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# An assessment of the accuracy of interpolated daily rainfall for New Zealand

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## Abstract

Daily rainfall data from about 200 automatic weather stations are operationally interpolated onto a regular grid of points covering all of New Zealand at a resolution of 0.05 degrees lat/long (approximately 5 km). These data, as well as daily values for 10 other climate variables, are known as NIWA's Virtual Climate Station (VCS) data. There is a need to understand the accuracy of the daily rainfall estimates, particularly for hydrological assessments. The provision of historic daily rainfall data from more than 700 Regional Council locations (many of which are no longer operational) not used in the generation of the VCS estimates, has enabled a robust error assessment. Using a regression model approach (where the VCS rainfall is the independent variable and the Regional Council rainfall is the dependent variable), bias corrections were determined and applied to every VCS daily rainfall ≥ 1 mm. The bias-corrected VCS rainfall mean absolute error for locations below about 500 m elevation is approximately 2-4 mm (95% of the range) when rain days only (VCS rainfall ≥ 1 mm) are analysed. The error (and its spatial variation) is higher in areas above 500 m elevation, at approximately 5-15 mm. For daily VCS rainfalls > 40 mm (heavy rain days), the errors are approximately 8-12 mm (low elevation areas) and 10-40 mm (high elevation areas), and for monthly rainfall totals the corresponding errors are approximately 10-15 mm and 10-120 mm. For some uses of daily rainfall data, the installation of good quality telemetered rain gauges is the only option. However, if gauges can't be installed or the data collection cannot be maintained long-term, then using the bias-corrected VCS rainfall data is a viable option that is often a significant improvement over using data from distant stations that may not be in the same catchment or even located in a similar climatic zone.

## Keywords

Rainfall, interpolation, error analysis

## Introduction

Spatial estimation of daily rainfall is important in New Zealand, particularly for hydrological models and their applications. Hydrological models such as TOPNET (Clark *et al.*, 2008) and SPARROW (Schwartz *et al.*, 2001) are used to provide information about water flow and quality in New Zealand rivers. Over the last 20 years, such information has increasingly been used to assess resource consent applications where maintenance of minimum flows, flood protection and degradation of waterways are concerns. Given the sensitive and important nature of such decisions, it is critical that the hydrological models – and their key inputs – be as accurate as possible.

Although there is a relatively dense network of climate stations in New Zealand (currently there are about 680 open stations measuring rainfall, about 200 of which are automatic weather stations), the majority of these stations, 93%, are at elevations below 500 m above mean sea level. Thus, there are many mountainous areas and many river catchments where daily rainfall observations are not recorded. Hydrological models for these catchments are forced to rely on rainfall data from outside of the catchment area, which introduces additional uncertainty into the calculations.

In 2005, the National Institute of Water and Atmospheric Research Ltd. (NIWA) developed an interpolated daily climate dataset, named Virtual Climate Station (VCS) data. Along with 10 other climate variables, daily rainfall (9 am-9 am total) observations are operationally interpolated onto the VCS grid (0.05 degrees lat/long (approximately 5 km) covering all of New Zealand; with 11491 grid points) every day and stored on the NIWA National Climate Database (CliDB). The rainfall interpolation methods and a comparison of different techniques for estimating rainfall where no observations have been made are described in Tait *et al.* (2006). In brief, rainfall is interpolated independently each day using a thin plate smoothing spline interpolation with two position variables (latitude and longitude) and a covariate of the 1951–80 mean annual rainfall (which is based on a digitised hand-drawn contour map). The interpolation software used is ANUsplin v4.2 (Hutchinson, 2010) and the level of smoothing is determined via minimization of the generalized cross-validation error. Historic daily rainfall observations going back to January 1960 have also been interpolated onto the VCS grid, yielding 50-year time series of uninterrupted daily rainfall estimates that are updated every day for anywhere in the country. The interpolation methods and error assessments of other VCS variables have also been described (see Tait and Woods, 2007; Tait, 2008; and Tait and Liley, 2009). The VCS data can be accessed for free from http://cliflo.niwa.co.nz (select "Special Data Sets" > "Virtual Climate Network" when choosing Data Type).

Data from the VCS network have been successfully and widely used in many studies. VCS data are the base dataset used in New Zealand for empirical statistical downscaling of Global Climate Model projections (e.g., Ministry for the Environment, 2008) and are the primary dataset for most climate change impact model analyses. The data have been used to better understand the influences of Southern Hemispheric atmospheric circulation on New Zealand's rainfall (Ummenhofer *et al.*, 2009) and are currently being used to develop 15-day weather forecasts for the country (Renwick *et al.*, 2009). The data are used in physiological models, including pasture, crop, forest and animal production models, hydrological assessments, soil moisture and drought models, the development of a New Zealand snow model, ground water recharge models, renewable energy assessments, weed and pest habitat models, human disease models and water quality models (e.g., Clark *et al.*, 2009; EcoClimate, 2008; Elliott and Harper, 2010; Kirschbaum et al., 2010; Romera *et al.*, 2010; Tait *et al.*, 2008; Woods *et al.*, 2006). Furthermore, several Regional Councils use VCS data operationally for water allocation decisions (e.g., Environment Canterbury, Environment Waikato and Hawke's Bay Regional Council). It is generally accepted that the VCS interpolation methodology and implementation are appropriate, but the sparseness of the rainfall data input into it affect its accuracy. There is thus a need to better understand the accuracy of the daily estimates such that users can determine whether the data can be suitably applied within certain confidence bounds, or whether more detailed site-specific data collection is required.

There is no generally accepted "best method" for analysing the accuracy of spatial data, rather a combination of methods involving independent data is suggested (Daly, 2006). Tait *et al.* (2006) analysed the mean *annual* rainfall root mean square error (RMSE) using modelled and observed mean annual river flows (where the modelled flows used the VCS rainfall as input). They showed that the mean annual rainfall RMSE for all of New Zealand is approximately 15% and the mean bias is approximately -7%. The RMSE varies spatially, and is greatest for high elevation catchments (up to 50%) and least in lower elevation catchments, particularly in the North Island (~10%).

Other than the above validation exercise based on river flows (which also included a comparison with some short-period high elevation rainfall data) and a study using models for estimating pasture growth and soil drainage (Cichota *et al.*, 2008) there has not been a detailed validation study of VCS daily rainfall. However, in 2009 NIWA obtained the permission of almost all the Regional Councils in New Zealand to use daily rainfall data from their networks for hydrological model validation, including validation of VCS interpolated rainfall data. These Regional Council data are not stored in the NIWA National Climate Database and hence are not used in the derivation of the VCS rainfall estimates. Furthermore, the coverage of the sites is extensive (Fig. 1). There are 732 sites, with the longest data record being 14,470 days (approximately 40 years) and the shortest data record being 142 days. The average data record is 4965 days (approximately 13.5 years). The highest elevation site is 1980 m, with 192 sites above 500 m. Provision of these data has enabled a detailed independent validation study of the VCS rainfall data.

This paper presents the results of this independent validation study. The first section outlines the results from an initial data exploration. Maps of the daily rainfall data median bias and mean absolute error are then presented, and a regression-based bias correction. This section also includes an error analysis of the daily data after the VCS values have been binned into days greater than 40 mm (i.e., heavy rain days), and aggregated into monthly totals. This is followed by a discussion of the errors and the suggested appropriate uses, based on the Regional Council data comparison, of the daily VCS rainfall data. Some conclusions and next steps are then presented.

## Data selection and exploration

The following data selection procedure was carried out for each of the 732 Regional Council rainfall sites:

a) Discard Regional Council sites with less than 1 year of data;
b) Identify and discard any Regional Council sites with poor quality data, based on visual inspections of the time series (some Regional Council sites had periods of poor quality data but the remaining data were considered to be good quality, so the Council site was retained with the poor quality data deleted);
c) Identify the nearest VCS gridpoint to each Regional Council site and calculate the daily difference.

