Ministry for Primary Industries
Manatū Ahu Matua

The 2012-13 drought: an assessment and historical perspective

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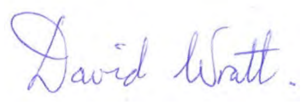


Dr David Wratt

Executive summary

Dry conditions during the 2012−13 agricultural season were unusually widespread across New Zealand, and particularly serious in the North Island. The Ministry for Primary Industries (MPI) requested an assessment by NIWA of the 2012−13 drought and, in particular, a comparison of the severity of the 2012-13 drought against previous droughts in New Zealand, as far back as records allowed.

Our assessment is made using meteorological characteristics of the drought — principally based on estimates of soil water content during the dry period. A single-layer water balance model is used to calculate accumulated potential evapotranspiration deficit (PED), as a measure or index of drought, to compare the intensity and duration of the present drought with historically similar events. PED, derived from estimates of both the use of water by plants and the loss of water from the pasture environment, and measured in mm, can be thought of as the amount of water needed to be added as irrigation, in order to keep pastures growing at optimum levels.

The areas most affected by the 2012−13 drought were: southern Northland, South Auckland, Waikato, Bay of Plenty and the Central Plateau, Wairarapa, Rangitikei, Ruapehu, Gisborne, Hawke's Bay, and parts of the north and west of the South Island.

The PED calculations, derived for the months of July to May, were applied to selected long-period station observations, extending back as far as the early 1940s, and also to a 5km gridded data set covering all of New Zealand. The latter data set, known as NIWA's Virtual Climate Station Network (VCSN), begins in 1972.

Both analyses show that the 2012−13 drought was one of the most extreme on record for New Zealand. For much of southern Northland, Auckland, Waikato, Bay of Plenty, Gisborne, Hawke's Bay, and West Coast, the July 2012−May 2013 PED accumulation was the largest in the 41-year VCSN record. The longer-record station calculations indicate an event of similar severity occurred in the 1945−46 season.

The PED calculations on the VCSN grid allow us to estimate the areal extent of the drought compared to previous events over the 41 years of VCSN data. The PED accumulation to the end of May 2013 was the highest in 41 years at 34% of the North Island VCSN grid-points, which is a much larger areal coverage than any other drought in the VCSN period. For the Auckland, Waikato and Bay of Plenty regional council regions, the 2012-13 PED was the highest since 1972 over about 70% of each region, and one of the three highest over about 95% or more of each region. Considering the 2007-08 drought for comparison, in the Waikato the 2007-08 event was the worst at only 14% of VCSN-points, and one of the three worst over about 80% of the region.

The immediate cause of the 2012−13 drought was the persistence of slow-moving or 'blocking' high pressure systems over the Tasman Sea and New Zealand over the summer season. The reason for such persistence will need further research. In this particular instance, the El Niño-Southern Oscillation was in its neutral phase and was not a factor.

1 Introduction

Dry conditions during the 2012−13 agricultural season were unusually widespread across New Zealand, and particularly serious in the North Island. On 27 February 2013 the Minister for Primary Industries declared a medium scale adverse event due to the drought in Northland and North Auckland. By 15 March 2013, drought status had been declared for the whole of the North Island, and a week later this declaration was extended to the Buller and Grey Districts in the South Island.

The Ministry for Primary Industries (MPI) has the lead role to provide recovery support measures to farmers and rural communities impacted by adverse climatic events, natural disasters or biosecurity incursions. The Primary Sector Recovery Policy guides the government response to these events when the scale and impact is such that is beyond the reasonable capacity of the community to cope.

This report, commissioned by MPI, compares the severity of the 2012−13 drought against previous droughts in New Zealand, as far back as records allowed. The report was compiled by NIWA (The National Institute of Water and Atmospheric Research).

In this report, our assessment is made using meteorological characteristics of the drought — principally based on estimates of soil water content during the dry period. We have used a single layer water balance model to calculate *accumulated potential evapotranspiration deficit* (PED, see next section), as a measure or index of drought, to compare the intensity and duration of the present drought with historically similar events. This index is a standard calculation used operationally on New Zealand's National Climate Database, managed by NIWA.

In **Section 2** we present a time series of PED accumulations for each of the sample areas indicated in Figure 2-1. The data are drawn from representative sites for each area respectively. For each area we also include time series of seasonal rainfall and potential pasture growth, to help illustrate the onset and evolution of the 2012−13 dry season.

In **Section 3** we present a series of analyses (maps, time series, and tables) based on a 41-year data set of rainfall and evapotranspiration interpolated onto a 5km grid covering all of New Zealand. This data set is known as NIWA's Virtual Climate Station Network (VCSN), and allows a detailed comparison of the severity and spatial extent of the 2012−13 drought relative to other events. For completeness, national maps of PED accumulations for each July−May year in the VCSN period are provided in the Appendix.

In **Section 4** a brief discussion is provided of various drivers of drought occurrence. It has been recognised previously that El Niño and La Niña episodes can both lead to droughts in New Zealand. The 2012−13 summer was an ENSO-neutral season, but was notable for persistent high pressure systems over the Tasman and New Zealand.

The drought assessment reported here is based on data for the 2012−13 growing season until the end of May. We compare the current growing season with all previous growing seasons from 1972 (mapped PED) and from the mid-1940s (time series PED plots).

1.1 Water balance calculation

The single layer daily soil moisture calculation used in this study is illustrated in Figure 1-1 below. Incoming rainfall minus outgoing evapotranspiration are calculated on a daily basis, and the resulting soil moisture deficit is shown for the current season (red curve), and for last season (blue curve). The long-term average estimated from all years is shown by the black curve.

In this model, the available water capacity is assumed to be 150 mm, which is typical of the pasture root zone of a medium silt-loam soil. For well drained soils under pasture, the soil water content is taken to be at field capacity (i.e. zero deficit) a day or so after cessation of sufficient rainfall to fill the soil pores. The model estimates the moisture deficit balance between the net loss of soil moisture by evaporation and transpiration (evapotranspiration) and incident rainfall. As the growing season advances, and evapotranspiration typically exceeds rainfall, the moisture deficit increases. In the method used here, once the deficit exceeds 75 mm, we assume that pasture production is moisture constrained, and evapotranspiration can no longer meet atmospheric demand (Porteous *et al*., 1994). The difference between the demand or *potential* evapotranspiration and the constrained or *actual* evapotranspiration is termed the potential evapotranspiration deficit (PED).

In practice, PED can be thought of as the amount of water needed to be added as irrigation, or replenished by rainfall, in order to keep pastures growing at levels that are not constrained by a shortage of water.

We accumulated PED on a daily basis at rainfall measuring locations in our observing network, and at grid points of the VCSN, to derive monthly totals for the seasons that we compared. (See appendix of Mullan *et al*. (2005) for the relevant equations).

It is important to note that PED estimates, for which rainfall is typically the largest component, are strongly dependent on the accuracy with which rainfall measurements are recorded. Rainfall by its nature is highly variable over short distances, and, therefore, complete and comprehensive representation of rainfall events is typically constrained by the low density of the measuring network. One often hears, for example, farmers say that their neighbours received rainfall when they themselves did not.

In our treatment of long-term climate station records, we have used averaged PED values across selected stations in reasonably homogeneous climate zones, to help better represent the spatial characteristics of the dry periods. In the case of the VCSN data, we used standard interpolation techniques to derive spatial representation of the drought events across New Zealand.

In this report we have compared drought events using regions of New Zealand within which climate is reasonably homogeneous. Within these regions, onset and cessation of drought is typically region wide. While PED estimates provide a robust measure of drought severity and duration, their dependence on rainfall measurements mean that ranking the severity of droughts, when there are only small differences in total PED between one year and another, cannot be guaranteed to be conclusive.

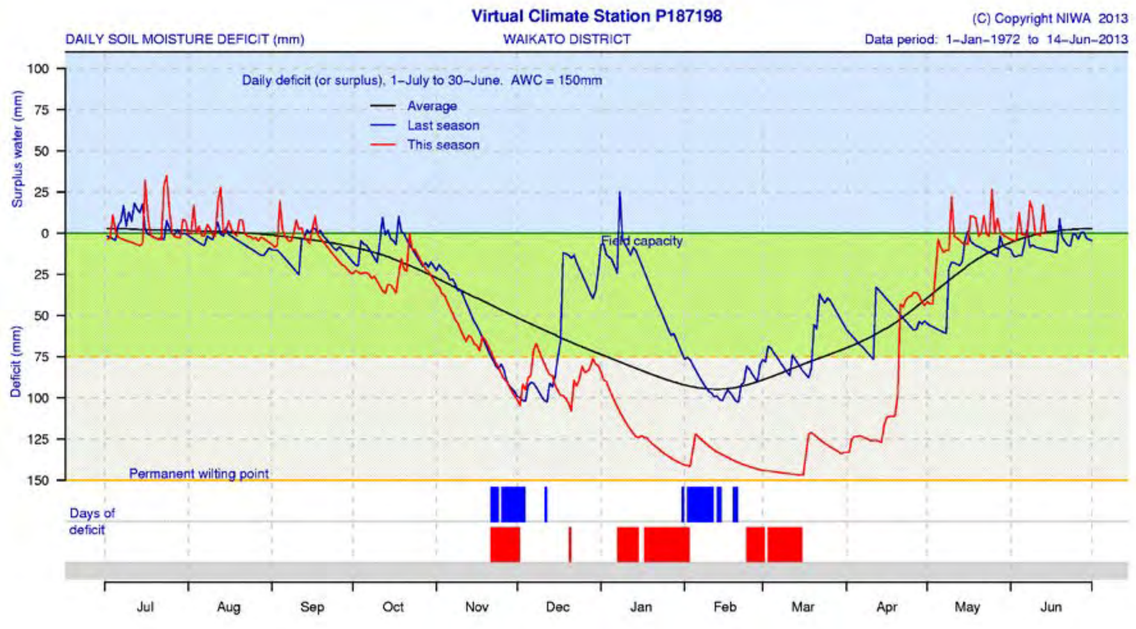


Figure 1-1: Modelled daily water balance at a climate grid point to the east of Hamilton. In this model, soil moisture deficits greater than 75 mm (i.e. below the green zone in the figure) are assumed to restrict evapotranspiration to less than potential (atmospheric demand) levels. This results in less pasture growth due to less ability to take up water from the soil. The red curve indicates the soil moisture deficit for the 2012–13 July to June season, the blue curve indicates the deficit for 2011–12, and the black curve shows the long term average deficit. The vertical bars at the bottom of the figure indicate days of restricted evapotranspiration (also referred to as days of deficit), for 2012–13 (red bars) and 2011–12 (blue bars).

1.2 Onset of dry conditions

Typical of how the present drought propagated across much of New Zealand, rainfall from about mid-October was lower than normal. This is illustrated in the soil moisture balance figure above (Figure 1-1) where the 2012–13 deficit (red curve) dropped sharply from mid-October, and reached 75 mm deficit about a month later. The figure suggests that reduced pasture growth would have been clearly evident in this location by mid-November. In many parts of New Zealand this onset of water-restricted pasture growth was at least a month or more earlier than usual.

Apart from brief respites with rainfall in December and February, and also in March (and this varied with location across the country), soils remained drier than normal until mid-April.

The lowest point on the red curve, which occurred on 17 March, is an indication of the driest point of the drought. An integration across the whole country of the soil moisture deficits on that date is shown in Figure 2-1 below.

2 2012–13 drought: the most affected areas

In this section we select and assess areas of New Zealand that were most affected by the 2012–13 drought.

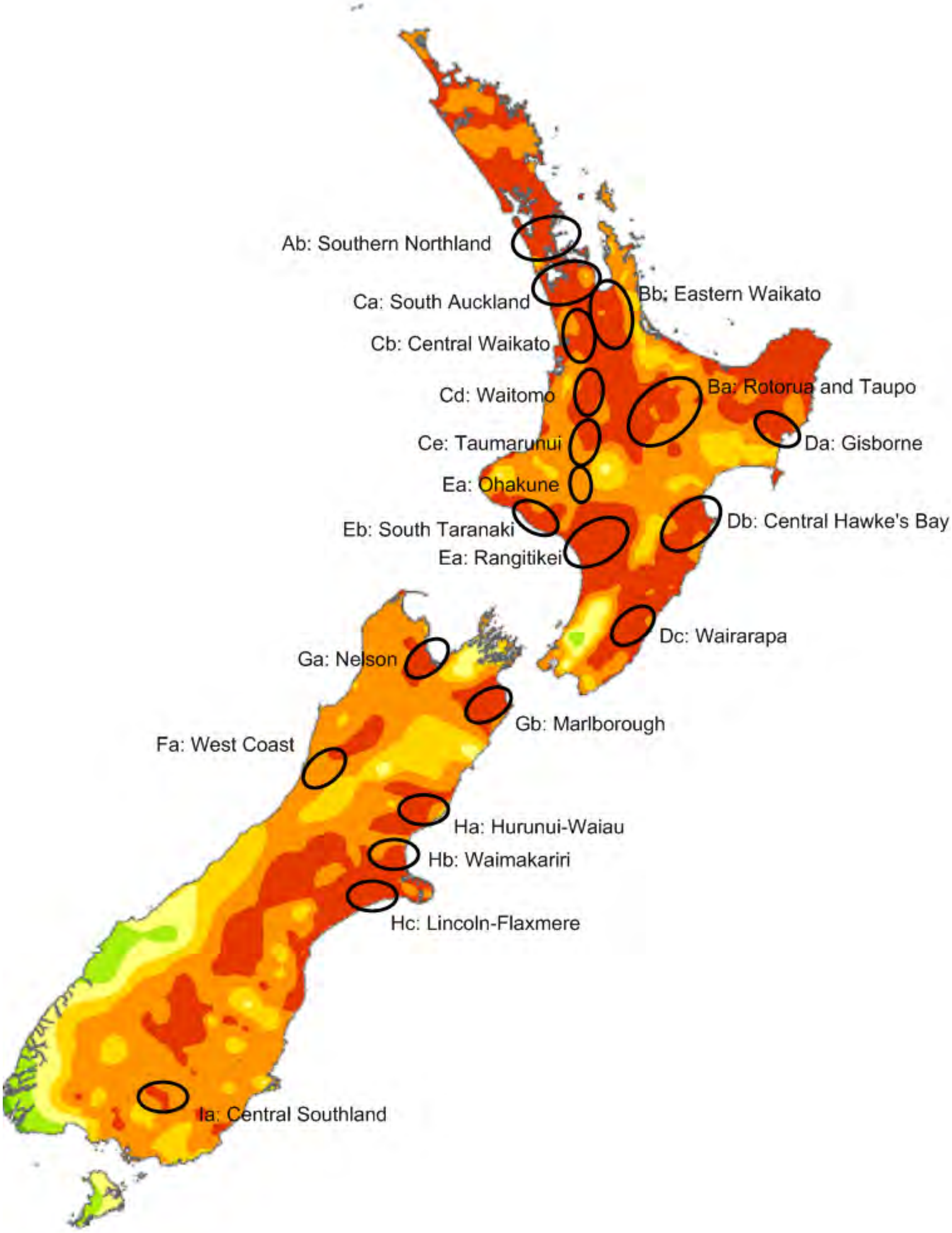


Figure 2-1: Soil moisture deficit calculated across New Zealand on 17 March 2013, probably the date in the evolution of the drought when soils were at their driest. Circled areas indicate sample locations used in the assessment of the 2012-13 drought.

The map to the left shows the soil moisture deficit for New Zealand on 17 March 2013, close to the height of the drought and immediately prior to a short period of wet weather that relieved soil moisture deficits in some areas of the country. Red shading indicates deficits greater than 130 mm.

The sample locations of the most affected areas used in this study are circled, and listed in Table 2-1 below.

Table 2-1: List of focus areas for this study, and the sites used as indicators for rainfall accumulation, accumulated potential evapotranspiration deficit (PED), and pasture growth index (PGI).

Section	Map reference	Sub-region	Representative site for rainfall accumulation and pasture growth index
2.2	Ab	Southern Northland	Warkworth
2.3	Ca	South Auckland	Pukekohe
2.4	Cb	Central Waikato	Ruakura-Morrinsville
2.5	Cd	Waitomo	Te Kuiti
2.6	Bb	Eastern Waikato	Paeroa and Coromandel
2.7	Ce	Ruapehu District	Taumarunui
2.8	Ba	Rotorua and Taupo	Rotorua (Rainfall and PGI) Taupo (PED)
2.9	Da	Gisborne	Gisborne
2.10	Db	Central Hawke's Bay	Waipawa
2.11	Dc	Wairarapa	Masterton
2.12	Ea	Rangitikei	Taihape VCSN (rainfall); Wanganui-Palmerston Nth (PED), Taihape (PGI)
2.13	Eb	South Taranaki	Hawera
2.14	Ec	Ruapehu District	Ohakune
2.15	Fa	West Coast	Hokitika
2.16	Ga	Nelson	Nelson Airport and Appleby
2.17	Gb	Marlborough	Blenheim
2.18	Ha	Hurunui-Waiau	Cheviot
2.19	Hb	Waimakariri	Rangiora (rainfall); Oxford-Rangiora (PED and pasture growth index)
2.20	Hc	Lincoln – Flaxmere	Lincoln
2.21	Ia	Central Southland	Gore

2.1 Area data

The sets of figures below show

(i) accumulated daily and monthly rainfall

(ii) accumulated monthly PED, and

(iii) an index of potential pasture growth (PGI).

PGI is a seasonally aware, normalised index of potential growth based on estimates of radiation, air temperature and soil moisture. Ideal conditions for growth occur when there is a combination of high soil moisture and solar radiation levels, with warm conditions, and are indicated when the index is high (close to 1). Poor conditions for growth (low moisture and radiation levels, and low temperatures) are indicated when the index is close to zero.

Brief notes are included with each set of figures to highlight key features in the data.

Notes on the following sets of figures (see Table 2-1 for list and Figure 2-1 for location)

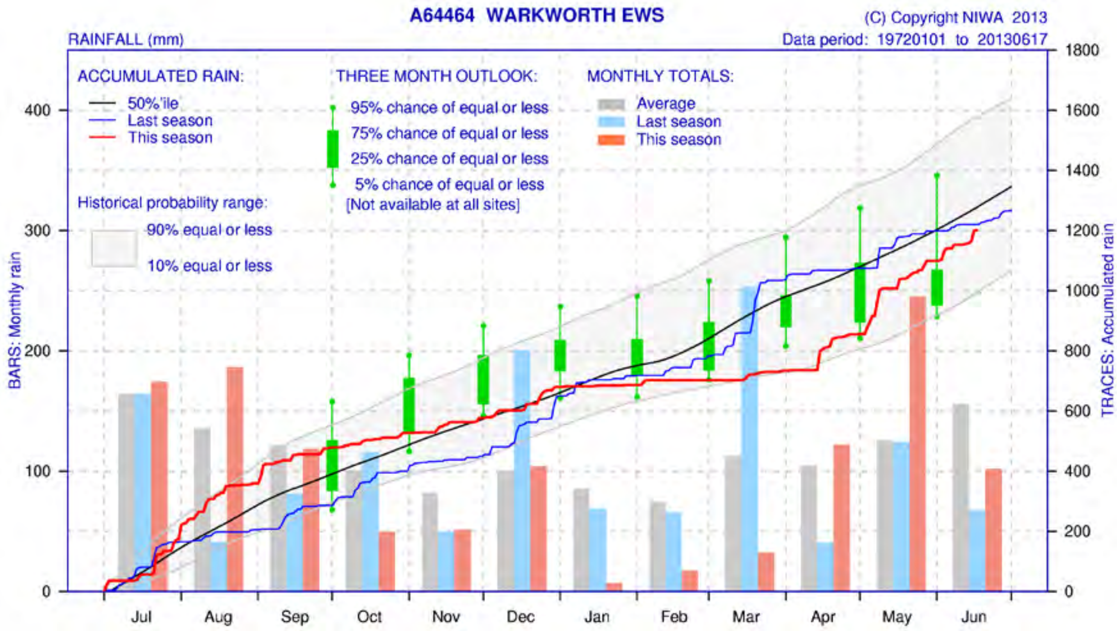
Accumulated rainfall figures
Accumulated rainfall figures shown on the following pages are taken from operational data visualization processes on the climate database. The figures show monthly rainfall totals for the long-term average (grey bars), last July to June season (blue bars) and the recent season (red bars). Daily accumulated values are indicated by the black curve (long term 50th percentile), blue curve (last season) and red curve (2012−13). The light grey shaded zone delineates the 10th and 90th percentile daily rainfall accumulations. The green 'box and whisker' plots are projected rainfall accumulations from the three-month outlooks, and are issued routinely with these figures. Rainfall projections are not available for all stations, but in any case such forecast information is not particularly relevant for this drought study.

PED accumulations
The PED figures (central figure on following pages) represent accumulations over the July–May growing year, averaged over a group of stations (number of sites indicated in figure headings). The date label corresponds to the start year; thus, the last histogram bar at year '2012' corresponds to the PED accumulation between July 2012 and May 2013.

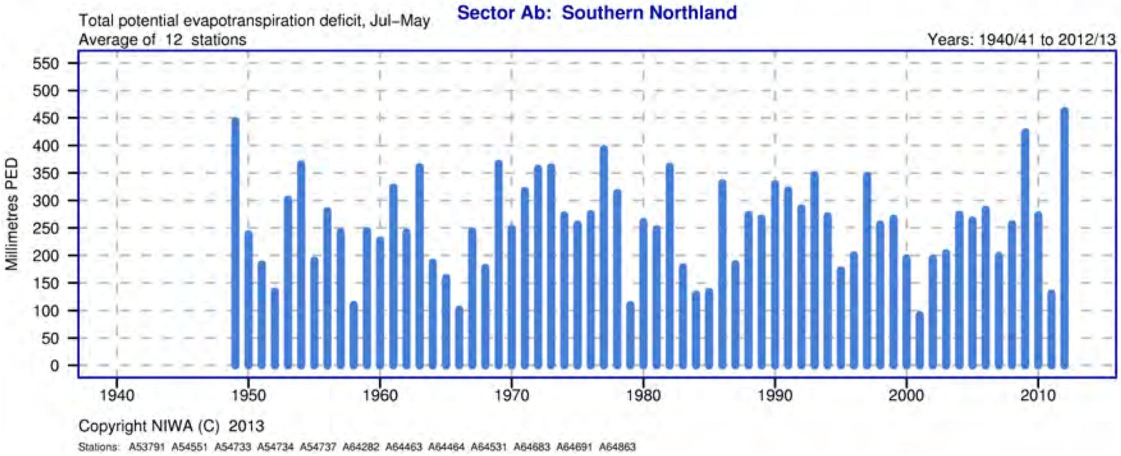
Note that the PED accumulations in these figures, and also in later Sections 3 and 4, cover the period from July to the following May. This report was finalised in Jun 2013 and so does not include the June PED data. However, by this time the drought had ended, soil moisture levels were close to field capacity everywhere, and thus accumulated PED was no longer increasing.

Figure annotations
Some annotations in the figures are abbreviated: 50%'ile is short for 50th percentile. Note that similar abbreviations occur in the pasture growth index plots.

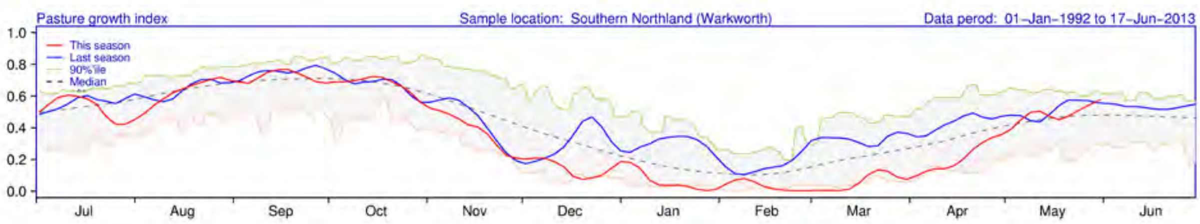
2.2 Southern Northland



Rainfall was below normal from early September and particularly low in January and February.

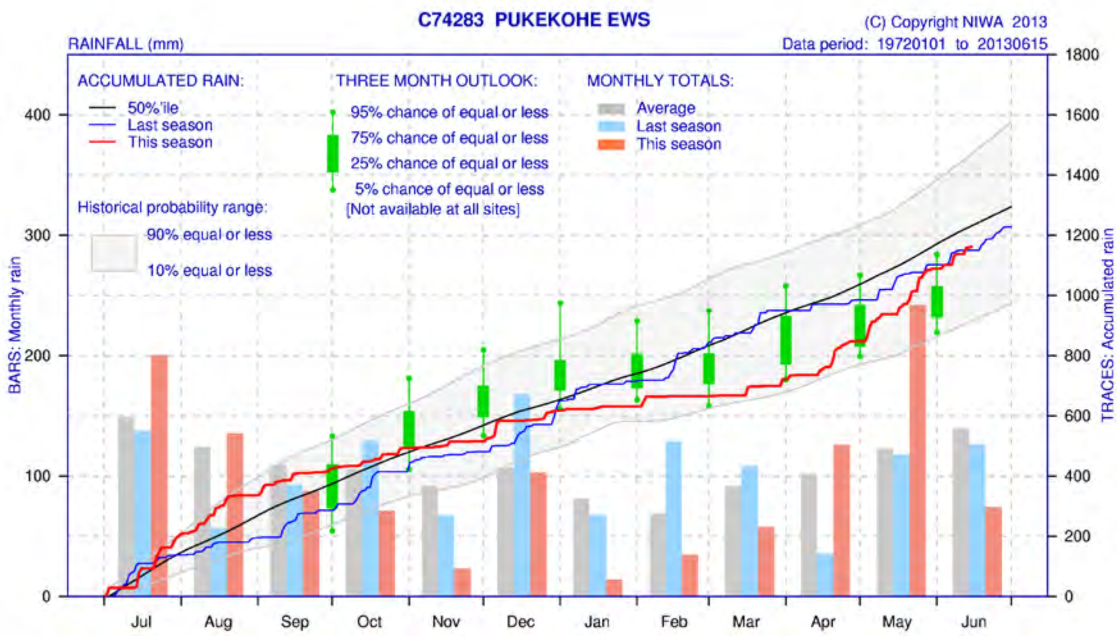


PED accumulation for 2012–13 was the highest by a few millimetres since 1949−50. A recent season, 2009–10, was also the driest since that year.

