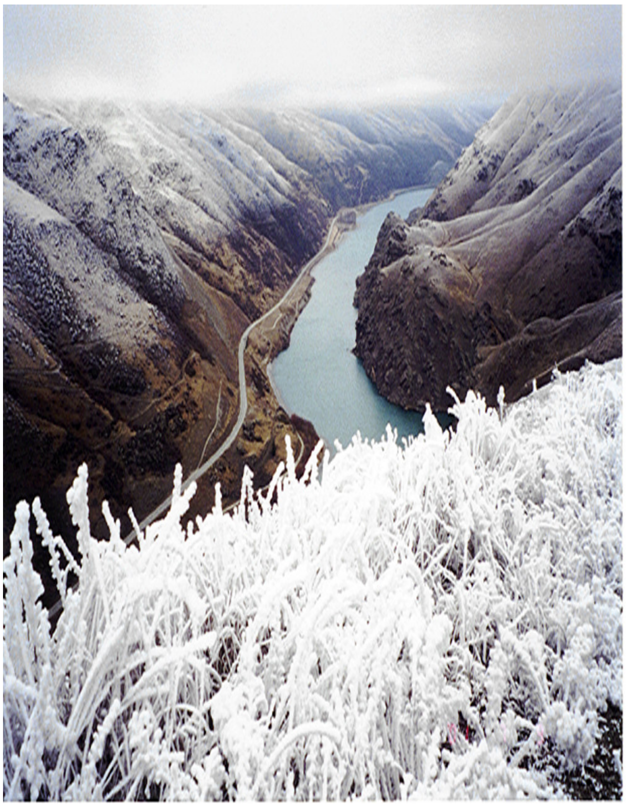
NIWA
Taihoro Nukurangi

Assessing Hawke's Bay Frost Risk



NIWA Client Report: AKL2003-128
October 2003

NIWA Project: HBG04101

Assessing Hawke's Bay Frost Risk

Authors
Ashmita Gosai
Dr Jim Salinger
Dr Andrew Tait

Prepared for

Hawke's Bay Grape Growers Association Inc.

NIWA Client Report: AKL2003- 128
October 2003

NIWA Project: HBG04101

National Institute of Water & Atmospheric Research Ltd
269 Khyber Pass Road, Newmarket, Auckland
P O Box 109695, Auckland, New Zealand
Phone +64-9-375 2050, Fax +64-9-375 2051
www.niwa.co.nz

Contents

Reviewed by: *Approved for release by:*

…………………… ……………………

Dr Brett Mullan **Jeff Bluett**

Formatting checked

………………………

Executive Summary

1. Grapegrowers in Hawkes Bay were adversely affected by three frosts during spring of 2002, during the early mornings of 15 September, 26 September and 5 October. These three frosts had a serious cumulative impact, with the news media reporting a 70% reduction was likely in the Hawkes Bay Chardonnay crop. Subsequent discussions between the Hawke's Bay Grapegrowers Association and NIWA established that research was necessary to assess the risk of damaging frosts in the typical grape growing areas of Hawke's Bay, with a particular focus on the Heretaunga Plains area.

2. This work assesses the spatial variation of frost hazard across present and some potential future grape-growing areas of Hawke's Bay based on the historical and current climate monitoring network. The coverage was augmented by shorter term temperature records from grower observational sites. As part of these investigations, evidence of long-term trends in frost frequency was analysed for differences in frost risk between the various phases of the Southern Oscillation: El Niño, normal and La Niña springs. Any evidence for relationships between frost risk and the Interdecadal Pacific Oscillation have also been examined.

3. Shorter term records together with a long-term site were successfully used to calculate pseudo records for long-term studies. This has enabled frost risk to be assessed in a wider area than that covered by long-term climate monitoring. The short term monitoring of temperatures can be used for this purpose with a minimum of four seasons data. The long term records were examined from three sites, with shorter term records used from twelve sites.

4. Three categories of critical minimum air temperatures were identified – light frost, moderate frost and severe frost. **Light Frost** is when the minimum temperature is in the range 0.0°C to –0.9°C, **Moderate Frost** –1.0°C to –1.9°C and **Severe Frost** –2.0°C and below.

5. There was considerable spatial variability in all categories of frost incidence. Typically frost probabilities were much higher in Kereru, Tikokino and Havelock North (old DSIR site) than in other parts of the Heretaunga Plains. Thus the risk of light or moderate frost extends right to the end of October at such locations, with a very low probability of light frosts in the first week of November. These locations also had a risk of severe frosts in October.

6. There were also locations with a low frost risk – Tukituki, Napier (Nelson Park), Hastings, Hastings Fire Station, Dartmoor and Taradale. At such locations frost risk was largely over by the end of September. For other locations, the risk of light frosts declined rapidly during September, with a 30% probability at the beginning of October declining to about 5% in the last week of October. Moderate frost probability was lower, declining from about 35% at the

beginning of September to 5-10% at the beginning of October. Severe frost probabilities declined from 25% in early September to nil for the period 6-10 October.

7. The various phases of the Southern Oscillation changed the frost risk probability. Frost risk was highest in the El Niño phase when more frequent cooler southwesterly airflow predominates over New Zealand. This increased the frost risk in the spring season, with the risk of freezing temperatures extended into late October, especially at the cooler sites analysed.

8. In comparison, La Niña springs with milder northwesterly winds and onshore north easterlies had a reduced risk of frost. The probability of frost occurrence in October was low. Neutral seasons displayed intermediary risk.

9. The incidence of frost in Hawke's Bay has changed between the negative phase (1946-1977) and positive phase (1978-1998) of the Interdecadal Pacific Oscillation (IPO). This is partly a result of regional increases in minimum temperature due to global warming, which has reduced the incidence of late frosts in the more recent positive IPO period. However, the occurrence of frost in the early part of spring *increases* in the positive phase of the IPO, compared with the negative phase, most likely because of the higher frequency of El Niño events and more frequent westerly winds in the positive IPO phase.

10. This assessment of spring frost risk in Hawke's Bay shows that there is considerable spatial variability in the Heretaunga Plains area. In some areas the risk is extremely low, and in others very high. Climate variability due to the phases of the Southern Oscillation and IPO alter the risk.

11. These studies are very cost-effective in providing information for decision-making on frost protection. The techniques can be used to analyse further sites, or more in-depth analysis for climate variability factors at more of the sites assessed.

Introduction

For some cropping activities, the effects of frost and damaging temperatures can be devastating. Certain crops planted during spring, or subtropical grass species, can be destroyed under the influence of freezing temperatures. Other crops, particularly fruit, rely on below freezing winter temperatures in order to induce flowering and fruit production during the following spring and summer.

After damaging temperatures have occurred, certain plants will look as if they have been burnt slightly once they are exposed to the sun. Further episodes of damaging low temperatures will be fatal. Many factors determine whether a given low temperature will cause damage to fruit, buds or blossoms. The length of time the low temperature persists, the stage of crop development, and the weather preceding and following the frost, are all important for the amount of damage sustained. Critical temperatures also depend on the crop cultivar. Some cultivars are relatively hardy, whilst others are more susceptible. The crop development stage is also important. The more advanced the cropping stage is, the higher the critical temperature. Critical temperatures for grapes are -1°C when buds are closed but showing colour and -0.5°C when flowers are in full bloom or there are small green fruit (Stans, 1970)

Grapegrowers in Hawkes Bay were adversely affected by three frosts during spring of 2002, during the early mornings of 15 September, 26 September and 5 October. These three frosts had a serious cumulative impact, with the news media reporting a 70% reduction was likely in the Hawkes Bay chardonnay crop. Screen frosts[1] do occur in September and October in Hawke's Bay. For example the previous five years of records from the automatic climate station at Whakatu (Lawn Road) indicate one frost in each of October and November (ie an average of 0.2 frosts per year), and an average of 3 frosts per year in September. However the 26 September and 5 October 2002 frosts were unusually severe for that time of year. During both frosts air temperatures recorded at Whakatu fell below –2°C, and were the lowest since 2 June 2002.

During November 2002 Drs Jim Salinger and David Wratt of NIWA met with Grapegrowers' Association and wine company representatives in Napier and Hastings. As a result of discussions during these meetings, a proposal was prepared describing

[1] A *screen frost* occurs when the temperature measured in an instrument screen at the standard height (1.3m above ground) drops below 0°C. A *ground frost* occurs when the "grass minimum" temperature (measured near ground level) drops below –1.0°C.

work that could be done to improve knowledge about frost characteristics and risk, focussing on information that would assist growers to make management decisions relating to frost protection. Following further discussions, agreement was reached with the Hawke's Bay Grapegrowers Association on an assessment of the frost risk in parts of the grapegrowing areas of Hawke's Bay.

This work addresses the spatial variation of frost hazard across present (and potential future) grape-growing areas of Hawke's Bay based on the historical and current climate monitoring network, with augmentation from grower based observing sites. As part of these investigations, evidence of long-term trends in frost frequency were analysed for differences in frost risk between the various phases of the Southern Oscillation: El Niño, normal and La Niña springs. Any evidence for relationships between frost risk and the Interdecadal Pacific Oscillation have also been examined.

Background

Frosts are commonly characterised as "advective", when winds transport a cold air mass into a region, or "radiative", when the ground loses heat to the sky by radiation on cloudless nights. During a simple radiative frost the air temperature generally increases significantly with height above the ground. This is called a "temperature inversion" and it may be possible to protect a crop by mixing down the warmer air from aloft with a helicopter or wind machine. In advective frosts, there is a deeper pool of cold air with little temperature inversion present, and air mixing techniques are unlikely to provide protection.

In the North Island frosts are usually primarily caused by radiation. However if this radiation is acting on an air mass, which is already cold (e.g. has been transported up in a cold southerly flow) there still are problems with air mixing. Another complication is that cold air can drain down valleys and into low-lying areas ("frost hollows") causing deeper cold pools.

Screen frosts do occur in September and October in Hawke's Bay, which coincides with the commencement of vine growth in grapes. Differences in the risk of spring screen frosts can be influenced on a seasonal basis by El Niño, normal and La Niña springs, and from decade to decade by the Inter-decadal Pacific Oscillation.

El Niño Southern Oscillation (ENSO)

El Niño is a natural feature of the global climate system. Originally, it was the name given to the periodic development of unusually warm ocean waters along the tropical South American coast. Now it is more generally used to describe the ocean warming along the Equator to the dateline and other associated atmospheric and oceanic changes that together constitute one extreme of the whole El Niño - Southern Oscillation (ENSO) phenomenon. La Niña refers to the opposite extreme of the ENSO cycle. El Niño events occur about 3 to 7 years apart, typically becoming established around April or May and persisting for about a year thereafter. At the same time, a seesaw of atmospheric pressure change occurs between the southeast Pacific Ocean and the Indonesian region. This is called the Southern Oscillation, and is measured by the Southern Oscillation Index (SOI), which is the difference in pressure between Darwin in Australia and Tahiti in the Eastern Pacific.

When neither El Niño nor La Niña are present, (usually referred to as "neutral" or normal conditions), trade winds blow westward across the Pacific, piling up warm surface water so that Indonesian sea levels are about 50 cm higher than those in Ecuador. The SOI is measure of the current state of ENSO. A negative SOI indicates El Niño, a positive SOI indicates La Niña.

Spring El Niño effects on Hawke's Bay

During El Niño, New Zealand tends to experience stronger or more frequent winds from the southwest in spring, with drier conditions in Hawke's Bay (Figure 1). Temperatures tend to be close to average.

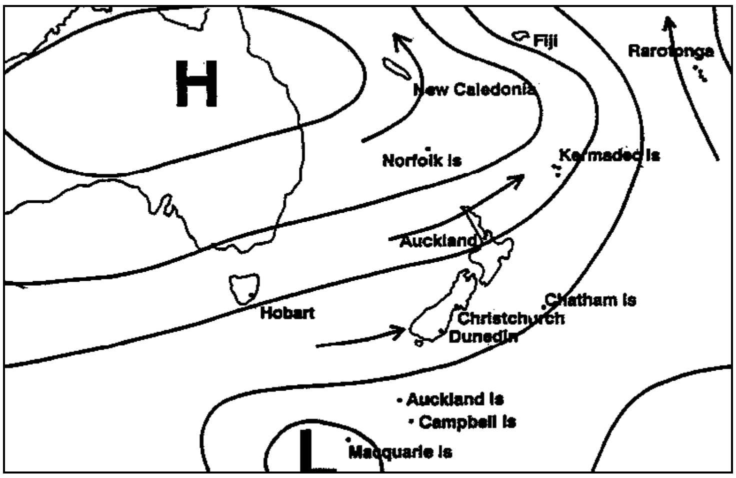


Figure 1: Typical El Niño Circulation Anomalies

Spring La Niña effects on Hawke's

During the positive (La Niña) phase of the Southern Oscillation, a 'typical' response over the New Zealand region in spring is firstly northwesterly, followed by northeasterly wind flows, caused by lower than usual pressures over Australia, and higher than usual pressures to the southeast of New Zealand. (See Figure 2). This causes above average temperature and rainfall in Hawke's Bay (Mullan, 1995).

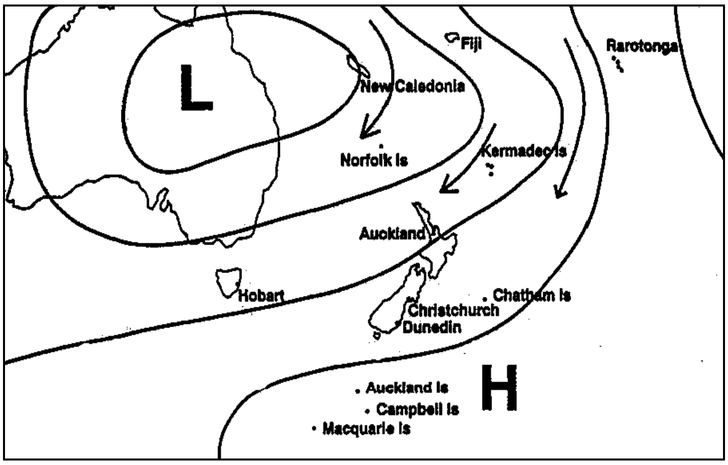


Figure 2: Typical La Niña Circulation Anomalies

Inter-decadal Pacific Oscillation and ENSO

The Inter-decadal Pacific Oscillation (IPO) is an "ENSO-like" feature of the climate system that operates on time scales of several decades. As with ENSO, there is coupling between the ocean and atmosphere changes, but there is considerable debate and ongoing research about the exact feedback mechanisms relevant to the decadal timescale. The main centre of action in the sea surface temperature (SST) departures is in the north Pacific centred near the date line at 40°N, with an opposing weaker centre just south of the equator in the eastern Pacific north of the Easter Island at 10°S. The matching atmospheric sea level pressure pattern (SLP) is one of an east/west seesaw at all latitudes, but again centred over the north Pacific, with the centre of action over the Aleutian Islands.

Three phases of the IPO have been identified during the 20th century, being: positive (1922-1944), negative (1946-1977) and positive (1978-1998). Recent findings show that there may be another shift towards a negative IPO since 1999 (Figure 3). These changes line up with the timing of distinct climate shifts observed throughout the Pacific Basin.

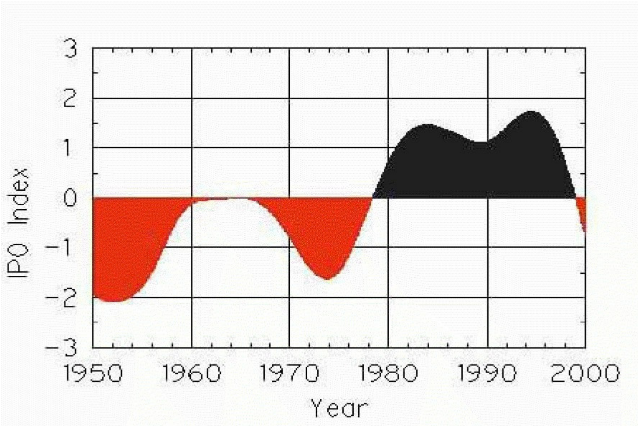


Figure 3: Phases of the Inter-decadal Pacific Oscillation from 1950 to 2000

Although the IPO and ENSO operate on different time scales, they are similar in their expression in Tropical Pacific SSTs, suggesting that the IPO exerts a modulating effect on ENSO (Power et al., 1999, Salinger et al., 2001). Based on the correlations between the IPO and SST, on average the IPO is positively associated with enhanced and more frequent El Niño events.

During the positive phase of the IPO, the intensity and frequency of El Niño increases. From the 1946-1977 negative IPO to the 1978-1998 positive IPO period, the frequency of El Niño months increased from 12% to 27%, and the average SOI during El Niño months intensified from –1.25 to –1.82 (ICU 23).

Recent research suggests that there are systematic decadal changes in year-to-year variability associated with ENSO (Salinger et al., 2001) Thus it appears that the ENSO teleconnections vary with the phase of the IPO.

In the positive phase of the IPO, southwesterlies are more dominant over the New Zealand area. The negative phase of the IPO brings a tendency for a reversal of SST and Sea Level Pressure (SLP) anomalies from the positive phase, and the prevailing winds for New Zealand region tend to be more due westerly and weaker (and thus a northeasterly anomaly from the long term average). Salinger et al (2001) examined SOI-climate correlations for New Zealand and Figure 4 shows the key result for sea level pressure (SLP).

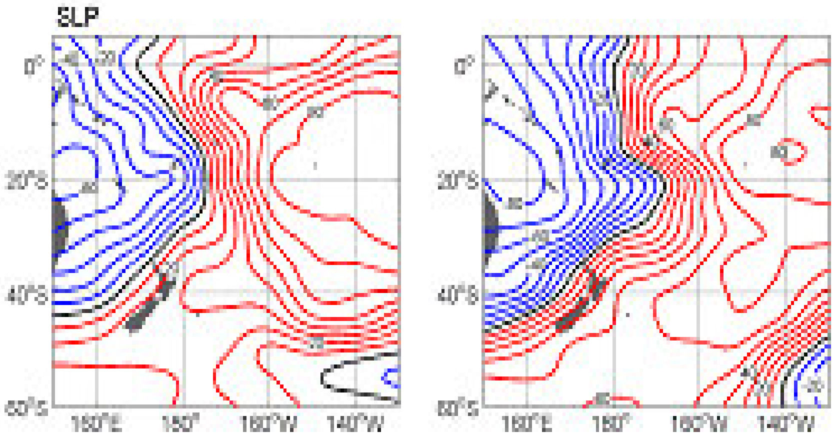


Figure 4: Correlation (percent) between the annual Southern Oscillation Index (SOI) and annual mean sea level pressure, for the most recent negative (left) and the positive (right) phase of the IPO. The blue represents negative and red positive correlations.

The basic ENSO teleconnection pattern is present in both IPO phases: that is, during El Niños the pressure is higher over Australia, more southwesterly winds occur over New Zealand, the South Pacific Convergence Zone shifts northeastward with cooler and drier conditions south of it and warmer and wetter conditions to the north. However, the intensity of this pattern is quite different in places between the IPO phases.

In positive IPO, the positive SOI-pressure correlation near Tahiti extends much further southwest towards Chatham Island, and the negative correlation is stronger in the north Tasman Sea. Thus the El Niño cold southwesterlies across and east of New Zealand are much more pronounced during the positive IPO period (stronger gradient in right SLP panel of Figure 4).

There is some evidence of an “additional” IPO effect over and above just the change in ENSO frequency. However, in New Zealand data this is really only apparent in rainfall for the west coast of the South Island and the east coast of the North Island, where the changes (rainfall increases and decreases respectively) between 1946-1977 and 1978-1998 are larger than would be expected from the increased frequency of El Niño events.

Selection of Stations and Acquisition of Data

Hawke's Bay region has limited number of long-term climate data available, therefore, this study had to reconstruct the short-term dataset into long-term series before assessing frost probabilities. The following section outlines the methodology used for estimation of long-term data series from short-term climate information.

Short-term to long-term daily minimum air temperature estimation

In order to calculate the long-term frost risk it is desirable to have minimum air temperature data from climate stations with long records. The Napier, Nelson Park climate station has an excellent air temperature record starting in 1940 and is still currently in operation. However, some of the climate stations in the Hawke's Bay area have relatively short records; Taradale, for example has data for the period April 1961 – December 1968. This section describes the method of estimating the long-term minimum air temperature data at these short-term locations, so that the long-term frost risk can be estimated.

Table 1: Climate stations, with owners in parentheses.

Station name	Period of record
Hastings Fire Station	September 1981 – December 1989
Hastings	December 1971 – October 1981
Waipukurau Aero	December 1944 – July 1994
Taradale	April 1961 – December 1968
Roys Hill (Villa Maria)	September 1999 – present
Crownthorpe (Delegats)	September 2000 – present
Pakowhai, Allen Road (Hort Research)	September 1997 – present
Bridge Pa (HB Regional Council)	February 1997 – present
Dartmoor (Mike Wills)	October 1999 – present
Kereru (Kemblefield)	September 1999 – present
Tikokino, Grocorp (Hort Research)	September 1997 – present
Tukituki (Alan Peak)	September 2000 – present
Napier, Nelson Park	January 1940 – present
Havelock North	January 1951 – December 1988

The daily minimum air temperature data from Napier, Nelson Park for the same period) and determines whether there is a linear relationship between the two datasets. Table 1 lists the short-term sites, and their period of record, analysed in this study.

Short-term stations

Daily minimum air temperature data for the spring months (September – November) from 12 short-term climate stations (8 of which are privately-operated) were compared to their contemporary data recorded at Napier, Nelson Park using a statistical linear regression analysis. A regression analysis plots one set of data (e.g. the daily minimum air temperature data from Taradale from 1961 – 1968) against another set of data (e.g.

Regression results

Appendix 1 figures, for which Figure 5 is an example, show the regression plots for each of the short-term stations. The straight line shown on the plot is the line which best fits the scatter of the data. The equation on the plot (e.g. y = 0.9152x – 0.2773) is the mathematical representation of this straight line, where "y" is the value of the vertical axis and "x" is the value of the horizontal axis. Lastly, the number on the plot (shown as the R^2, located below the regression equation) depicts the closeness of the points to the straight line (an R^2 of 1.0 means all the points lie on the straight line, while an R^2 of 0.0 means no relationship whatsoever). R^2 values greater than about 0.6 indicate that there is a distinct linear relationship between the two datasets.

