



# University of Fort Hare

*Together in Excellence*

An assessment of hourly rainfall on Sub-Antarctic Marion Island and the implications for  
climate change

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## DECLARATION

I declare that this dissertation is my original work and has not been submitted for a degree or any other purpose in institution. Where reference is made of other people's work, they are duly acknowledged.

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## **DEDICATION**

To my family: My husband Daniel Angwenyi my children Aming'a Christopher Angwenyi and Oyaró Zablon Angwenyi.

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## **ABSTRACT**

Hourly rainfall data from the South African Weather Service for the meteorological station on the eastern side of Marion Island were assessed (1995-2009) to investigate trends in rainfall intensity. For all categories the annual frequency of hourly rainfall shows no statistically significant increase or decrease over the recording period. This is in contrast to long-term change over the last forty years where the climate of Marion Island has changed significantly. The lack of change over the last 15 years may indicate stability with regards to annual rainfall. However, even though the frequency of hours with no rainfall for the recording period shows no linear temporal trend, significant increase in hours with no rainfall occurred during the summer months. From synoptic charts and data it is suggested that high intense hourly rainfall is associated with a strong cut-off low pressure system over Marion Island extending meridionally in a north-westerly direction. Mean air pressure is low and the meridional component in the dominant airflow explains the high humidity and suggests the potential to bring in a northerly maritime tropical air from lower latitudes west or north-east of the island. Climate change implications for hourly rainfall on Marion Island show various opposing trends. A decrease in low pressure systems and increase in anticyclonic conditions will increase the number of hours without rainfall (as seen from the data) especially in summer. A further implication is that the number of intensive hourly rainfall events could also decrease. However the possibility exist that Marion Island is becoming wetter and the data indicate that hourly rainfall over the last decade show an increase during the summer months. Further research is needed to ascertain the current rainfall trends on Marion Island.

## TABLE OF CONTENTS

<b>DECLARATION</b>	ii
<b>DEDICATION</b>	iii
<b>ACKNOWLEDGEMENTS</b>	iv
<b>ABSTRACT</b>	v
<b>LIST OF TABLES</b>	viii
<b>LIST OF FIGURES</b>	ix
<b>CHAPTER ONE: INTRODUCTION</b>	1
1.1. Background to the study	1
1.2. Defining Intensive rainfall events and its implications	6
1.3. Ecological consequences of climate change on Marion Island’s landscape	8
1.4. Synoptic forcing of heavy rainfall	12
1.5. Marion Island synoptic weather conditions and rainfall events	13
1.6. Research Aim and Objectives	14
1.6.1. Research Aim	14
1.6.2. Objectives	14
1.7. Research Questions	15
<b>CHAPTER TWO: LITERATURE REVIEW</b>	16
2.1. A synoptic assessment of intensive rainfall	16
2.2. Global view on the effects of intensive rainfall and future implications	20

<b>CHAPTER THREE: RESEARCH METHODOLOGY</b>	22
<b>CHAPTER FOUR: RESULTS</b>	24
4.1 Temporary trend of hourly rainfall intensity	24
4.1.1. No rainfall	28
4.1.2. Low rainfall intensity	31
4.1.3. Moderate rainfall intensity	33
4.1.4. High rainfall intensity	35
4.1.5. Severe rainfall intensity	37
4.2. Linking Intensive rainfall to synoptic weather	40
<b>CHAPTER FIVE: DISCUSSION</b>	44
<b>CHAPTER SIX: CONCLUSION</b>	47
<b>REFERENCE</b>	49

## LIST OF TABLES

Table 1: List of research questions	15
Table 2: Frequency of annual hourly rainfall for each category at Marion Island	24

