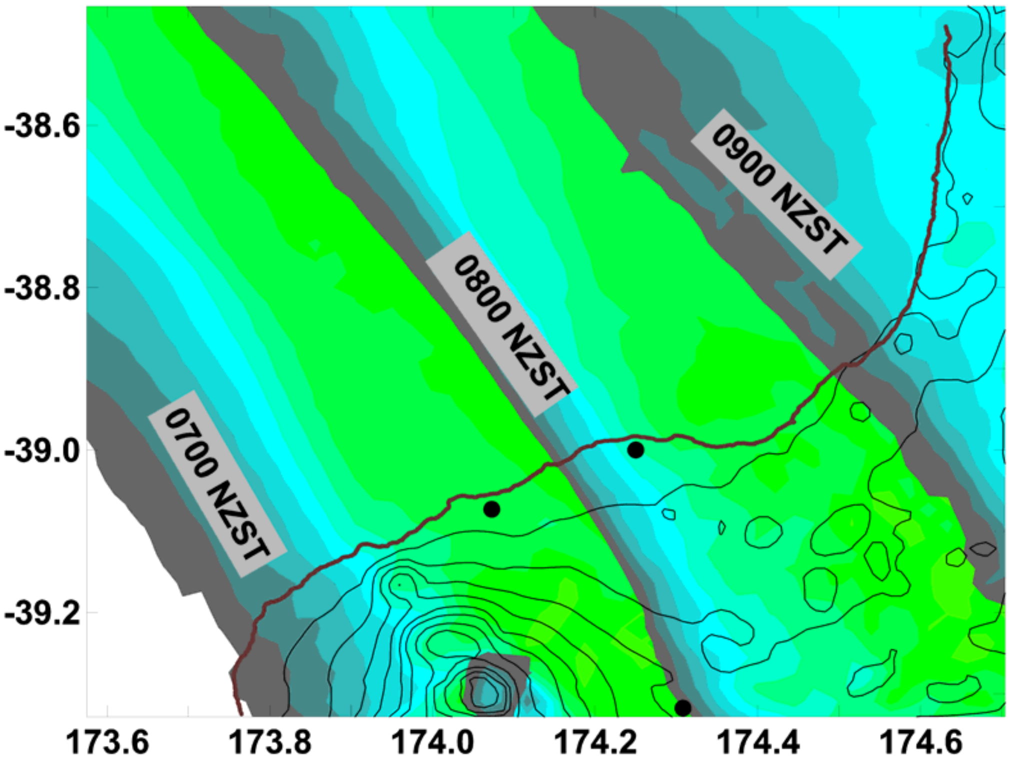


Figure 17 **The position of the cold frontal band, as indicated by the tight gradient in wind speeds on the morning of 15 August, 2004 as forecast by the RAMS 1 km model. The positions of New Plymouth, Waitara, and Stratford are marked by filled blacked circles. © NIWA.**

Figure 17 which shows the position of the cold front as forecast by the model indicates that the forecast had the cold front passing New Plymouth between 1 and 2 hours later than observed (based on changes in wind speed and direction at New Plymouth and Stratford). The orientation of the cold front appears to be well forecast also. Forecast surface (10 m above ground level) wind speeds ahead of the front at New Plymouth were about 55 km/h from 350º (based on a model forecast wind speeds of about 20 m/s (see Figure 18) at 95 m altitude and assuming a roughness length of 0.05 m and logarithmic profile), gradient level winds were forecast to be about 110 km/h (30 m/s) from 320º. These compare very well with the observations mentioned earlier of 52 km/h from 010º, and 113 km/h from 330º. The model also forecast the heavy showers (model rainfall rates of 15-25 mm/h) which occurred (see Figure 19). Thus we conclude that the high-resolution forecast has captured well the basic features of the flow that morning.

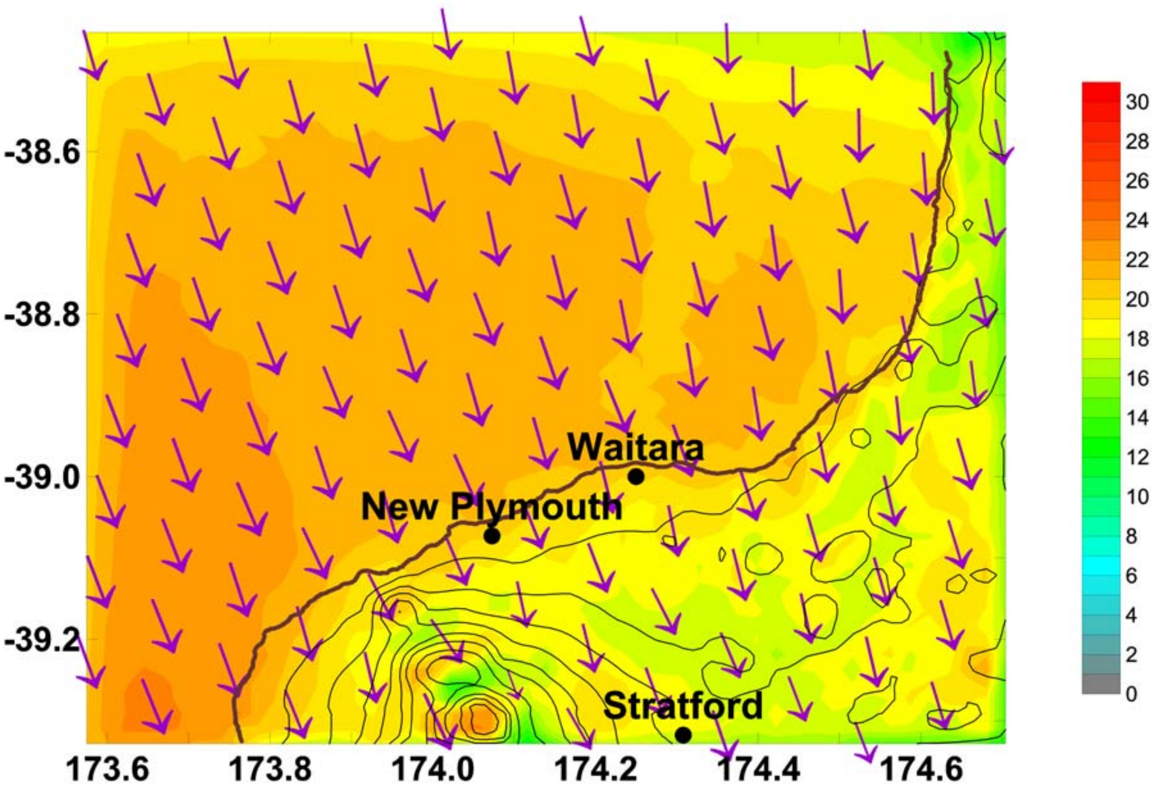


Figure 18 **Wind speed and wind vectors (every 47th vector only displayed) 95 m above ground level as forecast by the RAMS model on the 1 km grid at 0600 NZST 15 August, 2004. © NIWA.**

Since the tornado was short-lived occurred about 0600 NZST one to two hours ahead of the passage of the cold front we examined in detail the RAMS 1km model forecast about 0700 NZST (one to two hours ahead of the passage of the simulated cold front). This revealed a low-level feature embedded in the strong northwesterly flow in the vorticity and in the wind (mean flow removed) fields. Figure 20 shows the vertical component of relative vorticity (an indication of the amount of spin in the air, with negative values indicating cyclonic vorticity) over a portion of the 1 km grid at 0656 NZST at an altitude of 450 m above ground level and the south east track it took from 0644 to 0712 NZST (Figure 21). This vortex was at its most coherent during this period, it had developed in the northwestern part of the domain, strengthened as it moved southeast and decayed over land. It is intriguing that path was similar to that of the tornado (moving rapidly southeast from the sea and crossing the coast between Waitara and Urenui). It seems plausible that this forecast model feature might represent the parent mesoscale circulation that could have spawned the tornado.

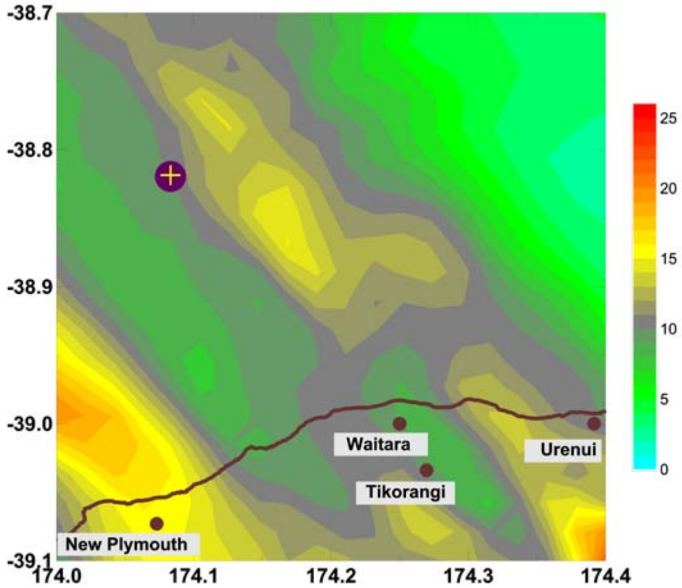


Figure 19 Instantaneous precipitation rate (mm/h) as simulated by the RAMS forecast model on the 1 km grid at 0656 NZST 14 August, 2005. © NIWA.

