Relationship between Climate Modes and Hawke's Bay Seasonal Rainfall and Temperature

Prepared for Hawke's Bay Regional Council

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Prepared by:
Nava Fedaeff
Nicolas Fauchereau

For any information regarding this report please contact:

Nava Fedaeff
Climate Scientist – Auckland
Climate Application
+64-9-375 6337
Nava.Fedaeff@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
Private Bag 99940
Viaduct Harbour
Auckland 1010

Phone +64 9 375 2050

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Contents

Executive Summary

This report, prepared for the Hawke's Bay Regional Council, describes the main climate modes affecting New Zealand and explores their relationship with temperature and rainfall in the Hawke's Bay Region.

Five large-scale climate oscillations (Interdecadal Pacific Oscillation (IPO), El Niño Southern Oscillation (ENSO), Southern Annular Mode (SAM), Indian Ocean Dipole (IOD) and the South Pacific Tropical Dipole (SPSD)) are reviewed and their effects on rainfall and temperature in New Zealand and the Hawke's Bay region summarised.

Homogeneity tests (to assess the quality of the data record) were performed on all of the climate data used for this report and composite records of data from two or more nearby climate stations were constructed, where necessary, to extend the length of the data records. The correlation between temperature, rainfall and the five climate modes identified as potential drivers of Hawke's Bay climate was established and additional composite analysis of the IPO and SPSD was carried out.

The results of this study have uncovered that the main climate signals to influence internal variability in rainfall and temperature are the SPSD, SOI and to some degree the IOD. The SPSD was found to be the most important climate mode influencing both rainfall (up to 15% of variation explained) and temperature (up to 41% of variation explained) with warm SSTs around NZ (positive SPSD) associated with warm and wet conditions in Hawke's Bay and vice versa.

ENSO was also found to have an impact on both rainfall in temperature in Hawke's Bay but on a lesser scale than the SPSD. The IOD was found to impact mean and extreme rainfall during spring (which coincides with the peak of this climate mode) as well exerting some influence on temperatures, while limited statistical significance was established between climate indices and the SAM and IPO climate modes.

Prior to this study the SPSD was not routinely calculated or used for climate forecasting in New Zealand. Given the significance of some of the presented results, there is an opportunity for a tailored seasonal statistical forecasting scheme to be developed for Hawke's Bay. Potential real-time predictors should include the SPSD index, one or several ENSO indices and the IOD.

1 Introduction

New Zealand's climate is complex and highly variable, ranging from warm and subtropical in the far north to cool and temperate in the far south. We can get intense storms from the roaring forties of the southern ocean as well as from ex-tropical cyclones from the north. Mountain ranges extending the length of the country cut across prevailing weather systems, and as a result rainfall patterns in New Zealand are strongly influenced by the interaction between its mountainous terrain and the predominant westerly circulation. This orographic effect means that a west-east gradient dominates the regional rainfall regime, with the greatest amount of precipitation falling along the west coast of the South Island, to the west of the Southern Alps. At the interannual to decadal time-scales, regional circulation is also significantly influenced by well-known climate oscillations such as the Interdecadal Pacific Oscillation, the El Niño Southern Oscillation, the Southern Annular Mode, the Indian Ocean Dipole and as uncovered in this study – the South Pacific Subtropical Dipole.

The Hawke's Bay Regional Council (HBRC) has identified weather and climate as having a far reaching effect on the Council's operations in such areas as civil defence, flood protection work, land management and water allocation. Extreme events such as flooding and drought have been linked to known climate cycles such as the El Niño/Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), and the (SAM) or Southern Annual Mode for New Zealand as whole, but only limited region-specific work has been carried out in Hawke's Bay up until now. In response to this, HBRC has commissioned NIWA to undertake a study to evaluate the relationships between climate modes and Hawke's Bay's seasonal rainfall and temperature.

This report reviews five large-scale natural climate cycles (The Interdecadal Pacific Oscillation, the El Niño Southern Oscillation, the Southern Annular Mode, the Indian Ocean Dipole and the South Pacific Subtropical Dipole) and provides an analysis of these climate modes on seasonal temperature and rainfall indices from climate records within the Hawke's Bay region. Although climate change is cited as a potential mechanism that may alter these cycles in the future, it is not analysed in depth in this report.

The results of this analysis provide base information which can be used to evaluate the likelihood of extreme seasons or events within Hawke's Bay, as well as being utilised to mitigate the effects of extreme events on people and the environment. The advice obtained will help to raise levels of awareness and preparedness of each of these teams to an extreme event and also improve the information conveyed to the public and the actions to be taken. By having forewarning signs of these events, mitigation measures can be put in place, such as encouraging water rationing when drought conditions look possible.

2 Methodology

2.1 Data availability and homogenisation

A search for long duration, high quality daily and monthly records of both temperature and rainfall in Hawke's Bay was carried out using the NIWA National Climate Database (Clidb) (http://cliflo.niwa.co.nz/). Stations were selected to maximise geographical coverage throughout the Hawke's Bay region and were chosen in consultation with the Council. One HBRC rainfall site was used to complement the selected NIWA National Climate Database sites. As long term climate analysis is the principal focus of this report, the primary requirements for data were:

- High data quality (i.e. relatively few missing records); and
- Extended record with minimal site changes and preferably still operative today. HBRC climate station sites generally have a shorter record these were not preferentially used.

Before data analysis could begin, a careful assessment of data quality was performed. This was particularly important for the assessment of extreme rainfall events, so manual quality checks were carried out for all stations. These records were checked for:

- Possible untagged accumulations – i.e. was a rainfall total from a period longer than 24 hours; and
- Nearest neighbour consistency – Stations which recorded 50mm or more in 24 hours were flagged and compared with records at other sites in the region to see if they also recorded high rainfall. Errors in the rainfall record can result from things such as untagged accumulations, keying errors (wrong or extra numbers typed in by mistake during digitisation or incorrect placement of the decimal point) and conversion errors (prior to 1972, rainfall was recorded in inches).

Manual nearest neighbour checks identified a number of potential outliers. The paper records for identified outliers were accessed to check for keying errors. If no keying errors were identified, information was sought from historic weather maps as well as newspaper archives of past extreme events. The actions applied to the identified outliers are detailed in Appendix A.

The second part of quality control was to carry out homogeneity checks. Inhomogeneities within climate records can arise due to a change in station or its operation. For example, there may be changes in the site or instruments used or a change in exposure or observation practice. Homogeneity testing is carried out to ensure that fluctuations in data are a result of weather and climate as opposed to non-climatic factors.

Homogeneity checks were carried out using the updated homogeneity testing package RHTestV4 (Wang 2003, 2008a) which was developed for the detection of change points in climatological datasets. A type-1 test was performed on log transformed monthly precipitation as well as daily and monthly maximum and minimum temperatures using this software. This type of test does not use metadata and is based on the penalised maximal F (PMF) test (Wang 2008a and Wang 2008b). No reference series were used during the homogeneity testing.

For instances where a change point was identified, station history files were accessed to check for possible reasons for the shift. Adjustment of daily rainfall data is known to be a complex task (Aguilar *et al.,* 2003) and so rainfall records where several inhomogeneities were identified were not used. During instances where a change point was detected but there was no supporting metadata to suggest a reason for this, the change point was ignored.

For temperature, the Napier Nelson Park record was adjusted for two site changes which coincided with identified change points. No other change points in the selected temperature records corresponded with events described in the station history and thus the data were not adjusted.

Homogeneity tests identified 15 rainfall (Table 1) and 7 temperature (Table 2) sites which had records suitable for further analysis. The sites chosen for analysis are also displayed spatially on Figure 1. For several sites, composite climate records were created to extend the record length and fill missing gaps. Further information about homogeneity testing of each series is available in Appendix B.

It must be noted that there are certain aspects of climate data which can compromise quality but are not taken into account. The accuracy of data is affected by the instrument accuracy. As an example, rain gauges are known to underestimate rainfall during windy conditions. Additionally, as the earlier records are all manual records, their quality is largely dictated by the diligence of the observer. In some instances, notes in the station history files state that there is concern over the observer not checking rain gauges every day but only on days when it rains. This means that days where they may have been a light overnight shower could have been missed. Although such detail would have minimal effect on seasonal rainfall totals, it may impact how many dry days (days with 0mm of rain) are counted. Despite this, the records selected for analysis are considered to be good quality for the purpose of this study.

Table 1: Rainfall records selected for analysis (shown in grey shading).

Rainfall records							
Station	**Location**	**Records**		**Years of record**	**Status**	**Altitude (m)**	**Notes**
		Begin	**End**				
D87731	Erepeti	1/05/1928	31/03/2007	78	closed	405	
D87712	Onepoto	1/09/1890	31/05/1935	45	closed	-	
D87812	Tuai	1/09/1923	28/02/2005	81	closed	274	
	Tuai composite	1/09/1923	31/03/2007	83			Base period 1971-2000
D97031	Wairoa, Waiputaputa Station	1/04/1911	31/12/2014	103	open	29	
D96081	Te Rangi Maungaharuru	1/01/1919	31/12/1983	64	closed	335	
D96251	Te Wairere	1/01/1932	31/12/2007	75	closed	564	Daily record starts in April 1932. Base period 1971-2000
D96281	Tutira	1/11/1894	31/08/2004	110	closed	201	
D96282	Tareha	3/11/1949	31/12/2014	65	open	430	

	Tutira composite	1/11/1894	31/12/2014	119			
D96541	Whanawhana	1/01/1906	30/04/1984	78	closed	293	Base period entire record
D96653	Rose Hill	1/01/1954	31/10/2014	60		171	Daily rainfall record starts in 1954. Base period 1981-2010
D96591	Napier Nelson Park	1/01/1870	31/12/2014	145	open	2	
D96484	Napier Aero Aws	1/10/1990	31/12/2014	24	open	3	
	Napier composite	1/01/1870	31/12/2014	145			Base period 1981-2010.
D96691	Havelock Nth, Te Mata	1/09/1889	28/02/1985	95	closed	140	Daily rainfall record starts in 1917
-	Kopanga Homestead	1/02/1938	31/12/2014	76	open	-	
D96681	Hastings	1/01/1928	31/08/1966	38	closed	14	
	Havelock North composite	1/09/1889	31/12/2014	124			Daily rainfall record starts in 1917. Base period 1981-2010.
D96882	Anawai	1/07/1925	30/04/2014	88	open	442	Base period 1981-2010.
D96741	Gwavas	1/09/1889	31/12/2014	124	open	244	
D96731	Smedley	1/11/1964	31/12/2014	50	open	457	
	Gwavas composite	1/09/1889	31/12/2014	124			Base period 1981-2010.
D96951	Mt Vernon 2	1/02/1886	31/12/2014	127	open	155	
D06051	Waipukurau Aero	1/01/1945	31/07/1994	49	closed	137	
D96962	Waipawa EWS	28/07/2007	31/12/2014	7	open	130	
	Mt Vernon composite	1/02/1886	31/12/2014	127			Base period 1981-2010.
D06181	Aramoana	1/01/1907	31/12/2014	107	open	27	Daily record begins in March 1907. Base period 1981-2010.
D96891	Waimarama	1/08/1888	30/11/1989	100	closed	3	
D06452	Tawadale, Wimbledon	1/01/1946	30/09/1999	53	closed	107	
B96051	Tarawera	1/07/1908	31/08/1975	67	closed	497	
D96483	Eskdale Hedgeley	1/08/1894	31/12/2014	129	open	34	Base period 1981-2010.
D96771	Koparakore	1/01/1902	30/04/2011	109	closed	48	
D96861	Pukehou, Te Aute Station	1/10/1892	31/07/1997	103	closed	107	
	Koparakore composite	1/01/1902	30/04/2011	117			Base period 1981-2010.
D96925	Makaretu North	1/01/1960	31/12/2014	54	open	396	

D06062	Waiwhero Station	1/03/1951	31/12/2014	63	open	194	
D06142	Flemington	1/12/1958	31/12/2014	56	open	174	
D06151	Motuotaria	1/09/1910	1/06/1962	51	closed	62	
	Flemington composite	1/09/1910	31/12/2014	103			Base period 1981-2010.

Table 2: Temperature records selected for analysis (shown in grey shading).

Temperature records							
Station	**Location**	**Records**		**Years of record**	**Status**	**Altitude (m)**	**Notes**
		Begin	**End**				
D87811	Waikaremoana Onepoto	1/06/1935	30/06/1990	18	closed	643	Daily data not digitised prior to 1972. Base period entire record.
D87812	Tuai	1/01/1982	8/07/1990	8	closed	274	
D97045	Wairoa, North Clyde Ews	31/07/1991	31/12/2014	23	open	15	
D97043	Wairoa Hospital	31/12/1971	31/07/1991	19	closed	20	
D97042	Wairoa, Frasertown	1/01/1964	31/10/1989	25	closed		Daily data not digitised prior to 1972
	Wairoa composite	1/01/1964	31/12/2014	50			Daily data not digitised prior to 1972. Base period 1981-2010.
D96591	Napier Nelson Pk	31/12/1939	31/12/2014	144	open	2	
D96484	Napier Aero Aws	30/09/1990	31/12/2014	24	open	3	
D96481	Napier Aero	31/10/1973	20/03/1990	16	closed	2	
	Napier composite	31/12/1939	31/12/2014	144			Base period 1981-2010.
D06051	Waipukurau Aero	20/12/1944	31/07/1994	49	closed	137	Base period 1961-1990.
D96962	Waipawa Ews	28/06/1907	31/12/2014	7	open	130	
D96743	Gwavas Forest	1/01/1948	30/08/1989	40	closed	335	Daily data not digitised prior to 1972. Base period entire record.
D06022	Kopua	1/07/1962	31/12/2014	52	open	311	Daily data not digitised prior to 1972. Base period 1981-2010.
D96680	Hastings Aws	1/10/1981	31/03/2014	32	open	16	
D96688	Hastings Fire Station	1/09/1965	31/10/1981	16	closed	12	Daily data not digitised prior to 1972
	Hastings composite	1/09/1965	31/03/2014	48			Daily data not digitised prior to 1972. Base period 1981-2010.

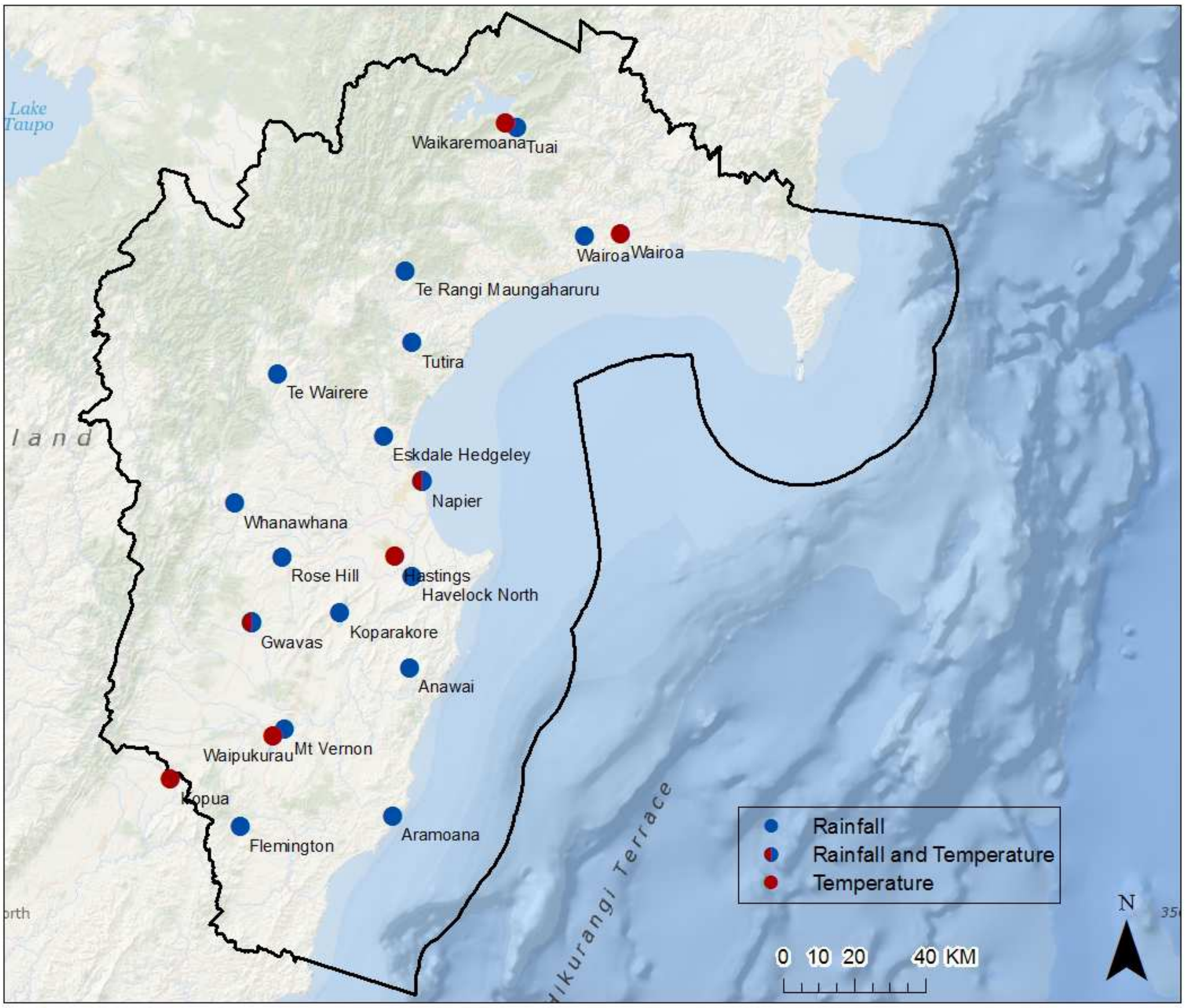


Figure 1: Rainfall and temperature sites used for analysis.

2.2 Derivation of seasonal climate indices

Data analysed in this report was aggregated at a seasonal timescale based on the four standard seasons: December–February (DJF), March–May (MAM), July–August (JJA) and September–November (SON). Seasonal anomalies were, when possible, calculated relative to the more recent climatological 'normal' base period of 1981–2010. During instances where records were not long enough to cover the 1981–2010 base period, the most recent available standard base period was used. For records where data was unavailable post 30/12/1990, the full record was used to establish a climatology. As an example, the Tuai composite record ends in 2007 so a 1971–2000 base period was used. The "Notes" column of Tables 1 and 2 specifies which base period was applied for each site.