Since identifying frost risk is the goal of this study, the location of the regression line was adjusted slightly on some of the plots to make sure it went through the data points located at the cold end of the scale.

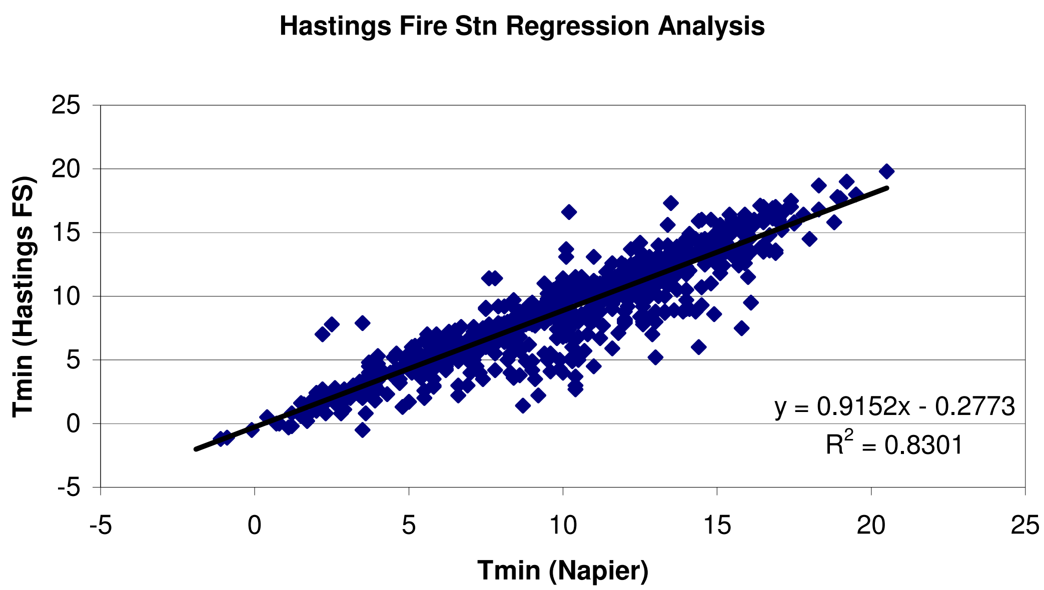


Figure 5: The regression relationship between spring daily minimum air temperature at Hastings Fire Station and Napier, Nelson Park.

Long-term data estimation

It can be seen from the plots in Appendix 1 that all of the regression analyses show significant linear relationships. This means that the spring minimum air temperatures at each of the 12 short-term locations are closely related to the spring minimum air temperature at Napier, Nelson Park; R^2 was greater than 0.6 in all cases. Thus, it is possible to use the regression equations shown on the plots to estimate the spring daily minimum air temperatures at the short-term locations for every spring day since 1940 (i.e. the beginning of the Napier, Nelson Park record).

The estimations back to 1940 for each short-term site are made using the respective regression equation. For example, the regression equation for Tukituki (See Appendix 1) and Napier, Nelson Park is y = 0.7447x + 1.7135. The "y" refers to the minimum air temperature at Tukituki and the "x" refers to the minimum air temperature at Napier, Nelson Park. Using this equation, the minimum air temperatures at Tukituki can be estimated by multiplying the minimum air temperatures at Napier, Nelson Park by 0.7447, and then adding 1.7135 °C.

Once all the long-term estimates were made for each of the 12 short-term locations, the long-term frost probabilities were calculated identically to those for Napier, Nelson Park. These frost probability plots are discussed in **Results and Discussions** and **Appendix 2**.

Methodology for Frost Estimation

This study uses 12 short-term sites plus 3 long-term sites in Hawke's Bay region to assess frost risk probabilities (See Table 1). Pseudo records were calculated for the short-term sites to assess the long-term frost risk in the area.

Based on the grape growing season and the crucial period being the start of the season, September, October and November were the months when frost probabilities were assessed. Daily minimum temperature (night time) determines the probability of frost occurrence. Three categories of critical minimum air temperatures were identified – Light frost, Moderate frost and Severe frost. **Light Frost** is when the minimum temperature is in the range 0.0°C to –0.9°C, **Moderate Frost** –1.0°C to –1.9°C and **Severe Frost** –2.0°C and below.

Daily minimum temperature was then pooled into five-day periods, for example, 1st to 5th September, 6th to 10th September until the end of November. Then number of days, which had frost, was counted within the five-day groups. There were three sets of analyses for the three categories of frost. The frequencies of days with frost (3 categories) during these five-day periods were used to calculate long-term probability of frost from September to November. Thirdly, the frequencies were used to assess frost probabilities during the phases of the El Niño Southern Oscillation (ENSO – La Niña, El Niño) and the Inter-Decadal Pacific Oscillation (IPO). There were 21 identified El Niño seasons and 14 La Niña seasons used for the composites.

Results and Discussion

Frost probabilities for all sites assessed in Hawke's Bay show that the chance of frost occurring is highest at the beginning of spring – September (Table 3 to Table 6), and trends downwards throughout the season. Minimum temperatures tend to be lower at the commencement of spring and warm towards summer. The percentage probability of risks of light, moderate, severe and all frosts for each respective month are shown. Cumulative probabilities for all sites are shown in Appendix 3.

Site	Monthly Probability September	Monthly Probability October	Monthly Probability November
Bridge Pa	15.6	3.7	0.3
Crownthorpe	19.1	4.8	0.6
Dartmoor	7.1	0.8	0
Hastings	6.4	1.6	0
Hastings FS	6.7	1.1	0
Havelock North	28.6	13.2	3.6
Kereru	33.9	15.9	3.5
Napier Airport	7.5	0	0.6
Napier Nelson Park	5.0	1.1	0
Pakowai	10.6	1.9	0.3
Roys Hill	9.6	1.6	0.3
Taradale	7.1	0.5	0
Tikokino	34.4	13.2	2.9
Tukituki	0	0	0
Waipukurau	20.4	9.5	2.4

Table 2 Light (0 to –1 °C) Frost Probabilities

Certain sites (Kereru, Havelock North, Tikokino and Waipukurau) have a higher risk of frost than other areas in Hawke's Bay region. Probabilities of some sort of screen frost in September are about 86%, 70%, 54% and 35% respectively at these sites, with November probabilities in the range of 3 to 5%. Typically, monthly probabilities are higher in September ranging from 0 to 85% for various sites in Hawke's Bay, October ranging from 0 to 27% and November ranging from 0 to 5%.

The highest frost probabilities for the whole spring season is at Kereru, which is a much cooler site compared to the other sites in Hawke's Bay region – 86% in September, 27% in October and 5% in November. Tukituki is a generally a very warm site where frost probabilities are nil for the whole spring season.

The observational sites at Napier (Nelson Park), Hastings and Hastings typically had lower frost probabilities of less than 10% in September, less than 2% in October and nil in November. In addition, the likelihood for light frosts is notably higher for most sites in Hawke's Bay region compared to moderate or extreme frost. For many locations the September probabilities of light frosts ranged from 10 – 30%, decreasing to 0 – 4% in November. Moderate frost probabilities were generally in the range of 5 – 20% in September and 0 – 1% in November, with severe frost probabilities ranging from 0 – 6% in September down to 0% in November except at the Kereru and Waipukurau sites.

Site	Monthly Probability September	Monthly Probability October	Monthly Probability November
Bridge Pa	5.0	0.8	0.3
Crownthorpe	8.2	1.1	0
Dartmoor	2.9	0.3	0
Hastings	2.4	0	0
Hastings FS	2.9	0	0
Havelock North	18.9	2.6	0.4
Kereru	30.7	6.9	1.1
Napier Airport	3.5	0.6	0
Napier Nelson Park	2.9	0	0
Pakowai	4.2	1.1	0
Roys Hill	1.6	0	0
Taradale	3.5	0.3	0
Tikokino	20.9	5.0	0.5
Tukituki	0	0	0
Waipukurau	11.4	2.7	0.3

Table 3 Moderate (-1 to –1.9 °C) Frost Probabilities

The locations that have higher probabilities are Kereru, Tikokino, Havelock North, Waipukurau, Crownthorpe and Bridge Pa. The low probability sites are Dartmoor, Hastings, Napier Airport, Napier Nelson Park, Pakowai, Roys Hill, Taradale and Tukituki. Cumulative probabilities for various sites are shown in graphs in Appendix 3.

The cumulative probabilities track chances through spring (see Appendix 3). For example, at a more typical grape growing site at Bridge Pa, the chances of frost are high at the beginning of September, but reduce to less than 40% by the beginning of October, and are very low at the beginning of November. At a cold site, such as at Havelock North, the chances of a frost are 100% throughout September, reducing to close to 50% by the end of October, but with no risk in November. Kereru shows a similar cumulative probability profile, but with some frost risk in early November.

Site	Monthly Probability September	Monthly Probability October	Monthly Probability November
Bridge Pa	4.0	0.3	0
Crownthorpe	4.2	0.3	0
Dartmoor	0.6	0	0
Hastings	0.3	0	0
Hastings FS	0.3	0	0
Havelock North	6.6	1.8	0
Kereru	20.9	4.0	0.5
Napier Airport	0	0	0
Napier Nelson Park	0	0	0
Pakowai	3.2	0	0
Roys Hill	1.6	0	0
Taradale	0.3	0	0
Tikokino	14.3	1.9	0
Tukituki	0	0	0
Waipukurau	3.5	0.6	0.5

Table 4 Severe (–2°C and below) Frost Probabilities

Site	Monthly Probability September	Monthly Probability October	Monthly Probability November
Bridge Pa	24.6	4.8	0.6
Crownthorpe	31.5	6.2	0.6
Dartmoor	10.6	1.1	0
Hastings	9.1	1.6	0
Hastings FS	9.9	1.1	0
Havelock North	54.1	17.6	4
Kereru	85.5	26.8	5.1
Napier Airport	11	0.6	0.6
Napier Nelson Park	7.9	1.1	0
Pakowai	18	3	0.3
Roys Hill	12.8	1.6	0.3
Taradale	10.9	0.8	0
Tikokino	69.6	20.1	3.4
Tukituki	0	0	0
Waipukurau	35.3	12.8	3.2

Table 5 Total Frost Probabilities (below 0°C)

Frost Probabilities and ENSO

Further assessment was done to understand the differences in frost probabilities under various ENSO phases (La Niña, El Niño and Neutral/Normal) for four reliable longer term sites – Bridge Pa, Havelock North, Kereru and Napier Nelson Park. Cumulative probabilities for these cases are shown in Appendix 2.

Generally, light frost probability is more likely to occur during El Niño events, while moderate frosts are most likely during neutral years when there is no ENSO event in place (See Figures 6 to 9). There are higher probabilities for light and moderate frosts during neutral years. However, in La Niña years, frost probability was much lower.

Assessment shows that Havelock North is quite frequently affected by frost especially in September and first two weeks of October. However, there is a higher frost probability during El Niño and neutral years (See Figure 10 to 13), than in La Niña years.

Kereru has increased frost probabilities during El Niño years. There are prolonged frost occurrences into early November during neutral years (See Figure 14 to 17). Furthermore, the probability seems be high for extreme frosts especially at the start of the spring season.

Frost probabilities at Napier (Nelson Park) are low compared to other long-term sites in the Hawke's Bay region (Figures 18 to 21). Once again, frost probability was lower in La Niña springs. Frost seems to be very patchy at this site with it spread over the season. Napier Nelson Park has more light frosts, which are quite erratic throughout the season.

Cumulative frost probabilities under various phases of ENSO are shown in the Appendix 2. There is increased chance for light frost at most sites throughout the Hawke's Bay region during El Niño events.

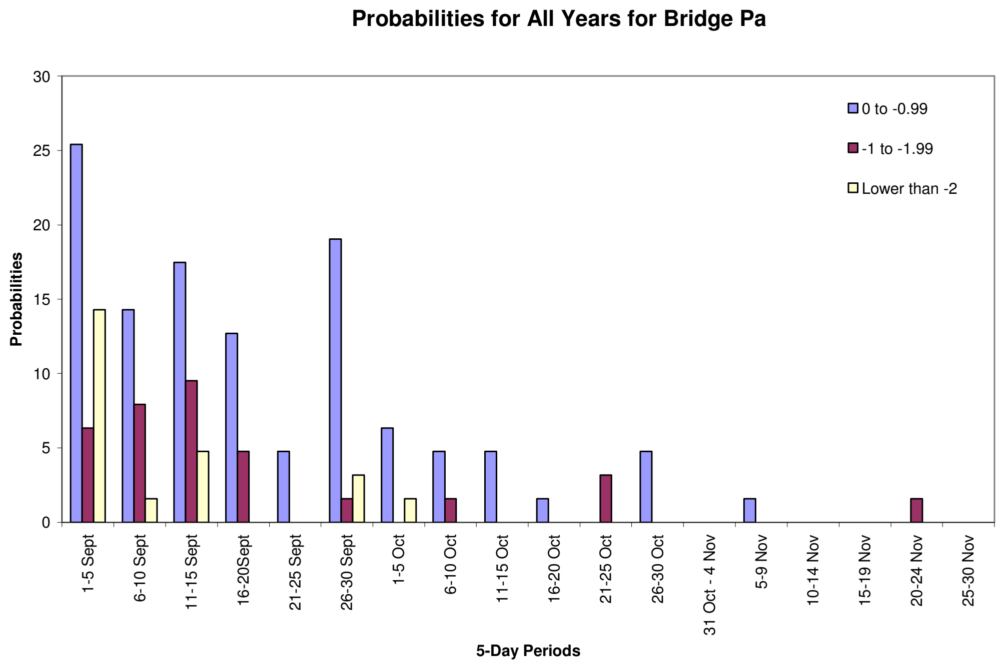


Figure 6: Bridge Pa - Frost probabilities for All Years (1940 – 2002)

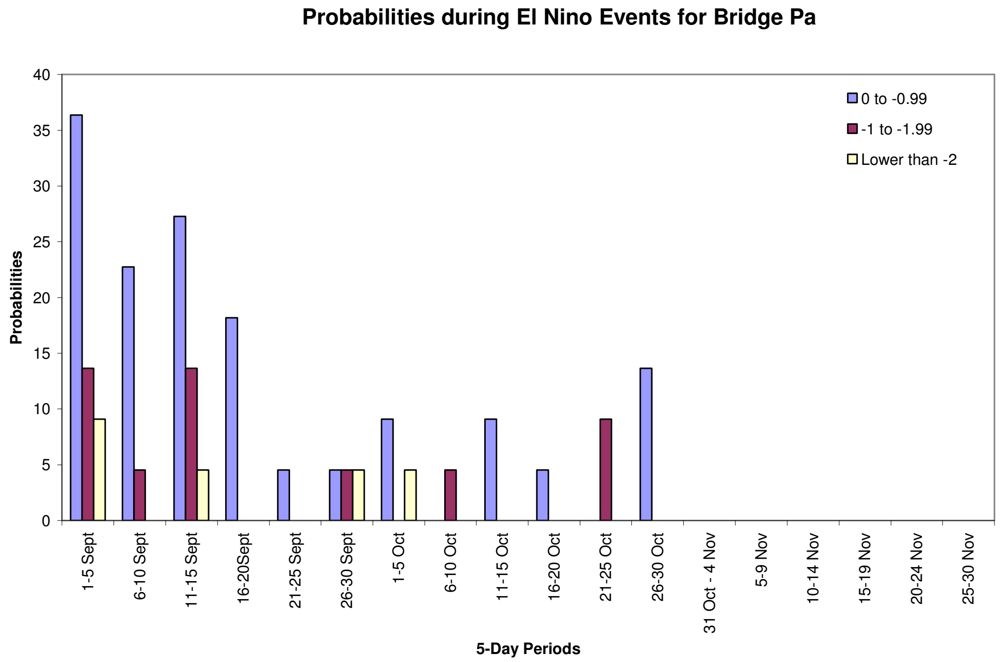


Figure 7: Bridge Pa - Frost probabilities during El Niño Years

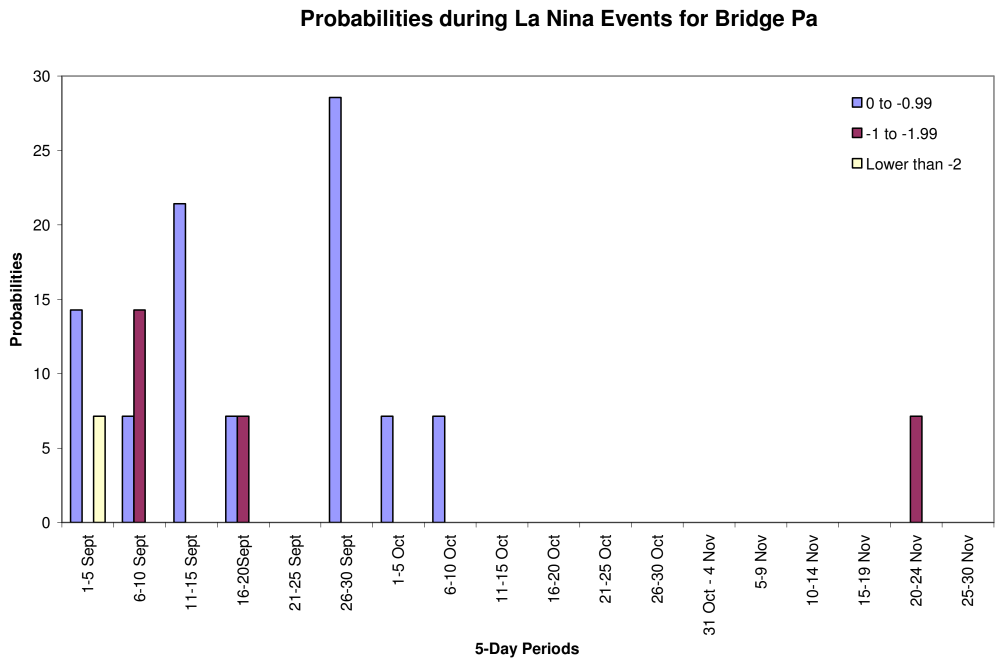


Figure 8: Bridge Pa – Frost Probabilities during La Niña Years

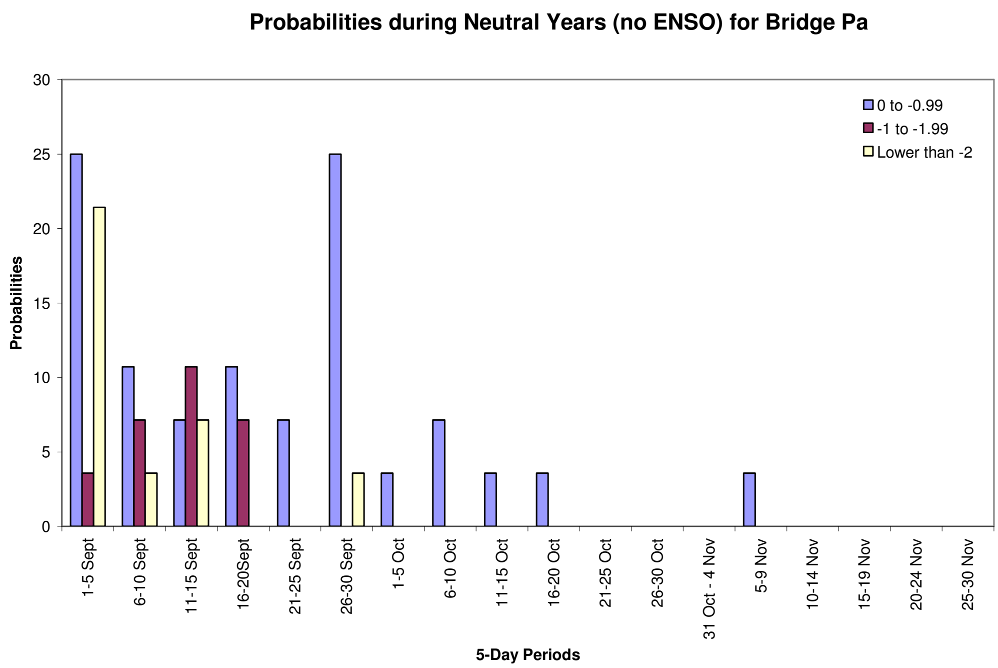


Figure 9: Bridge Pa – Frost Probabilities during Neutral Years (No ENSO event in the Tropical Pacific)

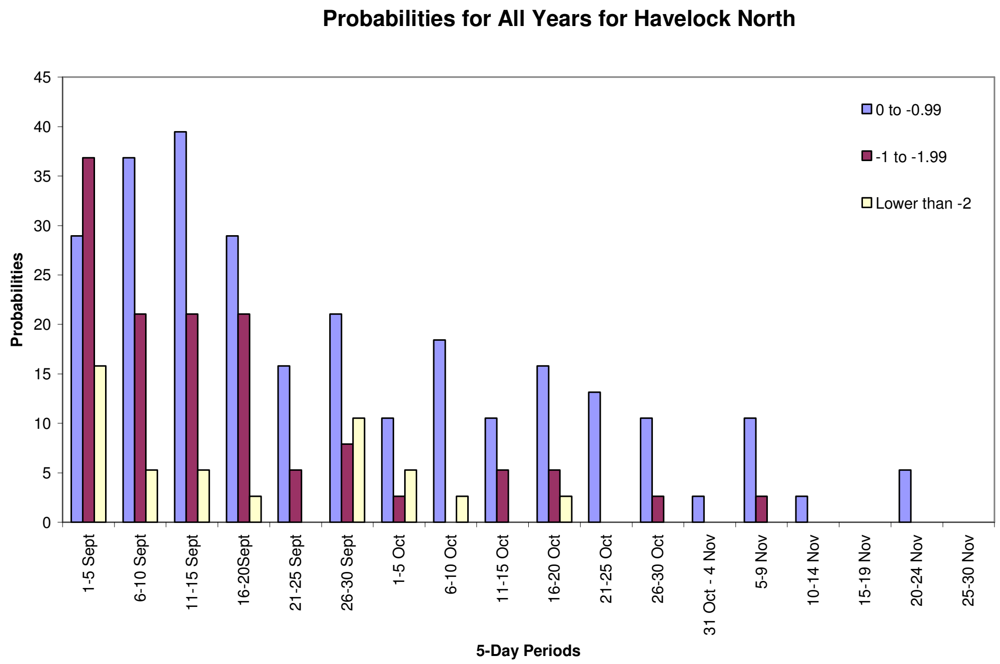


Figure 10: Havelock North – Frost Probabilities for All Years (1940 – 2002)