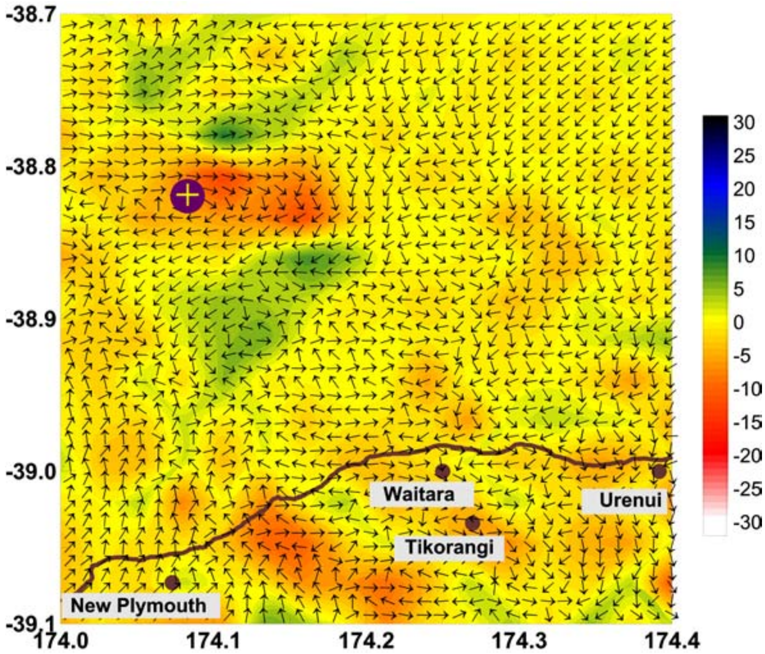


Figure 20 **The vertical component of relative vorticity (x10^{-4} m^{2}s^{-2}) as forecast by RAMS on a subset of the 1 km grid at 0656 NZST 15 August, 2004. The wind vectors with the background flow (westerly component 15 m/s, northerly component of 24.5 m/s) at 450 m above ground level removed are also shown. The apparent centre of the parent circulation is marked by the yellow cross in the purple circle. © NIWA.**

If it is the case that this feature does represent the parent mesoscale circulation that spawned the tornado, then it would be useful to document its model structure and the model environment it formed in. Firstly, this feature was shallow, it was only a noticeably coherent (vertically connected) feature below 1500 m (see Figures 22 and 23). At gradient level, above the track of the feature, lay an elongated region of maximum cyclonic vorticity stretched out parallel to and ahead of the front. The extreme values of SRH and EHI were -300 and -0.3. (SRH and EHI are discussed in section 2.2). Since hail was reported, strong updrafts and downdrafts associated with convection were likely occurring in the region and these may have been strong enough to tilt vorticity associated with the strong low-level shear to create a low-level mesoscale vortex that might spawned the tornado.

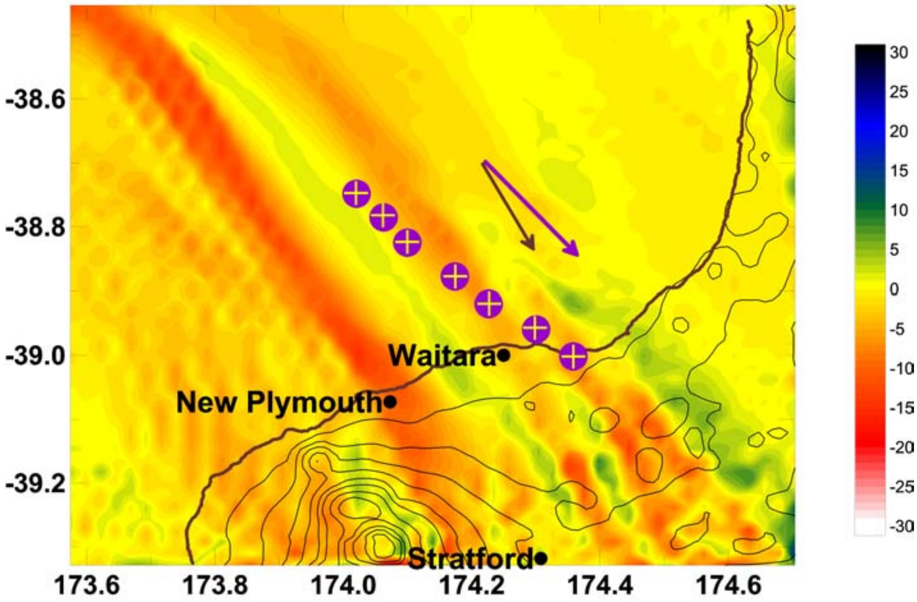


Figure 21 The "track" of the apparent centre of the parent circulation at 450 m above ground level as marked by the yellow crosses in the purple circles. The locations are marked every 4 minutes beginning at 0644 NZST and ending at 0712 NZST. The purple arrow shows the approximate mean direction of the track (which matches the wind at 1800 m AGL – close to the gradient level wind) and the brown arrow shows the mean wind at 450 m AGL. The colour filled contours are the vertical component of relative vorticity ($x10^{-4}$ m^2s^{-2}) at 1800 m AGL as forecast by RAMS on the 1 km grid at 1856 NZST 15 August, 2004. © NIWA.

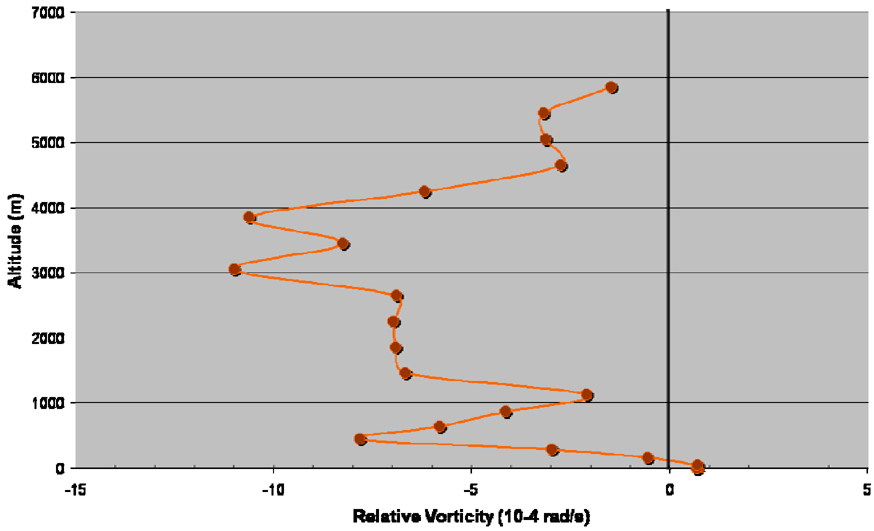


Figure 22 Vertical profile of the vertical component of relative vorticity at the location marked by the cross in Figure 17 at 0656 NZST 14 August 2006. © NIWA.

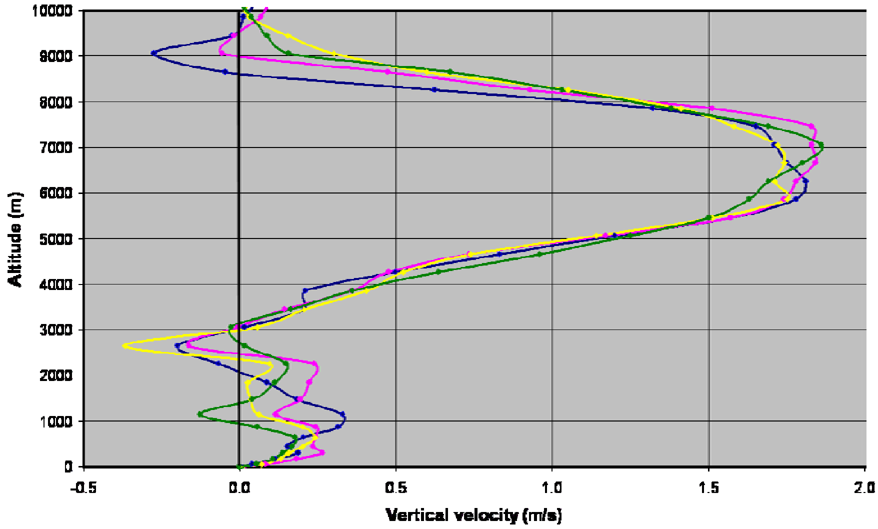


Figure 23 **Profiles of vertical velocity as simulated by the RAMS forecast model on the 1 km grid for 4 grid points near the location marked by the cross in Figure 17 at 0656 NZST 14 August, 2004. © NIWA.**

However, the model simulated vertical motions reveals upward vertical motion of only about 0.3 m/s below 2 km (Figure 23) in the vicinity of the vortex, which is much less than the 10 m/s than McCaul and Wesiman simulated with their low topped (3.5 km vertical extent) super cells for their low cape environment. (Although, their definition of a "low" value of CAPE is about 4 times higher than the values for the Waitara case). Stronger vertical motions (approx 2 m/s) were simulated between 6 and 8 km altitude (Figure 6.11), but these appear to be associated with the frontal dynamics as they were in a large elongated band parallel to the front. This suggests that a different mechanism might be responsible for the development of the low-level parent circulation than has been suggested by McCaul and Wesiman, for tornadoes spawned by low-topped supercells.