### Initial evaluation of the error and bias of the entire dataset

The data selection procedure reduced the number of Regional Council sites to 718. Combining the data from all these sites (a total of 3,622,392 days), the mean absolute error (MAE, the average of the absolute value of the daily differences) is 2.6 mm. However, this simple measure of the error is possibly biased to the long-term sites and potentially to high rainfall sites. The error value is also

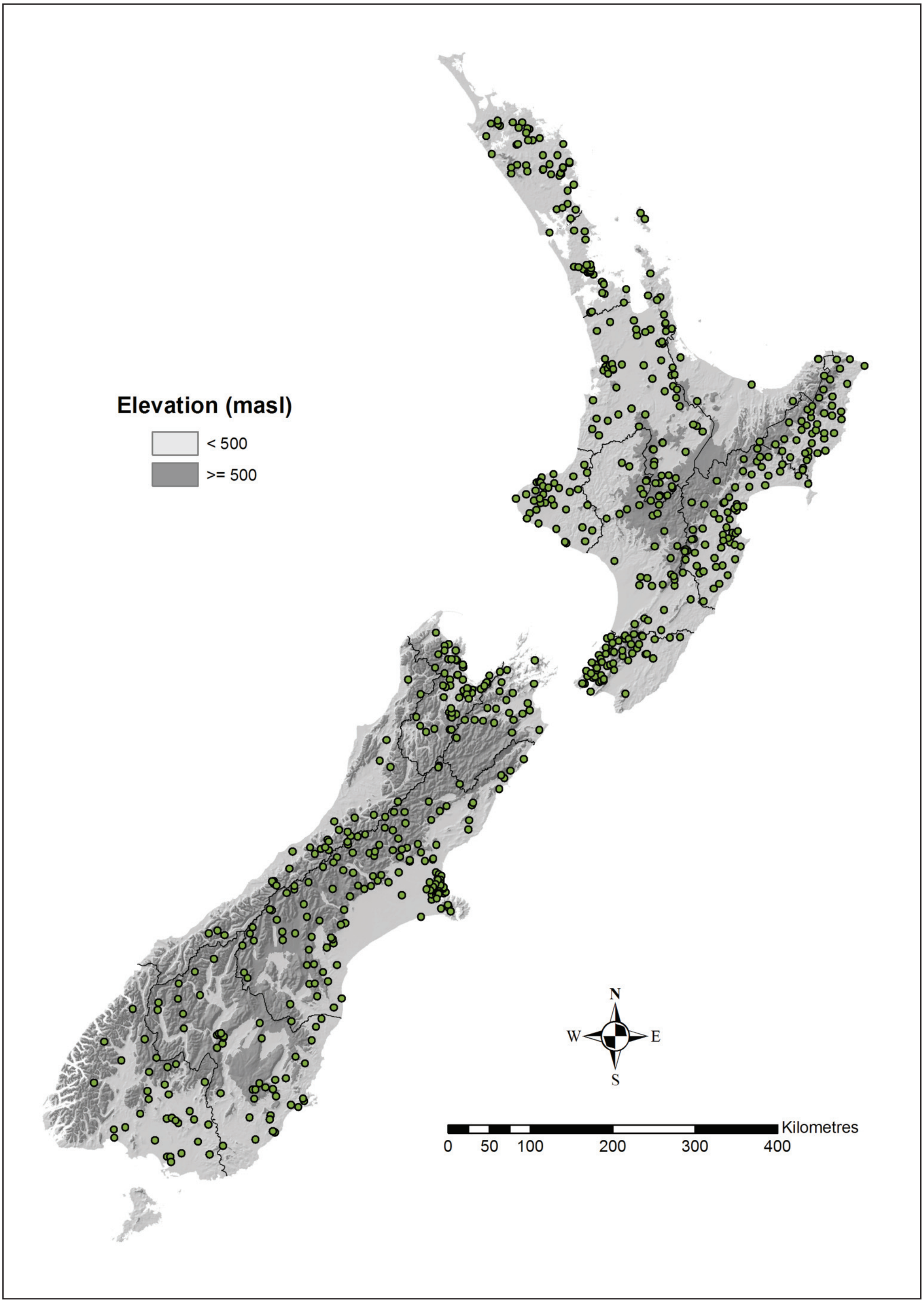



**Figure 1** – Location of the Regional Council rainfall sites used for validation of the Virtual Climate Station (VCS) rainfall estimates. Also shown are the boundaries of the Regional Councils and the land above and below 500 m asl.

**Table 1** – Contingency table showing the percentage of days (%), median error (VCS minus Regional Council (RC), mm) and mean absolute error (mm) [in order left to right] for each "Dry day" and "Wet day" combination of VCS and Regional Council daily values.

| | **VCS "Dry day" (rainfall < 1 mm)** | **VCS "Wet day" (rainfall ≥ 1 mm)** |
|---|---|---|
| RC "Dry day" (rainfall < 1 mm) | 59.4%, 0.0 mm, 0.0 mm | 5.0%, 2.1 mm, 4.6 mm |
| RC "Wet day" (rainfall ≥ 1 mm) | 5.4%, -2.2 mm, 4.8 mm | 30.2%, 0.3 mm, 6.9 mm |

skewed low, as more than half (59.4%) of the days are "Dry days" (rainfall < 1 mm) at both of the Regional Council and VCS pairs (Table 1). Table 1 shows that when both the Regional Council and VCS are "Wet days" (rainfall ≥ 1 mm; 30.2% of the days) the MAE is 6.9 mm and there is a slight VCS overestimation bias (represented by the median error, ME, the median of the daily differences) of 0.3 mm. On 5.4% of the days, the Regional Council is a "Wet day" and the VCS is a "Dry day". The MAE on these days is 4.8 mm and the ME is –2.2 mm (a VCS underestimation bias). The remaining days (5.0% of days) are when the Regional Council is a "Dry day" and the VCS is a "Wet day". The MAE on these days is 4.6 mm and the ME is 2.1 mm (a VCS overestimation bias). It should be noted that there is a possible spatial bias in these error values, as the density of the Regional Council stations varies across the country (Fig. 1). Section 3 below addresses this potential bias by mapping the error calculated at each Regional Council site.

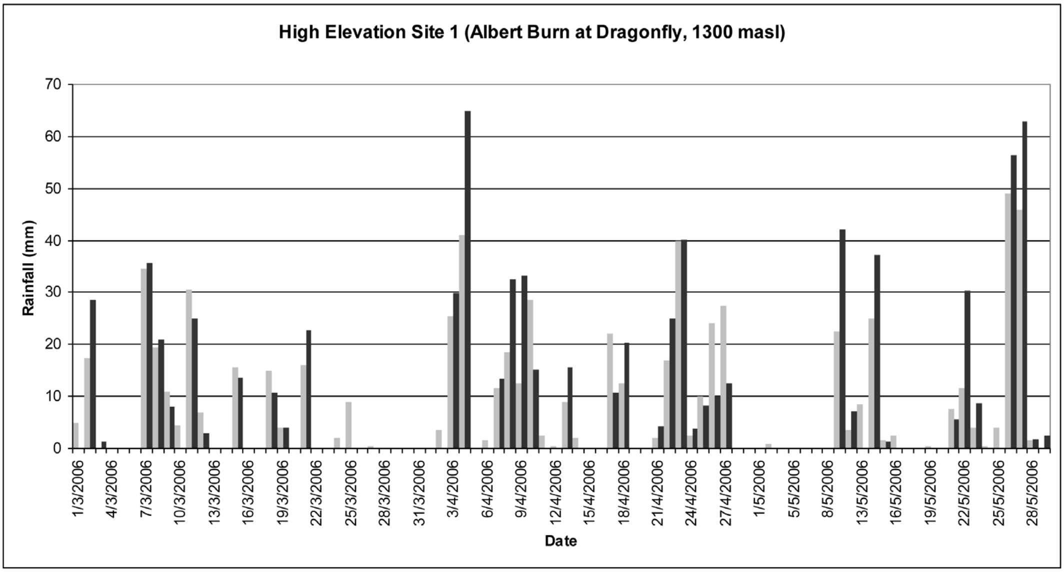
### Visual comparison of VCS and Regional Council rainfall time series

Based on general feedback from end users of the VCS data, such as the Regional Councils and modelers listed in the introduction, in addition to a few published studies (e.g., Tait *et al.*, 2006; Cichota *et al.*, 2008; Clark *et al.*, 2009; Romera *et al.*, 2010), there is a general consensus that the VCS data are reasonable estimates of daily rainfall, though the accuracy is lower in areas of complex mountainous terrain (a significant contributor to the overall MAE above). This general assertion is supported by daily rainfall comparisons at four sites in the South Island; two at high elevations and two coastal (Figs. 2a and b). It is evident from these figures that the timing of the daily rainfall is well captured in all cases, but that the totals, while reasonably well represented at the low elevation locations, are less well estimated for the higher elevation sites.

### Plots of VCS versus Regional Council rainfall

Additionally, for visual data comparison, the maximum daily rainfall in each month from the Regional Council station data was plotted against the maximum daily rainfall in each month from the corresponding closest VCS gridpoint. Plots were produced for each April-March year from 1990 to 2008 (e.g., Fig. 3). This comparison shows that the maximum VCS station rainfall intensities are of similar magnitude to the maximum Regional Council rainfall intensities, with no evidence of a significant bias.

