Secular changes in New Zealand rainfall characteristics 1950-2009

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Abstract

Current climate model projections suggest a warming climate will correspond to higher precipitation rates, as well as more frequent extreme rainfall events. Using daily rainfall from eight stations around New Zealand, we compare changes across two thirty year periods (1950-1979 and 1980-2009). We focus on changes in total annual precipitation, numbers of days with recorded rainfall, the intensity of these rainfall events and the mean seasonal cycle at each station. Our preliminary results show a pattern of rainfall decrease in the north and rainfall increase in the southwest, with matching changes to the number of rain days at some stations. While changes to overall daily rainfall total distributions are generally small, there is a strong correlation between changes in total annual rainfall and the frequency of heavy rain days. Further work is needed to understand the internal characteristics of future precipitation patterns with continued climate change. However, these results support current scenarios for New Zealand of rainfall decreases in the northern half of the North Island and increases in the west and south of the South Island.

1. Introduction

Increased moisture content in the lower atmosphere is a well-understood physical response to a warming climate, following the Clausius-Clapeyron relation between temperature and saturation specific humidity. For every degree of air temperature increase, there is maximum increase of about 7% in specific humidity (Mullan et al. 2008). Global climate model projections suggest that, for many regions, this will correspond to an increase in mean precipitation (Dai, 2006). Precipitation distributions are also expected to change, with increases in the frequency of extreme precipitation likely in most locations (IPCC 2012), as has already been observed (Alexander et al. 2006). However, under a changing climate, increases in the intensity of both heavy rainfall and long dry spells are expected in different regions and in different seasons, with contrasts between wet and dry regions, and wet and dry seasons expected to increase (IPCC, 2013). This is summarised by the rule of thumb that “the wet get wetter and the dry get drier”. Hence, understanding the characteristics of changing precipitation patterns requires analysis that extends beyond the evaluation of traditional measures such as annual rainfall totals (Sansom & Renwick, 2007).

New Zealand lies at an intersection of multiple large-scale atmospheric influences, including the Southern Annular Mode (SAM, Renwick and Thompson 2006, Renwick 2011, Thompson et al. 2011) and the El Niño Southern Oscillation (ENSO, Mullan 1995, Salinger and Mullan 1999). In addition, complex topographic features and prevailing westerly winds fundamentally determine the country’s mean climate (Sturman and Tapper 2006). It is therefore difficult to apply to New Zealand a simple translation of projected global changes with a warming climate, especially for rainfall patterns which are so easily influenced by the effects of orography and atmospheric instabilities.

Previous research on observed and modelled changes to precipitation patterns in New Zealand have tended to focus on the frequency of extreme events, and changes on annual-to-decadal timescales (Griffiths, 2007; 2011; Salinger & Mullan, 1999; Salinger and Griffiths, 2001). Changing seasonality of rainfall has also been studied both from an observational point of view (Griffiths 2007) and in terms of likely future changes (Mullan et al. 2008). In the annual mean, existing spatial gradients of rainfall are likely to increase (wet get wetter, dry get drier, Mullan et al. 2008). Seasonally, changes in average rainfall are expected to be largest in winter and spring, with a small reversal in background rainfall gradients (wet get drier) likely in summer and autumn (Mullan et al. 2008). Here we make a preliminary investigation of what changes (if any) to seasonality of rainfall have been observed in New Zealand over the past 60 years. We also investigate observed changes in total rainfall, rain days, and the frequency of heavy rainfall days around the country.

2. Data and Methodology

A set of pre-homogenised station rainfall data was obtained from the National Institute of Water and Atmospheric Research (NIWA), as used in previous research (Griffiths, 2011). See Griffiths (2011) for details of the data pre-processing and homogenisation. Daily (24-hr) rainfall totals recorded at 0900 local time were provided (in millimetres, to one decimal place) for a total of 22 different stations across New Zealand, with records starting as early as 1907. Data for this study were selected based on evaluation of the length and quality of the record and a final selection of stations was made based on suitable geographic spread and data consistency across the 60-year period 1950-2009 (Fig. 1). This time span was chosen as a sufficient sample size to examine changes between two thirty year periods, as well as for potential analysis of decadal trends. Six stations met all of these requirements: Ruakura (Hamilton), Palmerston North, Kelburn (Wellington), Milford Sound, Invercargill and Musselburgh (Dunedin). Two further stations, Tauranga and New Plymouth, were also used for analysis despite there being either short periods of missing data or occasional spurious values in the records.