Thus it is very encouraging – in terms of improving the prospects for actual forecasting of Taranaki (and most other New Zealand) tornadoes - that a low-level mesoscale circulation was developed by a model in the correct time (relative to the front) and location within an accurately forecast larger scale flow. However, the strength of the vertical motions (as evidenced by the presence of hail) was probably underforecast by the model, so it is possible that the simulated low-level mesoscale circulation would not have shared all the characteristics of that which likely spawned the tornado.

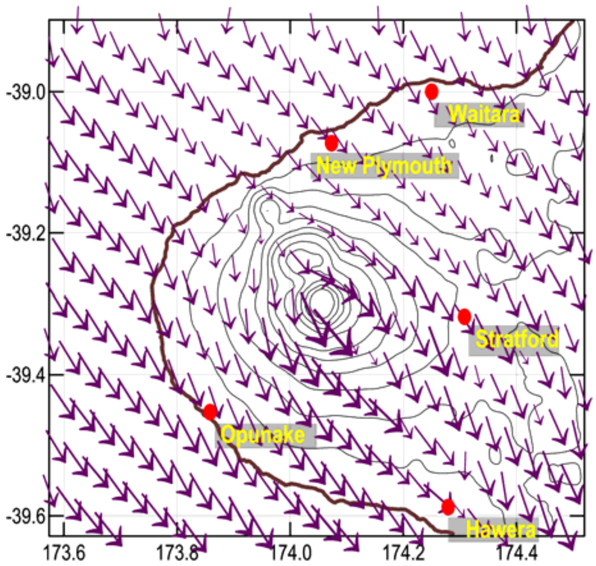


Figure 24 **Vectors showing deflection of wind (at 100 m altitude) caused by Mt. Taranaki form an idealized RAMS 1 km simulation of stable flow with a gradient level northwesterly of 15 m/s. © NIWA.**

On a final note, examining the wind vectors from the RAMS forecast model in the period 0 to 3 hours ahead of the front, showed that the pattern of deflection of the flow around Mt. Taranaki was more like that for a neutral case rather than a stable case (compare Figure 18 with 24) and there seems to be little influence on the flow in the area over the sea north and northwest of New Plymouth. Therefore, it would seem that Mt. Taranaki had little influence on the development, via enhanced helicity, on the Waitara tornado as suggested by Haslam (2006). Examining the pattern of SRH on high risk days (Figure 12) supports this contention where the influence of the central plateau is evident over the sparsely populated eastern Taranaki region, although the influence of Mt. Taranaki on SRH does appear as lobes of enhanced SRH whose axis from the east to points north and south of the mountain.

Haslam examined the use of a Storm-Relative Helicity Index (SRH), as a tornado forecasting tool (now in current operation by MetService and found that about 50% of damaging tornadoes could be forecast using the SRH Index. This included the Waitara event for which an SRH of -394 was computed, indicating that an F2 or F3 tornado was possible on that occasion, based on standard thresholds see Appendix 6). Haslam, however did not appear to look at false alarm rates which would have been very high. Similar detection numbers for SRH have been found examining the RAMS archive (Appendix 5). However, the EHI, with a reasonable threshold based on the low cape environments of many New Zealand tornadoes of -0.15, was found to detect over 90% tornado events that have occurred in New Zealand (predominantly in the West Coast and Taranaki) in the last 5 years (Appendix 5).

6.5 Annual variation of tornadoes in Taranaki

Analyses of the annual frequency of tornadoes in the Taranaki region (Figure 25), based on the 1951-2006 data), shows that tornadoes are relatively frequent in Taranaki, occurring in at least 50 percent of years, with an annual mean of 0.9 tornado days. Tomlinson's intensive study, based on the 1961-1975 period, showed higher values, with occurrences in 80 percent of years and an annual mean as high as 1.6 tornado days. A maximum of 5 days with tornadoes were reported in Taranaki during 1956. It is not possible to ascribe any long-term trend from the available data, due to the sporadic and isolated nature of many tornadoes, and limited reporting (not all occurrences will have been sighted) and resources.

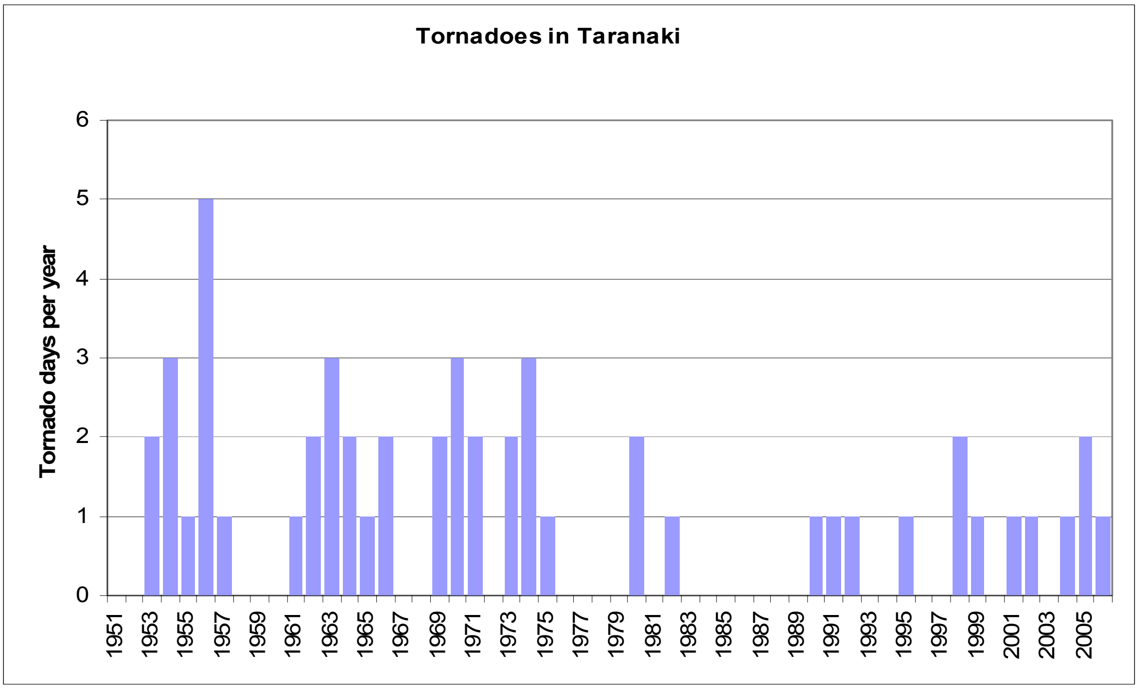


Figure 25 Annual days with tornadoes in Taranaki (1951-2006). © NIWA.

An inspection of the frequency of tornadoes in the Taranaki region, obtained from the tornado database prepared for this study (based on the available data from 1951-2006), shows that tornadoes were noticeably more frequent during August than other months (Figure 26). August had an accumulated total of 10 tornado-days, at least double the frequency of any other month. In contrast, tornado days were much less frequent in November, and were absent in January. A test of the tornado day data was conducted by stratifying the data into frequencies per decade (five decades). The analyses (Table 8) showed that the high frequency of occurrences in August was very noticeable between 1951 and 1960, less so between 1981 and 1990, and absent in the three other decades. This showed that a peak occurrence during August may not necessarily be an ongoing phenomenon. It is interesting to note though, that the most severe occurrences (the 1990 Inglewood and 2004 Waitara tornadoes) occurred during August.