Also, the probability that precipitation is above a given threshold, both for Regional Council station data and the corresponding closest VCS gridpoint, was plotted



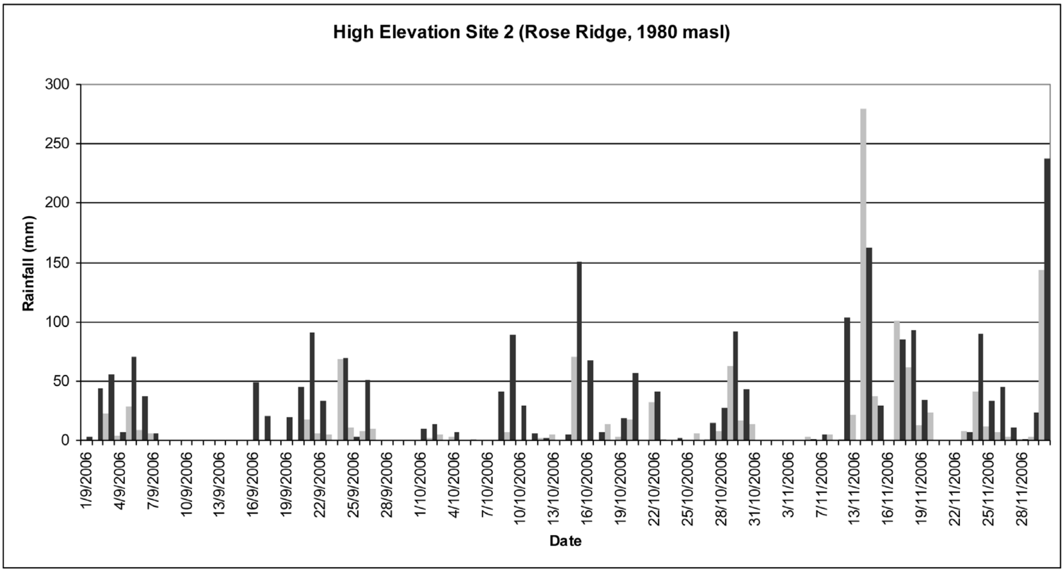
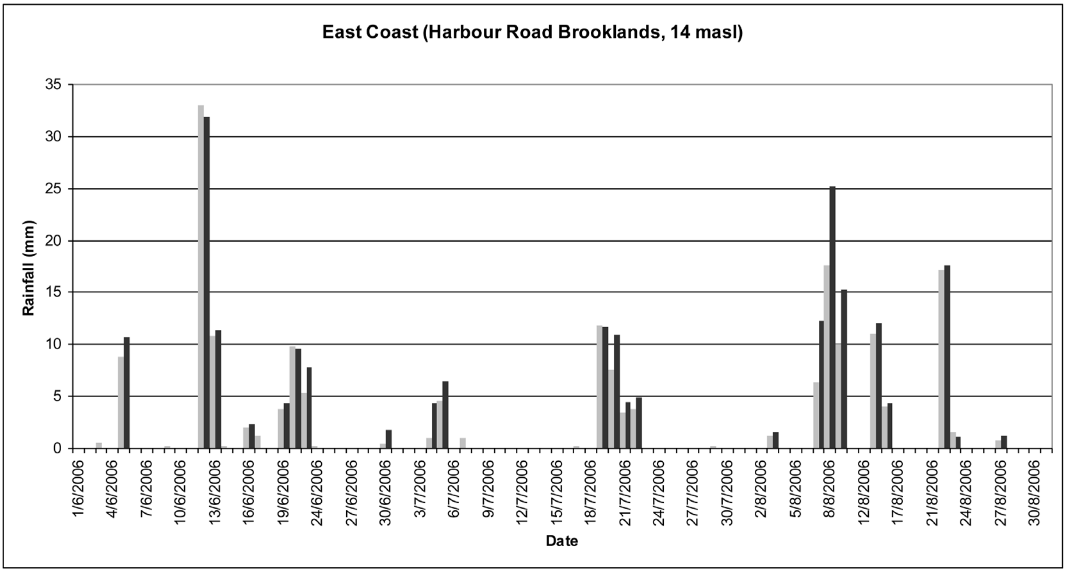




**Figure 2a** – Comparison of daily Regional Council rainfall (black bars) with the nearest VCS rainfall (light grey bars) at two high elevation locations in the South Island over four seasons from March 2006 to February 2007. Note the different scales on the Y-axes.



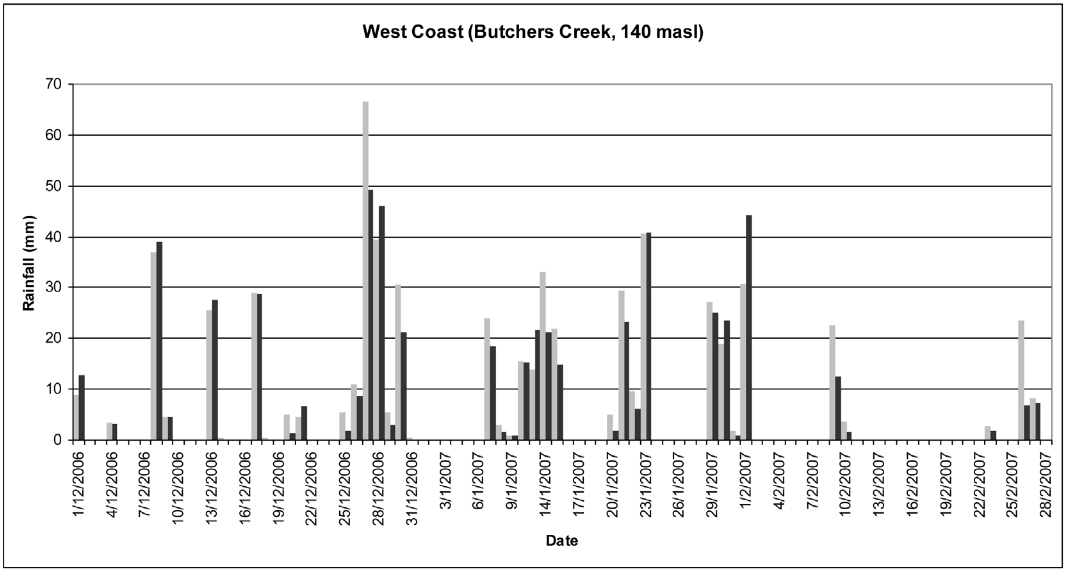




**Figure 2b** – Comparison of daily Regional Council rainfall (black bars) with the nearest VCS rainfall (light grey bars) at two coastal locations in the South Island over four seasons from March 2006 to February 2007. Note the different scales on the Y-axes.

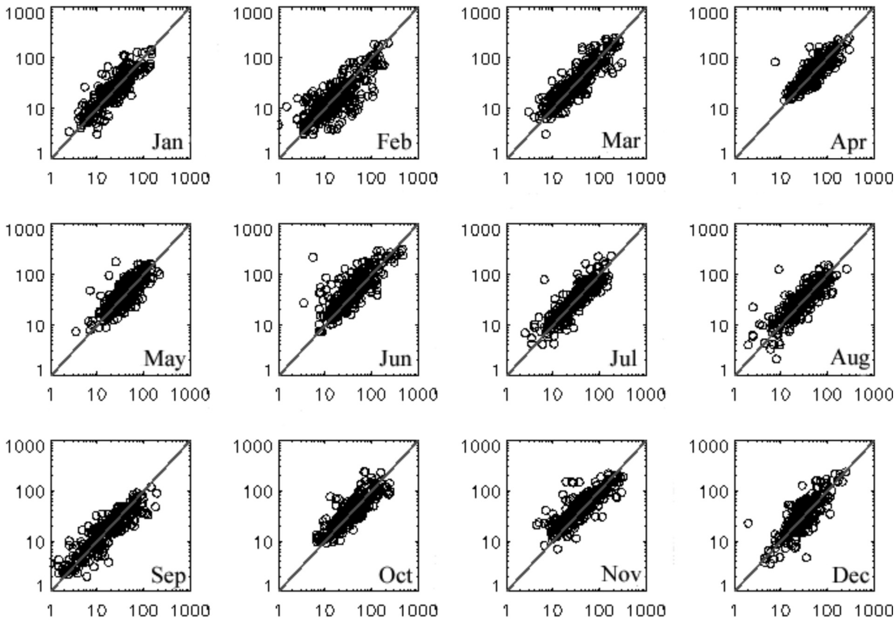



**Figure 3** – Maximum daily precipitation in each month from the Regional Council station data (X-axis) versus maximum daily precipitation in each month from the corresponding closest VCS gridpoint (Y-axis) for the 12 month period April 2006-March 2007 (as an example). Units are mm.

(e.g., Figs. 4–6). Thresholds chosen were every integer between 1 to 40 mm, inclusive. Figures 4-6 show that there is no noticeable bias in the probability above threshold plots, but that the scatter (i.e. the estimation error) progressively increases with increasing rainfall threshold.

