*Weather and Climate,* **27,** (2006), 45-63

# Heavy Rainfall Patterns in the Auckland Region, New Zealand

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## Abstract

The purpose of this study was to stratify rainfall patterns in the Auckland region (New Zealand). Principal component analysis (PCA) using the method of varimax rotation was used to reduce the dimensionality of the data. Three distinct precipitation patterns emerge caused by four synoptic situations. Given the great variability in the synoptic patterns that can occur in New Zealand, the similarities for each precipitation pattern in the Auckland region are good. The results demonstrate that the location of the two ranges in the Auckland region have a significant effect on the amount and distribution of precipitation in two of the distinct patterns.

## Introduction

The importance of mesoscale studies of rainfall patterns in New Zealand has been recognised, for example, by Salinger et al (1986), Daw (1994)and Neale & Thompson (1978). These studies examined the spatial variation of precipitation within a relatively small area of New Zealand, namely Wellington and Gisborne. Salinger et al (1986) examined the precipitation variation around Wellington in order to assess whether mesoscale effects could be identified in an orthographically complex area. A similar examination of the mesoscale patterns around Gisborne by Daw (1994) was of particular interest to the farming community as a forecasting tool. Both of these studies identified spatial rainfall patterns, with the aim of integrating the results into the forecast process to provide New Zealand be undertaken using the same methodology and intent as the previous studies.

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In the context of its orography and climate Auckland is an interesting and complex area to define. The region has fewer orographic influences and a milder climate than Wellington. It might be expected that the mesoscale patterns be less defined. There are two prime factors that affect precipitation variation: orography and climate.

Auckland lies in the northern part of the New Zealand and consists of an indented coastline, including the Waitemata, Manukau and Kaipara harbours. There are numerous islands around the coastline, the largest being Waiheke. The most obvious landforms in the city are the numerous small volcanic cones, the highest being Mt Eden (196 m). Although there is a lack of high mountains, there are two eroded ranges. In the west, the bush-clad Waitakere Ranges (up to 459 m), and further south the Hunua Ranges (688 m). Although of marginal height, it might be expected that there would be an increase in rainfall due to orographic uplift in both the Waitakere and Hunua Ranges.

Being surrounded by ocean, air temperatures remain comparatively low in summer and mild in winter under windy conditions (Hessell, 1988). Analysis of the wind information (Salinger, et al 1996) derived from the Auckland region shows that the most frequent wind directions are from: the south west (percentage frequency 29% in Auckland City, 21% at Ardmore and 24% at Auckland Airport) and west (percentage frequency 17% in Whenuapai and Auckland City and 15% at Auckland Airport). There is a secondary maximum from the north east (percentage frequency 13% at Auckland Airport and 19% in the South East Hills region). Auckland's heaviest rainfall occurs when there is a depression or front, to the north or north-west bringing easterly or north-easterly flows across the city. In these cases the eastern parts of Auckland are more exposed. Hessell (1988) found that these depressions are blocked from moving rapidly due to anticyclones to the south and east of the country. The comparatively warm seas in winter tend to lead to the destabilising of the south-westerly airstreams, which are common in the cooler half of the year. These south-westerly airstreams produce in contrast, cloudy showery weather in Auckland. As the cold fronts pass the showery activity increases, although it can be interrupted by a brief fine spell. Stormy westerlies also produce rainfall.

When these are strong they may be accompanied by thunderstorms. In these cases the western parts of Auckland are more exposed. Converging sea breezes sweeping in from the main east and west coasts meet along a band known as the Sea Breeze Convergence Zone: this zone is often cloudy and occasionally contains scattered showers and localised heavy showers.

## Method

A large amount of local data was needed to verify the findings. Consequently daily precipitation data from 56 stations within the Auckland region was analysed. These data were sourced from the NIWA database, Auckland Regional Council, Metrowater and Weatherwise Auckland raingauge networks. Figure 1, illustrates the boundaries of the Auckland region and identifies the location of the rainfall stations. Most of the rainfall sites use automatic tipping bucket rainfall gauges. When the rainfall is recorded it is corrected to the manual rain gauge to avoid small errors. The remainder of the rainfall sites use manual rainfall gauges. The data spanning the three years, 2002 – 2004 were used. This provided a sufficiently large sample to yield a viable analysis. The readings were recorded at 0900 local time. Light precipitation days were not the focus of this study and were removed from the analysis to avoid erroneous results. The threshold for removal was the cut-off value of less than 10 mm precipitation at any station in the Auckland region. This still yielded a sample of 730 days for scrutiny. Analysis was performed using Principal Component Analysis (PCA.) also called Empirical Orthogonal Function (EOF) (Von Storch and Zwiers, 1999). PCA provides a valuable tool, as the data reduction (simplification, refinement) with the minimum loss of information, reduced the large number of observed variables to a smaller set of principal components, for the purpose of interpretation and understanding (Barry and Carleton 2001)