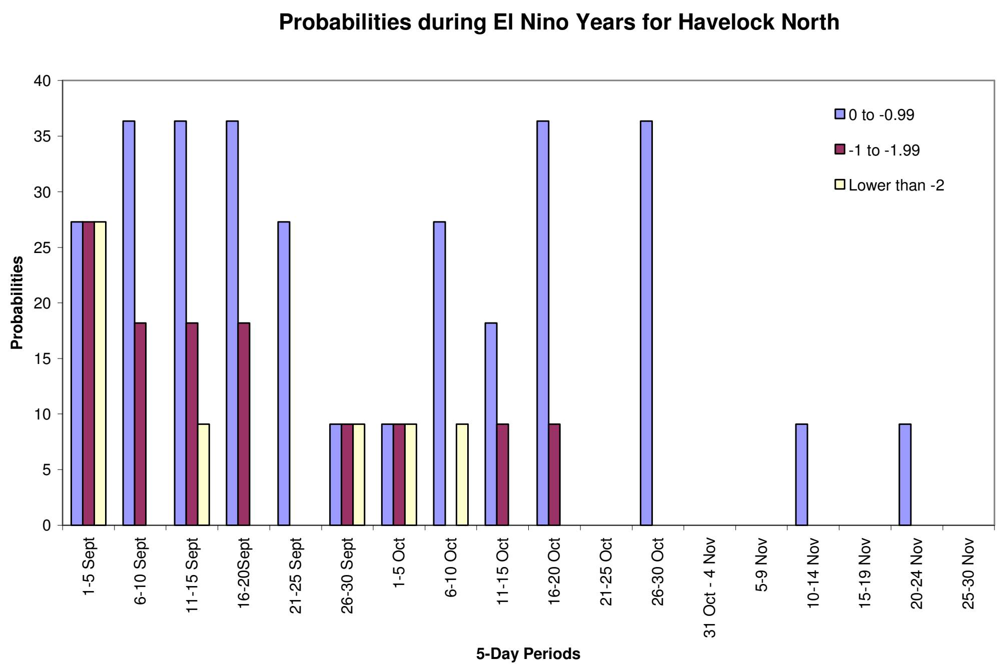


Figure 11: Havelock North – Frost Probabilities during El Niño Years

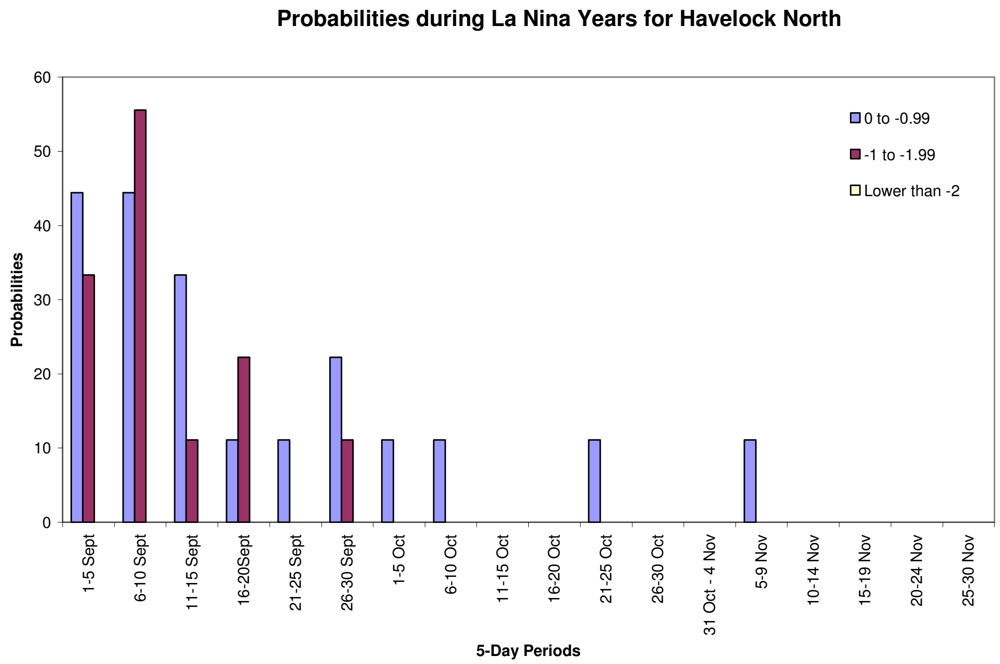


Figure 12: Havelock North – Frost Probabilities during La Niña Years

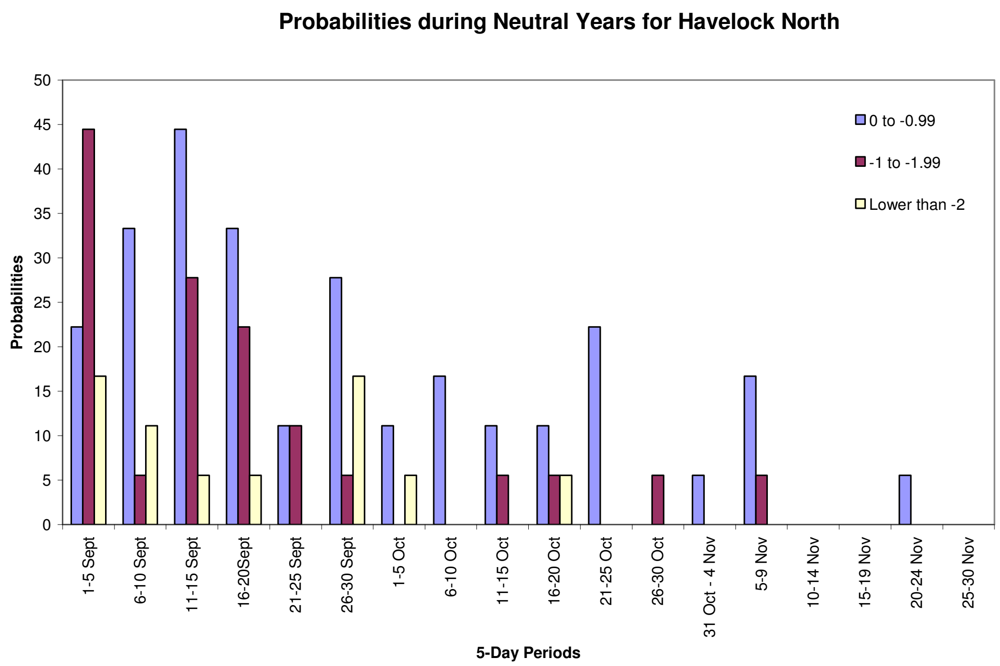


Figure 13: Havelock North – Frost Probabilities during Neutral Years (No ENSO Event in the Tropical Pacific)

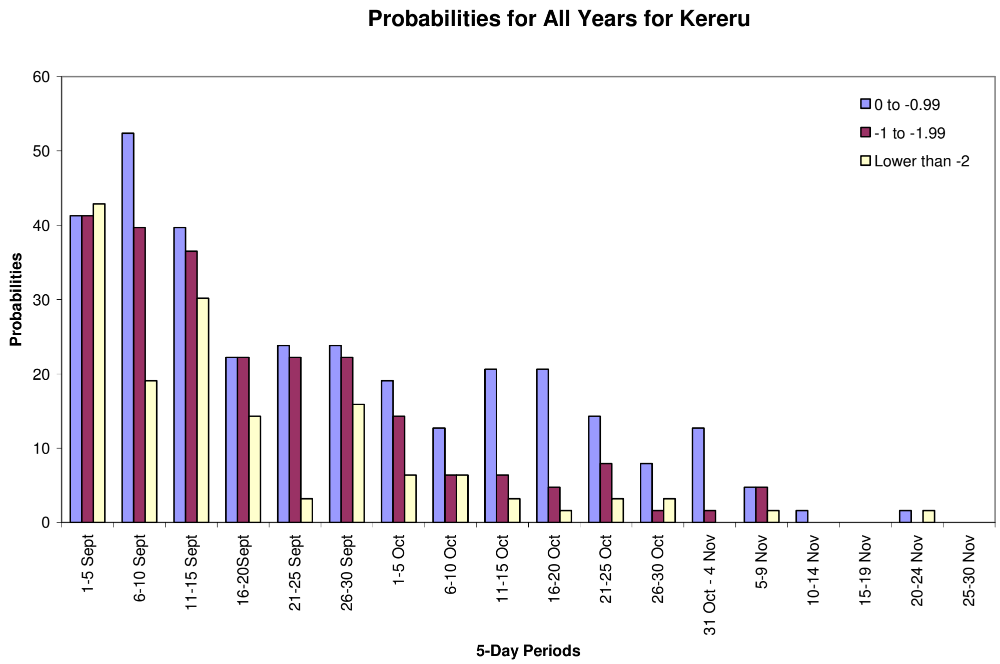


Figure 14: Kereru – Frost Probabilities for All Years (1940 – 2002)

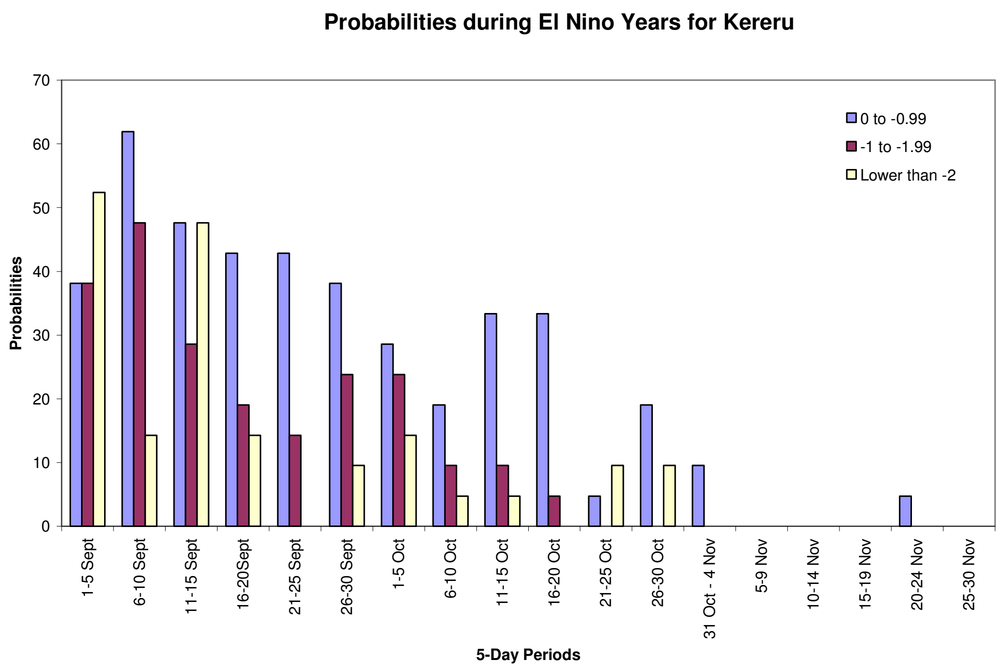


Figure 15: Kereru – Frost Probabilities during El Niño Years

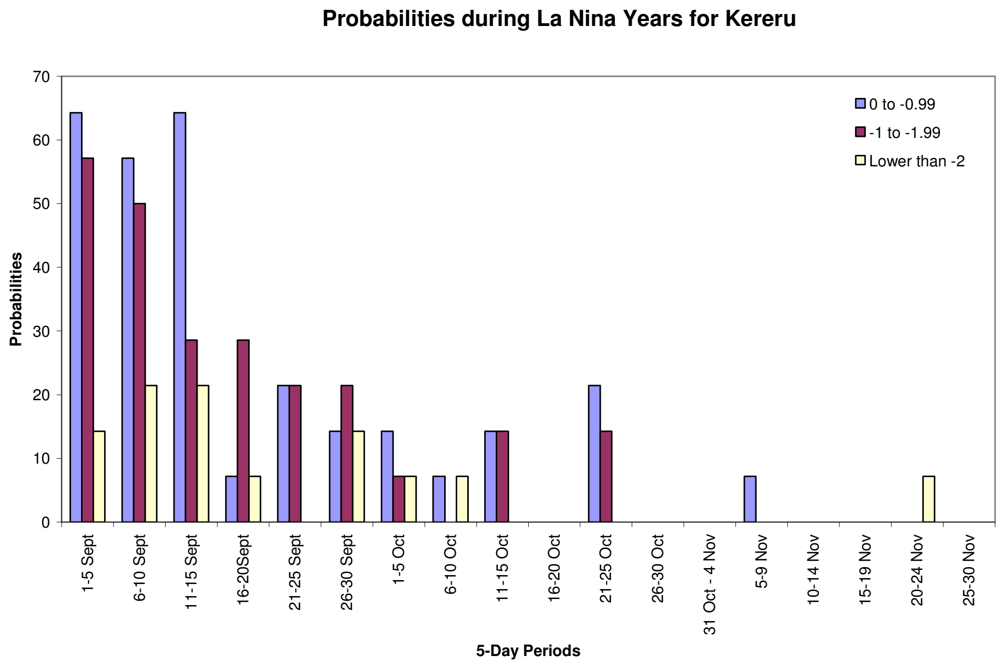


Figure 16: Kereru – Frost Probabilities during La Nina Years

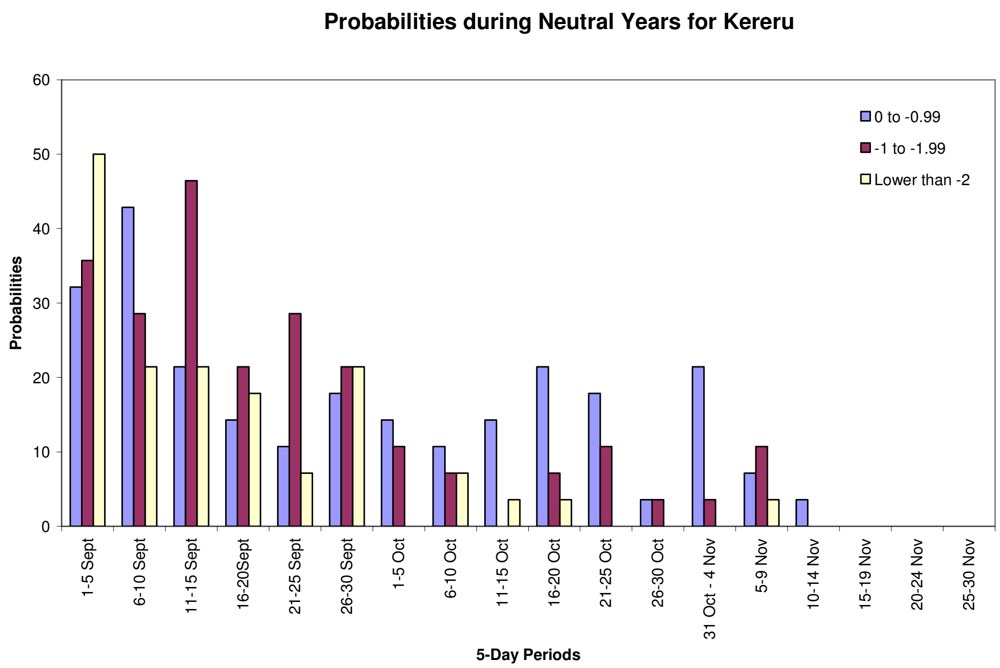


Figure 17: Kereru – Frost Probabilities during Neutral/Normal Years (No ENSO Event in the Tropical Pacific)

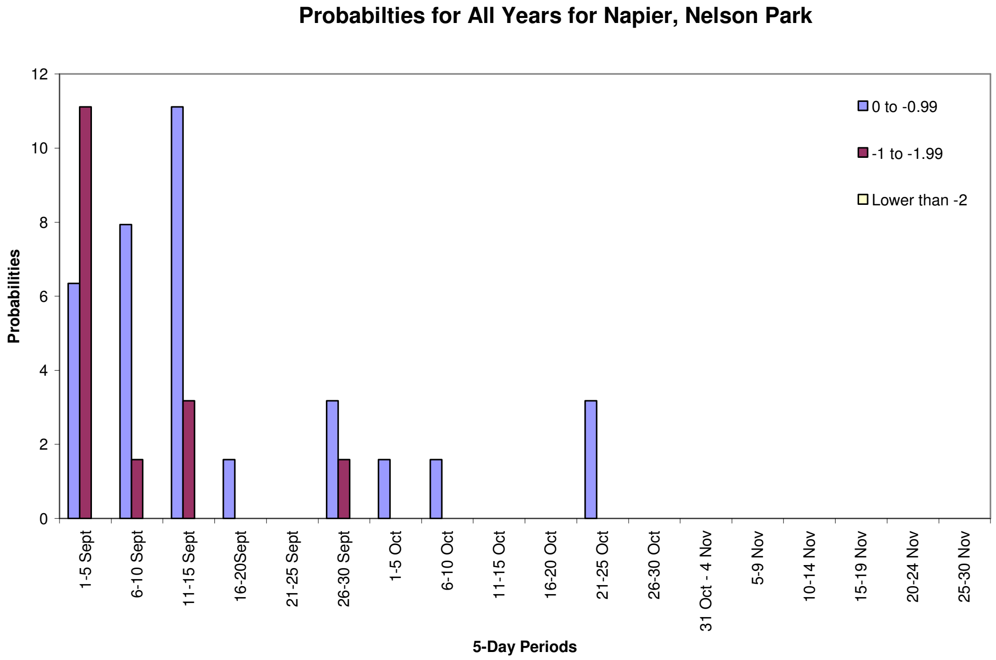


Figure 18: Napier Nelson Park – Frost Probabilities for All Years (1940 – 2002)

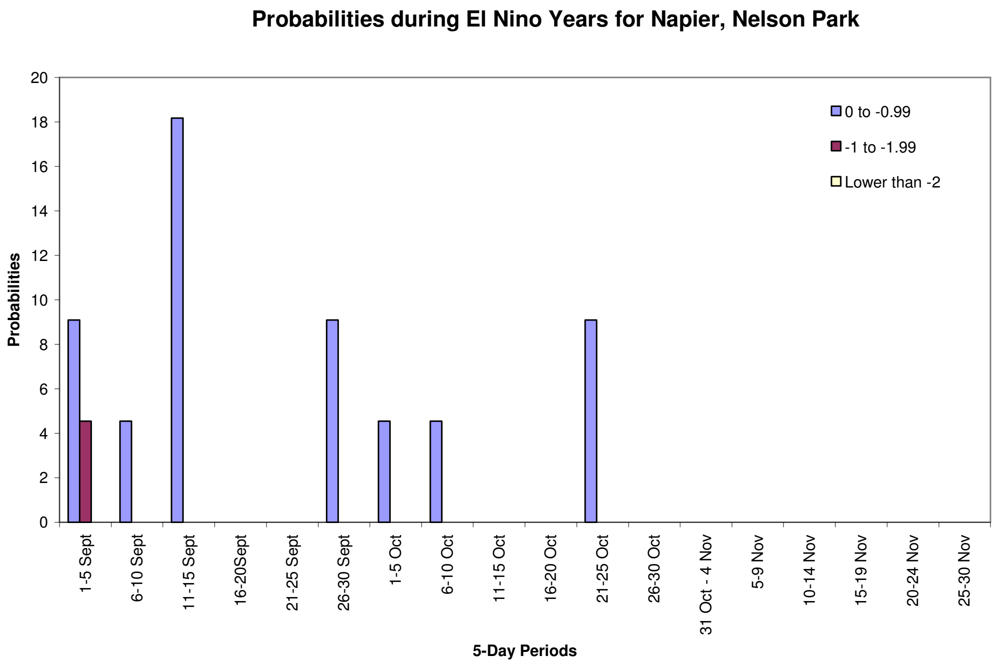


Figure 19: Napier Nelson Park – Frost Probabilities during El Niño Years

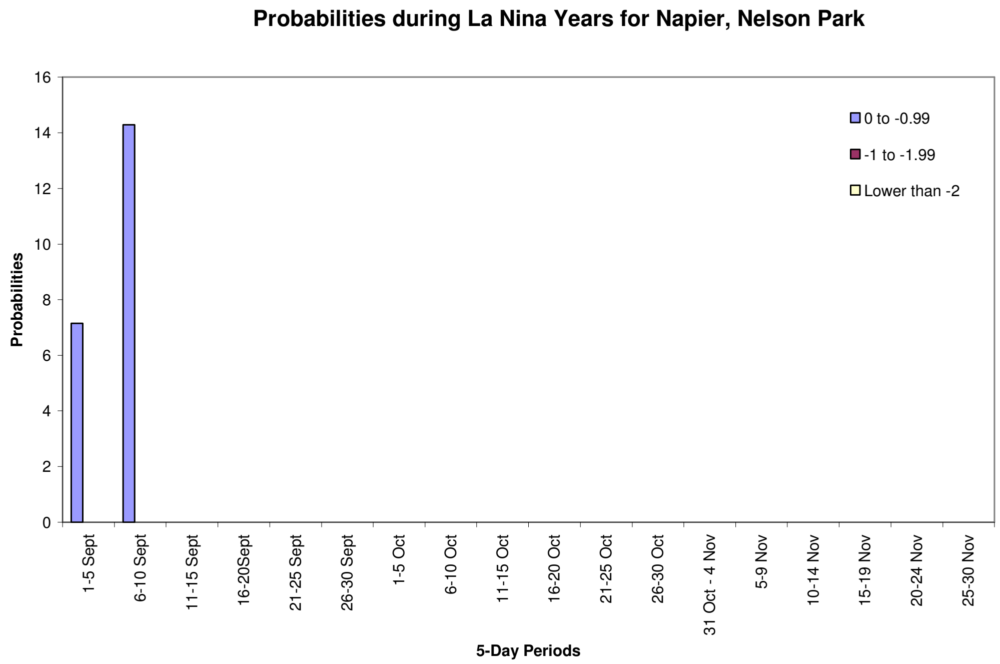


Figure 20: Napier Nelson Park – frost Probabilities during La Niña Years

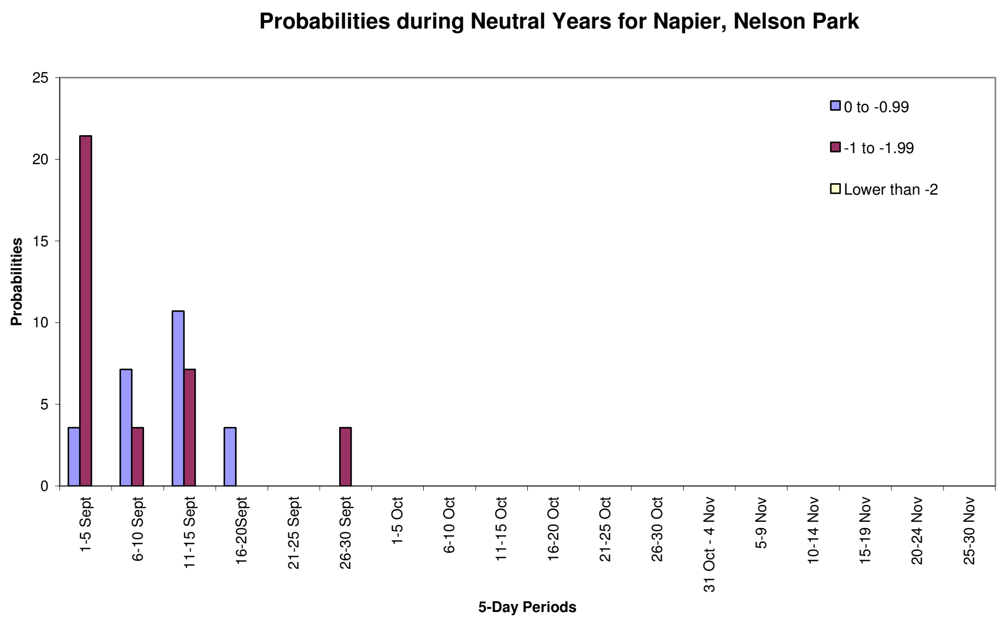


Figure 21: Napier Nelson Park – Frost Probabilities during Neutral Years (No ENSO Event in the Tropical Pacific)

Frost Probabilities and IPO

The IPO also appears to influence on the frequency of frosts in Hawke's Bay Region (Figures 22 to 26). The reasons for this are complex: there has been regional warming through the period (as part of the pattern of global warming), along with a large increase in the frequency of El Niño events relative to La Niña events in the later positive IPO period. The probability of frost, at least in the first half of the spring season, is higher during the positive phase of the IPO, the phase that promotes more westerly flow over New Zealand. This coincides with the previous section (ENSO and Frost) where there were increased probabilities during El Niño events. Conversely, the negative phase, associated with more easterly flow, reduces frost risk, in the first half of spring. There is also some evidence (Fig 22) that the risk of a late frost is *lower* during the positive IPO phase. Severe frost probabilities are nil at Napier Nelson Park. Further, there is significantly less chance of frost at Napier, Nelson Park, compared to the other sites in the Hawke's Bay region.