The above comparisons show that the daily rainfalls at the Regional Council sites and their nearest VCS gridpoints are reasonably similar, but that the differences vary with rainfall threshold. The following section presents maps of the ME and MAE for two thresholds and the monthly rainfall total such that the spatial pattern of the bias and error can be visualized.

## Bias and error spatial analysis

### Bias and bias correction

The spatial pattern of the median error (ME) is shown in Figure 7. Care should be taken interpreting this map (and the following maps) at locations where there are relatively few Regional Council sites (for example along the West Coast of the South Island), as the maps have been created using a simple inverse distance weighting interpolation. For this reason, coloured circles at the Council site locations representing the error calculated at each site have also been included on the maps. It can be seen that there is considerable spatial variability of the bias and that there are coherent regions of both positive and negative bias. This is a function of the location and density of the input data sites (Regional Council and the CliDB sites used to generate the VCS data), the quality and length of data record, and the comparability of point observations with a smoothed surface.

A simple bias correction, based on linear regression of the daily values at each Regional Council site (applied only to days with VCS rainfall ≥ 1 mm) was produced. This bias

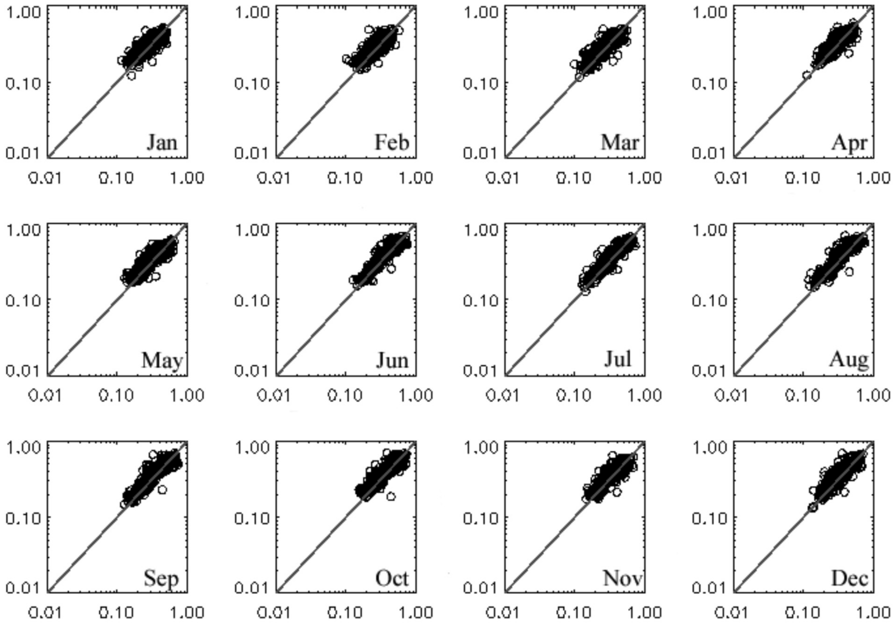



**Figure 4** – The fraction of days that precipitation is greater than or equal to 1 mm (i.e., "Wet" days) for the Regional Council station data (X-axis) and the corresponding closest VCS gridpoint (Y-axis).

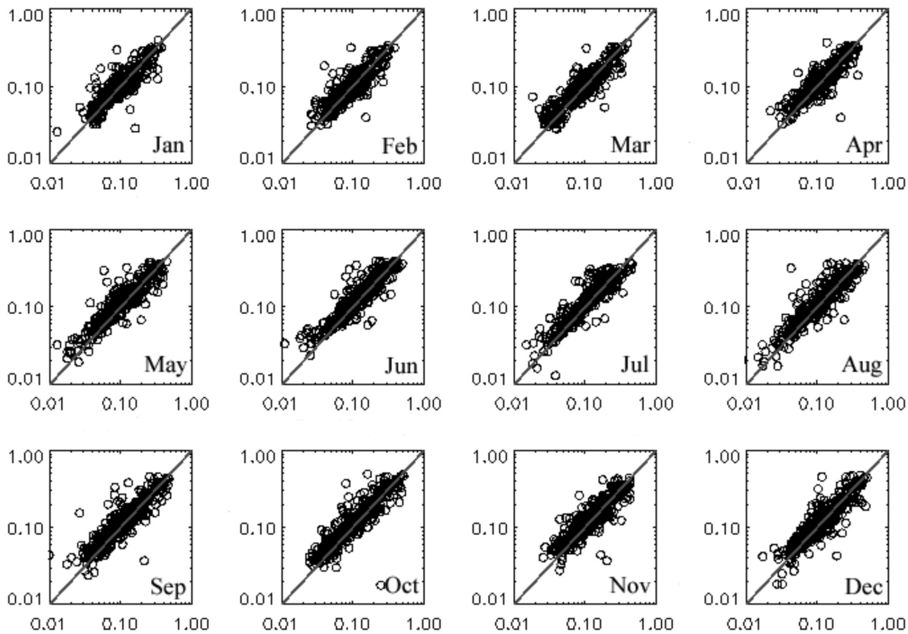



**Figure 5** – The fraction of days that precipitation is above 10 mm (i.e., steady to heavy rain) for the Regional Council station data (X-axis) and the corresponding closest VCS gridpoint (Y-axis).

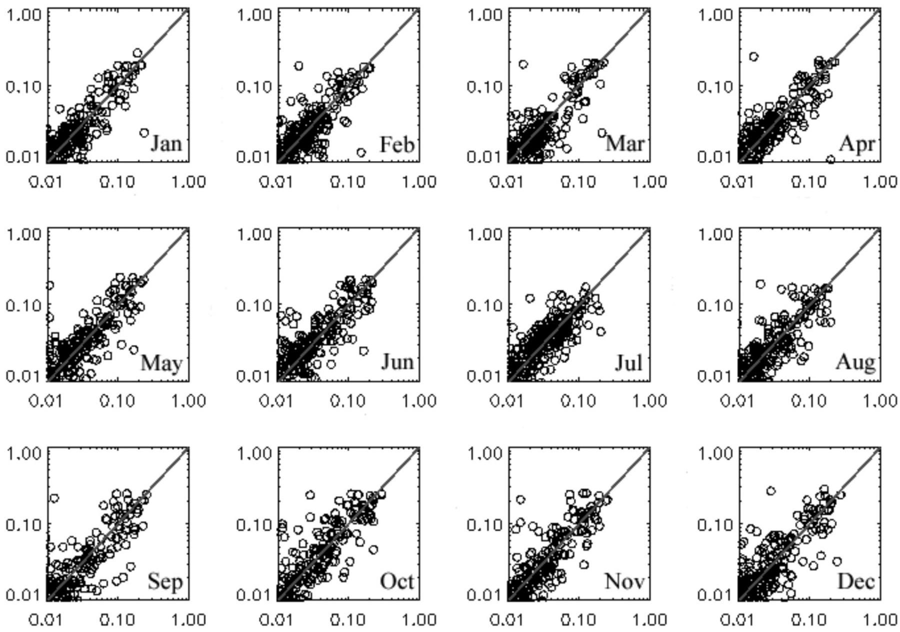



**Figure 6** – The fraction of days that precipitation is above 40 mm (i.e., heavy rain) for the Regional Council station data (X-axis) and the corresponding closest VCS gridpoint (Y-axis).

correction is to improve the operational VCS product, as a post-interpolation process. Although daily rainfall data are non-normally distributed, it is argued that the exclusion of days with rainfall less than 1 mm results in distributions that are reasonably parametric, such that linear regression is appropriate. Taking the square and cube roots of the values did not reduce the regression errors. The typical r-square values from the regressions are greater than 0.7, however 40 Regional Council sites were identified where the regression r-square is less than 0.5. These sites were investigated and were removed from further analyses, as there was some concern that the Regional Council data were not of good quality. In the majority of cases there were good quality Council sites nearby. Figure 8 shows maps of the interpolated slope and intercept from the regression analyses. The bias correction is applied as:

$$VCS\_corrected = regr\_intercept + regr\_slope * VCS \quad (1)$$

After the bias correction is applied, any VCS-corrected rainfalls less than 1 mm are set to zero, consistent with the operational VCS post-processing step (Tait *et al.*, 2006). Table 2 shows the same contingency table as shown in Table 1, but after the bias correction and post-processing step has been applied to the VCS values. All the median error values have been either reduced or are unchanged.