The following climate indices were analysed:

- Total rainfall (mm)
- Extreme daily rainfall (Rx1day, mm)

- Extreme 3-day rainfall (Rx3day, mm)
- Dry days (days with 0mm of rainfall, count)
- Heavy rainfall days (days with rainfall above 90th percentile, count)
- Average temperature (°C)
- Frost days (days with Tmin < 0°C, count)
- Hot days (days with Tmin > 25°C, count)

2.2.1 Rainfall indices

Daily rainfall data at several climate stations used for analysis included many accumulation totals. That is, rain gauges were sometimes not read daily but the total over several days was recorded. This was problematic for some of the climate indices used in this study. As an example, if there was a 48-hour accumulation with 5mm rain recorded we do not know if all of that fell on one day or over the two days. While this doesn't make a difference for seasonal rainfall totals, it does when calculating indices such as dry days (where we are counting the number of days with 0mm of rain). As a result, the daily rainfall datasets were split in two. One which included accumulation totals and one which treated accumulation totals as missing data.

When creating seasonal indices, any missing rainfall data in a season meant that a seasonal value was not created. Because of this there were many more data gaps for indices which relied on the "rainfall without accumulations" dataset. It is noted that while known accumulations were a common problem when compiling this dataset, untagged accumulations probably still remain in some rainfall records as a source of error.

The following climate indices were created using rainfall data:

- Total rainfall – the rainfall total (mm). Data with accumulations included were used to create this index.
- Extreme daily rainfall (Rx1day) – the most amount of rain recorded over one day (mm). Data with accumulations included were used to create this index. If the highest 1-day rainfall for the season was an accumulation then the entire season is disregarded. If, however, it was a 24-hour total then the value was used. This special query was created to calculate this index without disregarding a whole season just because it may have included a few multi-day accumulation totals.
- Extreme 3-day rainfall (Rx3day) – the maximum amount of rain recorded over 3 days (mm). Data with accumulations included were used to create this index. If the highest 3-day rainfall for the season includes an accumulation then the entire season is disregarded. If, however, it was a 72-hour total then the value was used. This special query was created to calculate this index without disregarding a whole season just because it may have included a few multi-day accumulation totals.
- Dry days – numbers of days with 0mm of rain (count). Data without accumulations were used to create this index.

- Heavy rainfall days – number of days with rainfall exceeding the 90th percentile (count). Data without accumulations were used to create this index. The 90th percentile was calculated for each season (DJF, MAM, JJA, SON) individually.

2.2.2 Temperature indices

Climate stations which record temperature are not as numerous as rain gauges and there are relatively few sites in the region with long records. Because of this, fewer temperature records were analysed in this study than for rainfall. During data compilation it was discovered that for several stations the daily data record was shorter than the monthly record. This is because some paper records of daily temperature have not been digitised prior to 1972. Because of this, the length of record used to calculate the number of frost days and number of hot days was shorter. As a result, the Gwavas and Onepoto daily temperature record prior to 1972 was digitised in order to enrich this study.

When calculating seasonal average temperature, up to 10 daily temperatures values in a month could be missing but no more than 5 consecutively.

For the number of frost and hot days, any missing temperature data resulted in the entire season being discarded from the analysis.

The following climate indices were created using temperature data:

- Average temperature – the mean temperature (°C).
- Number of frost days – the number of days where the minimum temperature recorded is 0°C or lower (count).
- Number of hot days – the number of days where the maximum temperature recorded is 25°C or higher (count).

2.3 Derivation of indices for the climate modes of variability

The variability over time of large-scale climate phenomena such as ENSO and the IPO is usually encapsulated by an index: i.e. a single time-series summarizing the changes in phase and intensity of the climate modes. In this section we describe how these indices have been calculated. With the exception of the Southern Annular Mode (SAM), the original indices were calculated in order to obtain both the longest period available and the most up to date information: this also ensures that we are not dependent on external institutions for the potential near real-time monitoring of these indices.

2.3.1 El Niño Southern Oscillation

ENSO events have been identified most commonly using either the Southern Oscillation Index (SOI) or an index of tropical Pacific sea surface temperature (SST) anomaly, usually for either the NIÑO3.4 region ("Oceanic Niño Index" or ONI: 5°N-5°S, 120°W-170°W) or NIÑO3 region (5°N-5°S, 90°W-150°W)

The ‘NIWA’ SOI has been used in this report. This index is calculated routinely by NIWA. The calculation follows the so-called “Troup method”, and is based on the mean sea level pressure difference between Tahiti and Darwin, with the climatological period taken to be 1941-2010. If T and D are the monthly pressures at Tahiti and Darwin, respectively, and Tc and Dc the climatological monthly pressures, then;

$$SOI = [(T - Tc) - (D - Dc)] / [StDev (T - D)]$$

The numerator is the anomalous Tahiti-Darwin difference for the month in question, and the denominator is the standard deviation of the Tahiti-Darwin differences for that month over the 1941-2010 climatological period. The answer is rounded to the nearest tenth (i.e., 1 decimal place).

The source of data for mean sea level pressures in Tahiti is:
ftp://ftp.bom.gov.au/anon/home/ncc/www/sco/soi/tahitimslp.html
and ftp://ftp.bom.gov.au/anon/home/ncc/www/sco/soi/darwinmslp.html for Darwin. The MSLP data is usually updated within the 5th day of each month, which allows NIWA to monitor the SOI in near-real time.

2.3.2 Interdecadal Pacific Oscillation

The Interdecadal Pacific Oscillation (IPO, see section 4.2) is widely considered to be the Pacific-wide manifestation of the Pacific Decadal Oscillation (PDO), originally defined by Mantua *et al.* (1997), over the Northern Hemisphere (north of 20°N). Because an updated index of the IPO is not readily available elsewhere (the most up to date one is available from the UK Met-Office and stops in 2008), we decided to derive an original IPO index following the methodology exposed in Folland *et al.* (1999). In brief, the IPO index used in this report is calculated as the 2nd Principal Component (PC) of time-filtered (low-pass filter, keeping only low frequency oscillations over 11 years) monthly sea surface temperature anomalies in the Pacific domain (50°S- 50°N, 120°E- 295°E) over the January 1920 – December 2014 period. The Dataset used is the Extended Reconstructed SST (ERSST) Dataset (Version 4) developed by the US National Oceanic and Atmospheric Administration (NOAA) and made available by the US National Climate Data Centre (NCDC). The Figure below presents NIWA’s IPO index.

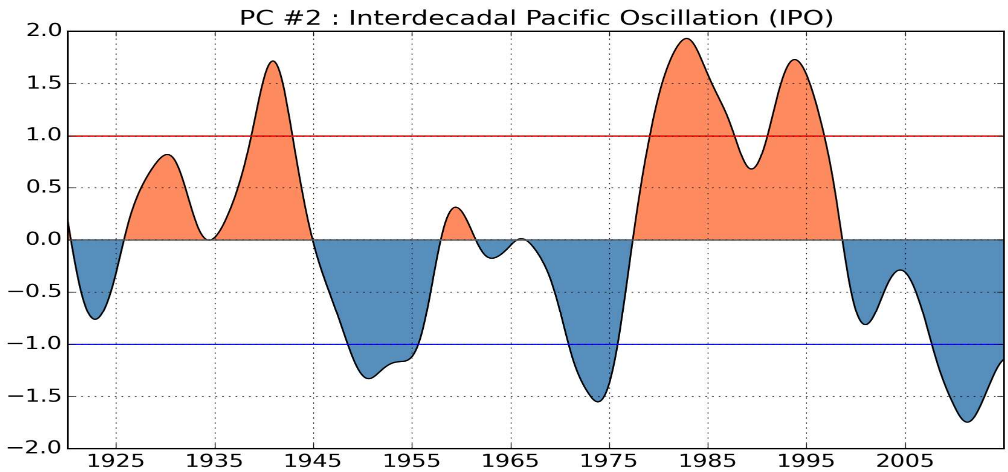


Figure 2: Phases of the Interdecadal Pacific Oscillation. Positive values indicate periods when stronger-than-normal westerlies occur over New Zealand, with more anticyclones than usual over northern New Zealand. Negative values indicate periods with more northeasterlies than normal over northern regions of the country. The red and blue lines indicate +/- 1 standard deviation threshold of the IPO index. Seasons above the positive and below the negative thresholds were used for composite analysis as described in Section 2.4.2

2.3.3 Southern Annular Mode

Indices used for quantifying the SAM are based on very limited observations prior to the satellite era (preceding 1979) as there were only a handful of climate stations over the high latitudes of the Southern Hemisphere and no continuous data records over Antarctica prior to 1958.

This study utilised the "Marshall" Index (Marshall, 2003) to assess the SAM. This index is available from 1957 onwards and can be accessed at: http://www.nerc-bas.ac.uk/icd/gjma/sam.html.

2.3.4 Indian Ocean Dipole

The Indian Ocean Dipole (IOD, see section 4.4) Index is calculated as the difference between monthly SST anomalies in the western (10°S – Equator, 50°W – 70°W) and eastern (10°S – Equator, 90°W – 110°W) tropical Indian Ocean. As for the IPO (see Section 2.3.2 above), we used the ERSST (V4) Dataset over the 1920–2014 period. The IOD index is thus positive when the western (eastern) Indian Ocean is warmer (cooler) than normal. Seasonal anomalies (DJF, MAM, etc.) were calculated from the monthly anomalies.

2.3.5 South Pacific Subtropical Dipole

The South Pacific Subtropical Dipole has been identified as a regional mode of SST variability influencing the climate of Hawke's Bay and a potential source of predictability (see Section 4.5). Using the ERSST (V4) Dataset, we derived a South Pacific Subtropical Dipole Index (hereafter SPSD) as the difference between the monthly SST anomalies in the northwest subtropical Pacific (50°S – 30°S, 170°E – 10°W) and the southeast extra-tropical Pacific (57.5°S – 45°S, 140°E – 120°W). Seasonal anomalies (DJF, MAM, etc.) are then calculated from the monthly anomalies.

2.4 Investigating the relationship between seasonal climate indices and climate modes of variability

The relationships between the seasonal climate indices of temperatures and rainfall in the Hawke's Bay region and the climate modes of variability (summarized by time-series of indices, see above) are investigated in two ways:

i) Calculation of the (linear) correlation coefficient between the time-series of seasonal climate indices and climate mode indices; and

ii) Calculation of 'composite' anomalies.

2.4.1 Correlation

The correlation coefficient used is the Pearson's correlation coefficient (Pearson's *r*): it is a measure of the linear correlation (dependence) between two variables X and Y, giving a value between +1 and −1 inclusive, where +1 is total positive correlation (peaks and lows are aligned; an in-phase relationship), 0 is no correlation, and −1 is total negative correlation (the peaks of one time-series are systematically related to the lows in the other; an out-of-phase relationship). It is widely used in the sciences as a measure of the degree of linear dependence between two variables.

The statistical significance of the correlation calculated between time-series of seasonal climate indices in Hawke's Bay and the climate mode indices is tested using a standard two-tailed test and correlations significant at the 90% confidence level (p-value < 0.1) were reported. As we are investigating time-series of seasonal values, the rank-1 autocorrelation is assumed to be negligible (e.g. the value of DJF total rainfall for the year 2014 is assumed to be uncorrelated to the value for DJF 2013): this assumption would be violated only in the case of a strong trend or strong cyclical component in the time-series.

2.4.2 Composite analysis

The goal of composite analysis is to determine how deviations in one climate signal may be associated with deviations in another climate signal. Let's say for example that we want to determine the typical precipitation anomalies at one station associated with El Niño events during the DJF season: the first step is to select DJF seasons when the Southern Oscillation Index (SOI, see Section 2.3.1) was strongly negative (corresponding to strong El Niño events). The second step is to select (sample) from the time-series of seasonal precipitation values for the same seasons. The average for this sample is then compared to either the long-term DJF average (climatology) or all the remaining DJF seasons. An advantage of composite analysis over the Pearson's correlation coefficient is that it can uncover potential non-linear relationships.

In comparing the means of two samples (the El Niño sample and either the climatological normal or all the remaining seasons), one can test whether the calculated differences are statistically significant at a given risk of error using the standard Student *T*-test (see. http://en.wikipedia.org/wiki/Student%27s_t-test). The assumptions made are that the two samples are approximately normally distributed and have similar variances, both reasonable assumptions when dealing with seasonally-aggregated values such as those investigated here.

In this report, composite analysis is used in two instances:

i) To calculate the typical total rainfall anomalies during the positive and negative phases of the IPO (see Section 6.1, Figure 12): In this case the seasons corresponding to the positive or negative phase of the IPO are selected using the seasonal IPO index (see Section 2.3.2) are selected based on a +/- 1 standard deviation threshold (i.e. for the positive phase of the IPO, seasons with IPO > +1 st.d.)

ii) To determine the average background state signal (through SST anomalies) associated with widespread dry / wet and cold / warm seasons in Hawke's Bay (see Section 6.3, Figure 21 & 22): In this case the composite seasons are selected according to the following criteria:

a. For dry seasons: at least 9 stations (out of the 15 available) registered seasonal rainfall anomalies below –1 standard deviations
b. For wet seasons: at least 9 stations registered seasonal rainfall anomalies above +1 standard deviations
c. For cold seasons: at least 4 stations (of the 7 available) registered seasonal temperature anomalies below -1 standard deviations
d. For warm seasons: at least 4 stations registered seasonal temperature anomalies above +1 standard deviations

Because SSTs are relatively slow varying (when monthly aggregated values are considered) and for the sake of uncovering potential predictability of Hawke's Bay climate derived from SST patterns, the composite SST anomalies are calculated for the month *prior* to the seasons determined above (e.g. for the DJF season, November anomalies were used).

3 General trends in rainfall and temperature

As with New Zealand as a whole, the climate of Hawke's Bay is largely influenced by the prevailing westerly winds and the mountain ranges in the west of the region. Rainfall is most commonly associated with cold fronts and falls as showers of relatively short duration. The distribution of rainfall across the region is closely related to elevation with the highest rainfall occurring over the ranges and lowest rainfall in lowland areas such as the Heretaunga and Takapau Plains (Figure 3). Rainfall is the largest climatic variable to influence flood risk. Consequently, it is important to assess the variability of past rainfall when planning future climate sensitive activities.

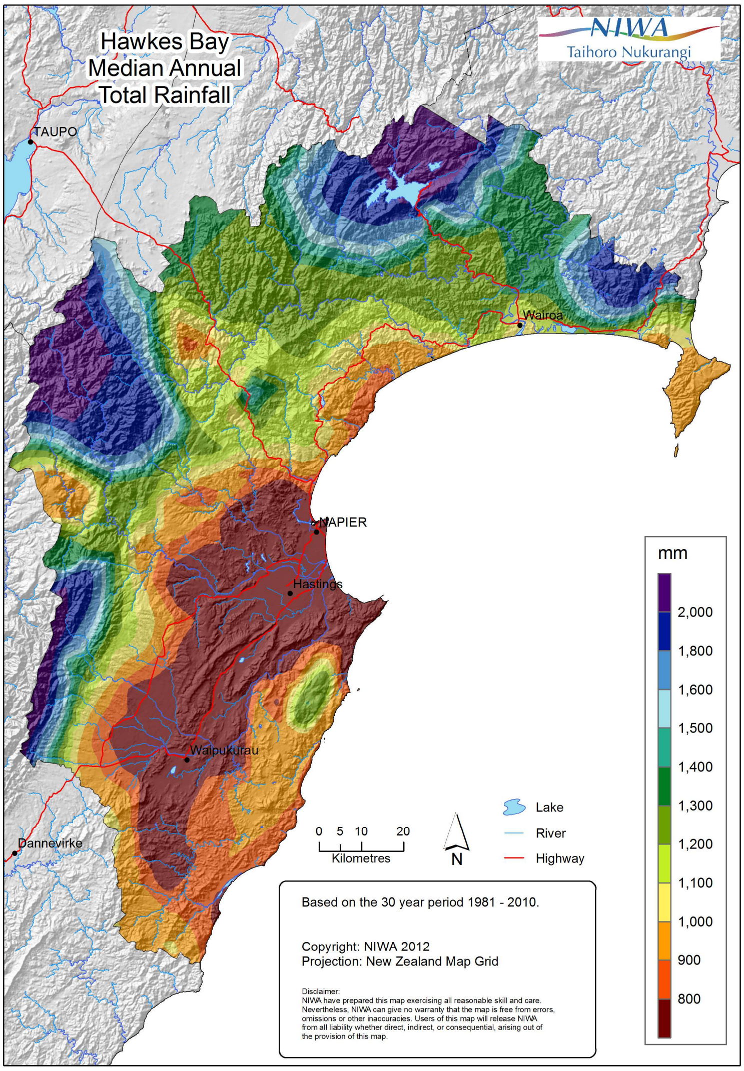


Figure 3: Hawke's Bay median annual total rainfall, 1981-2010.

Temperatures in Hawke's Bay also vary with elevation (Figure 4). Low-lying areas around the coast and Heretaunga Plains have a median annual temperature of around 13.5°C, whereas the inland ranges experience median annual temperatures of about 8°C. A westerly wind flow over the region often elevates temperatures by way of the foehn effect as air descending down the high country is drier and warmer. In general, Hawke's Bay experiences a high frequency of light winds and consequently a large number of frosts occur during the cooler months.

In terms of long term temperature trends, records compiled from 7 representative sites around New Zealand show that there is a significant rise in national temperature consistent with global warming of around 0.9°C since 1909 (Figure 5). More detailed modelling that removes data bias and takes local climatic processes into account affirms that the 50-year trends in New Zealand temperature cannot be explained by natural variability alone. An increase in southerly flow since about the 1960's has meant the observed temperature increase has been lower than expected, leading to a dampening of the influence of global warming in the New Zealand region (Clark, A.J. 2012).

For further information about the climate of Hawke's Bay, please consult the recently update edition of The Climate and Weather of Hawke's Bay (Chappell, P.R., 2013, http://www.niwa.co.nz/static/Hawkes%20Bay%20WEB.pdf).