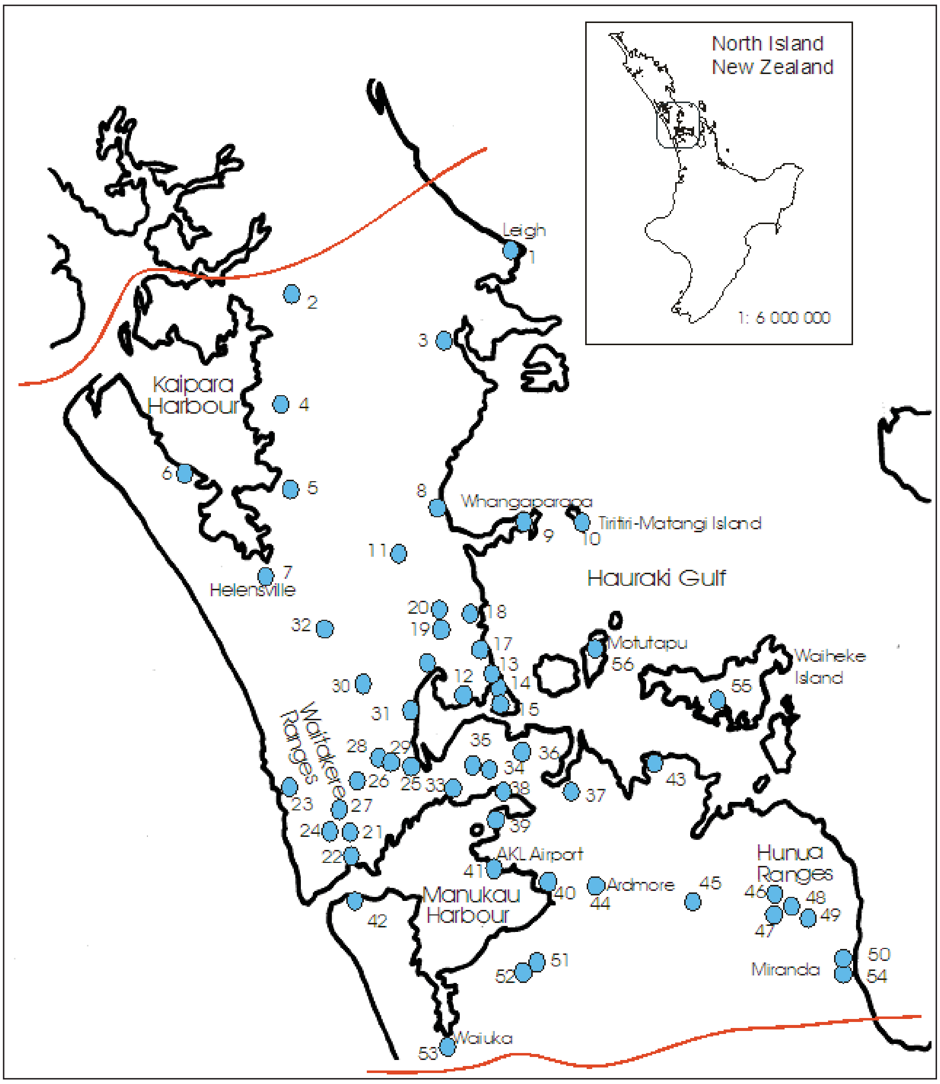



*Figure 1. Location of the rainfall sites in the Auckland region used in the analysis.*

The PCA was performed using the Systat package on a correlation matrix. The objective of the analysis was to ascertain the number of components that accounted for most of the variation in the original data, and further to, to determine the occurrence or non-occurrence of rainfall in localities within the Auckland region. To simplify interpretation, the principal components were rotated using the varimax rotation criterion. The varimax criterion maximises the variance or principal component loadings by making the high loadings higher and

| Rainfall Stations | | | |
|---|---|---|---|
| Number | Name | Latitude | Longitude |
| 1 | Leigh | -36.27 | 174.8 |
| 2 | Hoteo Oldfields | -36.42 | 174.45 |
| 3 | Warkworth | -36.44 | 174.67 |
| 4 | Kaipara Hills | -36.44 | 174.53 |
| 5 | Makerau | -36.39 | 174.65 |
| 6 | Mairetahi | -36.56 | 174.32 |
| 7 | Helensville | -36.6 | 174.5 |
| 8 | Orewa | -36.59 | 174.69 |
| 9 | Whagaparaoa | -36.61 | 174.84 |
| 10 | Tiritiri-Matangi Island | -36.6 | 174.83 |
| 11 | Dairy Stream | -36.68 | 174.65 |
| 12 | Inwards Reserve | -36.79 | 174.70 |
| 13 | Testing Station | -36.78 | 174.74 |
| 14 | Takapuna | -36.78 | 174.83 |
| 15 | Plymouth Reserve | -36.81 | 174.78 |
| 16 | Paremorema | -36.75 | 174.64 |
| 17 | Mairangi School | -36.74 | 174.74 |
| 18 | Glamorgan School | -36.70 | 174.73 |
| 19 | Albany WWTP | -36.74 | 174.71 |
| 20 | Albany Hts | -36.71 | 174.69 |
| 21 | Lower Nihotupu Dam | -36.57 | 174.36 |
| 22 | Lower Huia Dam | -36.59 | 174.34 |
| 23 | Waitakere Dam | -36.54 | 174.31 |
| 24 | Upper Nihotupu Dam | -36.53 | 174.33 |
| 25 | Henderson | -36.86 | 174.62 |
| 26 | Opanuku | -36.91 | 174.57 |
| 27 | Oratia Cemetery | -36.91 | 174.62 |
| 28 | Swanson Reserve | -36.84 | 174.59 |
| 29 | Swanson | -36.87 | 174.60 |
| 30 | Kumeu Maddrens | -36.78 | 174.55 |
| 31 | Whenuapai | -36.79 | 174.62 |
| 32 | Ararimu Zanders | -36.76 | 174.57 |
| 33 | Cutler Park | -36.92 | 174.68 |
| 34 | Mt Roskill | -36.8 | 174.6 |
| 35 | Mt Albert | -36.89 | 174.73 |
| 36 | Purewa | -36.88 | 174.83 |
| 37 | Pakuranga | -36.9 | 174.88 |
| 38 | Onehunga | -36.91 | 174.78 |
| 39 | Mangere Treatment | -36.96 | 174.77 |
| 40 | Manurewa | -36.9 | 174.7 |
| 41 | Auckland Aero | -37.01 | 174.79 |
| 42 | Manukau Heads | -37.05 | 174.54 |
| 43 | Beachlands | -36.9 | 174.9 |
| 44 | Ardmore | -37.03 | 174.96 |
| 45 | Hays Creek Dam | -37.04 | 175.01 |
| 46 | Cossey | -37.04 | 175.06 |
| 47 | Wairoa Dam | -37.06 | 175.07 |
| 48 | Upper Mangatawhiri | -37.05 | 175.09 |
| 49 | Mangatawhiri | -37.2 | 175.14 |
| 50 | Miranda Waitakaruru | -37.23 | 175.36 |
| 51 | Pukekohe MAF | -37.21 | 174.86 |
| 52 | Bucklands Pukekohe | -37.23 | 174.93 |
| 53 | Waiku | -37.26 | 174.67 |
| 54 | Miranda Hot Springs | -37.21 | 175.33 |
| 55 | Claris Great Barrier | -36.78 | 175.48 |
| 56 | Motatupu | -36.17 | 174.9 |