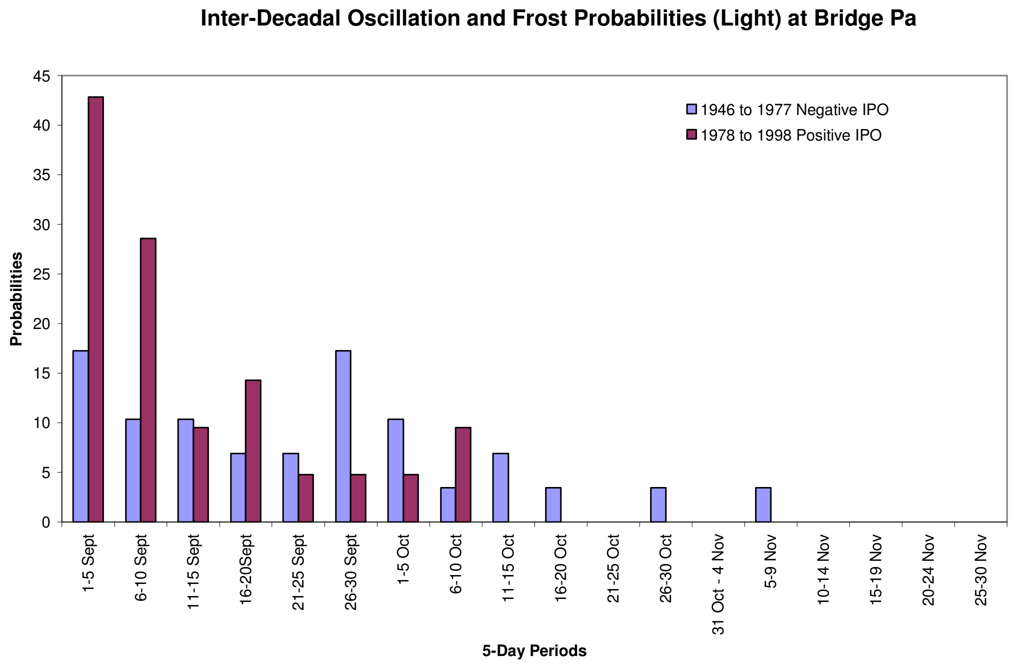


Figure 22: Light Frost probabilities and the Inter-Decadal Pacific Oscillation at Bridge Pa

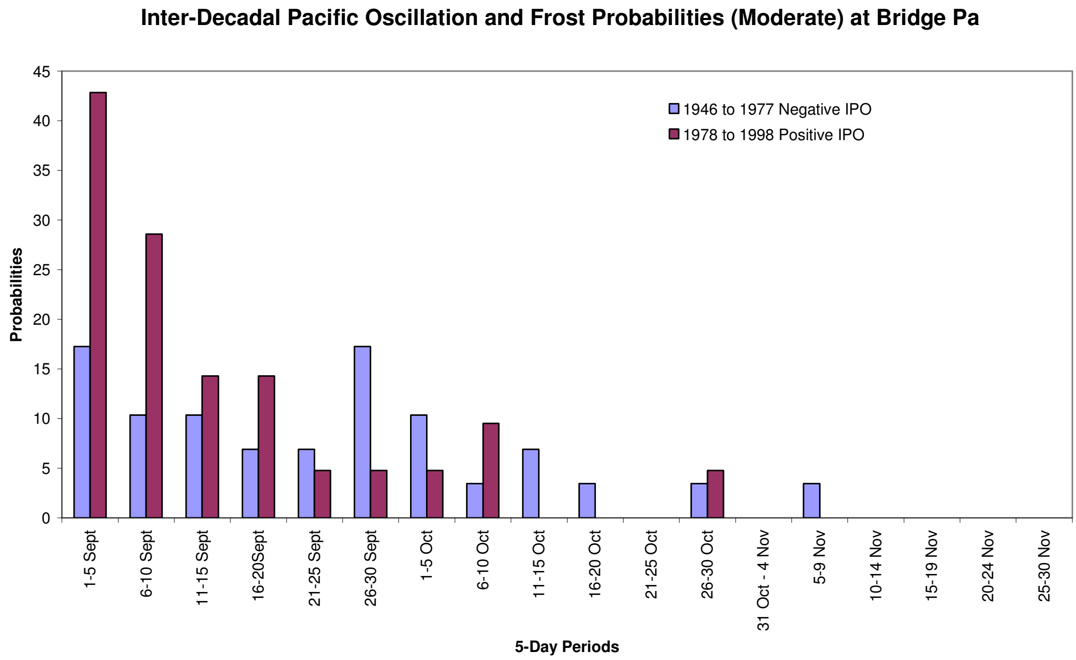


Figure 23 Moderate Frost Probabilities and the Inter-Decadal Pacific Oscillation at Bridge Pa

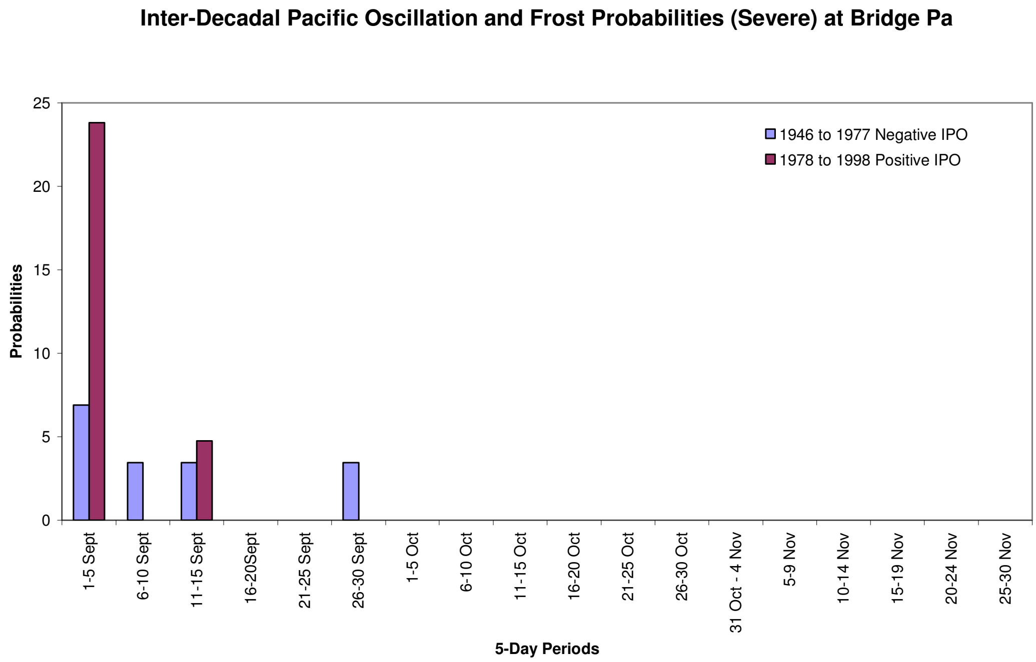


Figure 24 Severe Frost and Inter-Decadal Pacific Oscillation at Bridge Pa

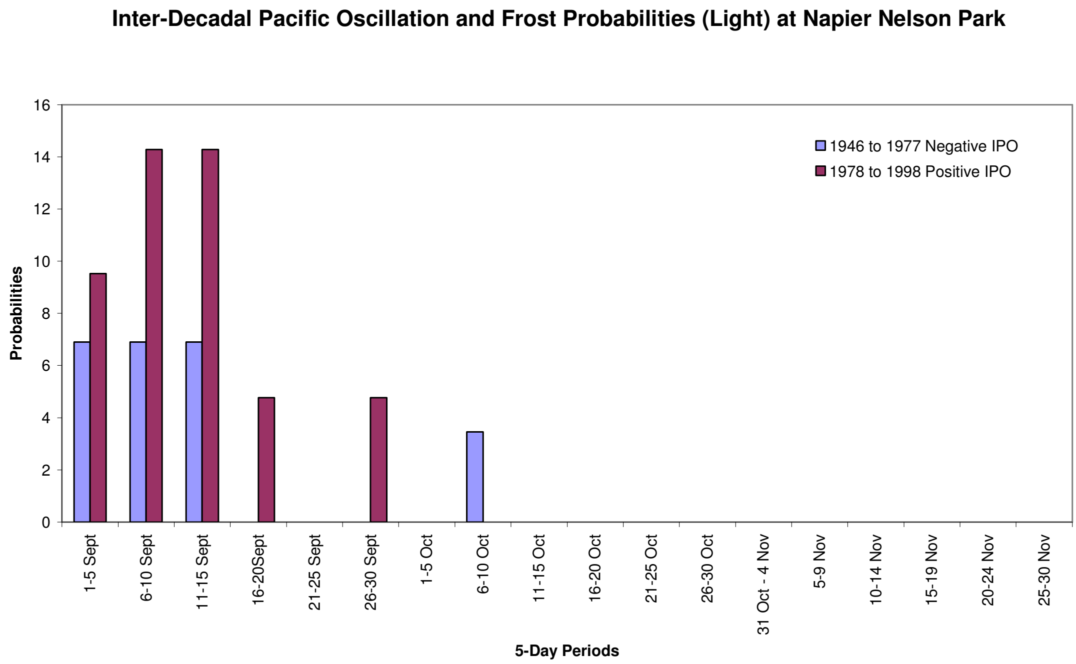


Figure 25 Inter-Decadal Pacific Oscillation and Light Frost Probabilities at Napier Nelson Park

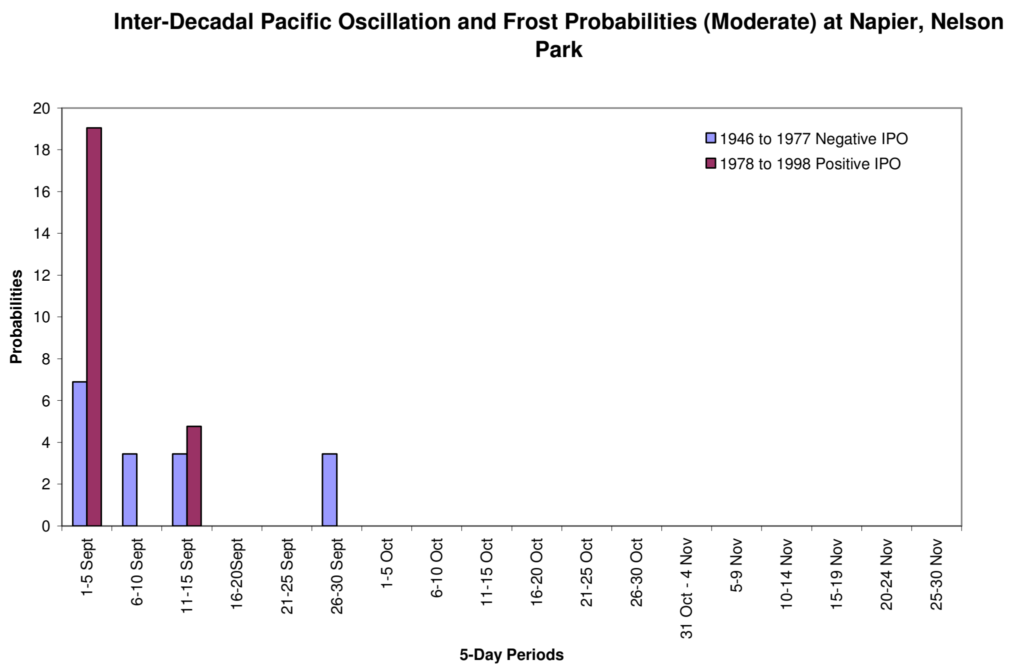


Figure 26 Inter-Decadal Pacific Oscillation and Moderate Frost Probabilities at Napier Nelson Park

Discussions and Conclusions

Climate studies usually require a long-term dataset prior to drawing conclusions about risks and probabilities of various climatic variables. This is particularly desirable when assessing the frost risk throughout a region. The grape-growing areas of Hawke's Bay, particularly on the Heretaunga Plains are renowned for their microclimates and complex changes in frost risk.

This study uses short-term sites together with a long-term site to calculate pseudo records for long-term studies. This has enabled frost risk to be assessed in a wider area than that covered by long-term climate monitoring. Thus short term monitoring of temperatures can be used for this purpose with a minimum of four seasons data.

Frost risk in the Heretaunga Plains area of Hawke's Bay showed quite some considerable variability. Those sites which were open to moderating effects from either the ocean, breezes or some form of urban warming had a much lower probability of frost, especially in September. Tukituki frost probabilities were nil, whilst those at Napier (Nelson Park), Hastings, Hastings Fire Station, Dartmoor and Taradale were low, being in the order of 10% in September and 1% in October. At the other end of the spectrum there were some sites of particularly high risk. These were either very sheltered sites, or those where cold air ponded. These occurred at Keruru, Tikokino and Havelock North (the old DSIR site) where there is a September air frost in at least half of the years, and probabilities of about 20% in October, and 4% in November.

Probabilities of severe frosts (of -2°C or more) do occur at Kereru, Tikokino, Havelock North, Crownthorpe, Bridge Pa and Waipukurau, mainly in September. This severity of frost generally only occurs at Kereru, Havelock North and Tikokino in October, with little incidence in November.

Long-term frost probabilities estimated at four locations for screen frosts in September, October and November, show differences in frost risk between El Niño, normal and La Niña springs. Generally frost risk is lowest in La Niña springs, increases with neutral seasons, but is highest in El Niño seasons. During La Niña seasons firstly mild northwesterly winds, then as the season progresses onshore easterly and northeasterly winds, are more prevalent. The higher seasonal air temperatures and the more prevalence of onshore winds are reflected in the lower frost incidence in such seasons.

El Niño seasons generally bring a predominance of more southwesterly winds, and lower air temperatures. The more frequent occurrence of cooler southwesterly quarter airflow raises the frost probability at all sites examined, extending the range of freezing temperatures right through October at the more frost-prone sites.

Finally, the incidence of frost in Hawke's Bay has varied with the IPO. Generally the occurrence of frost, particularly in the first half of spring, increased during the positive phase of the IPO, compared with the negative phase. During the positive phase of the IPO westerly and southwesterly airflow is more frequent, compared with easterly quarter airflow in the negative phase. Increased westerly flows associated with El Nino events are also more frequent during the positive IPO period. The increased westerly quarter flow brings offshore winds, and the cooler clearer conditions allow for periods when radiative cooling with resultant screen frosts is more frequent. This is despite the fact that the positive IPO years (1978-1998) were slightly warmer overall for the New Zealand region (including Hawke's Bay) because of global warming, compared with the negative IPO years (1946-1977). There does appear to be a slight reduction in the incidence of *late* frosts (at those colder sites where these occur) during the positive IPO phase. For a frost late in spring, there needs to be a larger deviation from climatology than early in the season, and regional warming may make this more difficult to achieve.

These studies are very cost-effective in providing information for decision-making on frost protection. The techniques can be used to analyse further sites, or for a more in-depth analysis for climate variability factors at the sites assessed.

Acknowledgements

The Hawke's Bay Grapegrowers Association (Inc) wish to acknowledge the financial assistance of the Hawke's Bay Regional Council to this project and thank the contributors of weather and climate data as follows:

Villa Maria Hawke's Bay Vineyards, Delegats Wine Estate Ltd., HortResearch, Hawke's Bay Regional Council, Kemblefield Estate Winery Ltd. and Alan Peak.

References

Mullan, B. 1995. On the linearity and stability of Southern Oscillation-Climate relationships for New Zealand. International Journal of Climatology, Vol 15, 1365-1386.

NIWA. 2002. August Island Climate Update 23.

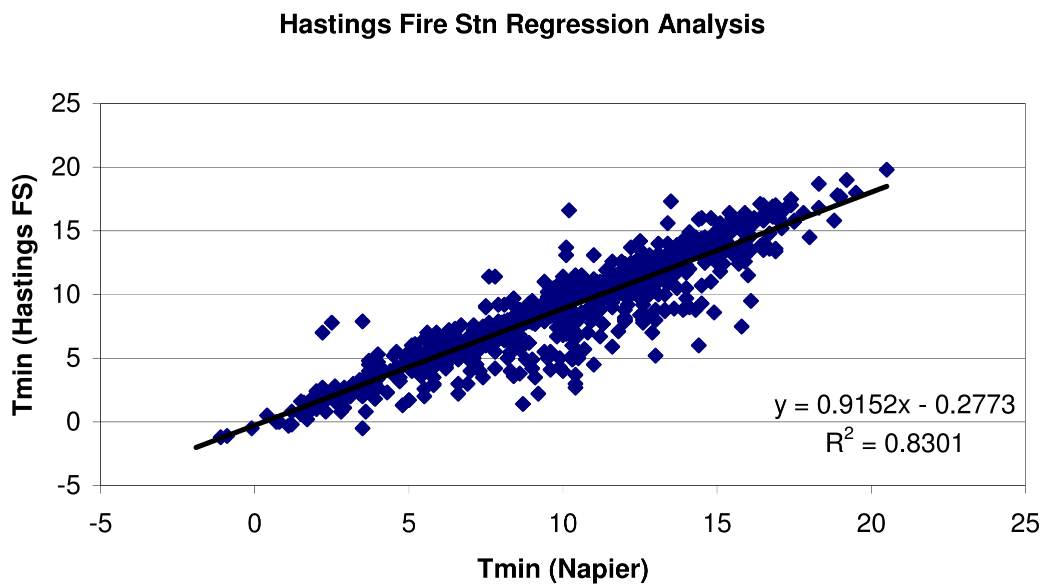
Porteous, AS., Mullan., AB and Basher, RE. 1998. New Zealand climate and La Niña: Prospects for 1998/1999. NIWA Report WLG/42, 19p.

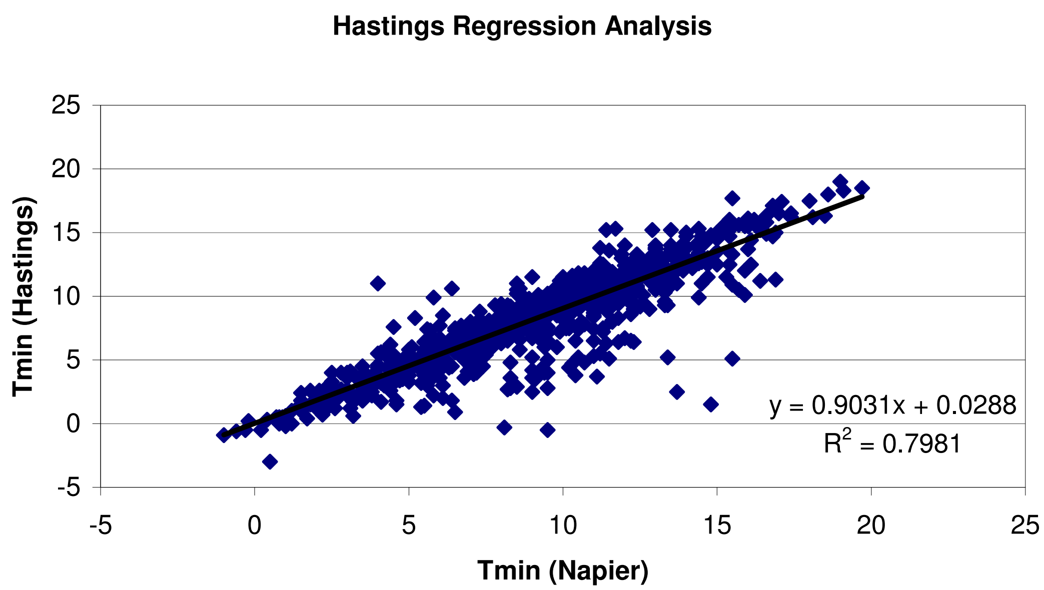
Power, S., Casey, T., Folland, C., Colman, A and Metha, V. 1999. Interdecadal modulation of the impact of ENSO on Australia. Climate Dynamics 15:319-324.