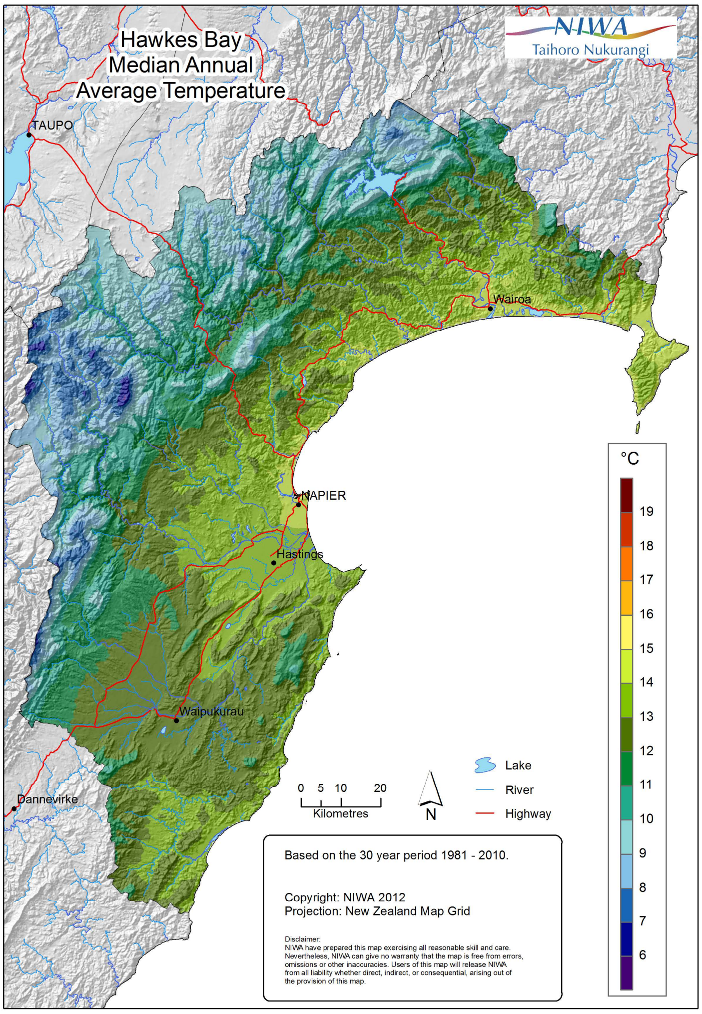


Figure 4: Hawke's Bay median annual average temperature, 1981-2010.

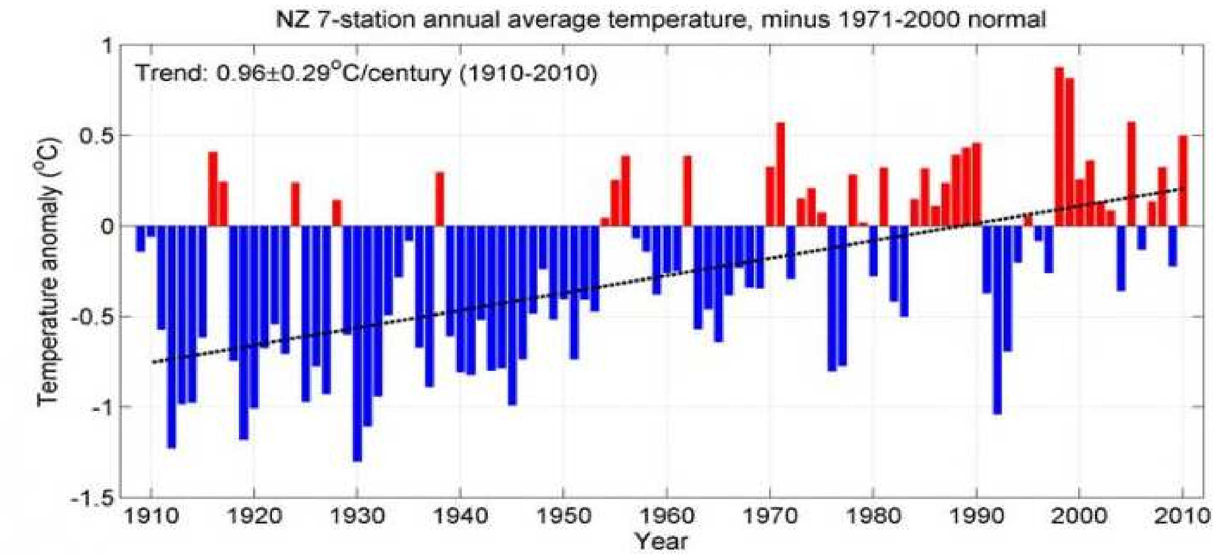


Figure 5: Mean annual temperature for New Zealand, calculated from NIWA's 'seven-station' series. The blue and red bars show the difference from the 1971-2000 average. The black dotted line is the linear trend over 1910 to 2010.

4 Background on climate modes and prior research

Interannual variability in New Zealand's climate has been linked to a number of large-scale Southern Hemisphere climate modes. The interaction between these cycles and the alpine ranges running the length of the country imposes strong spatial climate patterns and local climatic variations. The regional impacts of the Interdecadal Pacific Oscillation and El Niño Southern Oscillation on climate have been documented by a number of studies (Mullan, A.B (1995); Mosley, P. M. (2000); Salinger *et al.* (2001); Griffiths, G.M. (2011). Fewer studies on the Southern Annular Mode and the Indian Ocean Dipole have also been shown to have an effect on New Zealand's climate but on a lesser scale. No prior studies have considered the climatic impacts of the South Pacific Subtropical Dipole on New Zealand. This section provides a review of five large-scale natural climate cycles (The Interdecadal Pacific Oscillation, the El Niño Southern Oscillation, the Southern Annular Mode, the Indian Ocean Dipole and the South Pacific Subtropical Dipole) and their corresponding impacts on rainfall and temperature in New Zealand with a specific focus on the Hawke's Bay region.

4.1 The El Niño Southern Oscillation (ENSO)

The El Niño Southern Oscillation (ENSO) is a natural fluctuation of the global climate and refers to the variation in sea surface temperatures across the equatorial Pacific Ocean and in surface atmospheric pressure in the tropical Pacific. El Niño and La Niña refer to opposite extremes of the ENSO cycle and occur every 3-7 years on average. A common measure of the intensity and phase of ENSO is the Southern Oscillation Index (SOI) (Figure 6). This index is derived by calculating the air pressure difference between Tahiti and Darwin (see Section 2.3.1 for the details of the calculation of the 'NIWA' SOI). Persistence of the SOI below -1 coincides with El Niño events, and periods above +1 with La Niña events.

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 approximately 50 cm higher than those off the coast of Ecuador. Cool, nutrient-rich sea water wells up off the South American west coast, supporting marine ecosystems and fisheries.

During an El Niño, trade winds weaken which leads to a reduction in upwelling off South America and a rise in sea surface temperatures in the eastern equatorial Pacific. The opposite is true during La Niña events, when the trade winds strengthen to produce an intensified pattern of “normal” conditions with enhanced upwelling of cool water off the South American west coast.

Climatic differences arising from the ENSO cycle are seen most clearly in the tropics but the climate of New Zealand is also affected. In general, during an El Niño, New Zealand experiences a stronger than normal southwesterly airflow leading to wetter than normal conditions in western areas and drier than normal conditions in the east of the country (due to the rain shadow effect) (Figure 7a). Conversely, during La Niña, more northeasterly flows than normal ensue leading to wetter than normal conditions in the north and east of the North Island (Figure 7b). Individual ENSO events can differ substantially from this pattern and El Niño and La Niña effects are not exactly equal and opposite (Mullan, 1995).

ENSO can occur at any time of the year but usually peaks during the Southern Hemisphere summer. For this reason it is important to look at seasonal data when considering New Zealand climatic variability instead of only considering annual values (Mullan and Thompson, 2006). The recent development of computer models which simulate the coupled ocean-atmosphere dynamics of the central Pacific have been reasonably successful in forecasting the onset, development and breakdown of ENSO events (see e.g. Barnston *et al.*, 2012)et. Research on past events shows that El Niño and La Niña events tend to follow similar patterns of development and decay. Therefore, once El Niño or La Niña events have commenced, their evolution is partly predictable for the coming few months.

Limited prior research has been carried out investigating the impact of ENSO in Hawke’s Bay. Ummenhoefer and England (2007) found that the decrease in annual rainfall totals was as much as 400mm below normal during El Niño years in the northeast of the North Island. The opposite effect also holds true during La Niña events.

As rainfall and river flows are intrinsically linked, a similar relationship with ENSO and river flows was discerned by Mosley (2000) and Scarsbrook et al. (2003). Positive values of the SOI (La Niña conditions) were associated with increased river flows in the eastern North Island region. Conversely, El Niño conditions (negative SOI values) were found to be associated with a general decrease in river flows.

Temperature-wise, La Niña conditions tend to bring more northerly quarter winds than normal causing above average temperatures in the eastern North Island and a reduction in frost probability.

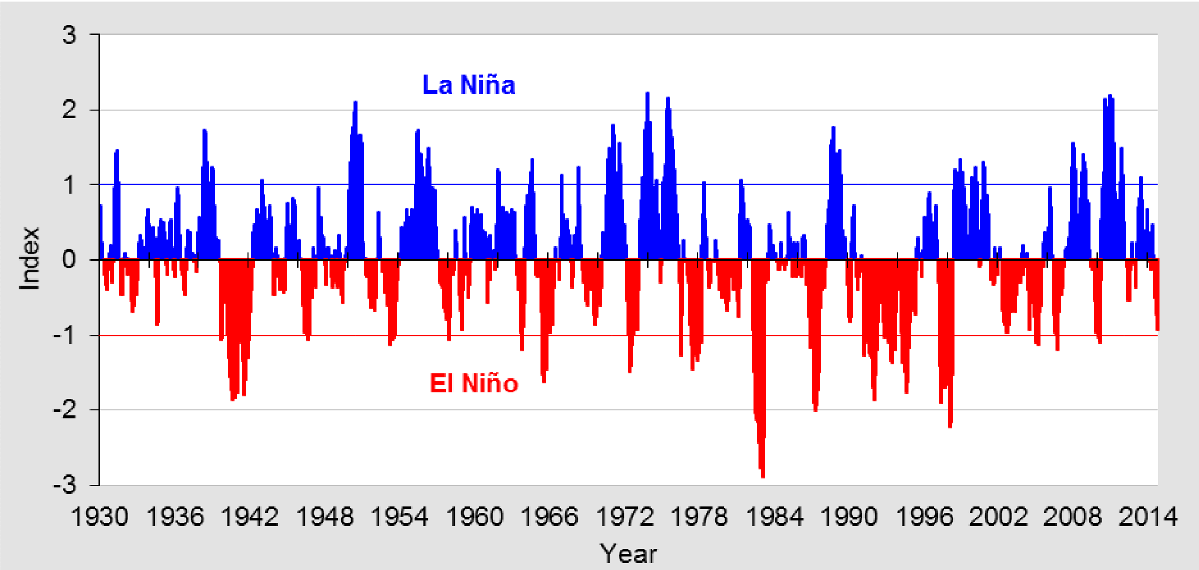


Figure 6: Time series of the Southern Oscillation Index from 1930-2014.

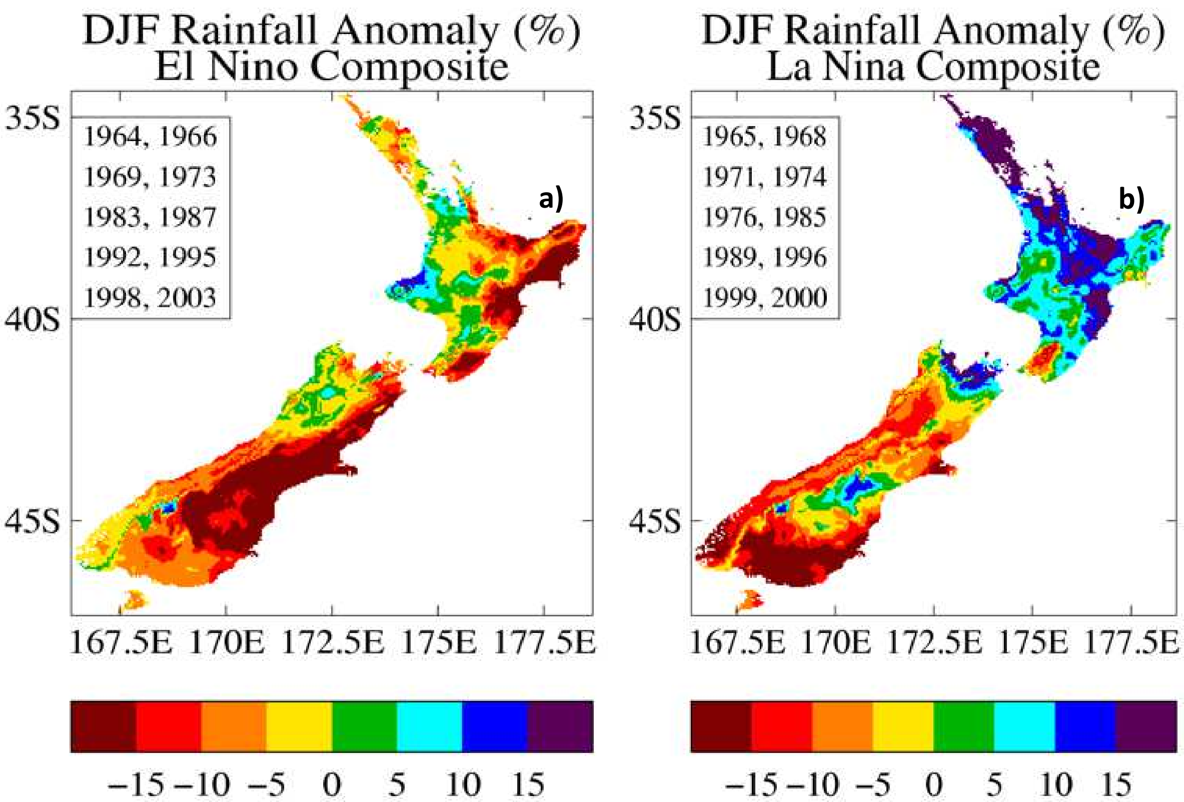


Figure 7: ENSO composite rainfall anomalies (in %) for summer (December-February), for the 10 strongest events 1960-2007 for New Zealand during El Niño (a) and La Niña (b) conditions. (The insert boxes indicate the years used, where 1964 is December 1963 to February 1964, etc.).

4.2 The Interdecadal Pacific Oscillation (IPO)

The Interdecadal Pacific Oscillation (IPO) is a natural fluctuation in the climate over the Pacific Ocean and is considered to be a Pacific-wide and low-frequency manifestation of the Pacific Decadal Oscillation (PDO), originally described by Mantua *et al.* (1997) over the north Pacific (north of 20°N). Schematically, the positive phase of the IPO is characterized by warmer SST in the northeast Pacific and to a least extent the eastern Equatorial Pacific, while cooler than normal ocean temperatures dominate the northwest Pacific (see Figure 8) and the southwest Pacific. The negative phase is associated with the reversed pattern.

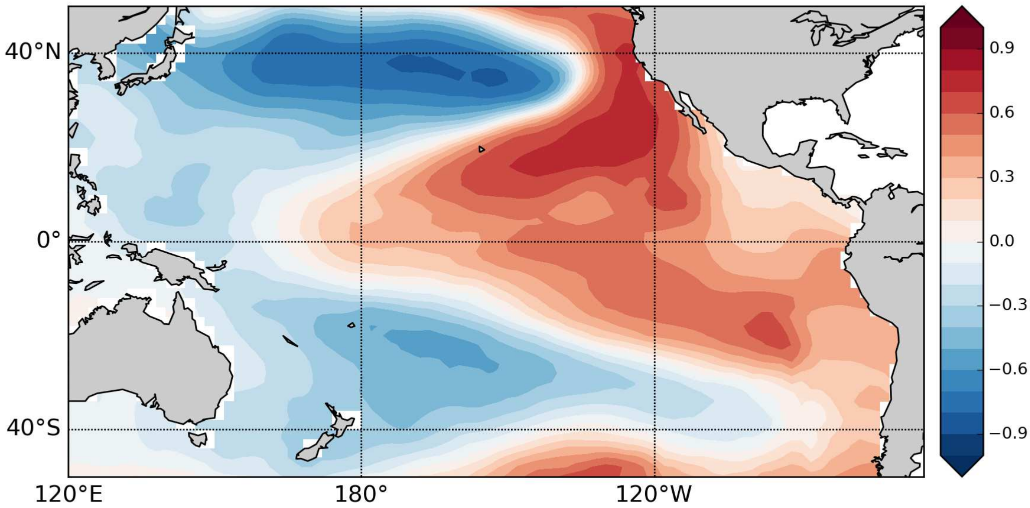


Figure 8: SST anomaly spatial pattern (Empirical Orthogonal Function, or EOF) associated with the positive phase of the IPO.

The IPO can also be regarded as the low-frequency counterpart of the ENSO phenomenon, although, in contrast with ENSO, the IPO is not a single physical mode of ocean-atmosphere variability, but rather the sum of several processes with different dynamic origins.

During the 20th century, three major phases of the IPO have been identified – a positive phase (~1922–1945) with augmented westerly circulation over New Zealand, a mostly negative phase (1947–1977) with weaker westerlies than normal over the country, and another positive phase (1978–1999). The start of the 21st century has seen a return to negative IPO conditions (Figure 2).

Long term fluctuations in New Zealand's climate show an association with changes in the IPO. Typically, SSTs around New Zealand tend to be cooler and westerly winds stronger than normal during the positive IPO phase (Salinger *et al.,* 2001). As displayed in Figure 9, this circulation leads to drier conditions along the eastern coasts of New Zealand and higher than normal rainfall along the west coast of the South Island. The opposite is true for the negative phase of the IPO. SSTs in the western Pacific cool and more easterly and northeasterly flows over New Zealand are favoured, compared with normal, which in turn bring enhanced precipitation to northeastern regions.

These patterns are the "average" response and do not mean that every year of a particular IPO phase will behave in the same way. 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.

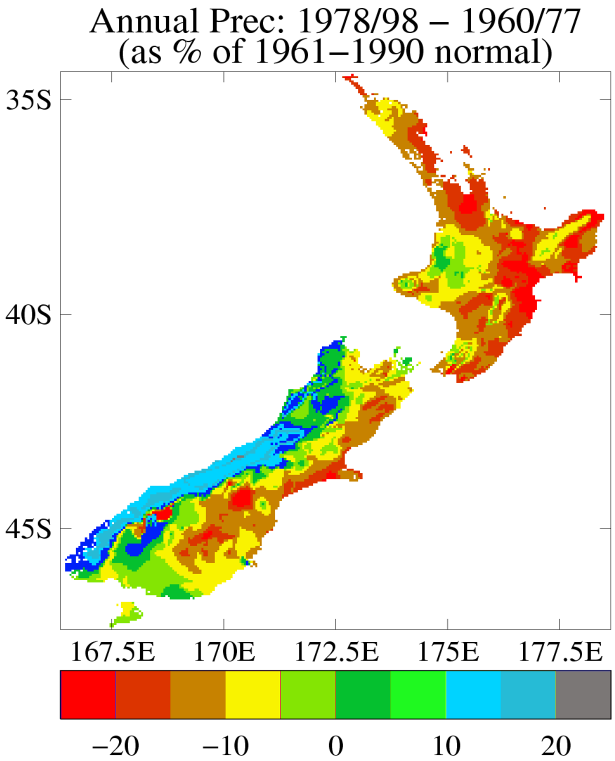


Figure 9: Percentage change in average annual rainfall, for the 1978-1998 period compared to the 1960-1977 period. **(***Note: From 1978-98 the IPO was in its positive phase, compared to the previous 18 years when the IPO was negative.*

4.3 The Southern Annular Mode (SAM)

The Southern Annular Mode (SAM) is a ring of climatic variability circling the South Pole and extending to the latitudes of New Zealand. The SAM generally describes the position of the westerly wind belt which in turn influences the strength and position of cold fronts, windiness and storm activity between the middle latitudes, where New Zealand lies (40-50°S), and higher latitudes, over the southern oceans and Antarctic sea ice zone (50-70°S). New Zealand is positioned in a zone where the SAM displays the greatest seasonality i.e. stronger westerlies in winter and weaker in summer, due to the influence of the southward-moving belt of sub-tropical anticyclones. The orography of the country also means that New Zealand's climate is strongly dependent upon wind speed and direction (Kidson, 2000). As the SAM is associated with pressure anomalies centred over Antarctica, the relative influence of the SAM is considered more dominant over the South Island than the North Island (Ummenhofer and England, 2007).