*Table 1 – Key given to the rainfall stations in Figure 1*

the low loadings lower. In order to determine the number of principal components (PCs) that were reliable and worthy of interpretation, for identifying the underlying synoptic weather patterns, a two step procedure was followed. First a simple graphical Scree plot developed by Cattell (1966) was examined. The eigenvalues in the steep descent were retained (Grimm & Yarnold 1995). Secondly, the test used to determine which PCs were retained, was the criteria of

Jolliffe (1987, 1990). The data were then interpreted, to determine patterns in the variables, which could be linked to synoptic situations.

## Selection of Case studies

Daily rainfall distribution over a region often consists of several component patterns. To determine the case studies to investigate; it was important to ascertain the one particular dominant component (highest score) on the selected day. The factor scores were analysed for the data pertaining to 730 input days. These scores are standardised for zero mean and unit variance. A positive score of 1 or more on a particular component, on a selected day, implies precipitation of at least the mean plus one standard deviation over the area in which the component is dominant. To select the case study days for the synoptic analysis the following criteria were used.

(1) Rotated PCs with positive scores higher than 1.00.

(2) The component was dominant on the selected day.

This criteria was used to ensure that high precipitation occurs in the area represented by a selected component. Precipitation distribution graphs were compared with the selected case study dates, to verify their selection, and close resemblances were achieved for each component pattern. Attention then focussed on establishing the link between the component rainfall patterns and the synoptic situation. Operational charts were investigated for the dominant days for each component. The charts were supplied by the New Zealand Meteorological Service National Weather Forecasting Centre. In addition, Kidson weather types (Kidson 2000) were examined on those dates when a particular component was dominant. To determine which chart was chosen to represent the synoptic situation for each rainfall pattern, data from 15 representative rainfall stations from the 56 identified in Figure 1 were examined. The recordings from those rainfall sites were taken at 5 minute intervals. This enabled the exact time of the heaviest rainfall to be noted and used to ascertain the correct chart for the synoptic analysis. This was important as the 0900 data reading crossed over two 0000 NZST operational charts. For each of the components at least six case study days, which satisfied the criteria, were examined to determine the key synoptic events. The component scores and the accompanying dates selected for the case study are shown in Table 2.

| Component scores | | | | | |
|---|---|---|---|---|---|
| Component | Date | 1 | 2 | 3 | Kidson weather types |
| 1 | 13-Feb-02 | 4.29 | -0.78 | 1.88 | TSW |
| | 27-Feb-03 | 6.29 | 0.89 | -2.36 | HSE |
| | 9-Jan-03 | 5.68 | -1.21 | 2.64 | HNW |
| | 30-Jul-03 | 6.29 | -2.14 | 1.87 | NE |
| | 8-Jan-03 | 4.35 | -1.42 | 0.92 | NE |
| | 21-Jul-04 | 6.87 | -2.78 | -0.07 | NE |
| 2 | 18-Dec-02 | -2.29 | 3.28 | 0.5 | HSE |
| | 29-Jul-03 | -0.23 | 5.18 | -2.55 | NE |
| | 16-Jul-04 | -0.61 | 1.76 | -0.53 | HSE |
| | 5-Jan-02 | -0.55 | 1.64 | -0.06 | SW |
| | 14-Jan-03 | -1.73 | 2.29 | 0.29 | HW |
| | 28-May-02 | -0.49 | 3.07 | 0.52 | SW |
| 3 | 9-Jun-03 | -1.16 | -2.17 | 10.14 | R |
| | 6-Sep-03 | 0.22 | -1.19 | 4.94 | T |
| | 23-Jul-04 | -0.28 | -0.58 | 1.53 | H |
| | 4-Jan-02 | -0.59 | -0.64 | 1.39 | T |
| | 8-Jul-03 | -0.08 | 0.19 | 3.58 | H |
| | 28-Apr-04 | -1.89 | -0.71 | 4.7 | HSE |

*Table 2 - Days with high rainfall selected for the case study.*

## Results

The first three components accounted for 77% of the variance. The relative percentage variance between the three components is fairly even. The entries

| Component | Total |
|---|---|
| 1 | 21.30% |
| 2 | 26.40% |
| 3 | 28.70% |

*Table 3 - Percentage of the total variance explained by the first three rotated principal components*

in Table 3 give the relative variance extracted by the first three rotated components. The other components had values that were much lower. Of the retained components, the variables loaded strongly together in distinctive patterns. The patterns indicate that the regions had maximised rainfall in their respective principal components, and minimised with the other two components. After interpretation of the data, it was evident that there were three distinct spatial patterns. Furthermore, the examination of the synoptic charts found consistency between the synoptic situations and the three dominant components.