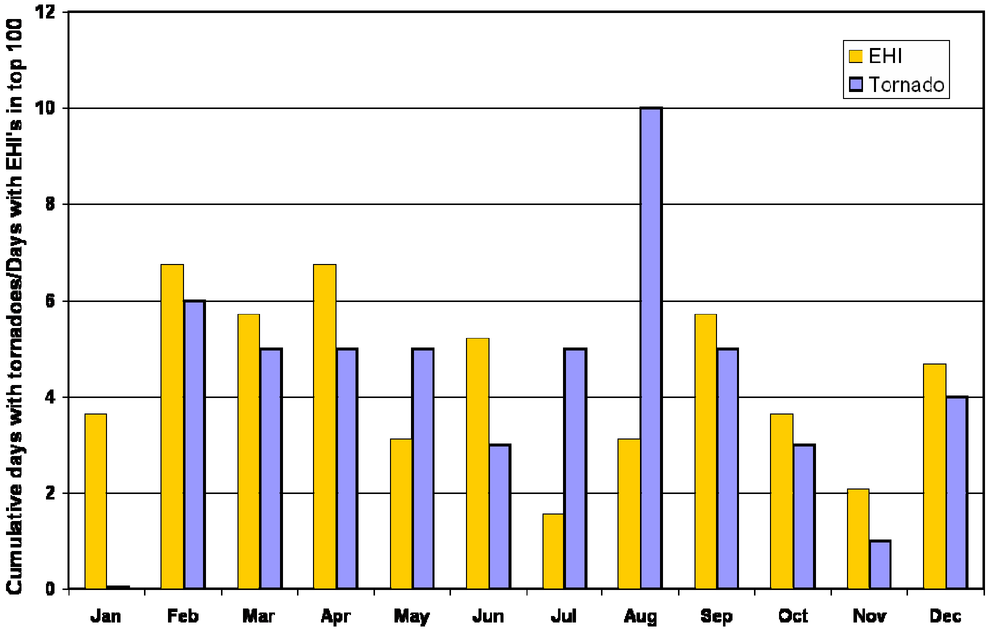


Figure 26 **Cumulative days with tornadoes in Taranaki between 1951 and 2006 (blue bars) and the monthly frequency (Jan 2002- April 2007) which had EHI's ranked in top 100 (yellow bars). © NIWA.**

Also plotted in Figure 26 is the number of top 100 EHI periods that occurred in each month (normalised to match the total number of tornadoes (52)), this captures the monthly trends reasonably well except that July and August are too low, and January too high. In contrast to the observations made earlier which indicated no trend in the time of day of tornado occurrence, a diurnal trend in EHI was noted, with about 20 (50%) more top 100 EHI periods being at 1200 and 1800 NZT than at 0000 and 0600 NZST. Given the relatively small number of tornado observations in the record and the fact that the time of occurrence was not always included with damage reports this does not discount the possibility that there is an actual diurnal trend.

PERIOD	SPRING (Sep-Nov)	SUMMER (Dec-Jan)	AUTUMN (Mar-May)	WINTER (Jun-Aug)	YEAR
1951-1960	2	1	3	6	12
1961-1970	3	4	4	5	16
1971-1980	1	1	4	4	10
1981-1990	1	0	0	1	2
1991-2000	1	2	2	1	6
2001-2006	1	2	2	1	6
1951-2006	**9**	**10**	**15**	**18**	**52**

Table 8 Accumulated days with tornadoes in Taranaki, by season

6.6 The El Niño-Southern Oscillation, Interdecadal Pacific Oscillation, and tornadoes

New Zealand's climate varies naturally with fluctuations in the prevailing westerlies and in the strength of the subtropical high-pressure belt. The two key natural cycles that operate over timescales of years (El Niño-Southern Oscillation, ENSO) and decades (Interdecadal Pacific Oscillation, IPO) have been described in an earlier report (Thompson et al., 2006).

The El Niño/Southern Oscillation (ENSO) modulates the occurrence of warmer and cooler than normal sea temperatures in the tropical Pacific (including the region surrounding New Zealand), and thus the occurrence of westerlies in our region. The Interdecadal Pacific Oscillation (IPO) is also known to modulate sea surface temperatures and possibly wind-flow over the Pacific Ocean.

The following sections try to identify any relationships between tornado frequencies in Taranaki and fluctuations in ENSO and IPO.

6.7 The El Niño-Southern Oscillation and tornadoes in Taranaki

The ENSO is a natural feature of the global climate system. El Niño events occur irregularly, often 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 events (Thompson et al, 2006) in New Zealand and the Pacific basin. These events are associated with changes in equatorial sea temperatures, which in turn affect the nature of the major convective and hence atmospheric circulation patterns, including the New Zealand region (Thompson et al., 2006).

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. The results are shown in Table 9. These results 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.

1951-2006	**El Niño**	**La Niña**	**Neutral**	**All**
Months with tornadoes	8 (16%)	11 (22%)	31 (62%)	50 (100%)
Months available	121 (18%)	89 (13%)	462 (69%)	672 (100%)
Anomaly	-2%	+9%	-7%	

1961-1975 (Tomlinson) only	**El Niño**	**La Niña**	**Neutral**	**All**
Months with tornadoes	1 (4%)	7 (29%)	16 (67%)	24 (100%)
Months available	20 (11%)	41 (23%)	119 (66%)	180 (100%)
Anomaly	-7%	+6%	+1%	

Table 9 Frequency of tornadoes in Taranaki, during El Niño, La Niña, and neutral seasons.

6.8 The Interdecadal Pacific Oscillation (IPO) and tornadoes in Taranaki

The Interdecadal Pacific Oscillation (IPO) is a long timescale oscillation in the ocean-atmosphere that creates shifts in the climate in the Pacific region every two to three decades. It is an ENSO-like feature operating on the decadal to multi-decadal time scale. A significant source of climate variation on the decadal scale in South West Pacific Region can be attributed to the phase of the IPO. More detail is given in Appendix 4, including classification of the phases.

The IPO has both positive and negative phases, which are associated with modulations in the frequency and intensity of ENSO events. During the positive phase of IPO, there is usually a tendency for an increase in frequency of El Niño events, with more prevalent westerlies over New Zealand and anticyclones in the north Tasman. In contrast, more La Niña episodes occur during the negative phase with weaker westerlies over New Zealand, and more easterlies and northeasterlies over northern New Zealand (Thompson et. al., 2006). Phase changes of the IPO occurred around 1922, 1945, and 1977. Despite phase changes, IPO values were near zero in the early 1960s. The IPO was also near zero in 2000, but has remained slightly positive since then.

IPO, 1951-2006	Positive	Negative	Neutral	All
Months with tornadoes	15 (30%)	24 (48%)	11 (22%)	50 (100%)
Months available	264 (39%)	207 (31%)	201 (30%)	672 (100%)
Anomaly	-9%	+17%	-8%	

Table 10 Frequency of tornadoes in Taranaki, during positive, negative, and neutral IPO periods.

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 are shown in Table 10. The results from Tomlinson's compilation could not be used because there were no data from the positive IPO phase. The results from the longer compilation 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. In summary, these results show the possibility (although it may be weak) of a relationship between the IPO and the occurrence of tornadoes in Taranaki.

6.9 High Risk Areas

Tornadoes pose a risk in that they produce high winds, which as detailed in this report, 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.

It does seem likely that the New Plymouth district may be more affected by Taranaki than other parts of Taranaki. Firstly, the majority (80%) of the reported tornadoes, including many of the severe cases, have occurred on the northern (New Plymouth) side of Mt Taranaki, the region being exposed to thunderstorms and unstable northwest air masses that have originated over the Tasman Sea in a region more prone to the development of tornadic storms (Figure 12). However, this study does show that 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 and seems to be due to the influence of the central plateau. There is a suggestion that the Mt. Taranaki influence although slight is most important in regions to the northeast and southeast of the mountain.

The worst tornados are serious enough to produce major structural damage to several buildings, along with some fatalities. The situation could be much worse if a severe tornado tracked through a very populated area, with a track several kilometres in length and possibly a few hundred metres wide. Perhaps it was fortunate that the fatal Waitara tornado missed the nearby Motunui synthetic fuel plant.

6.10 Knowledge gaps and future research

Prior to 2002 forecasts of tornadoes were not available so the conclusions reached by the modelling study are preliminary.

Some of the conclusions relating to the frequency and intensity of tornadoes reached in this study need to be treated as initial or at least minimal estimates, as not all tornadoes and their categorical details have been able to be captured.

In the mapping of tornado risk, similar maps with greater spatial resolution will only become available once a long period archive of higher resolution numerical analyses and forecast data become available. A 5 year archive of the 12 km New Zealand Local Area Model runs will be complete in July 2011. Alternatively, the forecasts for the top 100 EHI cases could be run on a high resolution RAMS grid, where results can be obtained within a few months.

One aspect that would benefit from further investigation is the detailed impacts of global climate change on tornado intensity and risk for the Taranaki Region. This would allow the determination of change in tornado risk over the region.

7. Climate change and high winds

Global warming effects are expected to accumulate during the 21st century, and enhance already observed changes in regional climate that have affected many physical and biological systems. Expected changes out to 2100 for New Zealand include: increases in westerly winds, increases in temperature of between 0.5 and 3.5°C, decreases in frost risk, wetter in the west and drier in the east, increases in the frequency of extreme daily rainfalls and sea level rises averaging 2 cm/decade.

