State of the Climate 2010

A snapshot of recent climate in New Zealand

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Executive summary

- New Zealand climate exhibits considerable variability from year to year, as the country sits in the turbulent mid-latitude westerly wind belt, and it is influenced by many features of the global circulation, notably the El Niño-Southern Oscillation (ENSO) and the Southern Annular Mode (SAM). Extremes of climate and weather are a routine feature of New Zealand seasonal climate, as illustrated during 2008 and 2009. The most damaging extreme events are floods and droughts, followed by wind storms and heat waves.
- 2008 was warmer than normal overall, but with many extremes of warm and cold conditions. Rainfall was higher than normal overall in many regions, but significant drought conditions occurred at the start of the year, and again towards the end of the year. Summer 2007/08 was the driest in a century in parts of the Waikato region.
- 2009 was somewhat cooler than normal over the country as a whole, a combination of heat waves in some months and record cold in others. August was the warmest on record, for the country as a whole. Rainfall was near normal or somewhat below normal over much of the country, with relatively few places receiving above normal rainfall. Despite this, the winter was exceptionally snowy, and there were a number of significant flood events around the country.
- For most of 2008, and in early 2009, La Niña conditions prevailed in the tropical Pacific, with a transition to El Niño later in 2009. Consistent with this, the Southern Annular Mode was mostly positive in 2008 and early 2009, but trended negative later in 2009.
- Beyond the large year-to-year variations in our climate, there has been a significant long-term warming trend over the country. The best-fit linear trend to the New Zealand 'seven-station' temperature series (which includes adjustments to correct for site changes) is a warming of 1.1℃ from 1900 to 2009, with a 95% confidence interval of ±0.3℃.
- There has also been a trend towards fewer cold nights around the country, but little trend in the number of hot days. Overall, South Island glaciers continued to lose mass in the 2007/08 and 2008/09 snow years. There is a trend towards wet western regions becoming wetter and dry eastern regions becoming drier, consistent with an increase in westerly winds over New Zealand since 1950.
- NIWA research is on-going into the causes and impacts of climate variability and change in New Zealand, the composition, chemistry, and radiative properties of the atmosphere (including greenhouse gas monitoring), modelling future climates and assessing changing climate-related risks.

1. Introduction

This report describes month-to-month and seasonal-scale variability in New Zealand climate over the two years 2008 and 2009. It is the first in a series of documents to be published every two to three years describing recent climate fluctuations in New Zealand, and how they relate to what's going on at broader scales in the climate system, across the Southern Hemisphere and the Globe.

1.1 Context – New Zealand in the global setting

New Zealand lies in the middle latitudes of the Southern Hemisphere (34°S to 47°S) and is open to influences originating from the Tropics to the sub-Antarctic. The climate is affected all year round by the mid-latitude westerly winds and by the sub-tropical high pressure belt. Both of these features move north and south with the march of the seasons. The westerlies are farthest north in winter and spring and the influence of the sub-tropical high is strongest in summer and autumn. The windiest season of the year is spring, as the subtropical high begins to migrate southwards and the surface pressure gradient across New Zealand strengthens. The country's day-to-day weather is influenced by the passage of fronts and depressions in the westerlies, which cross New Zealand longitudes every 4–5 days at all times of year (Maunder 1971, Sturman and Tapper 2006, Te Ara Encyclopedia of New Zealand 2010[1]).

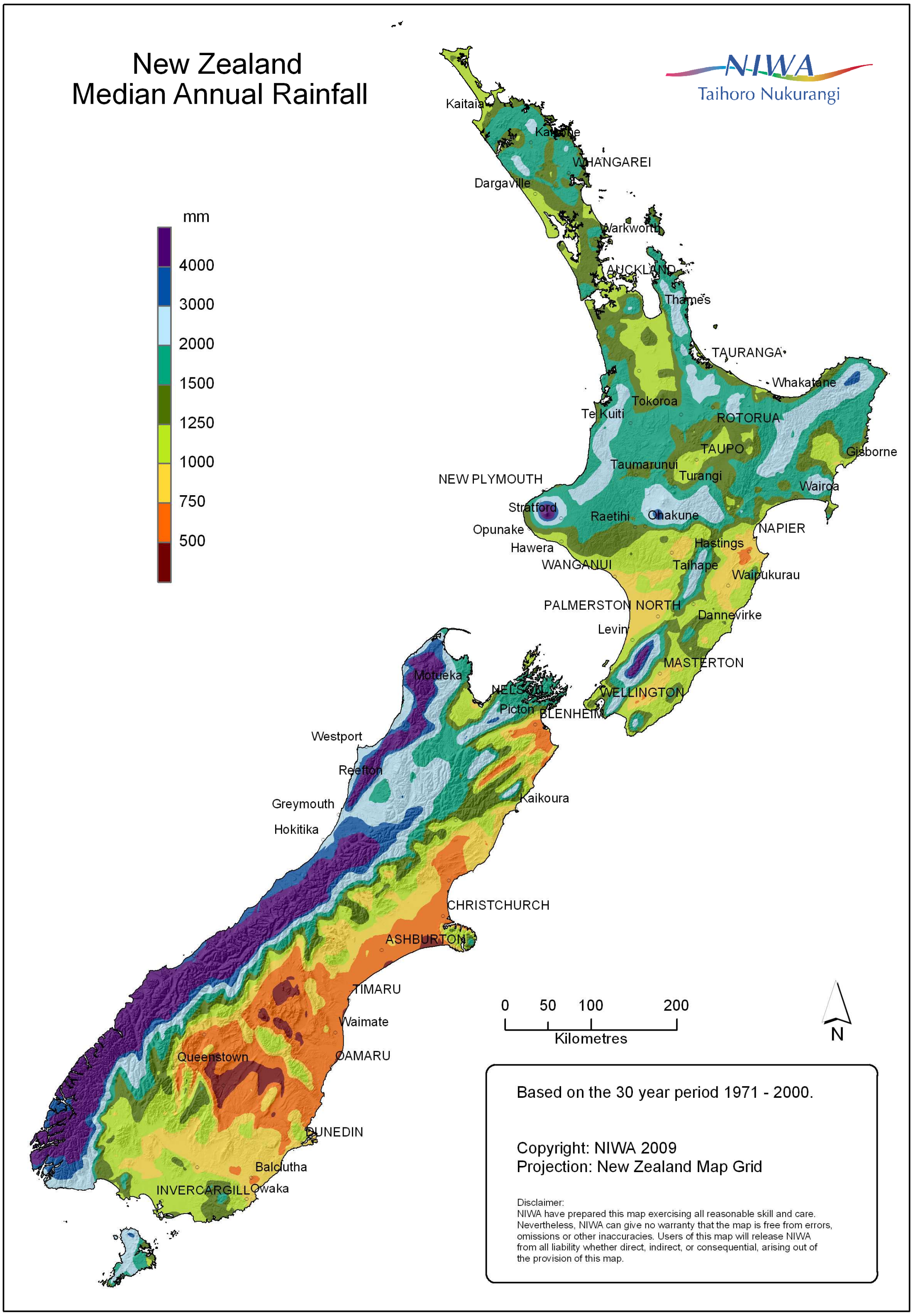
The main New Zealand mountains, particularly the Southern Alps, are aligned almost at right angles to the prevailing westerly wind flow and are a major barrier to the flow. Much of the rich regional detail in New Zealand climate comes from interactions between the large-scale atmospheric circulation and the rugged orography of the country, as illustrated in Figure 1. The most notable effect is the west-east gradient in rainfall, ranging from 3–4 m per year in Westland to 12 m or more in the Alps, but less than 500–700 mm in Otago and Canterbury (Wratt et al. 1996).

Year-to-year variability in New Zealand climate can be well understood in terms of changes in the wind circulation (Figure 2). Fluctuations in the average strength of the westerly flow over the country, and in the average component of north/south flow, determine to a large extent the seasonal or annual departures from normal in rainfall and temperature in most parts of the country. For example, warmer than normal[2] years tend to be associated with winds from the northerly quarter occurring more frequently than normal. Years where rainfalls in eastern regions are higher than normal tend to be associated with weaker than normal westerly winds, or a more frequent occurrence of winds from the east or south.

New Zealand climate is influenced by a number of components of the large-scale climate system, primarily through their influence on the wind circulation. The most notable are the El Niño-Southern Oscillation (ENSO) cycle (Gordon 1986, Mullan 1996), the Interdecadal Pacific Oscillation (IPO, Salinger et al. 2001), and the Southern Annular Mode (SAM, Kidston et al. 2009).

[1] http://www.teara.govt.nz/en/natural-environment/3

[2] Normal is defined as the average over a standard 30-year period. The standard period used by NIWA is presently 1971–2000.


New Zealand
Median Annual Rainfall
NIWA
Taihoro Nukurangi
mm
4000
3000
2000
1500
1250
1000
750
500
Kaitaia
Kaikohe
WHANGAREI
Dargaville
Warkworth
AUCKLAND
Thames
TAURANGA
Whakatane
Tokoroa
Te Kuiti
ROTORUA
TAUPO
Gisborne
Taumarunui
Turangi
NEW PLYMOUTH
Wairoa
Stratford
Raetihi
Ohakune
Opunake
NAPIER
Hawera
Hastings
WANGANUI
Taihape
Waipukurau
PALMERSTON NORTH
Dannevirke
Levin
MASTERTON
Motueka
NELSON
WELLINGTON
Picton
BLENHEIM
Westport
Reefton
Kaikoura
Greymouth
Hokitika
CHRISTCHURCH
ASHBURTON
TIMARU
0 50 100 200
Kilometres
N
Waimate
Queenstown
OAMARU
DUNEDIN
Balclutha
INVERCARGILL
Owaka
Based on the 30 year period 1971 - 2000.
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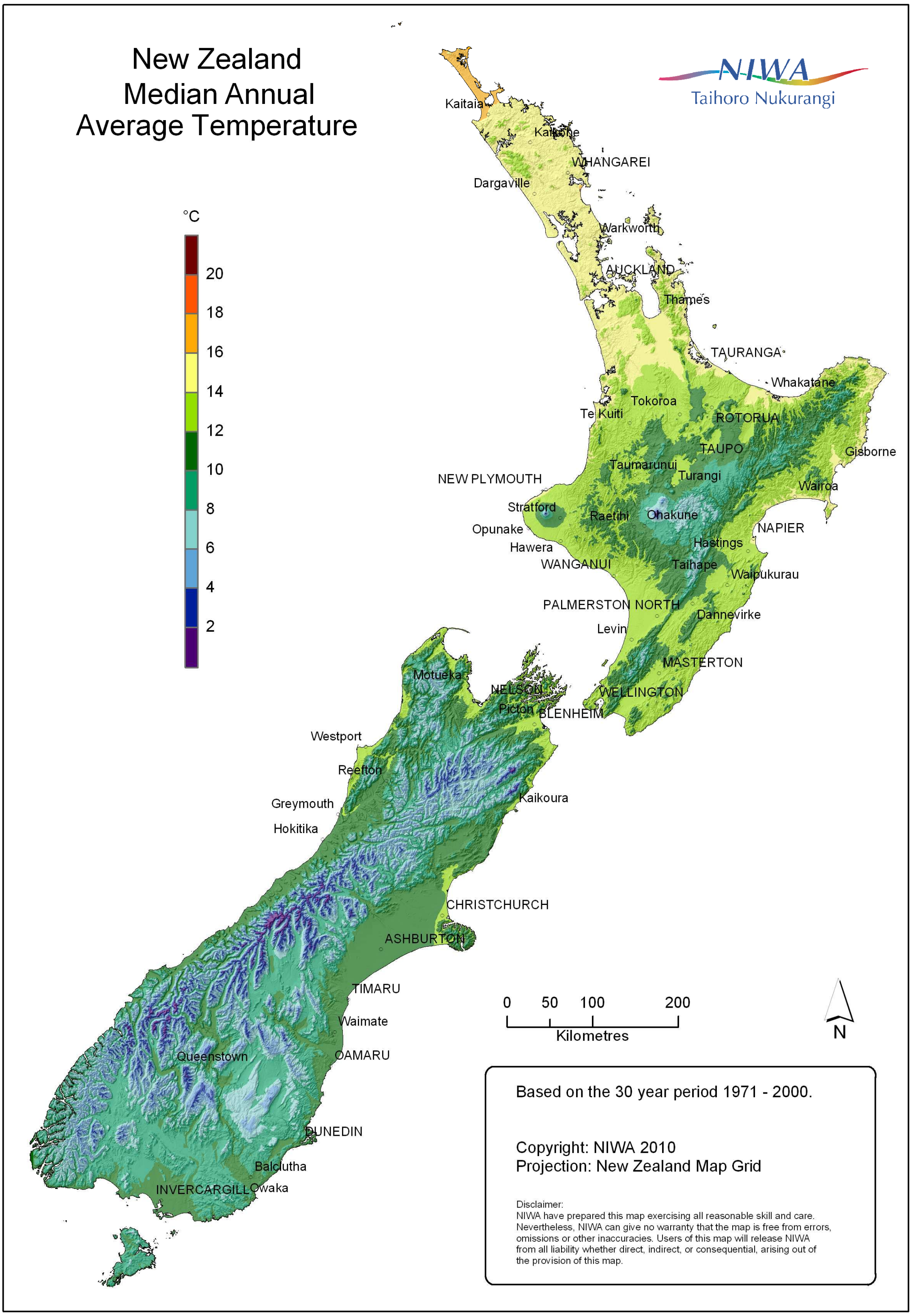

Figure 1: New Zealand median annual rainfall and average temperature, based on the period 1971–2000.

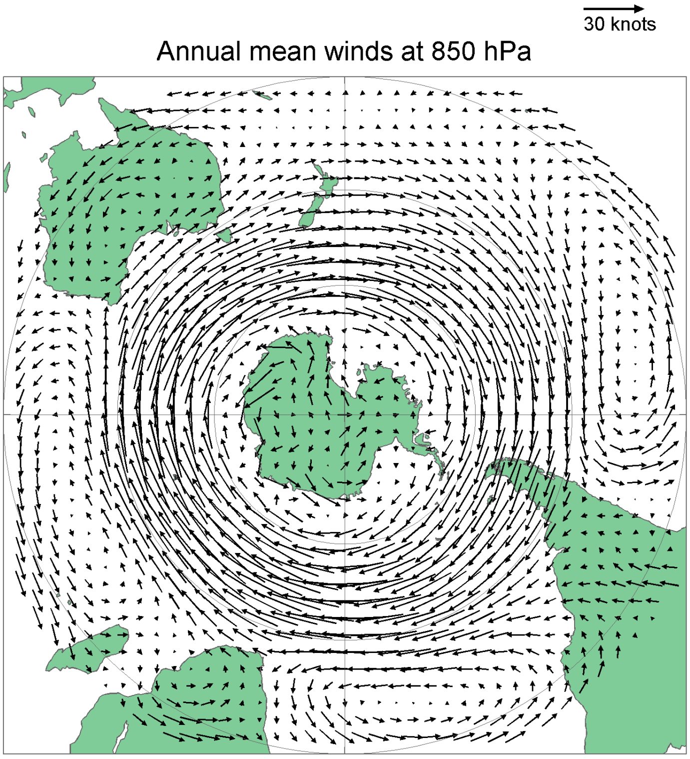

Figure 2: Average 850hPa winds over the Southern Hemisphere.

The length of the arrow indicates speed and the orientation indicates direction. The 850hPa level (the height at which the air pressure is 850hPa) is around 1.5 km above mean sea-level.

1.2 Sources & data

The climate data used in this report come largely from the National Climate Database maintained by NIWA, freely accessible at cliflo.niwa.co.nz. A number of useful products are derived from the basic observations held in the National Climate Database (see, for example, climate-explorer.niwa.co.nz). Notably, available station data are processed into a national gridded data set, known as the 'Virtual Climate Station Network' (VCSN). All available observations are interpolated onto a nationwide regular 5×5 km grid, taking account of site elevation, distance from the coast, etc. (e.g., Tait et al. 2006). The VCSN data set gives a geographically complete picture of climate variability over the country, and is useful for assessing regional patterns of climate variability and change (e.g., Clark and Sturman 2009).

A number of location-specific extreme statistics are described in the text below. The ranking of extreme values is calculated in terms of station observations available in real time, and may in some instances (as noted) be based on sets of observations from more than one observing site for a given location. Hence, the location-specific rankings (e.g., highest 1-day rainfall in Wellington) must be taken as provisional, as they are not based upon fully-homogenised long-term observational time series. In contrast, national average temperature statistics are based upon a homogenised long-term record, as described in Section 5. The tables in the Appendices make specific note (where appropriate) of which sites have been used for a given location.

Hemispheric- and global-scale information is taken from a number of centres internationally. Atmospheric circulation patterns are derived from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalyses (e.g., www.cdc.noaa.gov/index.html). Sea surface temperature information is taken from the US National Oceanographic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ERSL, www.esrl.noaa.gov/psd/data/). The state of the El Niño-Southern Oscillation (ENSO) cycle may be assessed through observations of the tropical Pacific ocean (www.pmel.noaa.gov/tao/jsdisplay/) and by the Southern Oscillation Index (SOI, e.g., www.longpaddock.qld.gov.au/SeasonalClimateOutlook/SouthernOscillationIndex/30DaySOIValues/).

For provision of the ozone information used in Section 9, we thank Dr Greg Bodeker of Bodeker Scientific, working under contract to NIWA. The ozone data are freely available at www.bodekerscientific.com/data/ozone.

1.3 Description of material

The sections that follow cover observed fluctuations and extremes in New Zealand surface climate, particularly rainfall and temperature, during 2008 and 2009. Detailed monthly, seasonal and annual statistical summaries of the climate for this period can be found at www.niwa.co.nz/our-science/climate/publications/all/cs. Observed variability is put in the context of regional-scale variations in weather patterns, and into the context of hemispheric- and global-scale variations in climate.

The report begins with a description of the large-scale climate patterns, their influence on New Zealand climate, and their recent variations. It then discusses rainfall patterns and drought occurrence, followed by temperature variations and frost occurrence. There is a section on extremes and significant weather events over the past two years, and a discussion of the state of snow and ice storage in the Southern Alps. The report ends with a summary of climate-related research being carried out at NIWA. There are a series of Appendices that illustrate observed climate through 2008 and 2009.

2. Global scale influences

The largest signal in the climate system on seasonal time scales is the changing of the seasons themselves, driven by the changing latitudinal distribution of solar heating as the Earth sweeps out its annual orbit around the Sun. After that, there are a number of modes of natural variability of the climate that involve exchanges of energy between different locations or different components of the system (atmosphere and ocean, for example). These features are not driven by external influences such as solar heating changes, but are intrinsic to the climate system itself. The three main modes of natural climate variability that are relevant to New Zealand are discussed below.

2.1 ENSO

After the regular seasonal change, the most import global effect is the El Niño-Southern Oscillation (ENSO) cycle (Philander 1990, www.niwa.co.nz/our-science/climate/information-and-resources/clivar/elnino). ENSO is an interplay between the Trade Winds and the surface ocean across the tropical Pacific. Normally, the Trade Winds blow from east to west, maintaining the warmest water in the western Pacific and cooler water in the east. Conversely, the sea temperature difference drives the Trade Winds by helping to maintain sinking air motion and high air pressures over the eastern Pacific, and rising motion and low air pressures over the western Pacific. An El Niño is a breakdown of this pattern, where the Trade Winds slacken and the sea surface temperature difference decreases, through a warming of the surface waters in the eastern Pacific. Opposite to El Niño is La Niña, an intensification of the normal pattern, where the Trade Winds become stronger, and the east-west sea surface temperature difference increases.