## Synoptic cause and the component patterns

The component patterns are illustrated in Figures 2 – 9 where 10mm was equalled or exceeded somewhere in the area. Contours are plotted showing correlation between the time series of precipitation and the time series of component scores. Six synoptic examples of each case study were taken from Table 2 to show their degree of similarity.

### *Component 1*

This pattern (Figure 2) features a maximisation of rainfall in the north and east of the region stretching from Leigh (station 1) Figure 1, across to Hotea (2) and then extending into the North Shore (stations 12-20). It also involves Waiheke Island and the north eastern fringe of the Hunua ranges. There is a minimisation of rainfall in the west and south of the region. The two examples of the actual distribution of precipitation (Figures 3) illustrate the precipitation distribution found for components 1. There are six examples in Figure 4 all showing similar synoptic patterns. The distinguishing feature of the synoptic situation found for component 1 is a trough and front moving over northern New Zealand towards the east of Auckland. Together they maintain moist easterly to north-easterly flow across the region. Concurrently anticyclones: extend a ridge across the South Island, and another to the east of New Zealand.

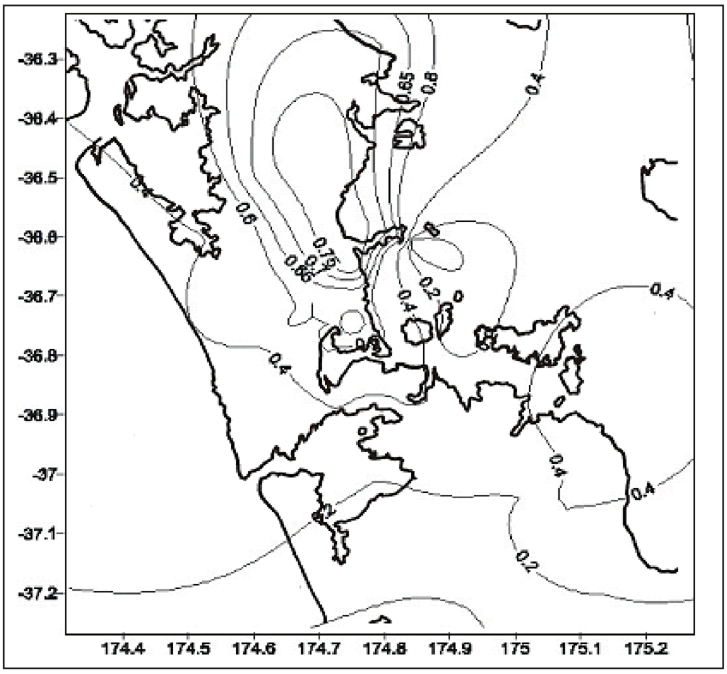



*Figure 2. Contour map showing the rotated component pattern when component 1 dominates. Contour interval is 0.2 starting at 0 and finishing at 0.8.*

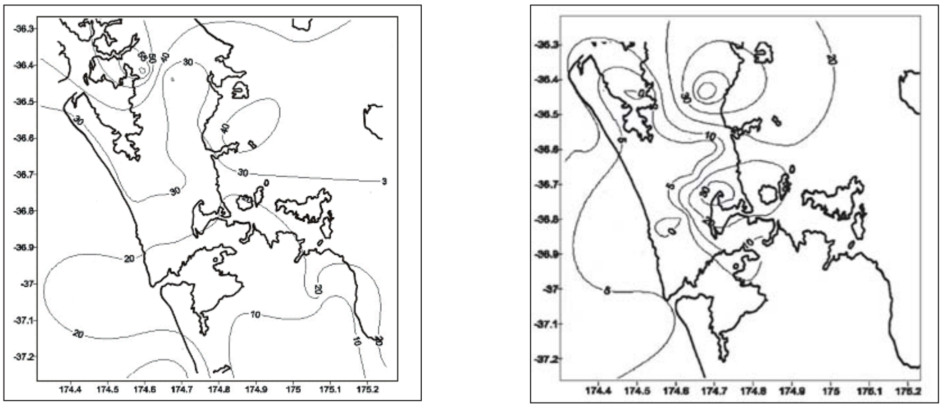


*Figure 3A and 3B. Distribution of precipitation on 30/7/2003 and 21/7/2004 which are examples of days when component 1 dominates. All significant rainfall was included*.