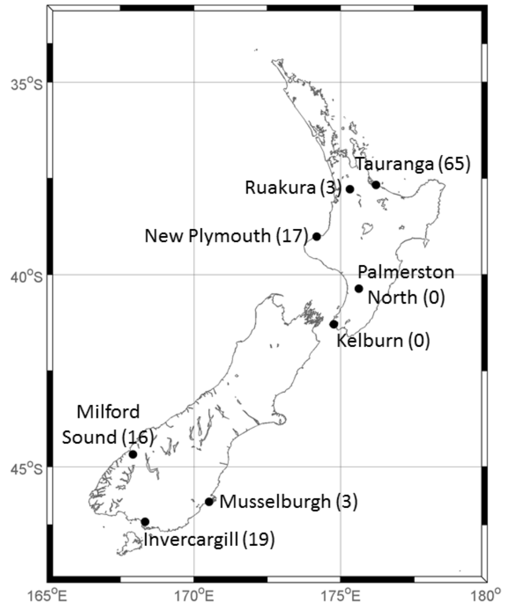

Figure 1: Map of New Zealand showing the location of the eight sites used in this study. The number in brackets after each station name is the number of missing values in the 1950-2009 rainfall record.

While there were two high quality records with zero missing entries (Kelburn and Palmerston North), the remaining stations fell into two categories: (1) those stations which had a block period of missing data, and (2) stations which had missing data distributed randomly throughout the record, totalling less than 100 days for the entire period. Stations that had more than 10 missing values in any one year were Tauranga with 39 missing in 1989 and Invercargill with 19 missing in 1984. New Plymouth had 15 days' data missing in 1994, and many days missing in 1992-93. The New Plymouth record was still used in this study however, after removal of 1992 and 1993 data and addition of 2010 and 2011 to make up the 60 years. Other stations (apart from Palmerston North and Kelburn) had a small number of missing data in particular years, scattered randomly through the period of record. In all cases, statistics were calculated for the available data in individual years then pro-rated by the ratio of the total number of days in the year divided by the number of non-missing days. In other words, missing days were treated as having annual average rainfall characteristics. At worst, this assumption could result in approximately a 10% error for a particular year, or less than 1% for statistics over 30 years.

Starting from daily rainfalls, accumulations were calculated for each month, season (3-month sums for DJF, MAM, JJA and SON) and year. Monthly and 3-month totals were often expressed as a percentage of the corresponding annual total. Numbers of wet (>1mm) and dry days were also derived, along with days of light rain (between 1 and 5 mm), moderate rain (5-15 mm) or heavy rain (>15 mm). Simple statistical test were employed throughout, mostly using a standard two-tailed t-test for difference in means (Wilks 1995).

3. Results

3.1. Rainfall Distribution Changes

Figure 2 shows the distribution of annual rainfall accumulations over the last sixty years, for the two 30-year periods 1950-1979 and 1980-2009. The three northernmost stations (Ruakura, Tauranga, and New Plymouth) exhibit statistically significant decreases in annual total precipitation, while the two southwestern-most stations (Milford Sound and Invercargill) exhibit statistically significant increases (two-tailed t-test for difference in means). In Tauranga, the frequency of occurrence of the driest years (precipitation 1000 mm or less) was much higher during 1980-2009 than during 1950-1979, while at Invercargill the frequency of occurrence of the wettest years (1200 mm or more) increased dramatically between the two periods and years of precipitation totals less than 1000 mm all occurred in the first 30-year period. Such a pattern is broadly consistent with circulation changes seen over the second half of the 20th century (Griffiths 2011) and is also consistent with climate model projections for the 21st century (Mullan et al 2008).