A standard measure of ENSO is the Southern Oscillation Index (SOI), which measures the difference in mean sea-level pressure between Tahiti (eastern Pacific) and Darwin (western Pacific). The SOI thus measures the strength of the Trade Winds: stronger than normal Trades are associated with a positive SOI (La Niña) and weaker than normal Trades are associated with a negative SOI (El Niño). ENSO is also measured in terms of related changes in the tropical climate, such as eastern Equatorial Pacific sea-surface temperatures[3], and changes in tropical Pacific rainfall[4].

When the eastern Pacific Ocean warms in an El Niño, the effect is to warm the whole tropical atmosphere, which affects global atmospheric circulation and the north-south temperature gradient in mid-latitudes. Over New Zealand, the result is a tendency for increased westerly and southwesterly winds (Figure 3). Hence, New Zealand typically experiences somewhat cooler than normal seasons in an El Niño, while rainfall is typically above normal in the south and west but below normal in the north and east.

In a La Niña, the westerlies over New Zealand tend to decrease, and the winds tend to come more often from the north, so we typically experience warmer than normal

[3] http://www.pmel.noaa.gov/tao/jsdisplay/
[4] http://trmm.gsfc.nasa.gov/

seasons, with above normal rainfall in northern and north-facing regions and below normal rain in southern and southwestern areas.

The ENSO cycle usually begins in late autumn or over the winter. Once in place, an event normally lasts through to the following autumn, with a peak in intensity over the summer months. In any given year, El Niño or La Niña conditions are about equally likely, each occurring about 25% of the time overall. During the other 50% of years, the tropical Pacific is in ‘neutral conditions’, neither El Niño nor la Niña. While the evolution of an ENSO event is quite predictable once one is under way, the triggers for an event often appear to be random fluctuations in the Trade Winds or in the upper ocean, and are intrinsically unpredictable far in advance.

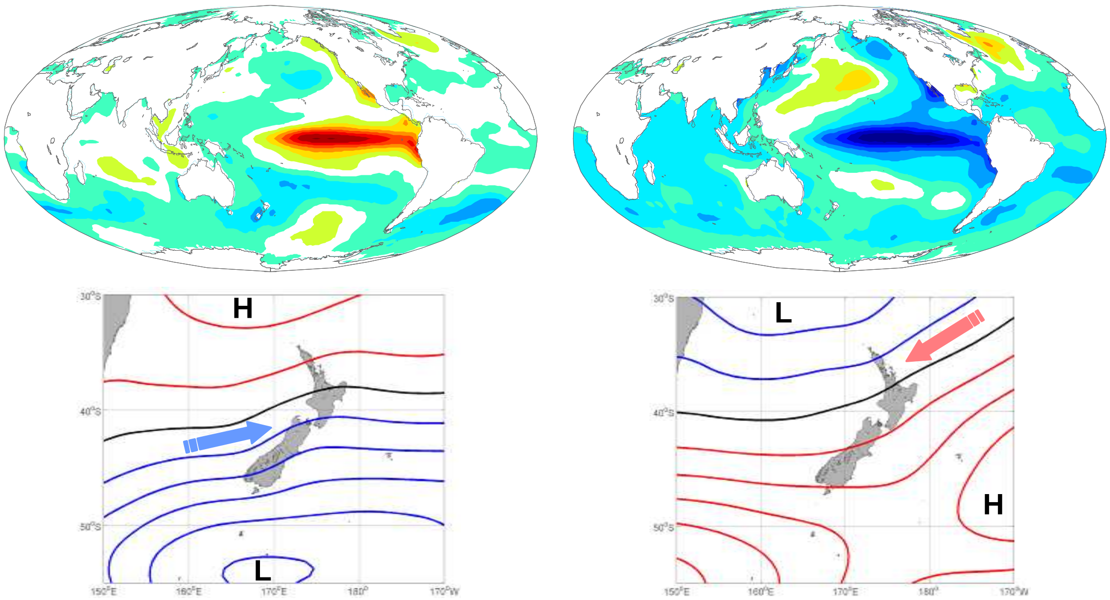

Figure 3: Typical patterns associated with El Niño and La Niña.

Typical patterns associated with El Niño (left) and La Niña (right). Sea surface temperature differences from normal (top row), and mean sea-level pressure differences from normal (bottom row). In the top panels, warm colours indicate temperatures higher than normal and cool colours indicate temperatures lower than normal. In the bottom panels, blue contours indicate pressures below normal and red indicate pressures above normal. The coloured arrows indicate the changes from normal in wind circulation: relatively more wind from the southwest during El Niño and from the northeast during La Niña.

2.2 IPO

The Interdecadal Pacific Oscillation (IPO) is the name given to a 20–30 year modulation in the behaviour of the ENSO cycle (Mantua et al. 1997, Power et al 1999, Salinger et al. 2001). The strength and sign of the IPO is illustrated in Figure 4, based on slowly-varying sea-surface temperature patterns across the Pacific Basin. During the ‘positive’ phase of the IPO (such as 1978–99), there is a tendency for stronger and more frequent El Niño events, with somewhat increased westerly winds on average over New Zealand, somewhat more rainfall than normal (10–15% above what is typical in the negative IPO phase) in western and southern regions, and cooler-than-normal conditions over much of the country. During the negative phase (such as 1947–1977, 2000–present), there is a tendency for weaker and less frequent El Niño events, with somewhat reduced westerly winds over New Zealand, increased rainfall in the north and east of the country and reduced rainfall in the southwest, and warmer than normal conditions over much of the country.

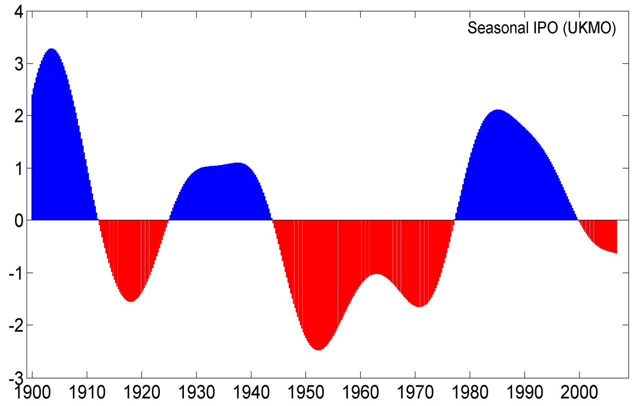

Figure 4: Time series for the IPO index, based on SST data from the UK Met Office.

The IPO has recently (around 1999–2000) gone into a negative phase, associated with fewer and/or weaker El Niño events than normal. Going by past negative IPO periods, over the next 20-30 years New Zealand may experience somewhat weaker westerly winds and less mean rainfall in western and southern areas than would otherwise be the case, and more rainfall than would otherwise be the case in eastern and northern areas (there is of the order of 10% change between positive and negative phases of the IPO). This is acting in the opposite sense to changes in the westerlies and rainfall projected as a result of climate change from human-induced greenhouse gas emissions[5].

2.3 SAM

The Southern Annular Mode (SAM) is a fluctuation in the westerly wind circulation over the middle and high latitudes of the Southern Hemisphere (Kidson 1988, Thompson and Wallace 2000, Kidston et al. 2009). On time scales of a few weeks, the circulation can switch between stronger than normal westerlies over the southern oceans (the 'positive' phase of the SAM, with higher than normal mean sea-level pressures over New Zealand) and weaker than normal westerlies over the southern oceans (the 'negative' phase of the SAM, with lower than normal mean sea-level pressures over New Zealand). The switch usually happens in the space of a day or two, and is triggered by storms affecting the location of the jet stream over the southern oceans. Figure 5 shows the typical pattern of mean sea-level pressure differences from normal during the positive SAM.

[5] http://www.mfe.govt.nz/issues/climate/about/impacts.html

The positive SAM is usually associated with higher than normal pressures over New Zealand, and relatively settled and often dry conditions. The negative SAM is usually associated with lower than normal pressures over New Zealand, and a tendency for storms to track across the New Zealand region, accompanied by unsettled and often wet conditions in parts of the country.

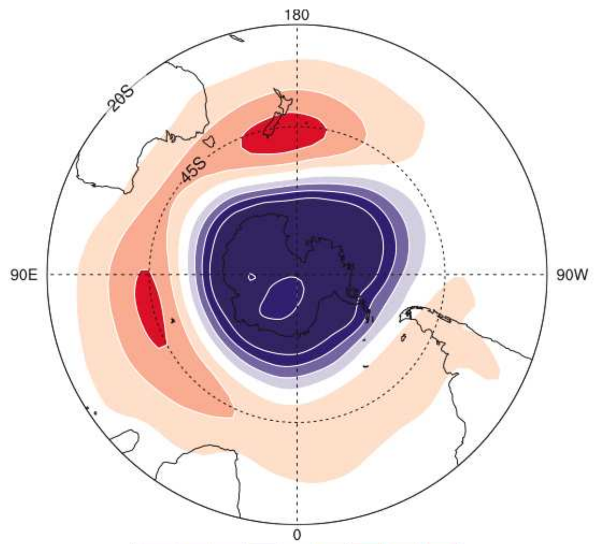

Figure 5: The spatial pattern of the Southern Annular Mode (SAM).

The spatial pattern of the Southern Annular Mode (SAM), shown in its positive phase with higher than normal pressures (red colours) over mid-latitudes and lower than normal pressures (blue colours) over high latitudes. During the positive SAM, westerly winds over the southern oceans (between the high and low pressure anomalies) are stronger than normal.

2.4 Large-scale climate conditions during 2008 and 2009

The evolution of ENSO from mid-2007 to the end of 2009 is illustrated using the SOI in the bar graph in Figure 6. Early and late months of 2008 experienced La Niña conditions, with close to neutral ENSO conditions mid-year. 2009 saw a progression from La Niña conditions through to a moderate El Niño state by the end of the year. To have two La Niña events in succession, as happened in 2007/08 and 2008/09, is somewhat unusual, occurring once every 15 or 20 years.

In broad terms, the predominance of La Niña conditions in 2008 contributed to the relative warmth of 2008 over New Zealand (average temperature 0.3°C above the 1971-2000 normal, based on a long-running homogenised seven-station data record – see Section 5 and the NIWA web site[6]) and the tendency for slightly higher than normal frequency of northerly winds. In 2009, the development of El Niño conditions in the latter part of the year helped to contribute to the relative coolness of the year as a whole (average temperature 0.2°C below normal, again based on the seven-

[6] http://www.niwa.co.nz/our-science/climate/news/all/nz-temp-record

station record, which includes corrections to account for site changes), and the overall tendency towards winds from the south and southwest.

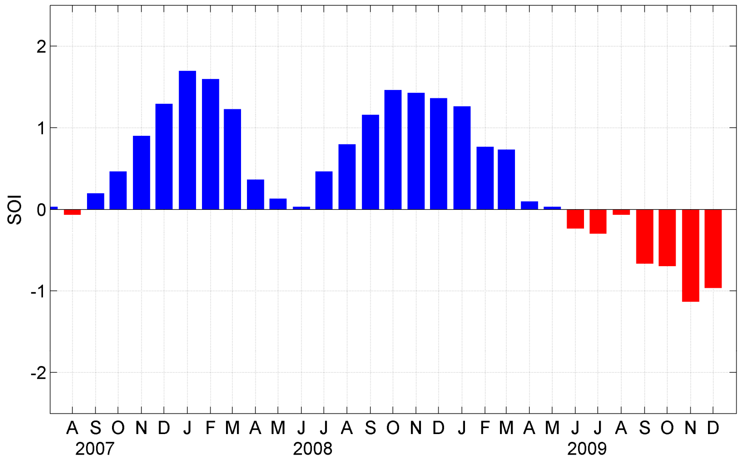

Figure 6: The Southern Oscillation Index (SOI).

The Southern Oscillation Index (SOI) is a measure of the mean sea-level pressure difference between Tahiti (eastern Pacific) and Darwin (western Pacific), from mid-2007 to the end of 2009. Values plotted have been lightly smoothed with a 3-month running mean. Values of +1 or more indicate the presence of La Niña conditions, while values of –1 or below indicate the presence of El Niño conditions.

As noted above, the IPO switched to its negative phase around the year 2000. It is expected that this will be associated over the coming two to three decades with a tendency towards La Niña events, and a relative lack of strong El Niño events.

The Southern Annular Mode (SAM) was predominantly in its positive phase during 2008 and early 2009, but was mostly negative in the latter half of 2009 (Figure 7). Such a progression mirrors to a certain extent the evolution of the SOI and the ENSO cycle, consistent with the known tendency for the positive SAM during La Niña conditions and the negative SAM during El Niño conditions (L'Heureux and Thompson 2006).

The summer of 2007/08, while La Niña conditions were in place in the tropical Pacific, was marked by a particularly strong and positive SAM, with persistent high pressures in the New Zealand region. This contributed to the development of drought conditions in many parts of the North Island and eastern South Island during early 2008 (see section 4).

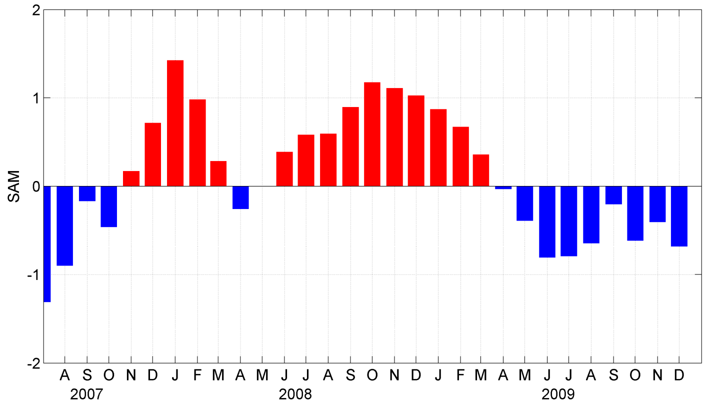

Figure 7: The SAM index from mid-2007 to the end of 2009.

Values plotted have been lightly smoothed with a 3-month running mean. The index is calculated as the amplitude of the leading pattern of variability in the Southern Hemisphere (south of 20°S) 700hPa height field[7].

[7] Data available at www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/aao/aao.shtml

3. Weather Patterns

The day-to-day weather over New Zealand may be defined in terms of wind and pressure patterns across the country. Twelve ‘weather types’ were defined by Kidson (2000), as illustrated in Figure 8. For any day, the weather (or mean sea-level pressure) pattern may be categorised as one of the 12 types: the one it most closely resembles. Kidson grouped the types into three ‘regimes’: the trough regime (mostly unsettled weather); the zonal regime (mostly westerly flow over New Zealand); and the blocking regime (mostly slow-moving anticyclones over New Zealand). The monthly frequency of occurrence of the types and the regimes are a way to characterise the type of weather experienced around the country.

On average (over the period 1958-2009), the trough and blocking regimes each occur around 37% of the time, with the zonal regime accounting for the other 26% of cases. In any month, the frequency of occurrence of any regime can vary from near zero to over 90% of days.

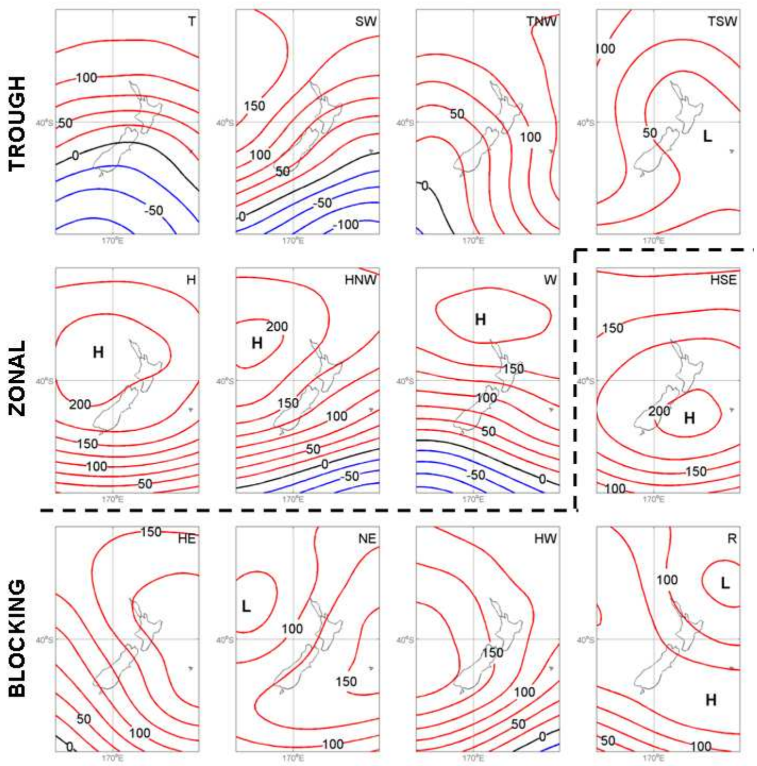

Figure 8: The twelve Kidson weather types.

The twelve Kidson weather types, shown as average patterns of 1000hPa height (analogous to mean sea-level pressure). Names for the types are indicated in top right of each panel, where ‘T’ stands for Trough, ‘SW’ for Southwest, ‘TNW’ for Trough-Northwesterly, ‘TSW’ for Trough-Southwesterly, ‘H’ for High, ‘HNW’ for High to Northwest, ‘W’ for Westerly, ‘HSE’ for High to Southeast, ‘HE’ for High to East, ‘NE’ for Northeasterly, ‘HW’ for High to West, and ‘R’ for Ridge. The three regimes are indicated at left: the top row is the trough regime, the first three in the middle row are the zonal regime, and the rest are the blocking regime. See Kidson (2000) for further details.

The occurrence of each weather type varies with El Niño and La Niña (Jiang et al. 2004; Jiang 2010). During an El Niño, there is usually a higher frequency of the trough and zonal types, such as ‘SW’ and ‘HNW’, and lower occurrence of the ‘NE’ weather type (see caption of Figure 8 for definitions of the types). This has implications for both mean rainfall and flood-producing extreme 1-day rainfall totals in New Zealand.

Extremely large daily rainfalls in the northeast of the North Island are strongly related to occurrence of the ‘NE’ weather type (Griffiths, 2006), with a higher frequency of ‘NE’ weather types equating to larger extreme 1-day rainfall events in this region. Extreme daily rainfall totals in Gisborne and Hawkes Bay are significantly affected by the ‘R’ weather type, with larger 1-day rainfall totals occurring with a higher frequency of this weather type. Extreme 1-day rainfall in the southeast of the South Island is linked to the frequency of the ‘TSW’ weather type – more ‘TSW’ events typically produce more extreme 1-day rainfalls in this region.

The monthly frequency of occurrence of each of the three regimes is shown in Figure 9. The summers of 2007/08 and 2008/09 both show a predominance of blocking types, at the expense of the zonal (westerly) type. Blocking dominated particularly during the summer of 2007/08, when drought conditions developed over much of the North Island (see Section 4). October 2008 was a very zonal month, mostly related to the predominance of type ‘HNW’ associated with high pressures to the northwest of the country. The frequency of occurrence of HNW in October 2008 was around five times the long-term average frequency.