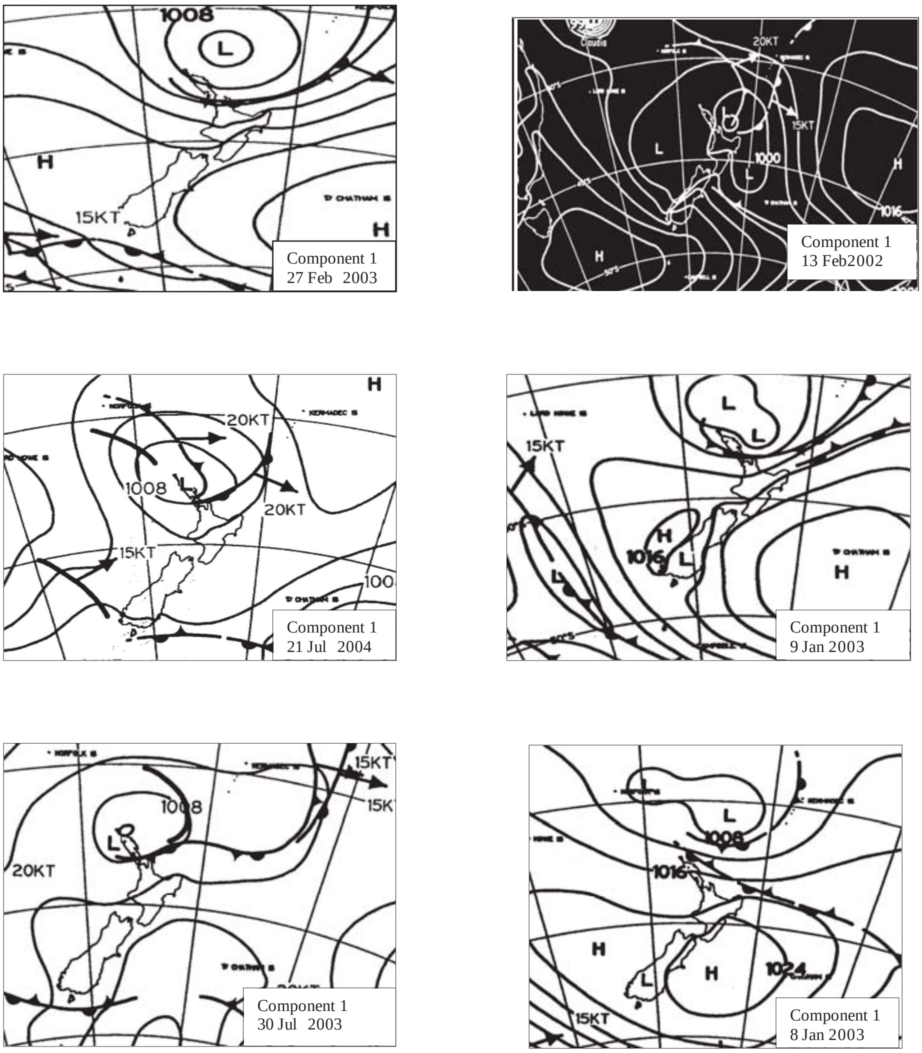



*Figure 4A to 4F. Synoptic charts from case study examples when component 1 dominates. All the weather charts in component 1 were recorded at 0000 HRS NZST.*

Together these anticyclones act as a block and prevent the trough from rapidly traversing the Auckland region. The Kidson weather types associated with component one were compared with the synoptic situation, and close resemblances were achieved. Both identified the distinguishing feature of the north-easterly flow across the region.

## *Component 2*

The second pattern (Figure 5) shows a rainfall maximum in the south of the region, stretching from Miranda (Station 54) to Pukekohe (51). An area of note

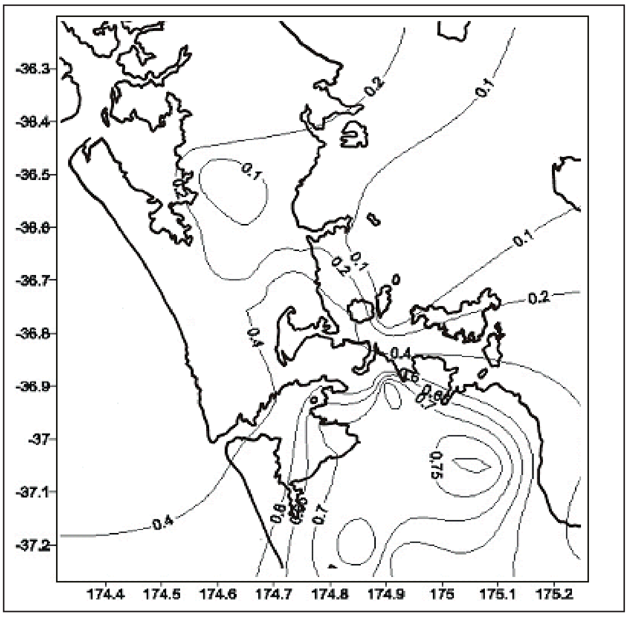



*Figure 5. Contour map showing the rotated component pattern when component 2 dominates. Contour interval is 0.2 starting at 0 and finishing at 0.8.*

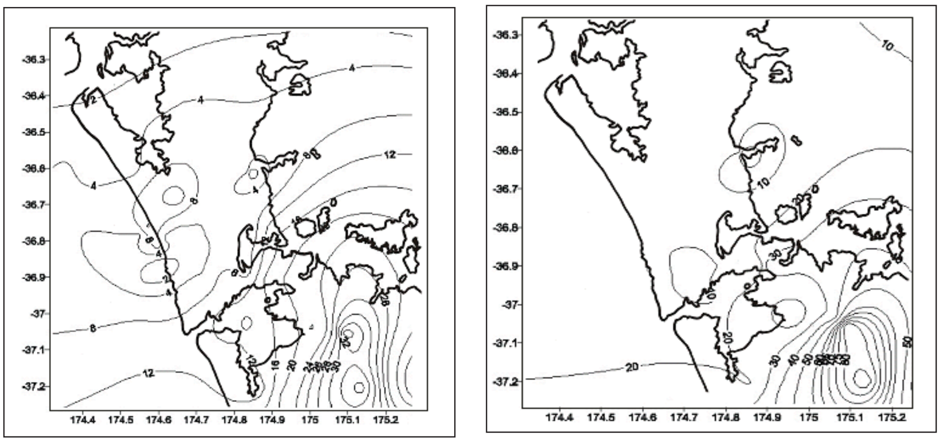


*Figure 6A and 6B. Distribution of precipitation on 29/7/2002 and 13/7/2002 which are examples of days when component 2 dominates. All significant rainfall distribution was included.*

