Diurnal variations in precipitation frequency in New Zealand

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Abstract

Diurnal and annual precipitation variations for 58 weather stations distributed across New Zealand are analysed. For many stations an annual peak is observed in precipitation frequencies in winter and a diurnal peak is observed in the early morning. This is in line with previous studies from a much smaller number of New Zealand stations. Station patterns are analysed using hierarchical clustering to reveal groupings of locations with similar patterns. This cluster analysis identifies differences in the peak time and diurnal pattern of rainfall frequency, associated with location and orography. The West coast of the South Island experiences the most frequent precipitation, due to prevailing westerly winds in combination with local orography. The South East of the South Island exhibits lower rainfall frequency and little seasonality. The central North Island and to a lesser extent the North coast experience relatively high precipitation frequencies in the afternoon, possibly caused by convection.

1. Introduction

This study addresses the diurnal variation of rainfall frequency in New Zealand, including how it varies spatially and seasonally. As pointed out by Rouault, Roy, & Balling Jr. (2013), significant gaps occur in the documentation of the diurnal cycle of rainfall in many parts of the world, even though this is an important component of regional precipitation variability. Such information also has important practical implications, since occurrence of rainfall affects economic and social activities ranging from agriculture to outdoor recreation. Nevertheless, no long-term nation-wide New Zealand study of diurnal rainfall patterns has yet been published, although analyses at a few sites date back to the early days of climatological research in New Zealand. A detailed documentation of the diurnal variability - and ultimately also its interaction with lower frequency meteorological oscillations - is an important first step to improve both our understanding of the processes underlying precipitation as well as our abilities to forecast it.

New Zealand Meteorological Office Note No. 1 (Kidson, 1931) reported on hourly precipitation measurements for Kelburn, Wellington in 1928 and 1929. An increase in the average amount of rainfall during the “dawn hours” and “afternoon hours” was identified. The latter was attributed to convection while the cause for the former was reported to be unknown.

The average rainfall in 3-hourly segments for 16 stations was studied by Maunder (1957), describing four stations in detail. This study also mentions convective afternoon rainfall and tentatively attributes a "nocturnal" maximum to "variation in orographic rainfall".

A similar pattern was observed in a detailed study of rainfall patterns in the city of Invercargill (Sansom, 1988). It mentions an increase during the night due to "a convergence between night-time land breezes and the prevailing westerlies about the coast".

Published literature on observed diurnal rainfall variations and their causes in other regions of the globe has been summarised by Yang & Smith (2006). Common features include a maximum in late–evening/early-morning hours over the ocean in tropical and sub-tropical regions, and a mid-to-late afternoon maximum over land. For the South African summer, Rouault, Roy, & Balling Jr. (2013) report a midnight to early morning maximum in the frequency of rainfall events in coastal areas, a late afternoon to early evening maximum over the continental interior, and a nighttime maximum in mountainous areas. They attribute this behavior to convection, local land/sea breeze circulations, orography, convection, and mountain–valley processes.

Several authors have focused particularly on rainfall in mountainous regions. Cotton & Anthes (1989) reported an early-morning (0300 LT) maximum in precipitation amount and frequency in northern and central Colorado mountains, with a secondary maximum in the afternoon and early evening. But stations upwind of the main mountain crest in southern Colorado exhibited a pronounced afternoon maximum in precipitation frequency. Mandapaka, Germann, & Panziera (2013) observed a late afternoon peak in rainfall frequency in the European Alps in spring and summer.

This study analyses data from NIWA's climate database, CliDB, which serves as the national climate archive for New Zealand. The accumulation of over two decades of hourly rainfall data from stations covering the entire country allows for a comprehensive description of diurnal and annual variations in precipitation and subsequent comparison to other countries. Hierarchical clustering is performed on the derived patterns to identify regions sharing common features.

2. Methodology

2.1 Data

Hourly rainfall data in CliDB are collected from measurements using tipping-bucket rain gauges. By the beginning of 1995 this network provided reasonable coverage of the entire country. Quality assurance has been performed routinely on this data set and includes checks for inconsistencies, unrealistic values and strong divergences from nearby stations or past behaviour.