Figure 3 shows the change in distribution of the annual number of wet days (>1 mm) between the two periods. The pattern of change is somewhat different to that seen for annual rainfall totals in Fig. 2. Of the three northern stations that have experienced significant decreases in total annual rainfall, only Tauranga shows a significant decrease in the number of wet days while Ruakura shows a small but non-significant decrease. The two southern stations which have experienced significant increases in total rainfall, Milford Sound and Invercargill, show statistically significant increases in the number of wet days (two-tailed t-test). An analysis of the full distribution of wet day rainfall totals shows that there have been no statistically significant changes in rainfall amount distributions between the two 30-year periods (Chi-squared goodness of fit test, Wilks 1995).

Changes to the frequency of heavy rain day events (>15mm) are generally statistically insignificant (not shown), with the exceptions of Tauranga (significant decrease) and Milford Sound (significant increase, two-tailed t-test). These results are broadly consistent with Salinger and Griffiths (2001). Changes in the mean frequency of heavy rain days show a strong linear relationship with corresponding changes in annual rainfall totals. Figure 4 shows the relationship between the mean change in annual rainfall totals and mean heavy rain day (>15mm) anomaly, normalised as a percentage of the sixty-year mean value for each parameter. There is a very strong linear relationship (R^2 = 0.96) between