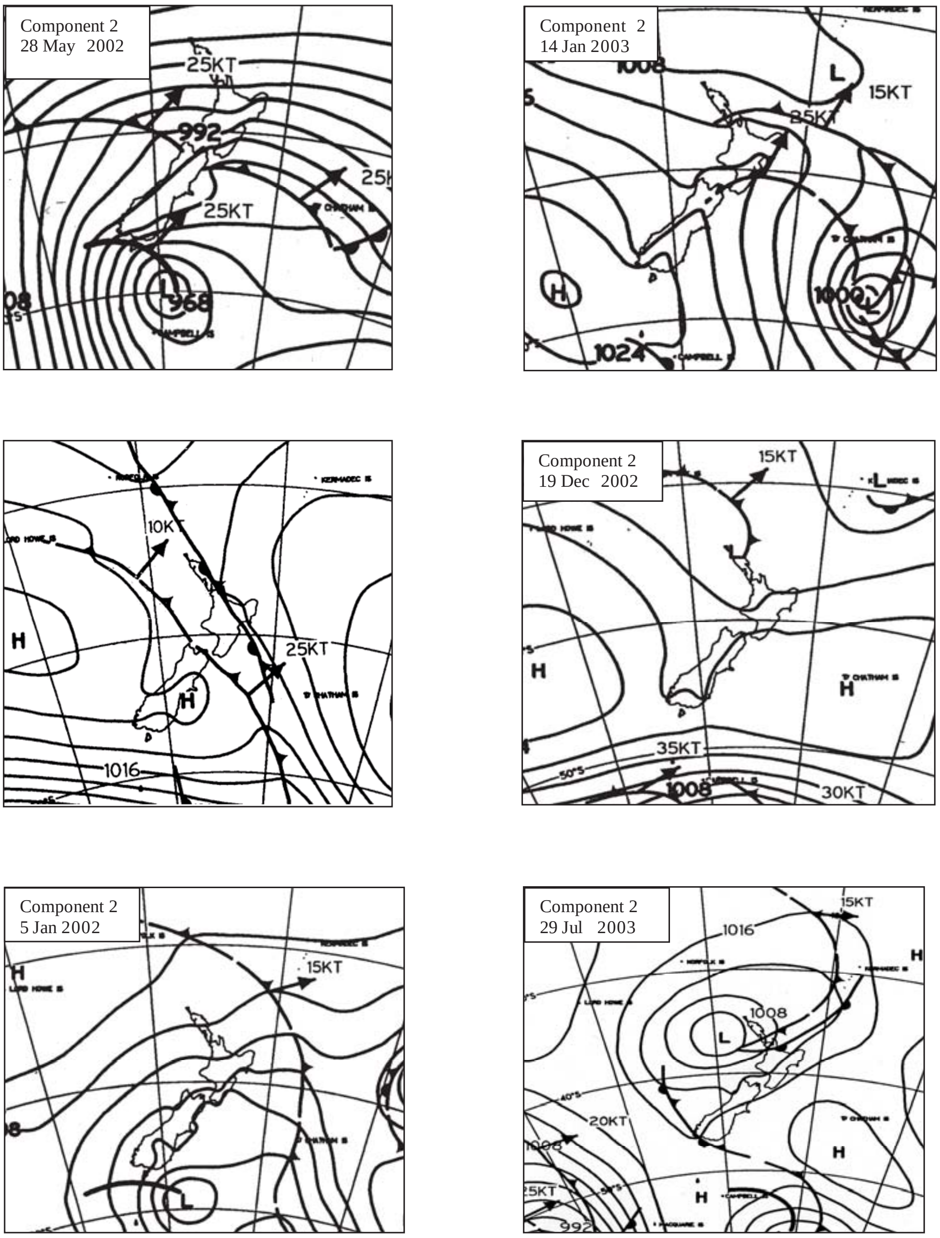



*Figure 7A to 7F. Synoptic charts from case study examples when component 2 dominates.*

where rainfall maximises is the hilly area of the Hunua ranges. The high precipitation belt extends as far north as Onehunga (38). There is a corresponding rainfall minimum in the west and north of the region. This pattern is illustrated in the distribution of precipitation in Figure 6.

The component two pattern is characterised by two synoptic situations shown in Figure 7. The first synoptic situation is defined by a ridge of high pressure moving away to the east allowing a trough of low pressure to move onto the country with disturbed west to south-westerlies. The associated frontal system moves in a south-westerly flow. As an anticyclone over the Tasman Sea moves eastward, the south-west air stream dies away. The second synoptic situation is characterised by a slow moving trough which has moved in a westerly, south-westerly flow, lying north-east of the North Island. It is prevented from moving away by an anticyclone to the east of New Zealand. The Kidson weather types associated with component two were compared with the synoptic situations and close resemblances were achieved. Both identified the following: a south-westerly flow across the region, and a high east of the South Island acting as a block to a trough moving in an easterly flow across the North Island.

### *Component 3*

Component 3 (figure 8) features a rainfall maximum in the west of the region stretching from Helensville (station 7) into the Riverhead Forest through Kumeu Whenuapai (31), Swanson (28), Oratia (27) and Cutler Park (33) and as far south as the Manukau Heads (42). The water supply dams in the west also benefit from this rainfall maximum. A corresponding rainfall minimum is found in the east and south of the region. The two examples of the actual distribution of precipitation are shown in Figure 9. In both cases, in the west of the region, rainfall maximised, whilst falls were lighter in the rest of the region. The distinguishing feature of this synoptic pattern is a low pressure trough approaching Northland from the eastern Tasman Sea moving eastward and northwards.(Figure 10). Moist northerly airstreams precede the front. There is a ridge east of the country and often an anticyclone forming in the south Tasman Sea. The Kidson weather types associated with component three were compared with the synoptic situation. Apart from the identification of the trough moving in a westerly flow crossing New Zealand, close resemblances were not achieved.