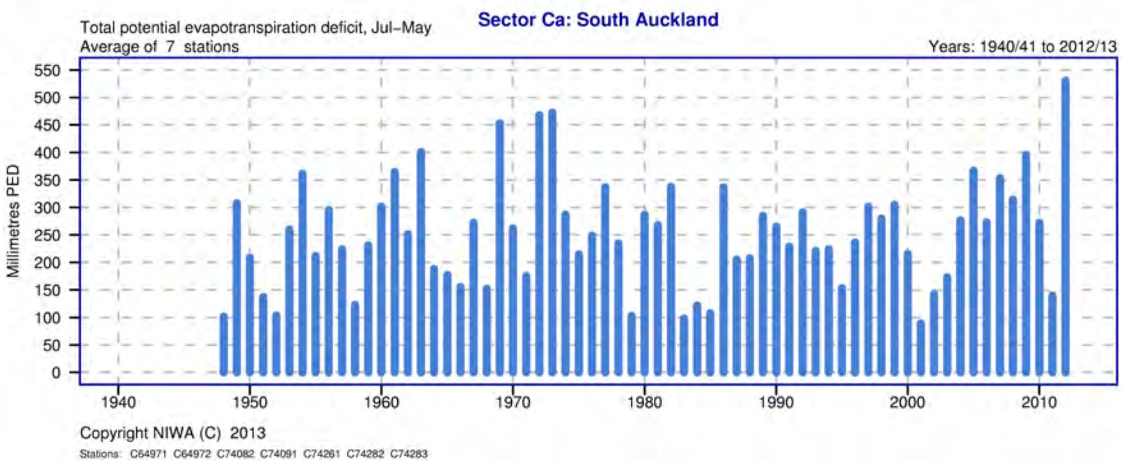


Pasture growth was likely to have been below the seasonal median (dashed line) from late October 2012 to the end of April 2013.

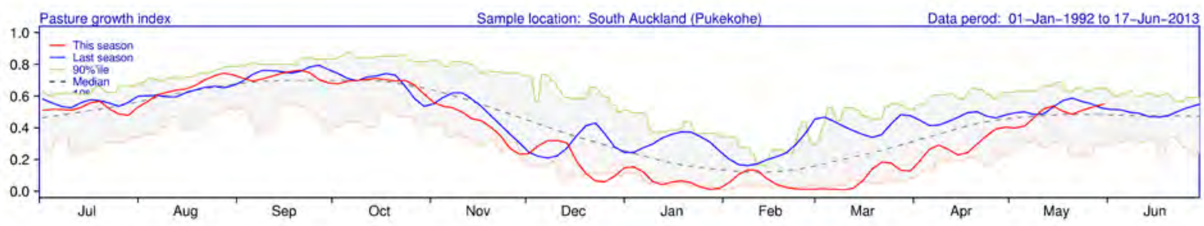
2.3 South Auckland



Rainfall was below normal from mid-September to mid-April, apart from near normal rainfall in December.

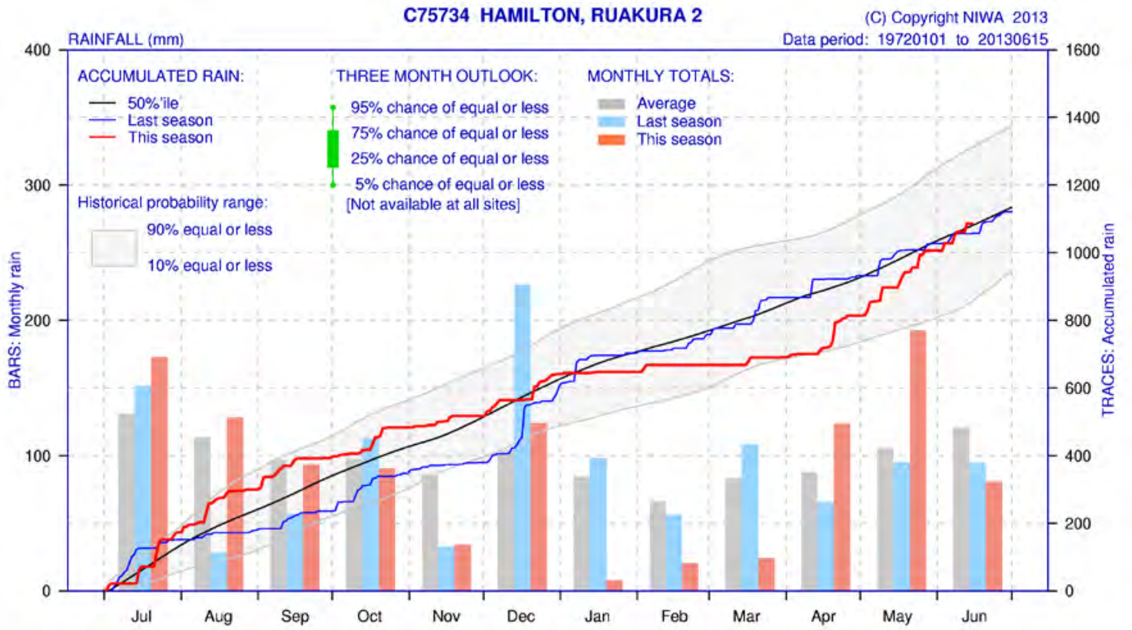


Total PED for the nine months to the end of May 2013 was the highest for the period shown, but very dry conditions also occurred in 1969−70, 1972−73 and 1973−74.

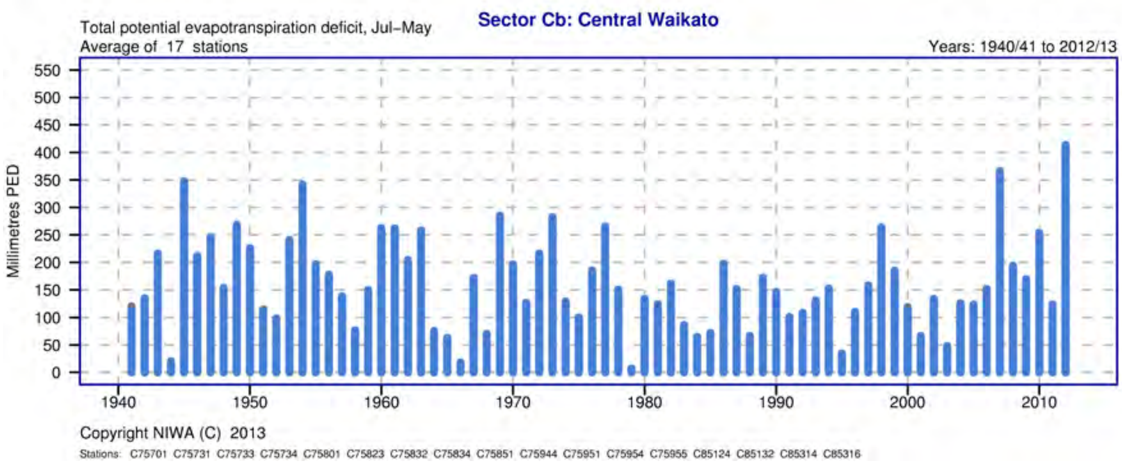


The potential for pasture growth remained below normal from late October until May.

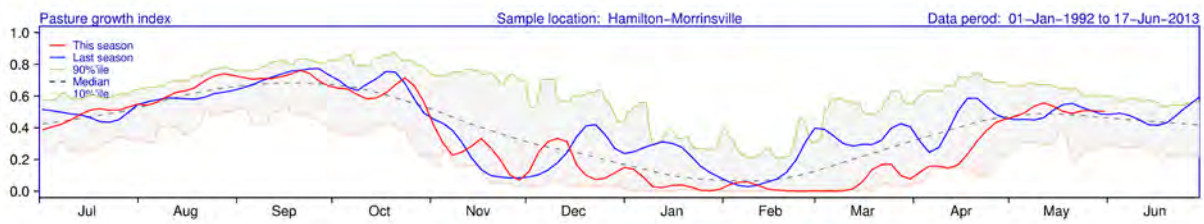
2.4 Central Waikato



Following good spring rainfall, November was drier than normal, and there was very low rainfall from January to mid April.

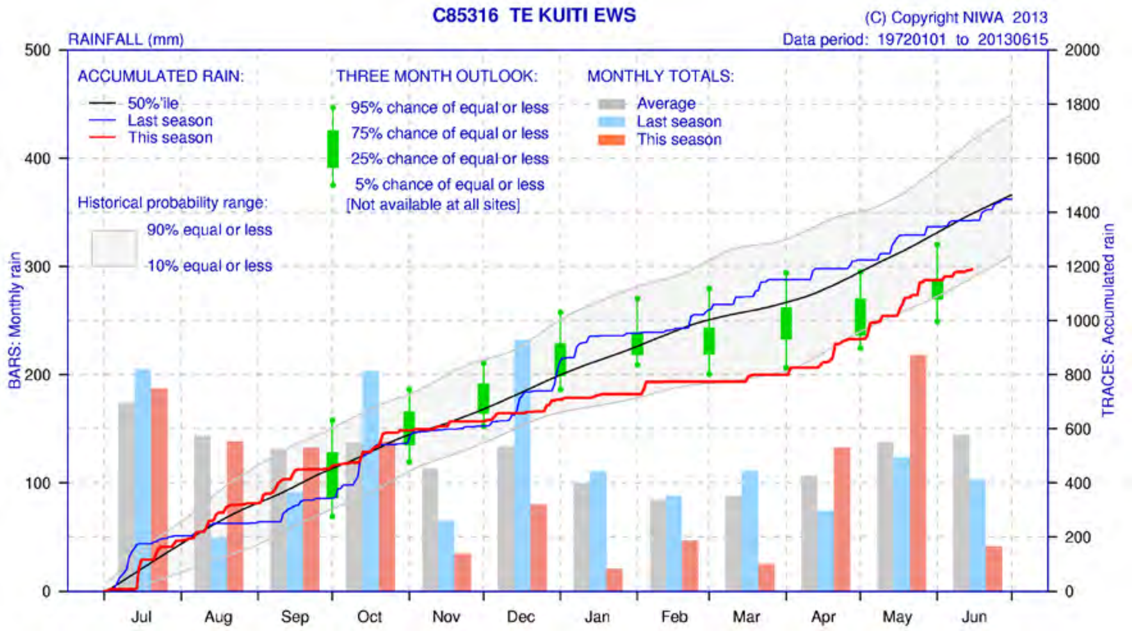


PED for 2012−13 was the highest in the available data series, although there were some similarly dry seasons in 1945−46, 1954−55, and 2007−08.

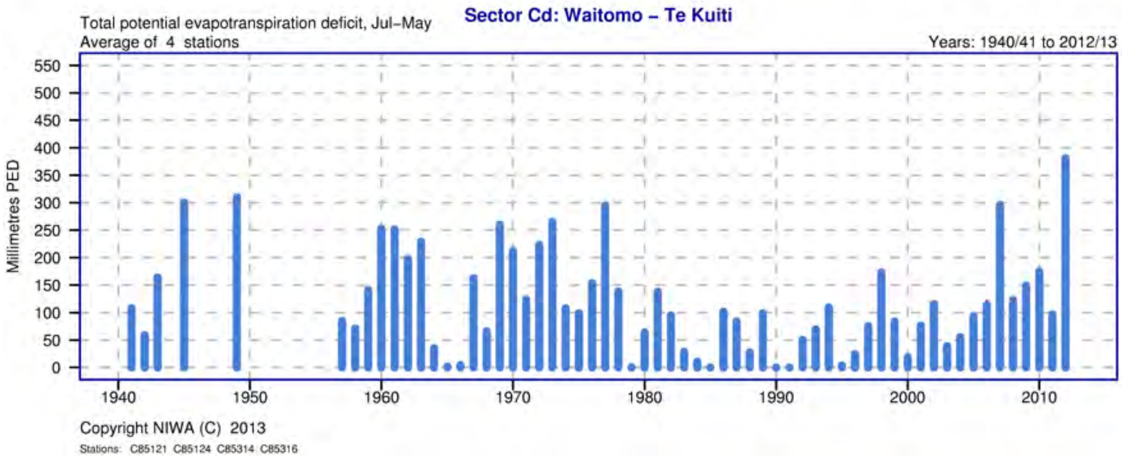


Pasture growth was likely to have been lower than normal in late spring. A brief recovery in December was followed by lower than normal growth until April.

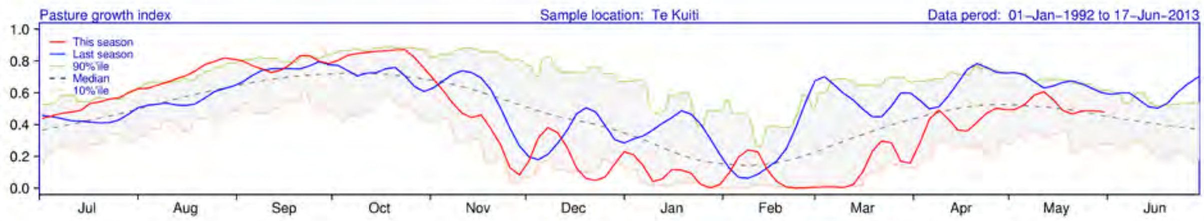
2.5 Waitomo – Te Kuiti



Rainfall at Te Kuiti was below normal from November to March. Total rainfall from 1 July to mid-April was in the lowest decile band (i.e. rarer than a 1-in-10 year event).

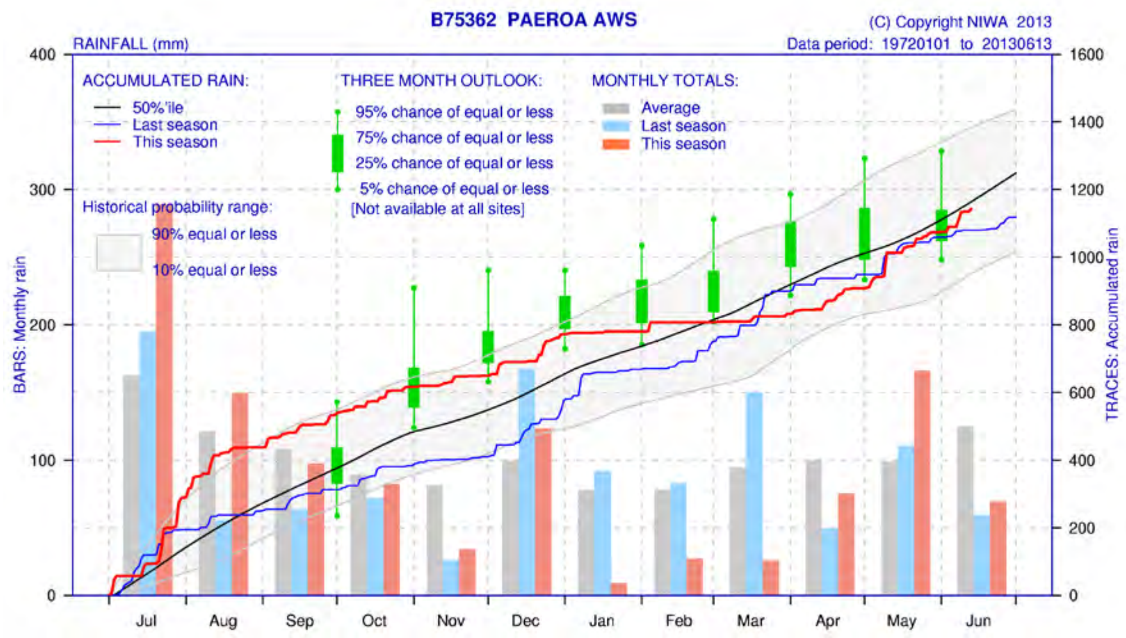


Total PED for the nine months to the end of May 2013 (~390 mm) was the highest in the available record.

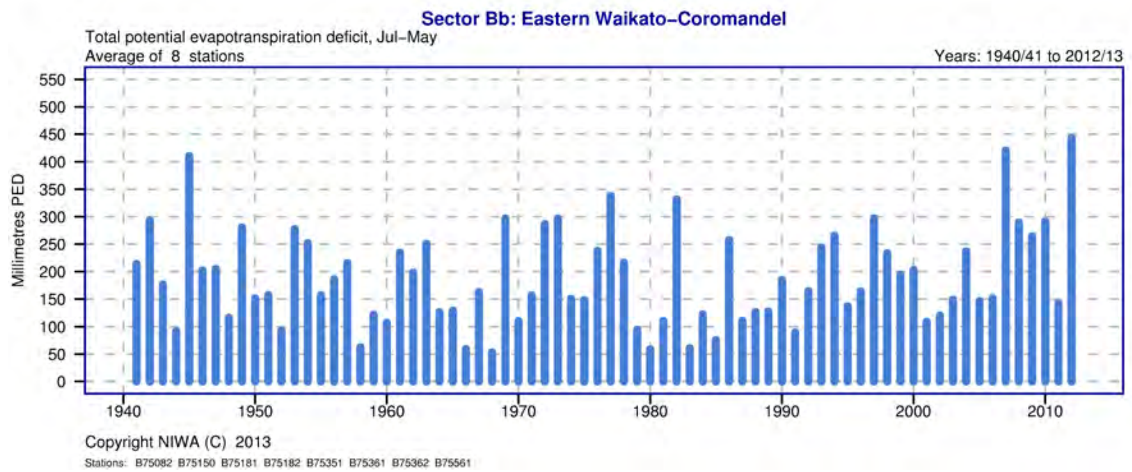


Pasture growth was likely to have been below normal from early November until the end of March, apart from a brief response to rainfall in early February.

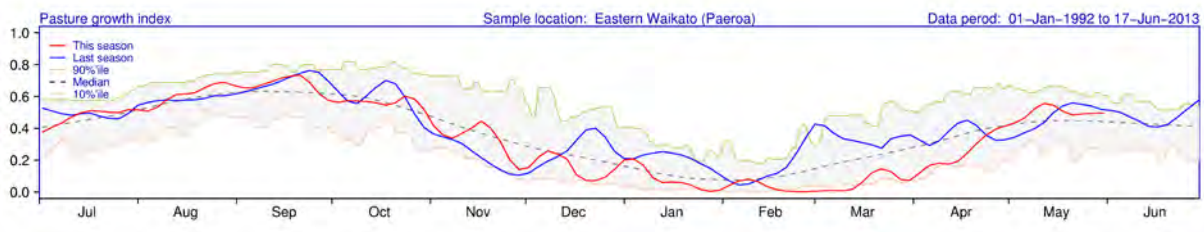
2.6 Eastern Waikato



Following a wet winter, rainfall was near normal rainfall in September, October and December, but otherwise much lower than normal. January was particularly dry.

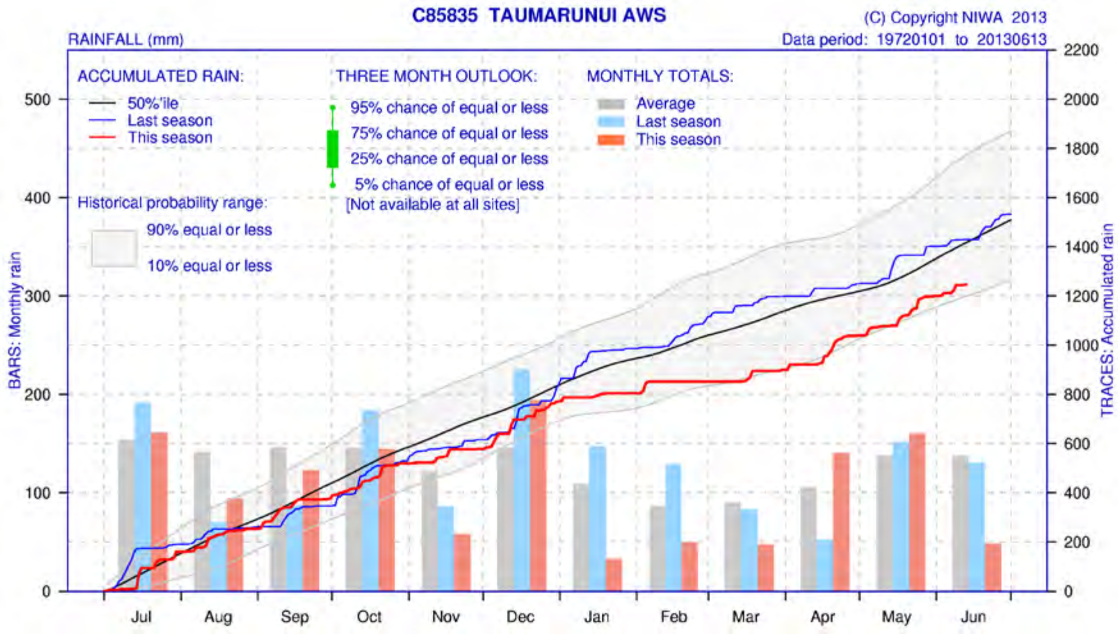


PED for 2012–13 was slightly higher than the two previously driest years of 1945–46 and 2007–08.

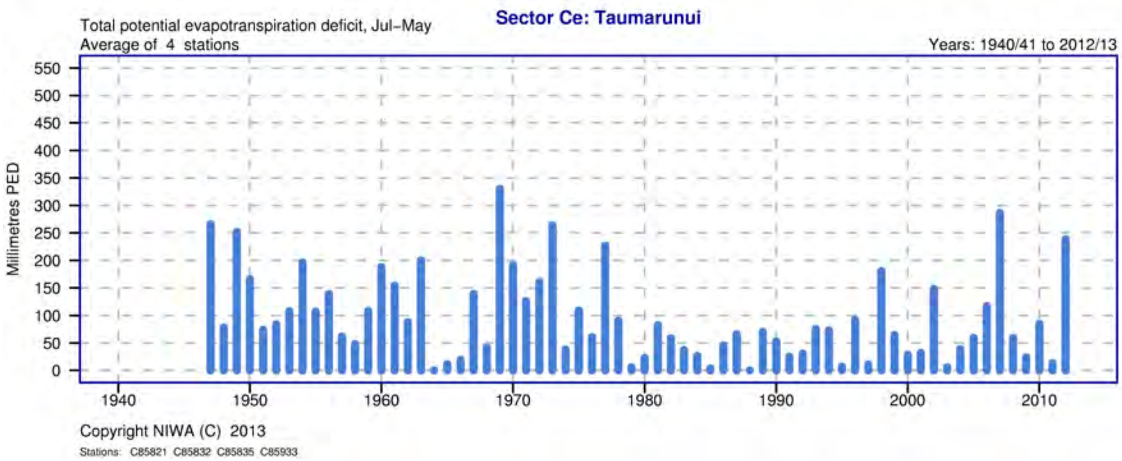


Pasture growth was likely to have been lower than normal for much of the time from late November to late-April.

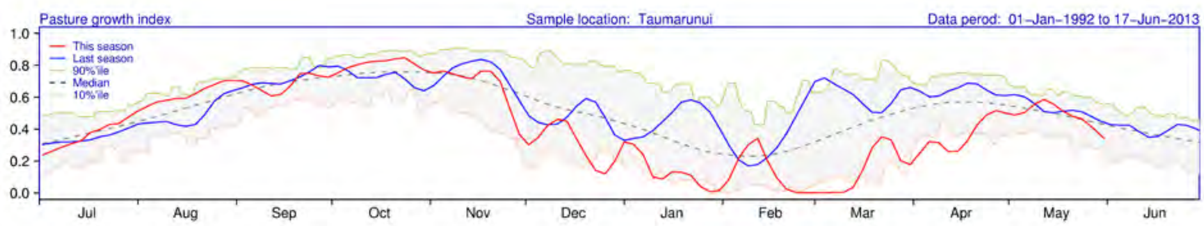
2.7 Ruapehu District – Taumarunui



November was drier than normal at Taumarunui, and rainfall was well below average from January to March.

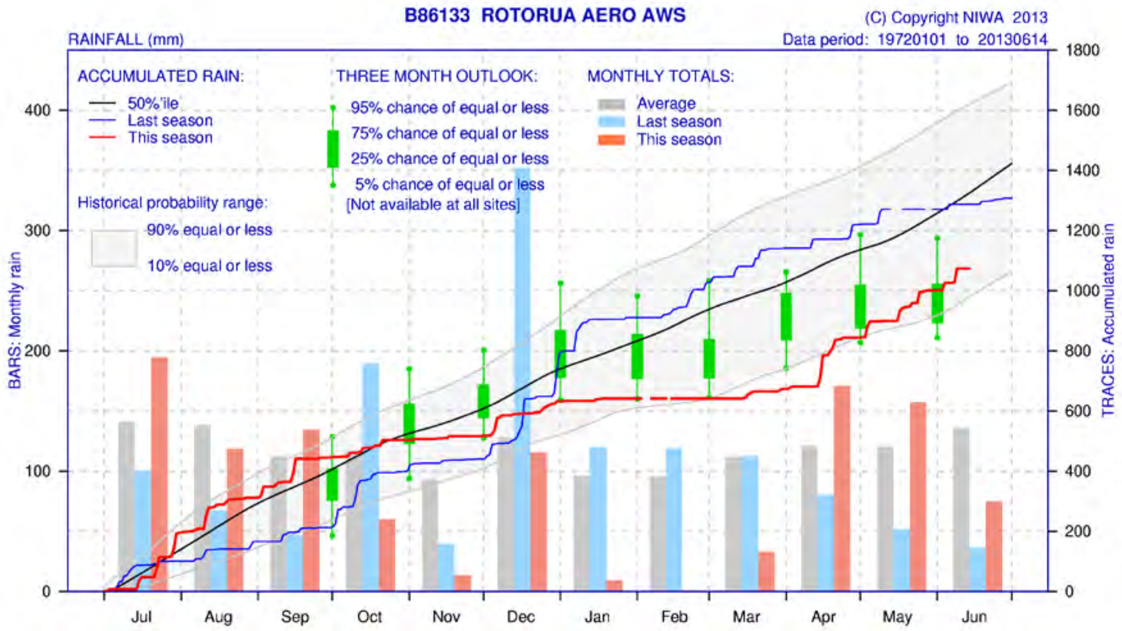


Since 1947−48, PED totals indicate that five previous seasons were drier than 2012−13.

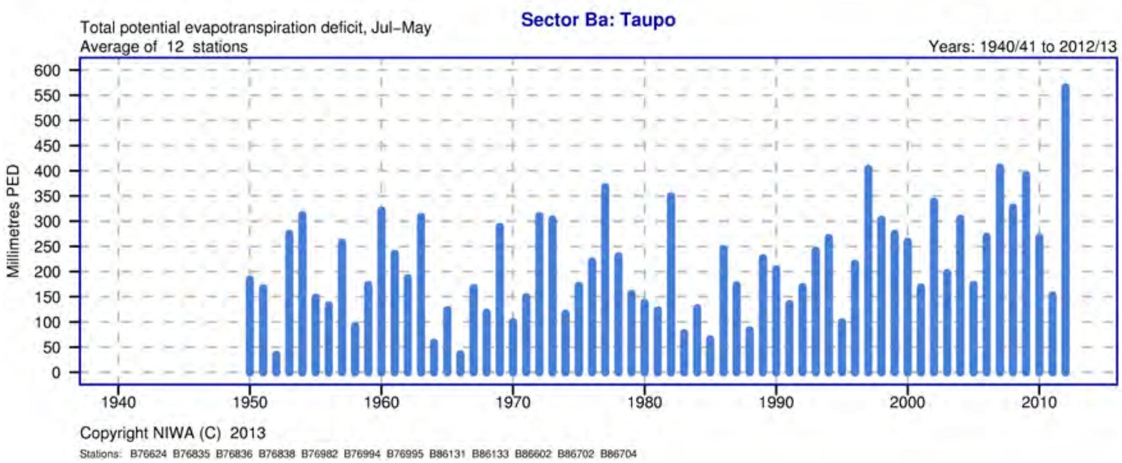


Pasture growth was mostly lower than normal from late November to early May, apart from a brief period in early February.