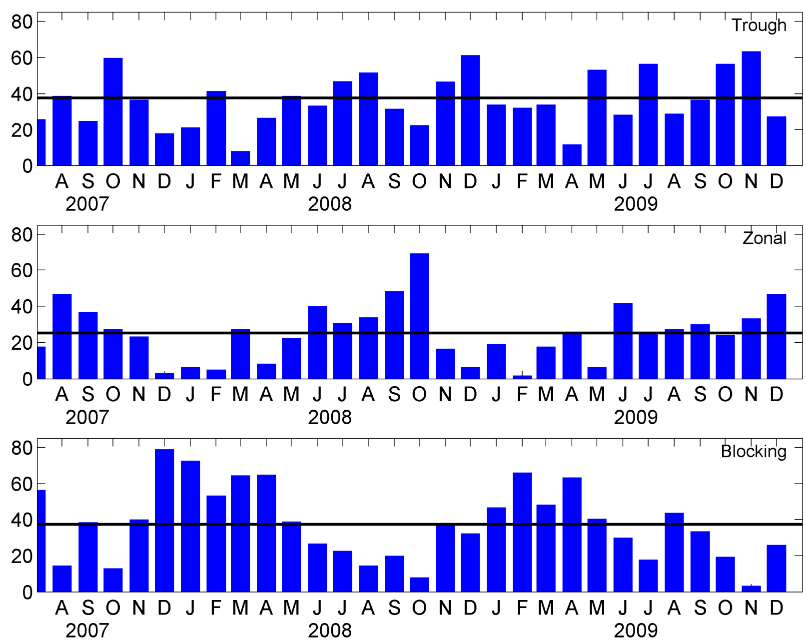

Figure 9: Monthly percent frequency of occurrence of the three Kidson regime types, mid-2007 to end 2009.

Black lines indicate the long-term mean frequency of occurrence of each regime.

4. Rainfall and drought

4.1 Rainfall in 2008

Annual rainfall was normal or above normal in most regions of New Zealand in 2008 (Figure 10). In broad terms, it was a wet year for the north and west of the North Island, Marlborough, the Kaikoura coast, North Canterbury, and parts of Nelson and the Lakes District. Rainfall in Northland, Wellington, Marlborough and North Canterbury was extremely high (about 130 percent of normal), and Wellington and Blenheim recorded the 3rd-wettest and 2nd-wettest year since records began, respectively. In contrast, annual rainfall was between 70 and 90 percent of normal in parts of Gisborne and Hawkes Bay, eastern Otago, and Fiordland. Of the regularly reporting gauges, Cropp River in the Hokitika River catchment recorded the highest rainfall of 2008 (10 940 mm). Alexandra, in Central Otago, was the driest of the sites where NIWA records rainfall, with 376 mm.

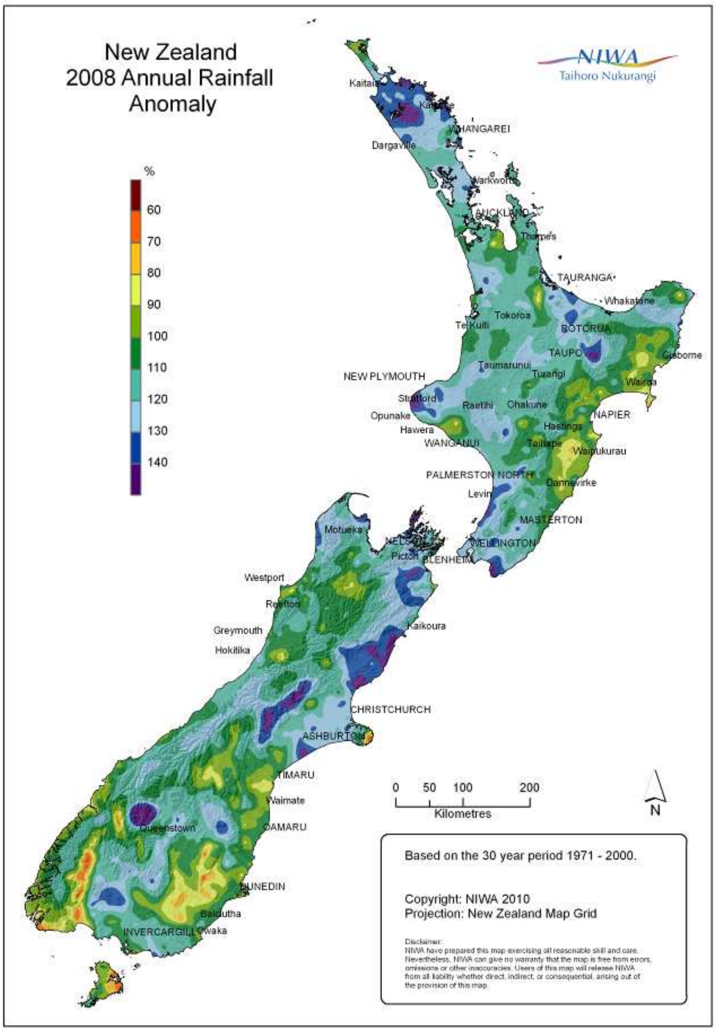

Figure 10: 2008 annual rainfall anomaly (percentage of the 1971–2000 normal).

The early part of 2008 (see Appendices), especially January and February, was marked by dry, anticyclonic conditions over much of the country, especially in the North Island. The Waikato region experienced its driest January in 100 years at some rainfall recording sites. This was brought about by a combination of La Niña and the associated strong positive SAM that lasted through to March 2008. April saw a change to more unsettled conditions, with storms to the north of the country and above normal rainfall over the North Island and northern South Island. There were a number of North Island flood events during April 2008, including one that resulted in the loss of seven lives. May was a month with anomalous south-easterly flow, and above normal rainfall in the eastern North Island but dry conditions over the South Island.

Unsettled conditions continued over the winter of 2008, with wet conditions in many places, notably the eastern South Island where significant flooding occurred. August also saw significant snowfalls on the North Island volcanic plateau, with the deepest snow base reported on Mt Ruapehu since 1992. The final four months of 2008 saw a mix of conditions: wet over the southern half of the South Island in September; and often drier than normal in eastern regions in October through December.

4.2 Rainfall in 2009

Annual rainfall for 2009 had a patchy distribution. It was close to normal in many regions (Figure 11), but well below normal (50 to 80 percent of normal) for parts of Auckland and Northland, the central North Island, and the north and east of the South Island, as well as in parts of Fiordland. Taupo, in the central North Island, recorded its driest year since records began in 1949 (712 mm). Near-record low annual rainfall totals were also observed at Whangarei, and in Central Otago and surrounds. In contrast, it was a very wet year in Gisborne, Manawatu, and parts of Westland, with areas of above average rainfall (more than 120 percent of normal). Of the regularly reporting gauges, Cropp River in the Hokitika River catchment (West Coast) recorded the highest annual rainfall total of 2009, with 10 956 mm. The driest site in New Zealand in 2009 was Ranfurly, Central Otago, with 263 mm of rainfall.

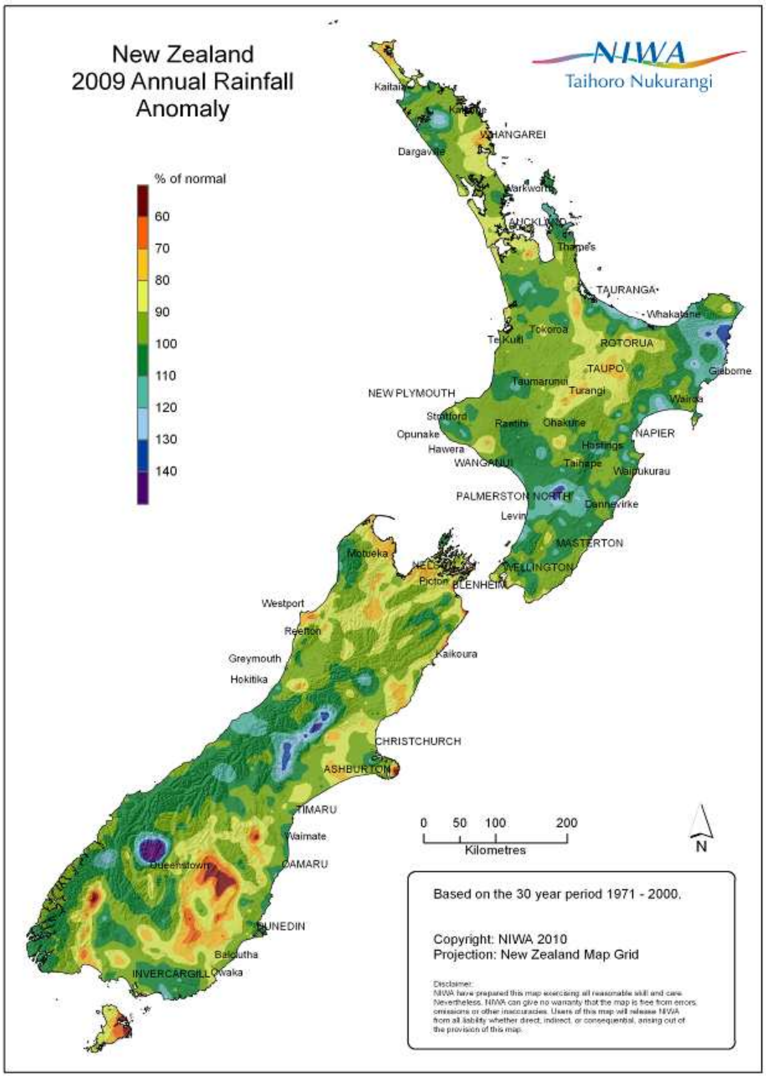

Figure 11: 2009 annual rainfall anomaly (percentage of the 1971–2000 normal).

The first four months of 2009 saw drier than normal conditions in most regions (see Appendices), apart from a very wet spell in the second half of February and a period of extensive rain and flooding in the western South Island in late April. May was unusually wintry, with well above normal rainfall across the eastern South Island. The unsettled pattern continued through June and July, with several heavy snow falls. A state of emergency was declared in Gisborne in late June because of flooding. Another cold spell in October brought heavy snow falls to the central North Island and Hawkes Bay.

The year ended firmly under the influence of El Niño, with drier than normal conditions in many places (particularly in Central Otago and Northland – see next section), apart from the south and west of the South Island and parts of the western North Island, associated with stronger than normal southwesterly winds.

4.3 Drought

Generally speaking, a drought is a rainfall deficit that restricts or prevents a human activity. Extended dry periods are typically experienced somewhere in New Zealand in most years, and because there is no absolute definition of drought, dry periods are often described as 'drought-like'. The impact of low rainfall is often most keenly felt by the agricultural community, hence it is generally left to the Ministry of Agriculture and Forestry and/or local authorities to declare dry periods as droughts. This comes from consideration of not just the contributing climate factors, but also the social and economic (including production) impacts, and often the contributing historical conditions such as residual damage from previous seasons. Any meaningful assessment of drought must take vulnerability into account.

Low rainfall is clearly also a significant factor in the management of other major activities such as hydroelectric water storage, and in natural systems such as river and stream ecologies. However in this section, the focus is on agricultural drought.

4.3.1 Soil moisture deficit as an index of drought

Maps of soil moisture deficit for 2008 and 2009 are included in Appendix 2. The availability of soil moisture in the pasture root zone varies with season: moisture levels are typically lower in summer when evaporation rates are high and there is generally less rain; while in winter evaporation rates are low. The maps introduce the important concept that it is not just the absolute availability of water that is important in defining drought (biological systems 'expect' dry and wet seasons), but it is also the duration and severity of the periods when there is less moisture than average for a season. Departure from the estimated long-term average (from 1972) availability of water to plants in the pasture root zone, on the last day of each calendar month, is shown in the appended maps. The maps highlight areas of unusual dryness that were further examined, in the section below, against historical records to determine their likelihood of occurrence.

4.3.2 Deficit statistics

Modelled soil moisture deficit data from 1972 to 2009 were analysed to estimate the relative likelihood of dry periods during the past two years (2008 and 2009), in the context of the 1972–2009 period.

Parts of Waikato, Bay of Plenty and King Country were affected by severe drought in the first three months of 2008. At one sample location in Waikato, 69 days of soil moisture deficit of 130 mm or more were estimated, the highest number since 1972. Relatively dry conditions in November and December 2008, and a dry start to 2009, heralded fears of a further serious drought until wet conditions in February restored soil moisture levels. Late in 2009, dry conditions developed in Northland and Bay of Plenty, and in parts of the South Island.

Data for the Waikato drought, and other examples, are shown in Table 1 below.

Table 1: Extreme soil moisture deficit statistics for 2008 and 2009.

Location of sample site	Dry period	Total days of deficit over 3 months	At modelled deficit level of:	Rank in period 1972–2009
Waikato	Jan to Mar 2008	69	130 mm	First
South Canterbury	Apr to Jun 2008	91	75 mm	First
Central Hawke's Bay	Nov 2008 to Jan 2009	84	110 mm	First
Dunedin	Nov 2008 to Jan 2009	92	75 mm	First equal
Central Otago	Oct to Dec 2009	59	110 mm	First equal
Far North District	Oct to Dec 2009	13	130 mm	First

5. Temperature & frosts

New Zealand temperatures often vary in concert across the country, associated with a tendency for either northerly (warmer in most places) or southerly (cooler in most places) wind flows. Exceptions occur due to the influence of topography, where eastern regions can be warmed by downslope föhn winds while western regions remain cool. Conversely, in strong easterly wind situations, western regions may be warmed by the same process while eastern regions remain cool.

Annual mean temperatures for 2008 and 2009 were 12.9℃ and 12.4℃, respectively, or +0.4℃ and –0.2℃ from the 1971-2000 normal, res pectively[8]. The values quoted are based on the NIWA seven-station temperature series, which draws on records from New Zealand's best long-term stations with data going back into the 19th Century, and which includes corrections to account for site changes. Information on the temperature series, and the data themselves, may be obtained from the NIWA web site[9]. The progression of New Zealand temperature departures from normal is illustrated in Figure 12 (annual and decadal mean values from 1910–2009) and Figure 13 (annual mean values for the full record from 1853).

There has been a significant long-term warming trend over the country. The best-fit linear trend to the New Zealand seven-station temperature series (which includes adjustments to correct for site changes) is a warming of 1.1℃ from 1900 to 2009, with a 95% confidence interval of ±0.3℃. Temperatu res also vary considerably from year to year (often by between 0.5℃ and 1℃).

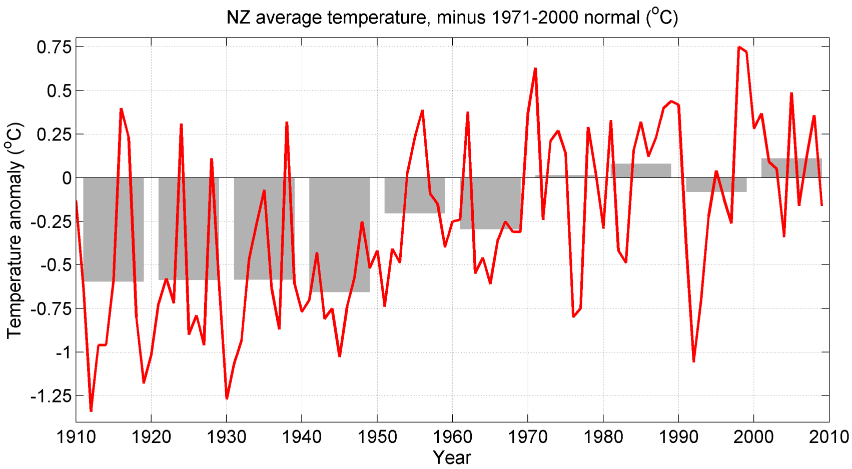

Figure 12: Mean annual and decadal mean NZ temperature differences, 1971-2001.

Mean annual (red line) and decadal mean (10 year mean, starting 1910, 1920, …, 2000; gray bars) New Zealand temperature differences from the 1971-2000 normal, based on the NIWA seven-station series, which includes corrections to account for site changes[9]. The period of data shown is 1910–2009 inclusive.

[8] The apparent inconsistency here results from rounding to 1 decimal place. To 2 decimal places, the 2008 and 2009 annual temperatures from NIWA's seven-station series were 12.94 and 12.42℃ (2009 0.52℃ cooler than 2008), corresponding to departur es of 0.36℃ and -0.16℃ from the 1971-2000 normal, respectively.

[9] http://www.niwa.co.nz/our-science/climate/news/all/nz-temp-record

5.1 Temperature in 2008

In 2008, New Zealand experienced five warm months with above average temperatures for the country as a whole and only one with below average temperatures (see Appendices). Annual temperatures were between 0.5 and 1.0°C above average in the north and west of the North Island, and up to 0.5 °C above average in most other regions (Figure 14). The exceptions were parts of the eastern Bay of Plenty, Gisborne and Hawkes Bay, around Westport and on the Kaikoura coast, where temperatures were between 0.5 and 1.5°C below average. The warmest location in 2008 was Leigh, with a mean temperature for the year of 16.5°C (0.3 °C above normal). Hawera and Cromwell recorded their 2nd warmest years on record (based on averaging the mean daily temperature). The highest recorded temperature of 2008 was 34.8°C, observed in South Canterbury, at both Timaru (on 2 occasions: 12 January, 19 March) and Waione (22 January). The lowest recorded temperature of 2008 was -9.5°C, observed at Mt. Cook on 20 August.

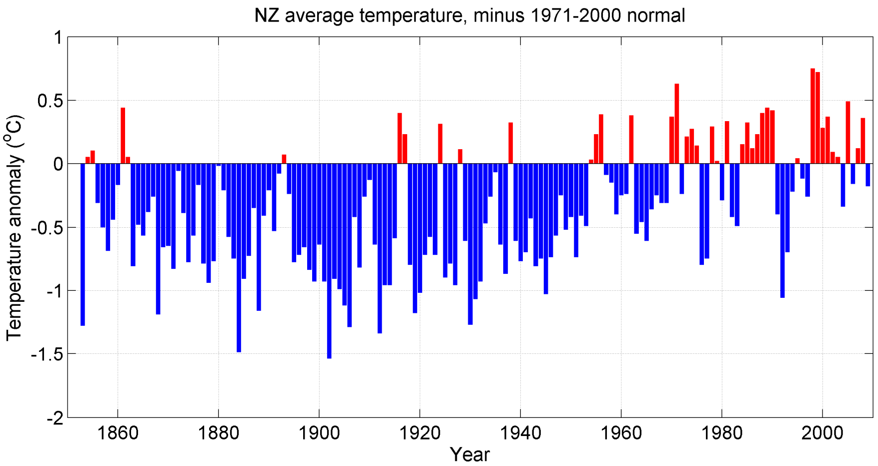

Figure 13: Mean annual temperature over New Zealand, from 1853 to 2009 inclusive.

Mean annual temperature over New Zealand, from 1853 to 2009 inclusive, based on the NIWA seven-station series (as in Figure 12), which is made up of long-term station records from between 2 (from 1853) and 7 (from 1908 onwards) locations. The seven-station series includes corrections to account for site changes. The blue and red bars show annual differences from the 1971–2000 normal.