## LIST OF FIGURES

Figure 1:	Map: Location of Marion Island in relation to other islands in the maritime sub-Antarctic, the Antarctic Polar Convergence and Antarctica (Hedding, 2005).	2
Figure 2:	Annual frequency of hourly rainfall in the five categories (1995-2009)	25
Figure 3:	Frequency of 0 mm of rainfall against annual rainfall total	26
Figure 4:	Frequency of hourly rainfall of 0 mm (January to June)	29
Figure 5:	Frequency of hourly rainfall of 0 mm (July to December)	30
Figure 6:	Frequency of hourly rainfall of between 0.1 mm and 1.99 mm (January to June)	31
Figure 7:	Frequency of hourly rainfall of between 0.1 mm and 1.99 mm (July to December)	32
Figure 8:	Frequency of hourly rainfall of between 2.0 mm and 4.99 mm (January to June)	33
Figure 9:	Frequency of hourly rainfall of between 2.0 mm and 4.99 mm (July to December)	34
Figure 10:	Frequency of hourly rainfall of between 5.0 mm and 9.99 mm (January to June)	35
Figure 11:	Frequency of hourly rainfall of between 5.0 mm and 9.99 mm (July to December)	36

Figure 12:	Frequency of hourly rainfall of 10 mm and above (January to June)	38
Figure 13:	Frequency of Hourly rainfall of 10 mm and above (July to December)	39
Figure 14:	Synoptic shipping chart for the 12 <sup>th</sup> January 2002 at 0 hours SAST	47
Figure 15:	Synoptic shipping chart for the 18 <sup>th</sup> January 2002 at 12 hours SAST	41
Figure 16:	Synoptic shipping chart for the 29 <sup>th</sup> January 2002 at 18 hours SAST	42