In its positive phase, the SAM is associated with relatively light winds and settled weather over New Zealand (Figure 10). Wind anomalies (differences from normal) over the summer are easterly and become northeasterly over the North Island and northwesterly over the southern South Island in winter (Kidston *et al.,* 2009). Conversely, the negative phase of the SAM results in more unsettled conditions with more and stronger westerly winds than normal.

Seasonal relationships between the SAM and New Zealand rainfall are a reflection of the prevailing winds and the orographic effect. Kidston *et al.* (2009) found that the positive phase of the SAM during summer induced wetter conditions than normal along the coastal region in the north and east of the North Island, Nelson and Marlborough and coastal north Canterbury with drier than normal conditions elsewhere. Likewise, the positive phase of the SAM in winter was found to bring wetter than normal conditions to the Bay of Plenty, Gisborne and parts of Hawke's Bay, Wellington, Nelson, Fiordland and Westland with drier than normal conditions elsewhere. Similarly, Ummenhoefer (2009) was also able to discern wetter than normal conditions along the east coast during positive SAM with the opposite true during negative SAM conditions.

On a week-to-week basis, the SAM can alternate between states, causing either windier or calmer weather over New Zealand. Although these changes in the SAM cannot be predicted more than few days in advance, once changed, the phases can persist for several weeks.

Over the past two to three decades, there has been a trend in the SAM towards more periods of the positive phase. The trend appears to be related to the reduction of stratospheric ozone over Antarctica and, to a lesser amount, the increase in greenhouse gases in the troposphere (Arblaster and Meehl, 2006; Thompson *et al.,* 2011) and is thus a manifestation of anthropogenic climate change.

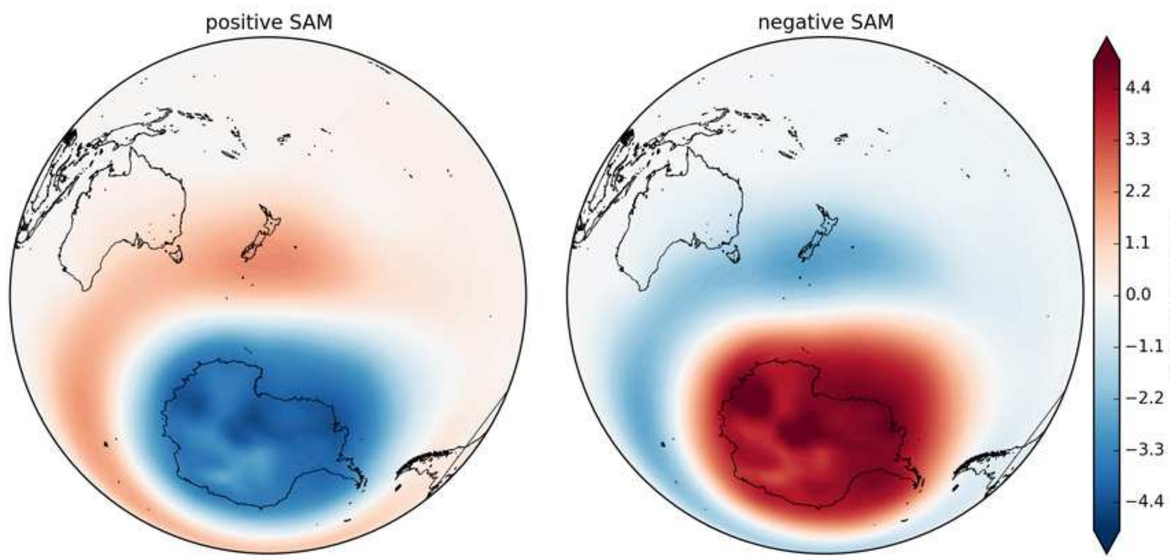


Figure 10: Pattern of the pressure variations associated with the positive (left) and negative (right) phases of the SAM. Blue shading indicates below-average pressures and red shading indicates above average pressures. Monthly composites were made using the Marshall SAM index (Section 2.3.3) using a threshold of +/- 1 std. Data comes from http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html.

4.4 The Indian Ocean Dipole (IOD)

The Indian Ocean Dipole (IOD) is a coupled ocean-atmosphere phenomenon in the tropical Indian Ocean defined by the difference in sea surface temperature (SST) between two areas/poles – a western pole in the Arabian Sea (western Indian Ocean) and an eastern pole in the eastern Indian Ocean south of Indonesia. The SST difference usually develops and peaks between June and October, the IOD is thus strongly 'phase-locked' onto the seasonal cycle. A positive IOD is associated with above average sea surface temperatures and increased precipitation in the western Indian Ocean region with a corresponding cooling of water in the eastern Indian Ocean. The reverse effects prevail during negative IOD conditions.

Across New Zealand, the positive phase of the IOD is related to weakened storm track activity with a corresponding reduction in rainfall from June-November over northern parts of the country (Ashok *et al.,* 2007). In the negative IOD phase, storm related precipitation tends to be significantly enhanced over northern parts of New Zealand.

Indian Ocean sea surface temperature patterns are also known to modulate winter circulation patterns about New Zealand. Warmer Indian Ocean water in autumn is generally followed by more rainfall in western South Island and drier conditions in areas exposed to the north and east (Mullan, 1998).

4.5 The South Pacific Subtropical Dipole (SPSD)

The South Pacific Subtropical Dipole (SPSD) is a mode of SST variability recently described by Morioka *et al.* (2013) and Guan et al (2014) Statistically, the SPSD appears as the first empirical orthogonal function (EOF) mode of the SST anomalies in the South Pacific (20°S – 65°S, 150°E – 85°W) and is associated with a northeast–southwest-oriented dipole of positive and negative SST anomalies in the central basin (Morioka *et al.*, 2013) (Figure 11).

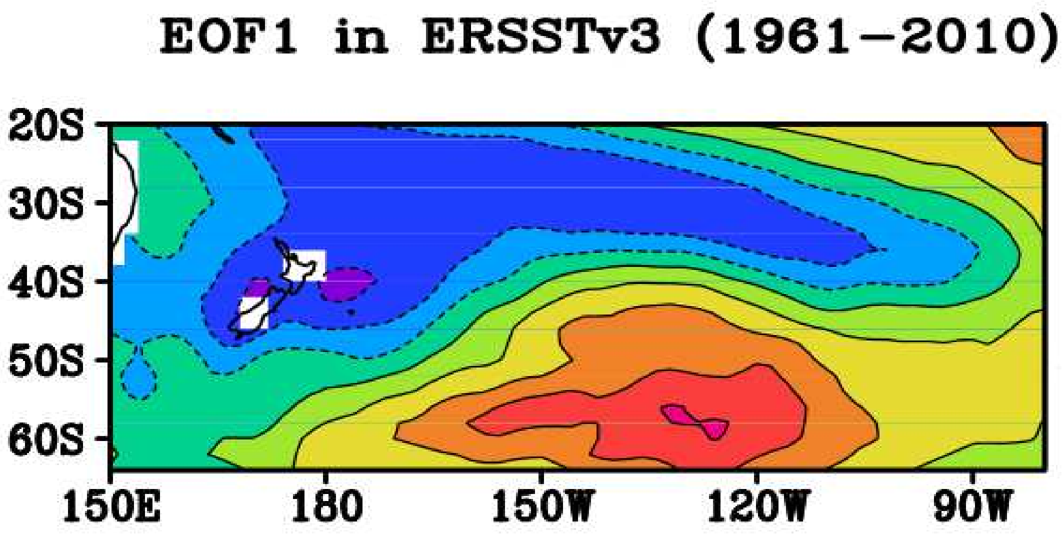


Figure 9: Pattern of the SST anomalies associated with the SPSD, taken from Guan et al, 2014 (Figure 4, p. 1652).

It is partly related to ENSO,and is also partly predictable at time-scales of a few months to seasons(Guan *et al.*, 2014).

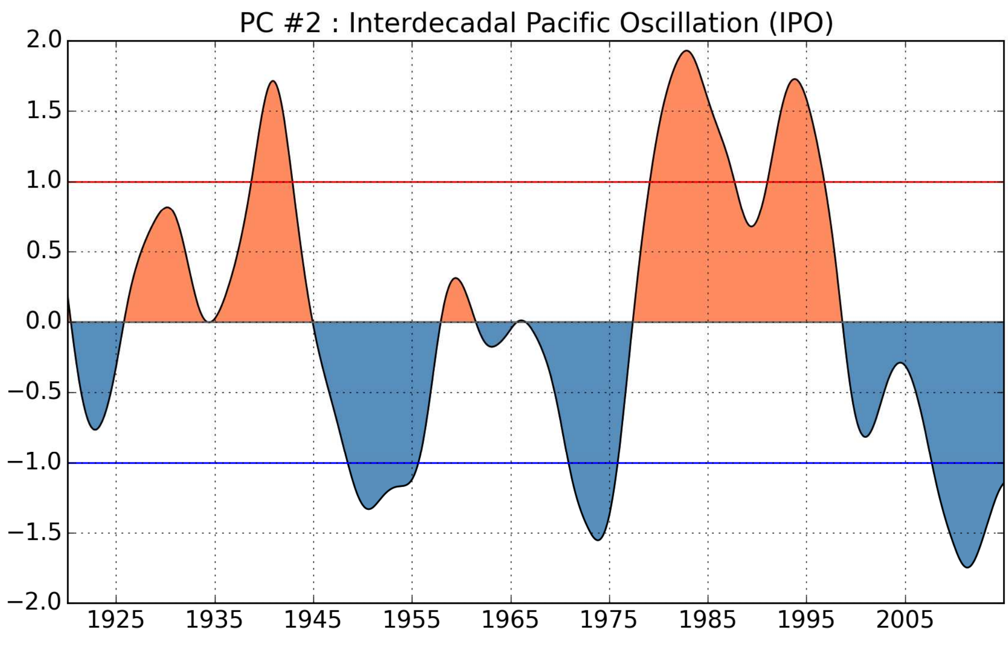
In Section 7, we found that large-scale droughts or floods in the Hawke’s Bay region, as well as large-scale warmer or cooler conditions, seem to be associated with distinctive patterns of SST anomalies in the South Pacific which resembles the SPSD. It prompted us to define an SPSD index (see Section 2.3.5) in order to investigate into more details the relationships between the HB seasonal climate indices and this mode of variability.

5 Climate Change

Although climate change is not directly assessed in this report it should be noted that the climate cycles described above will be superimposed on top of the impacts of climate change. Because of this, adaptation to changes in climate will need to incorporate both the shorter scale natural climatic variations as well as long term trends.

Present guidance for New Zealand (MfE, 2008) suggests that a currently-experienced extreme rainfall (e.g., 24-hour extreme with a 100-year return period) could occur approximately twice as often (i.e., 50-year return period) under a local warming of about 2°C. These more intense extreme rainfall events are projected to elevate future flood risk.

The increased flood peak resulting from increased precipitation extremes will also interact with rising sea levels making coastal settlements and stormwater drainage in low-lying areas particularly vulnerable (Hennessy *et al.,* 2007). Furthermore, several studies have shown that the increase in flood flow will be significantly greater than the percentage increase in short-term rainfall. This non-linearity arises due to a difference in infiltration rates and ground detention storage. The newly released IPCC AR5 WGII report list changes to flood frequency as a “key risk” in New Zealand (IPCC, 2014). Additionally, the recent IPCC AR5 WGII report states that time spent in drought for eastern areas of New Zealand is expected to double or triple by 2040.



6 Results

6.1 Rainfall

The results presented in this section are displayed graphically if four or more stations were found to have statistically significant relationships. A full table of results is available in Appendix C and D.

As the IPO was not analysed seasonally as described in the methodology section, the results are displayed in Figure 12. Tabular results are also available in Appendix D.

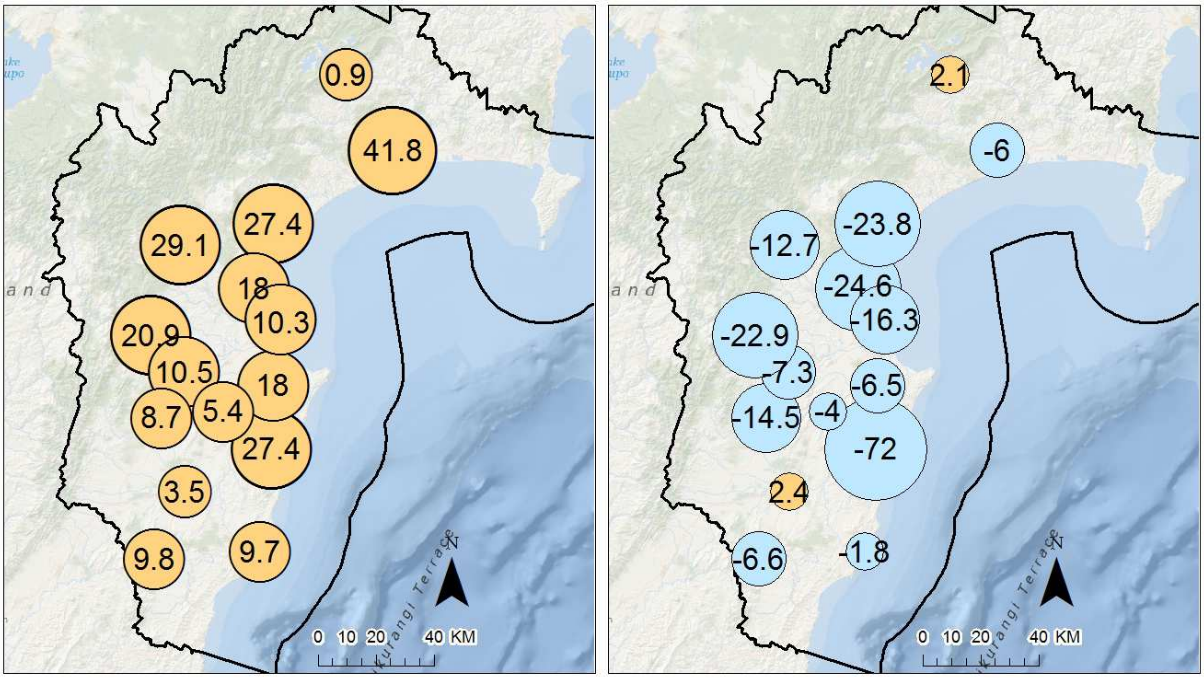


Figure 12: Seasonal total rainfall anomalies were confounded to create composite anomalies for the positive the negative (left) and positive (right) phases of the IPO. Anomalies are expressed in mm.

The positive phase of the IPO is generally associated with decreased seasonal rainfall in the Hawke's Bay region, while the negative phase is associated with increased rainfall. While these results are consistent with the broad-scale relationships evidenced between the IPO, New Zealand and South Pacific climate (Salinger *et al.*, 2001), none of the composite anomalies were found to be statistically significant (at the 90% confidence level). Note however that ideally, one would want to consider only the low-frequency component in the time-series of seasonal climate indices: unfortunately the presence of missing values precluded the application of a digital low-pass filter to these time-series.

6.1.1 Summer (December to February)

- No significant correlations were found for summer rainfall and the SAM and IOD climate cycles.
- The SOI was found to be positively correlated with total rainfall, heavy rainfall, extreme 1-day rainfall and extreme 3-day rainfall. These relationships were statistically significant for a number of stations (Figure 13).
- A positive SOI (La Niña conditions) is related to an increase in total rainfall, heavy rainfall, extreme 1 and 3 day rainfall and vice versa.
- The highest correlation for SOI and rainfall occurred at the Napier and Eskdale Hedgeley stations where up to 9% of variance in rainfall could be explained by the SOI.
- The SPSD was found to be positively correlated with total rainfall and heavy rainfall. This relationship was statistically significant for a number of stations (Figure 13) with the highest correlation occurring at Whanawhana where the SPSD was found to explain 14% and 10% of the variance in total rainfall and heavy rainfall respectively.

- Whanawhana was the only station to show a statistically significant relationship with extreme 1 and 3-day rainfall totals and the SPSD.

- The results for the SPSD show that warmer waters around New Zealand help to increase rainfall in the Hawke's Bay region, however there is only a relationship between SPSD and heavy rainfall for limited stations and even less so for extreme 1-day and 3-day rainfall. This shows that the SPSD is not strongly related to extreme events during summer such as those that contribute to flooding but rather acts to increase average seasonal rainfall totals.

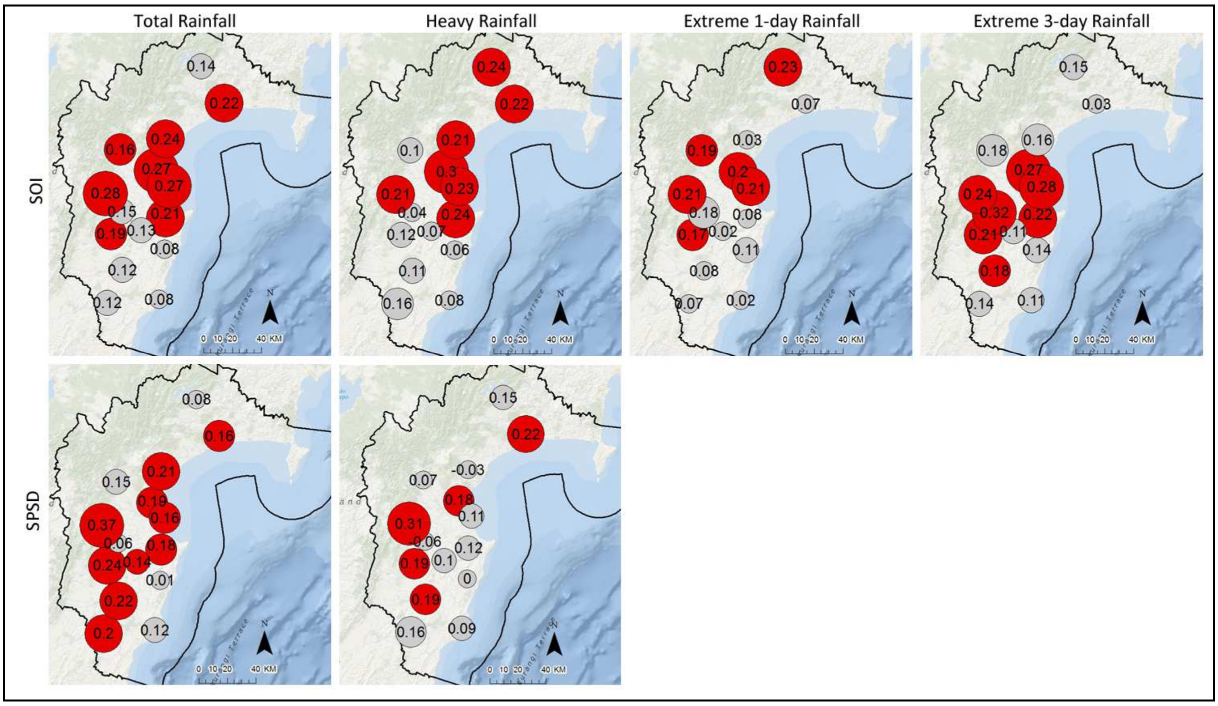


Figure 13: Summer (December to February) rainfall indices and their relationship with SOI and SPSD. Values within circles represent Pearson r values. Statistically significant (at 90% confidence level) correlations are highlighted in red. Circle size is related to the strength of the correlation.