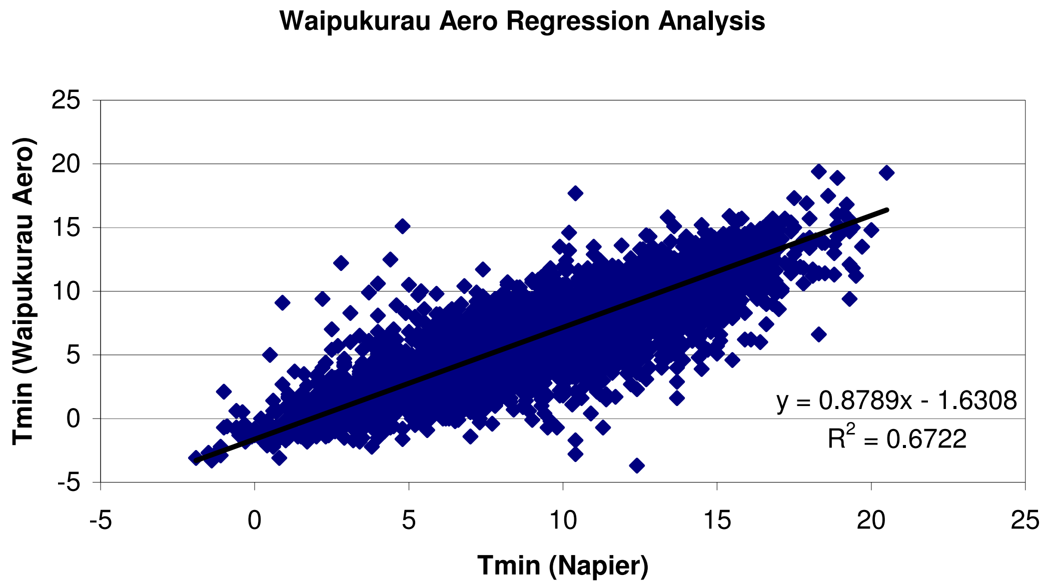
Rogers, WJ and Swift, HL. 1970. Frost and the prevention of frost damage. US NOAA, Department of Commerce, Washington D.C. 35p.

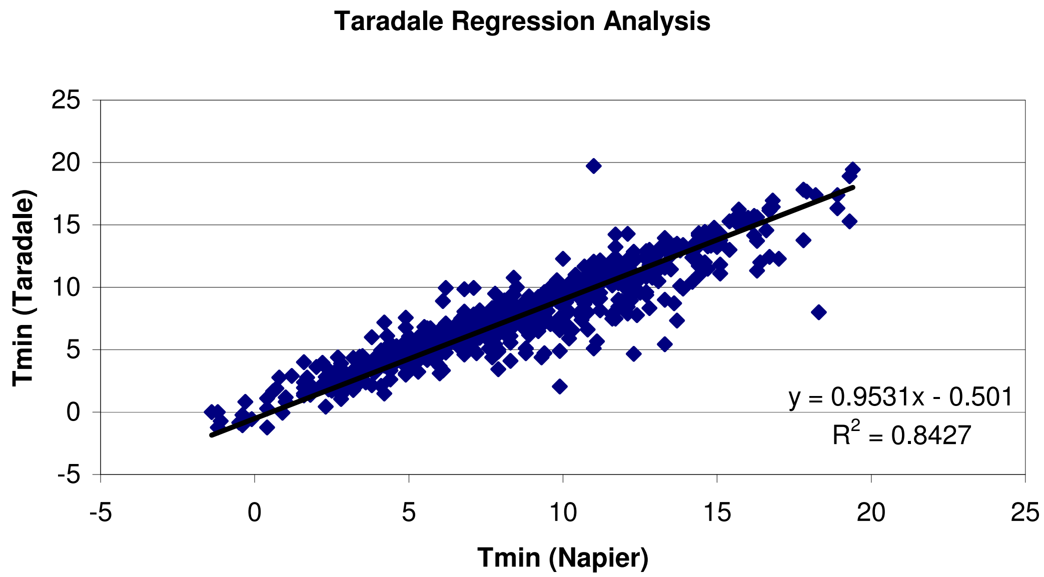
Salinger, MJ., Renwick., JA and Mullan., AB. 2001. Interdecadal Pacific Oscillation and South Pacific Climate. International Journal of Climatology 21:1705-1721.

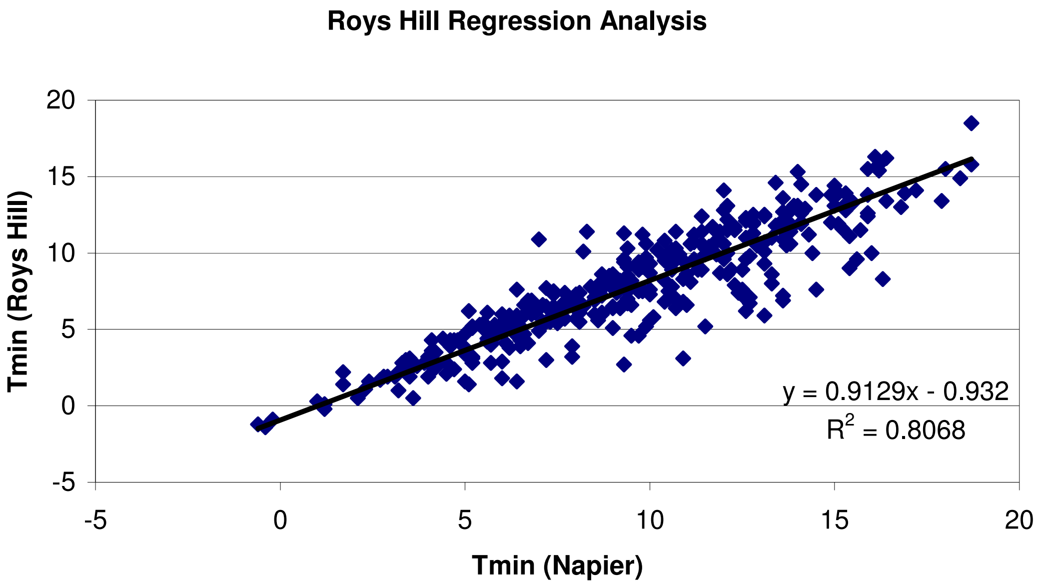
Appendix 1 Regression Analysis

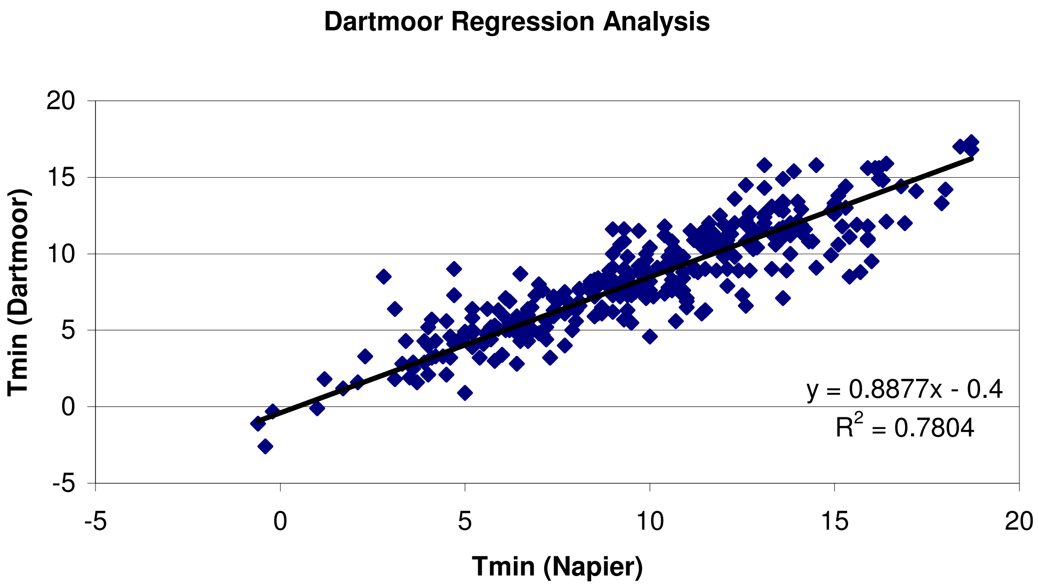




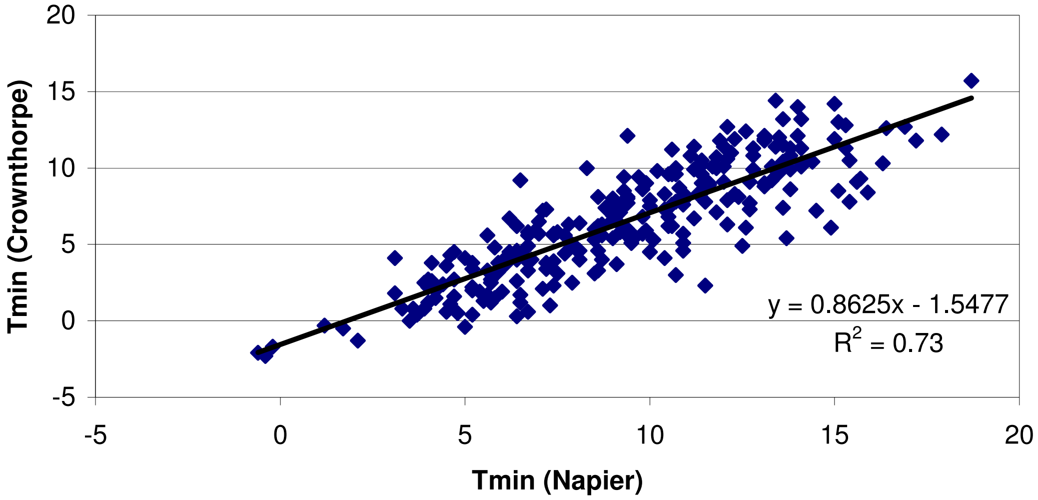

Waipukurau Aero Regression Analysis
Tmin (Waipukurau Aero)
Tmin (Napier)
y = 0.8789x - 1.6308
R2 = 0.6722
25
20
15
10
5
0
-5
-5
0
5
10
15
20
25


Taradale Regression Analysis
Tmin (Taradale)
Tmin (Napier)
y = 0.9531x - 0.501
R2 = 0.8427
25
20
15
10
5
0
-5
-5
0
5
10
15
20
25

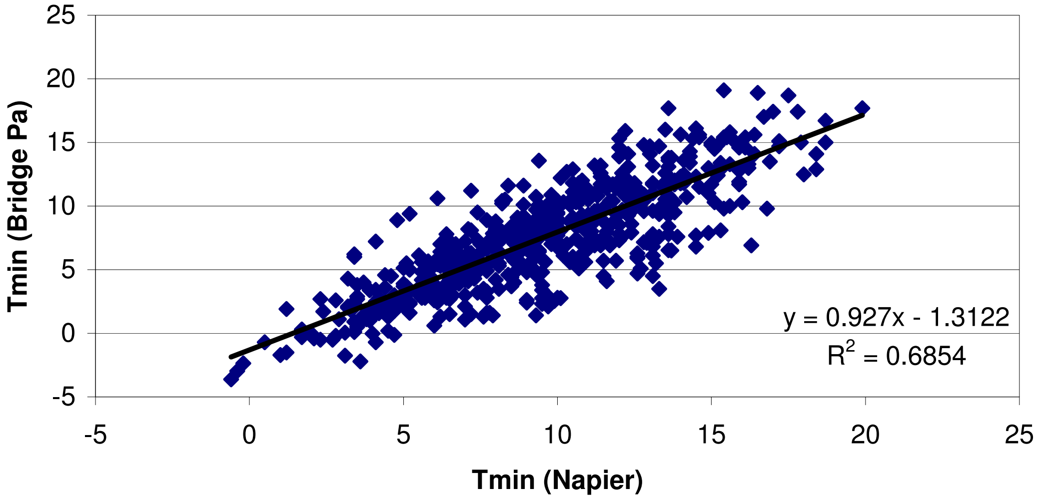

Roys Hill Regression Analysis
Tmin (Roys Hill)
Tmin (Napier)
y = 0.9129x - 0.932
R2 = 0.8068
20
15
10
5
0
-5
-5
0
5
10
15
20

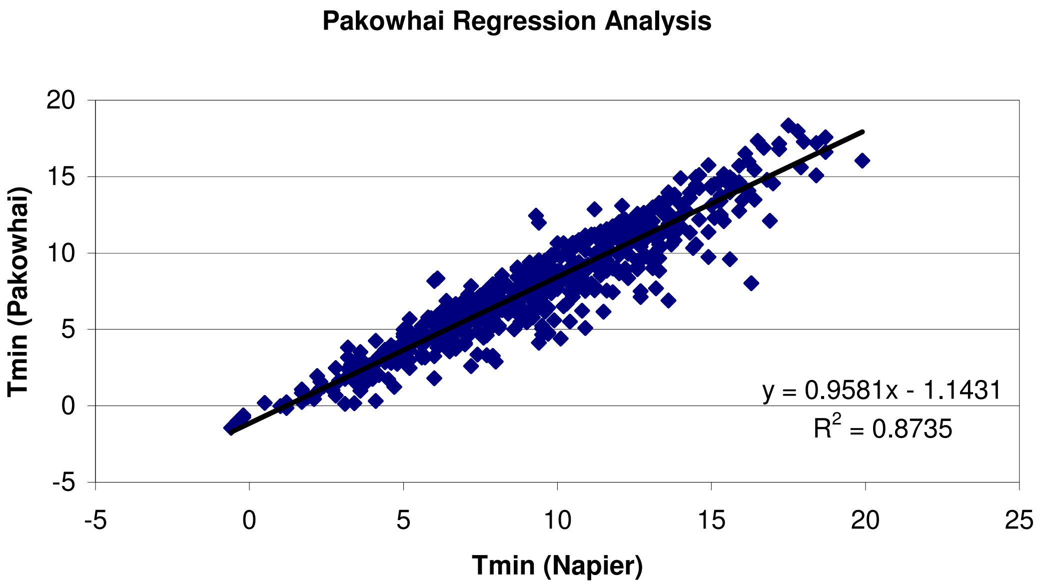

Dartmoor Regression Analysis
Tmin (Dartmoor)
Tmin (Napier)
y = 0.8877x - 0.4
R2 = 0.7804
20
15
10
5
0
-5
-5
0
5
10
15
20

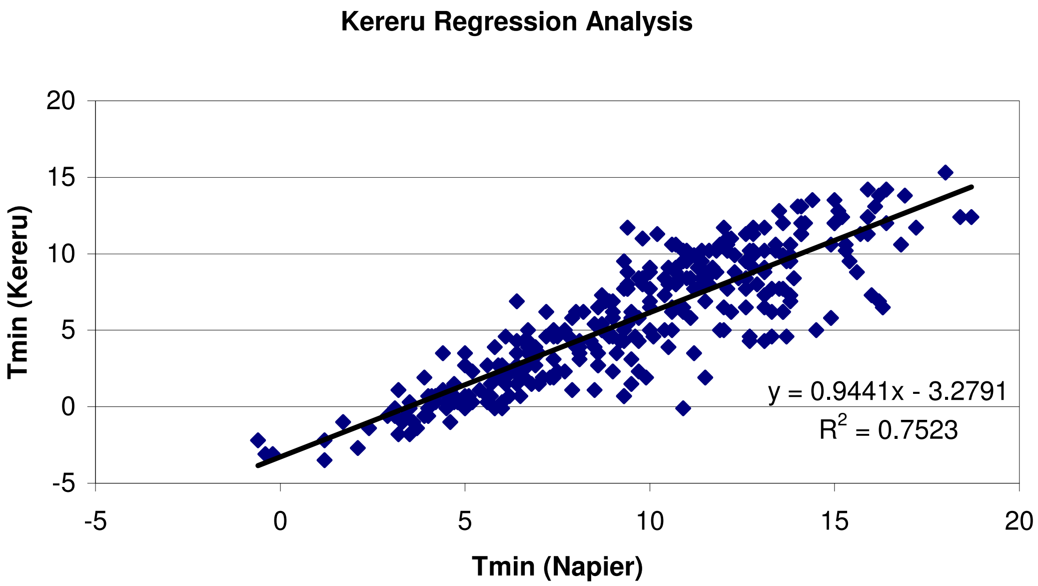
Crownthorpe Regression Analysis

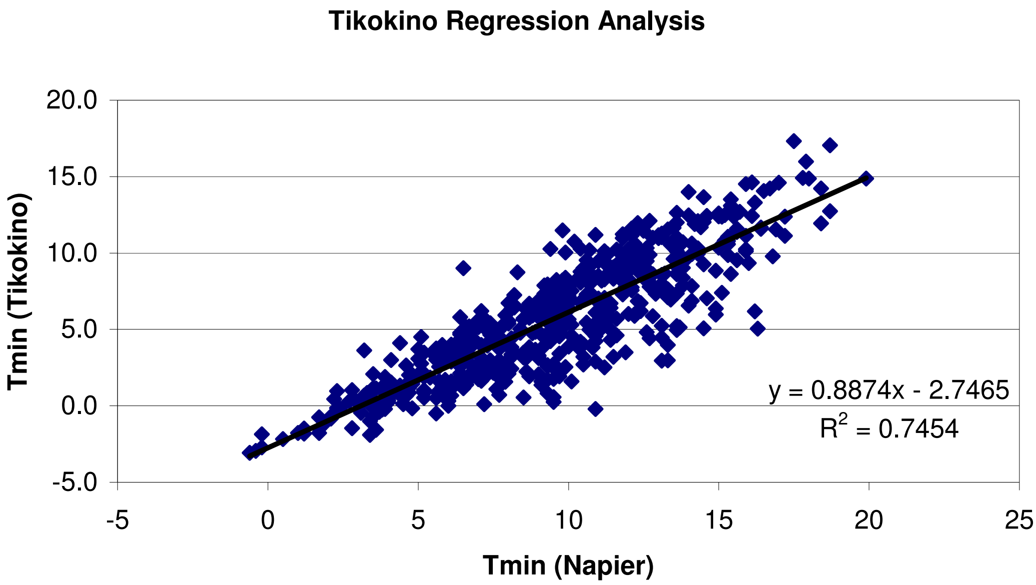


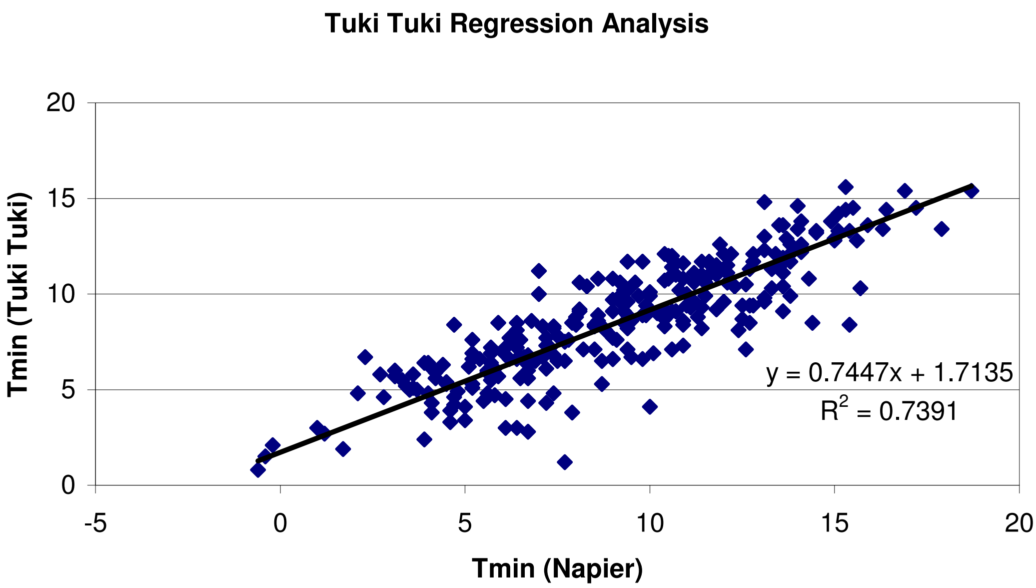
Bridge Pa Regression Analysis



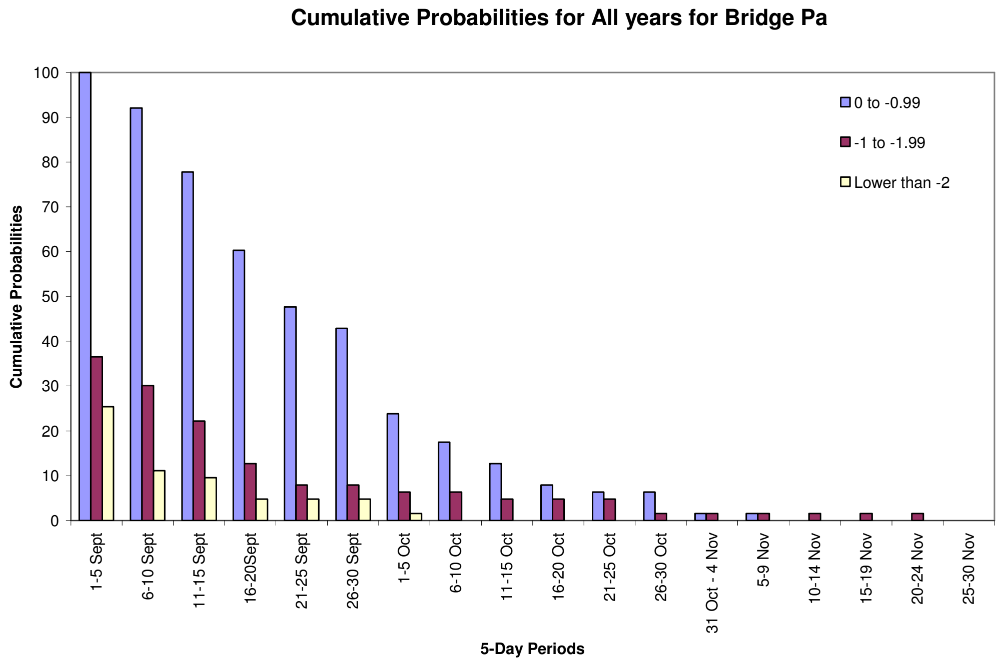

Pakowhai Regression Analysis
20
15
10
5
0
-5
Tmin (Pakowhai)
-5
0
5
10
15
20
25
Tmin (Napier)
y = 0.9581x - 1.1431
R2 = 0.8735