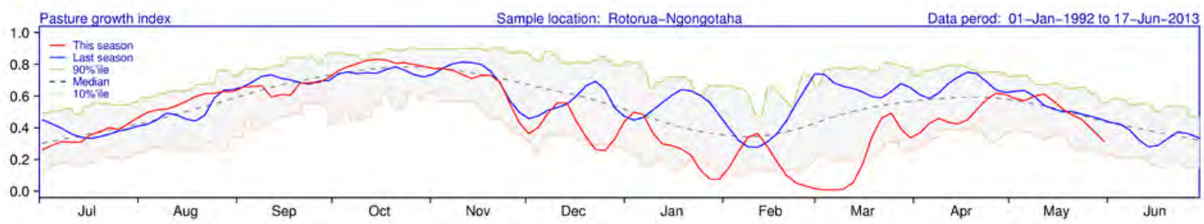
2.8 Rotorua and Taupo



Rainfall at Rotorua was lower than normal from October to mid-April 2013. During March, total rainfall since 1 July fell below the 10th percentile (i.e. rarer than a 1-in-10 year event).

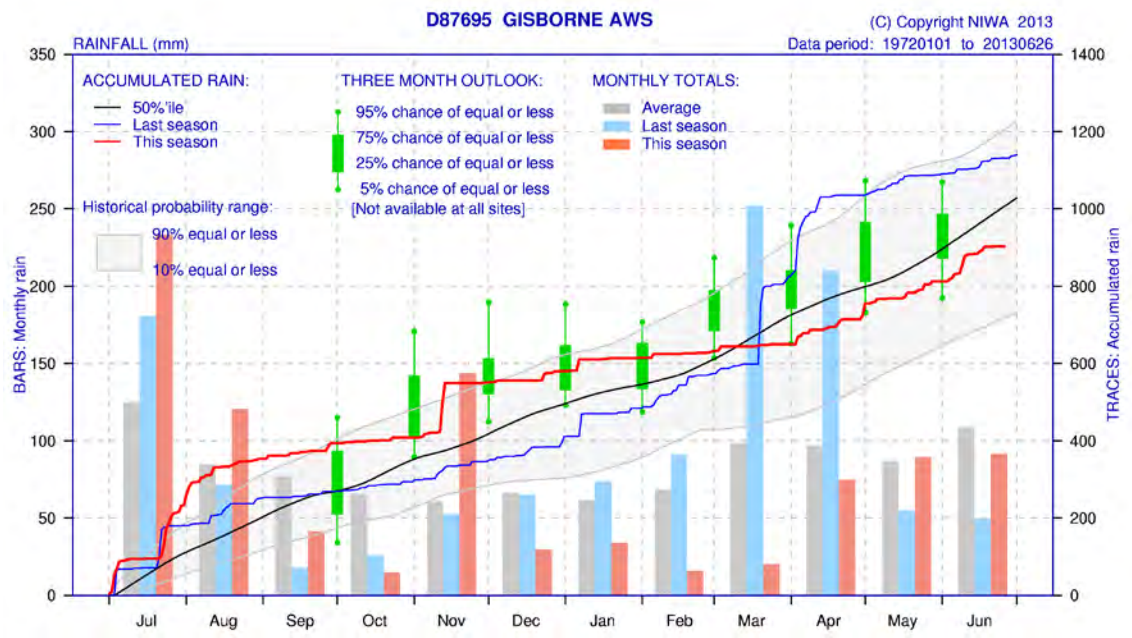


Total PED for the 2012–13 season exceeded by a large amount the July to May PED for all other seasons in this record (which started in 1950).

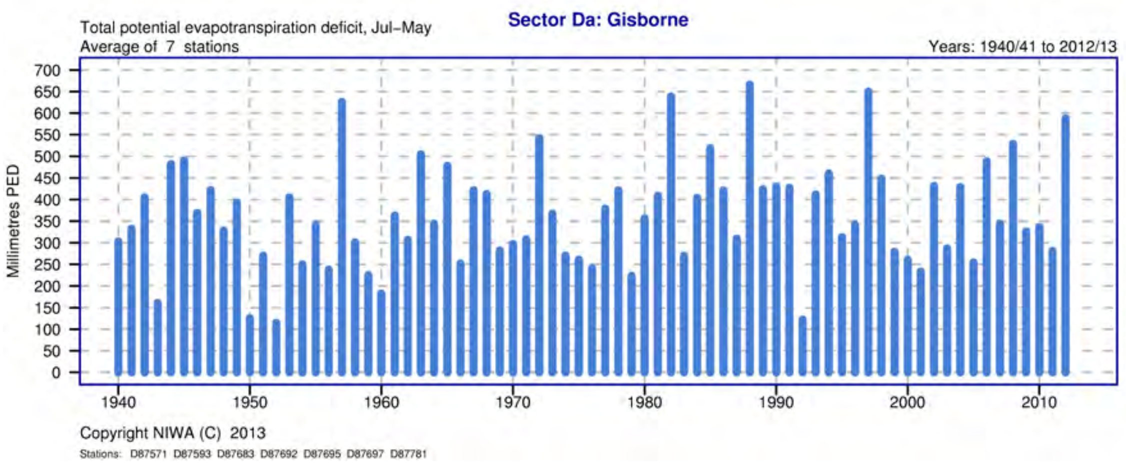


Pasture growth in the Rotorua area was likely to have been mostly below normal from late November to late April.

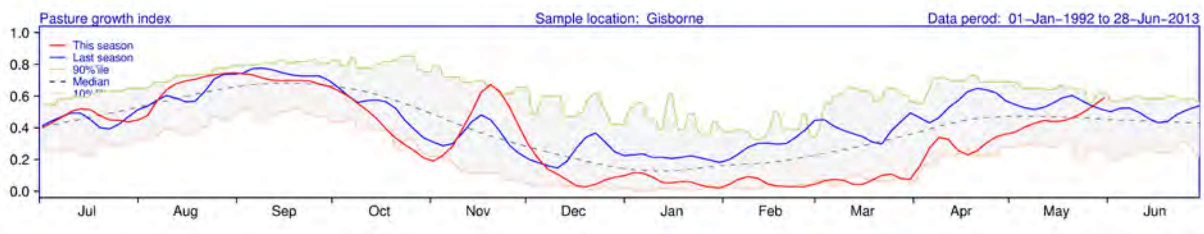
2.9 Gisborne



Spring was very dry in Gisborne prior to a wet period in mid-November. Following that event, rainfall was below normal until April.

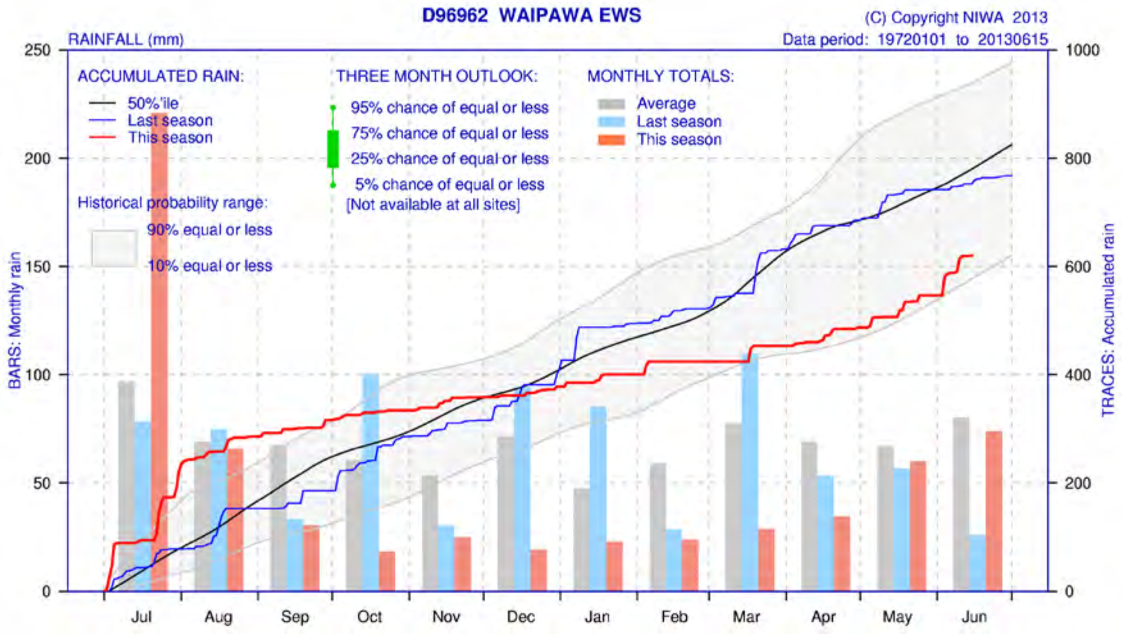


Total PED for 2012−13 was the highest since the El Nĩno drought of 1997-98, and about the fifth highest for the period of record since 1940.

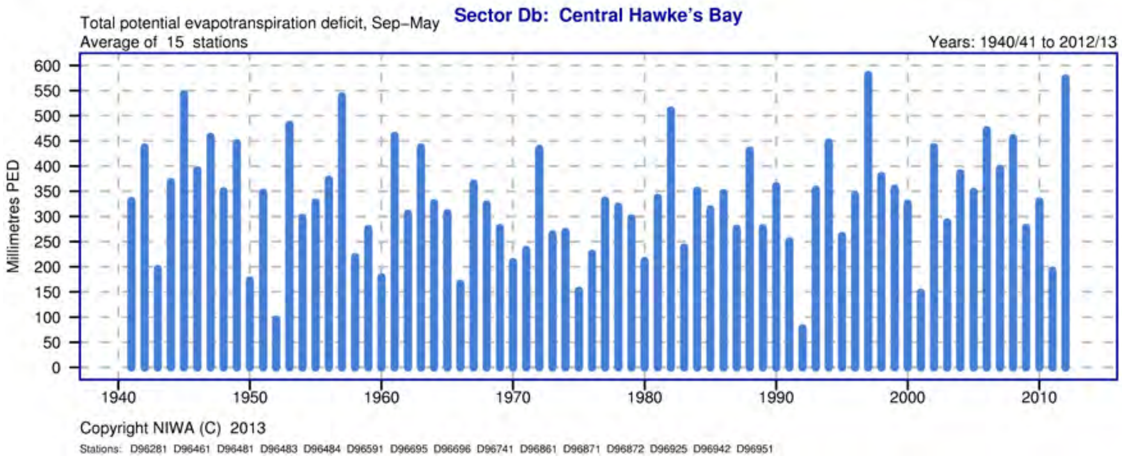


The pasture growth index shows lower than normal growth potential in October and again from mid-December to April.

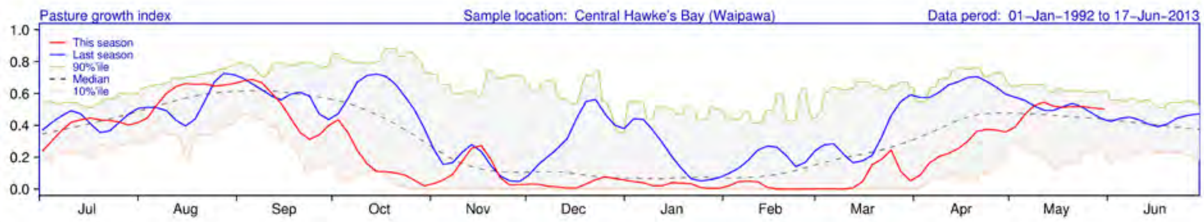
2.10 Central Hawkes Bay



Rainfall was below normal from September to April.

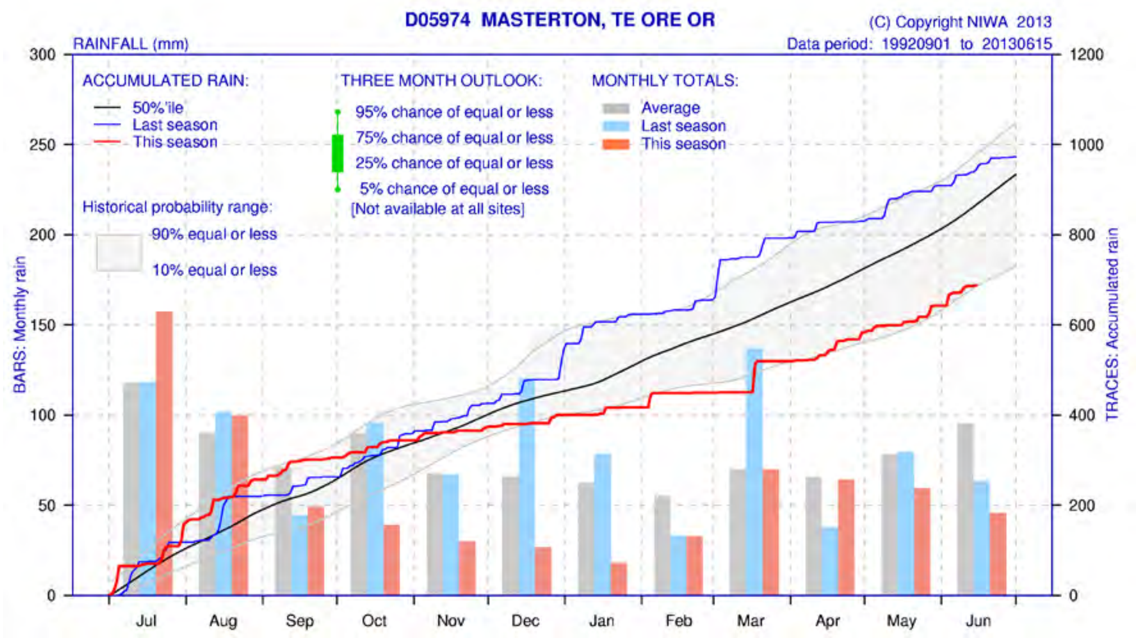


PED for 2012−13 was the second highest on record, just behind 1997–98. Very dry seasons are not unusual, and the differences between these two recent record seasons, and 1982–83, 1957−58 and 1945–46, are small.

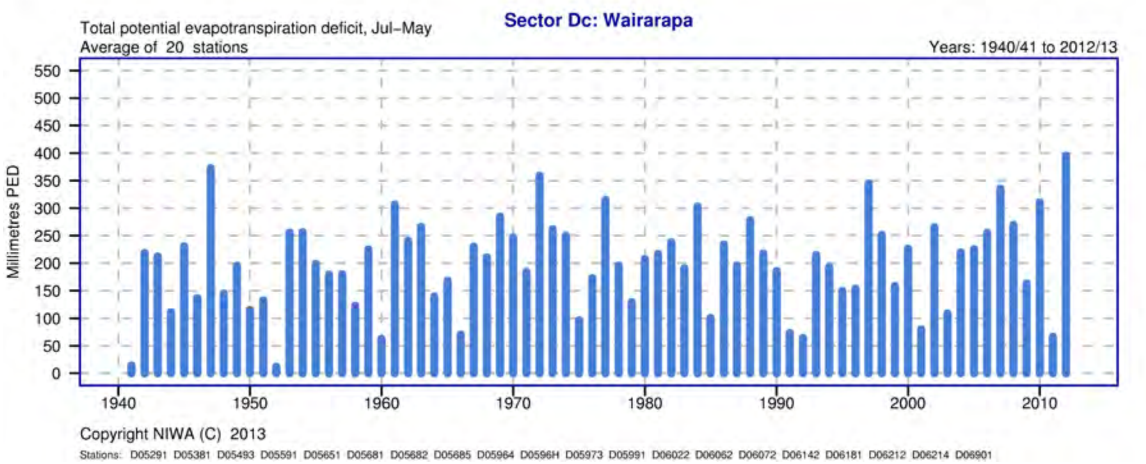


Potential pasture growth was lower than normal from about mid-September until early-May, apart from a brief recovery in November.

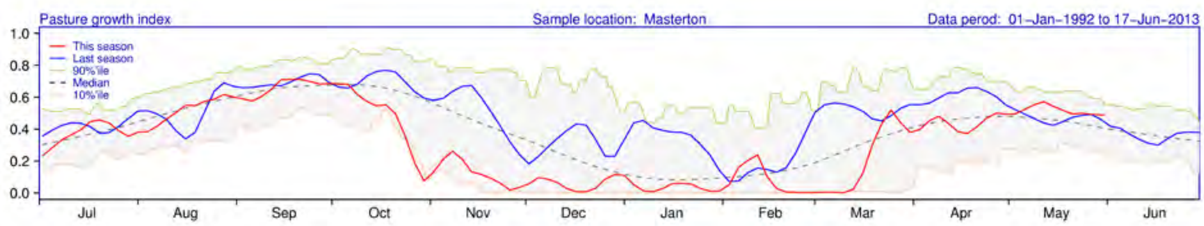
2.11 Wairarapa



Rainfall at this Masterton site was lower than normal from September to February.

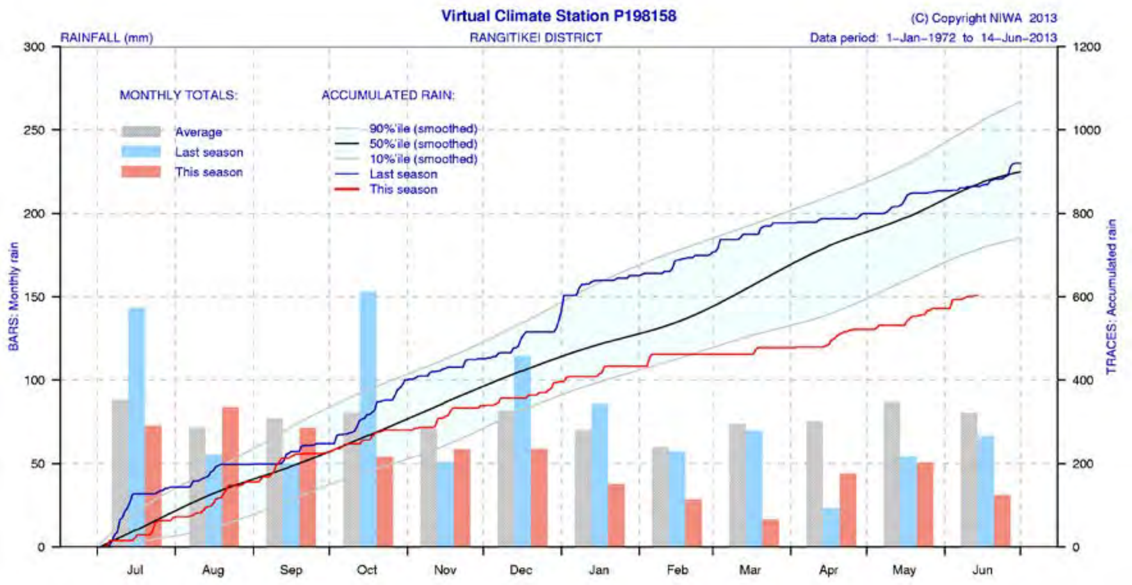


PED for 2012−13 was the highest on record, but not much above the totals for 1945–46 and 1972−73.

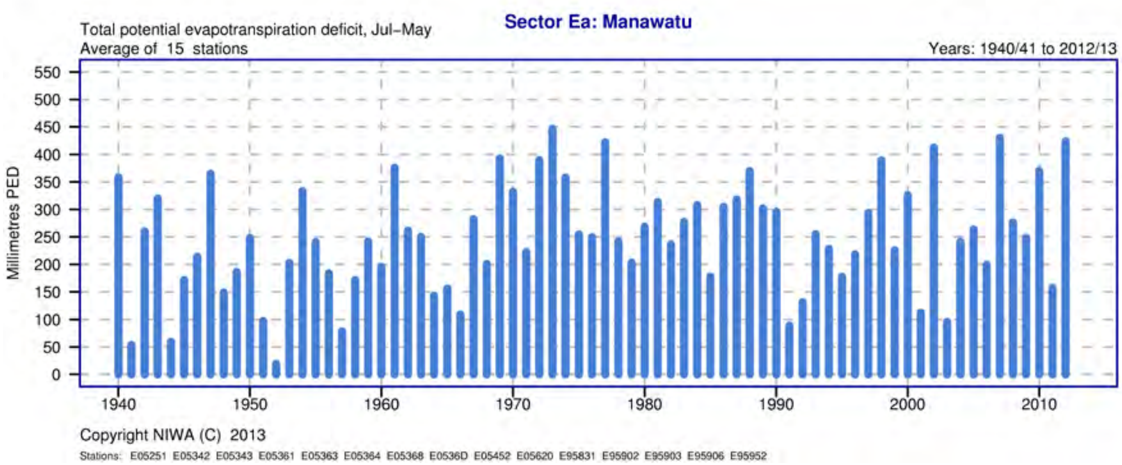


Pasture growth was mostly lower than normal from early October to mid-March, apart from a brief period in February.

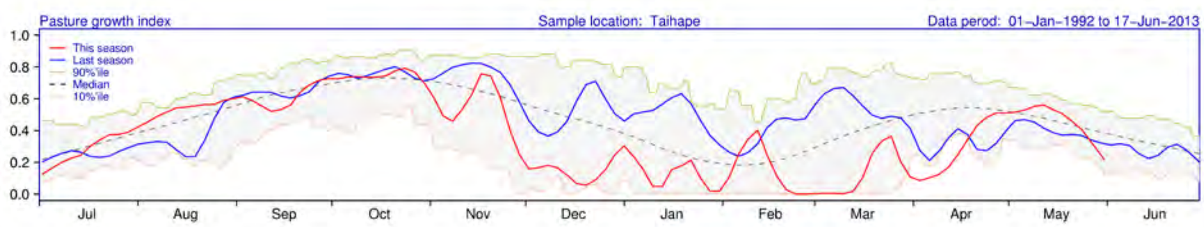
2.12 Rangitikei



Much of Rangitikei experienced lower than normal rainfall from October until May. Total rainfall since July was lower than the 10th percentile from late February through May.

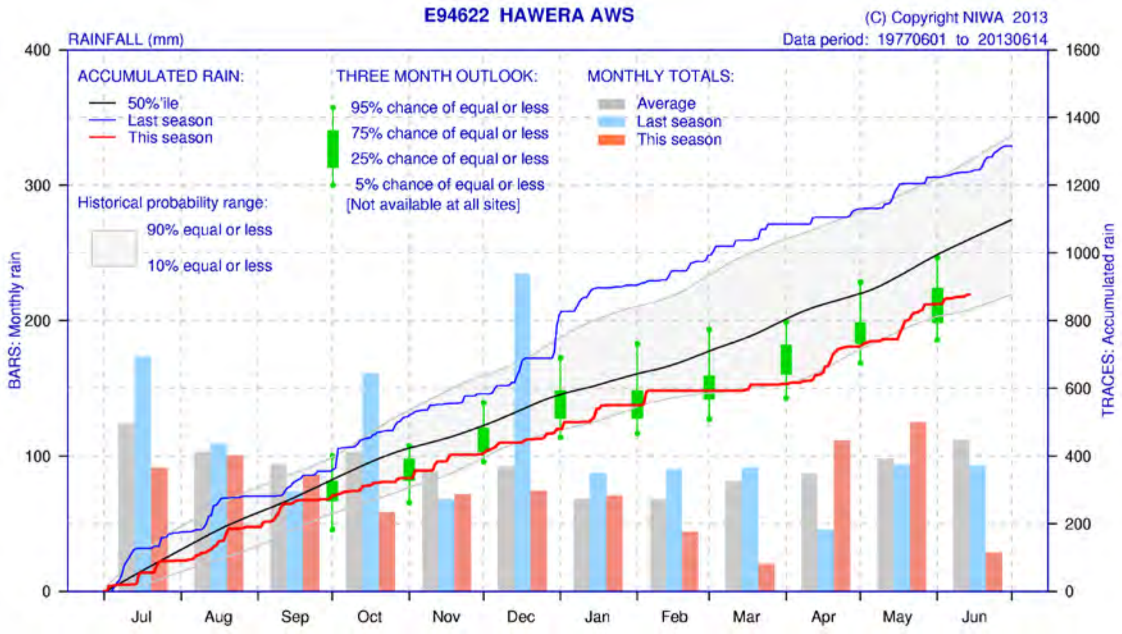


Total PED for July 2012 to May 2013 in the Manawatu was high but was exceeded in 2007−08 and 1973−74.

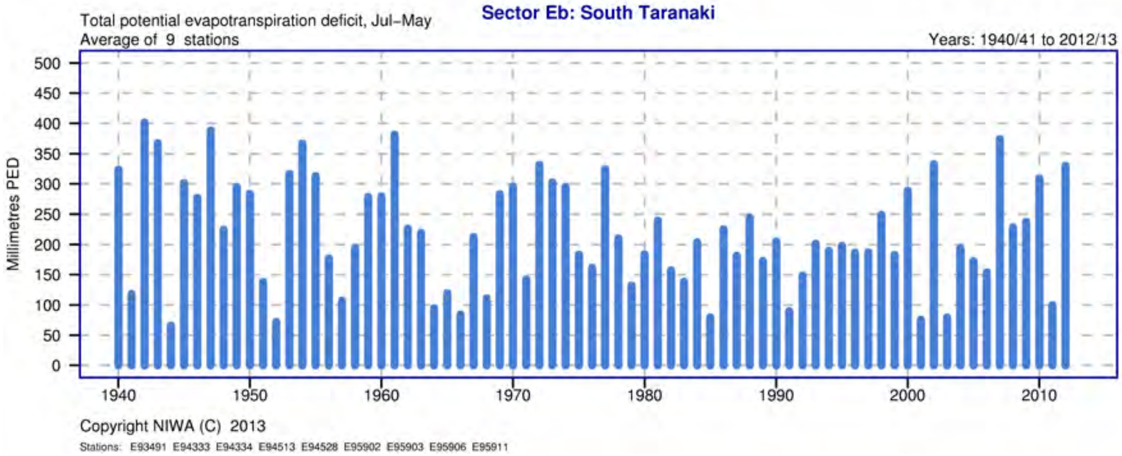


Around Taihape, the potential for pasture growth was lower than normal for much of the summer.