6.1.2 Autumn (March to May)

- No significant correlations were found for autumn rainfall and the SOI, SAM and IOD climate cycles.

- The SPSD was found to be positively correlated with total rainfall, heavy rainfall, extreme 1-day rainfall and extreme 3-day rainfall. These relationships were statistically significant for virtually all stations and accounted for up to 15% of variance in rainfall (Figure 14).

- These results show that warmer than normal seas around New Zealand during autumn contribute to increased total rainfall as well as higher rainfall during extreme events and vice versa.

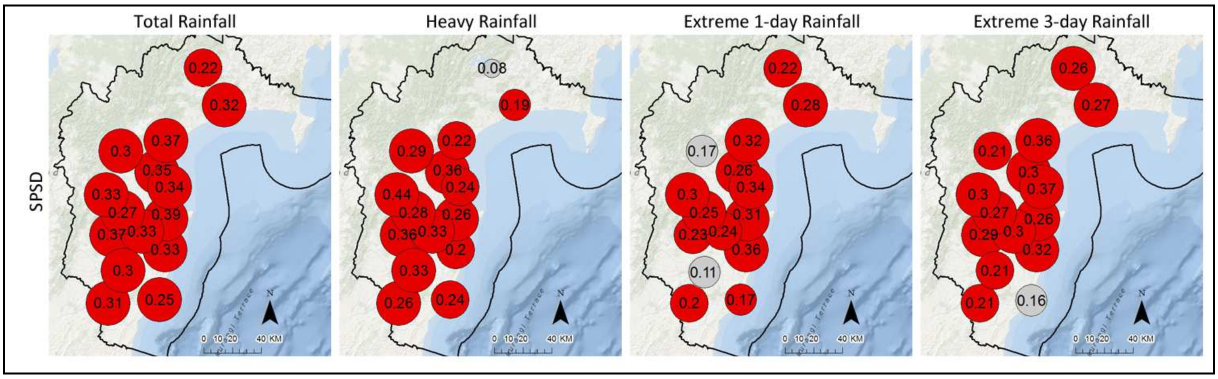


Figure 14: Autumn (March to May) rainfall indices and their relationship with SOI and SPSD. Values within circles represent Pearson r values. Statistically significant (at 90% confidence level) correlations are highlighted in red. Circle size is related to the strength of the correlation.

6.1.3 Winter (June to August)

- No significant correlations were found for winter rainfall and the SAM and IOD climate cycles.
- The SOI was found to be positively correlated with total rainfall and extreme 3-day rainfall. These relationships were statistically significant for a number of stations (Figure 15).
- The SPSD was found to be positively correlated with total rainfall, heavy rainfall, extreme 1-day rainfall and extreme 3-day rainfall. These relationships were statistically significant for several stations and accounted for up to 10% of variance in rainfall (Figure 15).
- The SPSD results show that warmer than normal seas around New Zealand during winter (as was the case in autumn) contribute to increased total rainfall as well as higher rainfall during extreme events and vice versa.

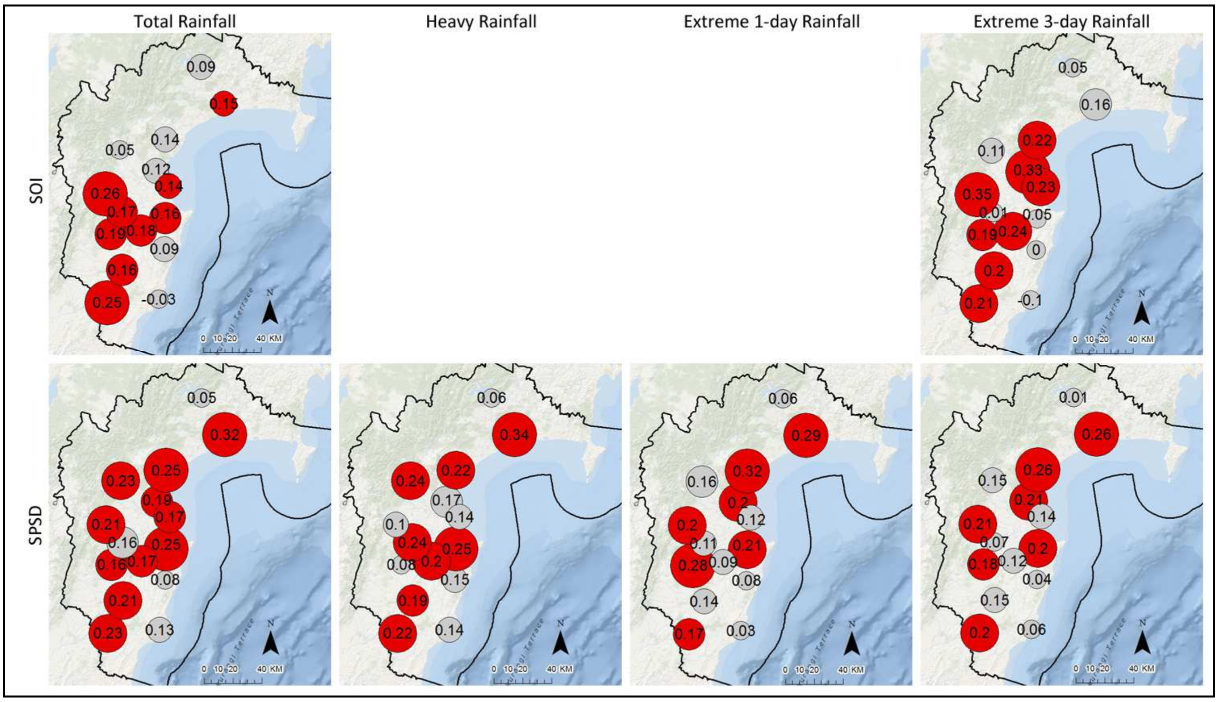


Figure 15: Winter (June to August) rainfall indices and their relationship with SOI and SPSD. Values within circles represent Pearson r values. Statistically significant (at 90% confidence level) correlations are highlighted in red. Circle size is related to the strength of the correlation.

6.1.4 Spring (September to November)

- No significant correlations were found for spring rainfall and the SAM climate cycle.
- The SOI was found to be positively correlated with total rainfall and extreme 3-day rainfall. These relationships were statistically significant for a number of stations (Figure 16).
- The SPSD was found to be positively correlated with total rainfall, heavy rainfall, extreme 1-day rainfall and extreme 3-day rainfall. These relationships were statistically significant for the majority of stations and accounted for up to 10% of variance in rainfall (Figure 16).
- The IOD was found to be negatively correlated with total rainfall, heavy rainfall, extreme 1-day rainfall and extreme 3-day rainfall. These relationships were statistically significant for several stations and accounted for up to 13% of variance in rainfall (Figure 16). Spring was the only season to have significant correlations with the IOD, which coincides with the peak months of this climate cycle.
- Negative values of the IOD index (negative phase) are associated with increased total rainfall as well as increased rainfall associated with extreme and heavy rainfall events. Conversely, positive values of the IOD index (positive phase) are associated with decreased total rainfall as well as decreased rainfall associated with extreme and heavy rainfall events.

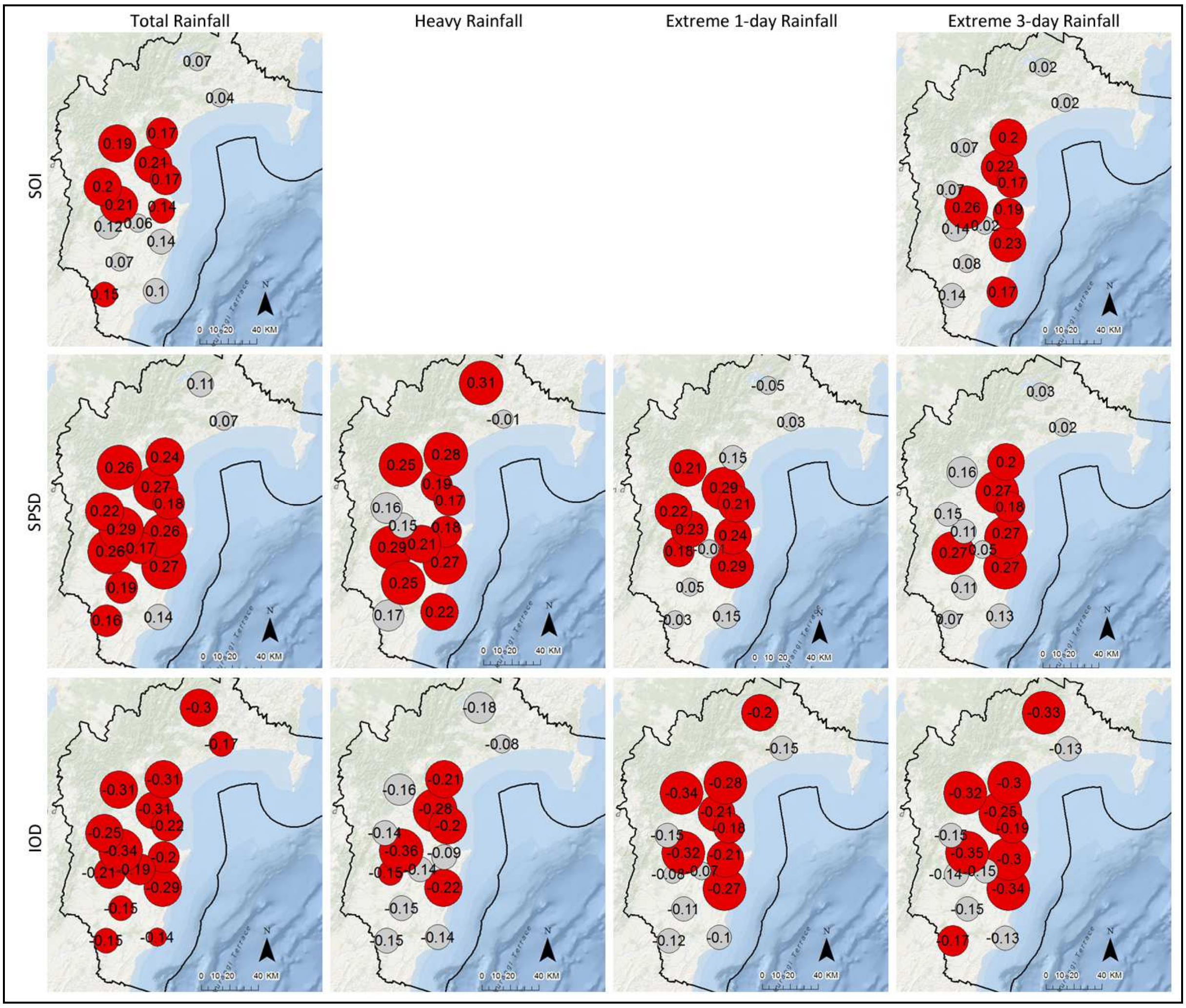


Figure 16: Spring (September to November) rainfall indices and their relationship with SOI and SPSD. Values within circles represent Pearson r values. Statistically significant (at 90% confidence level) correlations are highlighted in red. Circle size is related to the strength of the correlation.

6.1.5 Dry days

- The SPSD was found to have a negative relationship with the number of dry days during summer, autumn and to some extent winter. This relationship was statistically significant for several stations (Figure 17). This result highlights that cooler than normal water around New Zealand contributes to an increased amount of dry days, particularly during summer and autumn.

- The SOI was found to have a negative relationship with the number of dry days during summer but no other seasons. This relationship was statistically significant for 5 stations (Figure 17). This result shows that ENSO has a limited impact on the number of dry days during summer with El Niño conditions associated with an increased number of dry days and vice versa.

- The SAM was found to have a positive relationship with the number of dry days during winter but no other seasons. This relationship was statistically significant for 6 stations (Figure 17). This result shows that SAM has a limited impact on the number of dry days during winter.

- The IOD was found to have a positive relationship with the number of dry days during spring but no other seasons. This relationship was statistically significant for more than half of stations (Figure 17). This result shows that IOD has some impact on the number of dry days during spring.

- It is interesting to see that the relationships between dry days and climate modes are not as strong as for the other rainfall indices discussed. This suggests that climate drivers have a greater influence on seasonal rainfall totals when they are driven by high rainfall events. There is also a concern over data quality for the number of dry days index as there is some indication in the metadata (as described in the Methodology section) that some station managers were not checking rain gauges every day but only on "days it rained". Thus, if a small amount of rain fell and it went unnoticed there is a risk that the number of dry days may have been underreported for manual climate stations.

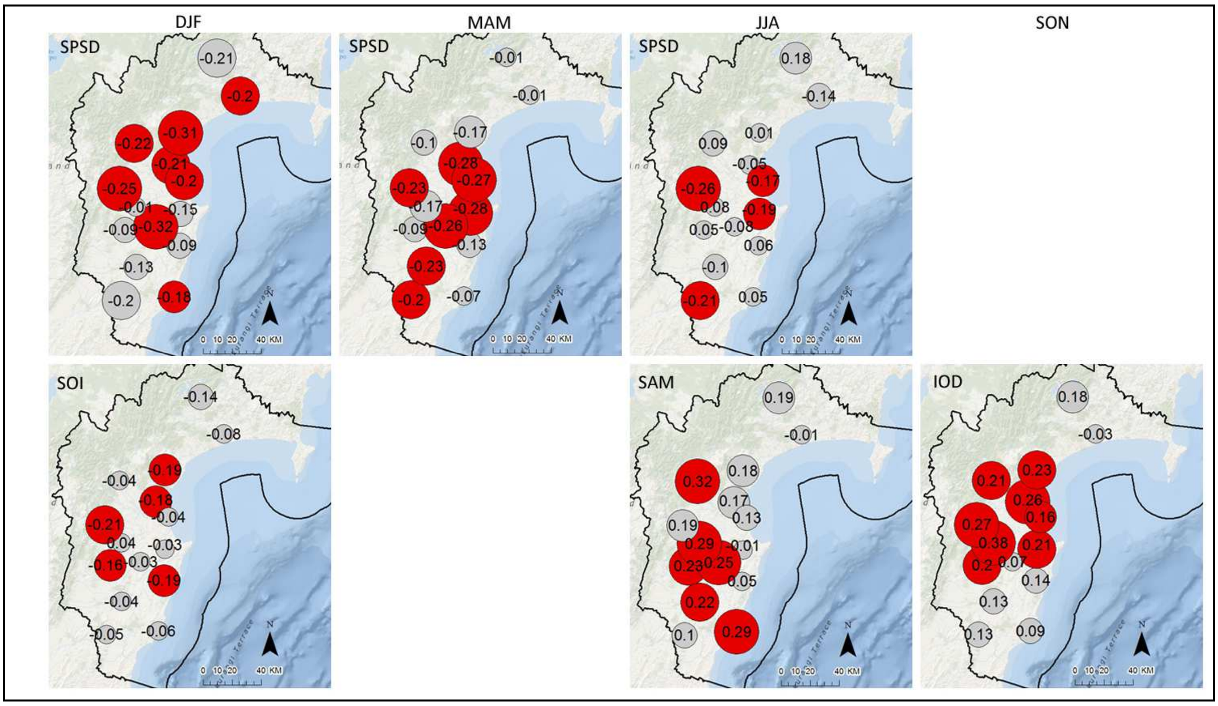


Figure 107: Seasonal relationships between the number of dry days and climate cycles. Values within circles represent Pearson r values. Statistically significant (at 90% confidence level) correlations are highlighted in red. Circle size is related to the strength of the correlation.

6.2 Temperature

The results presented in this section are displayed graphically if two or more stations were found to have statistically significant relationships. A full table of results is available in Appendix C.

6.2.1 Mean temperature

- The SOI was found to have a positive relationship with mean temperature during autumn, winter and spring. This relationship was statistically significant for all stations during spring and for some stations during autumn and winter (Figure 18). Up to 18% of the variation in temperature could be explained by the SOI. This result shows that a positive SOI (La Niña conditions) is associated with warmer than normal temperatures in Hawke's Bay and vice versa.

- The SPSD was found to have a positive relationship with mean temperature for all seasons. This relationship was statistically significant for virtually all stations (Figure 18). Correlations were generally very high with up to 41% of the variation in temperature explained by the SPSD. This result highlights that warmer than normal water around New Zealand is a large driver of warmer than normal mean temperatures in Hawke's Bay and vice versa.
- The SAM was found to have a positive relationship with mean temperature during summer and a negative relationship with mean temperature during autumn and spring. This relationship was statistically significant for some stations (Figure 18). This result shows that SAM has a limited impact on mean temperature, the positive phase of SAM is associated with increased temperatures during summer and decreased temperatures during autumn and spring and vice versa.
- The IOD was found to have a negative relationship with the mean temperature during winter. This relationship was statistically significant for two stations (Figure 18). This result shows that IOD has a limited impact on mean temperature during winter, with the negative phase associated with warmer than normal temperatures in Hawke's Bay and vice versa.