For this study, 58 stations from the two main islands as well as Stewart Island, Campbell Island and the Auckland islands were selected that started reporting hourly rainfall data on 1 January 1995 or before and were still active in 2015. Only stations with less than 10% missing data were used. The selected stations are shown in Figure 1. Note the big difference in the number of rainfall hours between west coast and inland stations on the South Island which is due to the Southern Alps mountain range combined with predominantly westerly winds. To ensure temporal overlap between the stations no data prior to 1 January 1995 were used. From the data, frequency of wet hours, defined as the number of wet hours (> 0 mm) divided by the total number of hours for which measurements were available, was derived for each station. To compare diurnal variability between individual stations, frequencies were normalised by calculating the z-score, which is obtained by subtracting the station mean and dividing by its standard deviation.

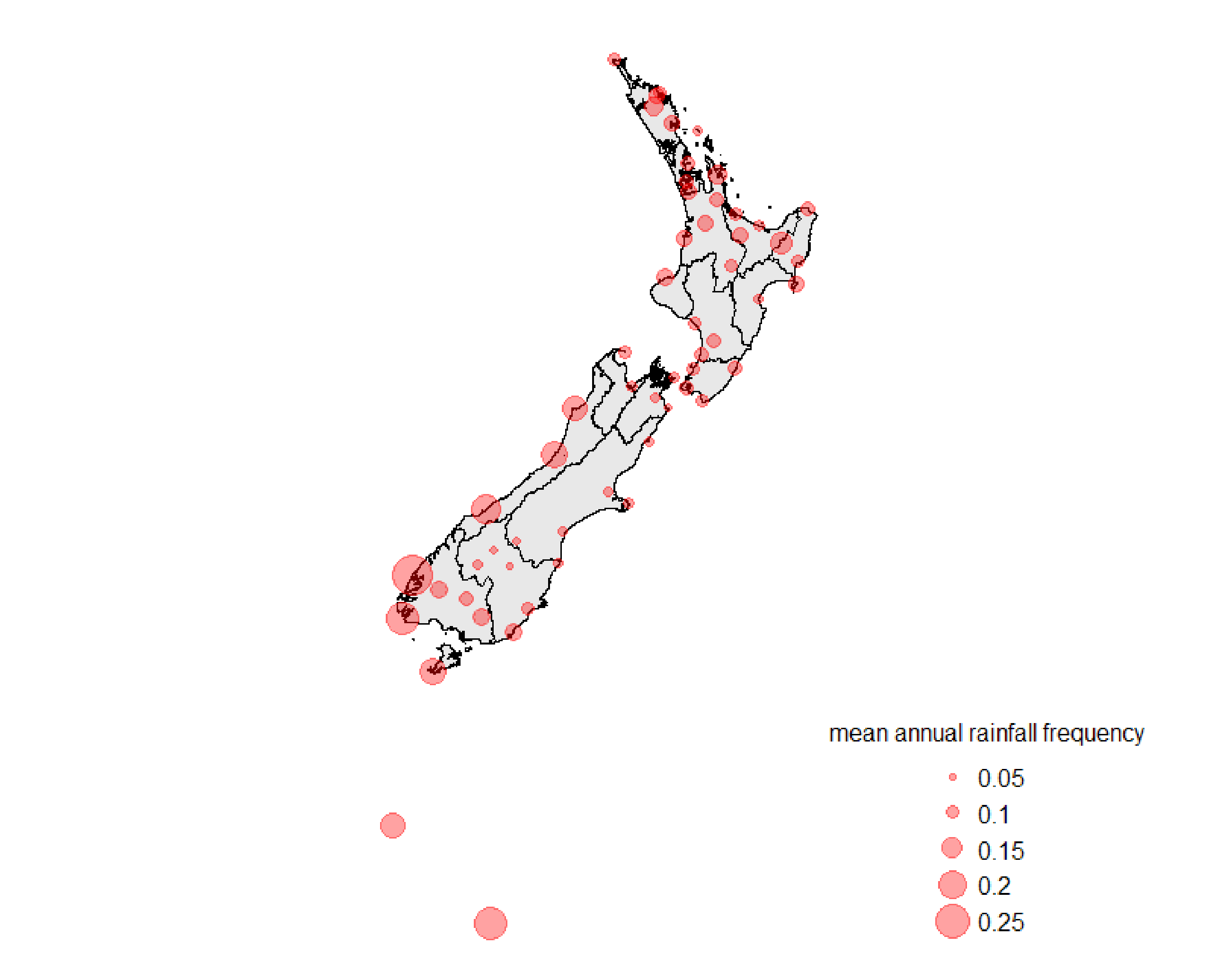

Figure 1: Locations of stations used in this study, sized by average annual frequency of wet hours.

2.2 Clustering

The complete linkage method for hierarchical clustering was used to identify possible groups of stations with similar features. Being an unsupervised method it does not require any a priori input or ground truth. An agglomerative (bottom-up) approach was used, where each station is represented by a feature vector. Pairs of stations are iteratively merged together into one, until all stations are merged. At each iteration, the two most similar stations are merged, based on a cost function representing the dissimilarity between the features of the two stations. The premise is that the cost of merging