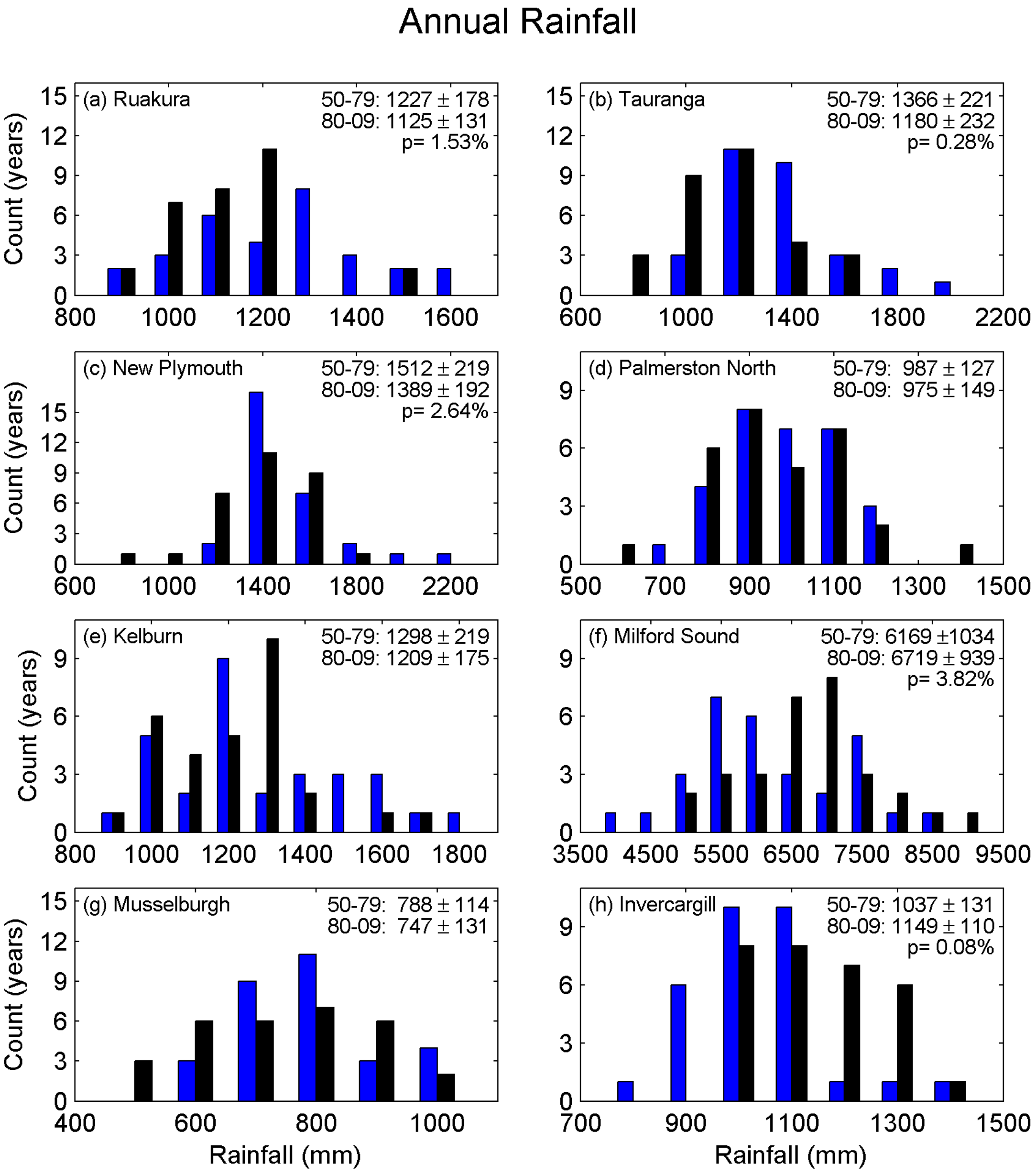

FIGURE 2: Histograms of annual rainfall totals for the periods 1950-1979 (blue bars) and 1980-2009 (black bars) for eight New Zealand rainfall stations: a) Ruakura, Hamilton; b) Tauranga; c) New Plymouth; d) Palmerston North; e) Kelburn, Wellington; f) Milford Sound; g) Musselburgh, Dunedin and h) Invercargill. Categories of rainfall amount vary according to the climatology at each station. Annual mean amounts (mm) on the x-axis indicate the centres of non-overlapping bins, e.g. 1200 at Ruakura is a count of all annual rainfalls between 1150 and 1249 mm. Statistics in the top right of each panel show the mean and standard deviation of annual rainfall totals for the two 30-year periods, and the statistical significance (p-value) of the difference in means (two-tailed t-test), if the p-value is 5% or less.