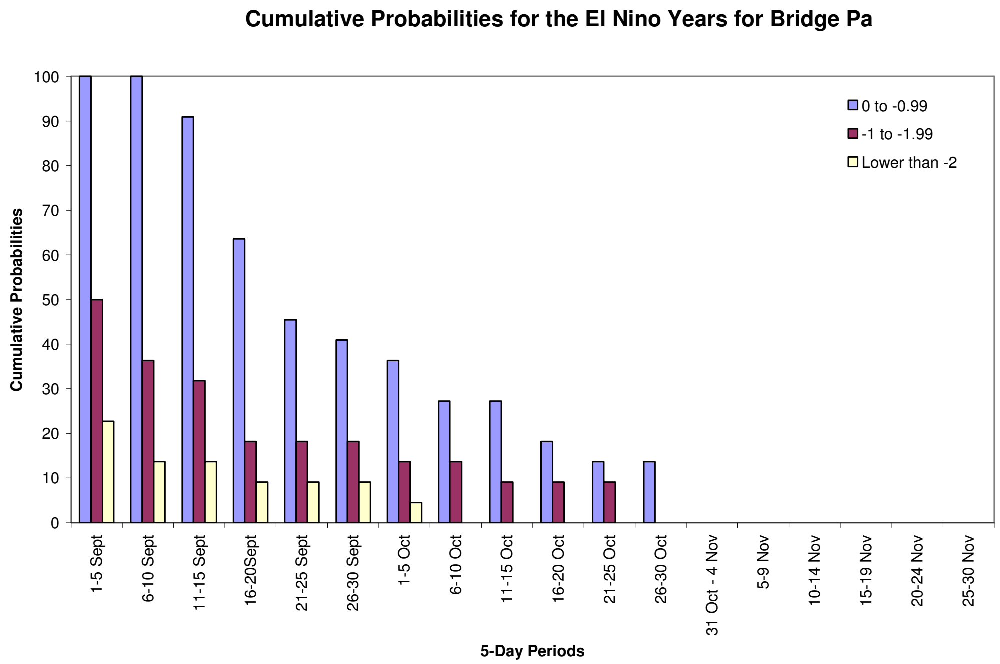

Kereru Regression Analysis
20
15
10
5
0
-5
Tmin (Kereru)
-5
0
5
10
15
20
Tmin (Napier)
y = 0.9441x - 3.2791
R2 = 0.7523

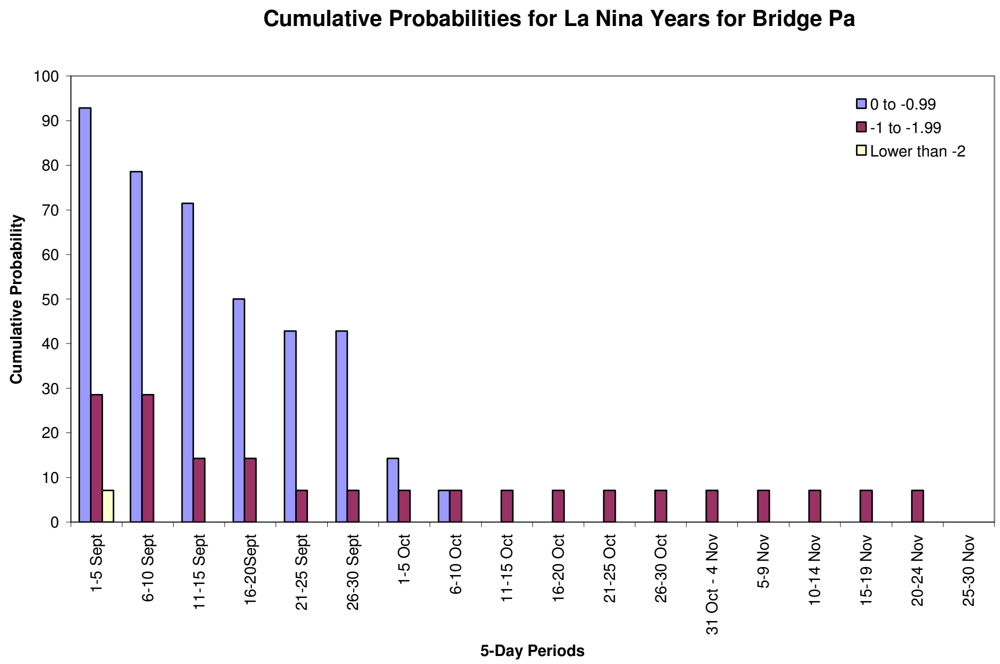

Tikokino Regression Analysis
20.0
15.0
10.0
5.0
0.0
-5.0
Tmin (Tikokino)
-5
0
5
10
15
20
25
Tmin (Napier)
y = 0.8874x - 2.7465
R2 = 0.7454

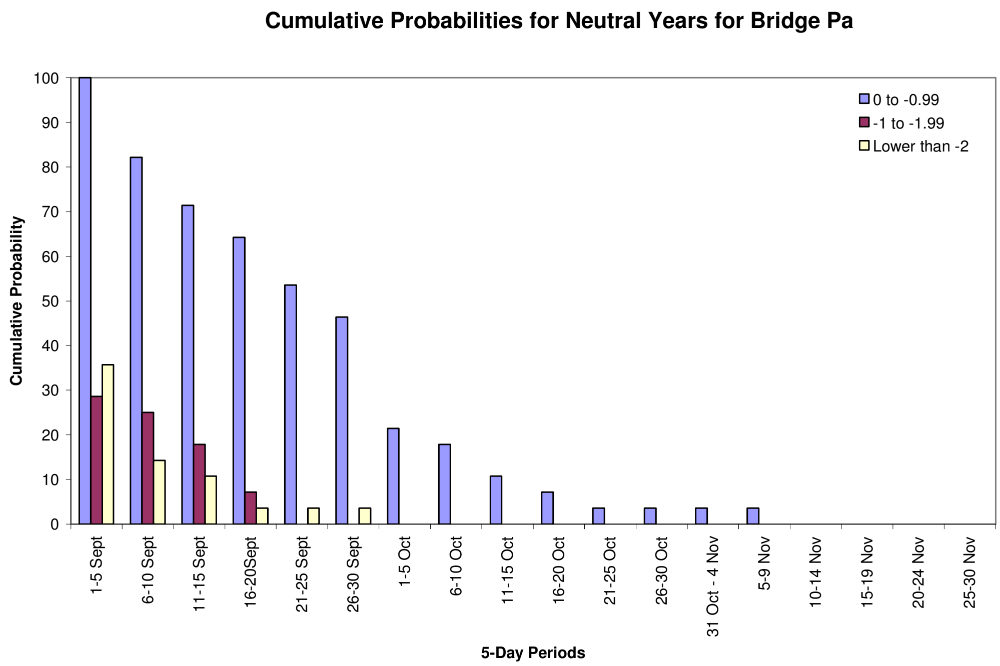

Tuki Tuki Regression Analysis
20
15
10
5
0
Tmin (Tuki Tuki)
-5
0
5
10
15
20
Tmin (Napier)
y = 0.7447x + 1.7135
R2 = 0.7391

Appendix 2 – Cumulative Probabilities during ENSO Events

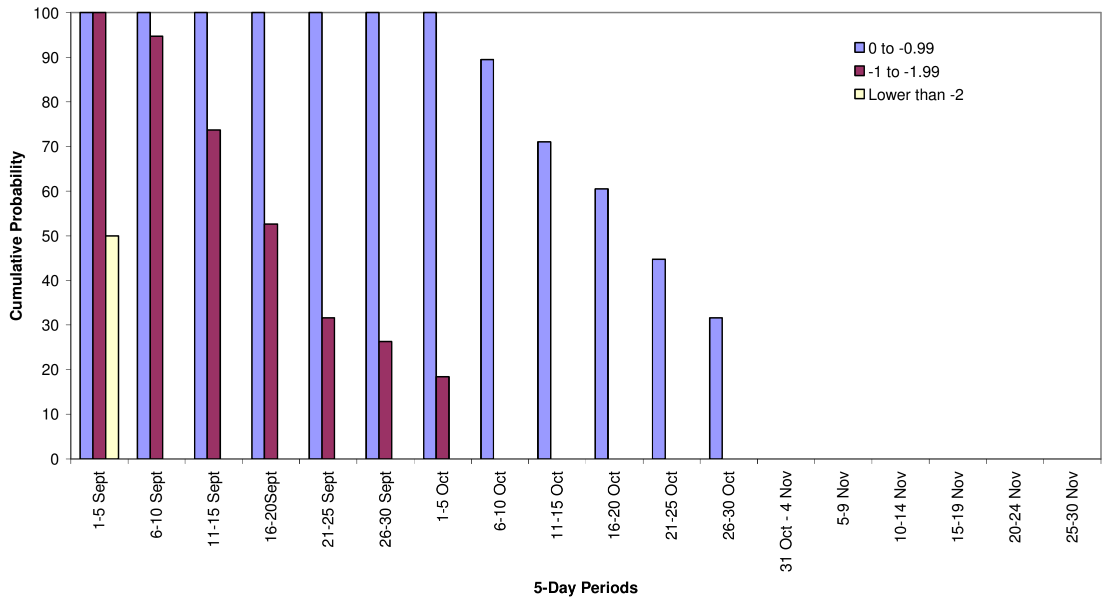




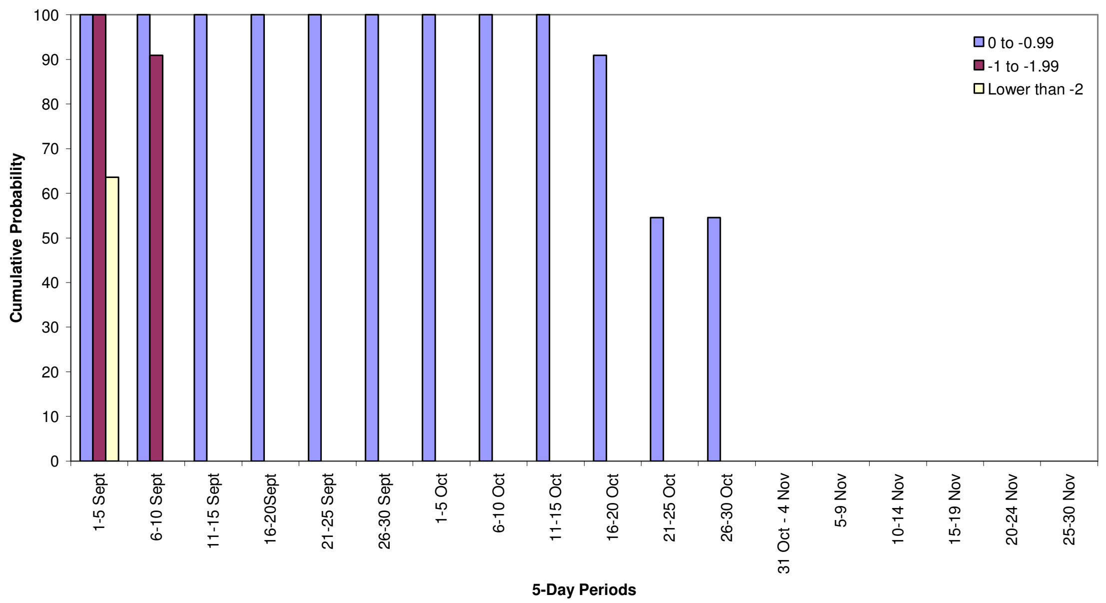

Cumulative Probabilities for La Nina Years for Bridge Pa
Cumulative Probability
100
90
80
70
60
50
40
30
20
10
0
0 to -0.99
-1 to -1.99
Lower than -2
1-5 Sept
6-10 Sept
11-15 Sept
16-20Sept
21-25 Sept
26-30 Sept
1-5 Oct
6-10 Oct
11-15 Oct
16-20 Oct
21-25 Oct
26-30 Oct
31 Oct - 4 Nov
5-9 Nov
10-14 Nov
15-19 Nov
20-24 Nov
25-30 Nov
5-Day Periods

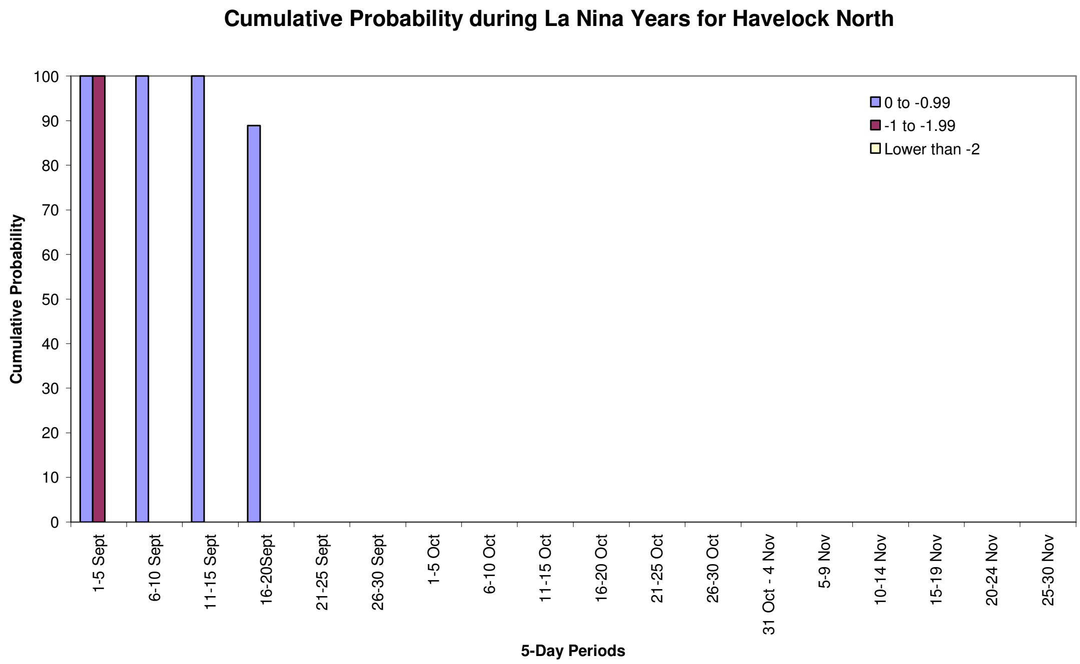

Cumulative Probabilities for Neutral Years for Bridge Pa
Cumulative Probability
100
90
80
70
60
50
40
30
20
10
0
0 to -0.99
-1 to -1.99
Lower than -2
1-5 Sept
6-10 Sept
11-15 Sept
16-20Sept
21-25 Sept
26-30 Sept
1-5 Oct
6-10 Oct
11-15 Oct
16-20 Oct
21-25 Oct
26-30 Oct
31 Oct - 4 Nov
5-9 Nov
10-14 Nov
15-19 Nov
20-24 Nov
25-30 Nov
5-Day Periods

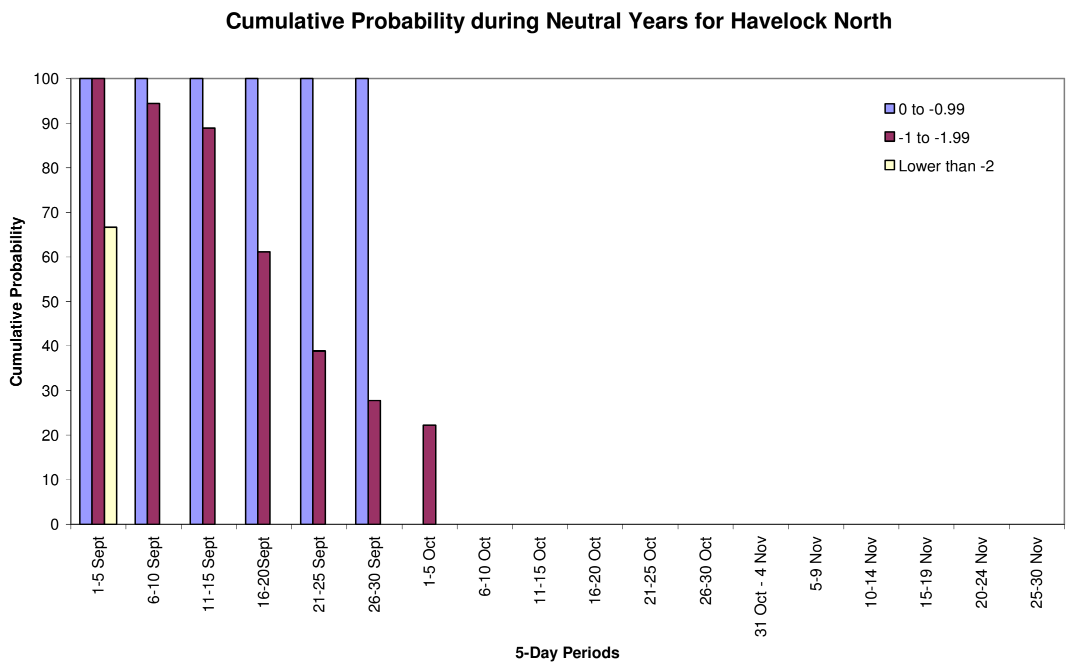
Cumulative Probability for All Years for Havelock North



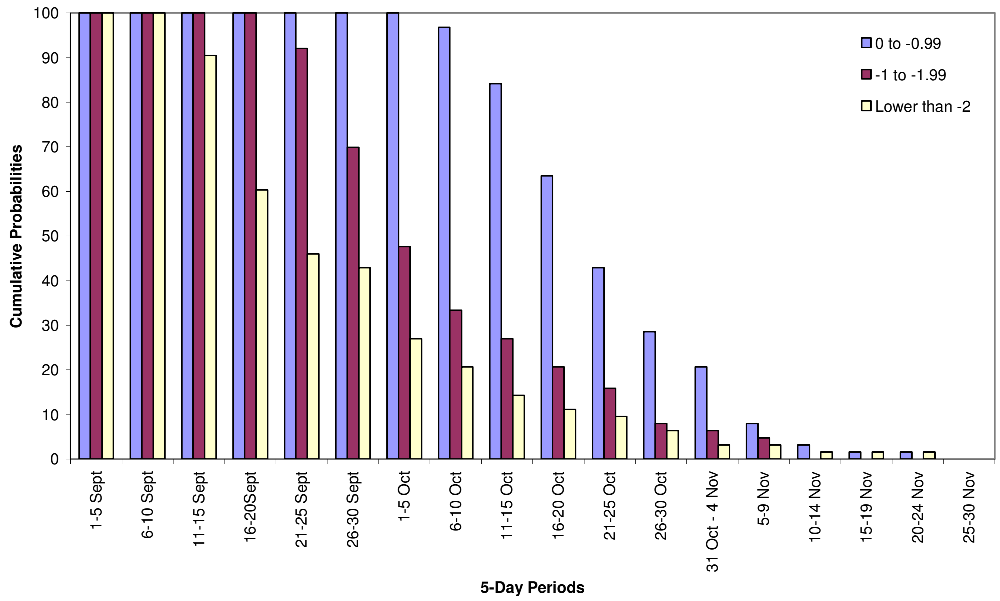
Cumulative Probability during El Nino for Havelock North



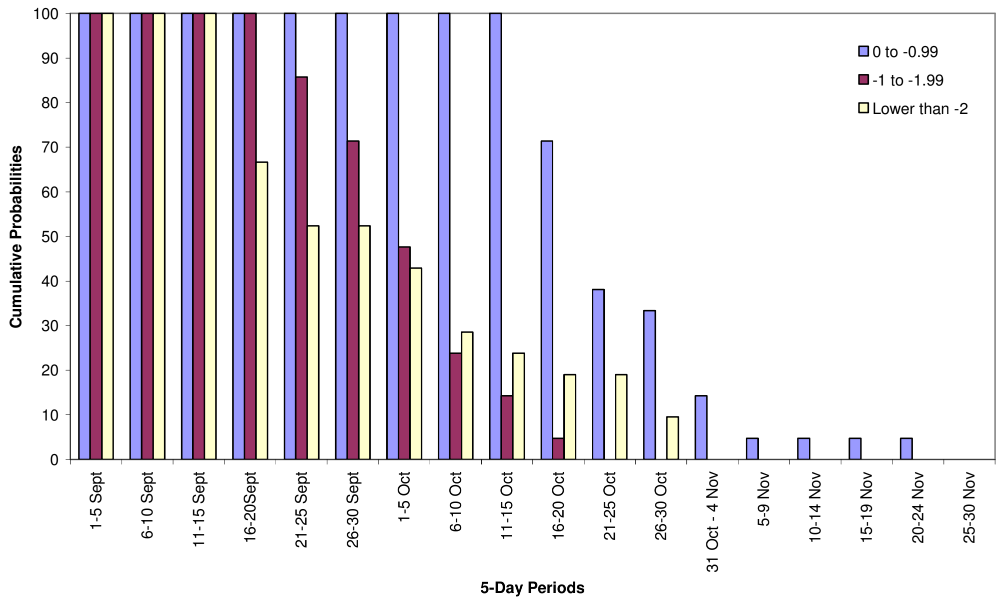

Cumulative Probability during La Nina Years for Havelock North
Cumulative Probability
5-Day Periods
0 to -0.99
-1 to -1.99
Lower than -2
1-5 Sept
6-10 Sept
11-15 Sept
16-20Sept
21-25 Sept
26-30 Sept
1-5 Oct
6-10 Oct
11-15 Oct
16-20 Oct
21-25 Oct
26-30 Oct
31 Oct - 4 Nov
5-9 Nov
10-14 Nov
15-19 Nov
20-24 Nov
25-30 Nov