The Intergovernmental Panel on Climate Change (IPCC) concluded in their Fourth Assessment Report that there is very high confidence that the globally averaged net affect of human activities since 1750 has been one of warming, and that warming is now unequivocal. The equilibrium climate sensitivity is a measure of the climate system response to sustained radiative forcing. It is not a projection but is defined as the global average surface warming following a doubling of carbon dioxide concentrations. It is *likely* to be in the range 2 to 4.5°C with a best estimate of about 3°C, and is *very unlikely* to be less than 1.5°C (IPCC, 2007).

Observed changes in regional climate have already affected many physical and biological systems, and further changes are expected to accumulate during the 21st century. Reductions of greenhouse gas emissions, even stabilisation of their concentrations in the atmosphere at a low level, will neither altogether prevent climate change or sea-level rise, nor altogether prevent their impacts. This is because of the inertia of the earth's interacting climate, ecological and socio-economic systems.

The broad pattern of expected New Zealand changes out to 2100 for New Zealand include: increases in westerly winds, increases in temperature of between 0.5 and 3.5°C, decreases in frost risk, wetter in the west and drier in the east, increases in the frequency of extreme daily rainfalls and sea level rises averaging 2 cm/decade.

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

Table 11 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 the annual mean. The mid-range projection for the 2080s is a 60% increase in the annual mean westerly component of the flow. Projected changes in the north-south wind component are less clear.

	Summer	Autumn	Winter	Spring	Annual
Current climate					
Westerly	2.94	2.28	2.16	4.28	2.92
Southerly	-0.30	0.71	0.86	0.15	0.35
Change by 2030s					
Westerly	-0.60 to +1.20	-0.17 to +2.03	-0.83 to +2.39	-0.96 to +1.41	-0.21 to +1.47
Southerly	-0.09 to +0.53	-0.12 to +0.58	-0.58 to +0.11	-0.31 to +0.54	-0.08 to +0.29
Change by 2080s					
Westerly	+0.01 to +1.82	-0.63 to +3.71	-1.80 to +5.50	-0.28 to +2.79	-0.11 to +3.43
Southerly	-0.18 to +0.57	-0.52 to +0.20	-1.47 to -0.09	+0.08 to +0.79	-0.39 to +0.32

Table 11. Projected changes in seasonal and annual westerly and southerly wind components (in m/sec) (MfE, 2004)

A first estimate of the change in frequency of strong winds can be made by assuming the shape of the statistical distribution of wind speeds remains similar to the present, but the distribution is displaced a little towards high speed values. As a result, for mid-range temperature change scenarios, the highest wind speed expected to occur once per year could increase by about 3% by 2080. 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. Uncertainties in these projected changes in extreme wind speeds are considerable.

On this basis the frequency of gale and storm force winds from the westerly quarter are very likely to increase over Taranaki as the 21st century progresses.

8. Summary

This report has discussed the nature and occurrence of high winds and tornadoes that affect the Taranaki region.

From the analysis, high winds in the Taranaki region are influenced by the topography with Mt Taranaki producing some strong orographic effects. Westerly quarter winds gave extremely high speeds on the leeward slopes of the mountain, and New Plymouth has its strongest winds from the southeast direction, whereas Stratford has very low wind speeds from this direction. The most marked increases occurred in southeast and southerly flows in areas to the north and northeast respectively of Mt Taranaki summit.

For New Plymouth, although westerly winds were more common for the lower return period extreme winds, the very rare high extreme winds came from the southeast, and this was similar for other stations near New Plymouth, as well as the Maui Platform. However, at Stratford these were more from the northerly quadrant, and southerly direction. For Hawera and Normanby, northwest winds gave the highest speeds.

In the analysis of annual extreme winds at New Plymouth airport since 1972 show a decrease in the intensity and number of days of extreme wind gusts. El Niño/Southern Oscillation events have little influence on extreme winds, although the frequency may be increased during El Niño events. No clear cut relationship exists between extreme winds and phases of the IPO. Climate change projections for New Zealand indicate an increase in mean westerly wind speed across New Zealand suggesting that gale or storm force westerly winds are likely to increase during the 21st century.

Tornadoes in Taranaki appear to be generated during unstable flow from the north and west, usually during the presence of a trough of low pressure and frontal activity over or west of Taranaki. On average about one damaging tornado will occur somewhere in the Taranaki region per year, with a severe case once in four years. On a national basis the Taranaki region has a high rate. The largest proportions of occurrence of tornadoes were reported in the New Plymouth district, especially in our near New Plymouth city.

Two case studies were examined in detail, which showed these originated offshore as waterspouts travelling towards the south or southeast. The proximity of Mt Taranaki appears to have little influence on tornado development.

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Appendix 1

The Beaufort scale of wind force.

Beaufort Number	Classification	Mean speed km/h	Mean speed knots	Mean speed m/s	Approx. Wind Pressure Pa	Description of effects
0	Calm	<1	<1	0-0.2	0	Smoke rises vertically
1	Light Air	1 – 5	1 – 3	0.3 – 1.5	0.5	Smoke drifts
2	Slight Breeze	6 - 11	4 – 6	1.6 -3.3	5	Wind felt on face, leaves rustle
3	Gentle Breeze	12 - 19	7 - 10	3.4 -5.4	10	Leave and small twigs in constant motion, extend light flag
4	Moderate Breeze	20 – 28	11 - 16	5.5 – 7.9	25	Raises dust and loose paper, small branches are moved
5	Fresh Breeze	29- 38	17 - 21	8.0 – 10.7	50	Small trees in leaf begin to sway
6	Strong Breeze	39 – 49	22 - 27	10.8 – 13.8	90	Large branches in motion, some whistling, umbrellas used with difficulty
7	Near Gale	50 – 61	28 - 33	13.9 – 17.1	145	Whole trees in motion, inconvenience when walking against wind
8	Gale	62 – 74	34 - 40	17.2 – 20.7	215	Breaks twigs break off, generally impedes progress
9	Strong gale	75 – 88	41 - 47	20.8 – 24.4	305	Slight structural damage may occur
10	Storm	89 - 102	48 - 55	24.5 – 28.4	420	Trees uprooted, considerable structural damage
11	Violent Storm	103 - 117	56 - 63	28.5 – 32.6	560	Widespread damage
12	Hurricane Force	118+	64+	32.7+	640	---

Appendix 2

Tornadoes

The large scale environmental conditions in which tornadoes occur are well known and typical soundings (profiles of atmospheric temperature, moisture, and wind) favourable for tornado development are classified into three types (Bluestein, 1993). The most violent tornadoes are spawned from super-cells which can have very strong updrafts (over 50 m/s) and these are mainly associated with what are known as Miller Type I soundings and occur mainly in the central plains of the USA. The sounding on the morning of the 2004 Waitara tornado (Figure 1) was of a Miller Type II sounding. This type of sounding is conditionally unstable and is characterized by a deep moist layer. This sounding is associated with weaker (but still potentially dangerous) tornadoes than the Miller Type I and is often seen with tornado outbreaks that sometimes accompany land-falling tropical or ex-tropical cyclones. The only unusual aspect of the Waitara sounding is that the CAPE (a measure of energy available for convection and accelerating updrafts) was very low (approx 150 J/kg when compared with typical values for violent central plains tornadoes which are often greater than 2000 J/kg, or for land-falling hurricanes (over 1000 J/kg) (McCaul and Weisman 1996) and even for typical British waterspouts and tornadoes (500 J/kg) (Knightley 2005).

The Fujita Tornado Scale

The **Fujita scale** (**F-Scale**), or **Fujita-Pearson scale**, is a scale for rating tornado intensity, based on the damage tornadoes inflict on human-built structures and vegetation. The official Fujita scale category was determined by meteorologists (and engineers) after examining damage, ground-swirl patterns, radar tracking, eyewitness testimonies, media reports and damage imagery, as well as photogrammetry/videogrammetry if video was available.

Category	Wind speed **km/h**	Wind speed **knots**	Wind speed **m/s**	**Damage example**	
F0	<116	<63	<32		chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged.
F1	116-180	63-97	32 – 50		Moderate damage. The lower limit is the beginning of hurricane wind speed; peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed.
F2	181-250	98-135			Considerable damage. Roofs torn off
F3	251-330	135-178	70 - 92		Severe damage. Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.
F4	331-415	179-224	92 – 115		Devastating damage. Well-constructed houses leveled; structures with weak foundations blown away some distance; cars thrown and large missiles generated.
F5	416-510	225-275	116 - 142		Incredible damage. Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile sized missiles fly through the air in excess of 100 m (100 yd); trees debarked; steel reinforced concrete structures badly damaged; incredible phenomena will occur.

The Fujita scale has recently been decommissioned (since 1 February 2007) in favour of a more accurate Enhanced Fujita (EF) Scale, which replaces it. The EF Scale improves on the F-scale on many counts—it accounts for different degrees of damage that occur with different types of structures, both man-made and natural. It also provides much better estimates for wind speeds, and sets no upper limit on the wind speeds for its strongest level.