stations within a cluster is significantly smaller than the cost of merging stations representing two distinct clusters. By observing the monotonically increasing value of the cost function associated with each merge, clusters are identified by the occurrence of a strong increase between subsequent merges. For a more detailed explanation of the method see e.g. (Hastie, Tibshirani, & Friedman, 2009).

In this study, a vector of 96 features was constructed for each station by calculating the z-score of the precipitation frequency by hour of day and season, with (Austral) summer defined as the months of December, January and February, and so on. Each feature then represents the departure from the seasonal mean for a particular station in units of the seasonal standard deviation. The Euclidean distance between these feature vectors was used as the cost function representing the dissimilarity between two stations.

3. Results

Figure 2 shows the data aggregated over all stations and all years. The year has been divided by ordinal days into 24 quantiles to create a 24 by 24 grid showing frequency of rain by hour of day and time of the year. The plots show the column and row means where the red line shows the 2 dimensional Fourier fit using the first 3 by 3 components. The annual cycle peaks during austral winter. The diurnal cycle peaks early in the local morning corresponding to the late evening/early morning maxima that were reported in previous New Zealand and oceanic studies. Note that the amplitude of the diurnal cycle is about 11% of the mean, which is not far below the value of about 14%, which was reported for all tropical oceans by Imaoka & Spencer (2000).

The main aim of this study is to investigate local differences in diurnal precipitation frequency cycles.