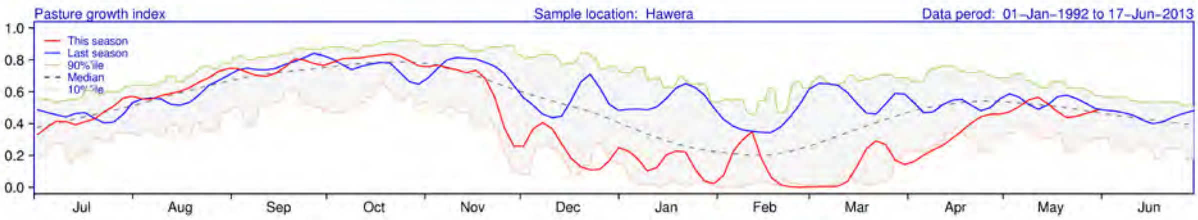
2.13 South Taranaki



Hawera AWS recorded less than normal rainfall from October to March. By early April total rainfall since 1 July was lower than the 10^{th} percentile.

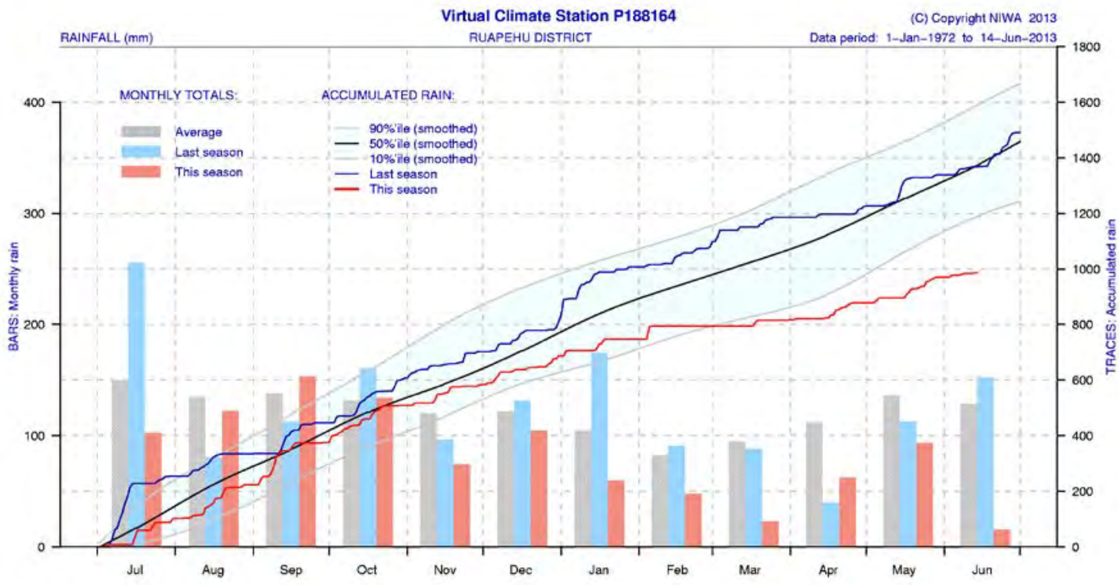


Total PED for 2012−13 was above average, but not particularly unusual.



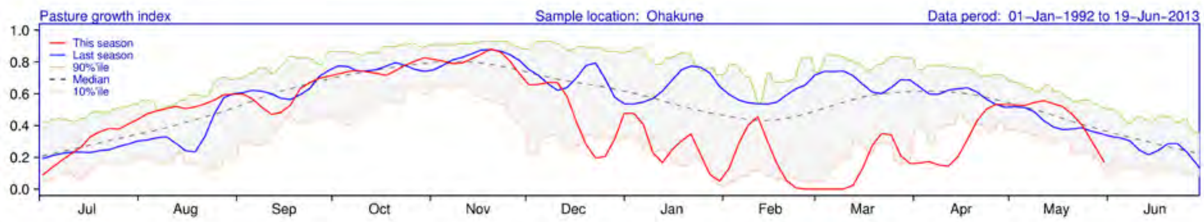
Pasture production was likely to have been below normal from about mid-November until late-April, apart from brief responses to rainfall at times, particularly in December and February.

2.14 Ruapehu District– Ohakune



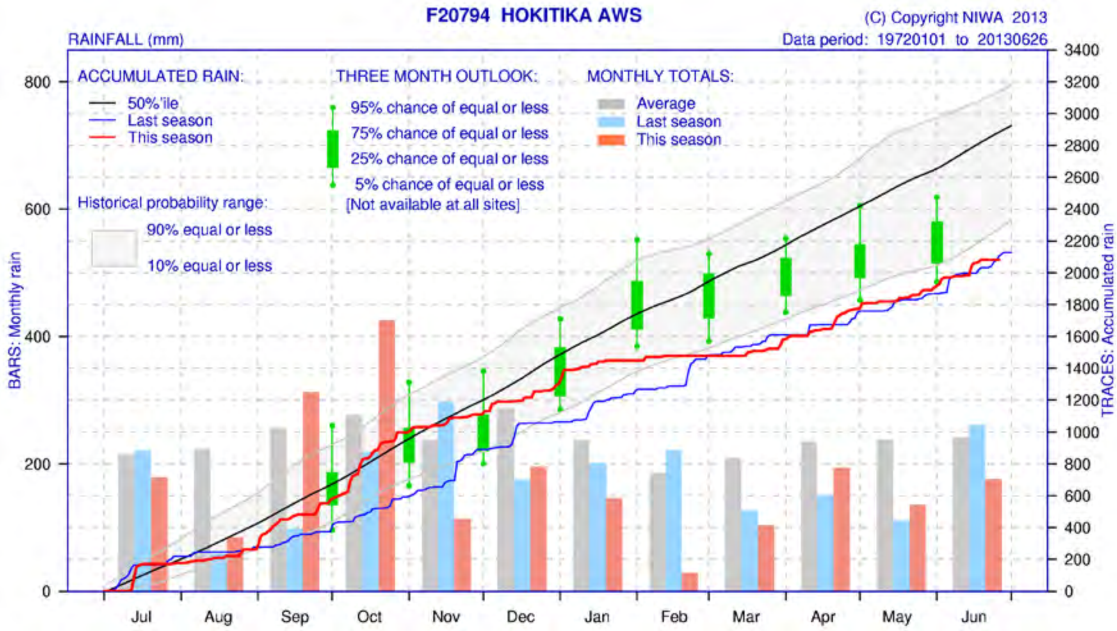
Rainfall near Ohakune was lower than normal from mid-October, and from late-March to early-June, the seasonal rainfall total from 1 July was lower than the 10th percentile.

No PED time series was calculated for this site due to this being a relatively high elevation region. At altitudes above 500 m, we are cautious about calculating potential evapotranspiration, (and hence PED), as the relationships between rainfall, topography and evaporation have not been widely studied in this environment, and there is generally little climate data available (Tait and Woods, 2009).

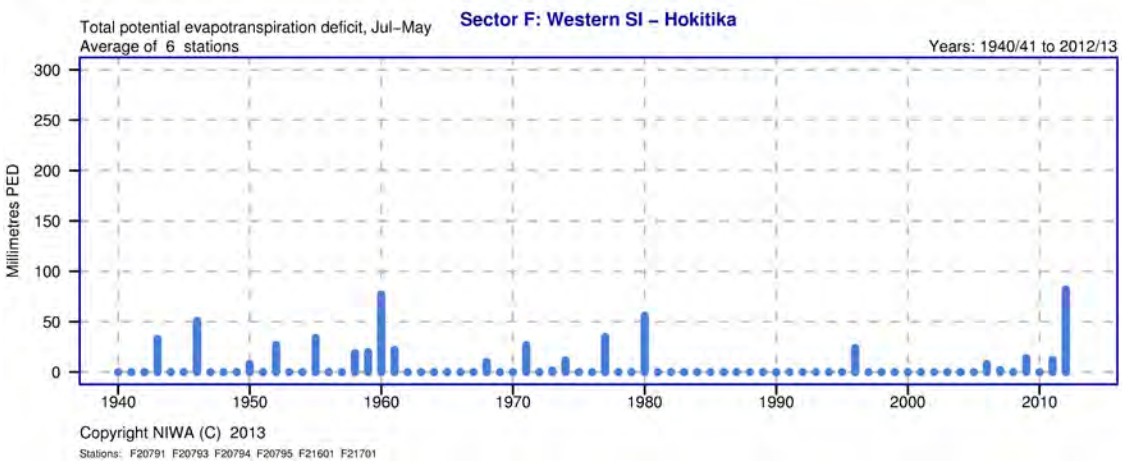


Pasture production was likely to have been below normal from about mid-December until late-April, apart from brief responses to rainfall at times.

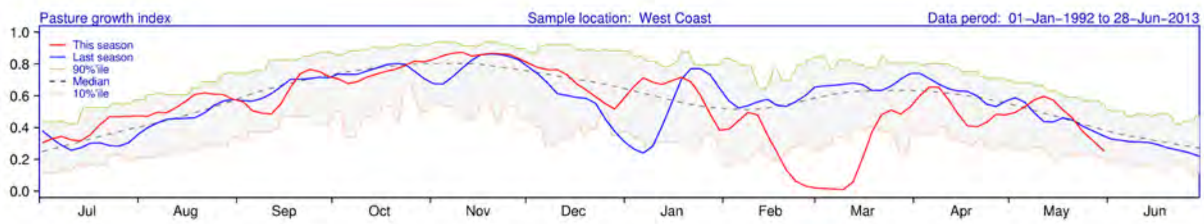
2.15 West Coast – Hokitika



Rainfall in Hokitika was lower than normal from November to May, with the driest period occurring from early January to late March.

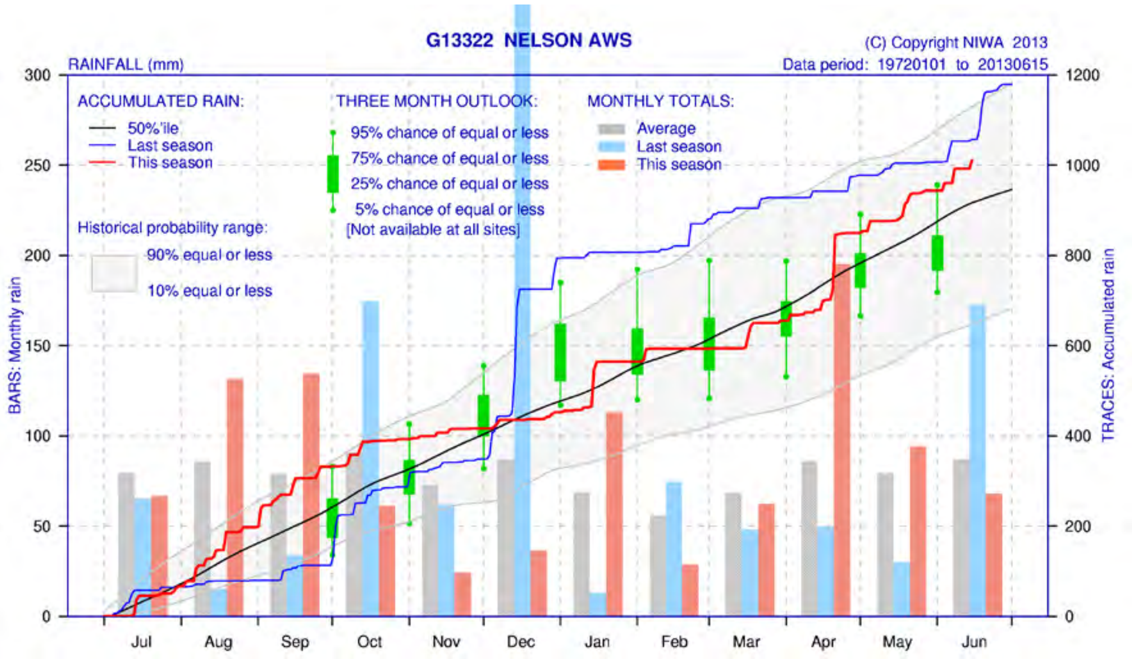


PED accumulation on the West Coast is typically infrequent, and when dry periods do occur, accumulated total PED is typically low compared to elsewhere in New Zealand. PED for 2012–13 was the highest on record for the sample area.

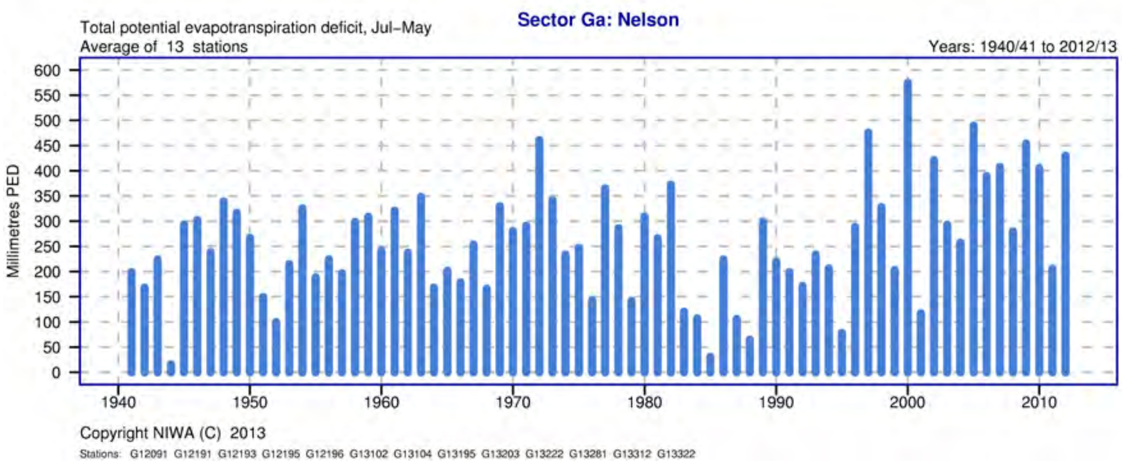


The pasture growth index shows a low growth period from mid-February to mid-March.

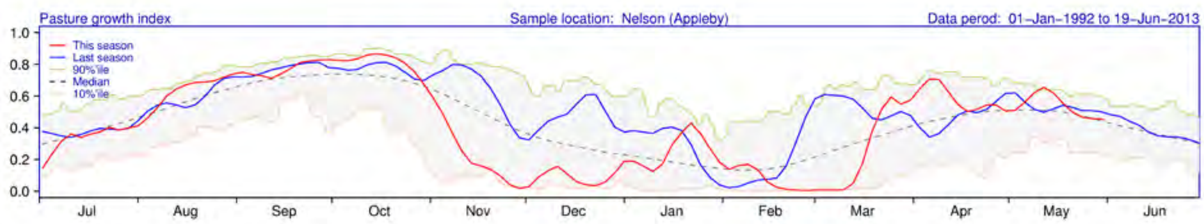
2.16 Nelson



In parts of the Tasman District, early season rainfalls were above normal. There was a long period of dry weather from mid-October to mid-January and from February to mid-March.

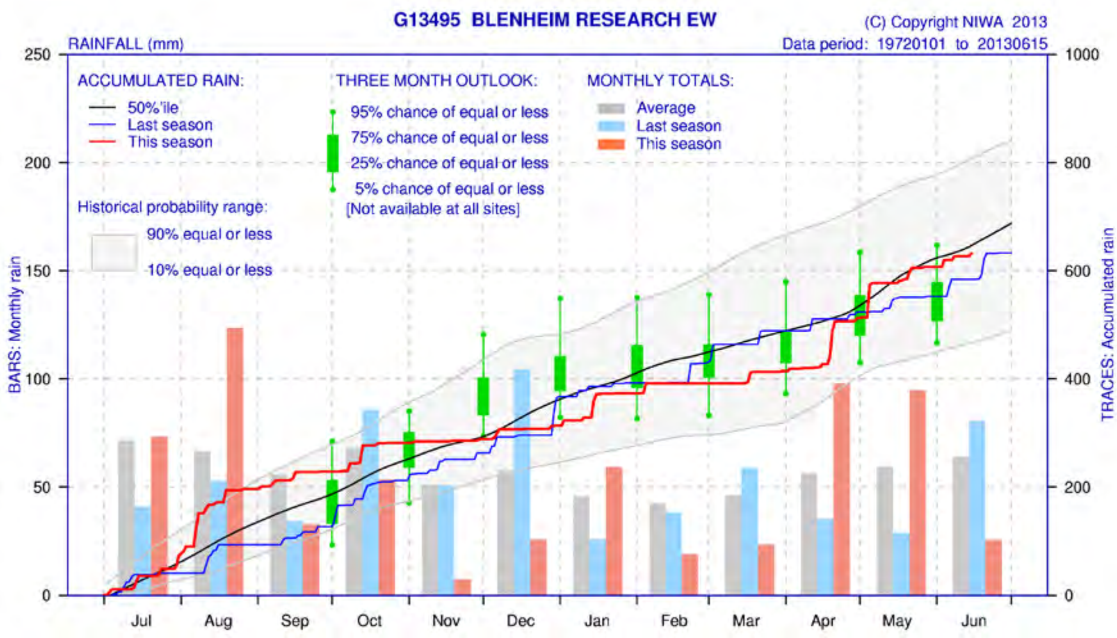


PED accumulation in the Nelson area during 2012−13 was higher than normal, but was similar to or less than several other recent seasons.

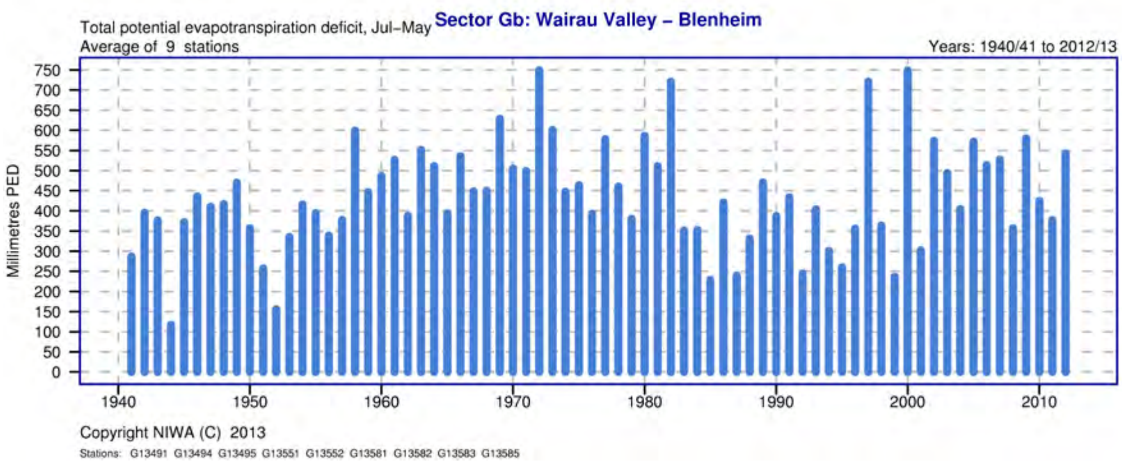


Potential pasture growth was likely to have been lower than normal from early November to late January, and again in much of February and March.

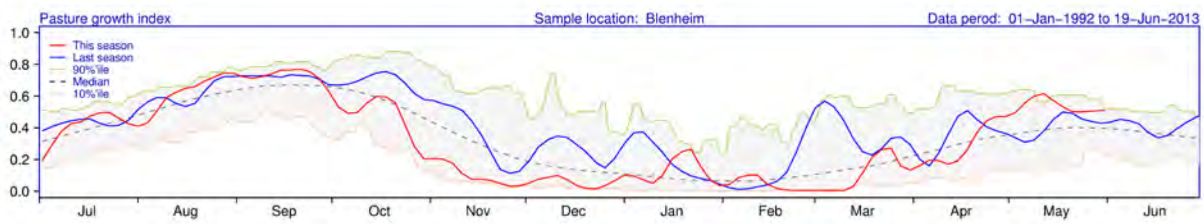
2.17 Marlborough



Marlborough experienced long dry spells, particularly from mid-October until the rainfall of mid-January, and again following that until mid-April.

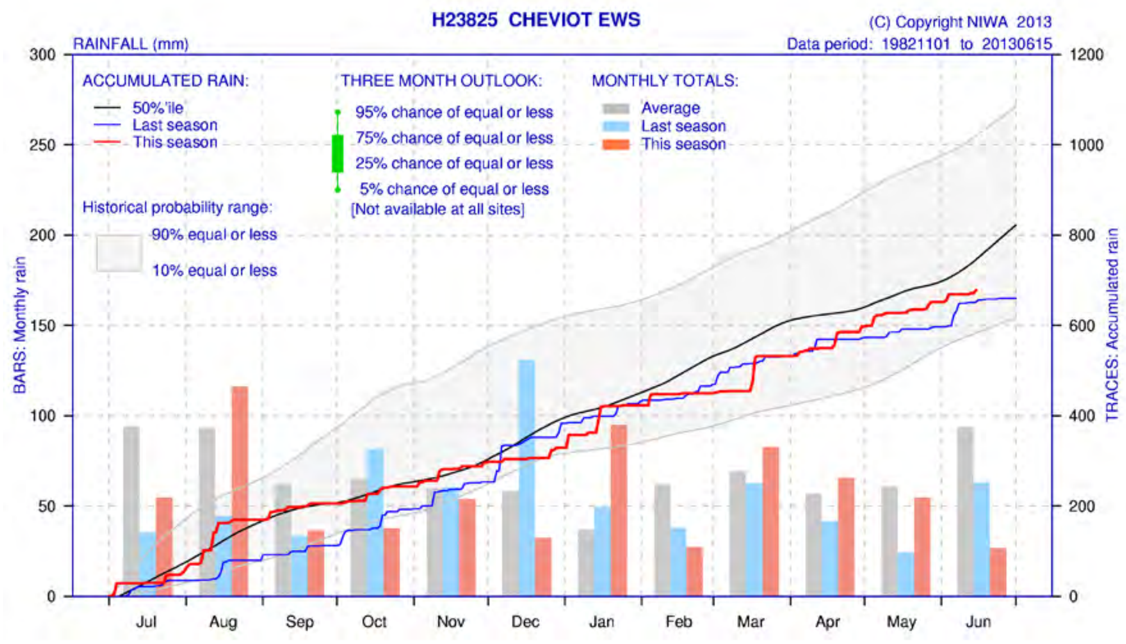


PED accumulation for the growing season to the end of May was higher than average, but not particularly unusual.

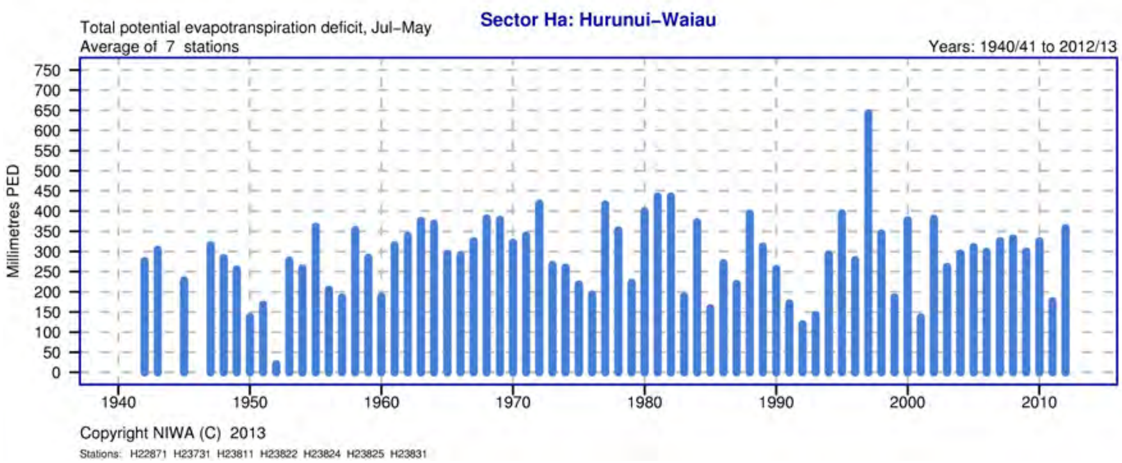


Pasture growth was likely to have been below normal from about mid-October until early January, and during much of February and March.

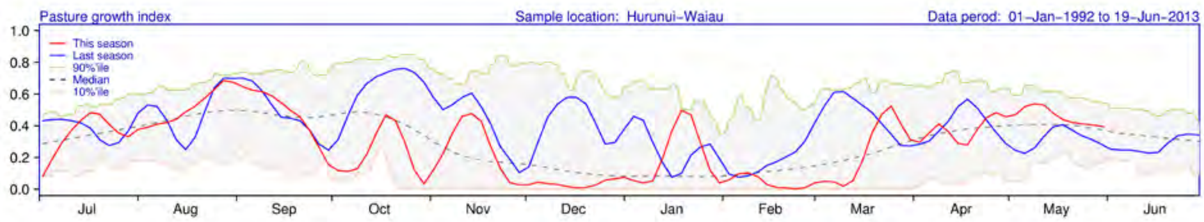
2.18 Hurunui-Waiau



Rainfall recorded at Cheviot was lower than normal from September to December and again in February.

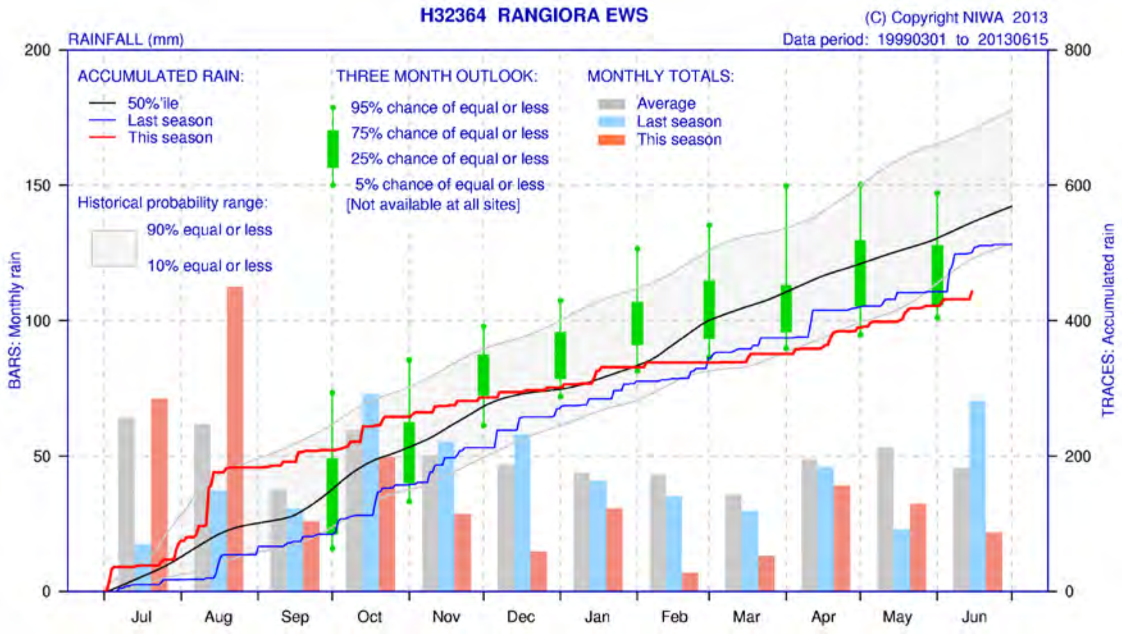


The driest conditions in the Hurunui-Waiau region very likely occurred in the 1997–98 El Niño drought; however the PED sample size used here was small due to the limited number of rainfall stations reporting in this area. PED for 2012–13 to the end of May was not particularly unusual.