January 2008 was very warm in most places, as a result of the strongly anticyclonic (settled and sunny) conditions. Temperatures continued often higher than normal through April, especially in western and northern regions. May 2008 was cold and frosty, the coldest May since 1992, based on the seven-station temperature series. Cold air was brought over the country by a series of very cold south-easterly wind flows. June and July returned to milder conditions (relative to normal), with June being much warmer than normal in the inland South Island. However, both months experienced several wintry cold snaps, with frosts in Auckland in early July. The rest of 2008 was a rather mixed bag, with near-normal temperatures in many places, but November was relatively warm in several regions. Whanganui had its highest recorded minimum temperature (19.2°C, records began in 1972), while a cold blast early in November brought wintry conditions to the Tour of Southland bicycle race and late frosts to crops.

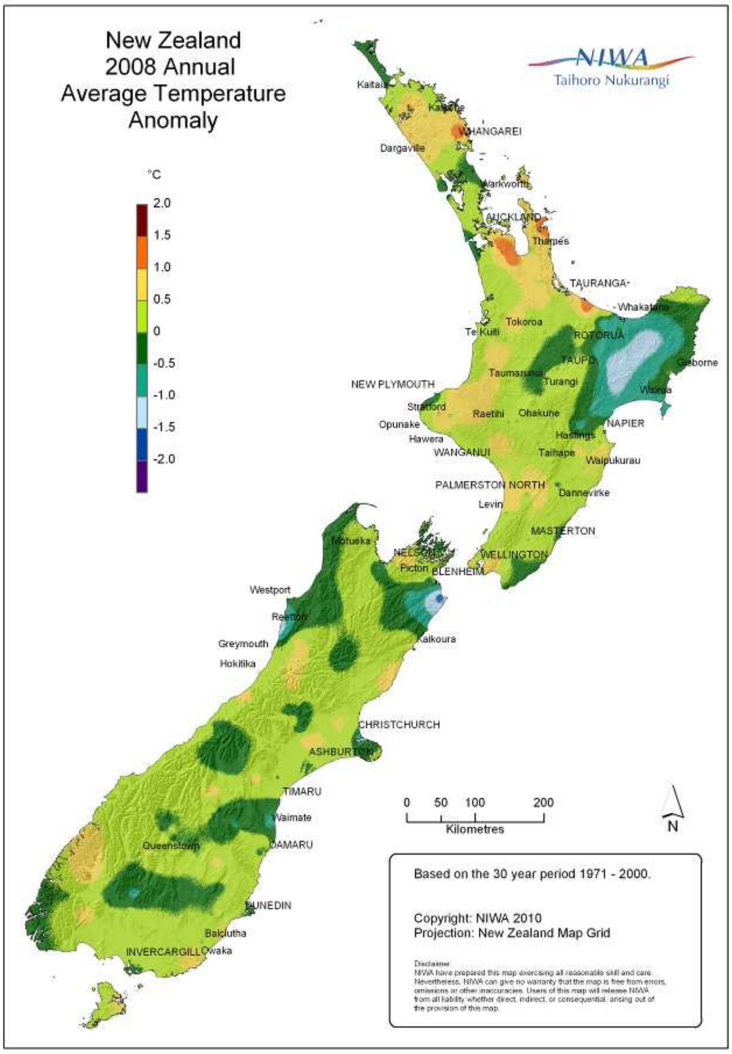

Figure 14: 2008 annual average temperature anomaly (difference from the 1971-2000 normal).

5.2 Temperature in 2009

The New Zealand national average temperature[10] for 2009 was 12.4℃, 0.2℃ below the 1971–2000 normal, consistent with the southwest circulation anomaly over the country during the year. However, the decade 2000–2009 was one of the warmest in the instrumental record for New Zealand (Figure 12), with a 10-year average temperature of 12.7℃.

Annual temperatures in 2009 were near average (within 0.5℃ of the long-term average) for most of New Zealand (Figure 15). The exceptions were parts of Auckland, Waikato, Manawatu, Hawkes Bay, Wairarapa, Wellington, Marlborough, inland Canterbury, and Otago, where annual temperatures were between 0.5 and 1.0℃ below average. In contrast, in the northeast of the country (Northland,

[10] http://www.niwa.co.nz/our-science/climate/news/all/nz-temp-record

Coromandel and the western Bay of Plenty) annual temperatures were between 0.5 between 1.2℃ above average. The highest annual mean temperature for 2009 was 15.8℃, recorded at Whangarei (Northland). The highest recorded temperature in 2009 was 38.0℃, observed at Culverden (Canterbury) on 8 February. It was the highest February maximum temperature ever recorded at this location. The lowest recorded temperature in 2009 was –11.7℃, measured at Middlemarch, Central Otago, on 19 July.

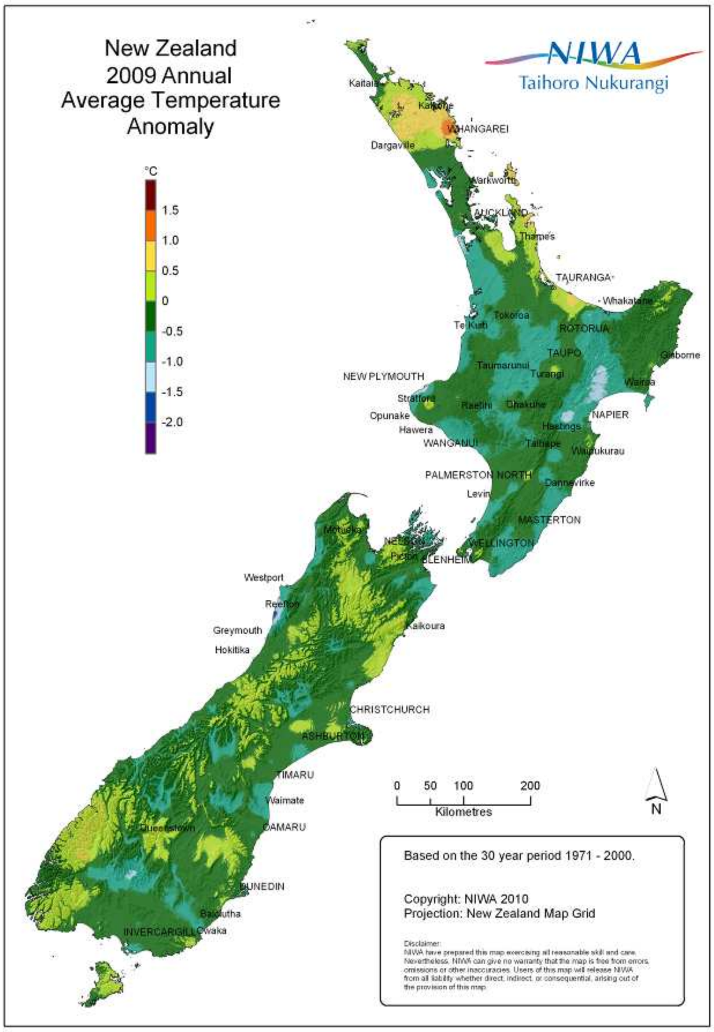

Figure 15: 2009 annual average temperature anomaly (difference from the 1971–2000 normal).

The year 2009 saw record swings in temperature, recording both coldest- and warmest-ever months for the time of year (see Appendices). January 2009, like the start of 2008, was very warm in eastern regions, especially in the South Island as a result of much stronger than normal northwest winds. The warmth continued into February, but lasted only until mid-month, leading into a series of mostly cooler than average months that lasted through to July. May 2009 was particularly cold, the coldest May on record at many places. This was brought about by a predominance of cold southerlies over the country associated with slow-moving storms to the east of

New Zealand (during a period of negative SAM). There was a major shift at the end of July, with August 2009 being the warmest on record for New Zealand (seven-station temperature series). The sudden warmth triggered many avalanches in alpine regions, as the winter to that point had been particularly snowy. However, October repeated the pattern of May, with strong southerlies and low temperatures. November and December continued somewhat cool, with the country under the influence of El Niño-induced southwest wind flows.

5.3 Frosts

Unseasonal frosts are a major natural hazard for New Zealand's agriculture, particularly its horticulture industries. The pattern of frost occurrence influences where particular crops can or can't be grown, while efforts to mitigate frosts such as using helicopters and wind turbines come at some expense to producers. The number of air frost days (days when air temperature falls below 0°C, measured at 1.3 m above ground level) in 2008 and 2009 is mapped in Figure 16. The effects of cold conditions upon crops are complex, and damage to crops can be sustained even when air temperatures are above freezing.

The maps in Figure 16 highlight that in 2009 the country experienced more frost days than in 2008, consistent with average temperatures being around 0.5°C cooler overall in 2009 compared to 2008. For example Southland, the Canterbury Plains and the Wairarapa experienced over 20 frost days in the growing season in 2009, with zero frost days in 2008. The majority of the Southern Alps experienced 200 or more frost days for the year in 2009, while the area of the Alps with over 200 frost days was much smaller in the previous year.

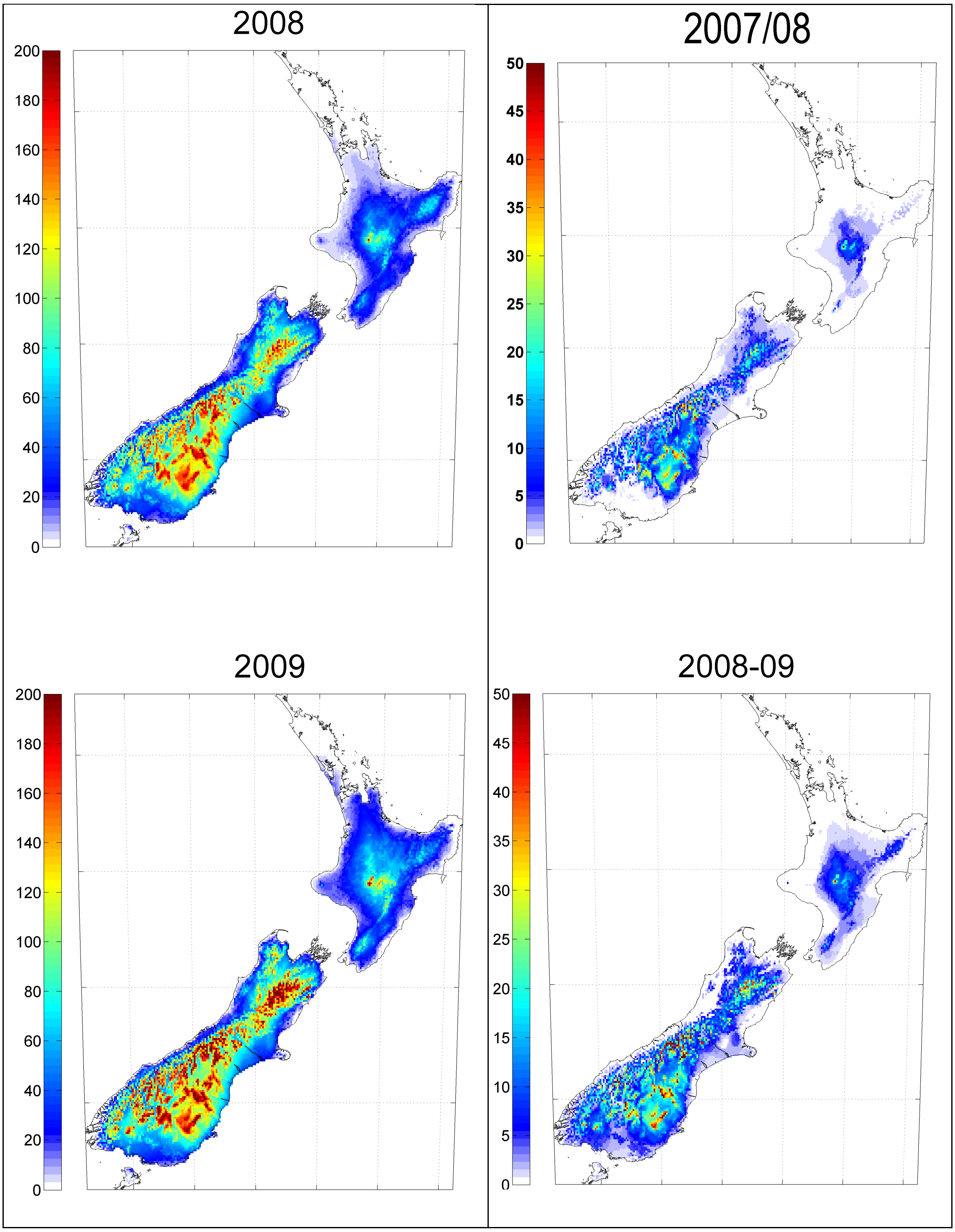

Figure 16: No. of frosts for calendar years and October–April growing seasons.

Maps of the number of frosts (daily minimum air temperatures below 0°C) for calendar years (left) and October–April growing seasons (right). The top row shows 2008 (Oct 2007-Apr 2008 on right) while the bottom row shows 2009 (Oct 2008-Apr 2009 on right). Based on VCSN data (see section 1, and Tait 2008).

6. Significant weather events

6.1 2008

The most notable weather event of 2008, in terms of economic impact, was the drought in the western North Island in early 2008. This was followed by the April floods, which caused loss of life in the central North Island, the damaging floods in July and August in Marlborough and Canterbury, with further loss of life, and significant snow storms in August. The July and August events had estimated insurance costs of $73 million[11].

6.1.1 Devastating drought

Agriculture Minister David Carter stated in August 2009 that the nationwide drought between spring 2007 and autumn 2008 cost the New Zealand economy $2.8 billion[12].

Extremely low rainfall occurred in January 2008 in many areas, with monthly totals of less than 10 mm in the Hauraki Plains, Waikato, King Country, coastal Marlborough and parts of North Canterbury. In Waikato it was the driest January in over 100 years of records at some sites. The dryness (50% or less of normal rainfall) continued in many regions right through to March. As a result, severe soil moisture deficits persisted in the period January–March 2008 in Waikato, parts of Bay of Plenty, South Taranaki and northern Manawatu, Hawke's Bay, Wairarapa, as well as Marlborough, and parts of South Canterbury, Otago and Southland (see Appendices).

Dairy farmers continued drying off stock, with sheep farmers selling stock early, as stock feed remained very low in the drought areas. April rainfall ended the severe soil moisture deficits in much of the North Island, and May rains brought relief in other areas. This drought dramatically affected production from pastoral agriculture in the west of the North Island, with MAF reporting an eleven percent fall in sheep numbers[13] (from the combined effects of the drought, and land-use change).

Figure 17: Steven Stark on his farm at Taupiri in the Waikato, 14 February 2008.
Credit: APN/ Chris Skelton.

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[11] Insurance Council of N.Z. - http://www.icnz.org.nz/current/weather/

[12] *http://www.scoop.co.nz/stories/PA0908/S00195.htm*
[13] http://www.maf.govt.nz/mafnet/rural-nz/statistics-and-forecasts/farm-monitoring/2008/pastoral/

6.1.2 Heat waves

2008 was notable for two periods of significant heat waves, one in January and the other in March.

From 30 December 2007 to 22 January 2008, and 18–21 March, heat wave conditions with temperatures of 30℃ or more affected inland and eastern areas of the South Island. Towards the end of the first period, numerous forest and scrub fires occurred. New extreme temperature records were set during 20–22 January at numerous climate stations in western areas of the North Island, between Hamilton and Wellington. Wallaceville (Upper Hutt) recorded its highest January temperature since records began in 1941, 30.9℃ on the 21st, and Palmerston North, 31.8℃ on the 22nd (records began in 1918). During the March heat wave, many locations recorded their highest March temperatures ever. Timaru recorded 34.8℃, and Woodbury and Culverden recorded 35℃ (to the nearest degree), on 19 March. However, New Zealand's all-time March record high temperature of 36℃, recorded at Ashburton in 1956, remained intact.

6.1.3 14–16 April floods in the central North Island causing loss of life

Heavy rainfall and flooding in Northland, Bay of Plenty, the Central North Island and Nelson occurred during 14–16 April, with the passage of a low pressure and frontal system over the North Island. There were eight deaths; one from a lightning strike, and seven in a flash flood. On 14 April, heavy rainfall occurred in the Nelson area, with 132 mm in 24 hours at Takaka, and 99 mm at Appleby, causing isolated slips and brief floods. In Northland, intense rain rates were observed on the 15th, with 55 mm in an hour in the Hokianga, and 94 mm in 3 hours. A man and his horse were struck by lightning and killed near Dargaville. Another lightning strike near Kaitaia caused the Doubtless Bay area to be without power for 3 hours. Further south, 1-day rainfall totals of 126 mm at Matamata, 108 mm at Rotorua and 101 mm at Taupo caused flooding and slips. The deluge caused flooding of some homes in Rotorua, and a flash flood on the Mangatepopo stream 25 km west of Turangi, drowning seven people.

6.1.4 Damaging floods in July and August in Canterbury and Marlborough

Heavy rain affected many regions of the country on 29–30 July. A state of emergency was declared by Marlborough District Council on July 30th, due to heavy rain and extensive surface flooding. In Nelson, the storm knocked out an important water pipeline. Picton police and volunteers sandbagged the waterfront in an effort to save the town from flooding. Severe flooding in the small South Island town of Sefton meant that 12 people had to be evacuated. In Northland, two people drowned while attempting to cross a swollen stream near Kawakawa.

Figure 18: Traffic makes its way through the flooded roads near Sefton, North Canterbury, 31 July 2008.
Credit: APN/Simon Baker.

In mid August, heavy rain and severe wind in North Canterbury and Marlborough caused massive landslides, and flattened hundreds of hectares of pine plantations. The cold, wet, weather came in the middle of lambing and calving, following hard on the heels of the clean-up of the July storms. Record high groundwater levels in Levin caused the town's four sewage containment ponds to overflow.

On 26 August, 126 mm of rain fell at Kaikoura, which was the second highest 1-day August rainfall for this location since records began in 1898. The intense rainfall in Marlborough and North Canterbury resulted in several landslides, surface flooding, disruption of the clean water supply, road and rail closures, damage to bridges, evacuations of residents and the death of many livestock, including newly-born lambs.

6.2 2009

Notable weather events of 2009 included the heat wave of early February, the April West Coast floods, and the floods in late June in Gisborne and the Manawatu-Whanganui region (causing a State of Emergency to be declared in Gisborne). Widespread and significant snowfalls occurred in both islands on 31 May, and unseasonable, heavy, snow fell over the lower North Island on 4–6 October, causing significant impacts on communities.

6.2.1 February heat wave

Heat wave conditions were experienced in central and eastern areas of the entire country, from Northland to Canterbury, from 7–12 February, when temperatures of 34℃ or more occurred in many locations on each day. Many places experienced their highest-ever recorded February maximum and minimum temperatures during the heat wave. The highest temperature for 2009 was observed during this event (38.0℃, measured at Culverden on 8 February), which was the highest February maximum temperature for this location since records began in 1928.