The Enhanced Fujita Tornado Scale (replaced the older scale, from 1 Feb 2007)

Category	Wind speed **km/h**	Wind speed **knots**	Wind speed **m/s**	**Damage example**	**Potential damage**
EF0	105-137				Light damage. Peels surface off some roofs; some damage to gutters or siding; branches broken off trees; shallow-rooted trees pushed over.
EF1	138-178				Moderate damage. Roofs severely stripped; mobile homes overturned or badly damaged; loss of exterior doors; windows and other glass broken.
EF2	179-218				Considerable damage. Roofs torn off well-constructed houses; foundations of frame homes shifted; mobile homes completely destroyed; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
EF3	219-266				Severe damage. Entire stories of well-constructed houses destroyed; severe damage to large buildings such as shopping malls; trains overturned; trees debarked; heavy cars lifted off the ground and thrown; structures with weak foundations blown away some distance.
EF4	267-322				Devastating damage. Well-constructed houses and whole frame houses completely leveled; cars thrown and small missiles generated.
EF5	>322				Incredible damage. Strong frame houses leveled off foundations and swept away; automobile-sized missiles fly through the air in excess of 100 m (109 yd); high-rise buildings have significant structural deformation; incredible phenomena will occur.

http://en.wikipedia.org/wiki/Fujita_scale

Appendix 3. El Niño/Southern Oscillation (ENSO) and Interdecadal Pacific Oscillation (IPO)

El Niño/Southern Oscillation

The El Niño is a natural feature of the climate system. The term was originally used by fishermen for the occasional warming of waters along the Peruvian coast, which typically happens 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". 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 indicated in Figure 3, but its climate is significantly affected by changes in the atmospheric circulation (winds).

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 southwesterlies lead to lower rainfall. La Niña events bring roughly the opposite changes, with weaker westerlies in summer, and more northerly quarter winds, usually associated with enhanced rainfall in the district in winter and spring. 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 out of the north Tasman.

Interdecadal Pacific Oscillation

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.

The IPO also affects New Zealand's climate, and affects temperature and rainfall averages in each phase. The IPO is strongest in the North Pacific, but sea temperatures in the eastern equatorial Pacific ("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 Nino-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.

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. Westerly quarter winds and anticyclones are more prevalent over Taranaki, with slightly drier conditions and more showery rainfall from the west and south west. In the negative phase, with weaker westerlies over the country, more easterlies and north easterlies occur over northern New Zealand, and with increased tropical disturbances.

The IPO exhibits phase reversals once every 20-30 years. Previous phase reversals of the IPO occurred around 1922, 1945, and 1977. Because the IPO is a low frequency oscillation, values at the end of the series cannot be accurately estimated and might change significantly with an extra year of data. The IPO returned to near zero in 2000, but has since remained slightly positive because of El Niño activity since 2000. In the early 1960s and since 1998 IPO values were near zero: these periods were classified as IPO **neutral** in this study (Appendix 4).

Appendix 4: Catalogue of tornado and waterspout events reported in Taranaki and offshore areas.

DATE & Time	DESCRIPTION & reference	DISTRICT & location	DESCRIPTION OF DAMAGE, & TRACK DETAILS	FUJITA TORNADO SCALE & estimated wind speed	WEATHER CONDITIONS	ENSO PHASE	IPO VALUES
17 MAY 1934, 5pm	Tornado (a,b)	NEW PLYMOUTH City	LOCALISED SEVERE 8 house roofs damaged or totally lifted. Emerged from behind the Sugar Loaves at Moturoa and took an easterly course.	F1 116-180 km/h		Neutral	Positive
29 AUG 1936, afternoon	Tornado (b)	SOUTH TARANAKI Te Kiri (10km E of Opunake)	LOCALISED SEVERE Cow shed lifted 200 ft (61 m) into air and transported some distance. Other cow shed, haystacks, and house demolished. Path 2 miles (3.2 km) long, by 200 yards (183 m) wide.	F1-2 116-250 km/h	Torrential rain	Neutral	Positive
1937-1950	Insufficient information available					Neutral	Neutral
27 MAY 1953	Whirlwind (c)	NEW PLYMOUTH City	LOCALISED	F0 < 116 km/h		Neutral	Negative
17 AUG 1953	Tornado (c)	TARANAKI site not known	LOCALISED	F0 < 116 km/h		El Niño	Negative

Appendix 4 (continued): Catalogue of tornado and waterspout events reported in Taranaki and offshore areas.

DATE & Time	DESCRIPTION & reference	DISTRICT & location	DESCRIPTION OF DAMAGE, & TRACK DETAILS	FUJITA TORNADO SCALE & estimated wind speed	WEATHER CONDITIONS	ENSO PHASE	IPO VALUES
22 APR 1954	Whirlwind (c)	NEW PLYMOUTH Bell Block	LOCALISED SEVERE Farm buildings wrecked	F1 116-180 km/h	Cumulonimbus cloud	Neutral	Negative
14 OCT 1954	Whirlwind (c)	NEW PLYMOUTH Waitara	LOCALISED SEVERE Cottage lifted into the air, several sheds wrecked	F2 181-250 km/h	Cumulonimbus cloud	Neutral	Negative
17 DEC 1954	Whirlwind (c)	SOUTH TARANAKI Hawera	LOCALISED	F0 < 116 km/h		Neutral	Negative
10 AUG 1955	2 small tornadoes (c)	NEW PLYMOUTH City & Waitara	LOCALISED	F0 < 116 km/h		La Niña	Negative
7 JUN 1956	Small tornado (c)	NEW PLYMOUTH Bell Block	No damage reported			La Niña	Negative
29 JUN 1956	Small tornado (c)	NEW PLYMOUTH Oakura	No damage reported			La Niña	Negative
24 AUG 1956	2 small tornadoes (c)	TARANAKI site not known	No damage reported			La Niña	Negative

Appendix 4 (continued): Catalogue of tornado and waterspout events reported in Taranaki and offshore areas.

DATE & Time	DESCRIPTION & reference	DISTRICT & location	DESCRIPTION OF DAMAGE, & TRACK DETAILS	FUJITA TORNADO SCALE & estimated wind speed	WEATHER CONDITIONS	ENSO PHASE	IPO VALUES
26 AUG 1956	Small tornado (c)	TARANAKI Site not known	No damage reported			La Niña	Negative
12 SEP 1956	Small tornado (c)	NEW PLYMOUTH Waitara	No damage reported			Neutral	Negative
20 MAR 1957	Small tornado (c)	NEW PLYMOUTH City	LOCALISED SEVERE Considerable damage	F1-2 116-250 km/h		Neutral	Negative
10 FEB 1961, 9am	Waterspout (d)	NEW PLYMOUTH Urenui	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud	Neutral	Neutral
3 AUG 1962, 1am	Tornado (d)	NEW PLYMOUTH City	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud, moderate rain, WNW, 1006 hPa	Neutral	Neutral
5 SEP 1962, 3am	Tornado (d)	NEW PLYMOUTH City	LOCALISED SEVERE	F0 < 116 km/h	Thunderstorm, moderate rain, W, 1006 hPa	Neutral	Neutral

Appendix 4 (continued): Catalogue of tornado and waterspout events reported in Taranaki and offshore areas.

DATE & Time	DESCRIPTION & reference	DISTRICT & location	DESCRIPTION OF DAMAGE, & TRACK DETAILS	FUJITA TORNADO SCALE & estimated wind speed	WEATHER CONDITIONS	ENSO PHASE	IPO VALUES
28 MAR 1963, 10.30am	Tornado (d)	NEW PLYMOUTH Brixton (near Waitara)	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud, calm, 1024 hPa	Neutral	Neutral
8 NOV 1963, 11am	Tornado (d)	SOUTH TARANAKI Kapuni	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud, Strong N in New Plymouth, 999 hPa	Neutral	Neutral
15 DEC 1963, 2pm	Tornado (d)	SOUTH TARANAKI Okaiawa-Kapuni	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud, light NW in New Plymouth, showers 1015 hPa	Neutral	Neutral
14 JUL 1964, 1.45pm	Tornado (d)	NEW PLYMOUTH City	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud, light rain, Fresh N, 992 hPa	Neutral	Neutral
6 AUG 1964, 8am	Tornado (d)	NEW PLYMOUTH Urenui	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud, mod rain, Fresh NW , 989 hPa	La Niña	Neutral
20 MAY 1965, 4.10pm	Waterspout (d)	NEW PLYMOUTH City	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud, recent heavy rain, Mod NW, 1005 hPa	Neutral	Neutral

Appendix 4 (continued): Catalogue of tornado and waterspout events reported in Taranaki and offshore areas.