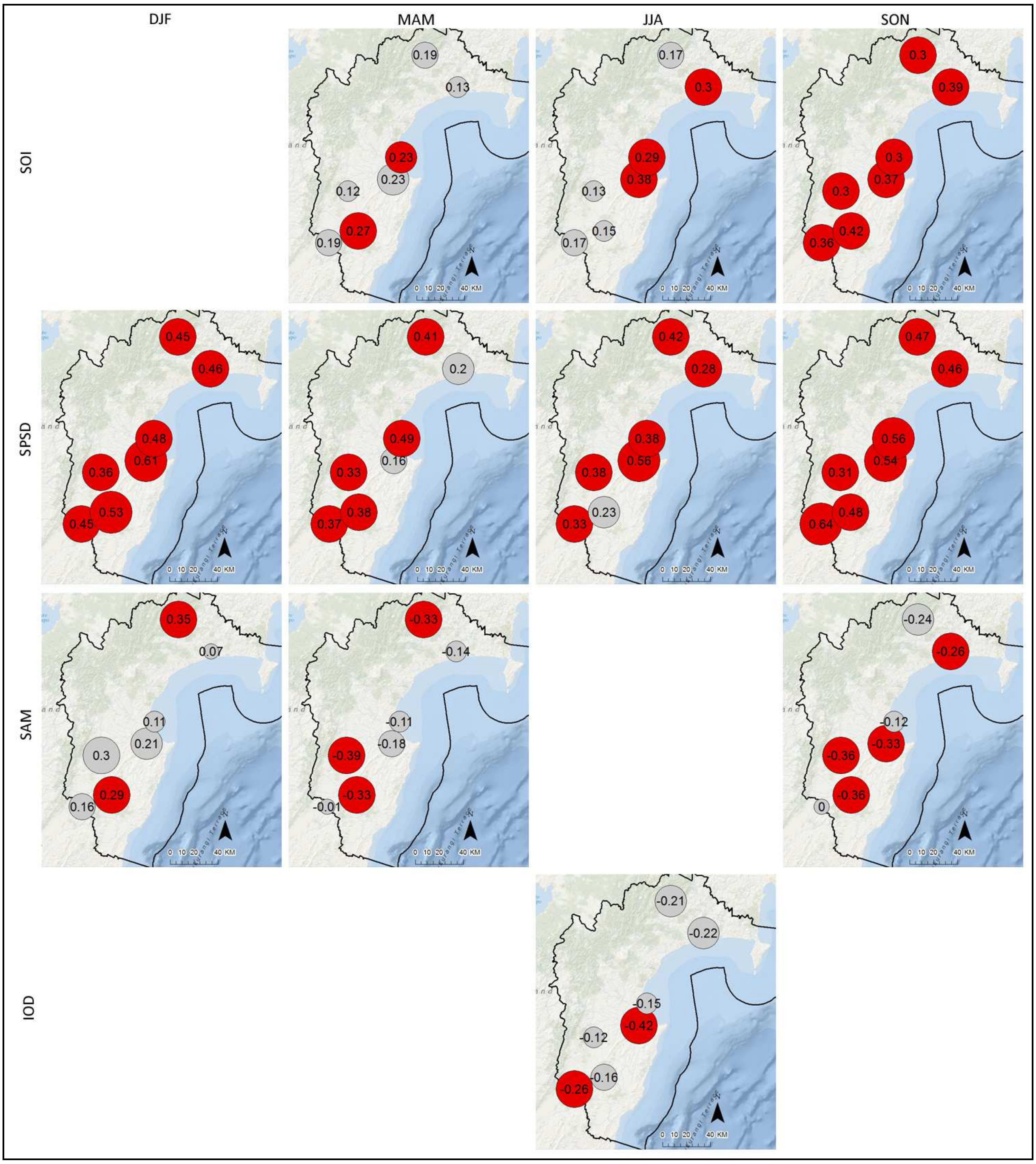


Figure 18: Seasonal relationships between mean seasonal temperature and climate cycles. Values within circles represent Pearson r values. Statistically significant (at 90% confidence level) correlations are highlighted in red. Circle size is related to the strength of the correlation.

6.2.2 Hot days

- No significant relationship between the SOI and the number of hot days in a season could be established.

- The SPSD was found to have a positive relationship with the number of hot days during summer. This relationship was statistically significant for 4 out of 7 stations (Figure 19). This result highlights that warmer than normal water around New Zealand contributes to the number of hot days during summer.

- The SAM was found to have a negative relationship with the number of hot days during autumn and spring. This relationship was statistically significant for 3 out of 7 stations (Figure 19). This result shows that SAM has a limited impact on the number of hot days, the positive phase of SAM is associated with fewer hot days during autumn and spring and vice versa.

- The IOD was found to have a negative relationship with the number of hot days during autumn. This relationship was statistically significant for two stations (Figure 19). This result shows that IOD has a limited impact on the number of hot days during autumn, with the negative phase associated with warmer than normal temperatures in Hawke's Bay and vice versa.

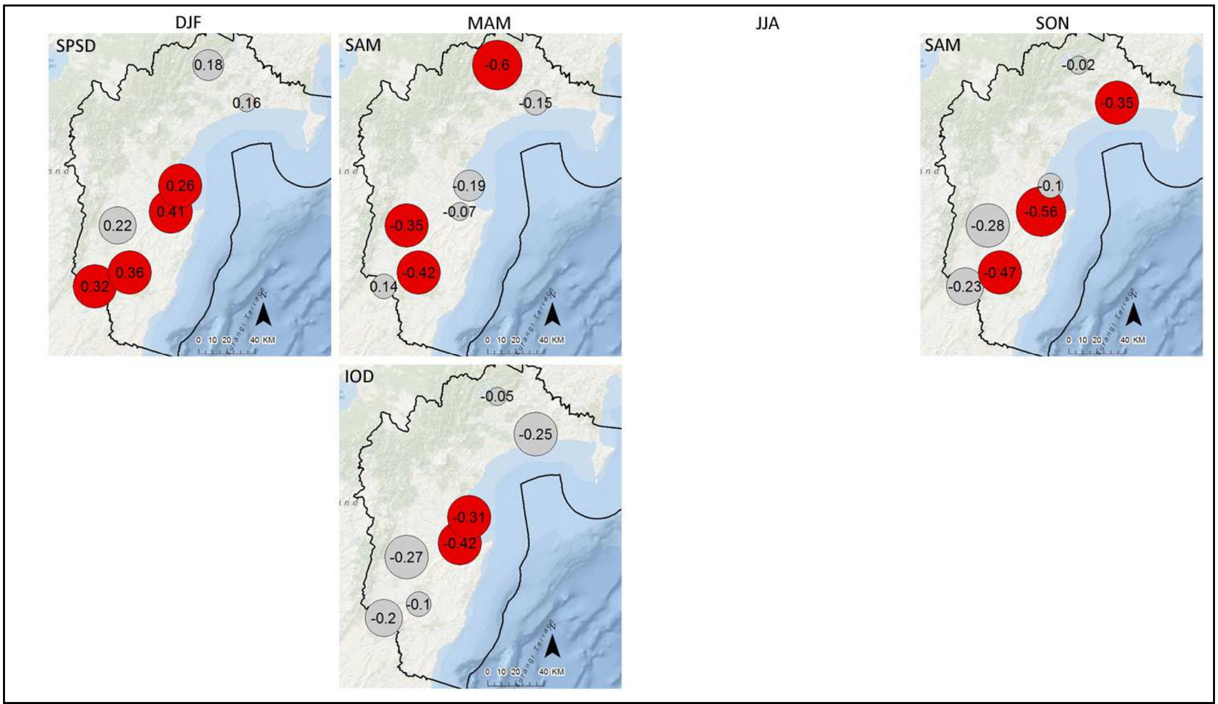


Figure 19: Seasonal relationships between the number of hot days and climate cycles. Values within circles represent Pearson r values. Statistically significant (at 90% confidence level) correlations are highlighted in red. Circle size is related to the strength of the correlation.

6.2.3 Frost days

- The SPSD was found to have a negative relationship with the number of frost days during autumn and winter. This relationship was statistically significant for 2 out of 7 stations (Figure 20). This result shows that the SPSD has a limited impact on the number of frost days during autumn and winter. Cooler than normal seas around New Zealand contribute to an increase in the number of frost days in Hawke's Bay and vice versa.

- The IOD was found to have a positive relationship with the number of frost days during winter and spring. This relationship was statistically significant for some stations (Figure 20). This result shows that IOD has a limited impact on the number of frost days during winter and spring with the positive phase associated with an increase in the number of frost days in Hawke's Bay and vice versa.

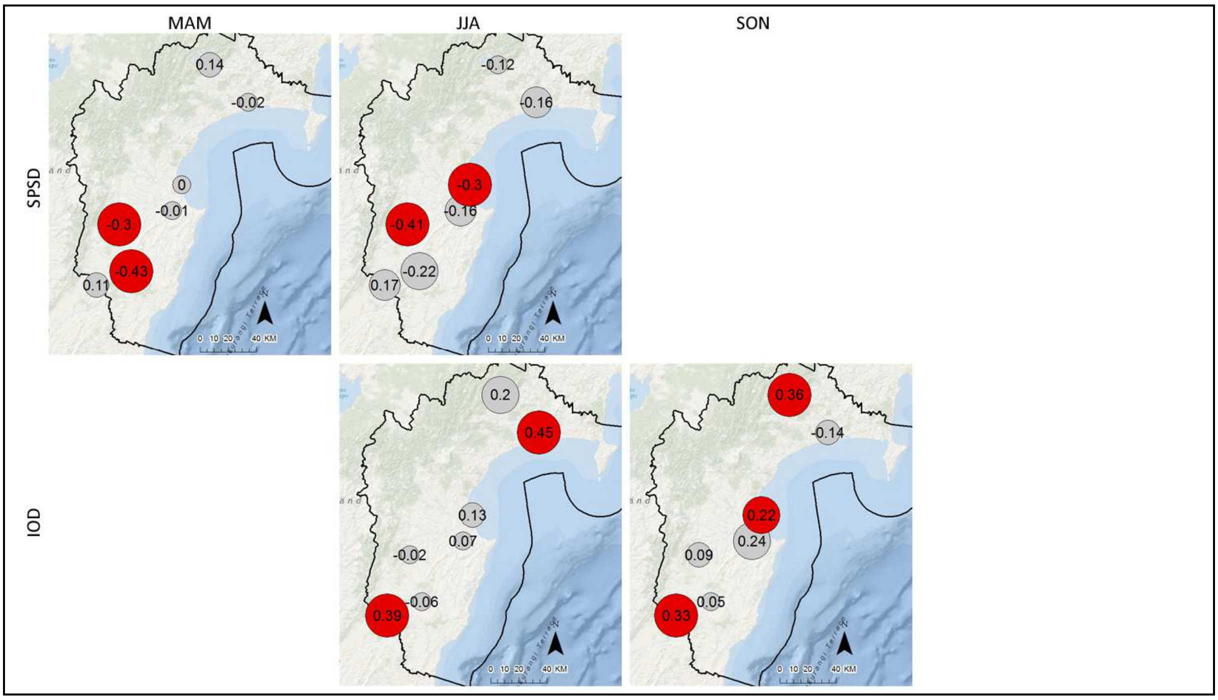


Figure 20: Seasonal relationships between the number of frost days and climate cycles. Values within circles represent Pearson r values. Statistically significant (at 90% confidence level) correlations are highlighted in red. Circle size is related to the strength of the correlation.

6.3 SST anomalies

The results presented in Section 6.1 and 6.2 brought to light that the SPSD was the most important climate mode driving rainfall and temperature anomalies in Hawke's Bay. In general, warmer than normal seas to the east of New Zealand were associated with higher than normal average and extreme rainfall for most seasons as well as warmer than average temperatures. The reverse applied for cooler than normal SSTs around New Zealand.

This result prompted further analysis of the role of SSTs and extreme climatic events in the Hawke's Bay region. SST composites were created for dry and wet seasons where at least 9 Hawke's Bay stations (out of the 15 analysed) registered seasonal rainfall anomalies below –1 and above +1 standard deviations respectively. The same methodology was applied to cool and warm seasons where at least 4 Hawke's Bay stations (out of the 7 analysed) registered seasonal temperature anomalies below –1 and above +1 standard deviations respectively.

Because SSTs are relatively slow varying (when monthly aggregated values are considered) and for the sake of uncovering potential predictability of Hawke's Bay climate derived from SST patterns, the composite SST anomalies were calculated for the month *prior* to the seasons determined above (full methodology described in Section 2.4.2).

From Figure 21a, an El Niño pattern can be seen when looking at the SST anomalies off the South American coastline. SSTs to the east of New Zealand are however cooler than average, which is the opposite of the typical El Niño pattern. Overall the results, are in line with what the SPSD correlations have shown and that cooler than normal SSTs to the east of New Zealand are often a precursor for drought conditions in Hawke's Bay. The opposite is true for widespread wet seasons in Hawke's Bay

(Figure 21b). SSTs off the coast of South America show a slight La Niña pattern, and SST around and to the east of NZ are slightly warmer than normal. These anomalies are consistent with both La Niña and the SPSD.

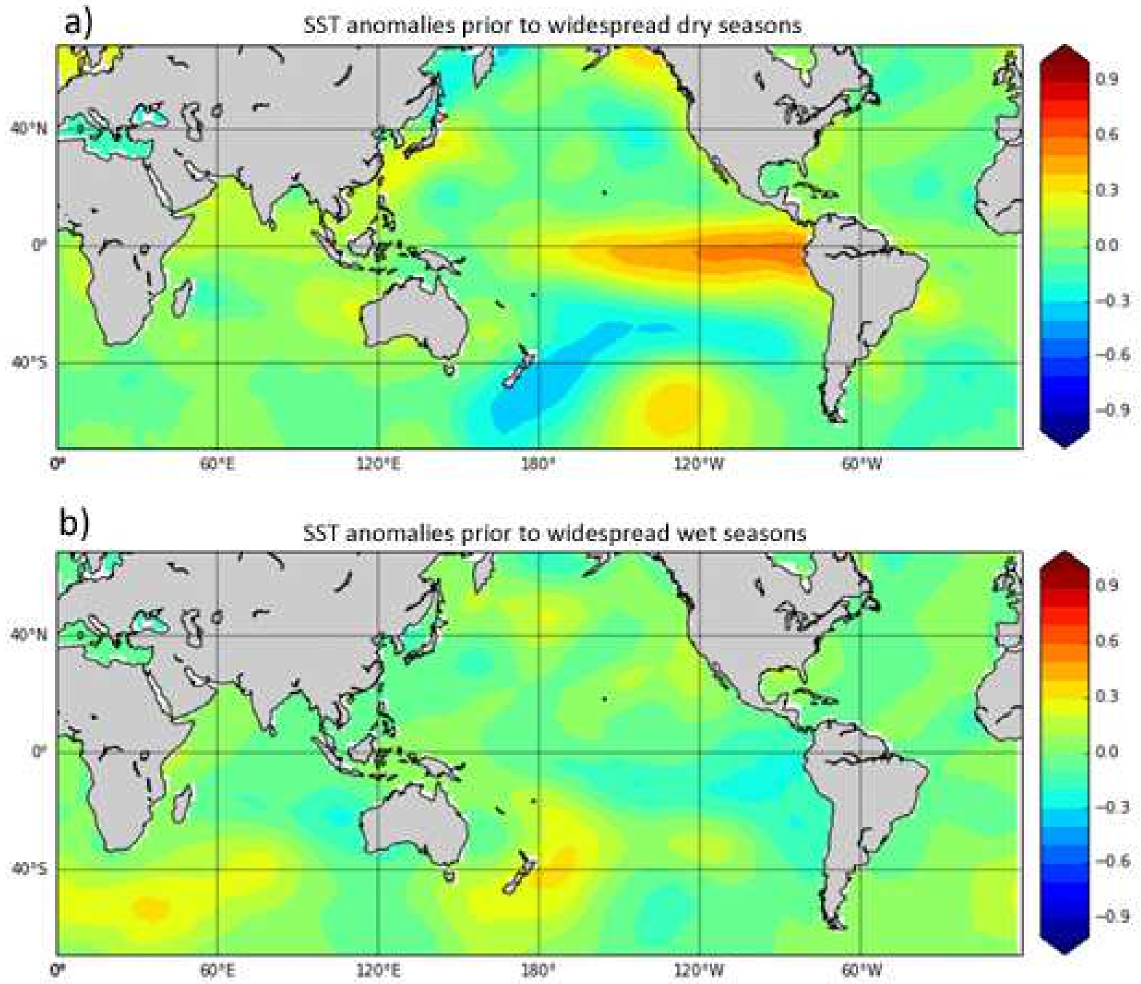


Figure 21: Results from composite analysis showing SST anomalies prior to widespread dry seasons in Hawke's Bay (a) and wet seasons (b).

When considering widespread warm seasons in Hawke's Bay, high SST anomalies were present around New Zealand and particularly centred off the east coast of the North Island (Figure 22a). The opposite association can be seen when considering widespread cool seasons, with SST's cooler than normal around New Zealand and particularly off the east coast of the North Island (Figure 22b). This result is consistent with the SPSD outcomes presented in Section 6.2. SSTs off the South American coast prior to widespread cold seasons show slight El Niño patterns which is also consistent with the results in Section 6.2.1.

In summary, persistent warmer than normal SSTs around New Zealand and in particular off the east coast of the North Island are associated with warmer and wetter conditions in the Hawke's Bay region. Likewise, persistent cooler than normal SSTs around the country and particularly off the east coast of the North Island were found to occur during cool and dry seasons in Hawke's Bay.

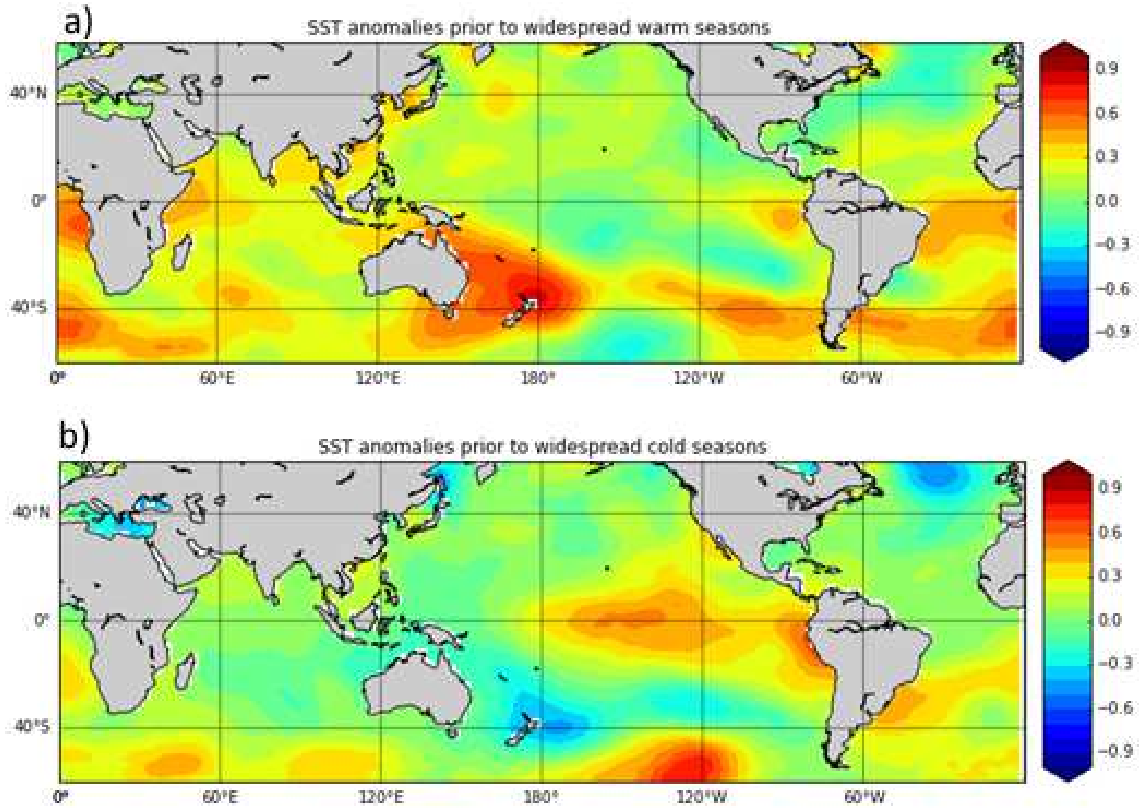


Figure 22: Results from composite analysis showing SST anomalies prior to widespread warm conditions in Hawke's Bay (a) and cold conditions (b).