6.2.2 April West Coast floods

On April 27, Mt Cook recorded 341 mm of rainfall (its highest April 1-day total since records began in 1928). Torrential rain also occurred in Greymouth on the 27th, and roads became impassable there. At least nine homes were evacuated on the eastern side of town. Flooding also forced the closure of State Highway 6 at Punakaiki, and between Haast and Makarora. Trampers were stranded in the Mueller Hut in Aoraki Mt Cook National Park, and about 120 people were evacuated by helicopter from the Milford Track.

6.2.3 State of Emergency in Gisborne

On 28–30 June, a slow-moving low pressure system brought heavy rain, strong winds and thunderstorms to the northeast of the country. Thunderstorms and heavy rain affected Northland and Auckland on the 28th. The system then brought heavy rain to Coromandel, Bay of Plenty, Gisborne, and Hawke's Bay on June 29th, as well as snow to the Central Plateau. Heavy rain caused slips and the closure of State Highway 4 between Raetihi and Whanganui on the 29th. State Highway 57 between Palmerston North and Linton was also flooded, and slips occurred in the Manawatu Gorge. On June 30th, the residents of the small settlement of Mangatuna, just outside Gisborne, were evacuated following further heavy rainfall. Many slips affected the Napier-Taupo Road and State Highway 2 between Napier and Wairoa, although both remained open. A Civil Defence Emergency was declared in the Gisborne District on the morning of the 30th, due to flooding.

Figure 19: The effects of rain and flooding near Tolaga Bay, June 2009.
Credit: Gisborne District Council.

6.2.4 Heavy snowfall 31 May 2009

On May 31st, heavy snowfall and wintry conditions affected many regions of the country, from Southland to Gisborne. Snow and slips closed the highway between Opotiki and Gisborne. Snow fell to sea level from Southland to the Kaikoura Coast, and along Wellington's south coast. It blanketed high-country passes, including the Rimutaka Hill Road summit and Desert Road. Snow settled down to about 200 m around Canterbury, with about 8 cm on the ground near Springfield and in parts of Otago.

6.2.5 Exceptional, unseasonable snowfall in October

The snow on 4–6 October in the Hawkes Bay and Central North Island was exceptionally late in the season, and very heavy, and estimated to be the worst in October since 1967. Hundreds of travellers were stranded in up to 50 cm of snow along the Napier-Taupo Highway. Most were rescued by the army, but some spent the night in their vehicles. Unexpected snow in the Motu-Matawai area, and further south at Te Pohue, caused significant losses in newborn lambs and calves. Numerous roads were closed, including State Highway 1 between Turangi and Taihape, and State Highway 5 from Taupo to Napier. The Desert Road, Napier-Taupo Road and State Highway 38 in the Urewera National Park remained closed until 7 October. Snowfall was also observed in Taranaki, Waikato and Rotorua on 6 October, this being the first October snowfall in about 30 years around Rotorua.

Figure 20: Snow traps Napier-Taupo motorists, 5 October 2009.
Credit: Jessica Johnson.

7. Extreme rainfall and temperature variability

Since 1950, mean annual rainfall totals have increased in the southwest of both islands, and decreased in eastern regions (see Griffiths, 2006). Simply put, it has got wetter in western areas and drier on the east coast over that time, because of an increase in westerly circulation over the country, and a decrease in north-easterly air streams (the 'NE' weather type). This is associated with a change from negative to positive IPO phase in the late 1970s (see section 2).

Extreme daily rainfalls have generally followed suit, with increases in extremely large daily rainfalls in the southwest, and decreases in eastern areas (Griffiths, 2006). Figure 21 is an illustration of this, showing changes in the annual number of days with more than 25 mm of rainfall since 1950. Not all of these observed changes in daily rainfall extremes are statistically significant, but they do show clear spatial patterns (for example, daily rainfall at most sites between North Cape and East Cape has become less extreme over the period analysed).

The frequency of extremely cold nights has reduced almost everywhere in New Zealand since the 1950s (Salinger and Griffiths, 2001), but the number of hot days (with maximum temperature above 25℃) has generally shown very little change in many regions of New Zealand. The notable exception to this is the northeast of the North Island, where the number of hot days has increased since 1950 (although the change was small, from around 10 per year in the 1950s to around 25 per year in the 1990s).

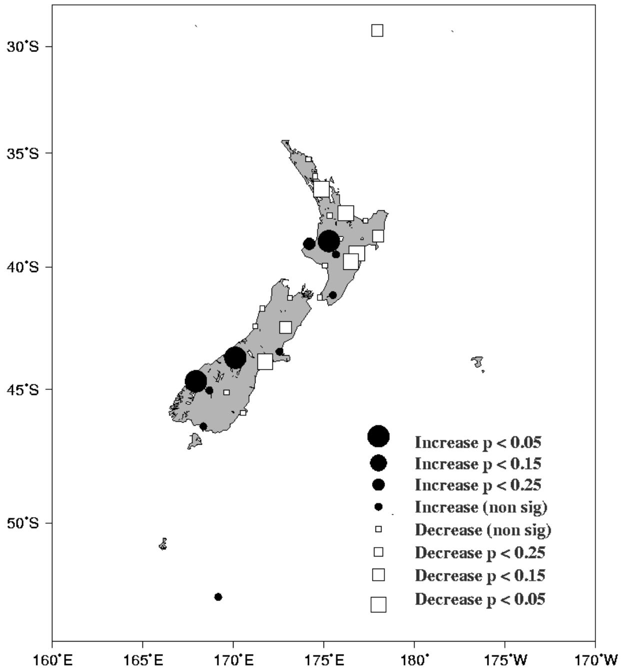

Figure 21: Changes in the annual number of rain days with more than 25 mm of rainfall, for the period 1950–2004.

Increases are shown as black circles, decreases as white squares. The larger the symbol, the more statistically significant the change.

7.1 Extreme rainfalls – 2008 and 2009 compared to other years

The extreme rainfalls of 2008 and 2009 for the six main centres (Auckland, Tauranga, Hamilton, Wellington, Christchurch and Dunedin) were not at all notable, in the historical context. At all six centres, historical extreme 1-day rainfall totals have been double or treble (or more times) those observed in 2008 and 2009.

For example, Auckland[14] received 162 mm on 16 February 1985, compared to a peak of only 58 mm in 2008 and 50 mm in 2009. Rainfall in April 1923 was extremely high in both Hamilton and Dunedin, with Hamilton recording 126 mm on April 20th, and Dunedin measuring an enormous 229 mm on April 23rd (the all-time record high daily rainfall at this site), resulting in widespread flooding (Figure 22). The extreme 1-day rainfalls for Hamilton and Dunedin for 2008 and 2009 were, in comparison, around the 50 mm mark (Table 2).

The two stand-out extreme daily rainfalls at Tauranga were 228 mm on 17 April 1948, and 241 mm on 18 May 2005. The May 2005 event resulted in a state of emergency from Tauranga to Matata, with an estimated cost of $30.7M[15]. The highest daily rainfalls recorded at Tauranga in 2008 and 2009 were, in comparison, 91 mm and 78 mm, respectively.

The 152 mm of rainfall on 11 December 1939 at Wellington remains the most extreme daily total there, to this day[16]. In 2008, the highest daily rainfall in the capital was 94 mm, compared to only 55 mm in 2009.

The two most extreme 1-day rainfalls at Christchurch were 102 mm, recorded on 12 March 1975 (related to Cyclone Alison, see Bell, 1975) and 110 mm, observed on 2 January 1980. The latter was part of a widespread flooding event that affected Canterbury, Otago and Westland. In 2008, the highest daily rainfall recorded at Christchurch was 52 mm, compared to only 28 mm in 2009.

Table 2: Annual extreme daily rainfall (mm) - summary information at the 6 main centres.

Annual extreme 1-day rainfall	Auckland	Hamilton	Tauranga	Wellington	Christchurch	Dunedin
Average over available rainfall record	68	61	99	68	46	51
Highest recorded (year recorded)	162 (1985)	148 (1967)	241 (2005)	152 (1939)	110 (1980)	229 (1923)
Highest in 2008	58	48	91	94	52	55
Highest in 2009	50	51	78	55	28	49
2008 % difference from the average	-14%	-21%	-8%	**39%**	**12%**	**7%**
2009 % difference from the average	-25%	-17%	-21%	-19%	-39%	-5%

[14] Data and statistics taken from only continuous observation sites. See Griffiths, G.M. 2010: *Drivers behind extreme rainfalls in New Zealand*, in preparation for *Weather and Climate.*
[15] http://www.icnz.org.nz/current/weather/
[16] Rainfall confirmed by hydrology notes in http://www.hydrologynz.org.nz/downloads/JoHNZ_1964_v3_2_Cunningham.pdf

Figure 22: Dunedin floods, 1932.

This image is from a series of lanternslides commissioned by the Dunedin Drainage and Sewerage Board showing the floods in Dunedin, following heavy rain in April 1923. The picture shows flood water in Harrow Street not far from the Dunedin Railway Station. Reproduced with permission by Dunedin City Council Archives.

If we link the most extreme 24-hour rainfall of each year with its associated Kidson weather type at the time, it emerges that only three main weather types produce the vast majority of extreme rainfall events, at all six main centres. The weather types are 'NE', 'TNW' and 'TSW' (see Figure 8 for definitions), and this updated finding is consistent with previous analysis (Griffiths, 2006). The most extreme 1-day rainfall of the year is about five-to-six times more likely to be associated with the 'NE' weather type, than one would expect based on the average prevalence of this weather type, at Auckland, Hamilton and Tauranga, about four times more likely at Christchurch, and around twice as likely at Wellington and Dunedin. The link between extreme 24-hour rainfalls and the 'NE' weather type is clearly strongest in the north of the North Island. The 'TNW' weather type is roughly between two or three times more likely to be associated with extreme 24-hour rainfall events at all of the centres, except Wellington. Lastly, the 'TSW' weather type is strongly related to extreme daily rainfalls at Wellington (5 times more likely), Christchurch and Dunedin (three-to-four times more likely), and to a much smaller extent at Auckland and Tauranga (about twice as likely).

The normal frequency of the three weather types 'NE', 'TNW' and 'TSW' is shown in Table 3, as well as a comparison to 2008 and 2009 frequency. In 2008, the 'TSW' frequency was close to normal, the 'NE' frequency was 19% reduced, and the 'TNW' weather type 16% increased, compared to the long-term normal. The annual extreme daily rainfall in 2008 at the three northern North Island sites was smaller than the average, consistent with the strong reduction in, and influence of, the 'NE' weather type. In comparison, annual extreme daily rainfalls in 2008 were larger than average for the remaining three centres. In 2009, the frequency of 'NE', 'TNW' and 'TSW' weather types were all well down on normal, and this is consistent with the lower-than-average annual extreme daily rainfalls observed in 2009 at all of the main centres (Table 2).

Table 3: Comparison of the frequency of Kidson weather types in 2008 and 2009, compared to the long-term 1971-2000 normal.

Frequencies for the three weather types most closely associated with extreme rainfall are given in bold.

Kidson Weather type	Normal frequency (1971-2000)	2008 frequency	2009 frequency
TSW	**6.8%**	**6.7%**	**5.6%**
T	11.6%	10.8%	12.6%
SW	11.1%	9.6%	14.9%
NE	**5.9%**	**4.8%**	**3.7%**
R	4.9%	5.5%	4.4%
HW	5.5%	6.8%	7.7%
HE	7.3%	7.2%	8.9%
W	5.1%	4.4%	5.8%
HNW	7.1%	8.5%	5.6%
TNW	**7.5%**	**8.7%**	**5.5%**
HSE	14.1%	13.5%	11.6%
H	13.0%	13.5%	13.7%

7.2 Extreme temperatures – 2008 and 2009 compared to other years

The Virtual Climate Station Network (VCSN) data (see Section 1) have been used to see whether ‘hot day’ frequency has changed over the last 37 years (1972–2009) in each of the main centres, by selecting the nearest VCSN grid point to the six main centres. A ‘hot day’ is defined here as a day with maximum temperature above 25℃.

Auckland and Tauranga average about 20 hot days per year (Table 4), Hamilton and Christchurch average around 30, Dunedin can typically expect 17 per annum, and Wellington averages only two hot days per year. But there is large variation around these averages – for example, Hamilton and Christchurch can record up to about 60 hot days per year, as was observed in 1974 and 1998, respectively.

In 2008, there were many more hot days than usual in Auckland, Hamilton, Tauranga and Dunedin, but a close to average number for Wellington and Christchurch. The number of hot days in 2008 was the 3rd-highest since 1972 for both Hamilton (57 days) and Tauranga (36 days). In addition, the 44 hot days observed in Tauranga in 2009 was the 2nd-highest in its record, surpassed only in 1998. During 2009, a year of southwesterly airstreams, Auckland and Tauranga (located in the thin coastal margin in the northeast of the country) experienced more hot days than usual, as did Christchurch and Dunedin (lying in the lee of the Southern Alps). However, Hamilton and Wellington only observed an average number of hot days in 2009.

Of the main centres, only Tauranga and Dunedin have shown a significantly increasing trend[17] in the number of hot days over 1972–2009. Both are located in eastern regions, and this (updated) Tauranga result is consistent with previous

[17] Statistically significant at the 95% level.

findings. The remaining sites showed no trend in hot day frequency over the analysis period, although this is a short period on which to calculate a climate trend. Other studies which have analysed daily temperature data for trends in extremes do so over several full IPO phases, using 50-100 years of data (e.g., Alexander et al. 2007).:

Table 4: Annual count of 'hot days' (maximum temperature > 25℃) - summary information at the 6 main centres.

Number of Hot days per year	Auckland	Hamilton	Tauranga	Wellington	Christchurch	Dunedin
Average 1972-2009	19	32	21	2	31	17
Highest recorded (year)	48 (1974)	61 (1974)	45 (1998)	7 (1975,88,89)	57 (1998)	36 (1999)
Number recorded in 2008	24	57	36	2	30	28
Number recorded in 2009	25	32	44	1	37	25
2008 % difference from average	24%	80%	73%	**0%**	**-2%**	67%
2009 % difference from average	30%	**0%**	111%	**-50%**	20%	49%

8. End of Summer Snowline

The Foundation for Research, Science and Technology (FRST) funds NIWA to photograph and report on the state of 50 selected 'index' glaciers in New Zealand. This is a continuation of an annual glacier/climate monitoring programme, which began in 1977, of the position (altitude) of the end-of-summer snowline on selected index glaciers, arranged in several transects across the Southern Alps. The project aims to provide an annual snapshot of the 'health' of New Zealand's glaciers. The following is a synthesis of the 2008–09 glacier year (April 2008–March 2009).

Glaciers respond to the changing climate, and an integral of these changes are recorded by the annual aerial surveys. The surveys measure the altitudes of the snowlines of 50 glaciers at the end of summer, as a surrogate for annual glacier mass-balance. The surveys are carried out by hand-held oblique photography taken from a light aircraft. Both the absolute and relative position of the snowlines are recorded and this provides a time series of glacier-climate interaction back to 1977.

On average, the latest survey indicated a negative mass balance (ice loss) for the index glaciers for the 2008/09 glacier year. On average, the snowline this year was about 95 metres above where it would need to be to keep the ice mass constant. This is a continuation of the negative mass balance in the 2007–08 glacier year (see Figure 23). Larger index glaciers with well-defined permanent ice areas have lost ice during the course of the 33-year monitoring period. This mass loss has occurred during large negative mass balance years and has not been replaced after a cycle of positive mass balance years.

The inferred negative mass balance in the 2008–09 season was mainly due to the combination of above normal temperatures (+0.5 to +1.0 °C) and near normal or below normal rainfall for the Southern Alps during winter, and La Niña-like patterns producing more northerly flows creating normal-to-above normal temperatures (+0.5 to +1.5 °C), above normal sunshine, and well below normal precipitation for the Southern Alps particularly during late summer.

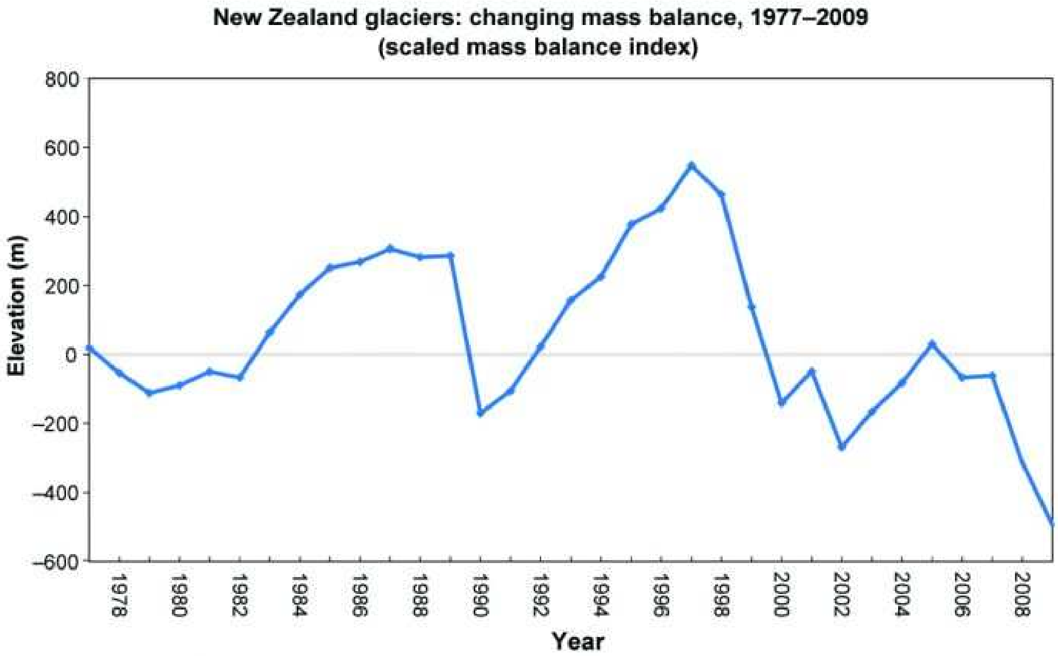

Figure 23: New Zealand Index Glacier Scaled Mass Balance: 1977–2009.

(See Willsman et al. 2009 for details and discussion about the methods used to scale and represent the index glacier data).

9. Ozone and UV Radiation

The ozone layer shields the surface of the Earth from much of the harmful ultra-violet (UV) radiation emitted by the sun. Discovery of marked springtime ozone depletion in the Antarctic (the 'ozone hole') raised fears of increased UV radiation at ground level, and associated health risks. It has been 25 years since the 'ozone hole' was first reported (Farman et al. 1985). Its mechanism is now largely understood, and measures taken under the Montréal protocol have seen its rapid growth halted. Figure 24 shows how the ozone hole has developed through time, since the start of satellite measurements (Bodeker et al. 2005, Müller et al. 2008), and how the ozone loss evolves through the year, typically reaching a peak (minimum ozone) around day 270 (late September). The area of the ozone hole grew rapidly during the 1980s and 1990s but has now levelled off. The large year to year variations are due to variations in the atmospheric circulation and temperature structure of the stratosphere. The ozone hole is still a significant event and will remain so for several decades (WMO 2007).