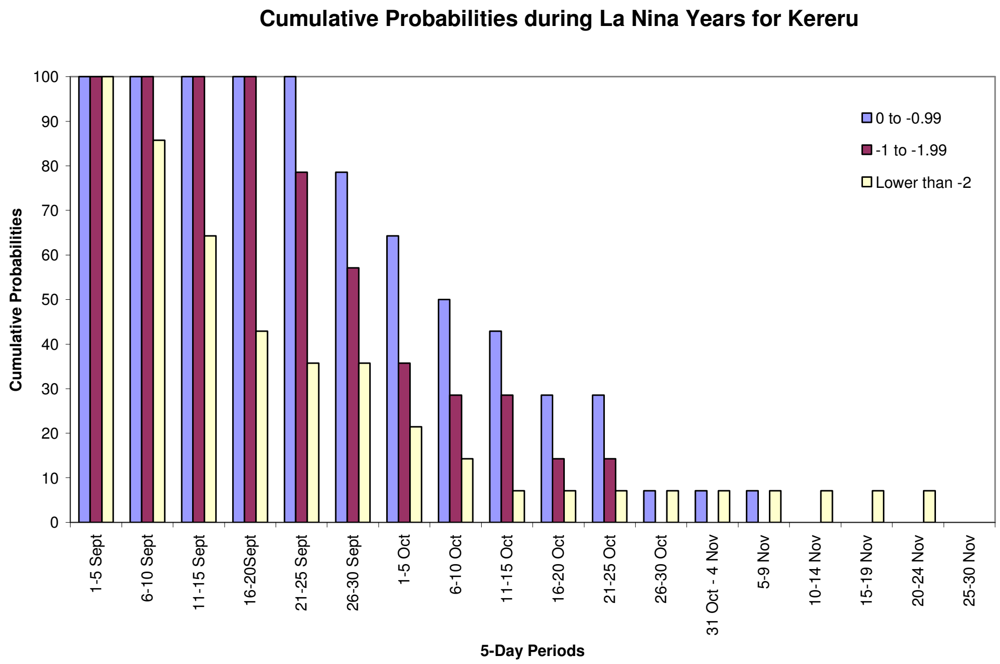

Cumulative Probability during Neutral Years for Havelock North
Cumulative Probability
5-Day Periods
0 to -0.99
-1 to -1.99
Lower than -2
1-5 Sept
6-10 Sept
11-15 Sept
16-20Sept
21-25 Sept
26-30 Sept
1-5 Oct
6-10 Oct
11-15 Oct
16-20 Oct
21-25 Oct
26-30 Oct
31 Oct - 4 Nov
5-9 Nov
10-14 Nov
15-19 Nov
20-24 Nov
25-30 Nov

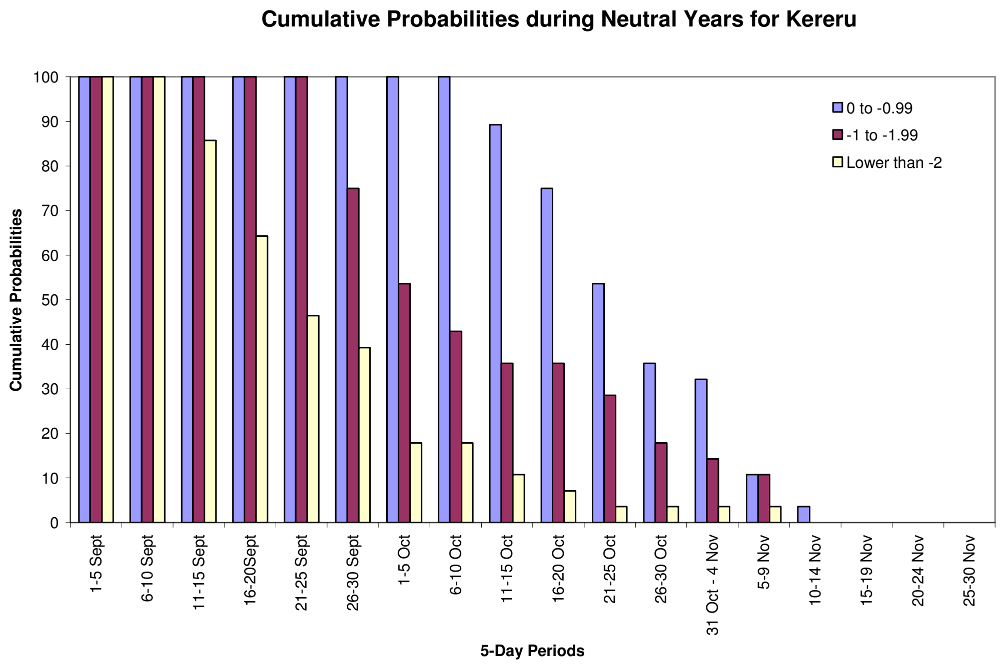
Cumulative Probabilities for All Years for Kereru

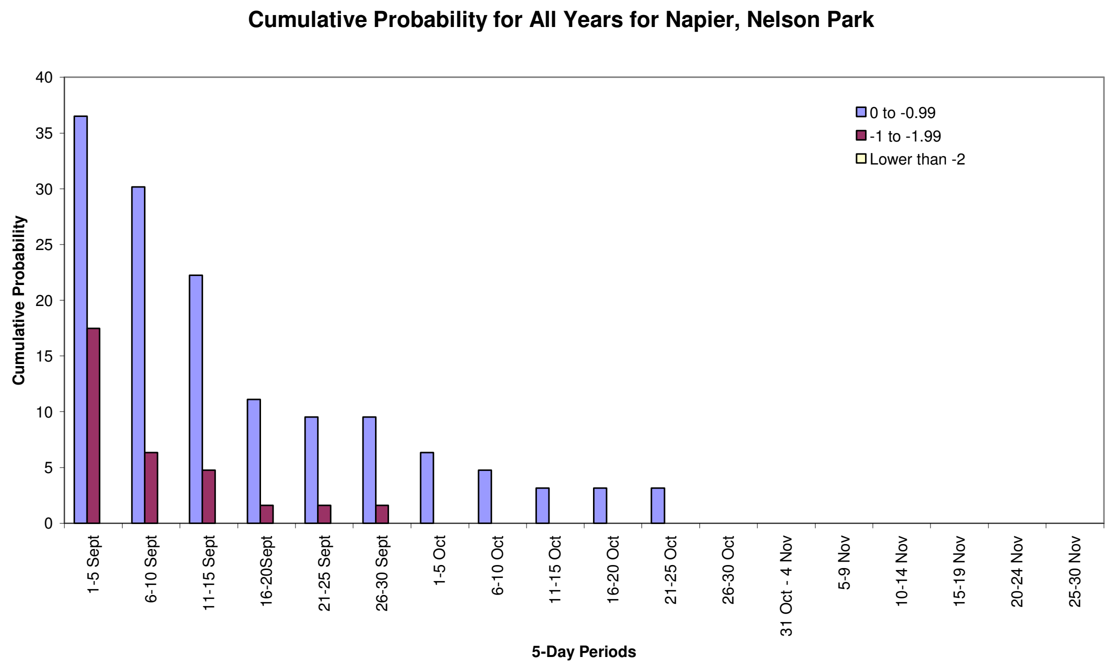


Cumulative Probabilities during El Nino for Kereru

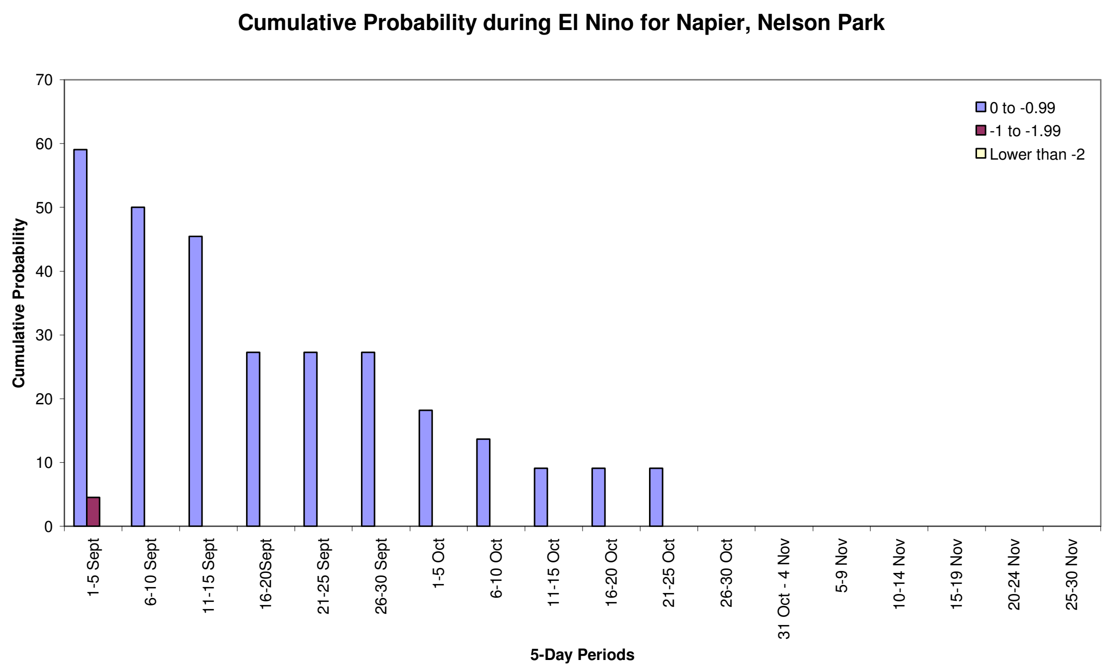



Cumulative Probabilities during La Nina Years for Kereru
Cumulative Probabilities
5-Day Periods
0 to -0.99
-1 to -1.99
Lower than -2
1-5 Sept
6-10 Sept
11-15 Sept
16-20Sept
21-25 Sept
26-30 Sept
1-5 Oct
6-10 Oct
11-15 Oct
16-20 Oct
21-25 Oct
26-30 Oct
31 Oct - 4 Nov
5-9 Nov
10-14 Nov
15-19 Nov
20-24 Nov
25-30 Nov


Cumulative Probabilities during Neutral Years for Kereru
Cumulative Probabilities
5-Day Periods
0 to -0.99
-1 to -1.99
Lower than -2
1-5 Sept
6-10 Sept
11-15 Sept
16-20Sept
21-25 Sept
26-30 Sept
1-5 Oct
6-10 Oct
11-15 Oct
16-20 Oct
21-25 Oct
26-30 Oct
31 Oct - 4 Nov
5-9 Nov
10-14 Nov
15-19 Nov
20-24 Nov
25-30 Nov

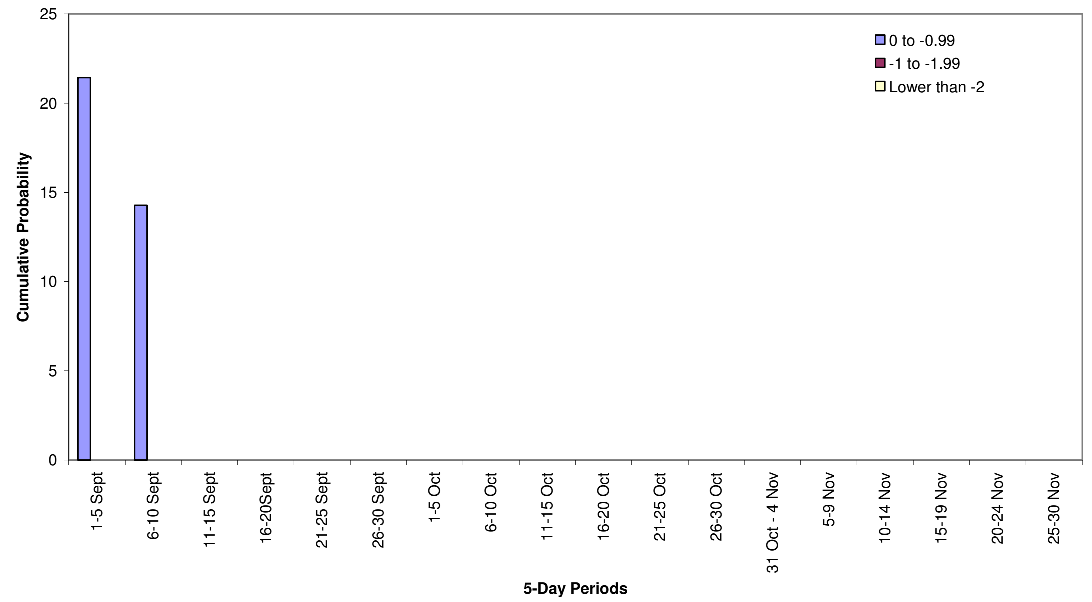


Cumulative Probability for All Years for Napier, Nelson Park
Cumulative Probability
0
5
10
15
20
25
30
35
40
0 to -0.99
-1 to -1.99
Lower than -2
1-5 Sept
6-10 Sept
11-15 Sept
16-20Sept
21-25 Sept
26-30 Sept
1-5 Oct
6-10 Oct
11-15 Oct
16-20 Oct
21-25 Oct
26-30 Oct
31 Oct - 4 Nov
5-9 Nov
10-14 Nov
15-19 Nov
20-24 Nov
25-30 Nov
5-Day Periods

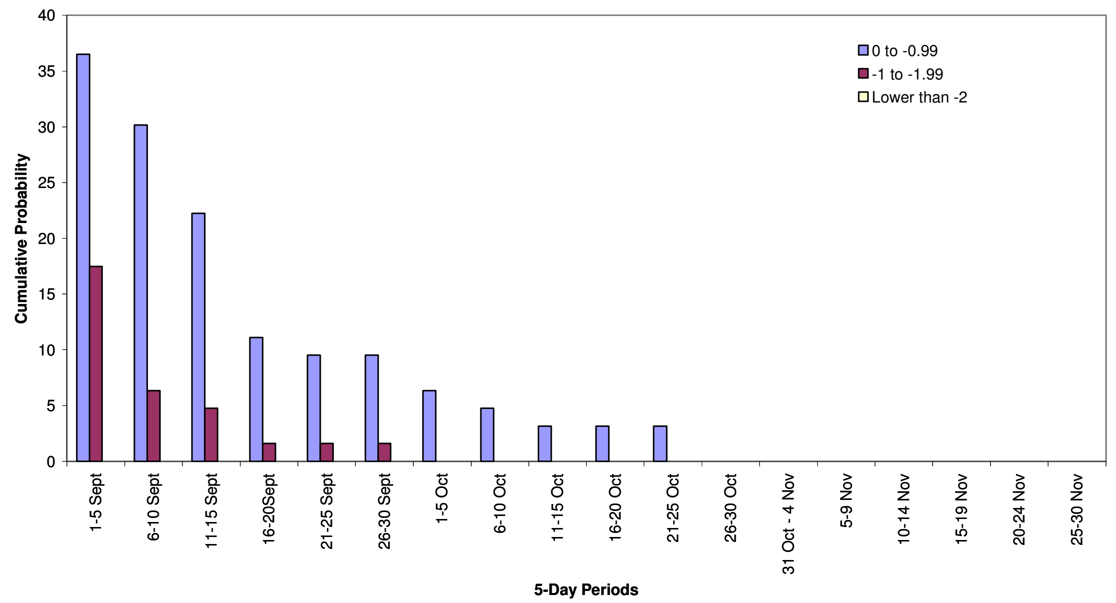


Cumulative Probability during El Nino for Napier, Nelson Park
Cumulative Probability
0
10
20
30
40
50
60
70
0 to -0.99
-1 to -1.99
Lower than -2
1-5 Sept
6-10 Sept
11-15 Sept
16-20Sept
21-25 Sept
26-30 Sept
1-5 Oct
6-10 Oct
11-15 Oct
16-20 Oct
21-25 Oct
26-30 Oct
31 Oct - 4 Nov
5-9 Nov
10-14 Nov
15-19 Nov
20-24 Nov
25-30 Nov
5-Day Periods

Cumulative Probability during La Nina Years for Napier, Nelson Park

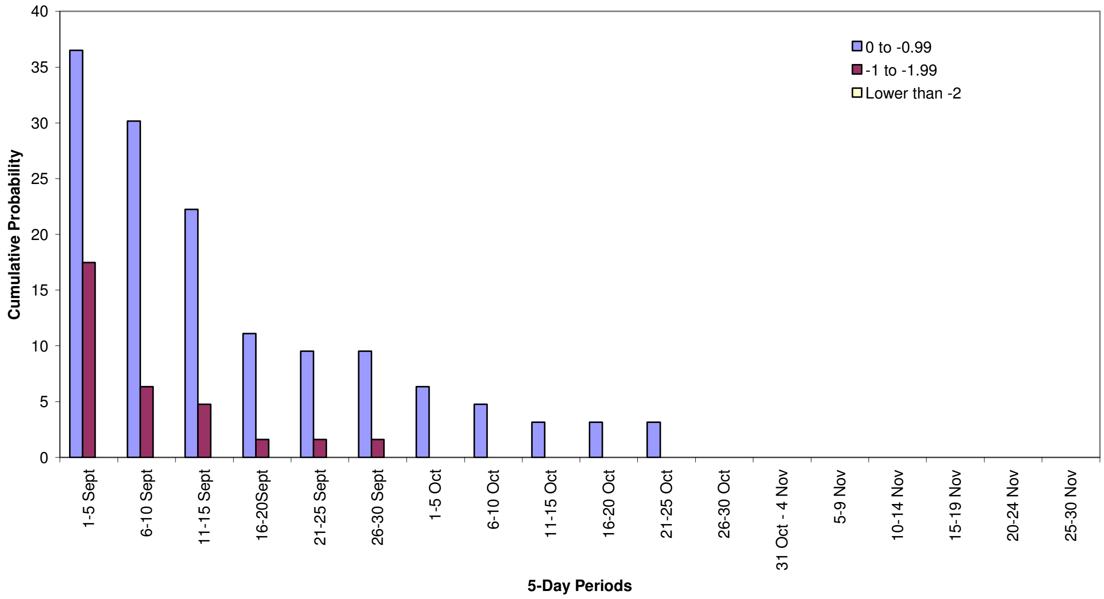


Cumulative Probability for All Years for Napier, Nelson Park

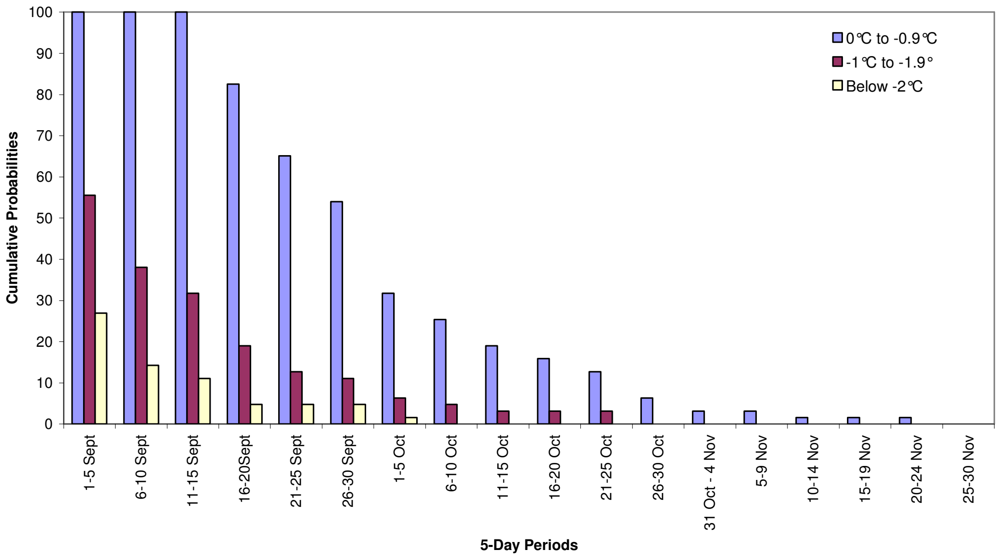


Appendix 3 – Cumulative Frost Probabilities for All Sites

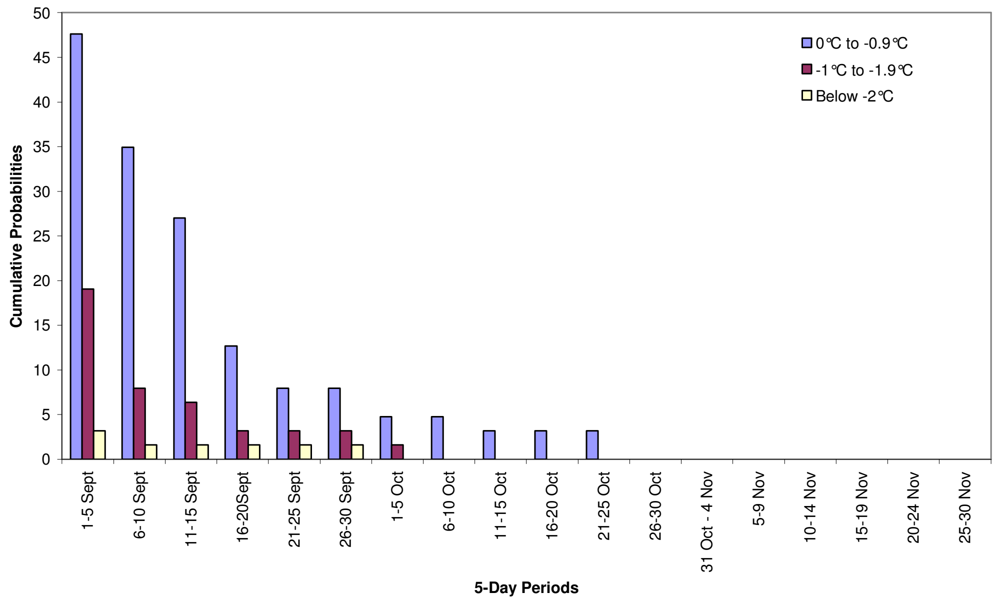
Cumulative Probability for All Years for Napier, Nelson Park