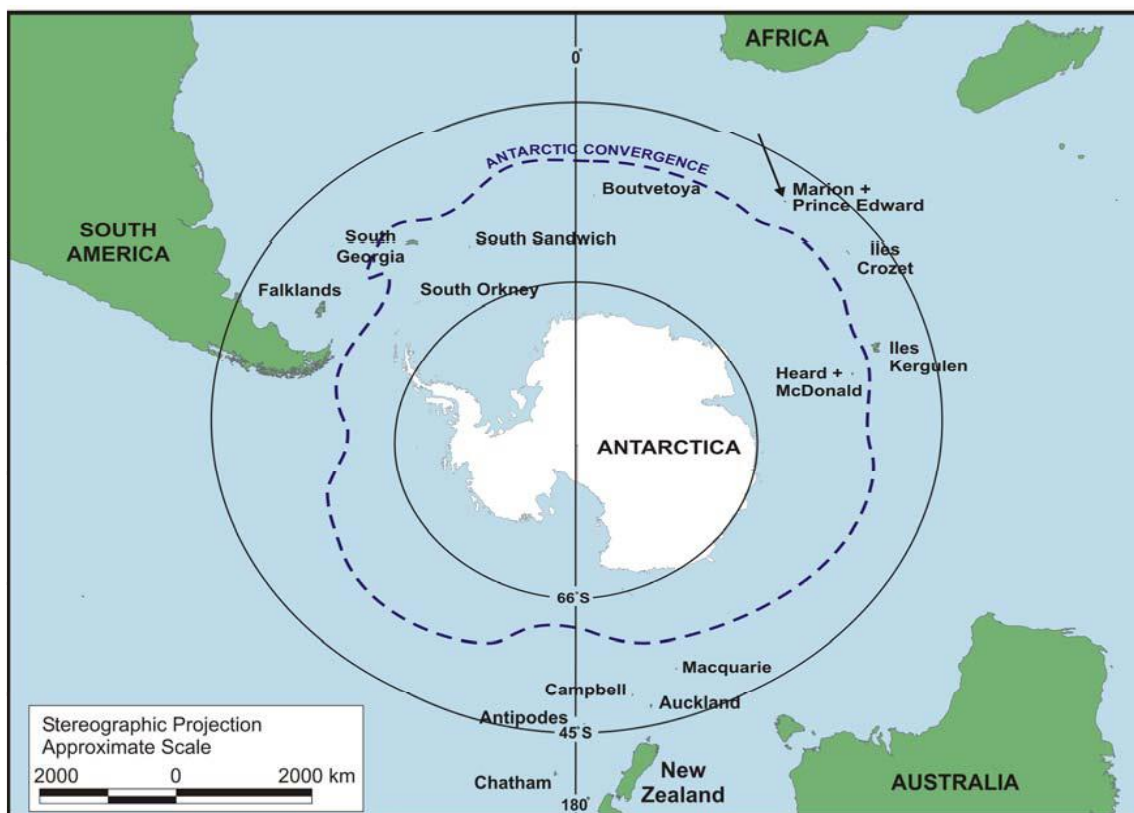
## CHAPTER ONE: INTRODUCTION

### 1.1. Background to the study

Marion Island (46° 54' S, 37° 45' E) located in the southern Indian Ocean is the larger of the two Prince Edward Islands and comprises the peak of a shield volcano (Fig. 1). The island has a maritime climate that is dominated by strong westerly winds and relatively low temperatures (Nel et al., 2003; Sumner et al., 2004). During summer the island experiences a maximum temperature of approximately 10.9°C and a minimum of approximately 5.2°C. During the winter the mean air temperature can reach approximately 6.6°C (Boelhouwers et al., 2003). Mean Annual Precipitation (MAP) is 2332 mm and on average precipitation occurs on 25.6 days of each month (Boelhouwers et al., 2003; Holness, 2004). Winds on the island have an average velocity of 32 km h<sup>-1</sup>, and main direction is the northwest (Boelhouwers et al., 2000; Hedding, 2005). An almost continuous cloud cover exists on Marion Island due to hyper-oceanic sub-Antarctic climate of low temperatures, high annual precipitation and low radiation inputs (Schulze, 1971; Holness, 2001).

Situated in the Southern Ocean, Marion Island is subjected to a succession of mid-latitude depressions, migratory anticyclones and frontal systems (Roualt et al., 2005; Le Roux, 2008). Mid-latitudinal depressions (cyclones) are initiated between 30° and 40°S latitude in the Atlantic Ocean (Schulze, 1971). Cyclones (depressions or low pressure systems) are associated with cloudy weather with a clockwise upward circulation. After a cyclone is formed, the main track of the cyclones moves to the south-east, usually passing over, or to the west of Marion Island (le Roux, 2008). Precipitation is prone to occur during the pre-cyclonic phase with the occurrence of high cloud cover and the strengthening of north-westerly winds. Cooler dry Antarctic air is forced over the island when the cyclone has passed; causing cold clear conditions with weak south-westerly winds (le Roux, 2008). By contrast, anticyclones move eastward after formation, passing far north of Marion Island (Schulze, 1971; le Roux, 2008).

Also known as high pressure systems they exhibit a downward movement of air surrounded by anti-clockwise rotating winds. Clear weather can be associated with this type of circulation since the air becomes drier as it warms when moving from high to low altitude (le Roux, 2008). It is also characterised by abundant precipitation, mostly rainfall, with 2326 mm of annual accumulation (Smith, 2004). However, recent rainfall data has indicated a decrease trend in rainfall received on the island which is associated with global climate change (Smith and Steenkamp, 1990; Smith, 2003; Roualt et al., 2005).



Figure, 1 Map: Location of Marion Island ( Source: Hedding, 2005).

Marion Island is characterised by low daily seasonal thermal variability, with the mean difference between maximum and minimum temperatures of  $<2^{\circ}\text{C}$  winter and  $<3^{\circ}\text{C}$  in summer. As such, sub-zero temperatures can be experienced during any months of the year, with temperatures regularly crossing the  $0^{\circ}\text{C}$  threshold (Boelhouwers et al., 2003). Marion Island's climate is generally characterised by high precipitation and humidity, strong winds and nearly

complete cloud cover. A significant proportion of the cloud cover in the eastern side of the island is associated with orographic origin with both low stratus and lenticularis clouds being commonly observed (Schulze, 1971). The island receives precipitation in a form of rainfall, snow, ice (hail) and mist, with some form of precipitation falling on most days. Snow and graupel are more common in the winter months than in summer months. The snow cover normally remain throughout the year in the higher altitudes. However recent research shows that snow cover above 750m only persists from May to October (Holness, 2003a) and only few patches survive summer (Smith, 2002). A small body of apparently rapidly melting ice can be found in the summit regions (Sumner et al., 2004).