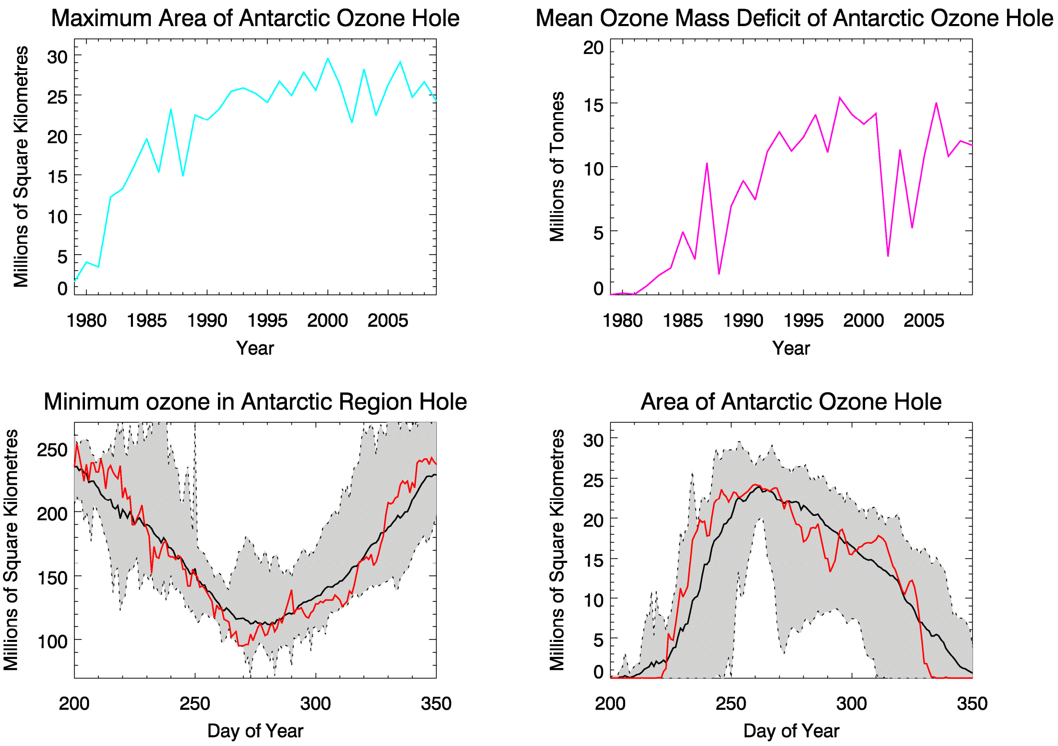

Figure 24: Ozone hole statistics.

Statistics of the 'ozone hole' a) The maximum area of each year's ozone hole, the area over which total ozone is less than 220 Dobson Units (1000 DU = 1 atmosphere-centimetre); b) The mean ozone mass deficit for each year's ozone hole. The mass deficit is the mass of ozone required to bring all of the ozone hole area up to 220 DU; c) Time evolution of the minimum total ozone measured during the 2009 ozone hole (red) compared with the mean (black line) and range for 1990-2009 (grey shaded area); d) The area of the 2009 ozone hole compared to 1990-2009 values, plotted as for c. Data are taken form the NIWA Assimilated Total Ozone Database, which uses information from several ground-based and satellite sources. Data are freely available from Dr Greg Bodeker, at www.bodekerscientific.com/data/ozone

Because of the proximity of New Zealand to Antarctica there is understandable concern as to how this affects New Zealand. When the ozone hole is at its peak size in September and October, it is well contained in the Antarctic vortex, a band of strong westerlies that acts as a barrier to limit air exchange. At this time, ozone over New Zealand is at a seasonal maximum. At the time when the vortex pattern and the ozone hole breaks up each year, usually in November or December, there is the potential to cause isolated and transitory events of low-ozone air passing over New Zealand (Bodeker et al. 2002, Ajtic et al. 2004). Such events are rare. More importantly, the overall impact of the ozone hole and its annual break-up is a general dilution of ozone in mid-latitude air, contributing to the lower ozone levels in mid to late summer.

The effect on New Zealand of the Antarctic ozone hole is thought to be a reduction by up to 5% in the ozone column over New Zealand in spring and summer. This change increases peak UV radiation under clear skies, which is about 40% greater in New Zealand than at equivalent northern latitudes in the U.S. or Europe (Seckmeyer and McKenzie 1992, McKenzie et al. 2006). These higher UV levels result in part from less stratospheric ozone as above, more so (7%) from the seasonal variation in Earth-Sun difference (the Earth being closer to the Sun in the Southern Hemisphere summer), but mostly from differences that are not fully understood. Tropospheric ozone and other gases over the more industrialised northern hemisphere can be much greater than over most of New Zealand.

There is also a large difference in mean air clarity, as New Zealand has some of the clearest air observed world-wide (Liley and Forgan 2009). Ten years of measurements of aerosol optical depth (AOD) at Lauder in Central Otago, a station of the Baseline Surface Radiation Network (BSRN), found monthly mean AOD at mid-visible wavelengths (500 nm) to be extremely low, in the range 0.02–0.05; comparable to measurements in the Antarctic or at the high-altitude Mauna Loa site in Hawaii.

Despite the 40% difference from equivalent northern latitudes, UV radiation in New Zealand is far from extreme; over 80% of the world's population lives in areas that can experience greater peak values. On the other hand, many of those populations have evolved skin type and sun-exposure habits to cope. The New Zealand population suffers from extreme rates of skin cancer, especially for melanoma, the most dangerous type, and Australia is close behind. In both countries, most of the population have skin type typical of higher-latitude Northern Hemisphere locations, poorly suited to the very high UV intensities experienced locally. Australia has more intense peak UV than New Zealand, but higher temperatures at those times can encourage people to seek shade. New Zealand's high rate of skin cancer is likely to be a result of high UV intensity even when temperatures are warm but not excessive.

10. Summary, and NIWA research programmes

New Zealand climate exhibits a lot of variability from year to year, as the country sits in the turbulent mid-latitude westerly wind belt, and it is influenced by many features of the global circulation, notably the El Niño-Southern Oscillation (ENSO) and the Southern Annular Mode (SAM). Extremes of climate and weather are a routine feature of New Zealand seasonal climate, as illustrated during 2008 and 2009. The most damaging extreme events are floods and droughts, followed by wind storms and heat waves.

2008 was warmer than normal overall, but with many extremes of warm and cold conditions. Rainfall was higher than normal overall in many regions, but significant drought conditions occurred at the start of the year, and again towards the end of the year. 2009 was somewhat cooler than normal over the country as a whole, a combination of heat waves in some months and record cold in others. Rainfall was near normal or somewhat below normal over much of the country, with relatively few places receiving above normal rainfall. Despite this, the winter was exceptionally snowy, and there were a number of significant flood events around the country.

Beyond the large year-to-year variations in our climate, there has been a significant long-term warming trend over the country. The best-fit linear trend to the New Zealand 'seven-station' temperature series (which includes adjustments to correct for site changes) is a warming of 1.1℃ from 1900 to 2009, with a 95% confidence interval of ±0.3℃. There is also a trend towards wet regions becoming wetter and dry regions becoming drier, consistent with an increase in westerly winds over New Zealand since 1950.

A number of NIWA research programmes are helping us understand the nature of climate variability and change over New Zealand, and how climatic impacts affect sectors of New Zealand society and the economy. Key research programmes include:

- Adaptation to Climate Variability and Change (ACVC)[18]: Fundamental monitoring and research on the nature of regional and hemispheric climate variability, in the atmosphere and oceans, including research on Antarctic climate and sea ice, and on snow and ice in New Zealand.
- The snow and ice monitoring network is an important new initiative that fills a key gap in our knowledge of New Zealand climate variability. It will be crucially important to understanding future change, and impacts on water resources.
- The ACVC programme also encompasses several areas of the impacts of climate variability and change upon New Zealand society and ecosystems, complementing several other research programmes listed below.
- Drivers and Mitigation of Global Change[19]: Fundamental monitoring and research on the composition of the atmosphere over New Zealand, the role of

[18] http://www.niwa.co.nz/our-science/climate/research-projects/all/adaptation-to-climate-variability-and-change#null
[19] http://www.niwa.co.nz/our-science/atmosphere/research-projects

atmospheric chemistry and radiation in climate variability and change, interactions between the atmosphere and ocean surface, and ocean biogeochemistry. This includes work on estimating national greenhouse gas emissions, in support of New Zealand's obligations to report on such emissions under the UN Framework Convention on Climate Change (UNFCCC).

- Regional Climate Modelling[20]: Involves a comprehensive suite of regional climate model simulations of future climate over New Zealand, linked to a number of 'downstream' models (river flow, glaciers, water resources, sea level rise, etc). The programme includes a component carried out jointly with GNS Science on analysing and modelling past climates to better understand natural climate variations on long time scales. Results will better quantify likely climate changes over New Zealand, and will provide further climate change scenario information to assist in strategic planning.
- Urban Climate Change[21]: A science-based risk assessment of the likely impacts of climate change upon urban environments, to help central and local government identify opportunities and reduce the impacts of climate change on urban and built environments and infrastructure. Work is being done jointly with GNS Science, BRANZ (Building Research Association of New Zealand), and MWH (Montgomery Watson Harza).
- Riskscape, and Weather-related Hazards[22]: The Riskscape programme, carried out jointly with GNS Science, is developing a generic model of environmental risks that will enable a comprehensive risk management process amongst users. The NIWA programme on Weather-related Hazards feeds into Riskscape by providing information on the risks of extreme weather events in New Zealand, and how climate variability and change is affecting the risk profile.

There are a number of other projects in progress, including work on changing risks of drought and extreme winds in New Zealand, modelling and assessing climate change across the southwest Pacific (in collaboration with the Centre for Australian Weather and Climate Research through the Pacific Climate Change Research Programme), and modelling the effects of stratospheric chemistry upon the climate of the Southern Hemisphere and New Zealand. More information can be found on the NIWA web site, at http://www.niwa.co.nz/our-science/climate/research-projects and related pages.

[20] http://www.niwa.co.nz/our-science/climate/research-projects/all/regional-modelling-of-new-zealand-climate
[21] http://www.niwa.co.nz/our-science/climate/research-projects/all/climate-change-and-urban-impacts
[22] http://www.niwa.co.nz/our-science/natural-hazards/research-projects

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Appendix 1. Detailed weather data, 2008 & 2009

Table A1: Annual rainfall totals for 2008 and 2009 for a selection of North Island locations. Sites must have no missing days of data. Record or near-record totals are highlighted.

Station Name	Average annual rainfall (mm)	2008 Rainfall total (mm)	2008 Percent of average (%)	2009 Rainfall total (mm)	2009 Percent of average (%)
Kaitaia Observatory	1334	1543	116	1406	105
Kaikohe	1517	1987	131	1705	112
Whangarei Aero	1402	1522	109	1066 [a]	76
Whitianga Aero	1719	1839	107	1775	103
Tauranga Aero	1214	1228	101	1221	101
Whakatane Aero	1169	1192	102	1348	115
Rotorua Aero	1389	1481	107	1164	84
Taupo	1003	985	98	712 [b]	71
Mangere	1176	1226	104	955	81
Auckland Aero	1108	1125	102	933	84
Pukekohe	1316	1302	99	1226	93
Hamilton	1208	1200	99	1088	90
Taumarunui	1517	1529	101	1453	96
New Plymouth	1440	1515	105	1316	91
Lower Retaruke	1539	1697	110	1580	103
Gisborne	1014	839	83	1153	114
Napier Aero	807	708	88	805	100
Paraparaumu	1031	1202	117	1004	97
Palmerston North	896	922	103	1000	112
Levin	1105	1211	110	1056	96
Wellington Aero	1005	1115	111	941	94
Wallaceville	1317	1353	103	1266	96
Stratford	2049	2099	102	1786	87
Whanganui	887	989	112	989	112

a. 4th lowest since records began in 1937 (based on the group of stations: Whangarei Aero AWS, Whangarei Aero, Whangarei Hospital, and Whangarei – Whau Valley)
b. Lowest since records began in 1949 (based on the group of stations: Taupo AWS, Taupo Aero, Taupo NZED, and Taupo – Lakewood Drive)

Table A2: Annual rainfall totals for 2008 and 2009 for a selection of South Island and Outer Islands locations. Sites must have no missing days of data. Record or near-record totals are highlighted.

Station Name	Average annual rainfall (mm)	2008 Rainfall total (mm)	2008 Percent of average (%)	2009 Rainfall total (mm)	2009 Percent of average (%)
Arapito	2397	2466	103	2307	96
Hokitika Aero	2875	3027	105	2832	99
Reefton	2015	1902	94	1661	82
Franz Josef	5457	4426	81	4586	84
Milford Sound	6761	5443	80	6638	98
Motueka, Riwaka	1404	1380	98	1108	79
Nelson Aero	942	1144	122	798	85
Appleby	968	1017	105	865	89
Blenheim Aero	740	994 [a]	134	812	110
Awatere Valley	665	640	96	511	77
Hanmer Forest	1144	1207	106	888	78
Kaikoura	823	922	112	574	70
Rangiora	680	739	109	518	76
Darfield	798	761	95	606	76
Christchurch Aero	630	704	112	589	94
Christchurch Gardens	653	717	110	638	98
Lincoln, Broadfield	652	722	111	623	96
Le Bons Bay	996	623	63	585	59
Lake Tekapo	600	506	84	539	90
Timaru Aero	564	487	86	584	103
Tara Hills	527	569	108	471	89
Wanaka Aero	611	612	100	495 [b]	81
Ranfurly	422	461	109	263	62
Middlemarch	520	386	74	365	70
Dunedin Aero	685	624	91	600	88
Dunedin, Musselburgh	805	705	88	736	91
Manapouri Aero	1280	1034	81	1078	84
Queenstown	913	799	88	853	93
Clyde	414	378	91	299	72
Ettrick	684	571	84	381	56
Gore	955	867	91	796	83
Invercargill Aero	1117	1045	94	1068	96
Nugget Point	938	810	86	731	78
Campbell Island	1329	1460	110	1384	104

a. 2nd highest since records began in 1927 (based on the group of stations: Blenheim Aero AWS, Blenheim Aero, Blenheim, Blenheim Research, and Blenheim Research EWS)

b. 4th lowest since records began in 1927 (based on the group of stations: Wamaka Aero AWS, Wanaka Park HQ, Wanaka, and Lake Hawea)

Table A3: Annual average and extreme daily maximum temperature for 2008 and 2009 for a selection of North Island locations. Sites must have no more than 10 missing days of data in either year. Record or near-record temperatures are highlighted.

Station Name	Average annual daily maximum temperature (℃)	2008 average annual daily maximum temperature (℃)	Highest daily maximum recorded in 2008 (℃)	2009 average annual daily maximum temperature (℃)	Highest daily maximum recorded in 2009 (℃)
Kaitaia	19.5	19.7	28.6	18.2 [a]	29.2
Kerikeri	20.0	20.0	27.7	20.4 [b]	29.2
Dargaville	19.6	19.2	28.0	18.2 [c]	30.8
Whangarei Aero	19.7	20.0	30.3	19.9	30.7 [d]
Warkworth	18.8	18.8	27.3	18.5	29.4
Tauranga Aero	19.0	19.4	30.4	19.5	30.3
Taupo	17.1	17.0	29.0	16.4	30.4
Opotiki	18.6	19.5	28.6	19.0	28.1
Mangere	18.8	18.8	28.2	18.1	27.1
Wiri, Auckland	18.9	18.7	26.6	18.3	26.9
Ardmore	19.3	20.7	30.5	20.4	31.2
Pukekohe	18.5	19.2	29.2	18.0 [e]	27.4
Hamilton, Ruakura	18.9	19.3	30.8	18.5	29.8
Te Kuiti	18.8	19.7 [f]	31.6	18.4	29.9
Taumarunui	18.6	18.3	30.0	17.4	29.4
New Plymouth	17.4	18.3 [g]	30.2 [h]	17.5	24.9
Lower Retaruke	17.9	18.6	31.0	17.6	31.3
Mt Ruapehu, Chateau	11.9	12.4	24.4	12.0	28.1
Dannevirke	16.9	17.8	31.4	16.7	29.6
Martinborough	18.4	18.3	31.1	17.5 [i]	34.1 [j]
Napier Aero	18.8	18.9	32.1	18.3	36.7 [k]
Whakatu	18.8	19.0	32.4	18.5	36.4
Paraparaumu	16.8	17.6	27.9	16.5	24.5
Palmerston North	17.5	18.3	31.2 [l]	17.0	26.7
Wellington Aero	16.6	17.1	28.3	16.1	27.3
Wallaceville	16.9	17.8	30.9 [m]	16.9	30.6 [n]
Stratford	16.0	16.4	27.7 [o]	15.5	25.8
Waiouru	13.8	14.4	27.6	13.4	28.0 [p]
Taihape	16.9	17.6	30.3	16.6	32.0
Whanganui	17.8	18.7 [q]	29.8	17.5	28.6

a. Lowest since records began in 1967 (based on the group of stations: Kaitaia EWS, Kaitaia Observatory, Kaitaia (agent numbers 1039 and 1040), and Kaitaia Aero EWS)
b. 3rd highest since records began in 1981 (based on the group of stations: Kerikeri EWS)
c. 2nd lowest since records began in 1943 (based on the group of stations: Dargaville 2 EWS, Dargaville EWS, Dargaville, and Dargaville NZED)
d. 3rd highest since records began in 1967 (based on the group of stations: Whangarei Aero AWS, Whangarei Aero, Whangarei Hospital, and Whangarei – Whau Valley)
e. Lowest since records began in 1969 (based on the group of stations: Pukekohe EWS, Pukekohe MAF, and Ardmore)
f. 2nd highest since records began in 1959 (based on the group of stations: Te Kuiti EWS, Te Kuiti, Otorohanga – Glenbrook, and Waitomo Caves)
g. 3rd highest since records began in 1944 (based on the group of stations: New Plymouth AWS, New Plymouth Aero, New Plymouth (agent 2278), and Lepperton – Puke Ra)
h. 2nd highest since records began in 1944 (based on the group of stations: New Plymouth AWS, New Plymouth Aero, New Plymouth (agent 2278), and Lepperton – Puke Ra)
i. 4th lowest since records began in 1986 (based on the group of stations: Martinborough EWS, Martinborough (agent 2651), Martinborough – Riverside, and Martinborough – Dublin Street)
j. 3rd highest since records began in 1986 (based on the group of stations: Martinborough EWS, Martinborough (agent 2651), Martinborough – Riverside, and Martinborough – Dublin Street)
k. Highest since records began in 1868 (based on the group of stations: Napier Aero AWS, Napier Aero, and Napier – Nelson Park)
l. 4th highest since records began in 1918 (based on the group of stations: Palmerston North EWS, Palmerston North AWS, Palmerston North (agent 3238), and Palmerston North – Kairanga)

m. Highest since records began in 1939 (based on the group of stations: Wallaceville EWS and Wallaceville)
n. 4th highest since records began in 1939 (based on the group of stations: Wallaceville EWS and Wallaceville)
o. Equal 4th highest since records began in 1960 (based on the group of stations: Stratford EWS and Stratford DEM Farm)
p. 4th highest since records began in 1962 (based on the group of stations: Waiouru AWS, Waiouru, and Waiouru Military Camp)
q. Highest since records began in 1937 (based on the group of stations: Whanganui – Spriggens Park, Whanganui AWS, Whanganui (agent 7519), and Whanganui Aero)

Table A4: Annual average and extreme daily maximum temperature for 2008 and 2009 for a selection of South Island and Outer Islands locations. Sites must have no more than 10 missing days of data in either year. Record or near-record temperatures are highlighted.