DATE & Time	DESCRIPTION & reference	DISTRICT & location	DESCRIPTION OF DAMAGE, & TRACK DETAILS	FUJITA TORNADO SCALE & estimated wind speed	WEATHER CONDITIONS	ENSO PHASE	IPO VALUES
18 SEP 1965, 2.25pm	Tornado (d)	NEW PLYMOUTH City	LOCALISED SEVERE	F0 < 116 km/h	Thunderstorms in the area, light rain, Mod N, 1011 hPa	El Niño	Neutral
9 APR 1966, after 10pm	Tornado (d)	NEW PLYMOUTH Waitara	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud, recent heavy rain, Mod NW , 1004 hPa	Neutral	Negative
29 APR 1966, 9pm	Tornado (d)	NEW PLYMOUTH City	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud, moderate rain, Fresh NNE, 1003 hPa	Neutral	Negative
26 FEB 1969, 10.20am	Tornado (d)	NEW PLYMOUTH City	LOCALISED SEVERE	F0 < 116 km/h	Rain in sight, Light NE, 1024 hPa	Neutral	Negative
27 JUN 1969 1.30am	Tornado (d)	NEW PLYMOUTH City	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud with cold front, moderate rain, Fresh NW, 997 hPa	Neutral	Negative
26 FEB 1970, 1.10pm	Waterspout (d)	NEW PLYMOUTH Waitara	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud, rain in sight, Light NW, 1018 hPa	Neutral	Negative

Appendix 4 (continued): Catalogue of tornado and waterspout events reported in Taranaki and offshore areas.

DATE & Time	DESCRIPTION & reference	DISTRICT & location	DESCRIPTION OF DAMAGE, & TRACK DETAILS	FUJITA TORNADO SCALE & estimated wind speed	WEATHER CONDITIONS	ENSO PHASE	IPO VALUES
12 JUL 1970, 4.30am	Tornado (d)	NEW PLYMOUTH Waitara	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud, light rain, Fresh N, 1010 hPa	Neutral	Negative
17 SEP 1970 5.30am	Tornado (d)	SOUTH TARANAKI Rahotu (8km SE of Cape Egmont)	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud, Near gale N, 1009 hPa	La Niña	Negative
12 MAY 1971	Tornado (d)	SOUTH TARANAKI Rahotu (8km SE of Cape Egmont)	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud	La Niña	Negative
14 MAY 1971, 4.30am	Tornado (d)	NEW PLYMOUTH City	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud, heavy rain, Gale NNE, 998 hPa	La Niña	Negative
14 MAY 1971, 5.20am	Tornado (d)	STRATFORD Midhirst (5km N of Stratford)	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud	La Niña	Negative
14 MAY 1971, early am	Tornado (d)	NEW PLYMOUTH Egmont Village (4km W of Inglewood)	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud	La Niña	Negative
28 AUG 1971, 10am	Tornado (d)	NEW PLYMUTH Okato (10km SW of Oakura)	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud, light rain, Fresh N, 1005 hPa	La Niña	Negative

Appendix 4 (continued): Catalogue of tornado and waterspout events reported in Taranaki and offshore areas.

DATE & Time	DESCRIPTION & reference	DISTRICT & location	DESCRIPTION OF DAMAGE, & TRACK DETAILS	FUJITA TORNADO SCALE & estimated wind speed	WEATHER CONDITIONS	ENSO PHASE	IPO VALUES
23 MAR 1973, 10pm	Tornado (d)	NEW PLYMOUTH City	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud, light rain, Fresh WSW, 1007 hPa	Neutral	Negative
22 APR 1973, 8.30am	Waterspout/Tornado (c,d)	SOUTH TARANAKI Opunake	LOCALISED SEVERE One man killed, considerable damage, with several houses seriously damaged or demolished. 16 km trail, 15-45 m wide, moved at 10-15 knots, began as waterspout	F2 181-250 km/h	Cumulonimbus cloud, Fresh NNW at New Plymouth, 1009 hPa	Neutral	Negative
1 MAR 1974, 6.30am	Tornado (d)	SOUTH TARANAKI Hawera	LOCALISED SEVERE 1.5 km trail	F0 < 116 km/h	Cumulonimbus cloud, followed by hail, cold front, 1007 hPa	La Niña	Negative
9 JUL 1974, 1pm	Waterspout (d)	NEW PLYMOUTH City	LOCALISED SEVERE 30 m wide trail, 7- 8 minutes	F0 < 116 km/h	Cumulonimbus cloud, preceding cold front, showers, Fresh NNW, 994 hPa	La Niña	Negative
9 DEC 1974, 1.30pm	Tornado (d)	NEW PLYMOUTH Oakura (near New Plymouth)	LOCALISED SEVERE	F0 < 116 km/h	Cumulonimbus cloud, preceding cold front, showers, Fresh NNW, 993 hPa	Neutral	Negative

Appendix 4 (continued): Catalogue of tornado and waterspout events reported in Taranaki and offshore areas.

DATE & Time	DESCRIPTION & reference	DISTRICT & location	DESCRIPTION OF DAMAGE, & TRACK DETAILS	FUJITA TORNADO SCALE & estimated wind speed	WEATHER CONDITIONS	ENSO PHASE	IPO VALUES
14 JUL 1975, 11am	Small tornado (c,d)	NEW PLYMOUTH City	LOCALISED SEVERE 2.5 km trail, 45 m wide, formed near coast	F0 < 116 km/h	Cumulonimbus cloud, Mod W, 1001 hPa	La Niña	Negative
JUL 1980	Tornadoes (c)	TARANAKI site not known	LOCALISED SEVERE damage to a number of farms	F0 < 116 km/h	Thunderstorm with hail	Neutral	Positive
10 Sep 1980, 3am	Tornado (c)	NEW PLYMOUTH site not known	LOCALISED SEVERE Considerable damage to farm buildings, loss of livestock	F0-F1 <116-180 km/h	Violent thunderstorms, heavy rain, Strong N, 991 hPa	Neutral	Positive
19 Sep 1982 7am	Tornado (c)	NEW PLYMOUTH near City	LOCALISED	F0 < 116 km/h	Thunderstorm, moderate rain, Fresh N, 1021 hPa	El Niño	Positive

Appendix 4 (continued): Catalogue of tornado and waterspout events reported in Taranaki and offshore areas.

DATE & Time	DESCRIPTION & reference	DISTRICT & location	DESCRIPTION OF DAMAGE, & TRACK DETAILS	FUJITA TORNADO SCALE & estimated wind speed	WEATHER CONDITIONS	ENSO PHASE	IPO VALUES
12 AUG 1990 3.22-3.32am	Tornado (e,f,g)	NEW PLYMOUTH Bellblock and Inglewood	LOCALISED SEVERE 69 houses damaged, 30 considerably so, 3 completely rebuilt. Extensive damage to Inglewood Primary School - reopened 16 Aug 1990. 179 Insurance claims totaling $1.4 M ($1990). Considerable amounts of damaged and uprooted trees. No serious injuries. Traveled from the coast into Inglewood and out towards South Inglewood. Trail of destruction 1.5 km long by 200 m wide.	F2 181-250 km/h	Preceded by large hailstones, Cumulonimbus cloud, Near gale NE AT New Plymouth, 166 km/h reported at Inglewood, 997 hPa	Neutral	Positive
18 AUG 1991 between 6 & 8am	Tornado (e)	NEW PLYMOUTH City	LOCALISED SEVERE Roof blown off houses (7 properties severely damaged) - damage estimated $1 M ($1991). 2 km long trail of destruction.	F1-2 116-250 km/h	Cumulonimbus cloud , showers, Near gale W, 1003 hPa	Neutral	Positive

Appendix 4 (continued): Catalogue of tornado and waterspout events reported in Taranaki and offshore areas.