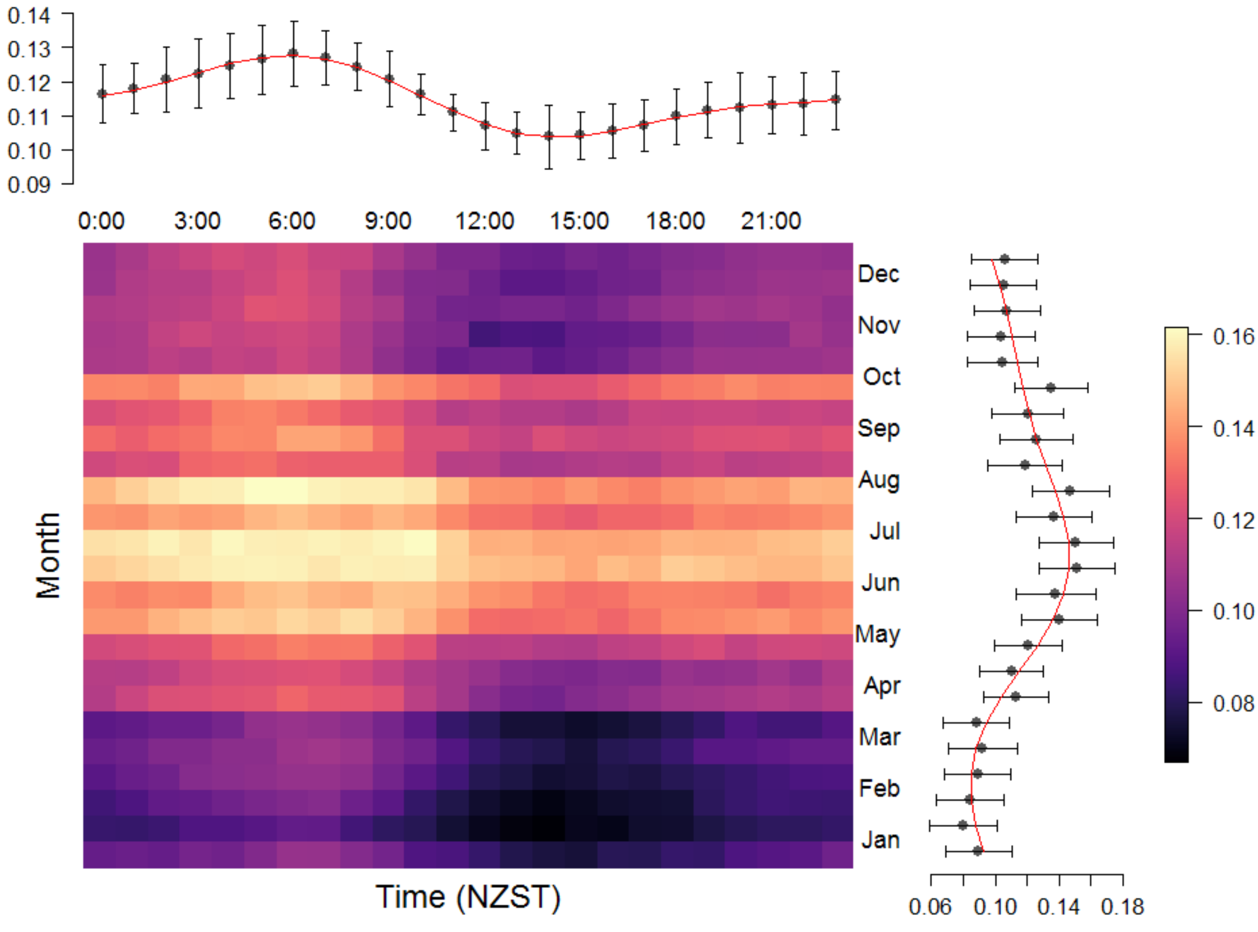

Figure 2: Diurnal and annual distribution of precipitation frequency for the entire data set. Columns represent hour of day and rows represent the ordinal day of the year divided into 24 quantiles. Side plots show the column and row means where the red line indicates a 2 dimensional Fourier fit using the first 3 by 3 components.

Figure 3 shows the dendrogram resulting from the aforementioned approach. Applying a cut-off at the biggest jump between subsequent merges yielded a separation of the stations into four distinct clusters as indicated by the red boxes. These groups also lie in close proximity spatially as shown in Figure 4.

Further investigation is needed to determine what distinguishes these groups of stations from each other. Figure 5 shows the mean frequency values for each cluster. From this the following observations were made.

The largest cluster, shown in black closely resembles the overall pattern as depicted in Figure 2 with maximum rainfall frequency in the early morning and a strong seasonality.

The blue cluster in and around the Otago region features a more or less constant mean frequency of hourly rainfall across the seasons and a strong apparent diurnal peak in precipitation frequency around noon in winter. The latter is an artefact that can be attributed to a known phenomenon in Southern stations where precipitation from e.g. fog or dew freezes onto the rain gauge during the night or morning and is released as temperatures rise above freezing point during the day.