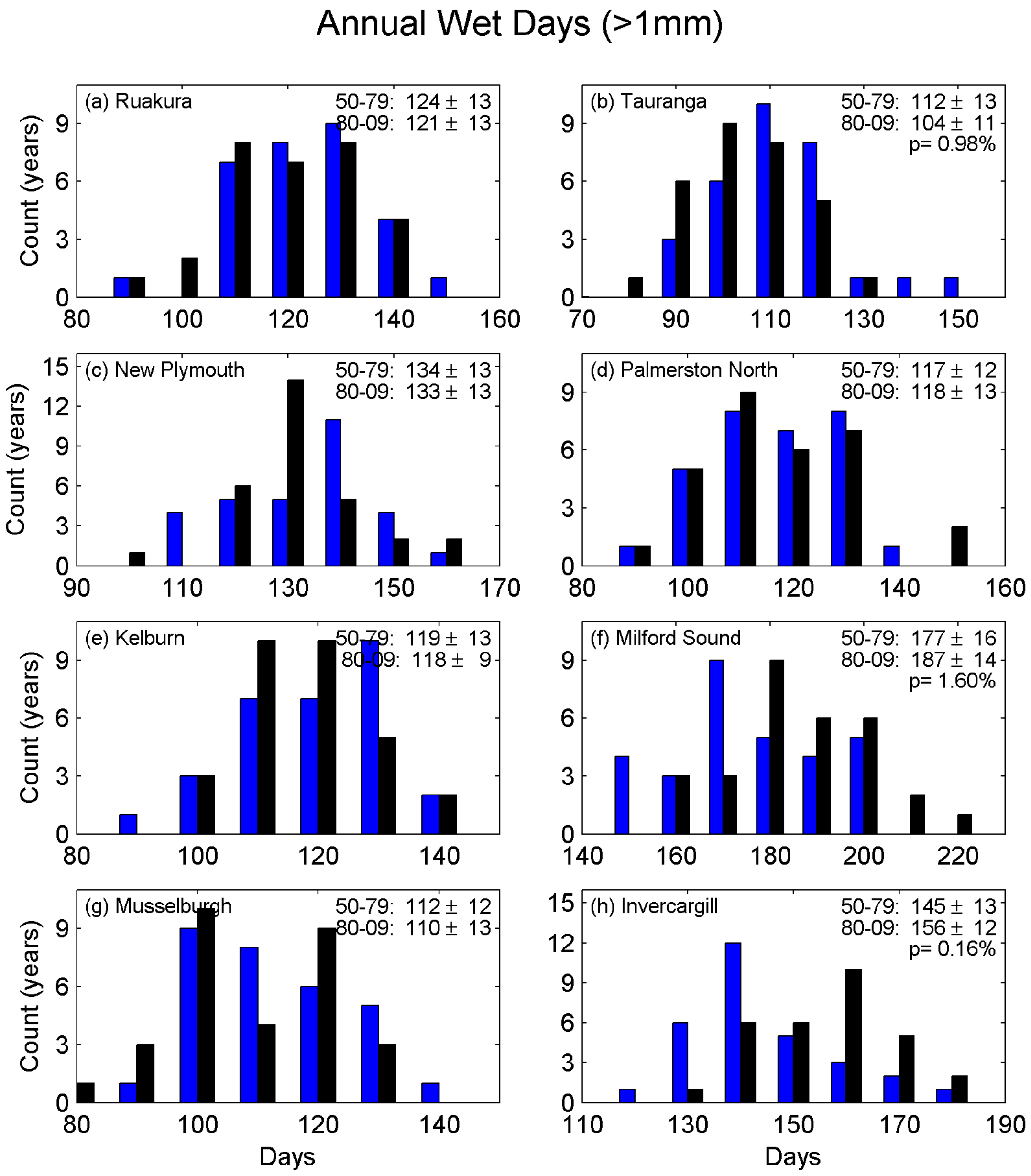

Figure 3: Same as Figure 2, but showing the changes to the frequency distribution of the number of wet days per year. Categories of numbers of wet days vary according to the climatology at each station. Numbers of days on the x-axis indicate the centres of non-overlapping bins, e.g. 120 at Ruakura is a count of all years with between 115 and 124 wet days.

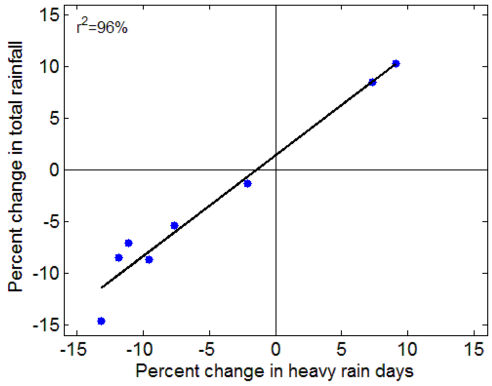

FIGURE 4: Relationship between percentage changes in annual precipitation totals and the number of heavy rain days (>15 mm) per annum. Percentages are calculated relative to respective 60-year means and the changes are differences between first and second 30-year periods. The straight line represents a linear regression fit between change in heavy rain days and change in total precipitation. The variance accounted for is 96%.

these two statistics for the eight stations analysed here. This result supports the suggestion that changes to precipitation patterns as part of a warming climate are associated with a corresponding change in the number of heavy rainfall events.

3.2. *Decadal and seasonal cycle changes*

Figure 5 shows the decade-by-decade progression of annual rain day anomalies for light and heavy rain days at each station. Stations showing statistically significant changes in precipitation (Ruakura, Tauranga, New Plymouth, Milford Sound and Invercargill) demonstrate matching decadal trends most clearly for the number of heavy rain days. Otherwise, there are no clear patterns to decadal-scale changes in light and heavy rain-day occurrences.