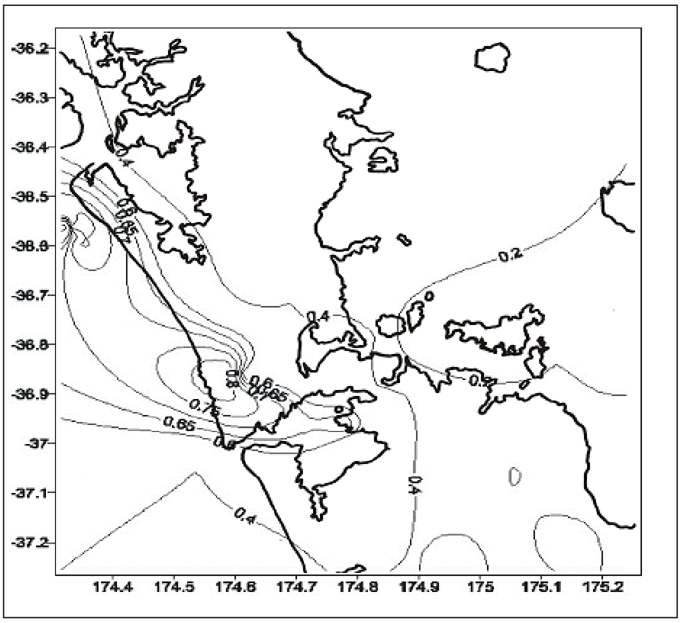
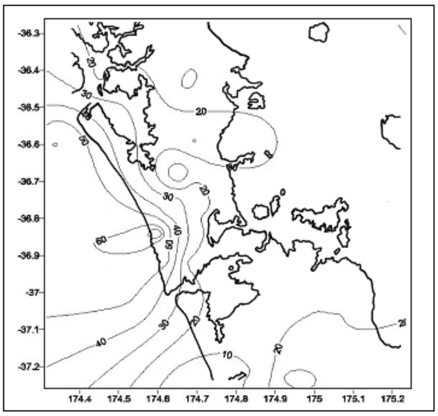



*Figure 8. Contour map showing the rotated component pattern when component 3 dominates. Contour interval is 0.2 starting at 0 and finishing at 0.81.*



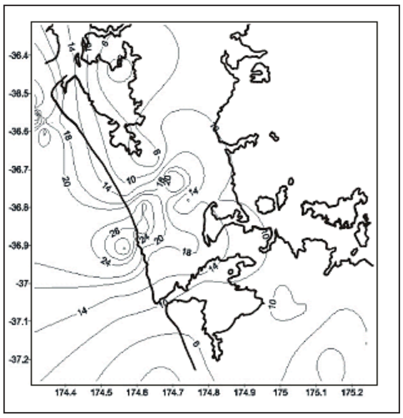
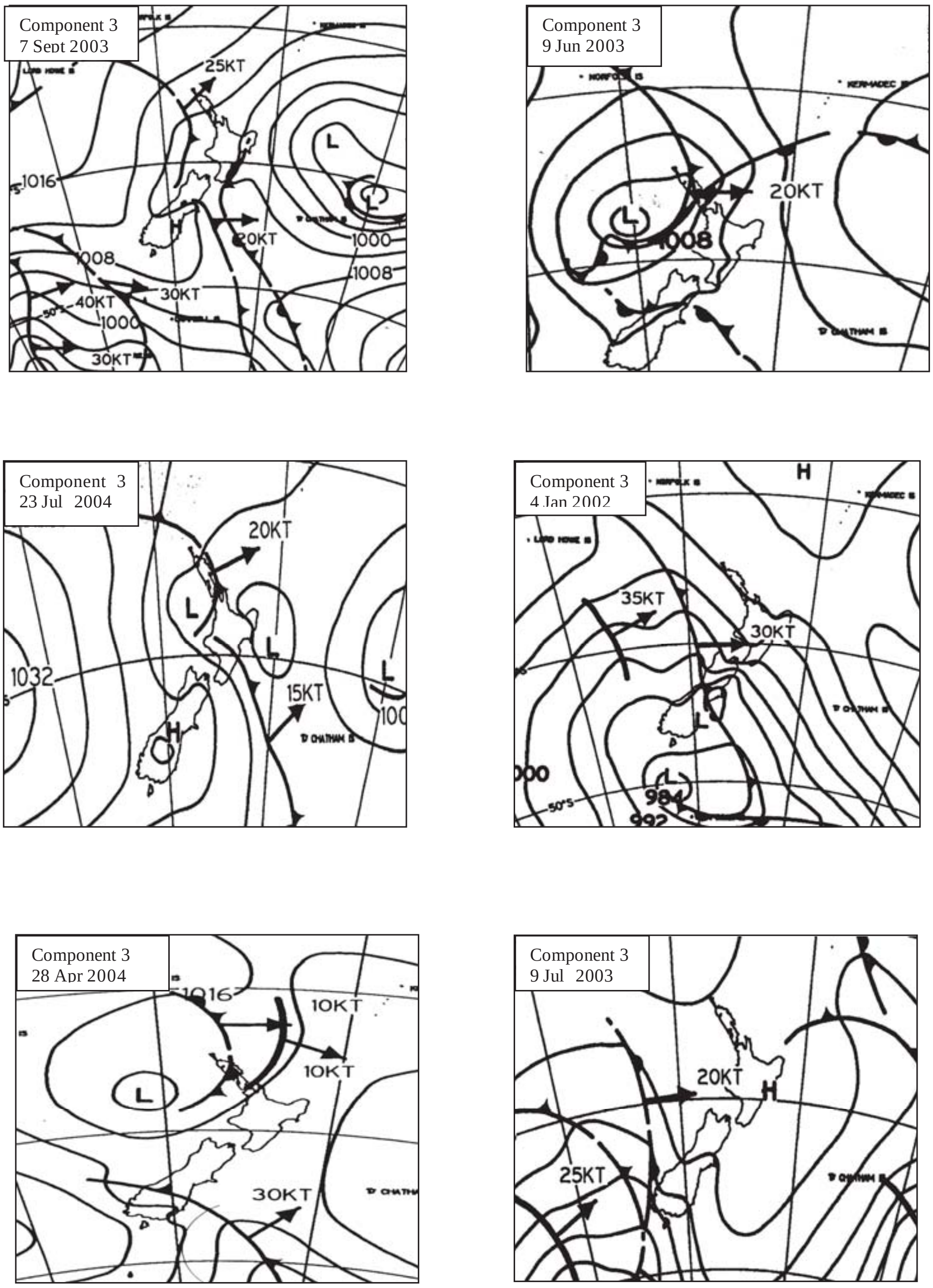