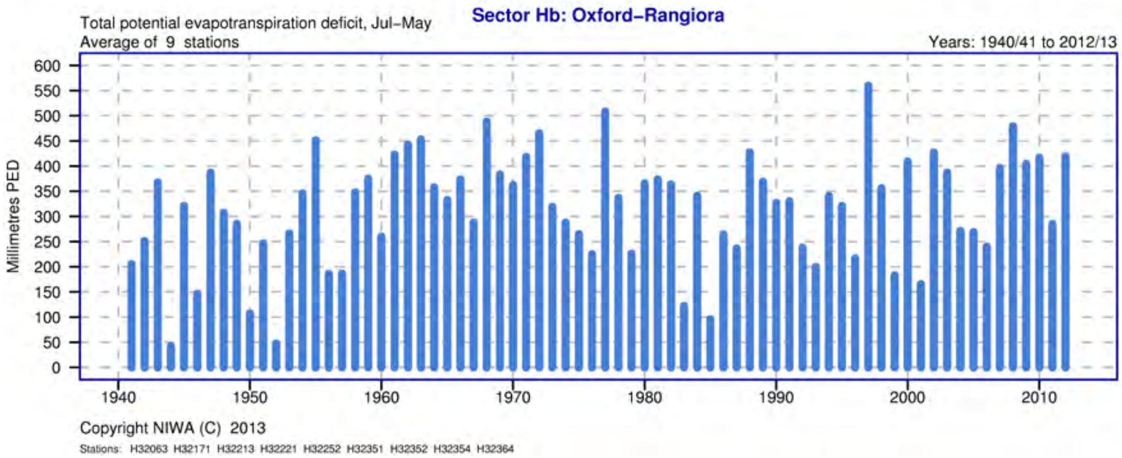


Pasture growth was likely to have been lower than normal from mid-November to early January, and again in February and March.

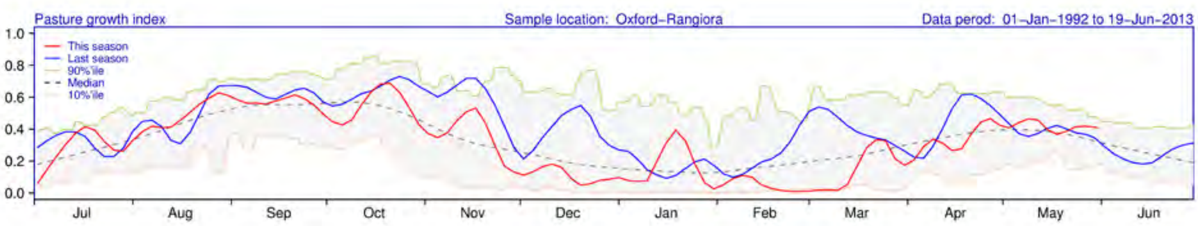
2.19 Waimakariri



Rangiora recorded high winter rainfalls but was drier than average from about mid-August.

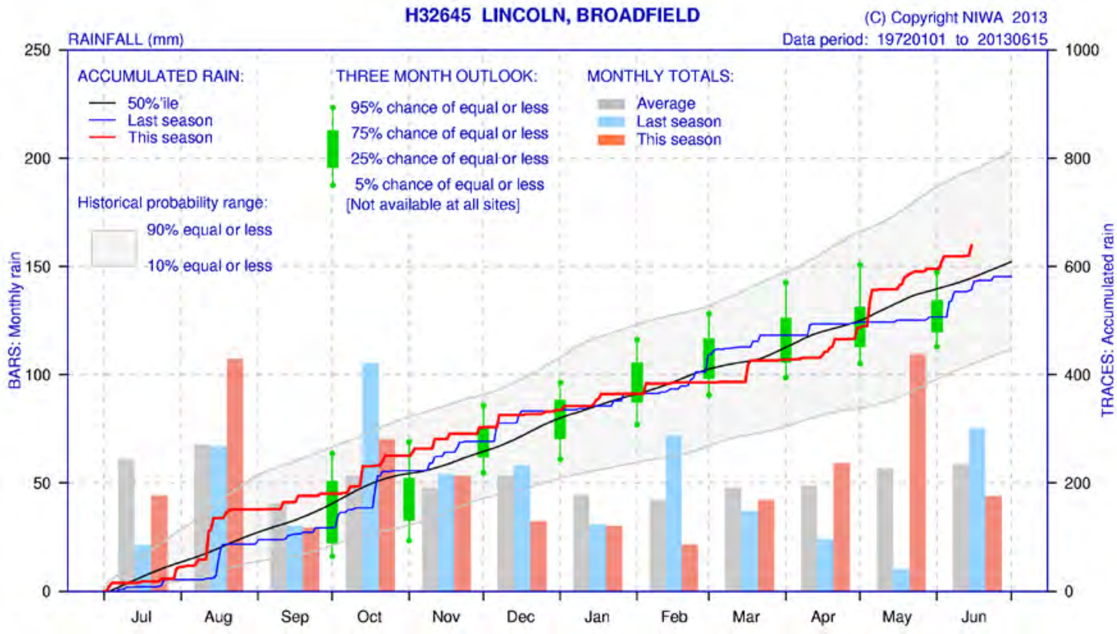


Total PED for July to May was above normal but lower than at least 8 other seasons during the period of available record.

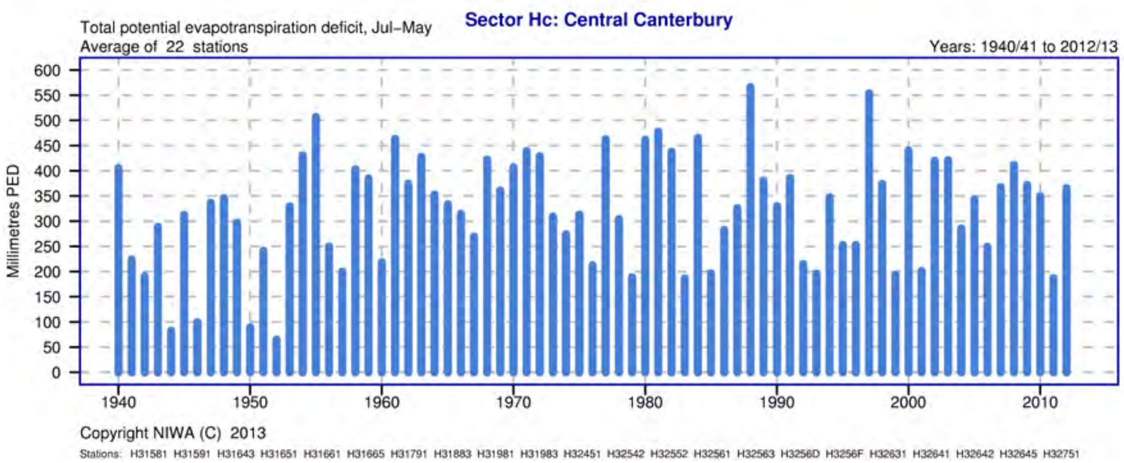


Pasture growth was likely to have been lower than normal from mid-November to early January, and again in February and March.

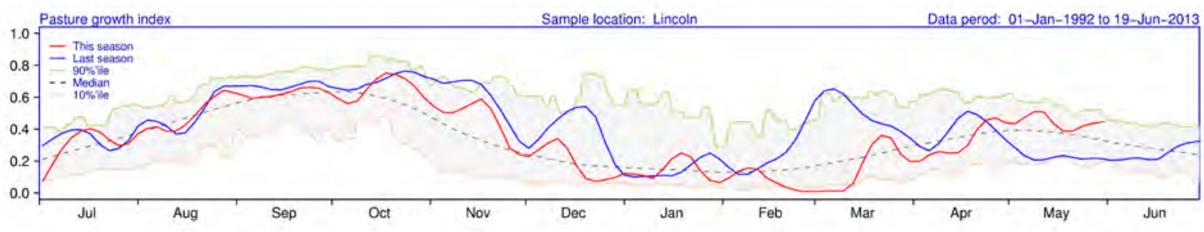
2.20 Lincoln-Flaxmere



Rainfall recorded at Lincoln was lower than normal in September, and from December to March.

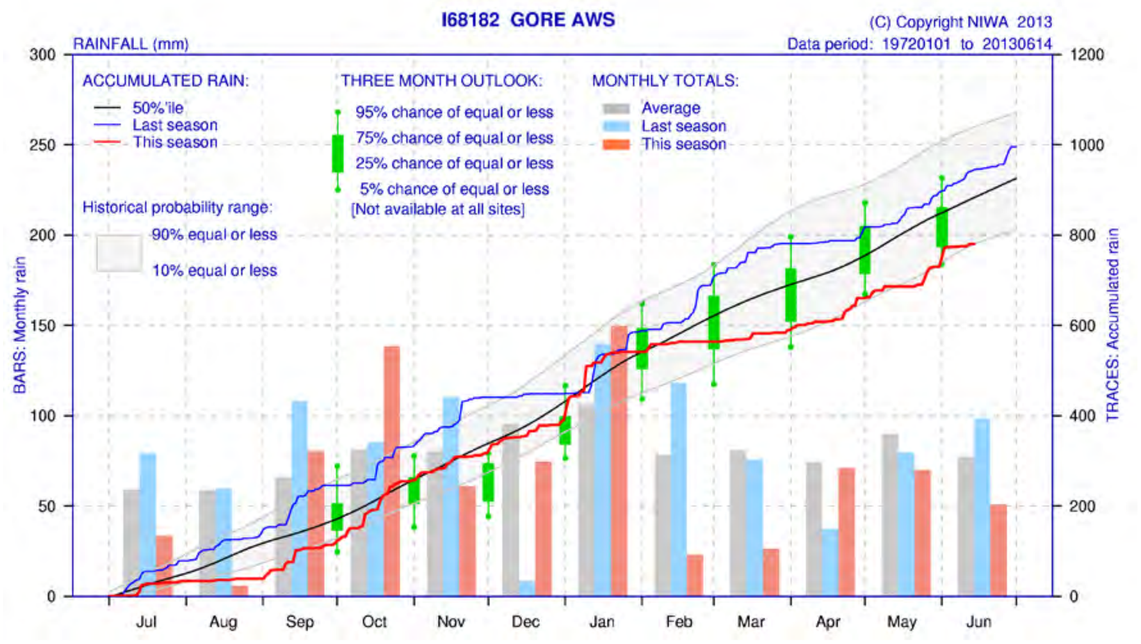


PED accumulation in Central Canterbury from July to May was not unusually high.

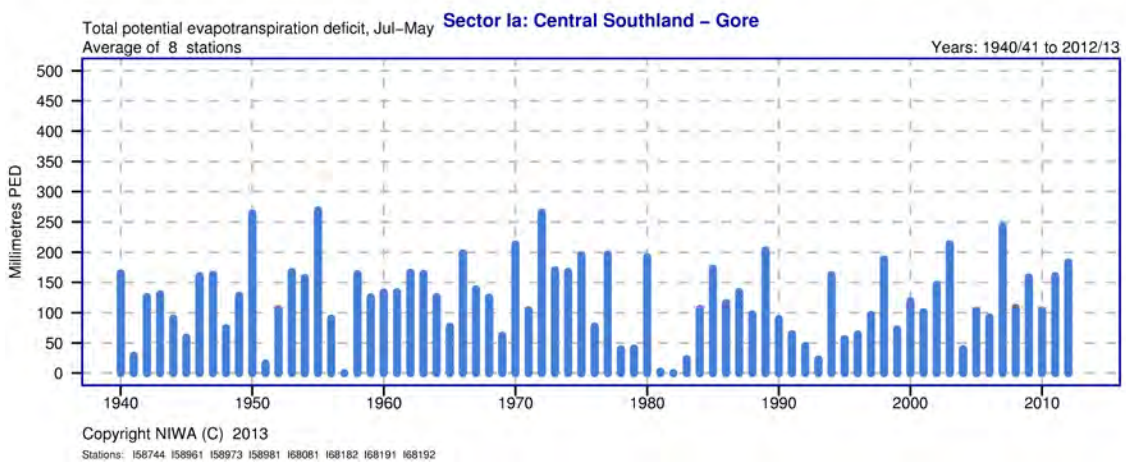


Pasture growth in the 2012−13 season was likely to have been above normal during spring, near normal in summer, and below normal from mid-February to mid-March.

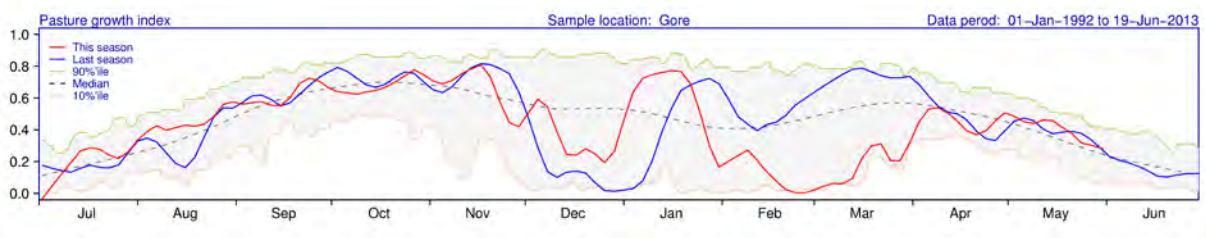
2.21 Central Southland - Gore



Rainfall recorded at Gore was very low for February and March.



PED accumulation in the Gore area during 2012−13 was not unusual.



Pasture growth in the central Southland region was likely to have been lower than normal in December and from February to mid-March.

3 PED maps based on VCSN data

In this section we present maps showing the spatial patterns of PED over the growing season from July to the end of May. The accumulated PED is calculated using the same water balance model described in section 1.1, but applied to daily rainfall (Tait et al., 2006) and potential evapotranspiration (Tait and Woods, 2009) data interpolated on to NIWA's Virtual Climate Station Network (VCSN). The VCSN data has the virtue of complete daily coverage of all of New Zealand, with no missing data, and has values every 0.05° in latitude and longitude (5 km in latitude and approximately 4−5 km longitude separation). The trade-off is that the VCSN covers a shorter period than the station time series of the previous section. Although daily VCSN rainfall is available from January 1960, potential evapotranspiration only starts in January 1972. This means that in the water balance years considered here (July−June), the PED calculations run from 1972−73 to 2012−13, a maximum of 41 years.

3.1 Historical Comparisons

Figure 3-1 (left-hand panel) shows the average deficit by the end of May, averaged over the 40 years 1972−73 to 2011−12 (i.e., every year in the VCSN data except for the latest 2012−13 year). In high altitude regions of both Islands, and on the West Coast of the South Island, accumulated deficits are small (less than 50mm). However, deficits in excess of 400mm are typical of eastern areas of both Islands.

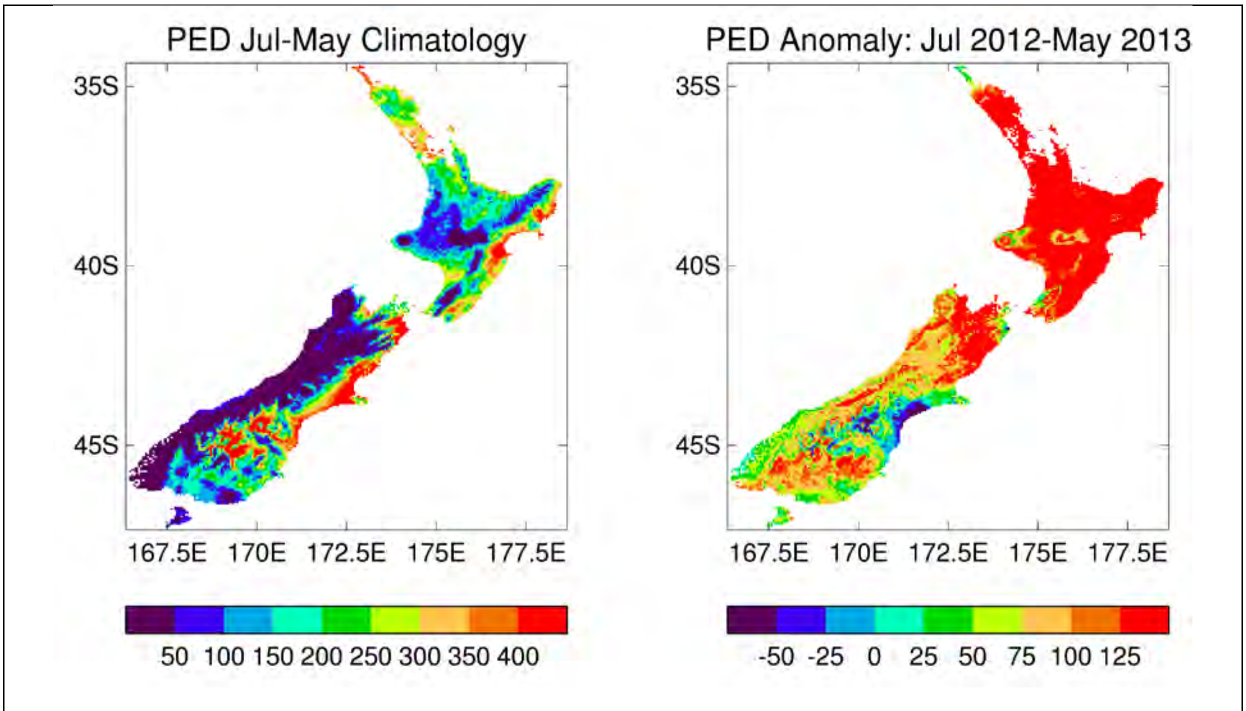


Figure 3-1: Accumulated PED (mm) over the 40-year climatology 1972−73 to 2011−12 for the July to May period of the growing year (left); PED anomaly (mm) for the July 2012−May 2013 period (right).

For the July 2012−May 2013 period, Figure 3-1 (right-hand panel) shows the anomalous PED relative to the climatology (left-hand panel). Virtually the entire North Island had a deficit at least 125mm greater than normal, and most of the north and west of the South Island had a deficit more than 75mm above normal. Appendix A shows a complete set of national maps of the PED anomalies (July−May period) for all other years in the VCSN data set.

The colour contours (Fig. 3-1 (right) and Appendix A maps) are selected to highlight dry years at a glance. It is common for New Zealand to experience dry conditions somewhere almost every year, but the spatial extent can vary dramatically. Some years show very little deficit at all (1979−80, 1983−84, 2001−02), whereas other years have widespread deficits (1972−73, 1977−78, 2007−08, 2009−10, and of course 2012−13).

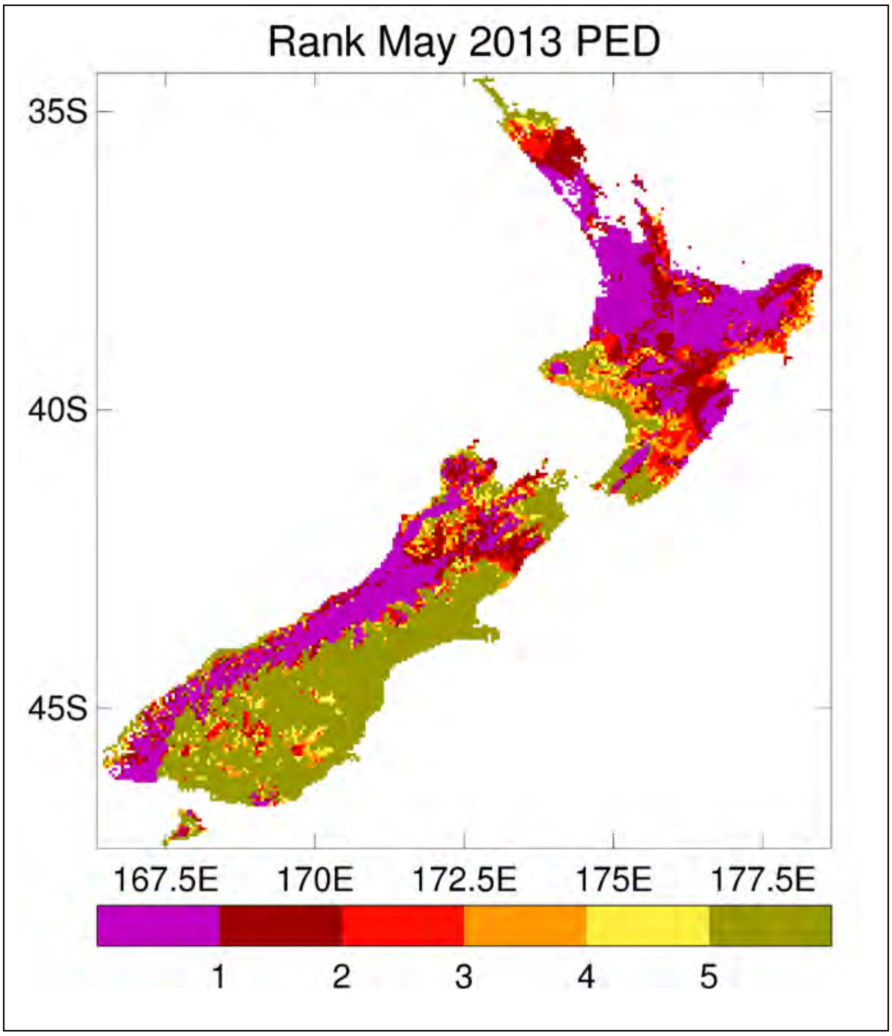


Figure 3-2: Ranking of July 2012−May 2013 PED relative to the other 40 years in the VCSN data set. Rank 1 (purple) means the highest PED in 41 years. Olive colours signify the PED was not in the top 5.

The very widespread deficit of the current year, 2012−13, is highlighted in Figure 3-2, which shows how the deficit at the end of May 2013 ranked against May deficits for other years in the VCSN period. It is apparent that this year's deficit was the 'worst' (Rank 1) in 41 years for a large part of southern Northland, Auckland, Waikato, Bay of Plenty, central North Island, Hawkes Bay, and the West Coast. This is supported by the longer-period time series plots of Section 2.

Figure 3-3 gives another illustration of how the severity of the 2012−13 droughts compare against other years in the VCSN period. Bar graphs, similar to those of Section 2, have been created by averaging the July-May accumulated PED over each Regional Council region. Only VCSN points lying below 500m altitude have been selected (higher altitudes being less relevant to agriculture and forestry). Note that in Figure 3-3 the year label corresponds to the end year (as opposed to the Section 2 PED figures which are referenced relative to the start year). For example, the histogram bar at year '2012' corresponds to the July 2011−May 2012 PED accumulation.

Figure 3-3 gives grid-point averages for all Regional Council regions, plus overall aggregates for North Island, South Island, and all-New Zealand. Note, too, that the results are a simple grid-point average on the 0.05° grid, and do not adjust for the shorter physical distance between grid-points at higher latitudes.

According to this calculation, the 2012−13 PED accumulation was the largest in the 41-year VCSN period for 5 Regional Council regions: Auckland, Bay of Plenty, Waikato, Manawatu, and West Coast. Note though that for Manawatu, there are two other years (1997−98 and 2007−08) that are almost exactly the same. For the Gisborne region, 2012−13 was almost exactly the same as the El Niño drought of 1997−98 and only marginally smaller than the El Niño drought of 1982−83. For both the Northland and Hawke's Bay region, the 2012−13 drought was the second worst over the past 41 years (to 2009−10 and 1997−98, respectively).

For the North Island as a whole, 2012−13 was also the driest year, with 1972−73 and 1977−78 being close runners-up. It is notable that 1984−1997 was generally a wet period for the North Island, but the majority of subsequent years have been drier. For the South Island as a whole, the 'worst' drought by this grid-point average measure was 1972−73, closely followed by 1977−78, both of these being El Niño years.

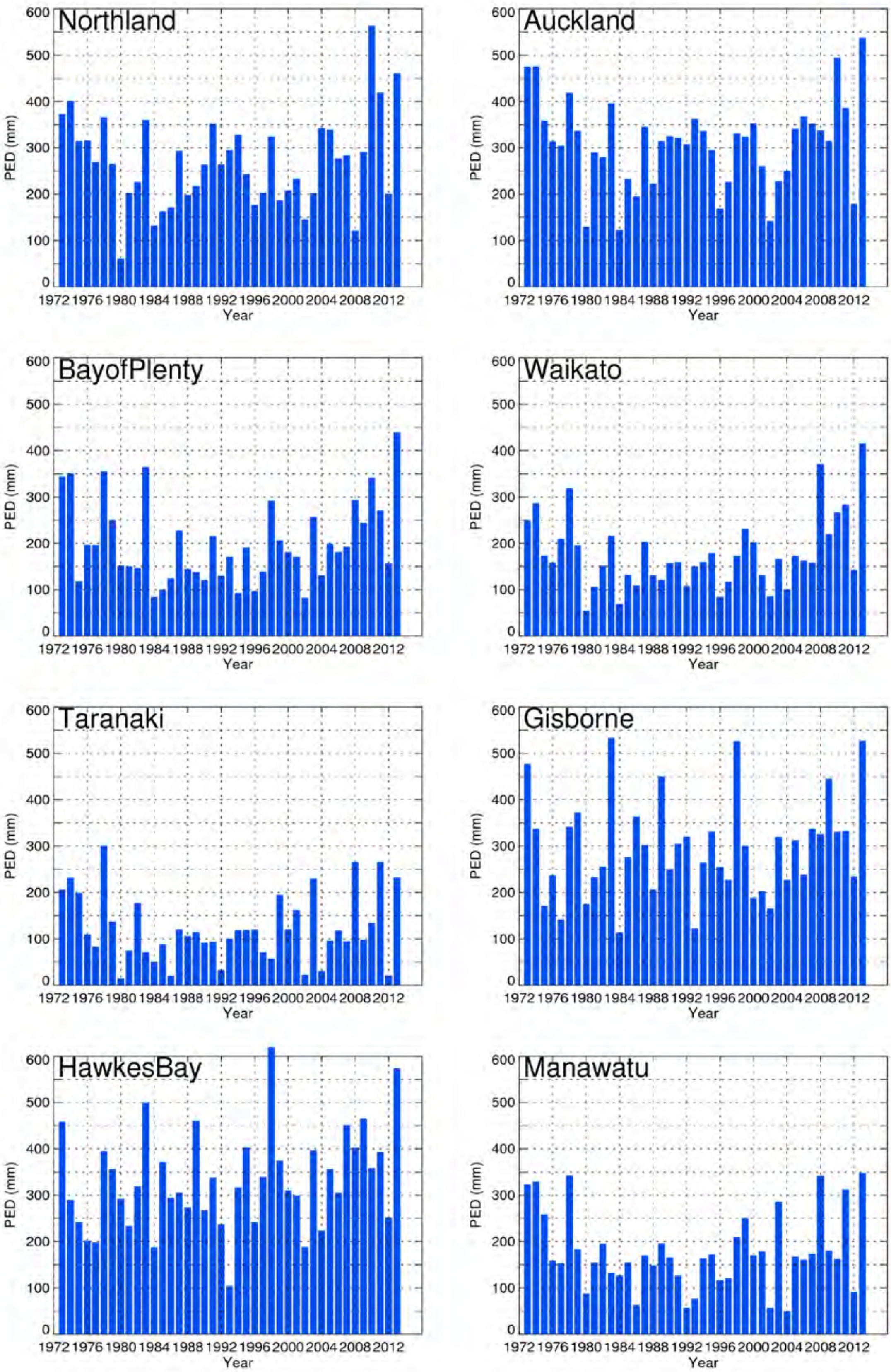


Figure 3-3: PED accumulation (mm) over July−May period, by region. Label on graph corresponds to year of the May end date, so first bar is for July 1972-May 1973.