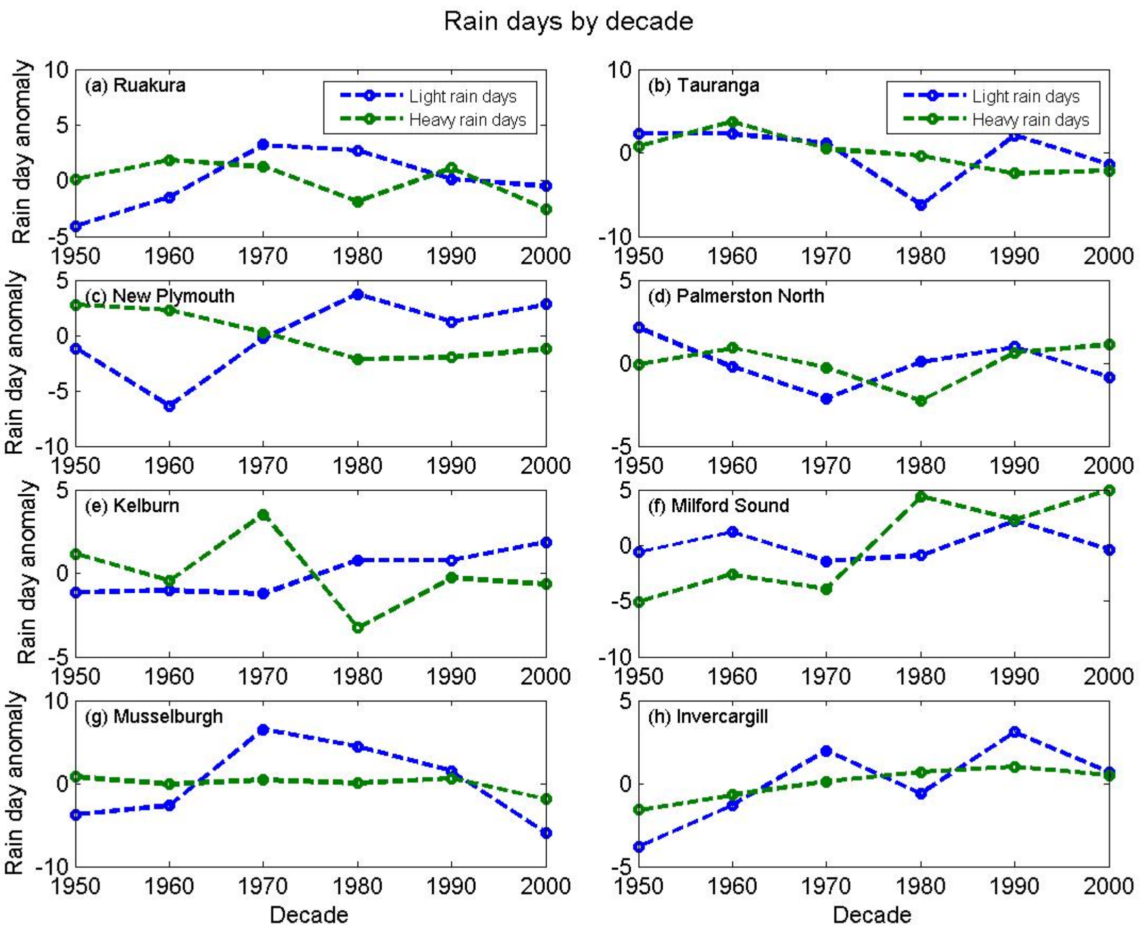

FIGURE 5: Decadal changes to number of annual wet days of different intensity for eight NZ rainfall stations for 1950-2009. Each decade has been averaged and subtracted from the 60-year mean number of rain days for two intensity criteria: light rain days (between 1 and 5 mm/day, blue); and heavy rain days (>15 mm/day, green).