## Error analysis

Figures 9-11 show the spatial pattern of the MAE for New Zealand based on VCS-corrected values ≥ 1 mm (Fig. 9), > 40 mm (Fig. 10) and aggregated to monthly totals (Fig. 11), before (left map) and after (right map) the bias corrections are applied. The MAE for all cases (Figs. 9-11) has decreased everywhere as the result of the bias corrections. For most of the country below about 500 m elevation, the MAE of the bias-corrected daily rainfall is approximately

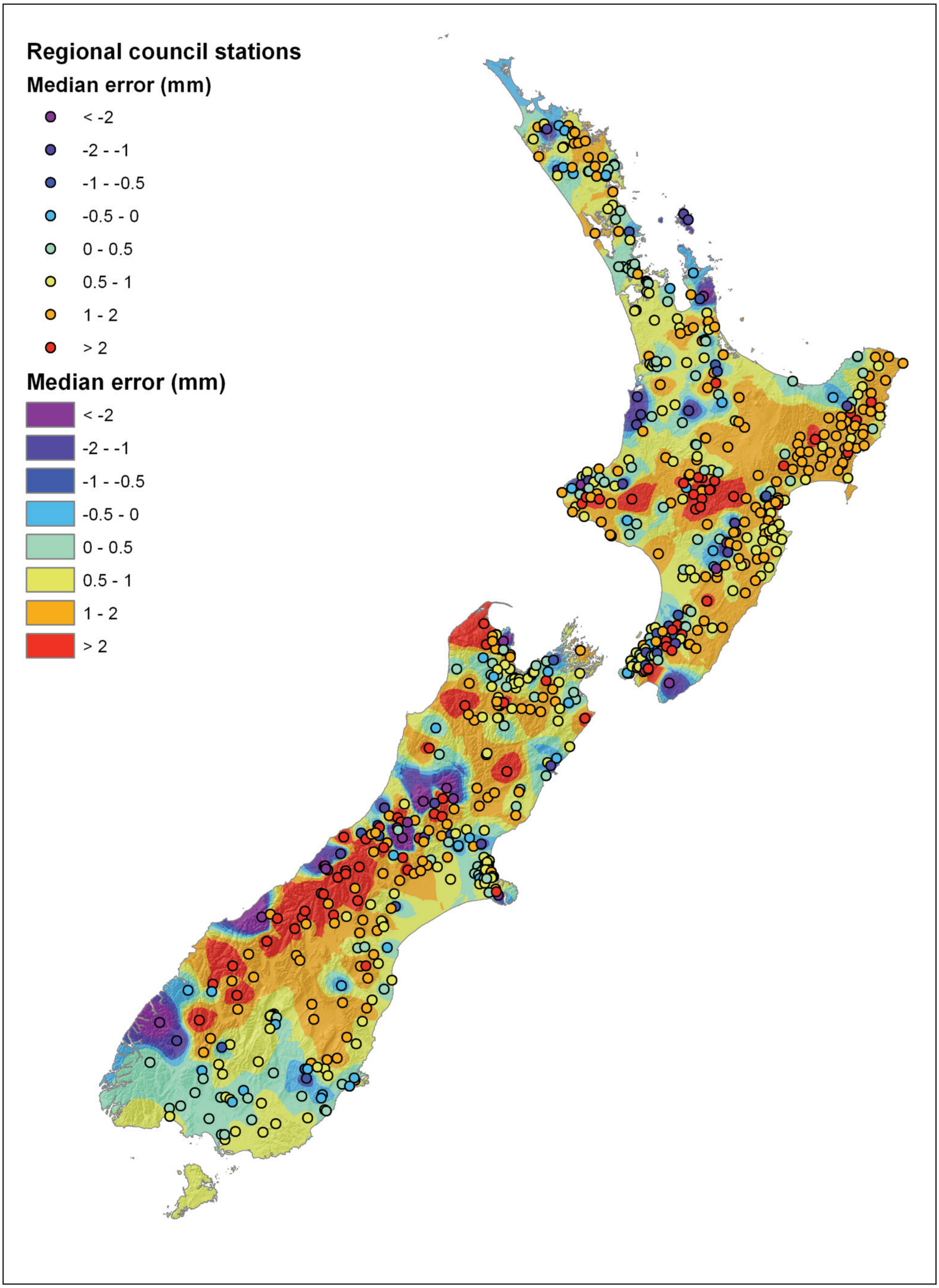



**Figure 7** – Interpolated map (using inverse distance weighting) of the median error (units are mm) calculated for Regional Council locations with good quality daily rainfall data and a period greater than 1 year. All daily values greater than or equal to 1 mm (based on the VCS) are included in the median error calculations. The values at the Regional Council locations are also shown as coloured circles.

**Figure 8** – Interpolated map (using inverse distance weighting) of the slope (left) and intercept (right) of the regression-based bias corrections. The VCS rainfall is the independent variable in the regression analyses.

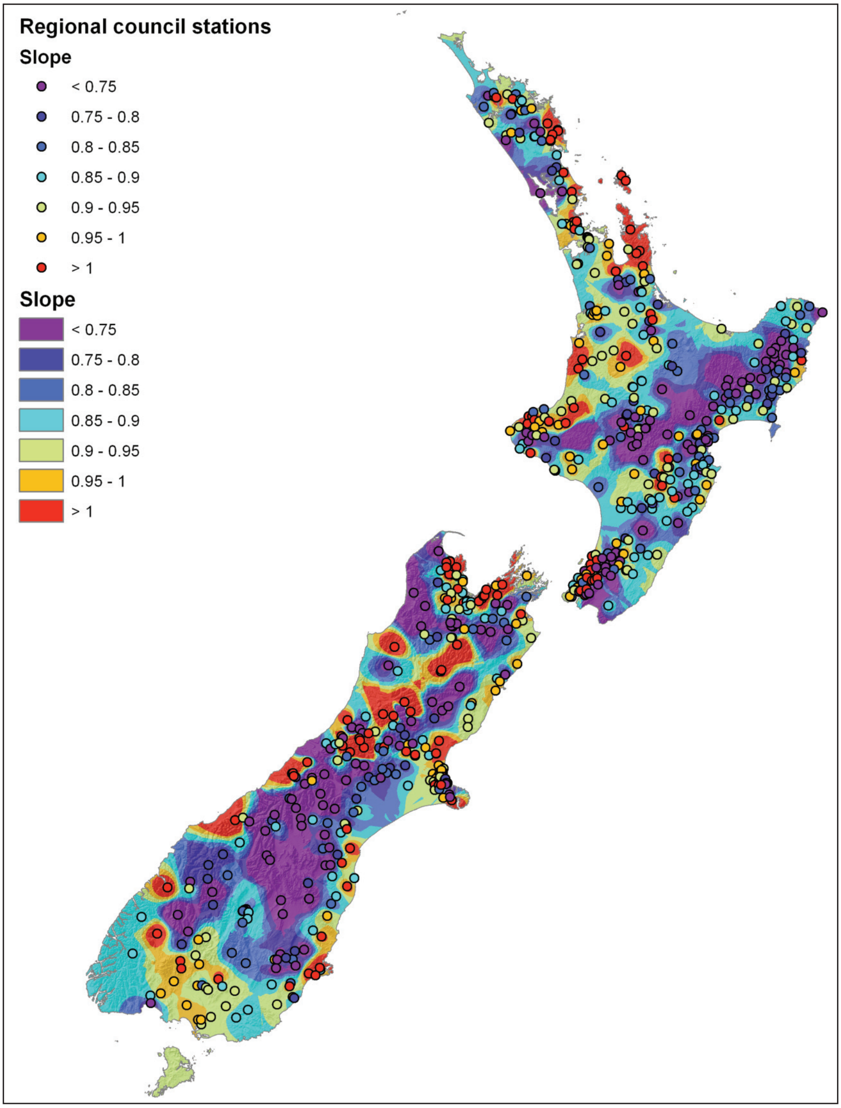
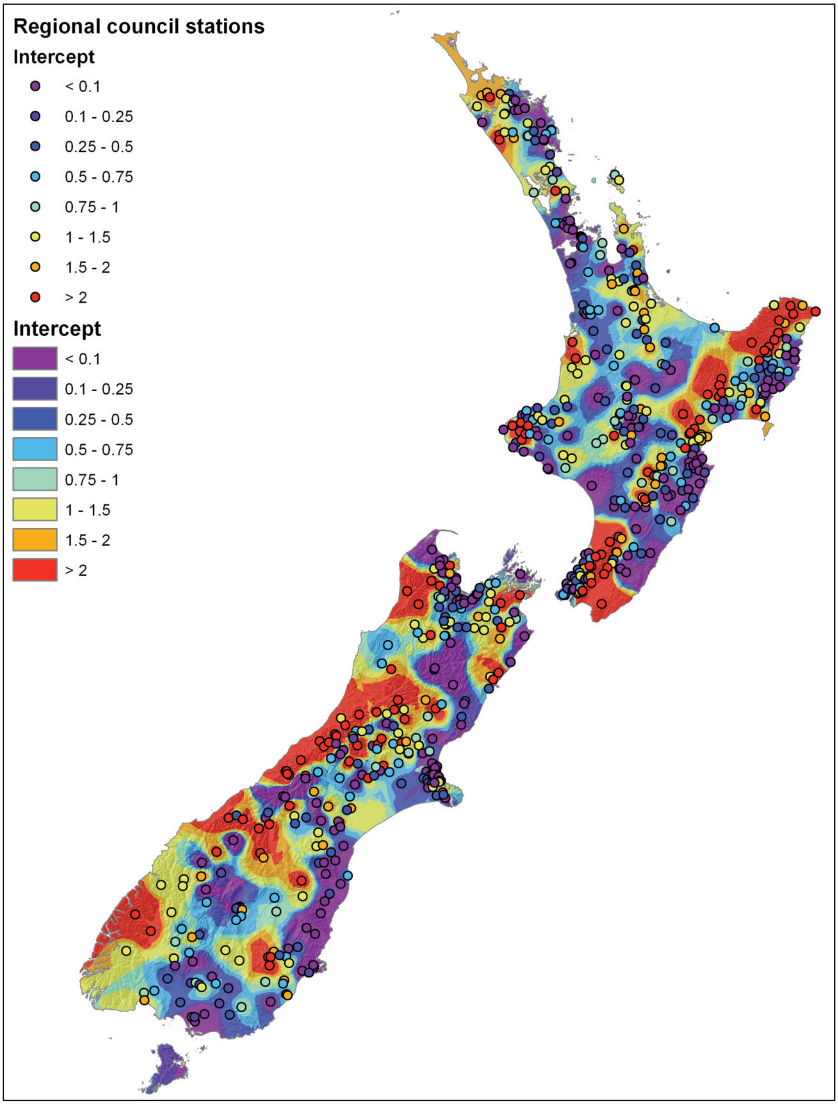