Rainfall is the dominant form of precipitation, with rainfall events of  $\leq 5\text{mm}$  and  $>5\text{mm}$  occurring on roughly 45% and 35% of days, respectively (le Roux and McGeoch, 2008). According to Smith (1979), mist is also an important form of precipitation since it leads to considerable condensation on some landforms and vegetation, especially when accompanied by strong winds. Marion Island also experiences thunderstorms and lightning. These events were rare in the past; however they are now occurring almost about four times in a year. Short periods of low humidity also occur due to Fohn winds on the leeward side. As the results of air masses movement to the central plateau, Fohn winds can rapidly raise air temperatures by  $10^{\circ}\text{C}$  and lower relative humidity by more than 20% (Schulze, 1971).

Marion Island has been experiencing a decrease in annual precipitation since the early 1960s. Smith and Steenkamp (1990) showed that total annual precipitation declined between 1963 and 1983 but thereafter the trend was increasing, this was up to 1988, the last year in the record data available at that time. Chown and Smith (1993) re-analysed the precipitation record up to 1991 and showed that annual precipitation decreased markedly in the 1960s and 1970s but it was relatively constant during the 1980s. According to Holness (2003b), precipitation occurs on 25.6 days of each month, with a mean annual total of 2332 mm. In

addition, Smith (2002) indicates a mean annual precipitation (MAP) of approximately 2000 mm with occasional snowfalls recorded at the meteorological station.

Smith and Steenkamp (1990) analyze maximum and minimum temperature using data recorded between 1952 and 1988 and the trend show an increase in both maximum and minimum temperatures. In addition, Smith (2002) indicated that the island is getting warmer, drier and with more sunshine hours each year with mean annual temperature of 6.0 to 6.5. Sunshine hours have increased and mean air temperature has increased by 1.2°C (Smith 2002). The greatest warming is from January to March with the average of 7.5°C. Winter months are very cold during January to September having an average of 3.6°C. An absolute maximum temperature of 23.8°C and an absolute minimum temperature of -6.8°C have been recorded in 2001, while the difference between extremes is close to 30°C.

Marion Island is located far from any land mass and within the belt of Westerly winds (Sumner et al., 2004). The wind speeds are often high and gale force winds (> 15m/sec) occur on approximately 107 days a year. Late summer winds are generally weaker (with disproportionately few gale strength winds) and have a stronger northerly component (Rouault et al., 2005). Summer diurnal variation in wind speed is much clear, with faster wind speed during the day than night. North-westerly winds are the strongest and most common (with the average of 30.2km/h) (Holness, 2001), whereas colder and drier weather is associated with the less common and little weaker, southerly winds (Smith & Steenkamp, 1990). The predominant wind direction is still westerly as expected from the island's location in the belt of strong, large-scale westerly atmospheric circulation (Rouault et al., 2005). Although the trend over the past 50 years has been a wind shift in a northerly direction. Recent investigations have demonstrated that the changing climate is a consequence of a southward shift in cyclonic activity associated with a change in the amplitude and phase of the Semi-Annual Oscillation Index in the Southern Hemisphere (Rouault et al., 2005).

Sub-Antarctic islands are characterised by a hostile environment and most of the plants and creatures at the continental environment will not survive there. An oceanic climatic condition and limited space in Sub-Antarctic islands restrict habitats and impoverish floras and faunas (Smith, 2003). Oceanic islands ecosystems are generally characterised by low numbers of species as compare to continental ecosystem which is known to be highly rich in biodiversity. Marion Island were never connected to, or even near any continent, as such the island has relatively few species of plants and animals which reach the island over long distances across the ocean (Smith, 2004). Therefore, due to its isolation and harsh climatic conditions, it is characterised by a typical sub-Antarctic biota with a scarcity of species (Nel et al., 2003). Lichen – a plant composed of fungus and algae – is found on the rocky outcrops. The island support relatively sparse biota, 21 alien plant species and 22 indigenous vascular plant species (Grobler et al., 1987) of which twelve exotic species and four species of unknown origin also occurs on the Island. There is a wider variety of lower plants species which includes 72 moss species, 35 species of liverworts and approximately 200 bryophyte and lichen species (Gremmen and Smith, 1981). However, much of the bare rock and scoria has no vegetation cover except for lichens and cushion dicots including *Azorella selago* and *Colobanthus kerguelensis*, on which grow graminoid species such as *Agrostis magellanica*, *Uncinia compacta*, and *Poa cookii*. However, despite the paucity of plant species, the isolated position and poor weather conditions there is a rich faunal assemblage as a result of proximity to the rich food source of the Antarctic Polar Convergence (Hall,1978). Thus Marion Island provides an extremely important site for breeding and moulting seabirds and ocean-going mammals. According to Williams et al., (1979); Gremmen and Smith, (1981) and Smith (1987) the islands also supports more than 26 species of breeding birds as well as 22 species of vagrant seabirds and 28 species of no-marine vagrant species. Marion Island is characterised by low biodiversity with the absence of herbivores and carnivores (Smith, 2004). There are no macro-herbivores and even the insects play only a small role as herbivores, so most of the energy and nutrients incorporated in primary production go through a detritus, rather than grazing, cycle.