Figure 6 compares the seasonal cycles for each of the two thirty year periods, as for previous results. Thirty-year mean monthly rainfalls were smoothed with a three-month running mean to emphasise seasonal-scale variations. The three North Island stations exhibiting significant decreases in total precipitation (Ruakura, Tauranga, and New Plymouth) show rainfall decreases in almost all months of the year, most notably in the winter months. Conversely, the two southern stations exhibiting significant increases in total precipitation (Milford Sound and Invercargill) show rainfall increases at most times of year, except for the autumn months (March-May). Also, the three South Island stations appear to have flatter (lower amplitude) seasonal cycles in later years. A move to a flatter seasonal cycle is also apparent in New Plymouth. Almost all stations show a decrease in average rainfall at the beginning of autumn (March-April).

It is important to reiterate that such changes to the structure of the seasonal cycle of rain are small - further statistical analysis and a longer record length are therefore needed to account for natural variations in seasonality.

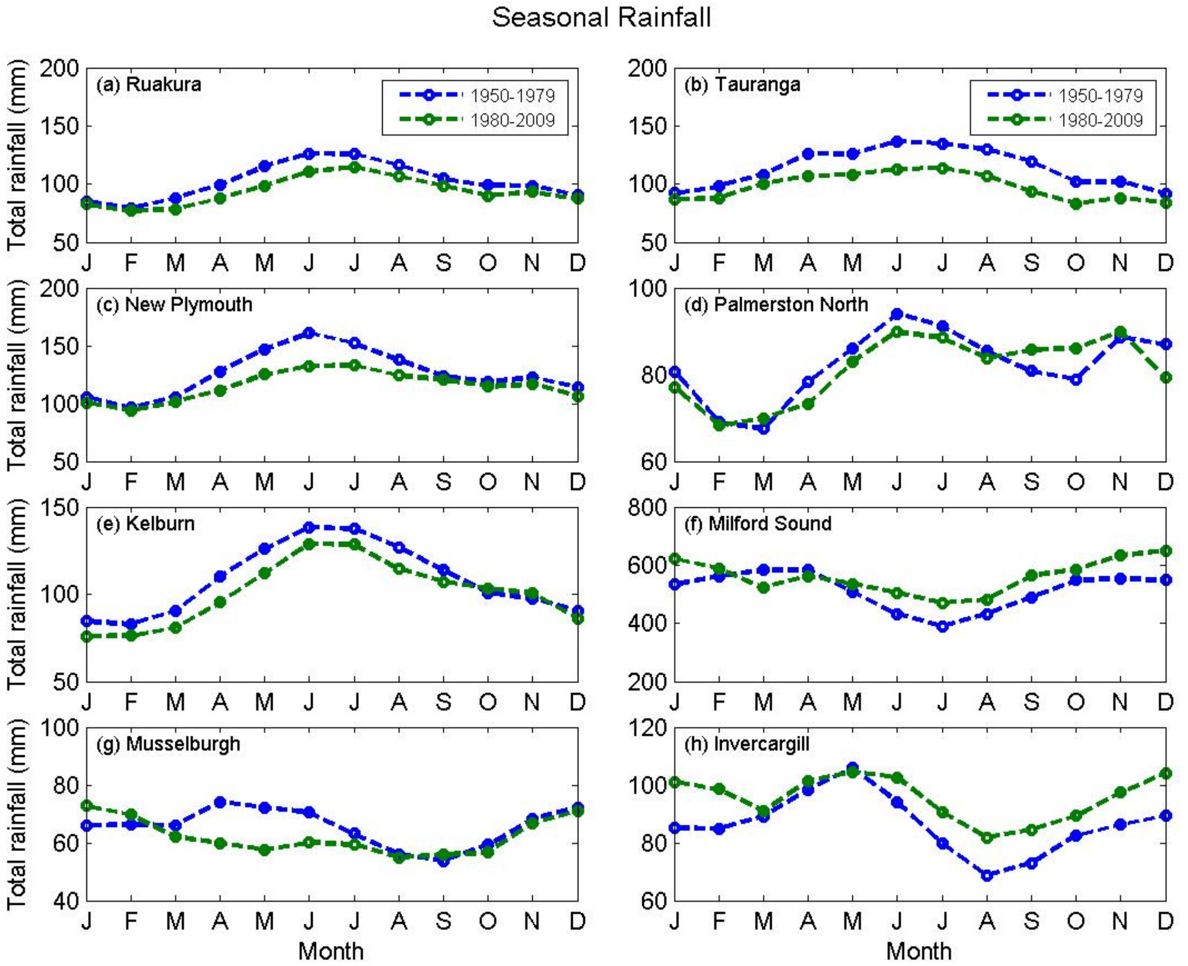

FIGURE 6: Change to the seasonal cycle of monthly total rainfall for eight rainfall stations (as in Figure 1). Thirty-year mean seasonal cycles have been calculated separately for 1950-1979 (blue) and 1980-2009 (green). A three-month running average has been used to smooth the monthly means, to emphasise seasonal-scale variability

4. Discussion and Conclusions

Analysis of changes in rainfall distributions was performed for eight New Zealand stations between 1950 and 2009. Mean changes between 1950-1979 and 1980-2009 show statistically significant decreases in annual rainfall at the northernmost stations and significant increases at the two southwestern-most. Such changes in rainfall totals are exhibited through most months of the seasonal cycle. A strong correlation ($R^2 > 0.9$) is found across the country between changes in the number of days of heavy rain (>15mm/day) and annual rainfall changes. In addition, there may be coherent changes to the seasonal cycle of rainfall, with most stations demonstrating reduced rainfall accumulations in late summer-early autumn.

Several large-scale climate patterns fundamentally influence New Zealand precipitation patterns. Griffiths (2011) identified three key modes of atmospheric variability: (1) variations in the position and intensity of the mid-latitude westerly wind belt, measured as changes to the Southern Annular Mode (SAM), (2) the tropical influence of El Niño Southern Oscillation (ENSO) and (3) Pacific Decadal Oscillation (PDO).