**Table 2** – Contingency table showing the percentage of days (%), median error (VCS minus Regional Council (RC), mm) and mean absolute error (mm) [in order left to right] for each "Dry day" and "Wet day" combination of *bias-corrected* VCS and Regional Council daily values.

| | **VCS "Dry day" (rainfall < 1 mm)** | **VCS "Wet day" (rainfall ≥ 1 mm)** |
|---|---|---|
| RC "Dry day" (rainfall < 1 mm) | 60.7%, 0.0 mm, 0.0 mm | 4.3%, 2.8 mm, 4.6 mm |
| RC "Wet day" (rainfall ≥ 1 mm) | 5.0%, -2.0 mm, 3.7 mm | 29.9%, 0.3 mm, 5.5 mm |

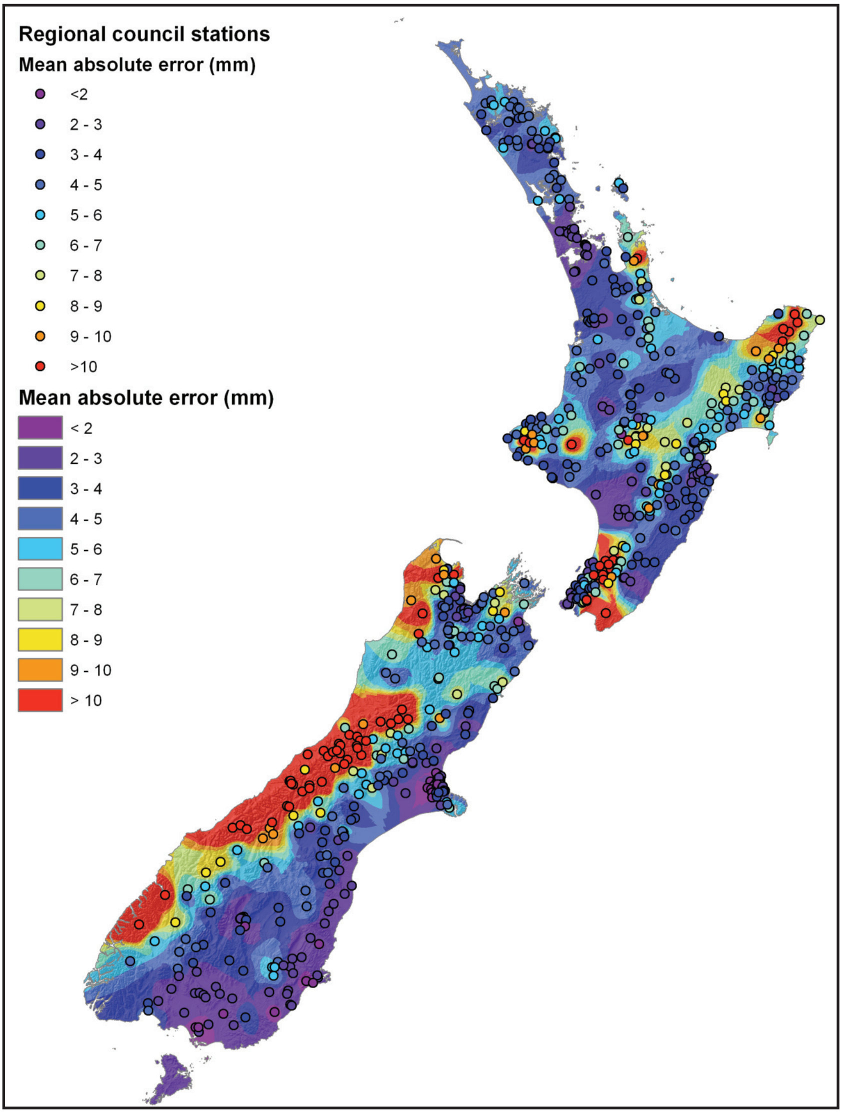



2-4 mm (95% of the range) for all VCS data greater than or equal to 1 mm; 8-12 mm for VCS data greater than 40 mm; and 10-15 mm for VCS data accumulated to monthly totals. For areas above about 500 m elevation, the corresponding MAE ranges are approximately 5-15 mm, 10-40 mm, and 10-120 mm (with rather a lot of spatial variation).

## Summary and discussion

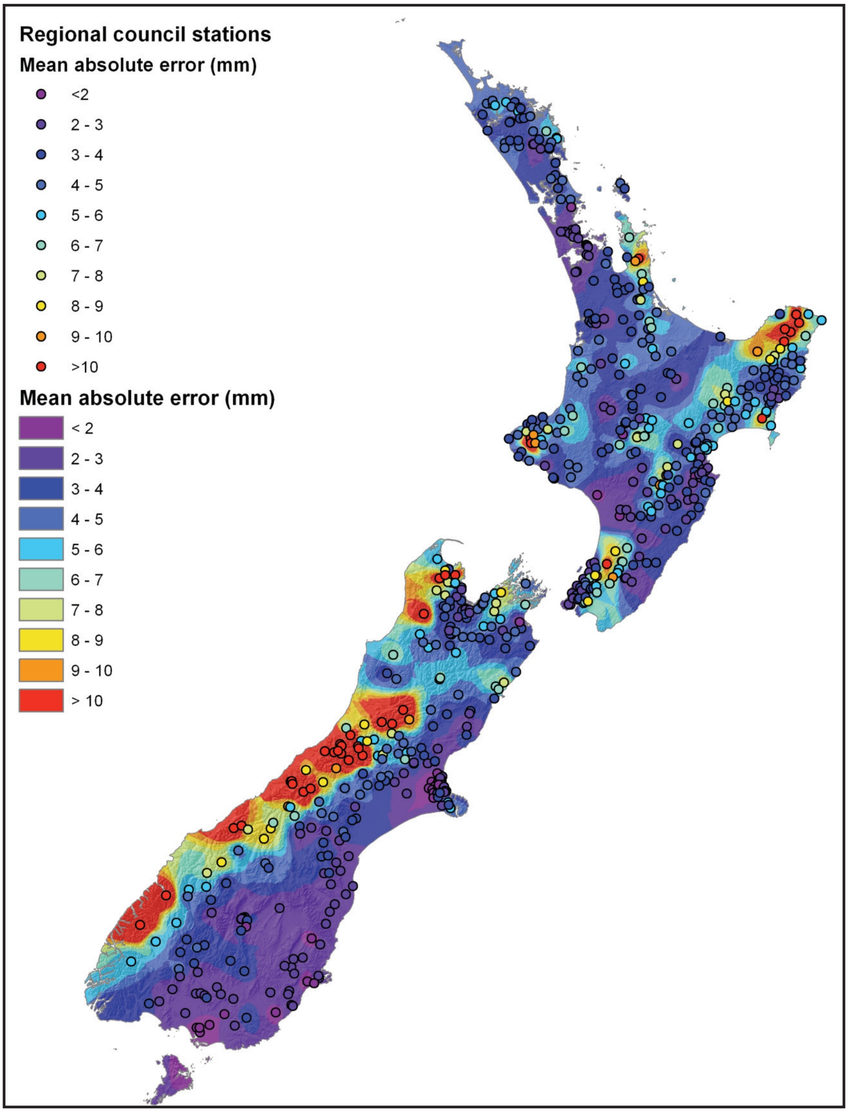
In 2005, when NIWA began developing the VCS dataset, the primary purpose was for the daily rainfall data to be used as input into a hydrological model, which in turn was to be used to assess water quality over several decades from small, rural and ungauged (both in terms of rainfall and stream flow) catchments. Since then, the interpolation methodology has gone through a series of refinements and the number of variables has increased from one (rainfall) to 11. The VCS data are now automatically updated every day from near real-time climate station observations stored in the NIWA National Climate Database,