Station Name	Average annual daily maximum temperature (°C)	2008 average annual daily maximum temperature (°C)	Highest daily maximum recorded in 2008 (°C)	2009 average annual daily maximum temperature (°C)	Highest daily maximum recorded in 2009 (°C)
Takaka	18.0	18.5	29.8	18.1	31.5
Arapito	17.0	17.4	26.0	16.7	26.1
Hokitika Aero	15.8	15.9	25.0	15.3	23.0
Reefton	16.6	16.7	30.2	16.5	29.6
Greymouth Aero	15.9	16.5	25.8	15.7	23.1
Franz Josef	15.6	15.5	25.8	14.8	24.7
Milford Sound	14.6	15.2	24.0	14.4	23.4
Puysegur Point	13.3	13.7	22.9	13.4	24.9
Motueka, Riwaka	18.0	18.4	28.9	17.8	30.5
Nelson Aero	17.3	17.8	28.8	17.3	29.2
Appleby	17.5	18.5	30.4	18.4 [a]	30.3
Blenheim Aero	18.2	18.6	34.6	18.1	34.1
Hanmer Forest	16.6	17.8	32.5	17.1	35.7
Arthurs Pass	12.0	12.7 [b]	28.5	11.6	26.3
Winchmore	16.4	17.2	33.5	16.5	35.2
Peel Forest	16.3	16.6	33.3	16.0	33.0
Rangiora	17.0	16.9	33.3	16.7	33.2
Darfield	17.5	17.6	33.2	16.7	36.4
Christchurch Aero	16.8	17.0	34.2	16.4	35.7
Christchurch Gardens	17.1	17.2	33.6	16.8	35.0
Lincoln	16.6	16.7	32.7	16.4	35.0
Lake Tekapo	14.3	15.1	30.7	14.4	31.8
Wanaka Aero	16.5	16.2	31.9	15.5	28.9
Windsor	15.6	16.2	30.9	15.4	31.7
Palmerston	15.8	16.3	31.5	15.7	32.2
Dunedin Aero	15.8	16.4 [c]	32.1	15.8	33.4
Dunedin, Musselburgh	14.7	15.0	29.4	14.5	32.4
Manapouri, West Arm	12.7	13.2	27.8	12.4 [d]	25.9
Queenstown	15.8	16.9	32.1	15.8	30.5
Lumsden	14.9	15.3	30.7	14.4	28.8 [e]
Alexandra	16.7	18.2	33.6	17.4	33.8
Clyde	16.9	17.1	32.6	16.3	32.4
Ettrick	16.5	17.0	33.5	16.1	34.4
Winton	15.0	15.9	32.0	15.1	30.2
Invercargill Aero	14.4	14.9	27.9	14.1	28.7
Tautuku	14.3	15.5	31.0	14.6	31.0
Raoul Island	22.0	22.2	28.4	22.0	29.8
Campbell Island	9.4	9.2	16.8	9.0	17.7
Chatham Islands	14.1	14.2	22.3	13.7	22.6

a. Highest since records began in 1943 (based on the group of stations: Appleby 2 EWS, Appleby EWS, Nelson Aero, and Nelson AWS)
b. 3rd highest since records began in 1978 (based on the group of stations: Arthurs Pass EWS, Arthurs Pass (agent 4513), and Otira Substation)
c. 2nd highest since records began in 1947 (based on the group of stations: Dunedin Aero AWS, Dunedin Aero, Dunedin – Musselburgh EWS, and Dunedin – Musselburgh)
d. Lowest since records began in 1991 (based on the group of stations: Manapouri – West Arm Jetty)
e. 4th highest since records began in 1982 (based on the group of stations: Lumsden AWS)

Table A5: Annual average and extreme daily minimum temperature for 2008 and 2009 for a selection of North Island locations. Sites must have no more than 10 missing days of data in either year. Record or near-record temperatures are highlighted.

Station Name	Average annual daily minimum temperature (℃)	2008 average annual daily minimum temperature (℃)	Lowest daily minimum recorded in 2008 (℃)	2009 average annual daily minimum temperature (℃)	Lowest daily minimum recorded in 2009 (℃)
Kaitaia	11.8	12.2 [a]	1.9	10.4 [b]	0.3
Kerikeri	10.5	11.0	-0.3	10.5	0.0
Dargaville	10.7	12.1	1.5	11.1	-1.4
Whangarei Aero	11.7	12.1	0.8	11.8	1.0
Warkworth	10.2	10.8	-0.3	10.1 [c]	-1.3 [d]
Tauranga Aero	10.1	11.4	-0.7	10.7	-0.2
Taupo	6.7	7.2	-4.2	6.3	-5.4
Opotiki	9.6	9.2	-3.0	8.6	-2.6
Mangere	11.9	12.0	-0.1	11.0	-0.6
Wiri, Auckland	10.7	12.0	0.2	11.6	0.3
Ardmore	9.5	8.9	-2.5	7.8	-3.5
Pukekohe	10.4	10.3	-0.6	9.2	-0.8
Hamilton, Ruakura	8.6	8.7	-4.5	7.7	-4.7
Te Kuiti	8.4	8.8	-2.3	7.5 [e]	-3.9
Taumarunui	7.4	7.6	-3.4	6.8	-4.6
New Plymouth	9.9	10.1	-2.0 [f]	9.4	-1.8
Lower Retaruke	7.0	7.2	-3.6	6.4	-4.5
Mt Ruapehu, Chateau	3.0	3.5	-8.1	2.6	-8.0
Dannevirke	8.0	8.2	-4.5	7.6	-3.4
Martinborough	7.9	7.7	-4.0 [g]	7.1 [h]	-3.3
Napier Aero	9.0	9.3	-1.7	8.7	-1.4
Whakatu	8.2	8.0	-3.8	7.3	-4.1
Paraparaumu Aero	9.2	9.7	-1.9	9.0	-4.4 [i]
Palmerston North	9.1	9.0	-2.5	8.2	-3.9
Wellington Aero	10.6	11.1	0.4	10.3	-0.6
Wallaceville	7.9	7.6	-4.2	6.8 [j]	-4.3
Stratford	7.4	7.9	-2.5	7.0	-3.1
Waiouru	4.5	4.6	-8.0	3.8	-6.0
Whanganui	10.0	10.3	0.3	9.5	-0.9

a. 4th highest since records began in 1967 (based on the group of stations: Kaitaia EWS, Kaitaia Observatory, Kaitaia (agent numbers 1039 and 1040), and Kaitaia Aero EWS)
b. 2nd lowest since records began in 1967 (based on the group of stations: Kaitaia EWS, Kaitaia Observatory, Kaitaia (agent numbers 1039 and 1040), and Kaitaia Aero EWS)
c. 2nd lowest since records began in 1966 (based on the group of stations: Warkworth EWS, Warkworth, and Leigh 2)
d. Lowest since records began in 1966 (based on the group of stations: Warkworth EWS, Warkworth, and Leigh 2)
e. 2nd lowest since records began in 1959 (based on the group of stations: Te Kuiti EWS, Te Kuiti, Otorohanga – Glenbrook, and Waitomo Caves)
f. 4th lowest since records began in 1944 (based on the group of stations: New Plymouth AWS, New Plymouth Aero, New Plymouth (agent 2278), and Lepperton – Puke Ra)
g. Equal lowest since records began in 1986 (based on the group of stations: Martinborough EWS, Martinborough (agent 2651), Martinborough – Riverside, and Martinborough – Dublin Street)
h. 2nd lowest since records began in 1986 (based on the group of stations: Martinborough EWS, Martinborough (agent 2651), Martinborough – Riverside, and Martinborough – Dublin Street)
i. 3rd lowest since records began in 1953 (based on the group of stations: Paraparaumu Aero EWS, Paraparaumu EWS, and Paraparaumu Aero)
j. 3rd lowest since records began in 1939 (based on the group of stations: Wallaceville EWS and Wallaceville)

Table A6: Annual average and extreme daily minimum temperature for 2008 and 2009 for a selection of South Island and Outer Islands locations. Sites must have no more than 10 missing days of data in either year. Record or near-record temperatures are highlighted.

Station Name	Average annual daily minimum temperature (℃)	2008 average annual daily minimum temperature (℃)	Lowest daily minimum recorded in 2008 (℃)	2009 average annual daily minimum temperature (℃)	Lowest daily minimum recorded in 2009 (℃)
Takaka	6.7	7.5	-2.5	6.7	-3.1
Arapito	8.3	8.0	-1.4	7.7	-1.6
Hokitika Aero	7.6	7.9	-2.8	7.5	-2.3
Reefton	6.0	6.1	-5.4	5.8	-5.8
Greymouth Aero	8.6	8.6	-1.5	7.8	-1.0
Franz Josef	6.6	6.1	-2.8	5.8	-2.5
Milford Sound	6.0	6.3	-1.8	6.2	-2.5
Puysegur Point	8.5	8.7	1.3	8.3	0.6
Motueka, Riwaka	6.8	7.2	-3.7	6.3	-4.8
Nelson Aero	7.7	8.4	-2.8	7.7	-3.3
Appleby	8.0	6.5	-5.7	6.5	-5.5
Blenheim Aero	6.9	6.7	-6.1 [a]	5.8 [b]	-5.5 [c]
Hanmer Forest	3.9	2.8	-8.9	2.6 [d]	-8.9
Arthurs Pass	3.2	3.6	-9.3	3.2	-7.7
Winchmore	5.8	5.9	-4.6	5.1	-3.6
Peel Forest	4.3	4.1	-5.7	3.9	-5.0
Rangiora	5.9	6.2	-4.5	5.8	-3.7
Darfield	6.0	6.9 [e]	-3.7	6.4	-2.8
Christchurch Aero	6.4	6.2	-4.4	5.8	-4.5
Christchurch Gardens	7.2	7.4	-5.2	6.8	-2.7
Lincoln	6.5	6.9	-3.9	6.4	-4.6
Lake Tekapo	3.4	3.0	-7.2	3.1	-11.0
Wanaka Aero	4.8	5.0	-4.7	4.9	-5.8
Windsor	6.4	5.0	-4.6	4.4	-5.3
Palmerston	4.8	4.7	-6.0	4.3	-5.4
Dunedin Aero	4.7	4.7	-6.1	4.6 [f]	-5.2
Dunedin, Musselburgh	7.5	7.6	-1.7	7.1	-1.5
Manapouri, West Arm	5.6	5.0	-3.9	4.9	-3.8
Queenstown	5.6	5.8	-3.7	5.4	-4.0
Lumsden	4.4	4.2	-5.9	4.0	-6.8
Alexandra	5.0	4.1	-7.6	3.8	-8.1
Clyde	4.1	4.3	-6.1	4.0	-7.2
Ettrick	4.2	4.0	-6.0	4.0	-5.2
Winton	5.2	5.4	-4.1	5.2	-4.1
Invercargill Aero	5.4	5.7	-4.8	5.6	-4.1
Tautuku	6.1	5.9	-2.5	5.8	-5.0
Raoul Island	16.7	17.0	10.1	16.4	9.6
Campbell Island	4.7	4.8	-2.2	4.7	-3.3
Chatham Islands	8.9	9.0	0.8	8.5	0.6

a. 2nd lowest since records began in 1932 (based on the group of stations: Blenheim Aero AWS, Blenheim Aero, Blenheim, Blenheim Research, and Blenheim Research EWS)

b. 2nd lowest since records began in 1932 (based on the group of stations: Blenheim Aero AWS, Blenheim Aero, Blenheim, Blenheim Research, and Blenheim Research EWS)

c. 4th lowest since records began in 1932 (based on the group of stations: Blenheim Aero AWS, Blenheim Aero, Blenheim, Blenheim Research, and Blenheim Research EWS)

d. Lowest since records began in 1906 (based on the group of stations: Hanmer Forest EWS and Hanmer Forest)

e. 4th highest since records began in 1939 (based on the group of stations: Darfield EWS, Darfield (agent 4836), Hororata – Illana, and Christchurch Aero)

f. 2nd lowest since records began in 1947 (based on the group of stations: Dunedin Aero AWS, Dunedin Aero, Dunedin – Musselburgh EWS, and Dunedin – Musselburgh)

Table A7: Annual sunshine hours totals for 2008 and 2009 for a selection of New Zealand locations. Sites must have no missing days of data. Record or near-record totals are highlighted.

Station Name	Average annual sunshine (hours)	2008 Sunshine total (hours)	2008 Percent of average (%)	2009 Sunshine total (hours)	2009 Percent of average (%)
Kaitaia	2098	2069	99	2326 [a]	111
Dargaville	1874	1908	102	2067 [b]	110
Rotorua Aero	2102	2261	108	2336	111
Mangere	2013	2108	105	2176	108
Tauranga Aero	2248	2355	105	2540 [c]	113
Hamilton, Ruakura	2001	2057	103	2120	106
New Plymouth Aero	2173	2271	105	2177	100
Dannevirke	1796	2141 [d]	119	2073	115
Martinborough	2001	2111	106	2019	101
Gisborne Aero	2176	2355	108	2333	107
Napier	2198	2382	108	2312	105
Paraparaumu Aero	2032	2163	106	2030	100
Palmerston North	1736	1891	109	1752	101
Wellington, Kelburn	2065	2212	107	2079	101
Stratford	1944	1935	100	1912	98
Arapito	1702	1901	112	2030	119
Hokitika Aero	1860	1954	105	1953	105
Nelson Aero	2405	2472	103	2572	107
Blenheim	2435	2505	103	2477	102
Christchurch Aero	2100	2234	106	2170	103
Lake Tekapo	2149	2444	114	2370	110
Palmerston	1746	1814	104	1701	97
Dunedin, Musselburgh	1592	1912 [e]	120	1704	107
Cromwell	2086	2399 [f]	115	2210	106
Queenstown	1921	1989	104	1822	95
Winton	1652	1788	108	1607	97
Invercargill Aero	1609	1907 [g]	119	1773	110

a. Highest since records began in 1985 (based on the group of stations: Kaitaia EWS, Kaitaia Observatory, Kaitaia (agent numbers 1039 and 1040), and Kaitaia Aero EWS)
b. 3rd highest since records began in 1943 (based on the group of stations: Dargaville 2 EWS, Dargaville EWS, Dargaville, and Dargaville NZED)
c. Highest since records began in 1933 (based on the group of stations: Tauranga Aero)
d. Highest since records began in 1963 (based on the group of stations: Dannevirke EWS and Dannevirke (agent 2534))
e. 3rd highest since records began in 1947 (based on the group of stations: Dunedin – Musselburgh EWS and Dunedin – Musselburgh)
f. 2nd highest since records began in 1979 (based on the group of stations: Cromwell EWS, Cromwell MWD, Cromwell 2, Cromwell Substation, and Northburn)
g. Highest since records began in 1935 (based on the group of stations: Invercargill Aero AWS, Invercargill Aero 2 EWS, Invercargill Aero, and Tiwai Point EWS)

Appendix 2. Temperature, rainfall, and soil moisture deficit anomalies, 2008 & 2009

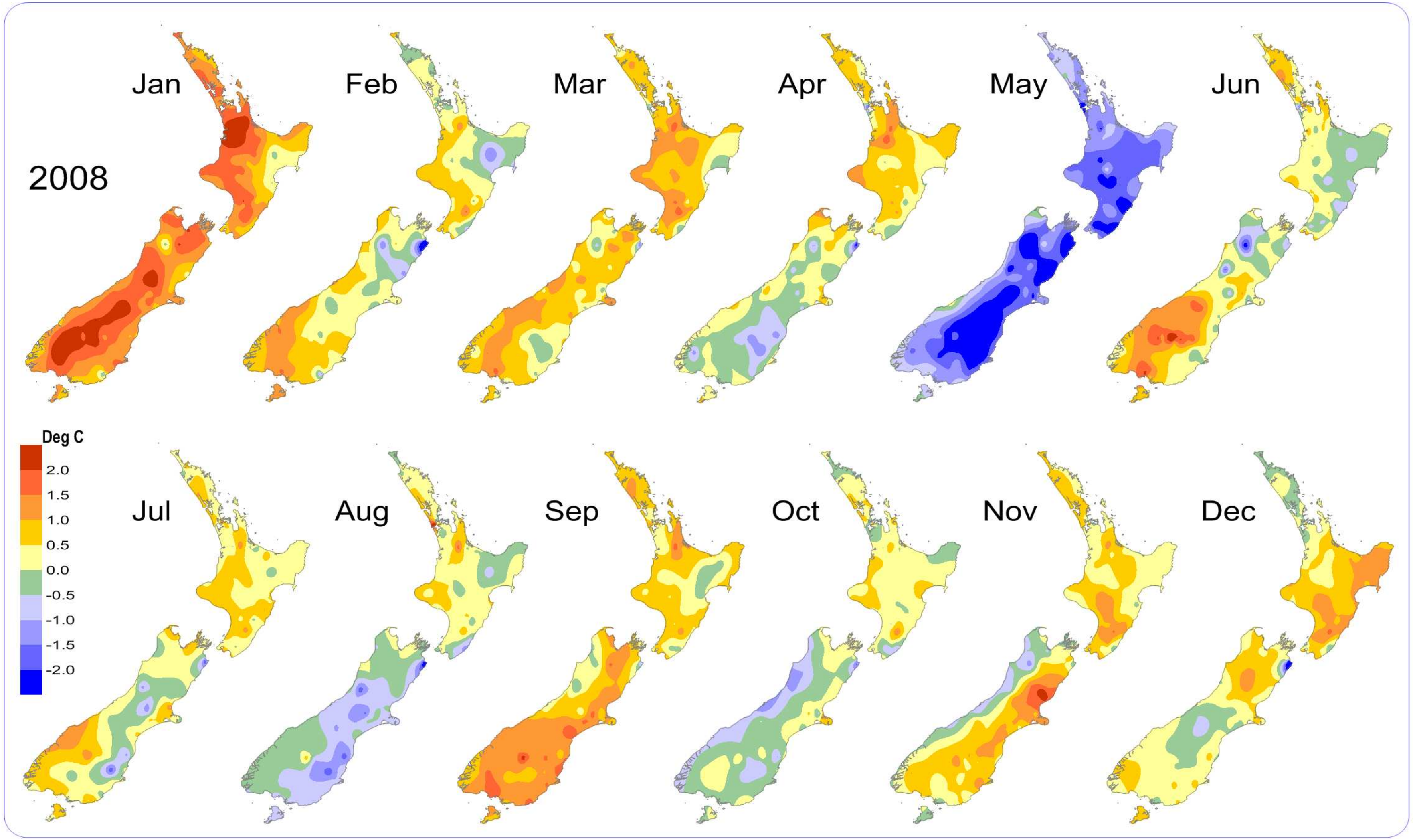

Figure A1: Monthly temperature anomalies (departures from normal) for 2008.