7 Interaction between climate modes

The climate modes described in Part 4 and presented in the results Section do not occur in isolation and can impose modulating effects on one another. The greatest interaction occurs between the IPO and ENSO cycles. Salinger *et al.* (2001) investigated the effect of the IPO on the South Pacific climate for the period 1931-1998. It was found that the IPO had a modulating influence on ENSO with a particular bias during the positive IPO phase during which stronger interactions between the two oscillations was apparent. Although the two cycles operate on different timescales, there are similarities in their expression in tropical Pacific sea surface temperatures. A positive IPO phase is, on average, associated with enhanced and more frequent El Niño events. Salinger *et al.* (2001) found that the frequency of El Niño months went up from 12% to 27% during the positive IPO phase. Conversely, the negative phase of the IPO is associated with an increase in La Niña conditions, and thus increased rainfall and river flows in eastern regions such as the Bay of Plenty.

Because ENSO largely dominates global climate variability at interannual time-scales, in effect very few modes of variability operating at these time-scales can be considered totally independent of ENSO, at least in a statistical sense.

Recent studies examining the relationship between the IOD and ENSO have found linkages between the two modes of variability. A study by Yuan and Li (2008) found insignificant correlations between the two cycles between 1940-1969. However, from 1970-2003 this relationship increased significantly. Most El Niño events were found to coincide with a positive IOD signal and almost every positive IOD happened in an El Niño year. It was suggested that the increased association between the two cycles was caused by the enhanced linkage between oceanic circulation between the eastern Indian Ocean and the western Pacific through the Indonesian throughflow. Similarly, the Southern Annular Mode (SAM) is also partially related to ENSO during the Southern Hemisphere summer (see e.g.(L'Heureux & Thompson, 2006; Pohl, Fauchereau, Reason, & Rouault, 2010).

While the South Pacific Subtropical Dipole is yet to be studied in detail, it has also been found to be partly related to ENSO during the summer half of the year (Guan *et al.*, 2014). The results of this study, particularly those presented in Section 6.3 also support this relationship at a seasonal scale.

As mentioned in Section 5, climate change interacts with the natural climate variability described above. For example, the recent trend towards more positive phase of the SAM has been clearly attributed to the combination of dynamical effects related to stratospheric ozone depletion and radiative forcing due to anthropogenic greenhouse gases. Some characteristics of ENSO are also expected to be affected by anthropogenic climate change: e.g. (Cai *et al*., 2014) indicated that the frequency of extreme El Niño events is expected to double in a warming climate.

Climate change can also compound the effects of natural climate variability. For example, existing flood risk near river mouths will be exacerbated by storm surge associated with higher sea level. Higher rainfall intensity and peak flow will also increase erosion and sediment loads in waterways.

8 Conclusions

Most aspects of the natural environment are well adjusted to mean climatic conditions and show little sensitivity to small perturbations about these means. Consequently, the critical impacts of climate are generally driven by extreme events as opposed to mean values. The ability for the environment and society to adjust without stress and damage markedly decline as conditions become progressively more extreme (Salinger and Griffiths, 2001). Because of this, the effects of climate modes on extreme rainfall and temperature using current and future climate scenarios should be carefully considered when carrying out planning of climate/weather sensitive activities.

The results of this study have uncovered that the main climate signals to influence internal variability in rainfall and temperature are the SPSD, SOI and to some degree the IOD. The SPSD was found to be the most important climate mode influencing both rainfall and temperature with warm SSTs around NZ (positive SPSD) associated with warm and wet conditions in Hawke's Bay and vice versa.

The relationship between mean rainfall and the SPSD was statistically significant for virtually all stations and all seasons with the greatest correlation occurring during autumn where up to 15% of the variation in rainfall being explained by the SPSD. Extreme rainfall (heavy rainfall, extreme 1-day and extreme 3-day rainfall) was also found to have a statistically significant relationship for many stations during all seasons other than summer with the greatest correlation occurring during autumn (up to 13% of variation in rainfall explained by the SPSD).

For temperature, the relationship between SPSD and mean temperature was statistically significant for virtually all stations and seasons with up to 41% of variation in temperature explained by this climate mode. Some correlation between the SPSD and hot days during summer and frost days during winter and spring was also apparent but not as significant and widespread as for mean temperature, suggesting that extreme hot or cold events are driven by other (probably weather-related) factors.

ENSO was also found to have an impact on both rainfall in temperature in Hawke's Bay but on a lesser scale than the SPSD. As highlighted by previous research carried out in the east of the North Island, El Niño is associated with decreased rainfall and cooler temperatures and vice versa during La Niña events. The relationship with total rainfall and ENSO was statistically significant for all seasons other than autumn. The relationship with extreme rainfall (heavy rainfall, extreme 1-day and extreme 3-day rainfall) was not as strong and largely only statistically significant during summer (the peak of the ENSO cycle). A relationship between ENSO and temperature was also evident from autumn to spring but not for frost and hot days, showing that ENSO is unlikely to be a significant driver of extreme temperatures.

The IOD was found to impact mean and extreme rainfall during spring (which coincides with the peak of this climate mode) as well exerting some influence on temperatures. Although some relationships between Hawke's Bay climate and the SAM and IPO were identified, these relationships were not as significant as the other cycles and do not exert as much of an influence on the climate in Hawke's Bay.

When considering the correlation results (Section 6.1 and 6.2) in conjunction with the composite analysis of SSTs (Section 6.3), there appears to be a teleconnection between rainfall and temperature and the SPSD and ENSO climate modes. Although the SPSD is related to ENSO it is more prominent than ENSO itself.

Overall, this research has uncovered the importance of the SPSD in driving some of the seasonal climate variations in Hawke's Bay. Additionally this study has reaffirmed the contribution of the ENSO cycle to temperature and rainfall in Hawke's Bay. While ENSO and the SOI are regularly monitored by NIWA with monthly updates provided through the Seasonal Climate Outlook (https://www.niwa.co.nz/climate/sco), prior to this study the SPSD was not routinely calculated or used for climate forecasting in New Zealand. Given the significance of some the presented results, there is an opportunity for a tailored seasonal statistical forecasting scheme to be developed for Hawke's Bay. Potential real-time predictors should include the SPSD index, one or several ENSO indices and the IOD, and the models should account for the significant seasonality in some of the relationships. This work would require additional funding support.

This study has examined and established the relationships between climate indices and climate modes in Hawke's Bay. Additional further work could be carried out to explore the results in a more probabilistic framework, i.e. given sea surface temperatures over a given threshold above/below normal what is the probability of experiencing drought/flood conditions or extreme temperatures.

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Appendix A Outlier check results

Net_no	Name	Date	Suspect rainfall	Investigation
D96591	Napier Nelson Park	13/12/1898	81.3mm recorded. Seems like untagged accumulation as several days with 0mm prior. Eskdale Hedgley (12km away) recorded 0mm on this day. No other sites in the region recorded significant rainfall	See scan 'D96591_18981213.pdf'. Glass broken over period 1-12 Dec. Noted as "bottle full" 3.2 inches (8.13 mm). Recommendation: Delete all values from 1-13 Dec.
D87812	Tuai	10/07/1990	This looks impossible. 199mm recorded with no stations in the region recording more than 15mm. Erepeti 15km away recorded 0mm	No 302 form for this month in folder. Missing! Recommendation: Delete value on 10 Jul.
D87812	Tuai	2/07/1998	273mm recorded. Erepeti 15km away recorded 65mm	See scan 'D87812_19980701+02.pdf'. Values have been correctly entered. Comment is "very wet". Recommendation: Accept value as legitimate.
D87812	Tuai	3/07/1998	123mm recorded. Erepeti 15km away recorded 23.5mm	See above. Same recommendation.
D96081	Te Rangi Maungaharuru	2/05/1934	44.5mm recorded. 17 other stations in the region with none recording more than 1mm. Tutira 15km away recorded 0mm	See scan 'D96081_19340501.pdf'. Value has been entered correctly. No reason to dispute. Still, seems odd that no other stations in the area recorded rainfall. Recommendation: Accept value as legitimate.
D96081	Te Rangi Maungaharuru	12/03/1980	95.4mm recorded. Tutira 15km away recorded 0mm. No significant rainfall at any stations	See scan 'D96081_19800311.pdf'. Value has been entered correctly. However, seems odd that the same value has been entered again for the 15th, but note at bottom of form says the greatest fall of 95.4 mm occurred on 2 days in the month. Recommendation: Accept value as legitimate, but flag as 'uncertain' accuracy.
D96281	Tutira	25/05/1909	110mm recorded. A site 20km away recorded just 7.6mm. No significant rainfall totals in the region.	See scan 'D96281_19090524.pdf'. Value has been entered correctly. No reason to dispute.

				Recommendation: Accept value as legitimate.
D97031	Wairoa, Waiputaputa Stn	28/10/1913	63mm recorded. No other stations in the regions (10 in total) recorded any rainfall. Possible untagged accumulation as other stations recorded significant rainfall 3 days prior but 0mm was put down for Wairoa	See scan 'D97031_19131017.pdf'. Value has been entered correctly. No reason to dispute. However, agree it's possibly a multi-day accumulation. Recommendation: Accept value as legitimate, but flag as 'uncertain' accuracy.
D97031	Wairoa, Waiputaputa Stn	25/03/1915	226.1mm of rain recorded. 10 other stations in region and none recorded more than 20mm. Closest site is Tutira (42km away) and 14.7mm was recorded there	See scan 'D97031_19150324.pdf'. Value has been entered correctly. No reason to dispute. Recommendation: Accept value as legitimate.
D97031	Wairoa, Waiputaputa Stn	24/03/1916	99.1mm recorded. 11 other stations in the region with none recording more than 3mm.	See scan 'D97031_19160323.pdf'. Value has been entered correctly. No reason to dispute. Recommendation: Accept value as legitimate.
D97031	Wairoa, Waiputaputa Stn	1/06/1921	70.9mm recorded. 13 other stations in the region with none recording more than 1mm.	See scan 'D97031_19210531.pdf'. Value has been entered correctly. No reason to dispute. Recommendation: Accept value as legitimate.
D97031	Wairoa, Waiputaputa Stn	8/01/1932	54.9mm recorded. 16 other stations in the region recorded 0mm.	See scan 'D97031_19320107.pdf'. Value has been entered correctly. No reason to dispute. Recommendation: Accept value as legitimate.
D97031	Wairoa, Waiputaputa Stn	10/10/1943	48mm recorded. 18 other stations in region record 0mm.	See scan 'D97031_19431009.pdf'. Value has been entered correctly. No reason to dispute. Recommendation: Accept value as legitimate.

Appendix B Further information about homogenisation of Hawke's Bay climate data

Temperature

- The Waikaremoana Onepoto (D87811) site has a long period, moderate quality temperature record. No Type 1 change points were identified at the monthly analysis level for either minimum or maximum temperature deeming the record homogenous. Daily temperature data for this site has only been digitised since 01/01/1972. Paper records going back to 1935 of daily data exist but require to be digitised. A type 1 homogeneity test identified one change point in the daily minimum temperature record but there is no metadata (i.e. site or instrument change) to support this and so it was ignored. No change points were found in the daily maximum temperature record.

- Tuai (D87812) – no type-1 change points identified for monthly data. Record too short to be used for analysis and data gaps in the Waikaremoana Onepoto record did not coincide with the Tuai record.

- Wairoa, Frasertown (D97042), Wairoa Hospital (D97043) and Wairoa North Clyde EWS (D97045) were made into a composite record. No Type-1 change points were identified in the daily minimum composite record. Three Type-1 change points were identified late in the daily maximum composite record, no metadata to support this and so it was ignored.

- Napier Nelson Park (D96591) – A site change in 1963 corresponds to a drop in minimum temperatures by 0.6°C when compared to well established records at Waingawa, Gisborne Aero, Kelburn and Hamilton. Temperatures prior to December 1963 were adjusted for this site change. Data gaps were filled by Napier Aero (D96481) and Napier Aero AWS stations (D96484) and were first adjusted. Maximum temperatures were found to be 2°C warmer at Napier Nelson Park than the airport and minimum temperatures were 1°C higher.

- A Type-1 homogeneity test on the monthly temperature record for Waipukurau Airport (D06051) identified one change point and one potential change point in the monthly and daily minimum temperature record. The dates associated with the change points were not the same for the monthly and daily tests and there was no metadata supporting these shifts so no adjustments were applied. No change points were identified in the monthly or daily maximum temperature record. Waipawa EWS (D96962) has been operational since 2007 and is located 8km from the historic Waipukurau climate station, however, as there is no overlap period between the stations a composite record could not be made.

- A Type-1 homogeneity test on the monthly temperature record for Gwavas Forest (D96743) identified one change point in both the monthly minimum and monthly maximum temperatures. The shorter daily record had one change point and one potential change point in the daily maximums and two change points in the daily minimums. There is no metadata to support the breaks. The record is considered to be of moderate quality.

- A Type-1 homogeneity test on the monthly temperature record for Kopua (D06022) identified one change point for both monthly maximum and minimum temperature in the early part of the record. This was no supported by any metadata. Daily temperature data for this site has only been digitised since 01/01/1972. No change points were detected for daily maximum and minimum data.

- A Type-1 homogeneity test on the monthly temperature record for Hastings Fire Station (D96688) identified one change point and one potential change point in the maximum temperature record and one change point in the minimum record. This station was closed 1981 and Hastings AWS (D96680) was opened within 200m of the Fire Station. One month of overlapping data showed little difference between the two sites and the records were combined into a composite with no adjustments. The AWS was shut down in 1990 but reopened in 2005, thus there is a large data gap. A homogeneity test of the composite record found no Type-1 change points in either the maximum or minimum record.

Rainfall

- Onepoto (D87712) has a patchy record and a Type-1 homogeneity test found it to be inhomogeneous so it was not used.

- Tuai (D87812) had no Type-1 change points. Some gaps were filled with Erepeti (D87731) which also had no Type-1 change points but quality concerns were raised in metadata post 1993. The composite record had no change points.

- Wairoa, Waiputaputa Station (D97031) – no Type-1 change points identified.

- Te Rangi Maungaharuru (D96081) – one Type-1 change point identified in April 1982. Deteriorating exposure conditions during the 1980's are cited in the metadata however this is a gradual change difficult to correct for and thus no corrections were applied. Data not used for analysis.

- Te Wairere (D96251) - no Type-1 change points identified.

- Tutira (D96281) had no Type-1 change points. Some gaps were filled with Tareha (D87731), which is 5km away from Tutira and had an R^2 correlation value of 85% with Tutira as well as a gradient of 1.05. Two Type-1 change points were identified in the Tareha record (June 1982 and April 1984). There were also concerns in the metadata that the Tareha rain gauge was not checked every day but only on days that the observed thought it rained. Because of this Tutira was used as the main record until the station closed. A homogeneity test of the composite record identified no change points.

- Whanawhana (D69541) - no Type-1 change points identified.

- Rose Hill (D96653) - no Type-1 change points identified.

- Both Napier Nelson Park (D96591) and Napier Aero AWS (D96484) had no Type-1 change points. For both daily and monthly rainfall statistics the primary record used was Napier Nelson Park with any gaps filled with the Napier Aero AWS station. The gradient of the overlap period between the two stations for monthly data was 0.95 and the R^2 value was 89%.

- Havelock North composite- Havelock North, Te Mata (D6691) was used for the early part of the record with some gaps filled with Hastings (D96681). There was one Type-1 change point identified in the late record for Havelock North, Te Mata. Kopanga Homestead (HBRC station) was used from 1985 onwards. No change points were identified in this record. The overlap period between Havelock North, Te Mata and Kopanga Homestead shows a 92% correlation between monthly data. A Type-1 test of the composite record identified no change points.

- Anawai (D96882) – 1 Type- change point identified in March 1970. This coincides with a site inspection where the following observation was made “The gauge had been surrounded bricks with concrete top, enclosing a 12 inch square. This was removed and gauge re-sited correctly. Gauge was found to be leaking into outer can and was replaced.” The rain gauge was also relocated in 2004 and 2013 around the property. Record ceased since April 2014 – observer moved away and new observer required. Record considered to be of moderate quality.

- Gwavas (D96741) - no Type-1 change points identified.

- Smedley (D96731) - no Type-1 change points identified. This station was used to fill in some of the gaps in daily rainfall data for the Gwavas station.

- Mt Vernon 2 (D96951) – no Type-1 change points identified and no missing monthly data post 1890. Some gaps in daily rainfall data were filled by Waipukurau Aero (D06051) and Waipawa EWS (D96962).

- Aramoana (D06181) - no Type-1 change points identified.

- Waimarama (D96891) – three Type-1 change points identified – data not used for analysis.

- Tawadale, Wimbeldon (D06542) – A very patchy record and one potential Type-1 change point identified. Data not used for analysis.

- Tarawera (B96051) – Inhomogenous record, 3 Type-1 change points identified. Data not used for analysis.

- Eskdale Hedgeley (D96483) - no Type-1 change points identified. Missing daily data from 1961-1967 but monthly totals are available.

- Koparakore (D96771) – no Type 1 change points identified. Some gaps were filled by Pukehou, Te Aute Stn (D96861) – two Type-1 change points identified.

- Makaretu North (D96925) - no Type-1 change points identified. Record not used for analysis as too short.

- Waiwhero Station (D06062) - no Type-1 change points identified. Record not used for analysis as too short.

- Motuotaria (D06151) - no Type-1 change points identified. Missing data and the late part if the record was filled in with Flemington (D06142) which also has no Type-1 change points.

Appendix C Correlation results

This appendix includes the full results from the correlation analysis described in Section 2.4.1. The values presented here are Pearson r values showing the relationship between the time-series of seasonal climate indices and climate mode indices. Grey shading indicates where correlations are statistically significant at the 90% level.