**Figure 9** – Interpolated map (using inverse distance weighting) of the mean absolute error (units are mm) before (left) and after (right) the VCS bias correction calculated for Regional Council locations with good quality daily rainfall data and a period greater than 1 year. All daily values greater than or equal to 1 mm (based on the VCS) are included in the error calculations. The values at the Regional Council locations are also shown as coloured circles.




and the scientific and practical applications of the data have expanded considerably. For example, within the NIWA National Climate Centre alone, VCS data are currently used as the basis for historical and month-to-date climate maps, up-to-date time series products (such as soil water balance plots), drought indices monitoring and maps, 15-day forecasts, seasonal outlooks and downscaling of global climate model projections of the future climate of the mid and late 21st century.

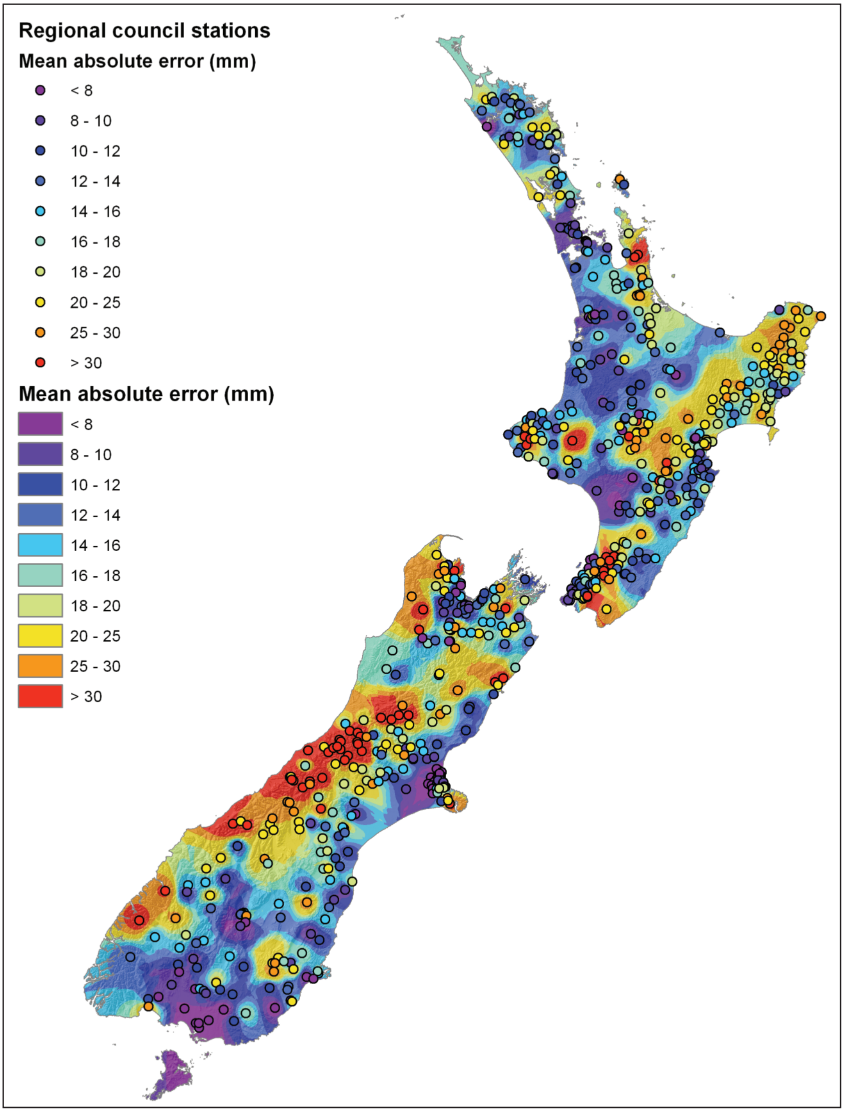
Due to the increasing amount of use of the VCS rainfall data in particular, notably now by many Regional Councils for the analysis of surface and groundwater availability, there is a much greater requirement to understand the accuracy of the estimates. The provision of historic daily rainfall data from more than 700 Regional Council locations not used




in the generation of the VCS estimates has allowed a robust error assessment and bias corrections.

In summary, the error analysis has shown that the bias-corrected VCS daily rainfall data are reasonable estimates of the Regional Council values. In particular, differentiation of dry days and rain days is captured well. However, for some uses of daily rainfall data, particularly operational uses where small rainfall changes incur significant effects, these errors may be too large. It is strongly suggested that for such situations the installation of good quality telemetered rain gauges is the best option. If the data collection cannot be maintained long-term, detailed on-site observations over the period of a year or two can be used to adjust the long-term and ongoing VCS estimates, to fine-tune the VCS data to the specific location. No change

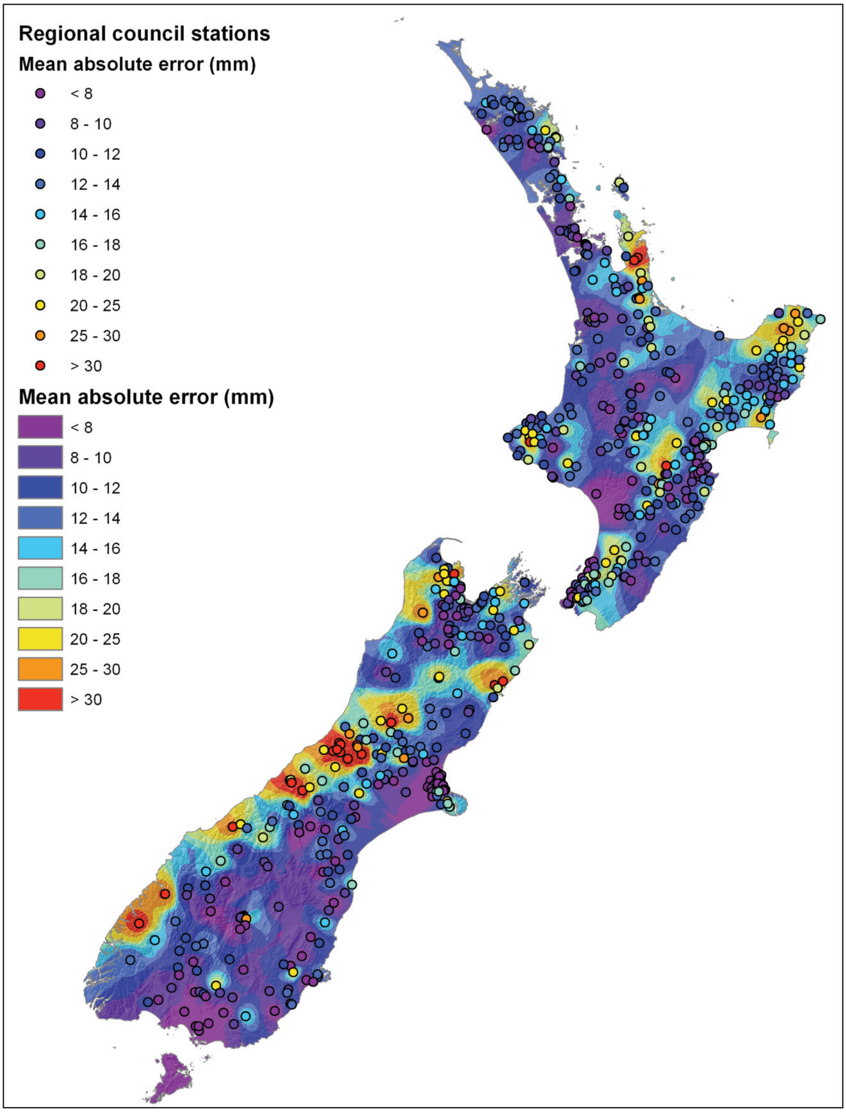
**Figure 10** – Interpolated map (using inverse distance weighting) of the mean absolute error (units are mm) before (left) and after (right) the VCS bias correction calculated for Regional Council locations with good quality daily rainfall data and a period greater than 1 year, but including only daily values greater than 40 mm (based on the VCS) in the error calculations. The values at the Regional Council locations are also shown as coloured circles.




is made to the operational VCS data in the Climate Database using this method; rather it is a way for users to reduce the estimation error at specific VCS data points for specific applications. This result was highlighted by Cichota et al. (2008) with respect to modelled soil drainage. For other uses, such as long-term analysis of rainfall trends or drought frequency, the VCS data are likely to be more than adequate. Furthermore, temporal and spatial averaging is a useful mechanism for reducing the error. Despite the uncertainty in the estimates, in most situations these rainfall data are a significant improvement over using data from distant stations that may not be in the same catchment or even located in a similar climatic zone.