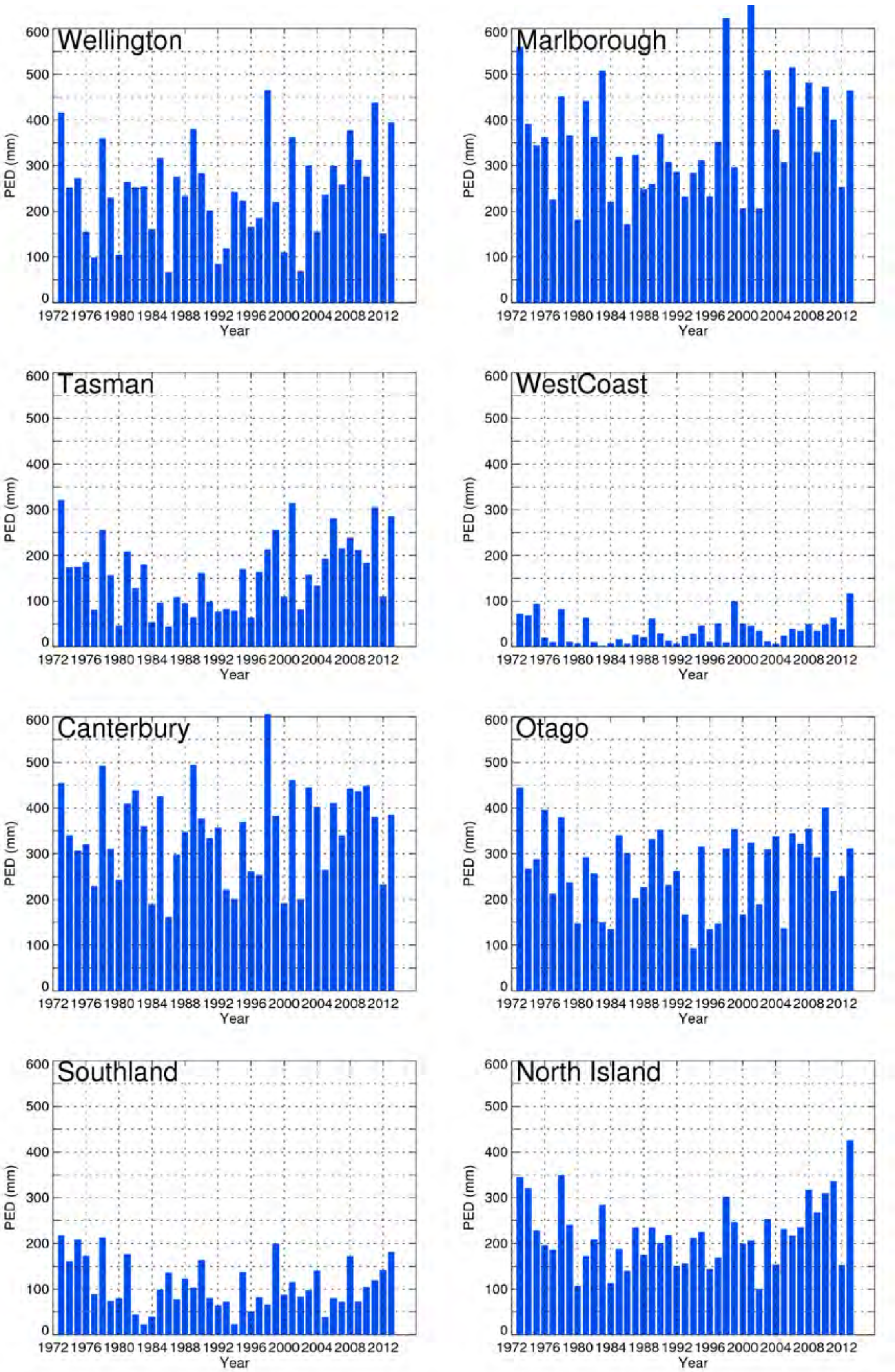
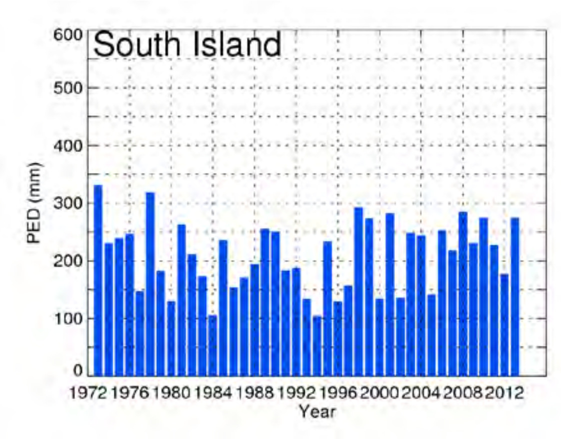


Figure 3-3 (continued). PED data are averaged over all VCSN grid-points below 500m altitude in each named Region.



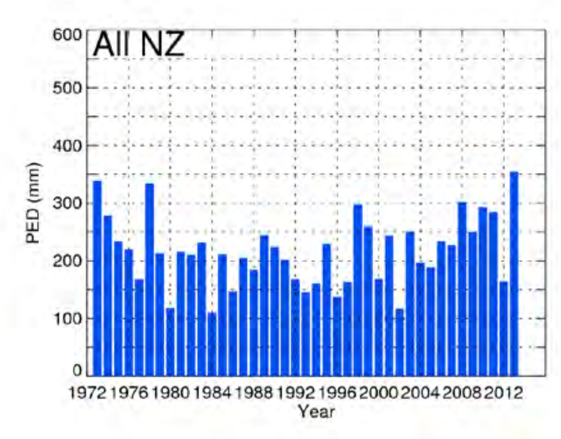


Figure 3-3 (continued).

Table 3-1: Tabulation by Regional Council area of the ranking of the 2012−13 PED (1=highest deficit, 41=smallest deficit), and list of worst three drought years (year and PED), within the VCSN period 1972−73 to 2012−13. The last three lines present results aggregated over the North and South Islands, and all New Zealand. All data are for the July-May accumulations.

Region	Ranking of 2012-13 PED	Worst drought year (PED, mm)	2nd worst year (PED, mm)	3rd worst year (PED, mm)
Northland	2	2009-10 (563)	2012-13 (461)	2010-11 (419)
Auckland	1	2012-13 (538)	2009-10 (495)	1973-74 (475)
Bay of Plenty	1	2012-13 (439)	1982-83 (364)	1977-78 (355)
Waikato	1	2012-13 (415)	2007-08 (371)	1977-78 (319)
Taranaki	4=	1977-78 (301)	2010-11 (265)	2007-08 (265)
Gisborne	2	1982-83 (534)	2012-13 (527)	1997-98 (526)
Hawkes Bay	2	1997-98 (620)	2012-13 (574)	1982-83 (500)
Manawatu	1	2012-13 (348)	1977-78 (342)	2007-08 (341)
Wellington	4	1997-98 (465)	2010-11 (438)	1972-73 (416)
Marlborough	8	2000-01 (660)	1997-98 (623)	1972-73 (560)
Tasman	4	1972-73 (322)	2000-01 (314)	2010-11 (306)
West Coast	1	2012-13 (117)	1998-99 (100)	1974-75 (94)
Canterbury	15	1997-98 (605)	1988-89 (495)	1977-78 (492)
Otago	15	1972-73 (444)	2009-10 (400)	1975-76 (396)
Southland	5	1972-73 (218)	1977-78 (213)	1974-75 (209)
North Island	1	2012-13 (426)	1977-78 (349)	1972-73 (345)
South Island	6	1972-73 (331)	1977-78 (318)	1997-98 (293)
New Zealand	1	2012-13 (354)	1972-73 (339)	1977-78 (334)

Table 3-1 presents information on the three highest deficit years for each Regional Council region, along with deficits aggregated over the North and South Islands, and over all New Zealand. The extreme dry years can be picked out visually from Figure 3-3. For some regions (e.g., Northland, Bay of Plenty, Canterbury), there is a big difference between the highest deficit and the second highest. For other regions (e.g., Gisborne, Manawatu, Southland), the worst three drought years all have very similar deficits.

Table 3-2: Tabulation by Regional Council area of areal coverage of the 2012−13 drought. For each region, the number of VCSN grid-points below 500 m altitude are noted, and the percentage of these grid-points which had the highest, 2nd highest and 3rd highest PED accumulation for July 2012−May 2013, relative to the other 40 years in the VCSN data period. The final column shows the worst year and its fractional coverage, if this is not 2012–13.

Region (number of VCSN grid-points below 500m)		% grid-points where 2012–13 worst	% grid-points where 2012–13 2nd worst	% grid-points where 2012–13 3rd worst	% coverage in worst year (year) [if not 2012–13]	
Northland	(478)	14.6%	37.0%	16.3%	81.4%	(2009-10)
Auckland	(197)	72.1%	22.3%	4.6%	-	
Bay of Plenty	(349)	68.2%	19.8%	6.9%	-	
Waikato	(830)	70.0%	23.3%	5.2%	-	
Taranaki	(286)	4.2%	3.9%	3.5%	53.2%	(1977-78)
Gisborne	(236)	22.9%	21.2%	27.1%	35.2%	(1997-98)
Hawkes Bay	(385)	26.0%	36.9%	14.8%	56.9%	(1997-98)
Manawatu	(651)	10.0%	15.4%	25.8%	18.9%	(1973-74)
Wellington	(306)	3.6%	9.5%	20.3%	59.2%	(1997-98)
Marlborough	(207)	0.0%	9.2%	7.7%	59.4%	(2000-01)
Tasman	(176)	0.0%	10.2%	10.8%	50.6%	(1972-73)
West Coast	(516)	35.7%	18.4%	9.1%	-	
Canterbury	(890)	0.0%	2.8%	2.7%	37.0%	(1997-98)
Otago	(682)	0.4%	0.4%	0.6%	33.6%	(1972-73)
Southland	(881)	7.4%	4.0%	3.1%	34.2%	(1972-73)
North Island	(3718)	34.2%	21.9%	13.9%	-	
South Island	(3352)	7.5%	5.8%	4.1%	21.7%	(1972-73)
New Zealand	(7070)	21.6%	14.3%	9.2%	-	

Another alternative historical comparison of the 2012−13 drought is given in Table 3-2. Here, we record the percentage of each Regional Council region where the 2012−13 drought was the worst (or 2nd or 3rd worst) over the past 41 years. The year with the largest areal coverage of highest PED is also noted: the year 2012−13 is the worst since 1972 for four Regional Council regions. Note that this measure can give a slightly different ranking at times to Table 3-1. For example, for the Manawatu Regional Council region, Table 3-2 shows that the 1973−74 year ranked worst at more VCSN grid-points than any other year, but averaging over all Manawatu grid-points gives a July 1973−May 1974 PED accumulation of 329 mm, which ranks fourth behind the three years of Table 3-1. Thus, we could say that the 2012−13 drought in Manawatu was more widespread, but that the 1973−74 drought was more intense at the affected locations.

Both Tables 3-1 and 3-2, which combine intensity and areal coverage measures, indicate that 2012−13 was the worst North Island drought over the 41-year VCSN period (highest deficit at 34% of the VCSN grid-points), whereas the worst South Island drought was in 1972−73 (22% of grid-points). To the extent that a 'nationwide' drought has any significance (and there is no land-use or economic weighting in our analysis), the latest drought of 2012−13 could be considered the worst in 41 years (and very likely in 70 years (Section 2 graphs).

Table 3-3 provides an overall picture of the ten most severe droughts in the North and South Islands, respectively. For every VCSN grid-point below 500m altitude in each Island, the July–May PED accumulation is ranked over the 41 years of the VCSN data set, and the highest three deficits recorded. The percentages of each Island with the highest ('worst' in Table 3-3), second highest, and third highest accumulations are then calculated.

The years are ordered according to the percentage recorded as the worst in 41 years. The 'top 10', however, are selected on the basis of the cumulative percentage (total of 1st, 2nd and 3rd). For example, the year 1984–85 has the highest PED accumulation over 1.6% of South Island grid-points (surpassing 2007–08 and 1975–76). However, the percentage coverage of second and third highest PED in 1984–85 was 3.3% and 4.0%, respectively, demoting this year to the 11th worst South Island drought.

Table 3-3: Top 10 droughts in North and South Islands since 1972, showing the percentage of VCSN grid-points (below 500m altitude) where July–May PED accumulations is the highest (determines the Order), 2nd highest, or 3rd highest, respectively, in the sample of 41 years.

	North Island				South Island			
Order	Year	% 1st	2nd	3rd Worst	Year	% 1st	2nd	3rd Worst
1	2012-13	34.2	21.9	13.9	1972-73	21.7	11.2	6.7
2	1997-98	14.3	6.9	3.3	1997-98	11.9	5.9	3.9
3	2009-10	12.0	6.7	5.7	1988-89	9.1	4.7	2.0
4	1977-78	9.1	8.3	15.0	2012-13	7.5	5.8	4.1
5	2007-08	6.6	18.9	9.4	1998-99	6.3	6.2	3.8
6	1973-74	5.7	10.2	9.1	2000-01	6.1	3.8	2.9
7	2010-11	4.5	7.6	12.0	1977-78	5.5	9.0	11.3
8	1972-73	4.3	5.4	9.5	2009-10	3.9	3.5	4.4
9	1982-83	2.8	6.5	7.9	2007-08	1.2	4.0	8.2
10	2002-03	2.7	2.6	1.6	1975-76	1.0	3.1	6.1

Thus, according to this overall drought measure, 2012–13 was the worst North Island drought in the 41 years of the VCSN data, whereas in South Island 1972–73 was the worst, and 2012–13 was the 4th most severe drought. Droughts that affected both Islands in this list are: 1972–73, 1977–78, 1997–98, 2007–08, 2009–10, and 2012–13. Half of these droughts occurred in the last seven years. At this time, we cannot ascribe any significance to this clustering; it may simply be natural variability.

3.2 Comparison with 20-year return period PED

As a final example, Figure 3-4 compares the July 2012–May 2013 PED accumulations across the country. For each of the 15 regions analysed, the July 2012–May 2013 PED (in red) is compared to the 40-year climatology (in blue, see Figure 3-1 for spatial map) and the estimated 20-year return period value (in green). The Mullan *et al.* (2005) report took the 20-year return period PED as a useful working definition of drought.

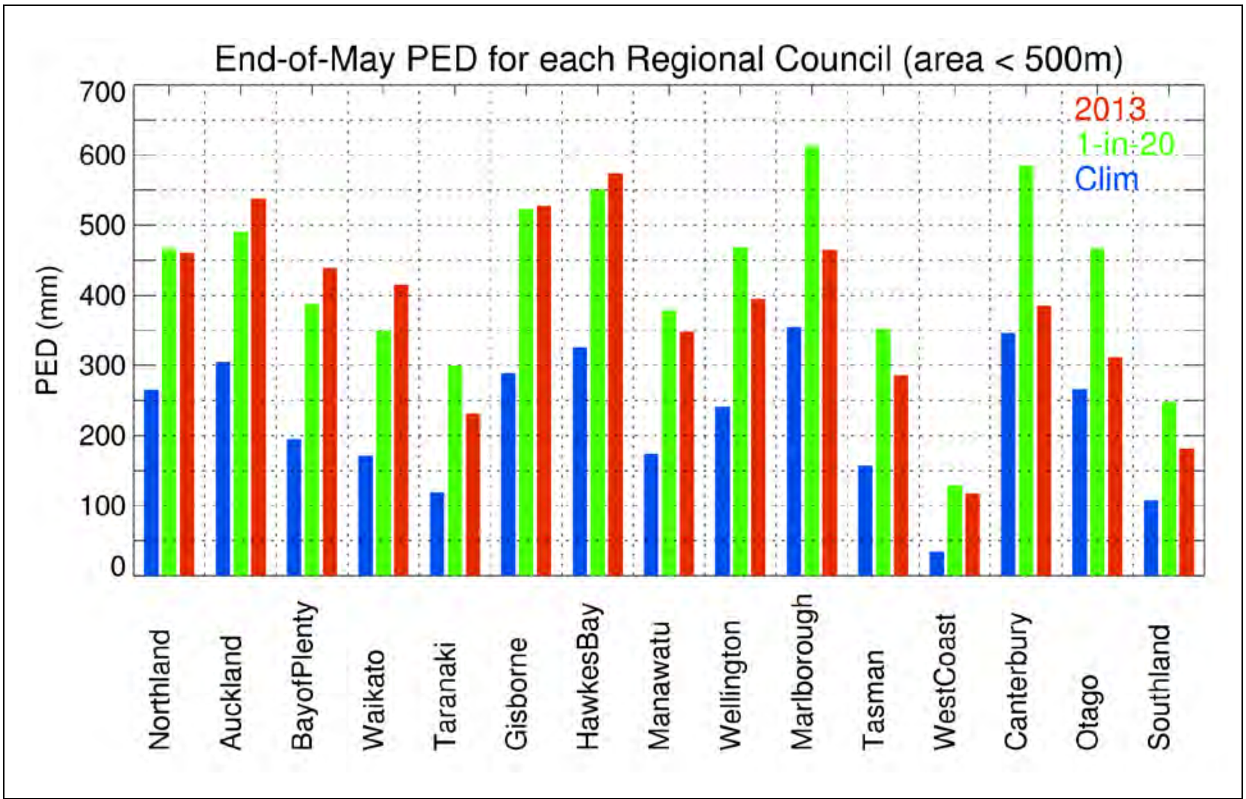


Figure 3-4: PED accumulation from the beginning of July to the end of May, for 15 regions of New Zealand. Each region shows three bars, corresponding to: the 40-year PED climatology (blue), the 1-in-20 year return period PED (green), and the PED as of July 2012–May 2013 (red).

Every single Regional Council region of New Zealand was drier over the period July 2012–May 2013 compared to the long-term July–May averages (Figure 3-4). The North Island regions of Auckland, Waikato, Bay of Plenty, Gisborne and Hawkes Bay also have area-average PED levels that exceeded the 'drought threshold' (i.e., the 1-in-20 year return period) of Mullan *et al.* (2005). Both Northland and West Coast came very close to this drought threshold, as an area average, and have obviously exceeded it for some parts of the regions (Figures 3-1 and 3-2).

It should be noted that the statistical algorithm that computes the return period (described in Mullan *et al.,* 2005) performs better when there is a long tail in the PED distribution. If the highest few PED years are all close together (e.g., Manawatu, Gisborne), or PED has many very small values (e.g., West Coast), then the algorithm may estimate a 1-in-20 year return period PED that is higher than any individual year, as occurs for Manawatu, Tasman and West Coast (comparing Figure 3-4 and Table 3-1).

4 Driving factors behind drought conditions

One very notable factor of New Zealand climate over the summer and early spring of 2013 was the dominance of slow-moving or 'blocking' high pressure systems. The intensity of the highs was sufficient to 'steer' rain-bearing weather systems around New Zealand.

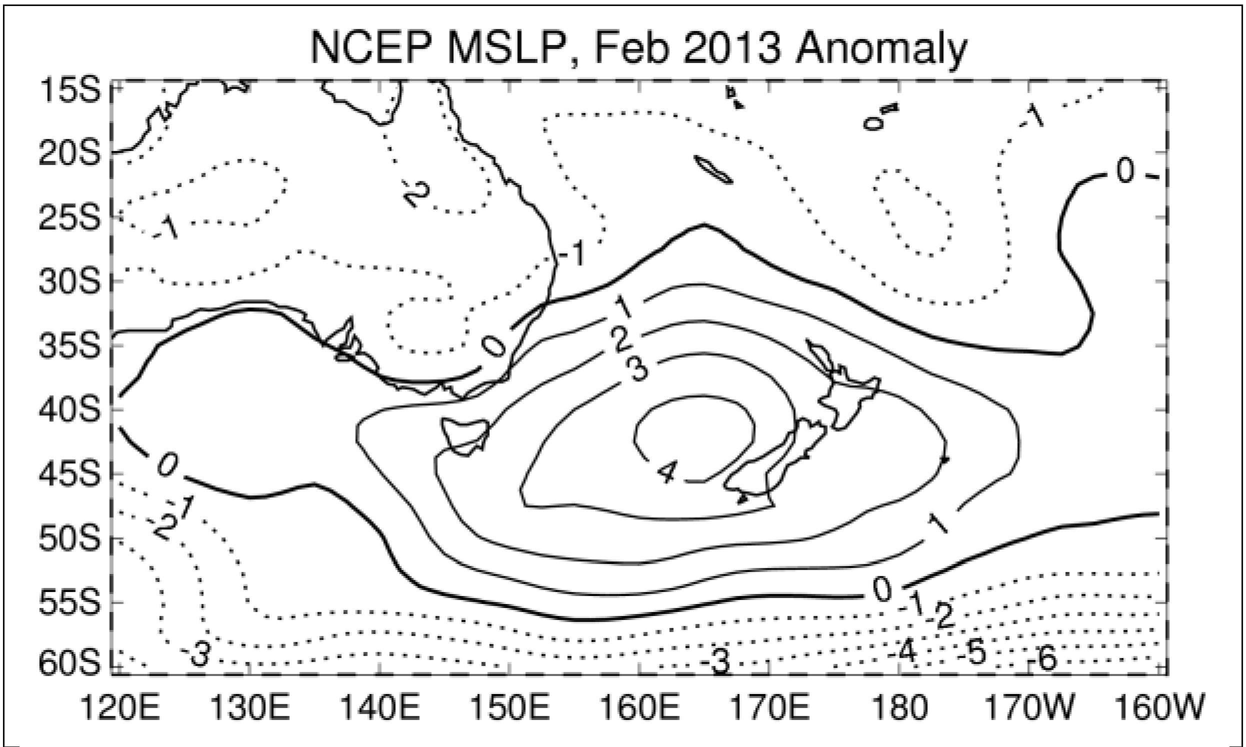


Figure 4-1: Mean Sea-Level Pressure anomaly (hPa) for February 2013, compared to NCEP 1971–2000 climatology.

According to NIWA's climate summary for December 2012−February 2013, (http://www.niwa.co.nz/climate/summaries), the frequent highs produced extremely dry conditions over most of the North Island, and a very sunny summer over most of the country with numerous summer sunshine records being broken. In the month of February (see Figure 4-1 for the map of mean sea-level pressure (MSLP) anomalies), record low rainfall was recorded in parts of Northland, Auckland and the Bay of Plenty.

4.1 Summer high pressure index

In order to assess how frequently high pressure anomalies like this persist during the New Zealand summer, we have calculated a pressure "index" by averaging the summer (December−February) pressures from six long-term recording sites: Auckland, Wellington, Hokitika, Christchurch, Chatham Islands, and Hobart. The shortest pressure record from these six locations is that of Wellington, which starts in January 1911.

Figure 4-2 plots the time series of regional summer pressures, starting with the December 1911–February 1912 summer. The 2013 summer (December 2012−February 2013) has a high value, but it is by no means the most extreme. Whether persistent high pressures result in widespread drought years depends on other factors as well: for example, if the high pressure is centred east of New Zealand, then there will be north-easterly airflow anomalies which could bring rain to north-eastern North Island regions. Furthermore, it can be very important just how dry the preceding spring was.

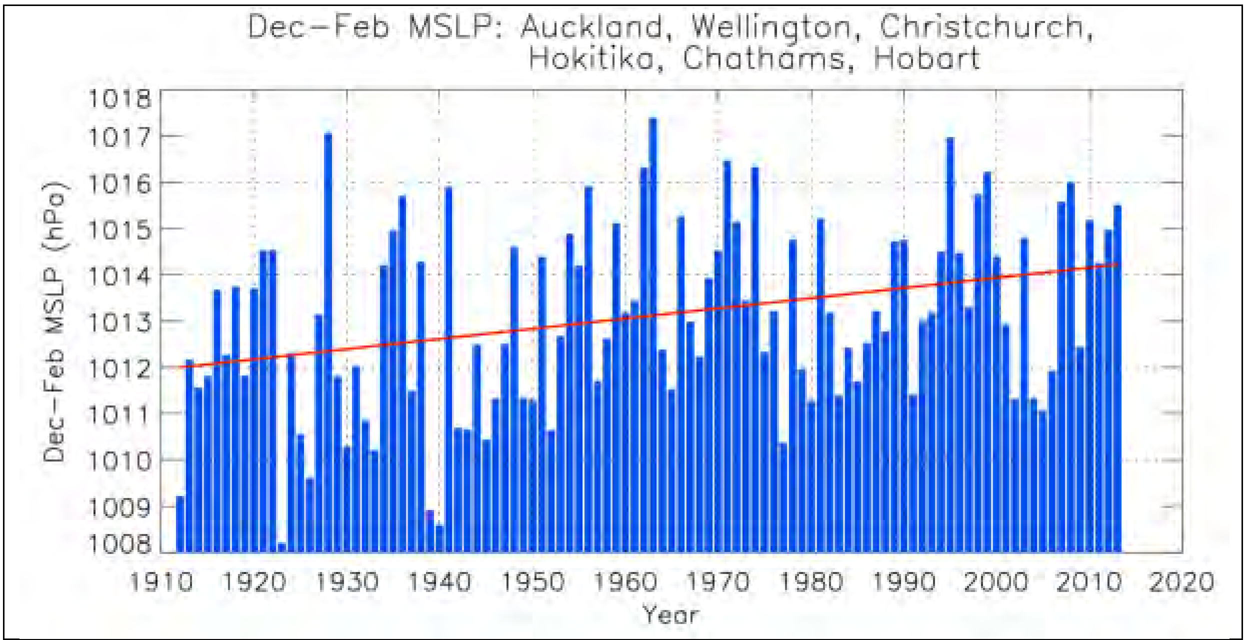


Figure 4-2: Time series of mean sea-level pressure (hPa), averaged over the summer months (December, January, February) and six observing sites as indicated in figure heading. (Years labelled according to Jan-Feb year, with last bar representing Dec 2012−Feb 2013). The red line represents a linear trend fitted to the seasonal data.