*Figure 9A and 9B. Distribution of precipitation on 8/7/2003 and 9/6/2003 which are examples of days when component 3 dominates. All significant rainfall distribution was included.*




*Figures 10A to 10F. Synoptic charts from case study examples when component 3 dominates.*

## Discussion

In the New Zealand area ten synoptic weather types have been identified in the climatological studies conducted by Jiang et al (2004). These types have counterparts in previous analysis Kidson (1994) and Kidson (2000). New Zealand lies largely within the prevailing westerlies associated with eastern progression of weather systems. On the mesoscale the interaction of synoptic airflow with orography in previous studies has been most important. Given the variability in weather systems and the general lack of high mountains and strong wind flows over the Auckland region it might be expected that the mesoscale patterns be less defined. Hence even superficial similarities in the synoptic patterns associated with each precipitation pattern would have been acceptable. In fact the three principal components were found to be associated with four consistent synoptic situations. Principal component analysis groups similar patterns of precipitation, and the varimax rotation meant each pattern differed from the other components. In component 1 the frontal zone demarks the boundary between airflow from the north east arriving from the Tasman Sea. The distribution of the precipitation maximum is displaced northwards where the orographic uplift is between 150 m and 300 m. The North Shore is exposed to north-easterly flow because there are no orographic barriers in its path. In the component 2 rainfall distribution pattern the uplift given to the airflow by the Hunua Ranges, which rise to above 300 m, and the remainder of the South Auckland area which rise from 150 m to 300 m may explain the pattern. The rainfall maximum only reaches as far north as Onehunga. In the component 3 synoptic setting areas in the north, north-east and south are sheltered by the Waitakere Ranges over 300 m. The rainfall maximum is confined to the Waitakere Ranges and the lower foothills. This is explained by the moisture laden westerly and north-westerly airstreams having condensed as they cross the Waitakere Ranges. The analysis suggests that, in many synoptic situations, there is qualitative information available on the distribution of rainfall in the Auckland region. A large amount of the variance is explained by the three different component patterns.

## Conclusion

A synoptic climatic classification approach has been applied to the analysis of rainfall distribution from 56 sites in the Auckland region. The analysis used data from the years 2002-2004. Using a principal component analysis with Varimax rotation, stations in distinct geographical areas that correlated highly with a particular component were produced. A high factor loading on one component was not repeated on the remaining components. It was expected that the mesoscale patterns in Auckland would be less defined as there were fewer orographic influences and a milder climate than Wellington. However in Auckland, as in other areas of New Zealand, namely Gisborne and Wellington, the regional topography provided the background with which the synoptic settings interacted, to produce the resulting precipitation patterns. The analysis of the data identified three significant principal component patterns for the Auckland region. The distinct patterns which emerged were caused by four different synoptic situations. Rainfall distribution on highly loaded factor scores, relates to localised heavy rainfall. On a few occasions falls were very local, and confined to within a few kilometres, leaving surrounding stations unaffected. These shorter duration rainfall events are often very local because of small scale weather systems such as wind convergence. They often occur mid-afternoon in summer when sea breezes from the main east and west coasts in Auckland sweep inland. These meet along a band known as the Sea Breeze Convergence Zone: this zone is often cloudy and occasionally contains scattered showers, and localised heavy showers. Those days where inaccuracies in the data at some stations were detected were not included in the case studies. The number of precipitation days (730) means that the sample is high enough to arrive at stable patterns between years. Although the relative variance explained by each component could change each year, the relative percentage variance between the three components in this study was fairly even. The heavy rainfall forecasts are currently provided for the entire Auckland region rather than concentrating on being specific within the area. Hence there was always the potential for a finer scale specification of heavy rainfall forecast information. The identification of the heavy rainfall synoptic systems provided in this study should help to improve storm rainfall and flood forecasting in the Auckland region.

## Acknowledgements

This research was completed while the first author was on a N.Z. Science, Mathematics and Technology Teacher Fellowship. This work was also supported by the New Zealand Foundation for Research, Science and Technology contract No CO1X0202 adaptation to climate variability and change. The work has been done with the support of and all the staff at NIWA Auckland, particularly Dr. Jim Salinger who acted as my host. The first author is indebted to NIWA, Auckland Regional Council, Watercare, Metrowater and Weatherwise Auckland for kindly providing the rainfall data.

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*Submitted to Weather and Climate , September 2005. Revised June 2006.*