## Conclusions and next steps

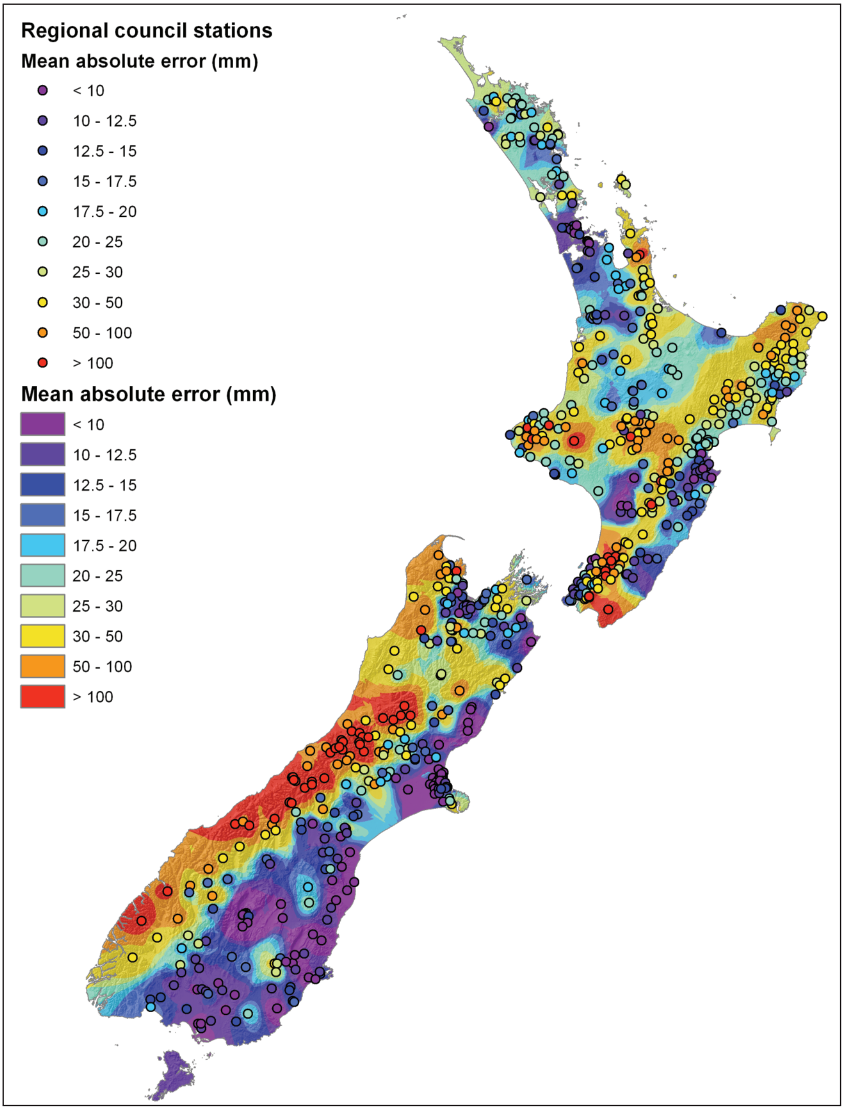
The daily VCS rainfall estimates, together with the other 10 climate variables, are a significant climate data resource for New Zealand.




Interpolation of the data from observation sites (where the observed data themselves are subject to measurement error) results in uncertainty that is greater in areas of complex terrain, low input station density and regions with spatially heterogeneous rainfall patterns. The errors reported in this paper can be used to assess whether the VCS rainfall estimates are suitable for particular applications, or whether spatial or temporal aggregation or additional on-site measurements are needed. It is hoped that similar error assessments may be possible for other VCS variables in the future, if independent datasets can be obtained.

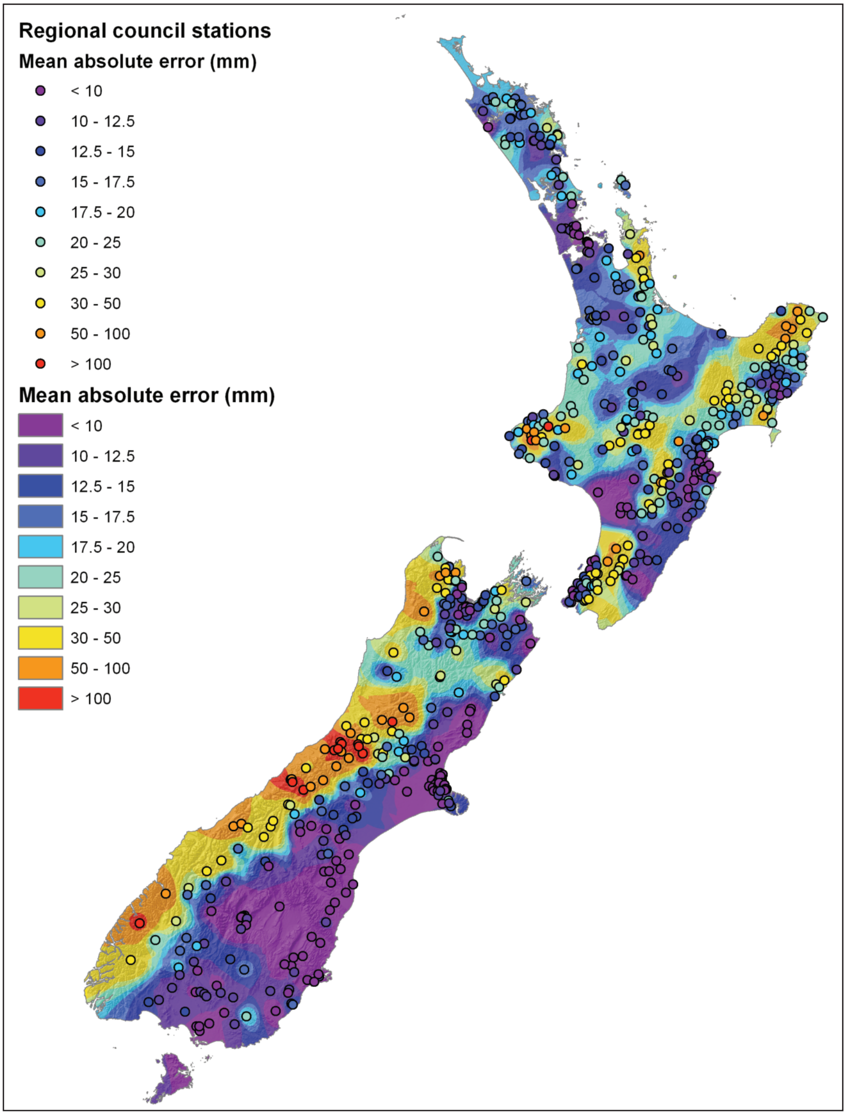
The Regional Council rainfall data used in this study are an invaluable dataset. The number of sites is of similar magnitude to the currently open NIWA and MetService sites in the National Climate Database (CliDB). The geographic distribution of the Regional Council sites is much more comprehensive

**Figure 11** – Interpolated map (using inverse distance weighting) of the mean absolute error (units are mm) before (left) and after (right) the VCS bias correction calculated for Regional Council locations with good quality daily rainfall data and a period greater than 1 year, with the rainfall data aggregated into monthly totals. The values at the Regional Council locations are also shown as coloured circles.




for high elevations, due to the primary use of the Council data for stream flow monitoring and modeling. However, regrettably, these valuable data are not used in the operational estimation of the daily VCS rainfall, as the majority of Regional Council data are not transferred in real-time (or ever) to CliDB. With this simple step it is argued that the errors in the VCS rainfall estimates could be halved. With many Regional Councils now using the VCS data for important water extraction and allocation decisions, we hope that a common sense solution to data sharing might be found.

Lastly, as was concluded in Tait *et al.* (2006), improvements to the rainfall estimates could be made by replacing the 1951-80 mean annual rainfall surface used in all the daily rainfall interpolations with expert-guided rainfall surfaces corresponding to different synoptic patterns. Such an approach has still yet to be fully explored.





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