Total rainfall																
	SOI				SAM				IOD				SPSD			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Anawai	0.08	0.11	0.09	0.14	-0.11	-0.09	-0.03	0.14	0.05	0.16	0.06	-0.29	0.01	0.33	0.08	0.27
Aramoana	0.08	-0.02	-0.03	0.1	-0.19	0.1	-0.18	0.06	0.14	0.02	0.07	-0.14	0.12	0.25	0.13	0.14
Eskdale Hedgeley	0.27	0.02	0.12	0.21	0.03	0.09	-0.05	0.07	-0.01	0.00	0.00	-0.31	0.19	0.35	0.19	0.27
Flemington	0.12	0.05	0.25	0.15	-0.17	-0.1	-0.19	0.01	0.14	0.01	-0.10	-0.15	0.20	0.31	0.23	0.16
Gwavas	0.19	0.04	0.19	0.12	0	0	-0.09	0.03	0.09	0.06	0.01	-0.21	0.24	0.37	0.16	0.26
Havelock North	0.21	0.01	0.16	0.14	-0.04	0.16	-0.04	0.07	0.04	0.04	0.01	-0.20	0.18	0.39	0.25	0.26
Koparakore	0.13	-0.01	0.18	0.06	0.06	0.06	-0.08	0.04	0.07	0.00	-0.01	-0.19	0.14	0.33	0.17	0.17
Mt Vernon	0.12	-0.05	0.16	0.07	-0.05	-0.01	-0.13	0.07	0.13	0.02	0.02	-0.15	0.22	0.30	0.21	0.19
Napier	0.27	-0.01	0.14	0.17	-0.01	0.13	-0.12	0.11	0.00	-0.01	0.00	-0.22	0.16	0.34	0.17	0.18
Rose Hill	0.15	0.05	0.17	0.21	-0.04	-0.07	-0.1	0.02	0.05	0.20	0.03	-0.34	0.06	0.27	0.16	0.29
Tuai	0.16	0.16	0.05	0.19	0.08	0.22	0.15	0.08	-0.05	0.02	-0.08	-0.31	0.15	0.30	0.23	0.26
Te Wairere	0.14	0.16	0.09	0.07	-0.05	0.07	0.09	0.13	-0.04	0.02	-0.06	-0.30	0.08	0.22	0.05	0.11
Tutira	0.24	0.09	0.14	0.17	0.02	0.15	0.12	0.11	0.01	-0.01	-0.03	-0.31	0.21	0.37	0.25	0.24
Wairoa	0.22	0.13	0.15	0.04	-0.01	0.21	-0.03	0.08	0.10	0.00	-0.07	-0.17	0.16	0.32	0.32	0.07
Whanawhana	0.28	0.06	0.26	0.2	0.17	-0.3	0	0	0.09	0.17	-0.02	-0.25	0.37	0.33	0.21	0.22

Extreme daily rainfall (Rx1day)																
	SOI				SAM				IOD				SPSD			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Anawai	0.11	0.08	0.02	0.24	0.01	-0.11	-0.14	0.03	0.03	0.10	0.08	-0.27	0.04	0.36	0.08	0.29
Aramoana	0.02	-0.02	-0.10	0.15	-0.07	0.10	-0.23	-0.04	0.17	0.06	0.03	-0.10	0.01	0.17	0.03	0.15
Eskdale Hedgeley	0.20	-0.04	0.28	0.22	-0.03	-0.06	-0.10	0.12	0.00	-0.01	-0.01	-0.21	0.13	0.26	0.20	0.29
Flemington	0.07	0.02	0.16	0.03	-0.15	-0.25	-0.11	0.16	0.13	0.11	-0.10	-0.12	0.11	0.20	0.17	-0.03
Gwavas	0.17	0.08	0.14	0.06	0.03	-0.04	-0.09	0.03	0.04	0.07	0.02	-0.08	0.12	0.23	0.28	0.18
Havelock North	0.08	0.06	0.01	0.21	0.06	0.02	-0.06	0.04	0.01	0.07	0.05	-0.21	-0.03	0.31	0.21	0.24
Koparakore	0.02	-0.06	0.13	-0.03	0.02	-0.01	-0.03	0.03	0.08	0.10	-0.04	-0.07	0.00	0.24	0.09	-0.01
Mt Vernon	0.08	-0.12	0.13	0.03	0.02	-0.15	-0.17	0.10	0.10	0.05	-0.03	-0.11	0.09	0.11	0.14	0.05
Napier	0.21	0.00	0.18	0.21	0.03	-0.04	-0.16	0.14	-0.03	-0.04	0.00	-0.18	0.05	0.34	0.12	0.21
Rose Hill	0.18	0.02	0.02	0.38	0.09	-0.09	-0.09	0.02	-0.08	0.10	0.17	-0.32	-0.12	0.25	0.11	0.23
Tuai	0.19	0.02	0.15	0.19	0.05	0.05	0.29	0.01	-0.02	-0.04	-0.16	-0.34	0.12	0.17	0.16	0.21
Te Wairere	0.23	0.13	0.07	-0.01	0.05	-0.04	0.06	0.04	0.01	-0.04	-0.05	-0.20	0.09	0.22	0.06	-0.05
Tutira	0.03	0.06	0.31	0.18	0.04	0.07	0.08	0.11	0.07	-0.02	-0.06	-0.28	0.01	0.32	0.32	0.15
Wairoa	0.07	0.14	0.19	0.00	0.00	0.00	-0.07	0.02	-0.01	-0.08	-0.09	-0.15	0.05	0.28	0.29	0.03
Whanawhana	0.21	0.07	0.36	0.03	0.15	-0.29	-0.04	-0.01	0.07	0.26	-0.01	-0.15	0.31	0.30	0.20	0.22

Extreme 3-day rainfall (Rx3day)																
	SOI				SAM				IOD				SPSD			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Anawai	0.14	0.08	0.00	0.23	0.02	-0.12	-0.15	0.15	0.06	0.12	0.07	-0.34	-0.01	0.32	0.04	0.27
Aramoana	0.11	-0.01	-0.10	0.17	0.04	0.09	-0.16	-0.04	0.14	0.05	0.00	-0.13	0.05	0.16	0.06	0.13
Eskdale Hedgeley	0.27	0.02	0.33	0.22	0.09	-0.01	-0.10	0.14	0.01	-0.03	-0.03	-0.25	0.13	0.30	0.21	0.27
Flemington	0.14	0.06	0.21	0.14	0.05	-0.20	-0.09	0.15	0.14	0.15	-0.09	-0.17	0.10	0.21	0.20	0.07
Gwavas	0.21	0.11	0.19	0.14	0.21	-0.04	-0.09	0.03	0.04	0.10	0.03	-0.14	0.15	0.29	0.18	0.27
Havelock North	0.22	0.10	0.05	0.19	0.21	0.04	-0.08	0.11	0.01	0.07	0.01	-0.30	0.04	0.26	0.20	0.27
Koparakore	0.11	0.04	0.24	0.02	0.20	0.07	-0.05	0.09	0.05	0.09	-0.10	-0.15	0.07	0.30	0.12	0.05
Mt Vernon	0.18	-0.06	0.20	0.08	0.25	-0.12	-0.13	0.13	0.10	0.09	0.01	-0.15	0.09	0.21	0.15	0.11
Napier	0.28	0.08	0.23	0.17	0.15	0.09	-0.18	0.15	-0.04	-0.04	-0.05	-0.19	0.10	0.37	0.14	0.18
Rose Hill	0.32	0.12	0.01	0.26	0.21	-0.08	-0.09	0.10	0.03	0.06	0.14	-0.35	-0.02	0.27	0.07	0.11
Tuai	0.18	0.11	0.11	0.07	0.11	0.05	0.28	0.09	-0.10	-0.09	-0.13	-0.32	0.12	0.21	0.15	0.16
Te Wairere	0.15	0.20	0.05	0.02	0.13	0.00	0.04	0.09	-0.02	-0.03	-0.03	-0.33	0.07	0.26	0.01	0.03
Tutira	0.16	0.14	0.22	0.20	0.08	0.06	0.07	0.14	0.04	-0.04	-0.06	-0.30	0.07	0.36	0.26	0.20
Wairoa	0.03	0.17	0.16	0.02	-0.01	0.10	-0.07	0.12	-0.01	-0.06	-0.07	-0.13	0.03	0.27	0.26	0.02
Whanawhana	0.24	0.03	0.35	0.07	0.31	-0.32	0.00	0.07	0.08	0.20	-0.06	-0.15	0.29	0.30	0.21	0.15

Heavy rainfall days																
	SOI				SAM				IOD				SPSD			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Anawai	0.06	0.01	0.08	0.13	-0.22	-0.13	-0.01	0.01	0.01	0.21	-0.04	-0.22	0.00	0.20	0.15	0.27
Aramoana	0.08	-0.07	0.00	0.08	-0.21	0.19	-0.09	0.01	0.08	0.05	0.04	-0.14	0.09	0.24	0.14	0.22
Eskdale Hedgeley	0.30	0.15	0.08	0.24	0.08	0.19	-0.09	-0.01	0.04	0.09	-0.06	-0.28	0.18	0.36	0.17	0.19
Flemington	0.16	0.10	0.11	0.15	-0.26	-0.25	-0.08	0.03	0.06	-0.06	-0.06	-0.15	0.16	0.26	0.22	0.17
Gwavas	0.12	0.02	0.09	0.08	-0.16	0.05	-0.02	-0.07	0.07	0.00	0.02	-0.15	0.19	0.36	0.08	0.29
Havelock North	0.24	0.02	0.10	0.01	-0.01	0.13	-0.08	0.04	0.05	0.12	0.05	-0.09	0.12	0.26	0.25	0.18
Koparakore	0.07	0.04	0.14	0.03	0.06	0.00	-0.06	-0.08	0.05	-0.03	-0.01	-0.14	0.10	0.33	0.20	0.21
Mt Vernon	0.11	-0.01	0.10	0.09	-0.08	-0.02	-0.10	-0.12	0.10	-0.02	0.02	-0.15	0.19	0.33	0.19	0.25
Napier	0.23	-0.05	0.13	0.17	-0.02	0.09	-0.12	-0.01	-0.06	0.06	0.00	-0.20	0.11	0.24	0.14	0.17
Rose Hill	0.04	0.10	0.24	0.10	0.05	0.07	-0.09	0.11	0.10	0.09	0.06	-0.36	-0.06	0.28	0.24	0.15
Tuai	0.10	0.08	-0.03	0.17	0.10	0.18	0.12	0.01	-0.08	0.00	-0.03	-0.16	0.07	0.29	0.24	0.25
Te Wairere	0.24	0.11	0.00	0.11	0.32	0.25	0.20	0.23	-0.08	0.01	-0.05	-0.18	0.15	0.08	0.06	0.31
Tutira	0.21	0.07	0.04	0.22	0.11	0.00	0.18	0.03	-0.04	0.09	0.00	-0.21	-0.03	0.22	0.22	0.28
Wairoa	0.22	0.06	0.03	-0.02	0.23	0.04	0.14	0.03	0.06	0.04	-0.05	-0.08	0.22	0.19	0.34	-0.01
Whanawhana	0.21	-0.01	0.13	0.14	0.02	-0.54	0.12	-0.40	-0.01	0.01	0.06	-0.14	0.31	0.44	0.10	0.16

Dry days																
	SOI				SAM				IOD				SPSD			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Anawai	-0.19	-0.16	-0.10	0.03	0.05	-0.16	0.05	-0.24	0.00	-0.05	0.05	0.14	-0.09	-0.13	0.06	0.15
Aramoana	-0.06	-0.06	-0.08	0.00	0.12	-0.08	0.29	-0.17	-0.05	0.01	-0.01	0.09	-0.18	-0.07	0.05	0.03
Eskdale Hedgeley	-0.18	-0.07	-0.05	-0.12	-0.24	-0.19	0.17	-0.18	-0.14	-0.02	-0.02	0.26	-0.21	-0.28	-0.05	-0.09
Flemington	-0.05	-0.13	-0.14	-0.19	-0.30	-0.03	0.10	-0.10	-0.02	0.03	0.01	0.13	-0.20	-0.20	-0.21	-0.11
Gwavas	-0.16	-0.18	-0.18	-0.03	-0.08	-0.20	0.23	-0.12	-0.03	0.03	0.23	0.20	-0.09	-0.09	0.05	0.10
Havelock North	-0.03	-0.16	-0.10	-0.16	-0.10	-0.15	-0.01	-0.24	0.04	-0.02	-0.02	0.21	-0.15	-0.28	-0.19	-0.09
Koparakore	-0.03	-0.11	-0.01	-0.02	0.37	-0.10	0.25	-0.02	-0.09	-0.07	-0.05	0.07	-0.32	-0.26	-0.08	-0.14
Mt Vernon	-0.04	-0.03	-0.22	-0.05	-0.04	-0.03	0.22	-0.09	-0.03	-0.02	0.13	0.13	-0.13	-0.23	-0.10	-0.06
Napier	-0.04	0.02	-0.01	-0.18	-0.14	-0.20	0.13	-0.17	-0.08	-0.09	0.05	0.16	-0.20	-0.27	-0.17	-0.17
Rose Hill	0.04	-0.16	-0.29	-0.10	0.01	-0.15	0.29	-0.09	0.08	-0.16	0.14	0.38	-0.01	-0.17	0.08	-0.13
Tuai	-0.04	-0.01	-0.15	-0.01	-0.09	-0.04	0.32	-0.20	-0.03	-0.11	0.04	0.21	-0.22	-0.10	0.09	0.02
Te Wairere	-0.14	0.00	-0.12	0.04	-0.33	-0.27	0.19	-0.33	-0.06	-0.12	0.05	0.18	-0.21	-0.01	0.18	0.08
Tutira	-0.19	0.00	0.06	-0.05	-0.19	-0.04	0.18	-0.16	0.00	0.17	0.24	0.23	-0.31	-0.17	0.01	0.02
Wairoa	-0.08	0.05	0.09	-0.01	-0.11	-0.15	-0.01	-0.24	-0.08	0.05	-0.02	-0.03	-0.20	-0.01	-0.14	-0.13
Whanawhana	-0.21	-0.19	0.01	-0.13	0.24	-0.32	0.19	-0.27	-0.11	0.08	0.20	0.27	-0.25	-0.23	-0.26	-0.03

Average temperature																
	SOI				SAM				IOD				SPSD			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Gwavas	0.08	0.12	0.13	0.30	0.30	-0.39	-0.17	-0.36	0.00	-0.02	-0.12	0.03	0.36	0.33	0.38	0.31
Hastings	0.25	0.23	0.38	0.37	0.21	-0.18	-0.10	-0.33	-0.04	-0.33	-0.42	-0.06	0.61	0.16	0.56	0.54
Kopua	0.06	0.19	0.17	0.36	0.16	-0.01	0.00	0.00	0.12	-0.06	-0.26	-0.16	0.45	0.37	0.33	0.64
Napier	0.10	0.23	0.29	0.30	0.11	-0.11	-0.06	-0.12	0.14	0.02	-0.15	-0.02	0.48	0.49	0.38	0.56
Waikaremoana	0.00	0.19	0.17	0.30	0.35	-0.33	-0.14	-0.24	-0.04	0.00	-0.21	-0.03	0.45	0.41	0.42	0.47
Waipukurau	0.17	0.27	0.15	0.42	0.29	-0.33	-0.26	-0.36	-0.13	0.01	-0.16	-0.18	0.53	0.38	0.23	0.48
Wairoa	0.09	0.13	0.30	0.39	0.07	-0.14	-0.03	-0.26	0.28	-0.22	-0.22	-0.08	0.46	0.20	0.28	0.46

Hot days																
	SOI				SAM				IOD				SPSD			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Gwavas	-0.15	-0.21	-	0.05	0.16	-0.35	-	-0.28	-0.04	-0.27	-	0.03	0.22	-0.04	-	-0.12
Hastings	-0.01	0.28	-	0.08	-0.25	-0.07	-	-0.56	-0.04	-0.42	-	0.03	0.41	-0.12	-	-0.02
Kopua	0.12	0.09	-	0.04	0.08	0.14	-	-0.23	0.19	-0.20	-	-0.02	0.32	-0.02	-	-0.15
Napier	-0.10	0.08	-	-0.02	0.04	-0.19	-	-0.10	0.01	-0.31	-	0.32	0.26	0.05	-	0.00
Waikaremoana	-0.11	-0.04	-	-0.25	0.39	-0.60	-	-0.02	-0.03	-0.05	-	0.07	0.18	0.09	-	-0.22
Waipukurau	0.25	0.04	-	-0.09	0.26	-0.42	-	-0.47	-0.15	-0.10	-	0.19	0.36	0.06	-	-0.11
Wairoa	-0.09	0.22	-	0.05	-0.12	-0.15	-	-0.35	0.21	-0.25	-	0.24	0.16	-0.11	-	-0.01

Frost days																
	SOI				SAM				IOD				SPSD			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Gwavas	-0.01	-0.21	-0.08	-0.28	0.17	0.02	0.09	0.20	0.23	0.05	-0.02	0.09	-0.24	-0.30	-0.41	-0.08
Hastings	-	0.04	-0.34	0.04	-	0.01	0.19	-0.07	-	0.08	0.07	0.24	-	-0.01	-0.16	-0.21
Kopua	-	0.08	0.01	-0.17	-	-0.11	0.20	-0.10	-	-0.01	0.39	0.33	-	0.11	0.17	-0.20
Napier	-	-0.12	-0.07	-0.14	-	-0.07	0.11	-0.10	-	0.04	0.13	0.22	-	0.00	-0.30	-0.12
Waikaremoana	-	-0.12	-0.12	-0.13	-	-0.09	-0.06	0.27	-	0.01	0.20	0.36	-	0.14	-0.12	-0.21
Waipukurau	-	-0.11	0.01	-0.19	-	0.23	0.34	0.29	-	0.04	-0.06	0.05	-	-0.43	-0.22	-0.19
Wairoa	-	0.08	-0.13	-0.02	-	0.12	0.05	0.01	-	0.06	0.45	-0.14	-	-0.02	-0.16	0.11

Appendix D IPO composite analysis results

This appendix presents the results of the composite analysis of the IPO and total rainfall (as described by the methodology in Section 2.4.2). The presented values are composite rainfall anomalies (mm) during the negative and positive phase of the IPO. None of the results were statistically significant.

Composite anomalies for total rainfall and the positive and negative phase of the IPO		
Name	**Negative IPO**	**Positive IPO**
Anawai	27.39	-71.98
Aramoana	9.7	-1.78
Eskdale Hedgeley	17.93	-24.64
Flemington	9.77	-6.56
Gwavas	8.65	-14.54
Havelock North	18.03	-6.49
Koparakore	5.38	-4.03
Mt Vernon	3.48	2.42
Napier	10.32	-16.29
Rose Hill	10.52	-7.27
Tuai	29.07	-12.65
Te Wairere	0.87	2.07
Tutira	27.45	-23.84
Wairoa	41.84	-6.05
Whanawhana	20.95	-22.85