DATE & Time	DESCRIPTION & reference	DISTRICT & location	DESCRIPTION OF DAMAGE, & TRACK DETAILS	FUJITA TORNADO SCALE & estimated wind speed	WEATHER CONDITIONS	ENSO PHASE	IPO VALUES
2 FEB 1992	Tornado (h)	NEW PLYMOUTH Motunui	No damage reported			El Niño	Positive
13 APR 1995, 3.30 pm	Tornado (i)	STRATFORD 2km south of Stratford	No damage reported		1011 hPa	Neutral	Positive
21 FEB 1998, 6.30-7.30am	Tornado (i)	SOUTH TARANAKI Hawera, Greenlane	No damage reported		1013 hPa	El Niño	Positive
15 OCT 1998, between 6 & 9am	Tornado (k)	TARANAKI site not known	No damage reported		Thunderstorms, Near gale N, 995 hPa	La Niña	Positive
23 MAR 1999, afternoon	Tornado (k)	NEW PLYMOUTH Okato (10km SW of Oakura)	No damage reported			La Niña	Positive
12 DEC 2001	Waterspout (l)	TARANAKI OFFSHORE from Maui Gas platform	No damage reported		Thunderstorm with heavy rain	Neutral	Positive
22 MAY 2002	Tornadoes (l)	NEW PLYMOUTH Inglewood (1) and Bell Block (2)	LOCALISED SEVERE Inglewood ripped apart a shed and snapped trees in two. Two small tornadoes also did minor damage at Bell Block.	F0 < 116 km/h	Thunderstorm with heavy rain, < 1005 hPa	El Niño	Positive

Appendix 4 (continued): Catalogue of tornado and waterspout events reported in Taranaki and offshore areas

DATE & Time	DESCRIPTION & reference	DISTRICT & location	DESCRIPTION OF DAMAGE, & TRACK DETAILS	FUJITA TORNADO SCALE & estimated wind speed	WEATHER CONDITIONS	ENSO PHASE	IPO VALUES
15 AUG 2004, 6am	Tornado (k,m,n)	NEW PLYMOUTH Motunui (near Waitara)	LOCALISED VIOLENT Very destructive, destroyed a house near Waitara to its foundations, dumping 4 sleeping occupants and resulted in the death a woman and one child. Another child seriously injured. The roof was lifted off another house, and sheds and a glass house were also damaged. Smashed a whole through a shelter belt. Snapped power poles, uprooted many trees, power cut to 1200 homes. Debris strewn several hundred metres. About 70 calves reported to have died. First fatal tornado event in NZ since 1991 in Albany, when 1 man was killed. Came off sea. Up to 10 km path of damage, reports varied width at least 20 m wide. Affected Epiha Road, assessed as F3 (Fujita scale), 70 calves lost, power supply cut to a large area from Motunui to Mt. Messenger after winds knocked down 4 power poles and damaged another 6, lines also damaged.	F3 251-330 km/h	Thunderstorms, heavy rain, small hail Strong N gust to 87 km/h at New Plymouth, 990 hPa	El Niño	Positive

Appendix 4 (continued): Catalogue of tornado and waterspout events reported in Taranaki and offshore areas

DATE & Time	DESCRIPTION & reference	DISTRICT & location	DESCRIPTION OF DAMAGE, & TRACK DETAILS	FUJITA TORNADO SCALE & estimated wind speed	WEATHER CONDITIONS	ENSO PHASE	IPO VALUES
2 MAY 2005, early am	Tornado (o)	NEW PLYMOUTH Motunui to Urenui	LOCALISED SEVERE High winds, attributed to a tornado, affected Taranaki, between Motunui and Urenui during the early morning on the 2nd, damaging an orchard, and destroying a farm shed.	F0 < 116 km/h	Heavy rain, NNW, gust to 45 km/h at New Plymouth, 1017 hPa	Neutral	Positive
9 OCT 2005	Tornado (o)	NEW PLYMOUTH City	LOCALISED SEVERE Roofs lifted off 6 houses, windows and doors blown in. flooding	F1 116-180 km/h	Thunderstorm with heavy rain	Neutral	Positive
8 FEB 2006, morning	Tornado (p)	NEW PLYMOUTH Oakura Holiday Park	LOCALISED SEVERE Hit beach camp, lifted 2 caravans, 2 cabins, and extensive damage to toilet block roof, and portable (3 Tonne) cabin, A few trees were missing, cost $40,000 ($2006).Sounded like a train coming. Trail of destruction, came from the beach headed inland.	F1 116-180 km/h	Heavy rain 1014 hPa	Neutral	Neutral

References for Appendix 4

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c Met. Obs. for 1951-87, N.Z. MetS., Misc. Pub. 109

d Tomlinson, A., I. and Nicol, B., 1976: Tornado Reports in N.Z. 1961-1975, N.Z.MetS. Tech Note 229

e N.Z. MetS. Monthly Climate Summaries, 1988-1991

f Civil Defence, CD 515, No 7.

g Taranaki Regional Council Report (1990)

h Unreferenced media articles

i Daily News, 1995

j Daily rainfall obs. Form 302, Hawera E94528

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l Met. Society of N.Z. (Inc.), Newsletters 76-106, (1999-2006)

m Macbrayne, R, The NZ Herald, 16 Aug 2004, & MacAskill, K.. 2005

n NIWA Climate Digest 1994-2006

o NIWA National Climate Summaries 1992-2006

p Taranaki Daily News (9 Feb 2006)

Appendix 5 Selected severe weather indices for recent Taranaki and other notable New Zealand tornadoes.

Table showing values of CAPE, SRH, and EHI severe weather indices for recent Taranaki tornadoes and water spouts as well as other recent notable New Zealand tornadoes. The rankings are from a population of 7400 analysis periods (every 6 hours from 1 Jan 2002 through 31 May 2007). Red boldfaced type indicates a rank in the top 100 (top 1.3%), green indicates top 200 (top 2.7%) and blue indicates top 600 (top 8%). Note, MX T indicates the ranking was from the maximum for all grid points within the Taranaki region, NP indicates the ranking was from the New Plymouth Grid point only, MX W indicates the ranking is from a separately analysed region around Greymouth. Model 100 m AGL wind speeds for points off the New Plymouth and Greymouth coasts are also shown.

TIMES NZST	CAPE		SRH		EHI		Speed/Dir
Taranaki	Rank	Value (J/kg)	Rank	Value (m^2/s^2)	Rank	Value(m^2/s^2)	km/h / deg
2002052300 (MX T)	**74**	*705*	**568**	*-253*	**53**	*-0.48*	
2005052300 (NP)	**62**	*375*	**484**	*-142*	**13**	*-0.33*	*27/350*
2004081506 (MX T)	2338	*137*	**66**	*-567*	**199**	*-0.29*	
2004081506 (NP)	1174	*120*	**113**	*-297*	**44**	*-0.22*	*74/350*
2005050212 (MX T)	1205	*248*	3224	*-82*	1066	*-0.10*	
2005050212 (NP)	**379**	*236*	2382	*-47*	**470**	*-0.07*	*24/350*
2005100812 (MX T)	**492**	*390*	854	*-211*	**157**	*-0.32*	
2005100812 (NP)	**225**	*279*	1079	*-88*	**116**	*-0.15*	*54/230*
2006020806 (MX T)	1951	*170*	3698	*-72*	3159	*-0.02*	
2006020806 (NP)	1297	*110*	4234	*-19*	1724	*-0.01*	*30/340*
Greymouth Area							
20030220 (MX W)	**199**	*511*	**148**	*-390*	**6**	*-0.75*	*49/280*
20030616 (MX W)	847	*290*	**267**	*-320*	**234**	*-0.24*	*50/260*
20050105 (MX W)	1466	*212*	**351**	*-293*	**503**	*-0.16*	*23/350*
2005031012 (MX W)	**209**	*502*	**331**	*-297*	**10**	*-0.58*	*62/320*

Appendix 5 ctd.

TIMES NZST	CAPE		SRH		EHI		Speed/Dir
	Rank	Value (J/kg)	Rank	Value (m^2/s^2)	Rank	Value(m^2/s^2)	km/h / Deg
Greymouth Area							
20050905 (MX W)	1157	*247*	**433**	*-275*	**561**	*-0.15*	*51/10*
2006061118 (MX W)	659	*325*	**286**	*-312*	**58**	*-0.45*	*49/330*
2007051112 (MX W)	**535**	*358*	**215**	*-341*	**88**	*-0.36*	*60/310*
Other Locations							
Waimate							
2006030812 (MX W)	**177**	*531*	**183**	*-357*	**34**	*-0.52*	*41/250*
Kapiti							
2006040812 (MX T)	**99**	*640*	**293**	*-327*	**16**	*-0.70*	*43/330*
Kaipara							
2006051106 (MX T)	**194**	*536*	1361	*-166*	**398**	*-0.21*	*42/330*
Waikato							
2006071212 (MX T)	**105**	*630*	**378**	*-192*	**489**	*-0.18*	*33/330*
Ohiwa/Waiotahi							
2006110912 (MX T)	683	*338*	708	*-231*	**180**	*-0.30*	*59/230*

Appendix 6: Thresholds for CAPE, SRH, and EHI used in severe weather forecasting.

Index	Range	Comment
CAPE	< 0 J/kg	Stable
CAPE	0 – 1000 J/kg	Marginally unstable
CAPE	1000-2500 J/kg	Moderately unstable
CAPE	2500-3500 J/kg	Very unstable
CAPE	>3500 J/kg	Extremely unstable
SRH	-150 - -299 m^2/s^2	Supercells with weak tornadoes according to Fujita scale
SRH	-300 - -499 m^2/s^2	Very favourable for supercell development and strong tornadoes
SRH	<-500 m^2/s^2	Violent tornadoes
EHI	=1 m^2/s^2	Possible tornadoes (CAPE Threshold 160,000)
EHI	>1 and < 2 m^2/s^2	Moderate to strong tornadoes (CAPE Threshold 160,000)
EHI	> 2 m^2/s^2	Strong tornadoes (CAPE Threshold 160,000)