A linear trend line has been fitted to the summer pressures of Figure 4-2. The slope of this trend line is: +2.21 hPa per century, with a 95% confidence interval of ±1.29 hPa/century. Thus, the historical trend towards increasing pressures over the New Zealand region during the 20th century in summer is statistically very significant.

Such a trend has been foreshadowed in previous analyses of global climate model projections (e.g., MfE, 2008; Mullan *et al*., 2005; Clark *et al*., 2011). As the globe warms under increasing greenhouse gas forcing, the models predict that the tropics will effectively 'expand': the sub-tropical high pressure belts, produced by air rising in the tropics and subsiding in the sub-tropics, are expected to intensify and move polewards in both hemispheres. Figure 4-3 (taken from MfE, 2008) illustrates such a projection, where the models suggest an increase of between 1 and 2 hPa over the century time-scale. This projected 100-year trend is similar in magnitude to the observed trend over the 1911–12 to 2012–13 summers in Figure 4-2.

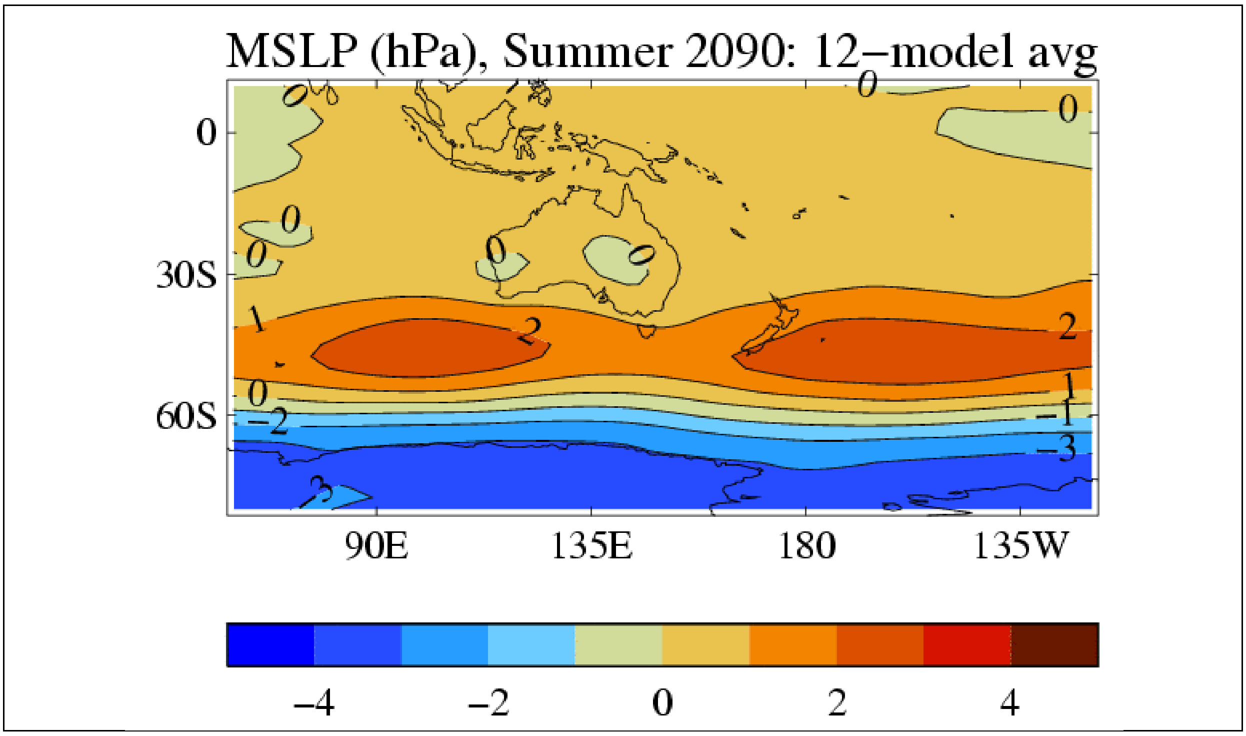


Figure 4-3: Projected change in summer MSLP (hPa) between 1980−1999 and 2080−2099, as averaged over 12 global climate models under the SRES A1B emission scenario. (Taken from MfE, 2008).

4.2 El Niño−Southern Oscillation effects

In addition to trends in high pressures and their possible association with climate change, it is also known that El Niño-Southern Oscillation (ENSO) conditions can be a factor in New Zealand droughts. The previous discussion has noted the significant drought conditions during the major El Niños of 1972–73 and 1997–98. Mullan *et al.* (2005) showed maps of PED composited over extreme ENSO years. During El Niño springs and summers, the westerly winds are stronger and more persistent than normal, and often produce droughts in eastern parts of New Zealand. During La Niña springs and summers, easterly anomalies predominate, and dry conditions can evolve in the west of the North Island and throughout the South Island.

Figure 4-4 updates the composite ENSO maps of Mullan *et al*. (2005), and also introduces a new composite for high MSLP summers. In each case, the 10 most extreme years (of the 41-year VCSN period) are selected, and the July–May PED accumulations averaged. The ENSO composites (top panel of Figure 4-4) use the 10 most negative (‘El Niño’) and 10 most positive (‘La Niña’) SOI years, based on the July-May average of the Southern Oscillation Index. The years going into the composite PED maps are listed in the heading of each map. Thus, the El Niño composite uses 1982−83, 1997−98, 1991−92, 1977−78, 1994−95, 1972−73, 2002−03, 1986−87, 2004−05, and 2009−10. Three of the ‘El Niño’ years, and four of the ‘La Niña’ years, also occur in the ‘High MSLP’ set.

El Niños tend to produce a very strong drought pattern in the north-eastern parts of both Islands. The La Niña PED pattern is weaker, and almost complementary in the North Island: i.e., restricted to western areas.

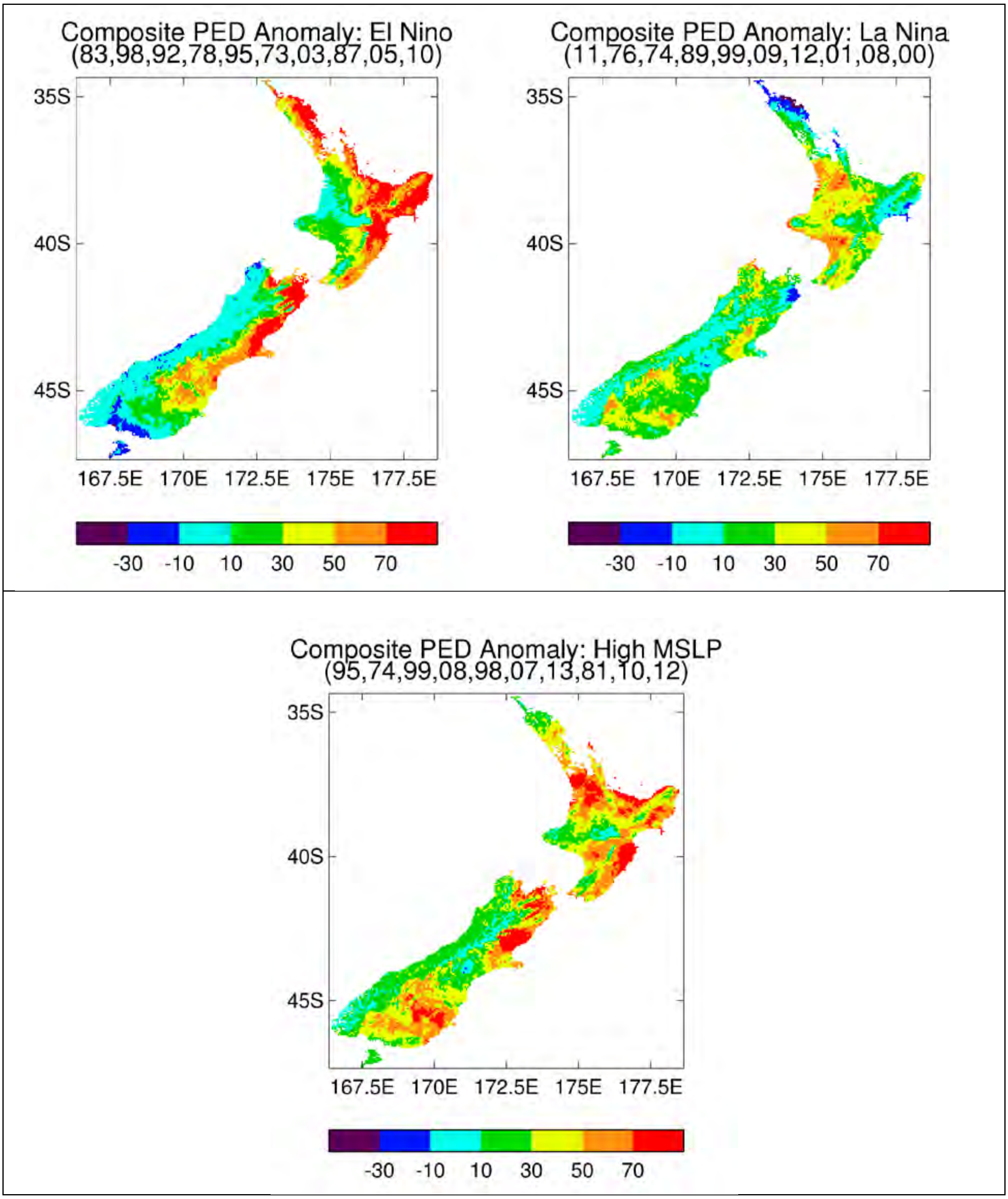


Figure 4-4: Accumulated July−May PED anomalies (mm), composited over selected 10 years in the 1972−73 to 2012−13 period: (top left) 10 lowest SOI years ('El Nino'), (top right) 10 highest SOI years ('La Nina'), (bottom) 10 years with highest summer pressures over the NZ-Tasman Sea region ('High MSLP') The figure heading shows the 10 years used in each composite, indicating the end year of the July–May period (e.g., 83 means July 1982–May 1983).

The ‘High MSLP’ summers that were ENSO-neutral (neither El Niño nor La Niña), and fell within the VCSN period were (in order, see heading embedded in Figure 4-4): 2006−07, 2012−13, and 1980−81. Of these, only the latest summer of 2012−13 produced exceptional widespread drought conditions. Other ‘High MSLP’ years, prior to the VCSN start date, include: 1962−63 (highest), 1927−28, 1970−71, and 1961−62. Based on the longer records of Section 2, none of these years appear to be particularly exceptional in terms of regional drought. Thus, other constraints, in addition to simply higher average pressures over the summer, would appear to be necessary to identify or predict such drought years in the future.

This analysis also ‘begs the question’ of why the 2012−13 summer experienced such large and persistent high pressure anomalies in the first place. Persistent enhanced convection in the tropical Pacific west of the Dateline may be factor, but this will need to be the subject of future NIWA research.

5 Conclusions

Dry conditions during the 2012−13 agricultural season were unusually widespread across New Zealand. The drought was particularly serious in the North Island, but also affected the West Coast of the South Island. This report has quantified the intensity and extent of the 2012-13 drought, and compared it to previous events, using accumulated *potential evapotranspiration deficit* (PED) as a drought index.

PED was accumulated over the months of July to May. The 2012-13 accumulations were compared to historical values, either from 1972 using the 5km gridded VCSN data set, or from the 1940s using longer station records. Both analyses show that the 2012−13 drought was one of the most extreme on record for New Zealand.

For much of southern Northland, Auckland, Waikato, Bay of Plenty, North Island Central Plateau, Gisborne, Hawke’s Bay, and West Coast, the July 2012−May 2013 PED accumulation was the largest in the 41-year VCSN record. The longer-record station calculations indicate an event of similar severity occurred in the 1945−46 season.

The July 2012–May 2013 PED accumulation was the highest in 41 years at 34% of the North Island VCSN grid-points, which is a much larger areal coverage than any other drought in the VCSN period. For the Auckland, Bay of Plenty and Waikato Regional Council regions, the 2012–13 PED was the highest over about 70% of the land area below 500m altitude.

After 2012–13, the next most severe droughts (in order) affecting the North Island, in terms of areal coverage of highest PED, occurred in: 1997–98, 2009–10, 1977–78, and 2007–08. For the South Island, the five most severe droughts (in order) were: 1972–73, 1997–98, 1988–89, 2012–13, and 1998–99.

The immediate cause of the 2012−13 drought was the persistence of slow-moving or ‘blocking’ high pressure systems over the Tasman Sea and New Zealand over the summer season. The reason for such persistence will need further research, but high pressures by themselves do not always lead to drought conditions. In this particular instance, the El Niño-Southern Oscillation was in its neutral phase and was not a factor.

6 References

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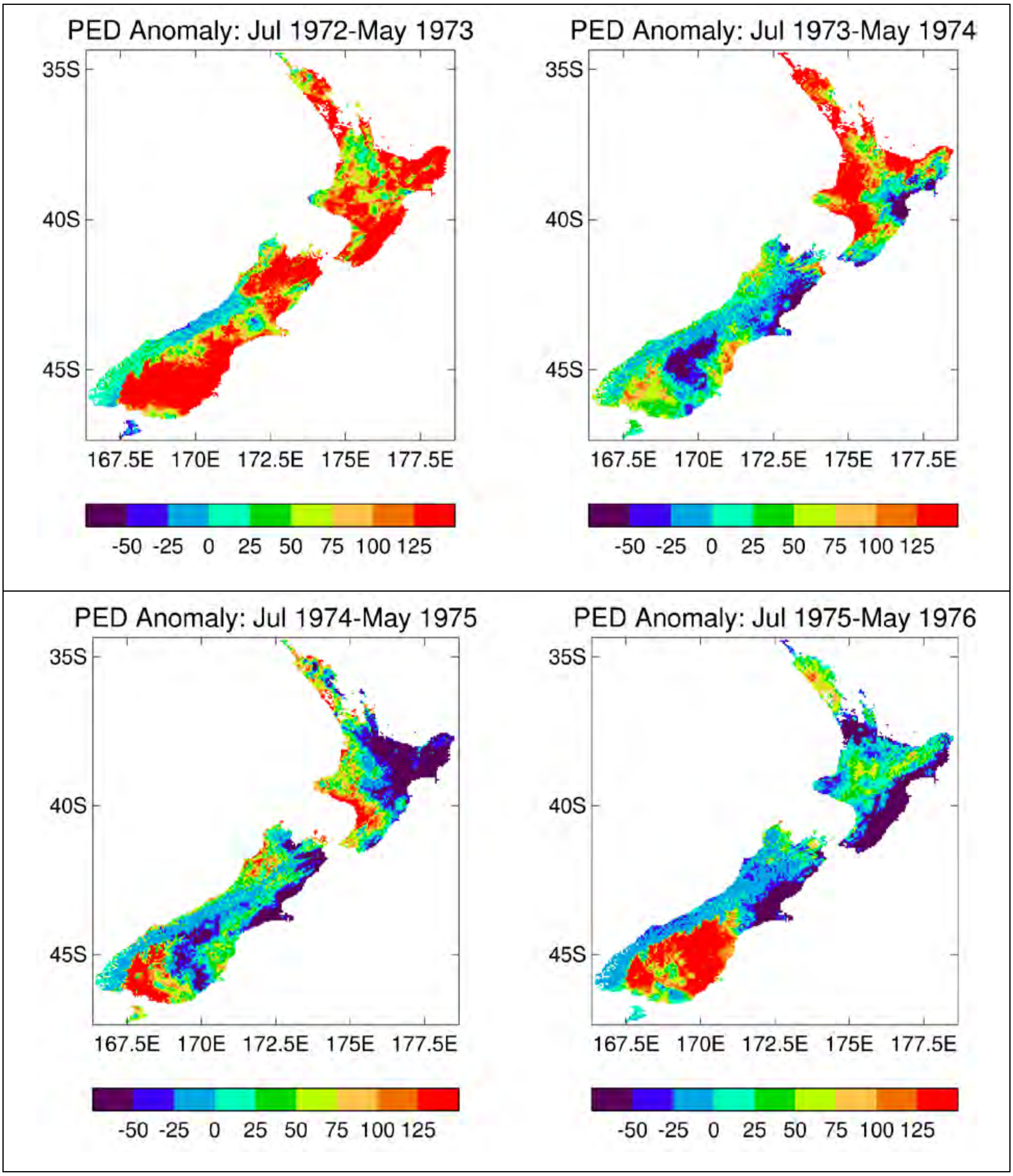
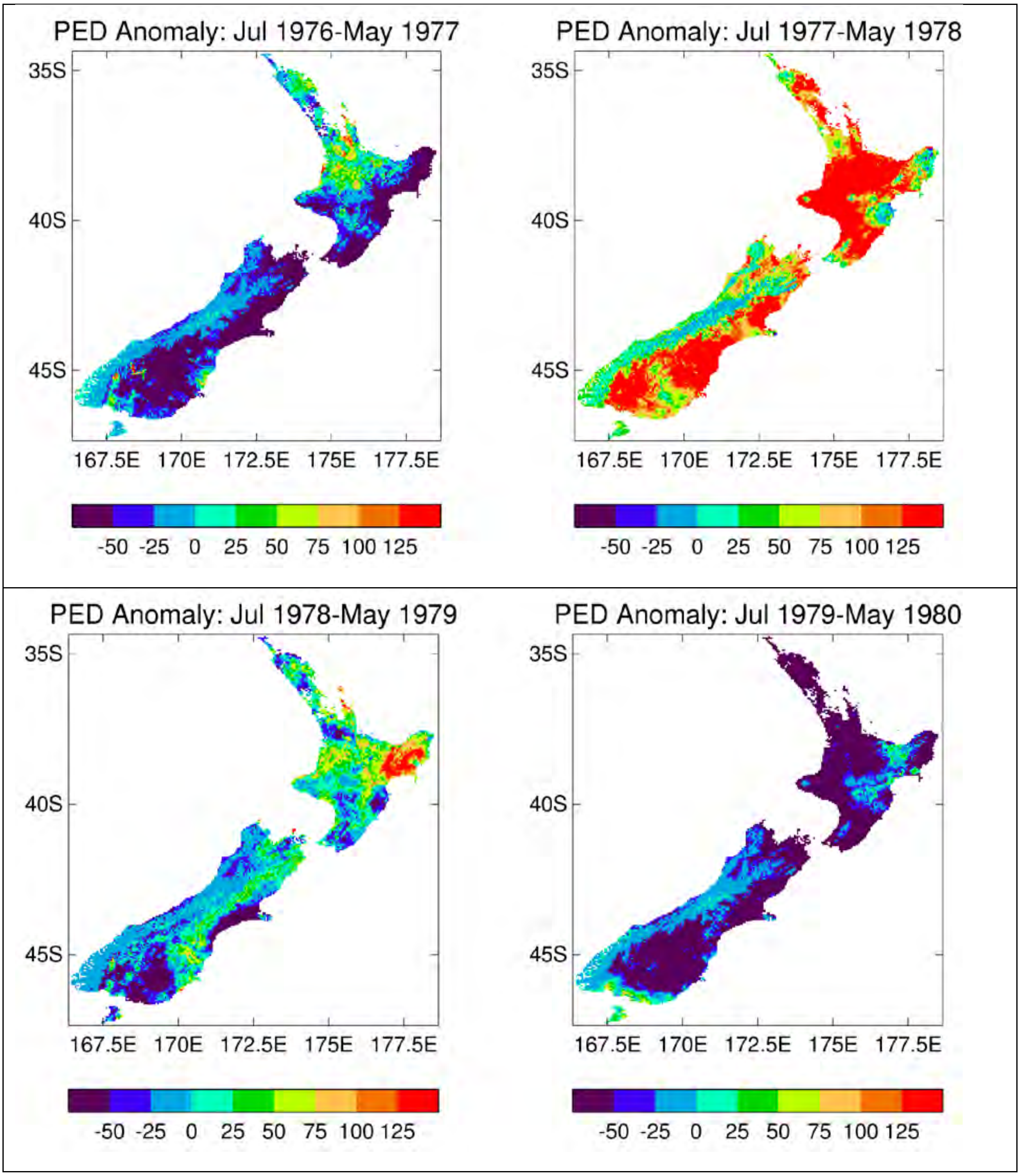
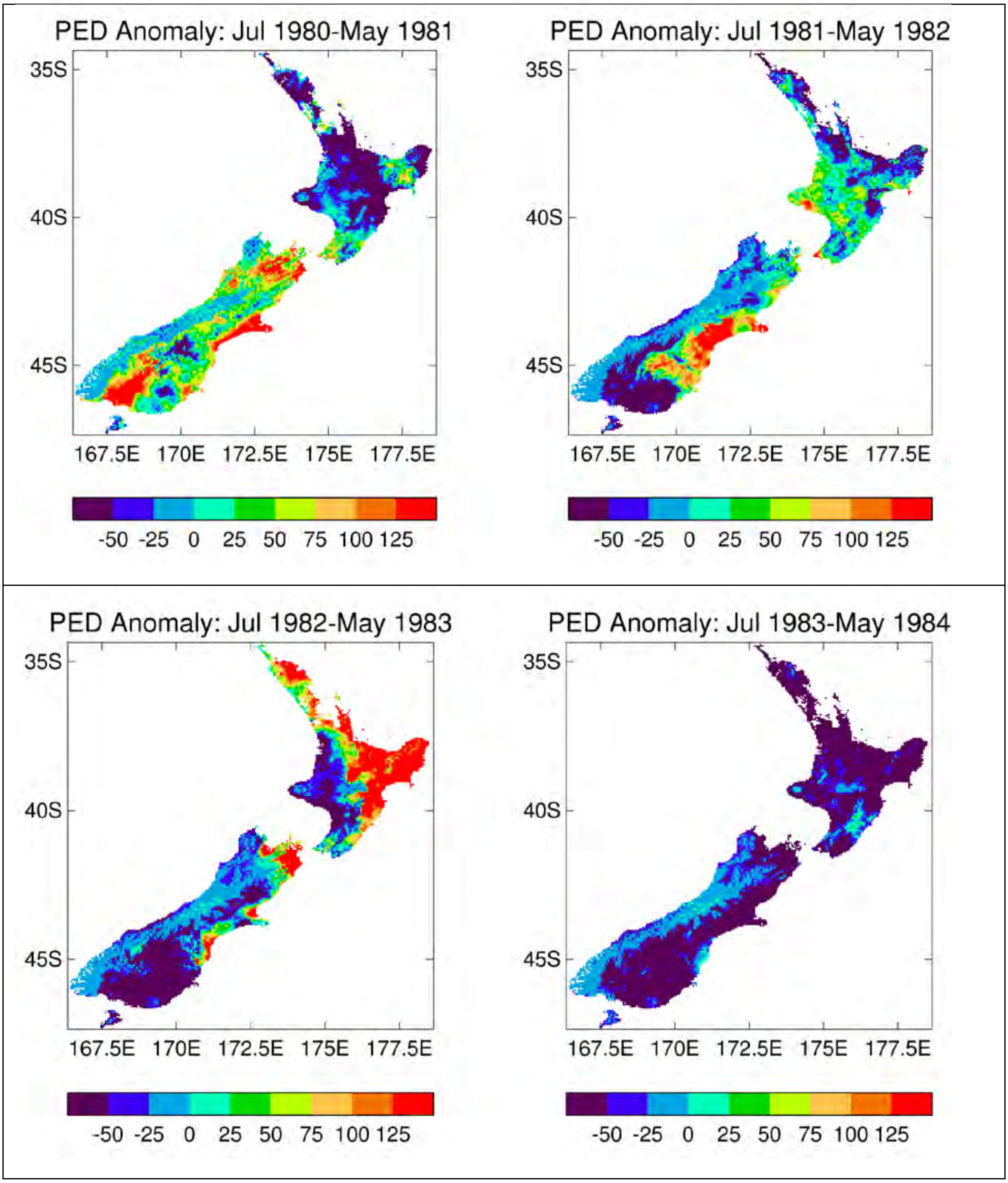
Appendix A

The following maps show the spatial variation of July-May PED accumulations for each year of the VCSN data set, from July 1972-May 1973 to July 2011-May 2012. The map for the current year (i.e., July 2012-May 2013) is given in the main text as Figure 3.1.