The Southern Annular Mode (SAM) can be defined as the mean sea level pressure (MSLP) difference between stations at 40°S and 65°S: a positive index corresponds to a poleward contraction of the mid-latitude jet and strengthening of associated westerly winds (Marshall, 2003). Previous work has demonstrated a clear link between SAM polarity and precipitation anomalies in New Zealand. Model results by Thompson et al. (2011) and Ummenhofer & England (2007) show a positive SAM mode corresponding to weakened westerly winds over New Zealand, with higher (lower) summertime precipitation rates in the eastern (western) South Island as a consequence.

Fluctuations in the SAM are known to persist on seasonal timescales, but long-term trends have also demonstrated a shift toward a more positive polarity over the last fifty years. Several forcing mechanisms contribute to changes in the strength of the Southern Annular Mode, particularly stratospheric ozone depletion and greenhouse gas increase. It is difficult to evaluate evidence for long-term changes to the Southern Annular Mode in the rainfall station data. Climate model projections suggest that annual average westerly wind strength is expected to increase over New Zealand, especially in the winter and spring months (Mullan et al. 2008). The increasing trend in rainfall at Milford Sound and Invercargill is consistent with the expected trend win westerly winds, and with observed changes in winds over New Zealand in recent decades (Salinger et al. 2005). However, understanding such links to the SAM and the background circulation requires further research.

ENSO is a tropical, Pacific-wide oscillation that affects pressure, winds, sea-surface temperature and rainfall. In the El Niño phase, New Zealand usually experiences stronger than normal south-westerly airflow, resulting in drier conditions in the north-east of the country and an anti-phase response for most of the South Island (Mullan et al. 2008). Conversely, a La Niña event brings enhanced north-easterly flows and wetter conditions in the north and east of the North Island. In the period under consideration here, there has been a weak but statistically significant trend towards more El Niño-like conditions, consistent with pattern of drying in the northeast and wetting in the southwest (Griffiths 2011).

The geographical patterns of change identified here are consistent with observed changes in large-scale influences such as the SAM and ENSO, and are also consistent with expected changes as a result of increasing atmospheric greenhouse gas concentrations. Future work will address the patterns of change in more detail and will attempt to attribute observed changes to natural or anthropogenic influences using GCM output from the CMIP5 archive.

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