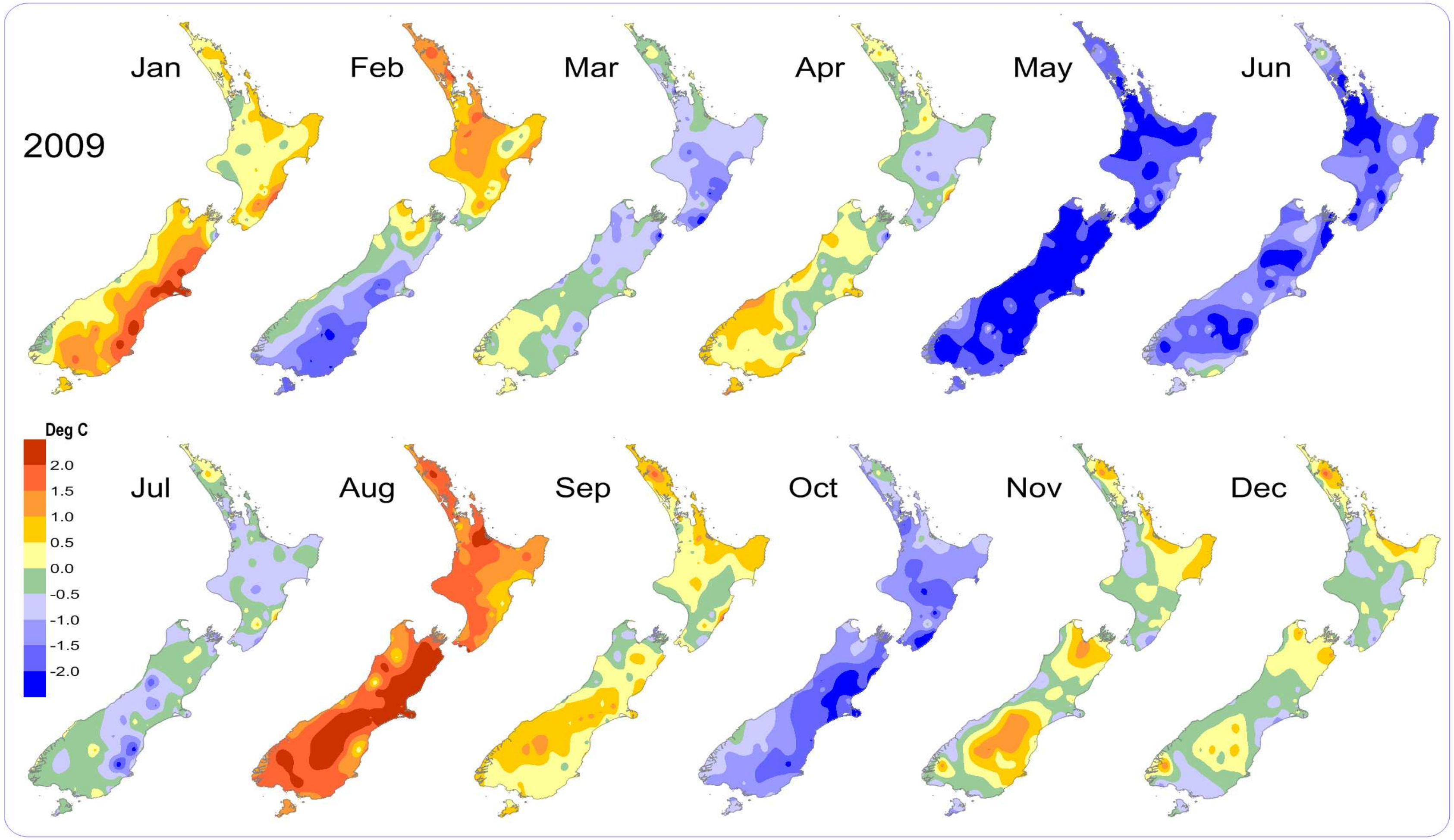

Figure A2: Monthly temperature anomalies (departures from normal) for 2009.

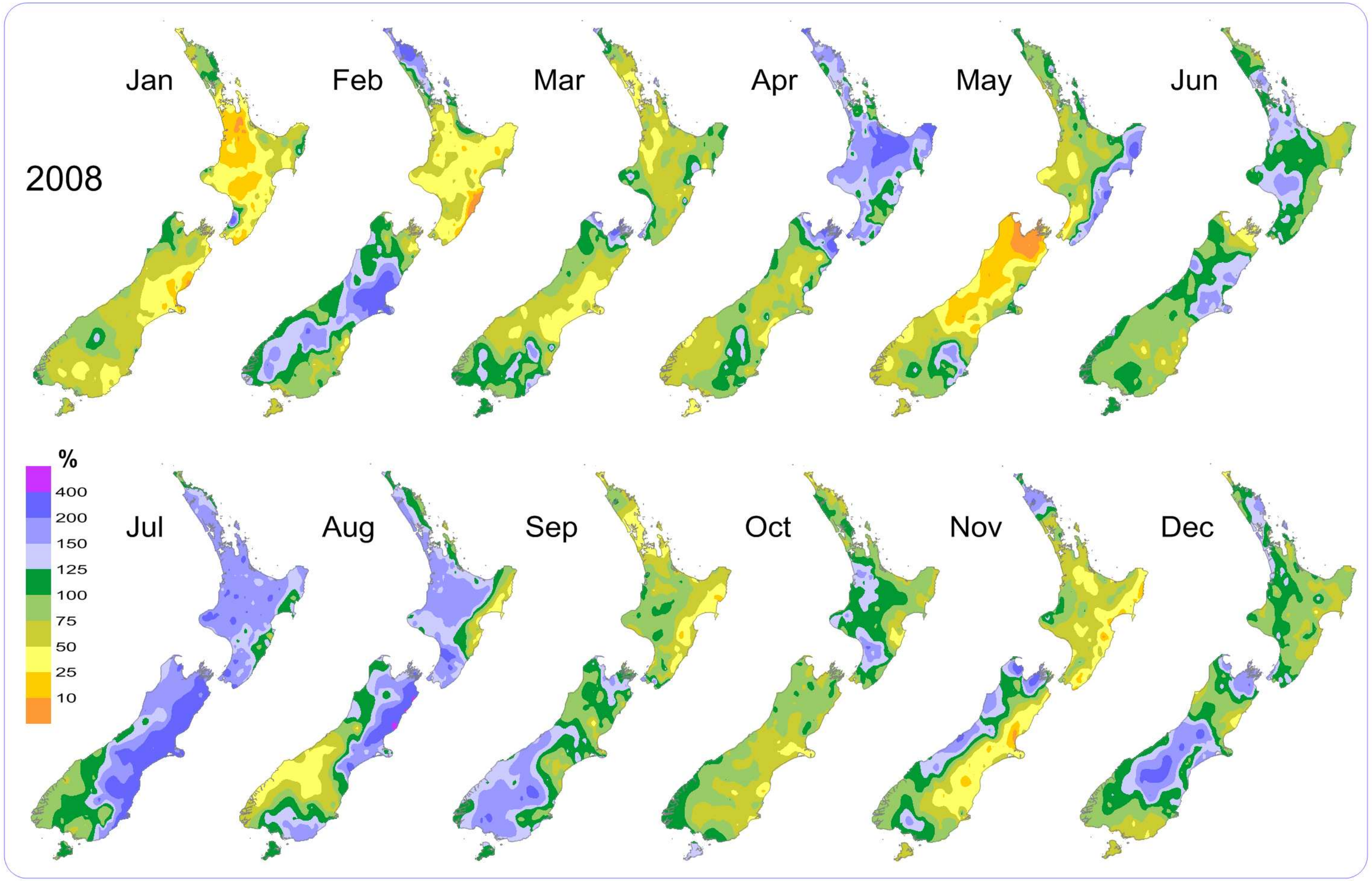

Figure A3: Monthly rainfall anomalies (departures from normal) for 2008.

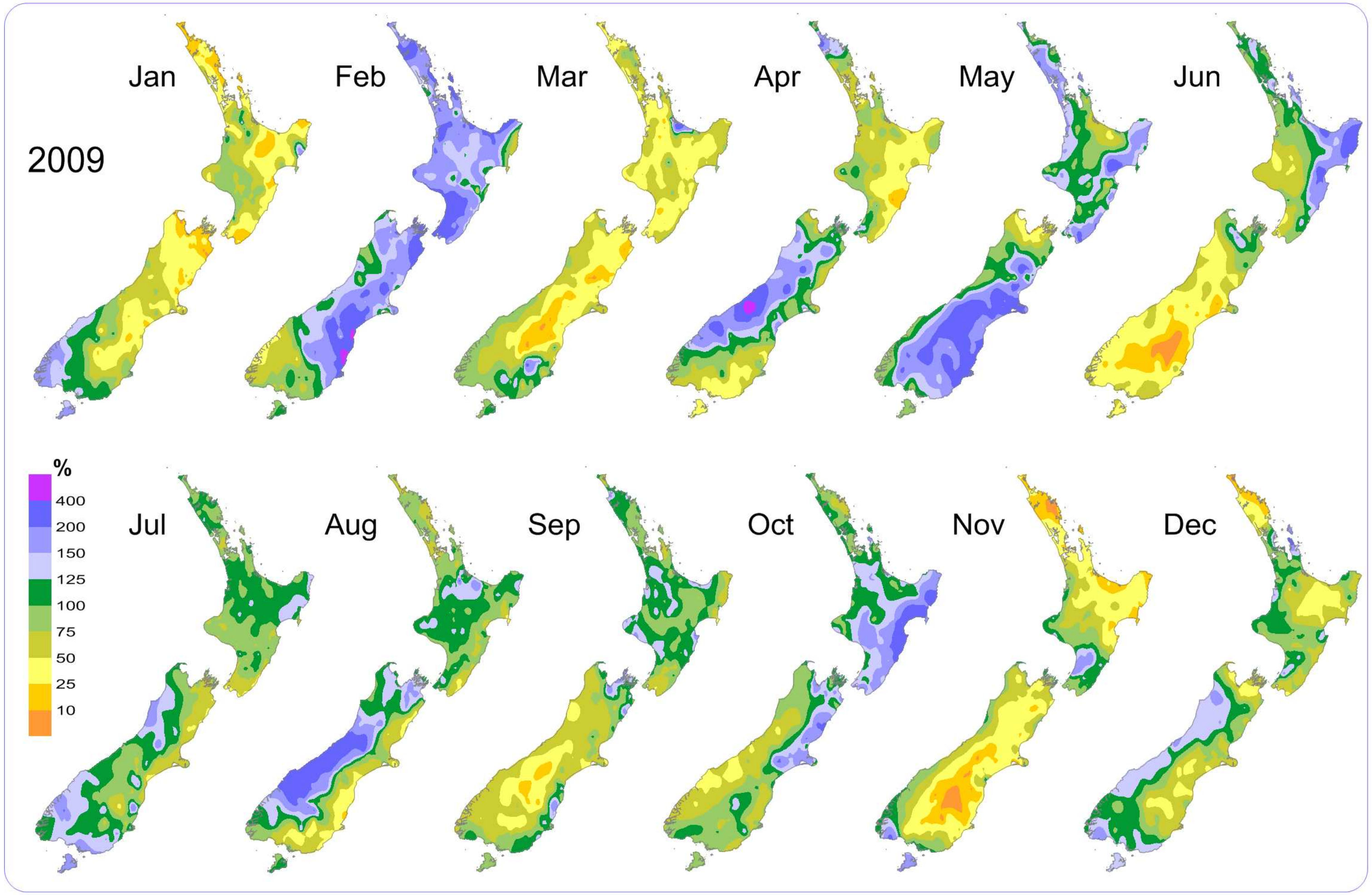

Figure A4: Monthly rainfall anomalies (departures from normal) for 2009.

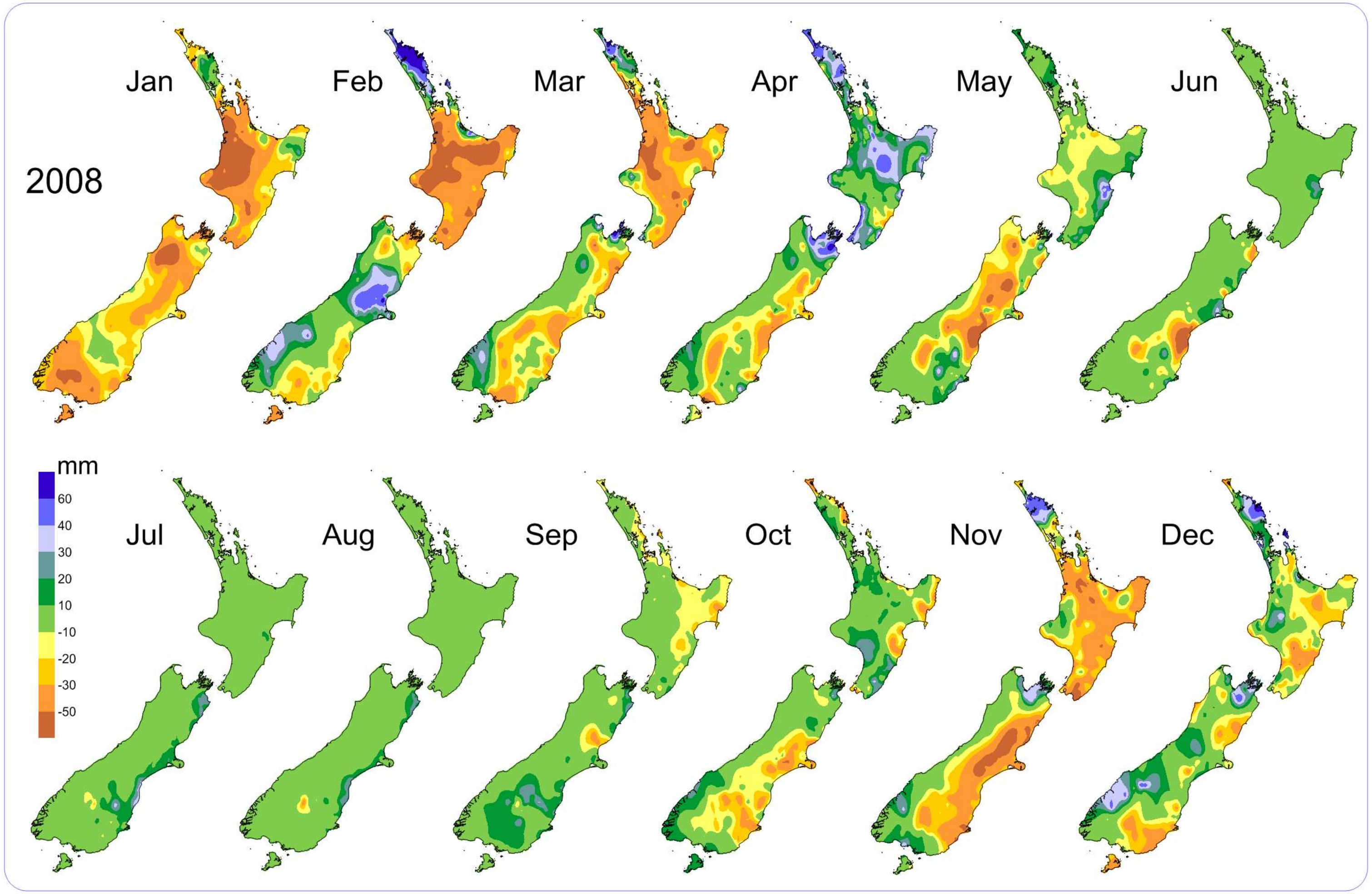

Figure A5: Departure from normal soil moisture deficit at the end of each month for 2008.

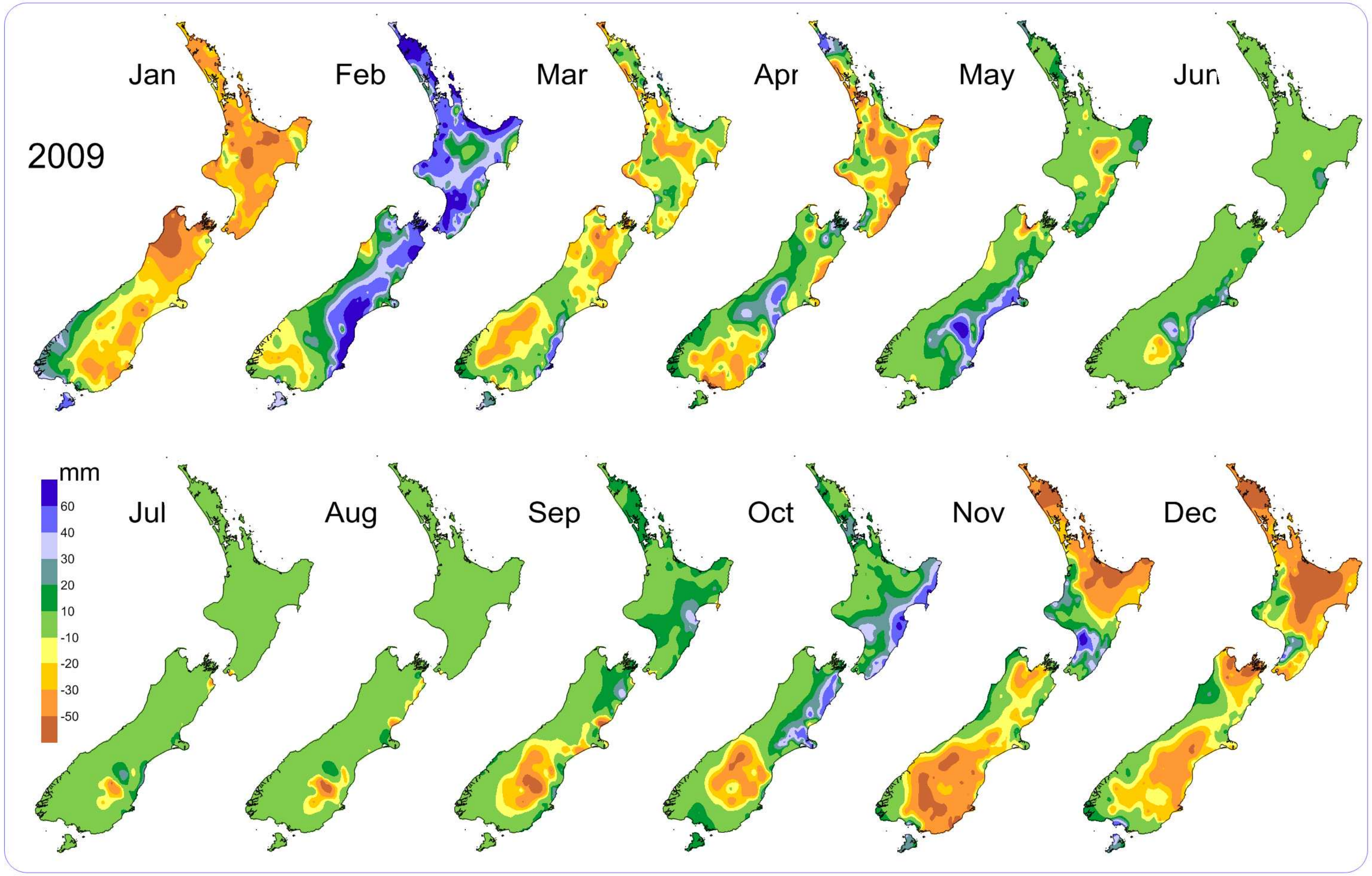

Figure A6: Departure from normal soil moisture deficit at the end of each month for 2009