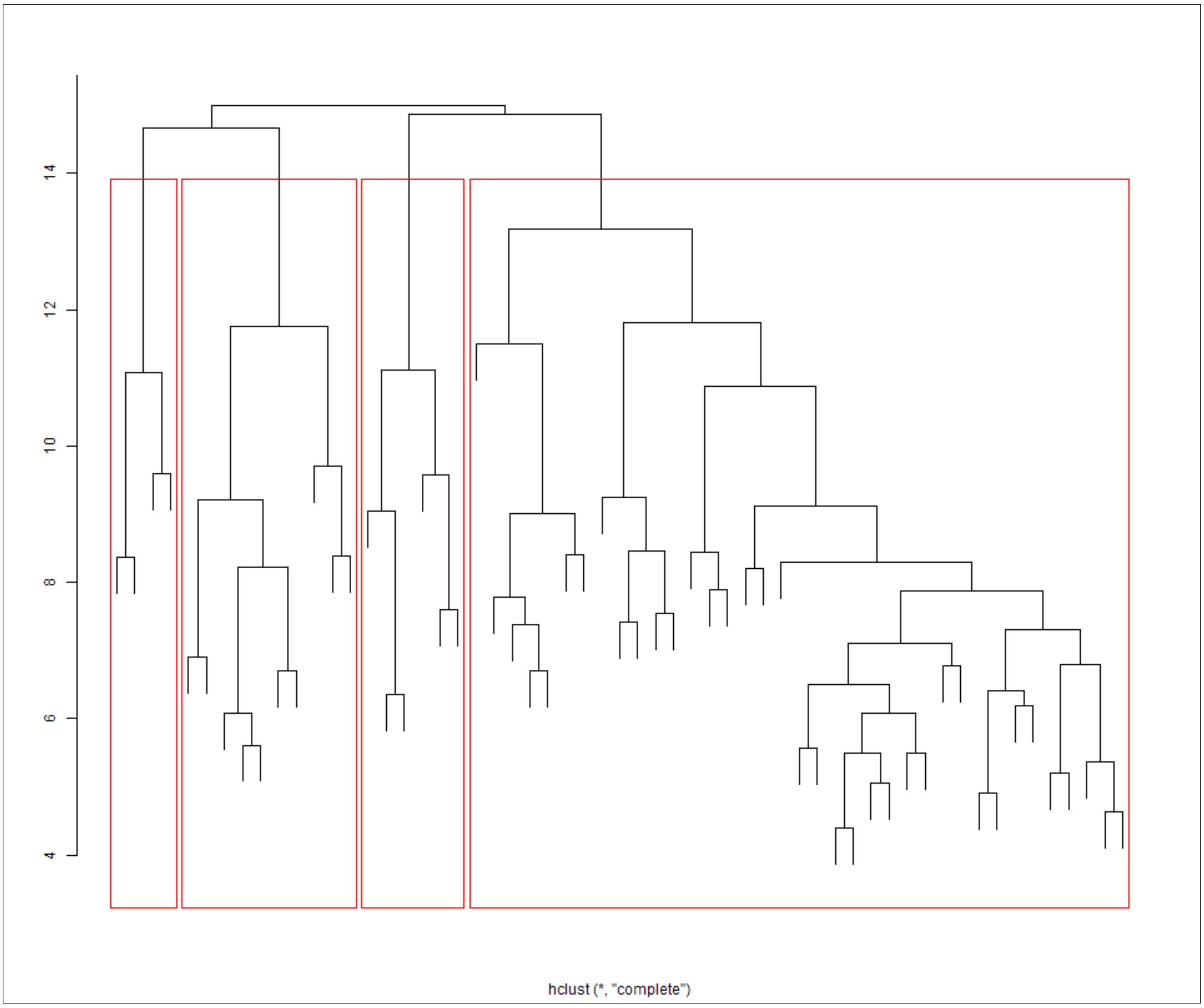

Figure 3: Dendrogram showing results of hierarchical clustering of station data.