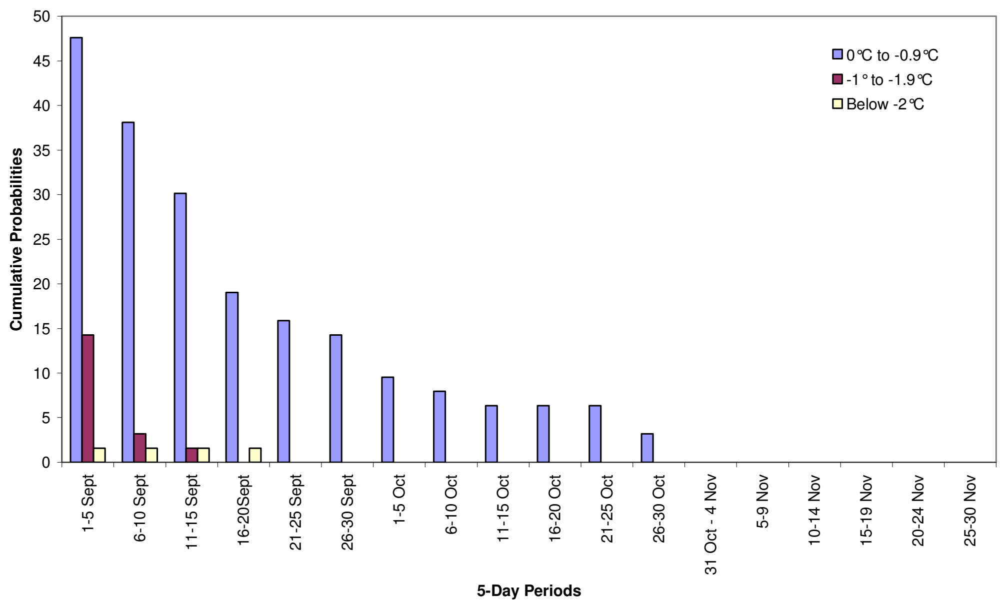
Cumulative Frost Probabilities at Crownthorpe for All years



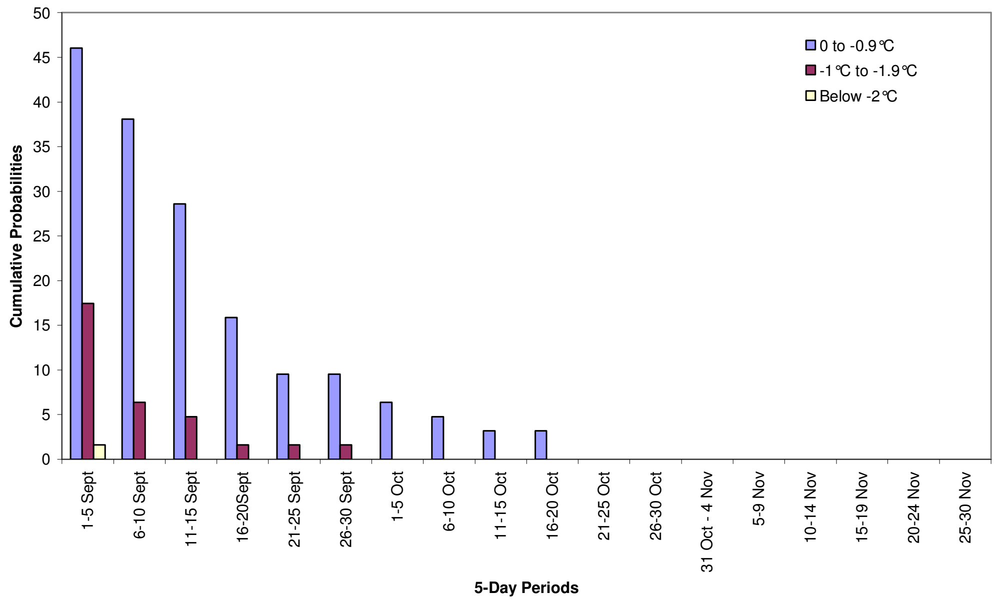
Cumulative Frost Probabilities for Dartmoor for All Years



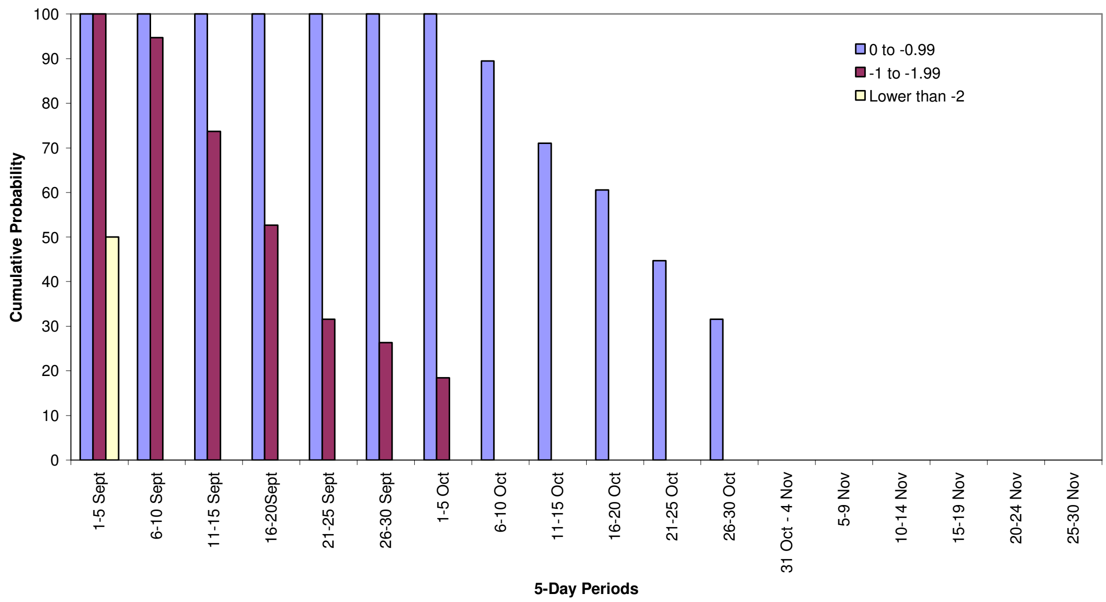
Cumulative Frost Probabilities for Hastings for All Years



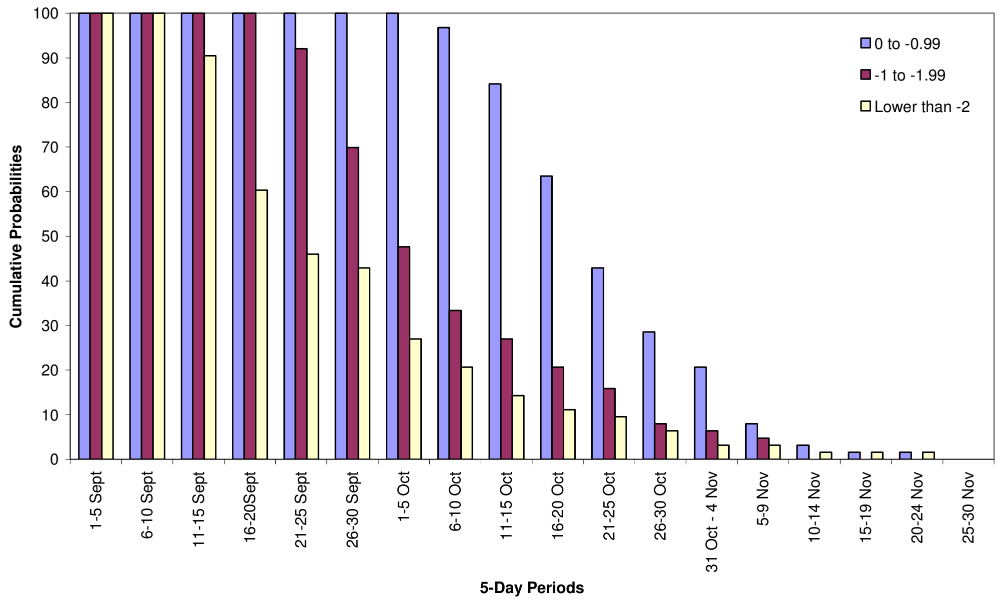
Cumulative Frost Probabilities for Hastings Fire Station for all Years



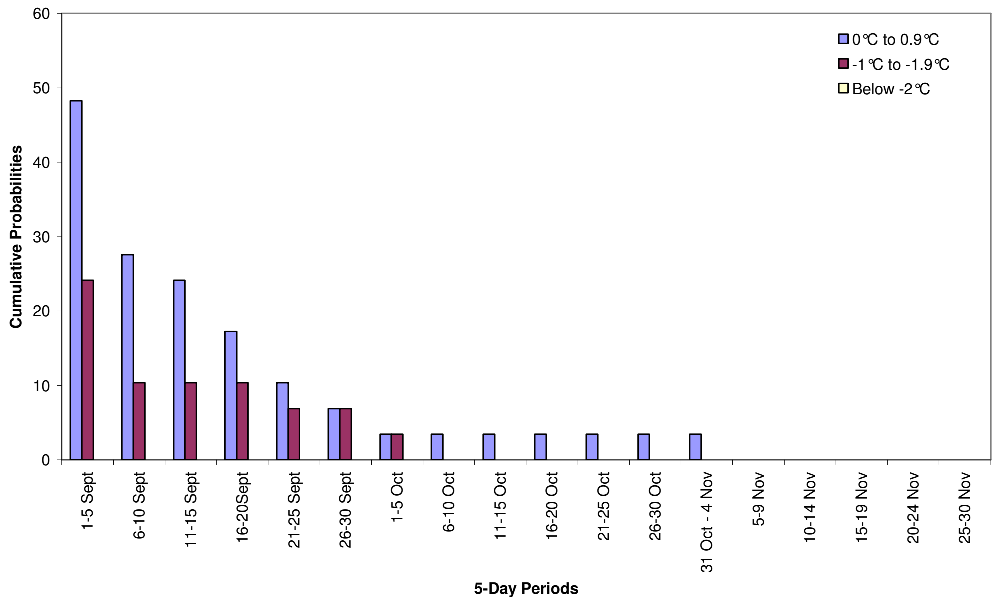
Cumulative Probability for All Years for Havelock North

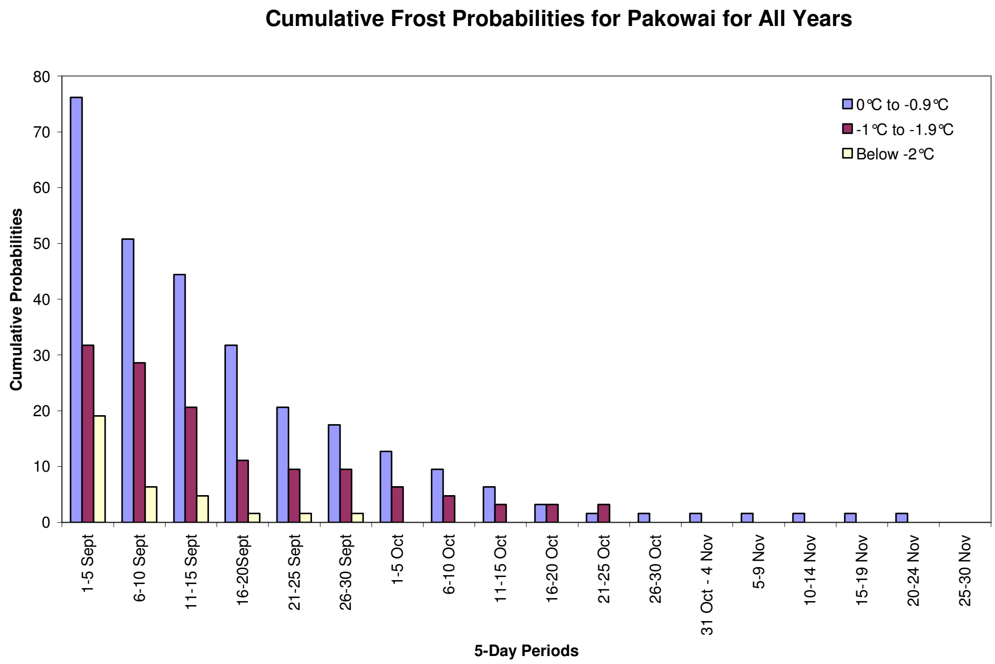


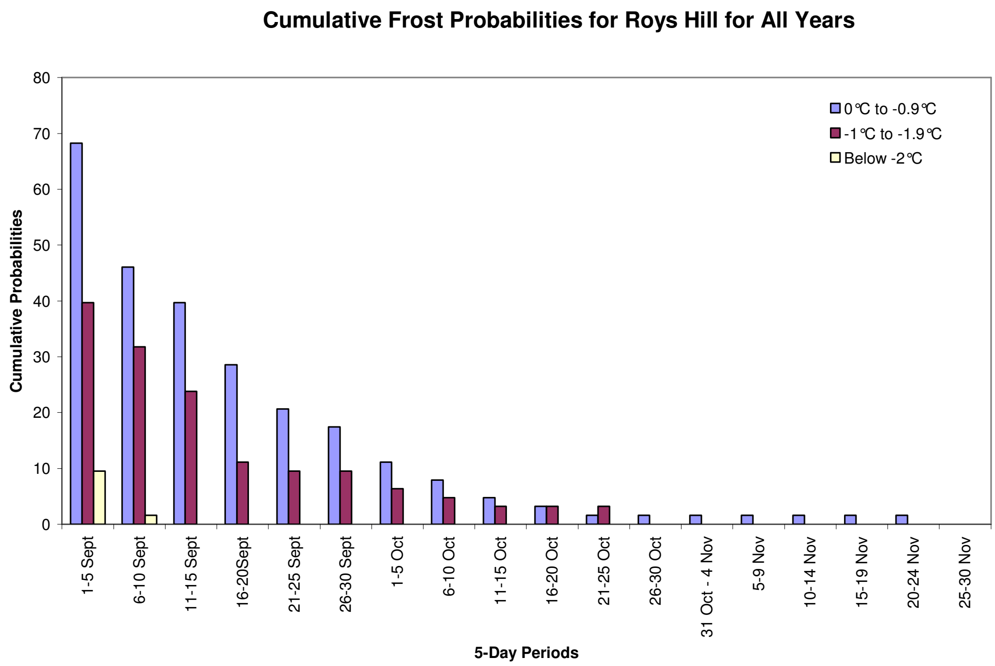
Cumulative Probabilities for All Years for Kereru



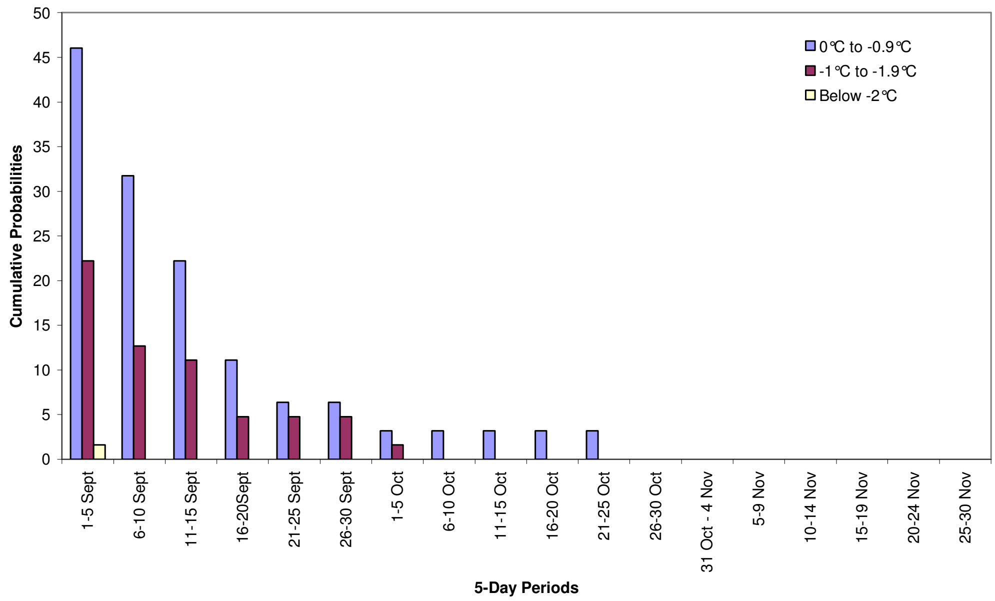
Cumulative Frost Probabilities for Napier Airport for All Years



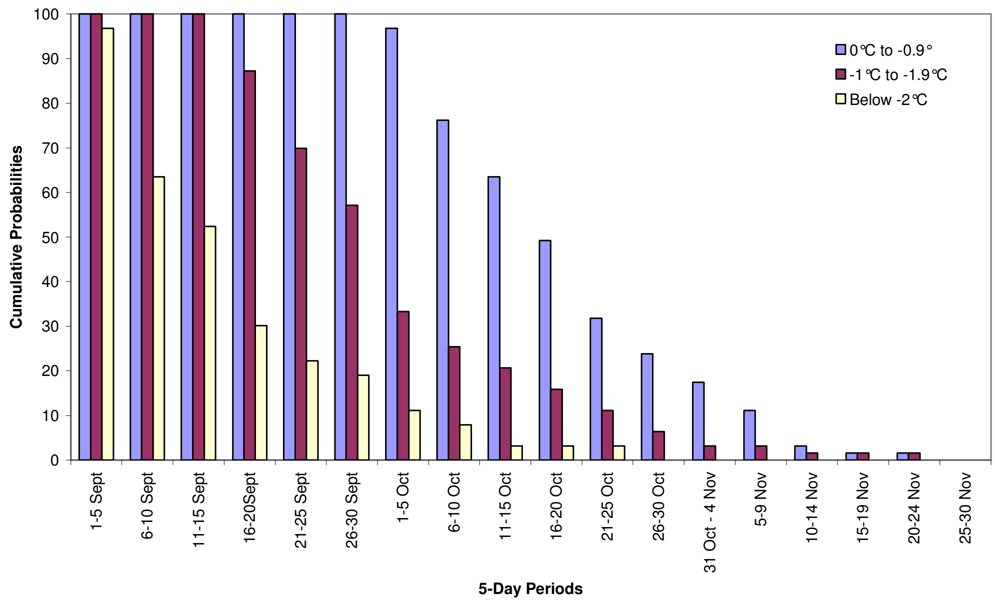

Cumulative Frost Probabilities for Pakowai for All Years
Cumulative Probabilities
5-Day Periods
0℃ to -0.9℃
-1℃ to -1.9℃
Below -2℃
0
10
20
30
40
50
60
70
80
1-5 Sept
6-10 Sept
11-15 Sept
16-20Sept
21-25 Sept
26-30 Sept
1-5 Oct
6-10 Oct
11-15 Oct
16-20 Oct
21-25 Oct
26-30 Oct
31 Oct - 4 Nov
5-9 Nov
10-14 Nov
15-19 Nov
20-24 Nov
25-30 Nov

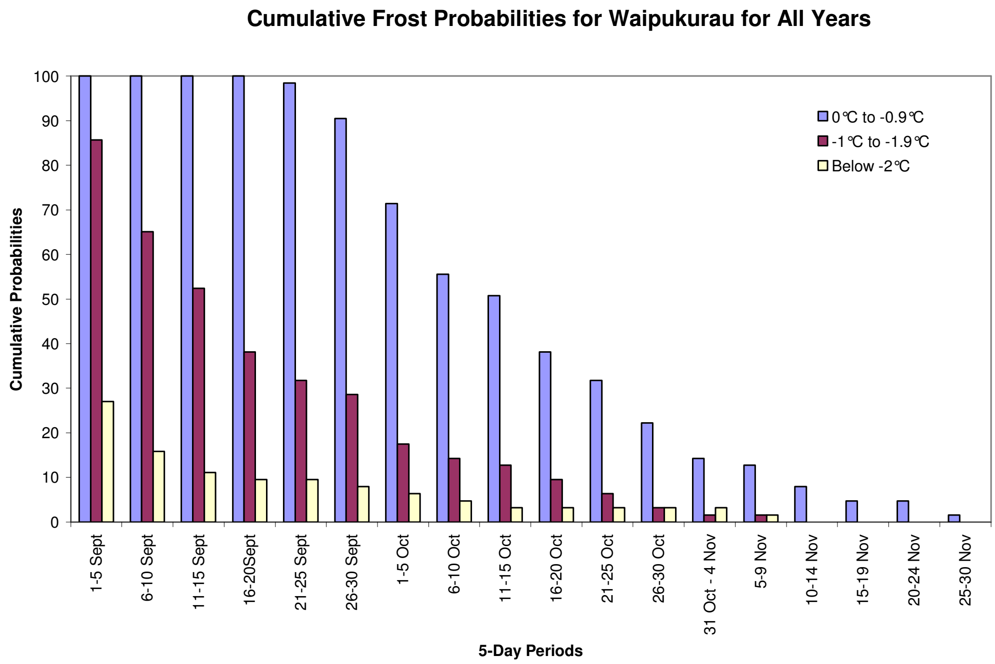

Cumulative Frost Probabilities for Roys Hill for All Years
Cumulative Probabilities
5-Day Periods
0℃ to -0.9℃
-1℃ to -1.9℃
Below -2℃
0
10
20
30
40
50
60
70
80
1-5 Sept
6-10 Sept
11-15 Sept
16-20Sept
21-25 Sept
26-30 Sept
1-5 Oct
6-10 Oct
11-15 Oct
16-20 Oct
21-25 Oct
26-30 Oct
31 Oct - 4 Nov
5-9 Nov
10-14 Nov
15-19 Nov
20-24 Nov
25-30 Nov

Cumulative Frost Probabilities for Taradale for All Years



Cumulative Frost Probabilities for Tikokino for All Years




Cumulative Frost Probabilities for Waipukurau for All Years
Cumulative Probabilities
100
90
80
70
60
50
40
30
20
10
0
0°C to -0.9°C
-1°C to -1.9°C
Below -2°C
1-5 Sept
6-10 Sept
11-15 Sept
16-20Sept
21-25 Sept
26-30 Sept
1-5 Oct
6-10 Oct
11-15 Oct
16-20 Oct
21-25 Oct
26-30 Oct
31 Oct - 4 Nov
5-9 Nov
10-14 Nov
15-19 Nov
20-24 Nov
25-30 Nov
5-Day Periods