PED Anomaly: Jul 1976-May 1977
PED Anomaly: Jul 1977-May 1978
PED Anomaly: Jul 1978-May 1979
PED Anomaly: Jul 1979-May 1980
35S
40S
45S
167.5E 170E 172.5E 175E 177.5E
-50 -25 0 25 50 75 100 125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PED Anomaly: Jul 1981-May 1982
PED Anomaly: Jul 1982-May 1983
PED Anomaly: Jul 1983-May 1984
35S
40S
45S
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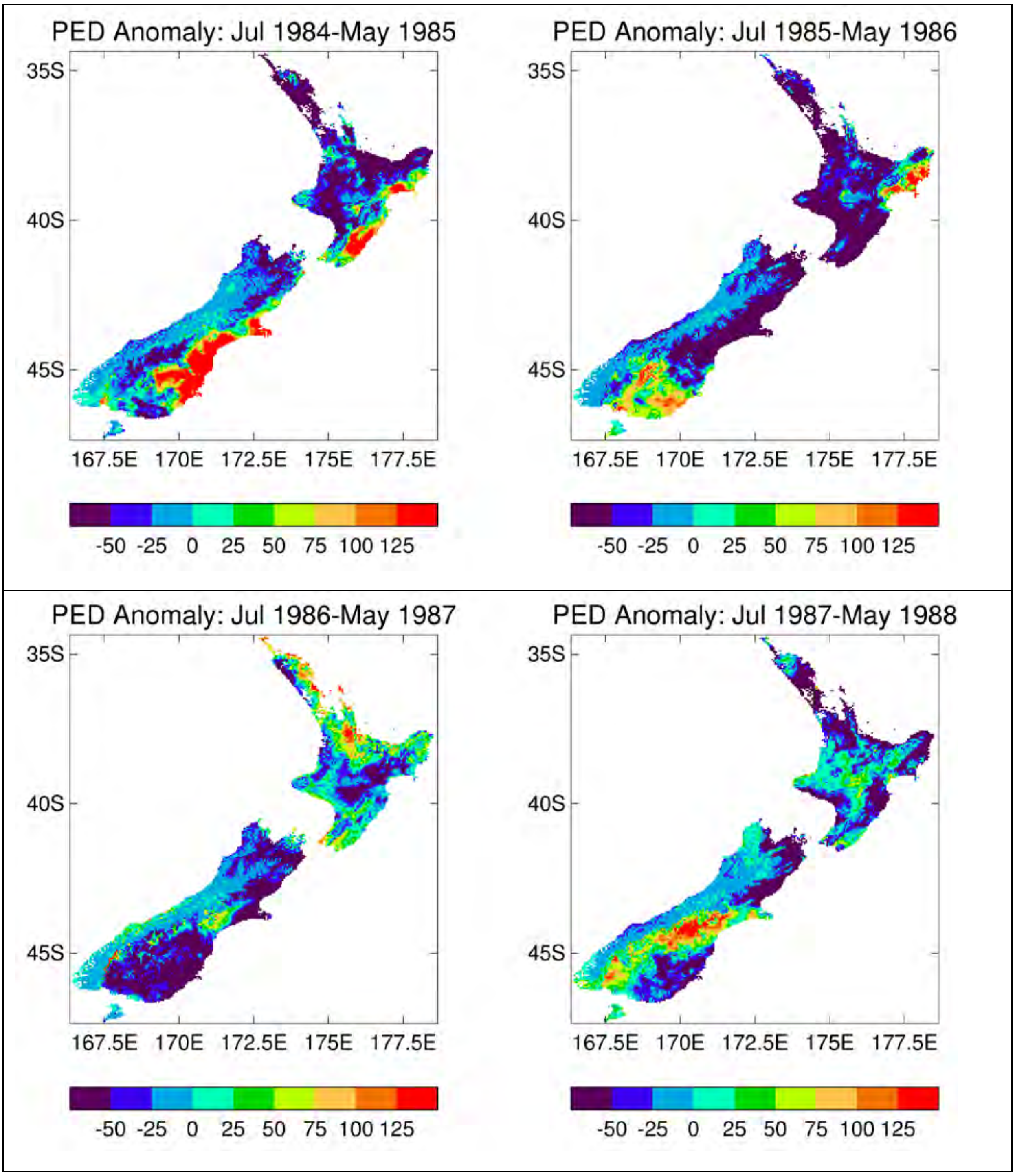
170E
172.5E
175E
177.5E
-50
-25
0
25
50
75
100
125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PED Anomaly: Jul 1985-May 1986
PED Anomaly: Jul 1986-May 1987
PED Anomaly: Jul 1987-May 1988
35S
40S
45S
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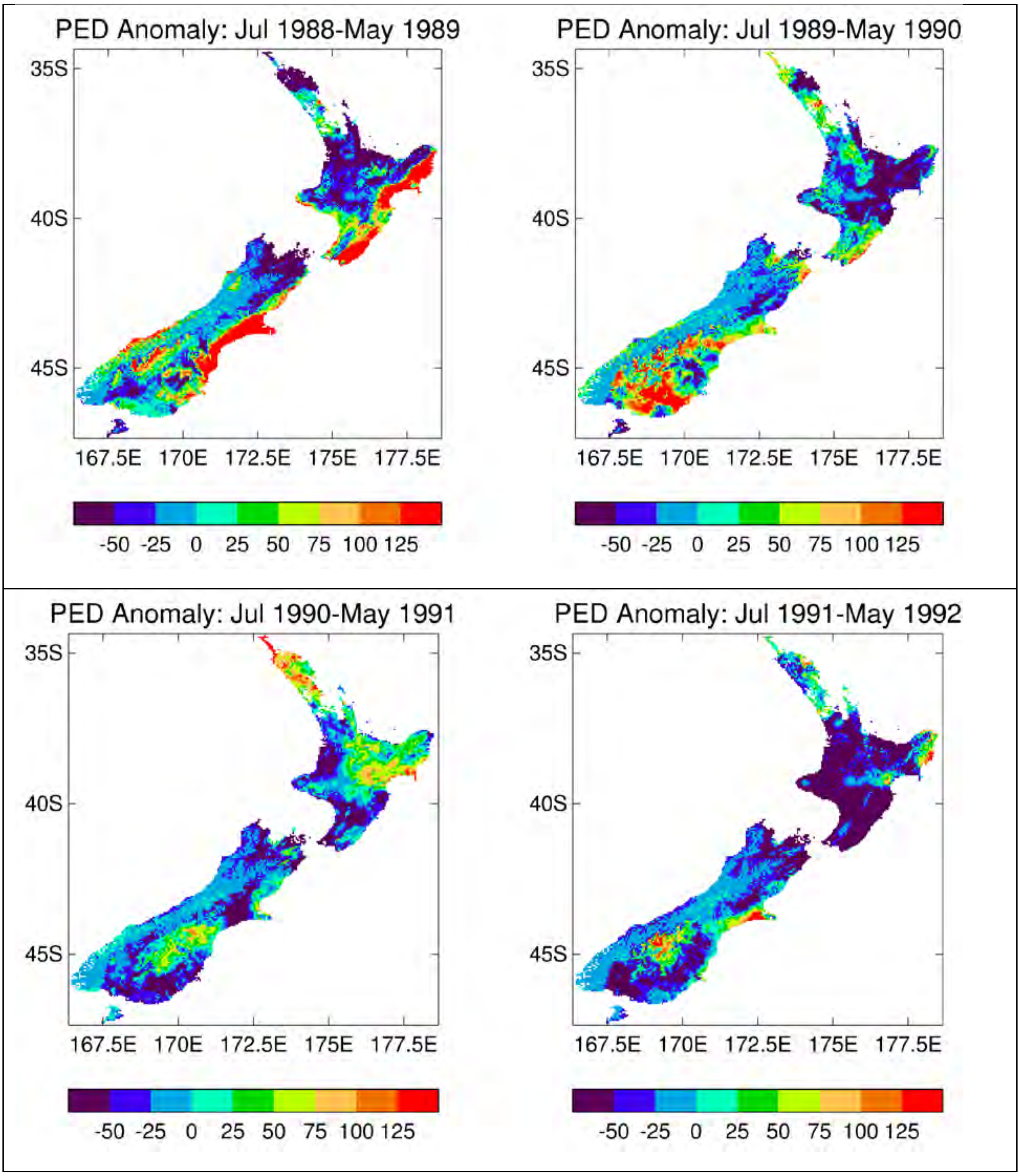
-50 -25 0 25 50 75 100 125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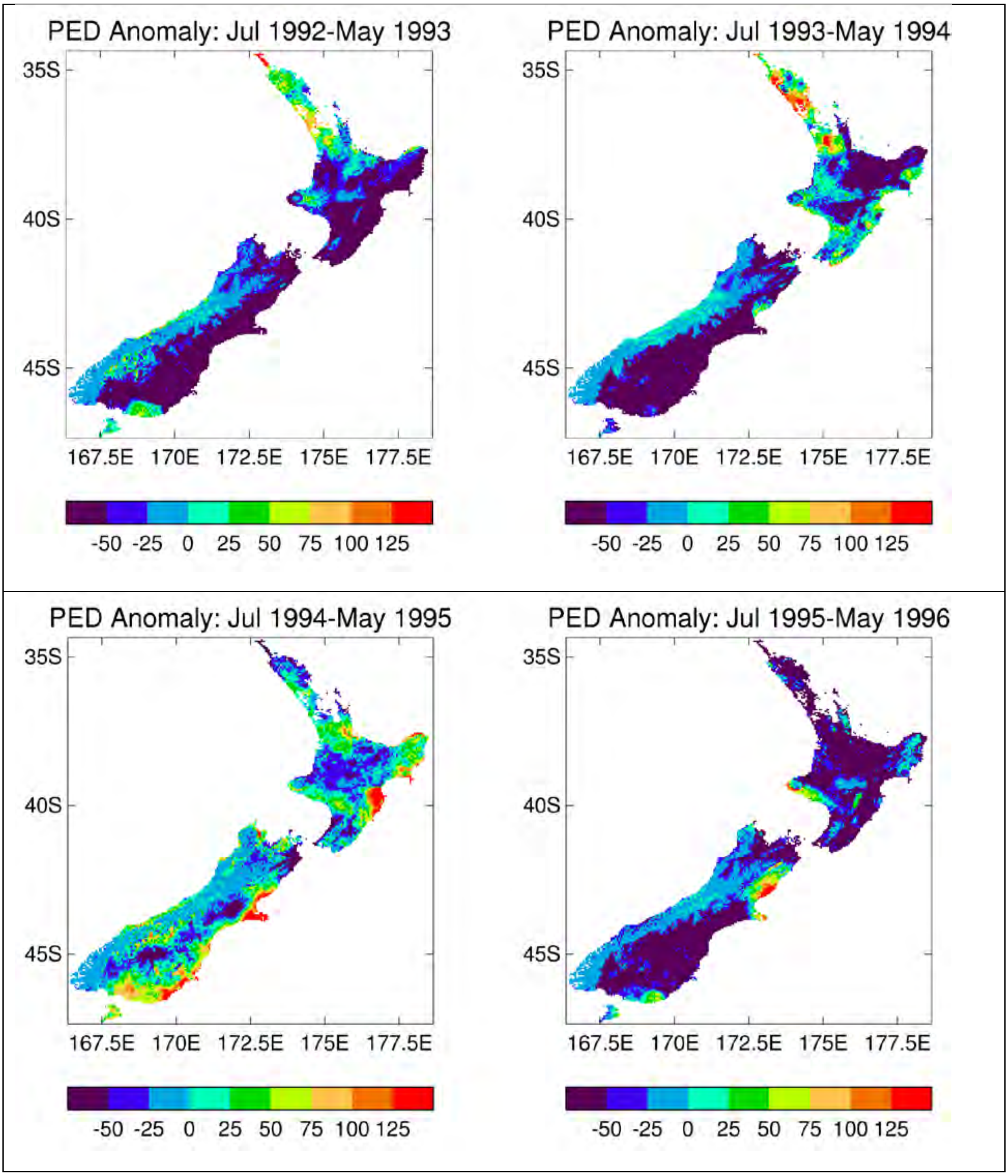
PED Anomaly: Jul 1989-May 1990
PED Anomaly: Jul 1990-May 1991
PED Anomaly: Jul 1991-May 1992
35S
40S
45S
167.5E 170E 172.5E 175E 177.5E
-50 -25 0 25 50 75 100 125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PED Anomaly: Jul 1993-May 1994
PED Anomaly: Jul 1994-May 1995
PED Anomaly: Jul 1995-May 1996
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40S
45S
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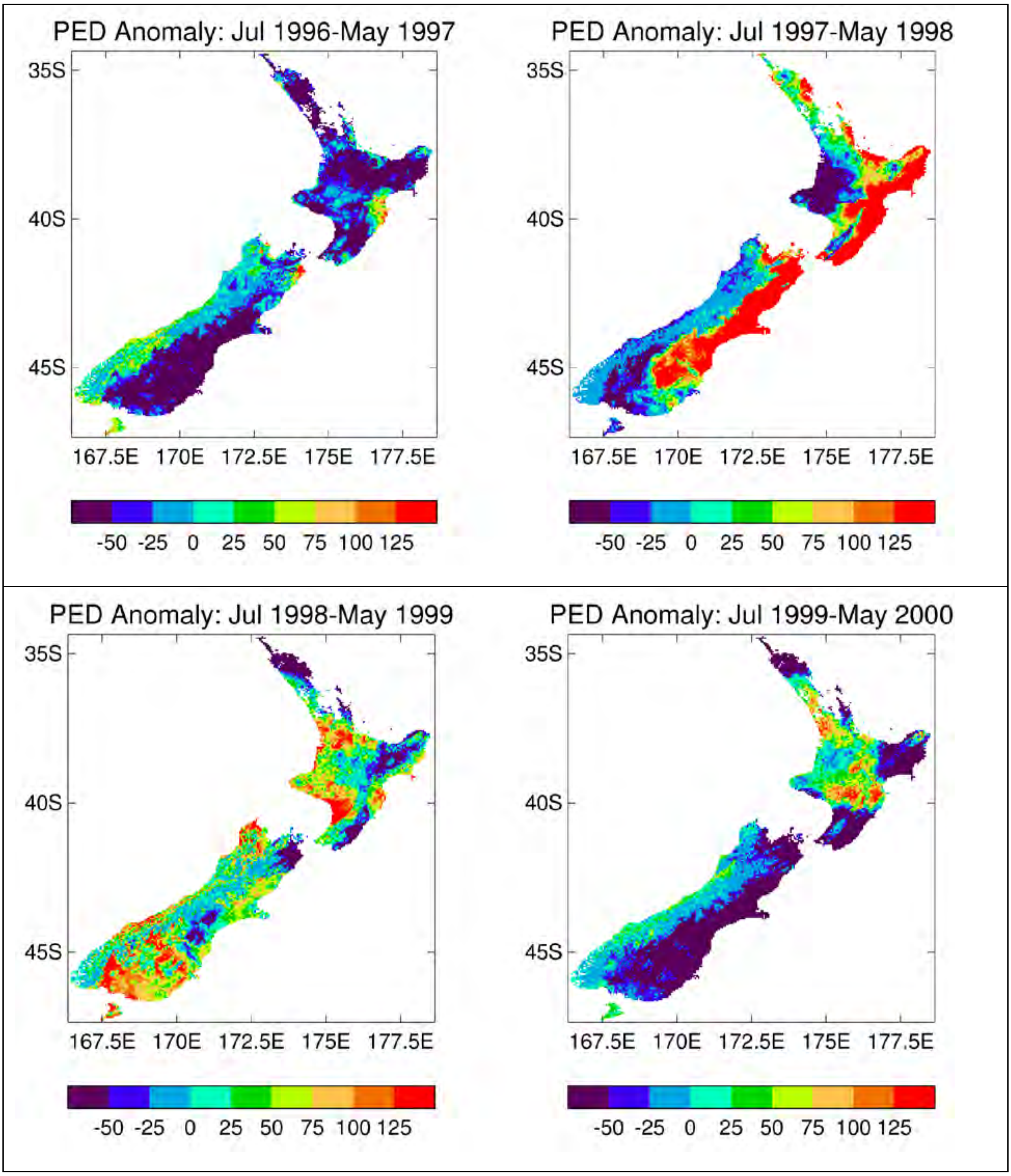
-50 -25 0 25 50 75 100 125


PED Anomaly: Jul 1996-May 1997
PED Anomaly: Jul 1997-May 1998
PED Anomaly: Jul 1998-May 1999
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35S
40S
45S
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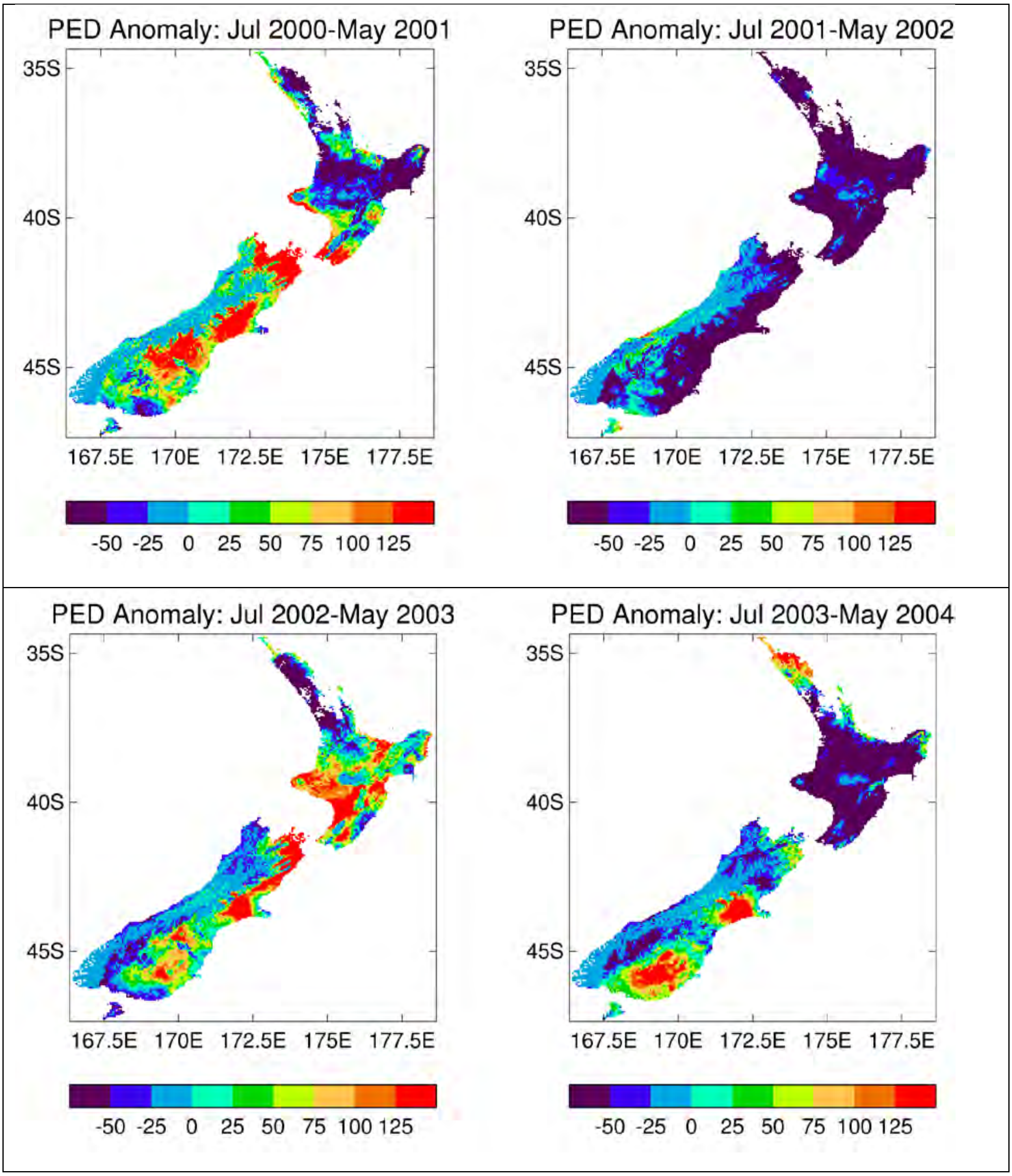
-50 -25 0 25 50 75 100 125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PED Anomaly: Jul 2001-May 2002
PED Anomaly: Jul 2002-May 2003
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40S
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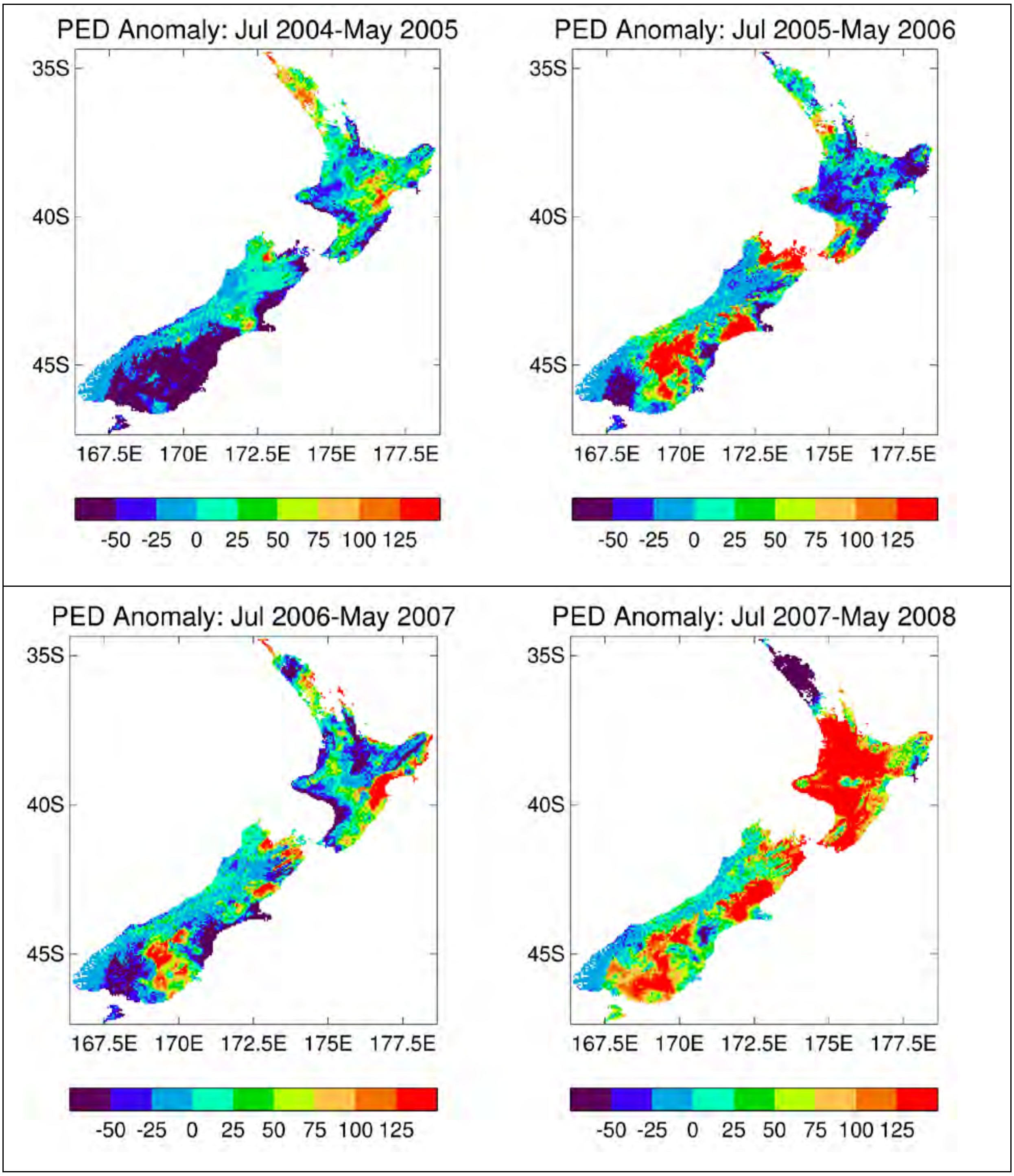
-50 -25 0 25 50 75 100 125


PED Anomaly: Jul 2004-May 2005
PED Anomaly: Jul 2005-May 2006
PED Anomaly: Jul 2006-May 2007
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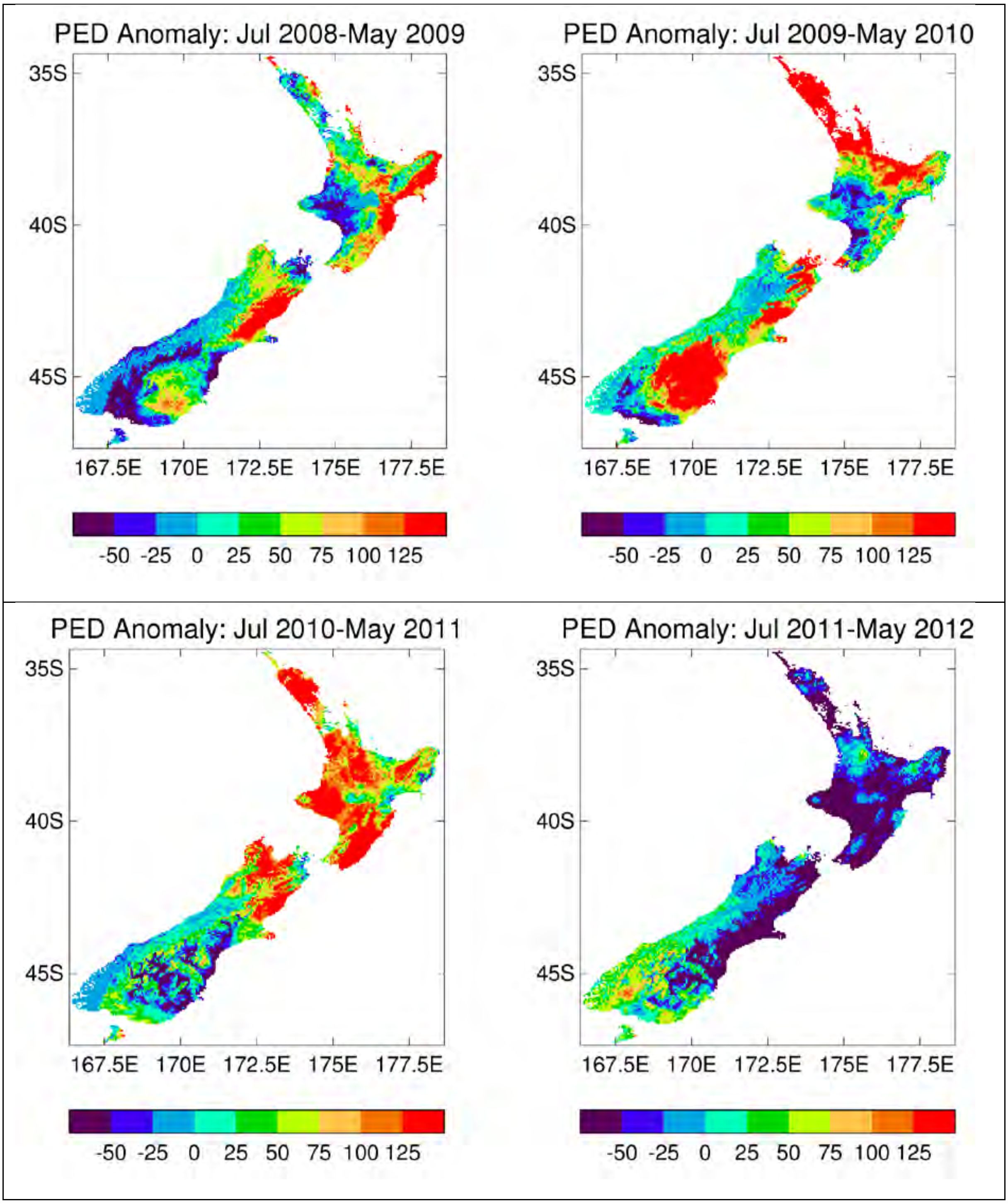
-50 -25 0 25 50 75 100 125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PED Anomaly: Jul 2009-May 2010
PED Anomaly: Jul 2010-May 2011
PED Anomaly: Jul 2011-May 2012
35S
40S
45S
167.5E 170E 172.5E 175E 177.5E
-50 -25 0 25 50 75 100 125