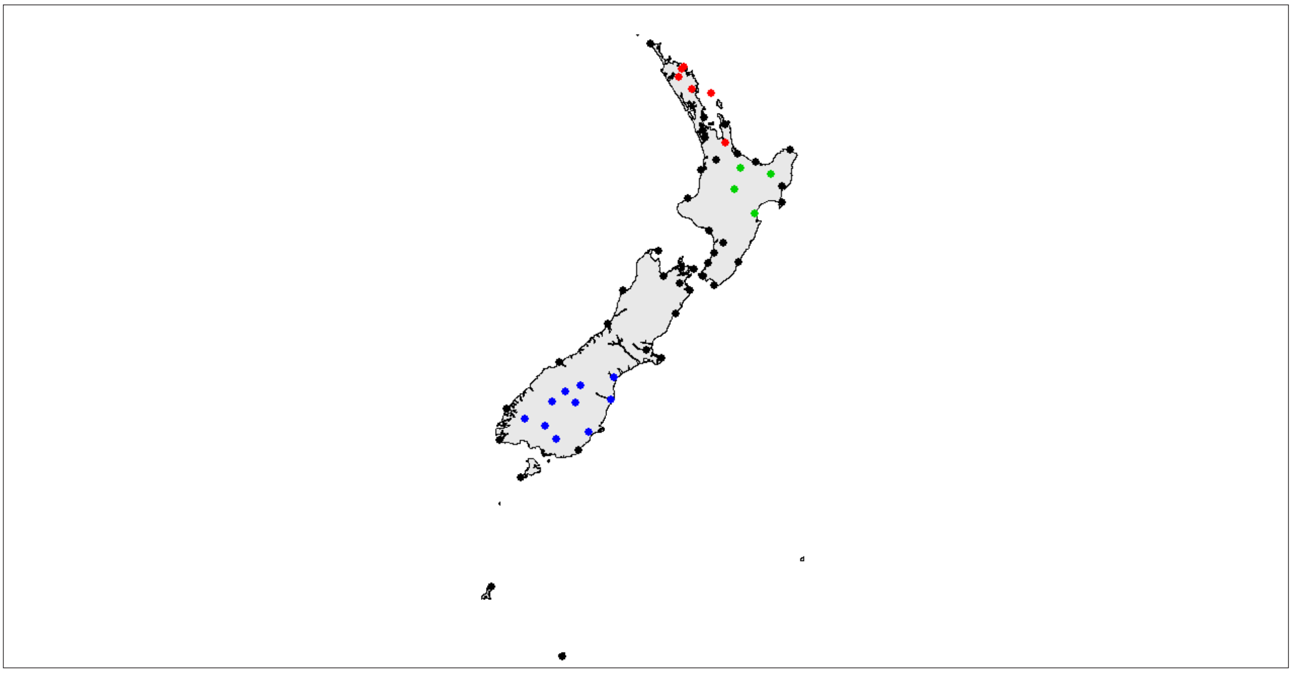

Figure 4: Spatial distribution of the four distinct station clusters, found using hierarchical clustering.

Figure 5: Mean hourly precipitation frequencies for each cluster.

The green cluster in the central North Island shows a double peak structure in precipitation frequency through the day, in which the late afternoon peak is likely caused by convective rainfall.

The red cluster around the Hauraki Gulf partly resembles both the green and black. It features an afternoon increase that is mostly weaker than the green cluster and most pronounced in winter.

From these results, the difference between precipitation frequency in afternoons and mornings as well as between summer and winter were identified as being the main distinguishing features in this data set. We define the diurnal and seasonal parameters D and S as follows.

$$D = f_{afternoon} - f_{morning}$$

$$S = f_{winter} - f_{summer}$$

Here, morning is defined as the 6 hours up until noon and afternoon as the 6 hours immediately after, while summer and winter are defined as before. Together with the mean precipitation frequency M (which did not play a role in the hierarchical clustering described earlier, because z-scores were used), these constitute three simple, interpretable statistics to describe the main features of precipitation patterns in this data set.

Figure 6 shows the station histograms for the z-scores of the D, S and M parameters. The most extreme negative values for D and S and positive values for M are colour coded and are indicated on the map in Figure 7. The West Coast of the South Island as well as the smaller islands to the South stand out by their high mean rainfall frequency, caused by moist air rising as the predominantly westerly winds from the Tasman Sea approach the Southern Alps or the small island orography (Wratt, et al., 1996). Conversely, stations to the East are sheltered by the orography and feature lower seasonality and low mean rainfall frequency. On the North Island the central stations and some of the North Coast stations show relatively high frequencies in the afternoon, resulting in a low D value.

4. Conclusions and outlook

Hourly precipitation data from the last 20 years show that many New Zealand locations experience precipitation most frequently in the early mornings and during austral winter. Hierarchical clustering was used to find regions that differ from this general behaviour. From these results three main parameters, diurnality D, seasonality S and overall mean M, were constructed that correspond to distinguishing features in the precipitation frequency patterns. The west coast of the South Island experiences the most frequent precipitation, due to prevailing westerly winds in combination with local orography. The South East of the South Island exhibits lower rainfall frequency and little seasonality. The central North Island and to a lesser extent the North coast experience relatively high precipitation frequencies in the afternoon, likely to be caused by convection.

This study was primarily focused on providing a description of the variability of diurnal precipitation patterns. Even though some tentative attributions have been mentioned, further research would be needed to provide a solid scientific understanding of the physical and meteorological processes that generate these observed precipitation patterns. In addition, scale interactions of the diurnal cycles with lower frequency modes such as the El Niño–Southern Oscillation (ENSO), the Madden–Julian oscillation (MJO) and the Southern Annular Mode (SAM) will be an important topic for further research.

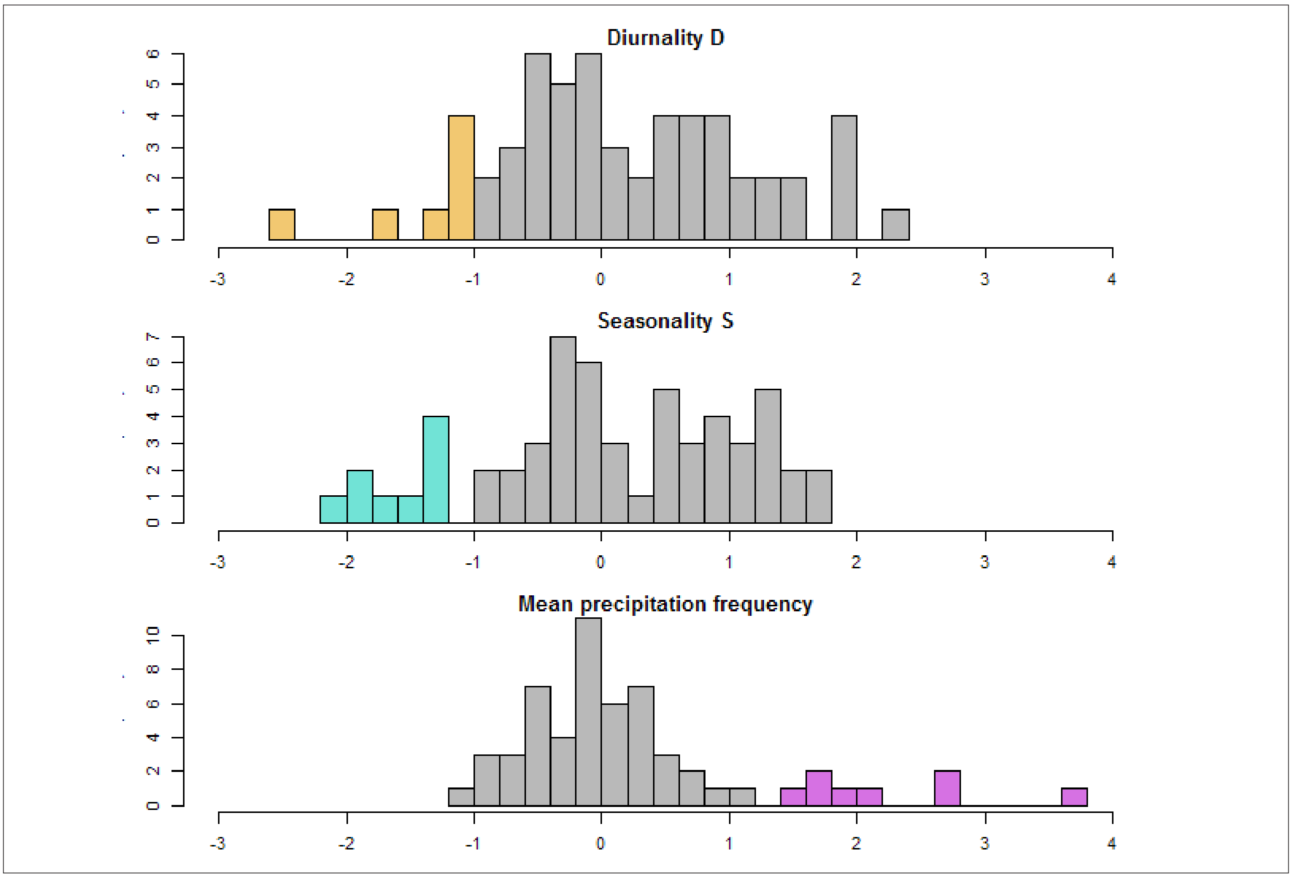

Figure 6: Histograms showing the distributions of the D, S and M parameters for individual stations. Units represent standard deviations from the mean.

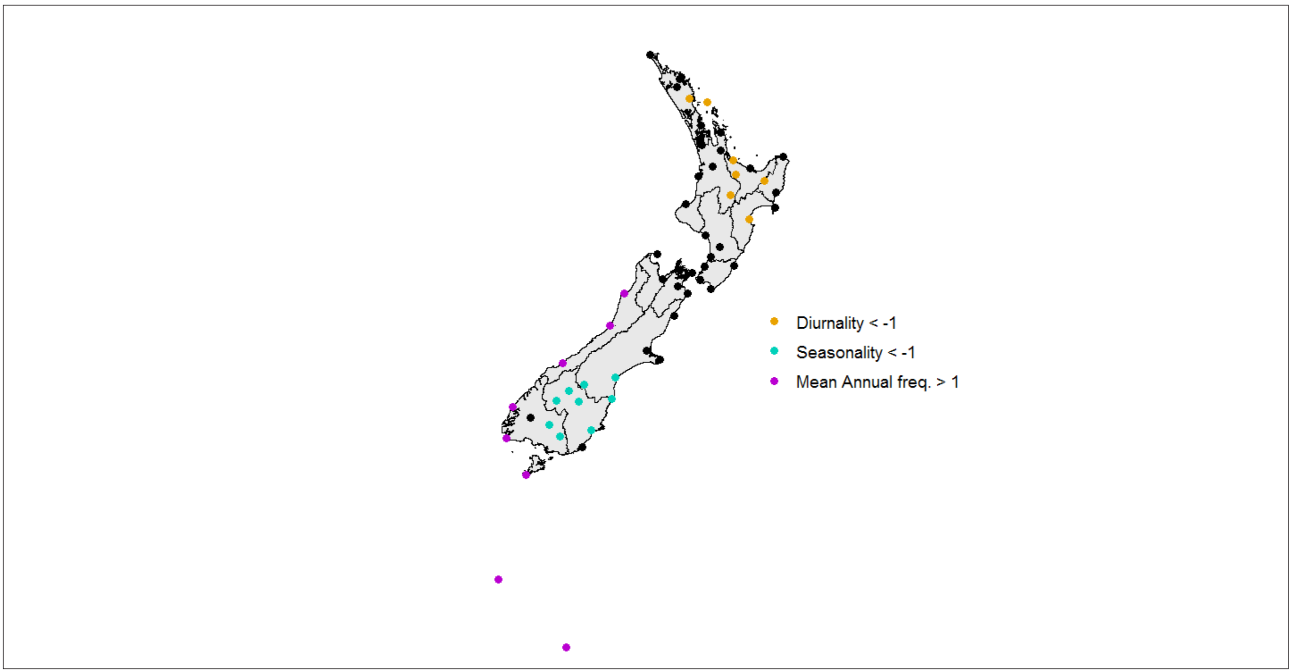

Figure 7: Spatial distribution of stations with low diurnal variation (D), low seasonal variation (S) or high mean value (M) of rainfall frequency. Units represent standard deviations from the mean.

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