The island was annexed by South Africa in 1948 for military reasons but Marion Island together with Prince Edward are now occupied primarily for the collection of meteorological data (Hänel and Chown, 1998). The continuous meteorological record shows that the island's mean temperature has risen for the past years, annual rainfall has dropped, and annual sunshine hours have increased since the 1960's (Smith and Steenkamp, 1990; Chown and Smith, 1993; Smith, 2002). However, trends in other parameters and changes in climatic variability, extreme rainfall events or aggregate measures of climate have not been examined, despite evidence that the recent rapid changes in climate have already impacted both terrestrial and marine systems in the region (Rouault et al., 2005).

## **1.2. Defining intensive rainfall events and its implications**

Intensive rainfall events are defined as 24 hours accumulative rainfall greater than a certain threshold. For example, rainfall events that exceed 100 mm in 24 hours can lead to severe floods and landslide risk (Carvalho et al., 2002). Frei and Schär (2005), state that heavy rainfall can either be intensive and of short duration in connection with thunderstorms, or less intensive and of several days duration in connection with stationary weather systems. Therefore, intensive rainfall can further be described as an extreme event of short duration approximately one to several hours with high intensity rainfall (Jones et al., 2004). Widespread flooding throughout the world in the past decades has enhanced the public concern that such heavy and prolonged rainfall events are a result of global warming (Fowler and Kilsby, 2002). Climate change is affecting the intensity and frequency of rainfall and this is demonstrated from daily basis rainfall series analysis (Brunetti et al., 2004; Schmidli and Frei., 2005). Recent research shows that an increase in global warming results in the increase of intense precipitation, but this may vary according to regions (Semenov and Bengtsson, 2002). In addition, higher and more intense precipitation has been observed in many areas of the world

and the trend is expected to be even more pronounced in a future warmer world (Zbigniew, 2003).

According to Westar et al., (2012), extreme rainfall events are on the increase over the course of the 20th and early 21st centuries at a global scale. In addition, when analysing the link between the intensity of rainfall extremes and a record of global mean near-surface atmospheric temperature, rainfall intensity is found to an increase at a rate of between 1.6 and 2.1 frequency/annum for each degree Celsius, depending on the method of analysis (Westar et al., 2012). These analyses predict more extreme rainfall event in the future if the intensity of extreme rainfall events is associated with the rate of the atmospheric temperatures. Some of the implications of increase rainfall intensity would be an increase in flash flood around the world. Based on Westar's et al., (2012) study, an average increase of atmospheric temperatures by 1.9 degree Celsius might sound small but if the rate of greenhouse gas emission follows the same trend there would be more increase in extreme rainfall events at a global scale.

A study conducted by Burnett and McNicoll (2000) in Italy suggest that an increase in rainfall intensity with the decrease in total rainfall is associated with an increase in global warming; which has a strong implication on the natural climate of the region and will in turn affect its regional landscape. Whereas in the central part of the United States, global warming is bringing more intensive rainfall events and in the upper Midwest the frequency of the most intense rainfall events have increased by 20% (Zhang et al., 2007).

Although it is widely recognized that there has been a detectable rise in global temperatures during the last decades, the regional distribution of temperature increase is not uniform and

some regions experienced greater changes than others. Therefore, at regional scale there is a distinct regional difference (Solomon et al., 2007). According to Westar et al., (2012) the greatest increases occurred in the tropical belt; while lower increases occur in the drier mid-latitudes where most of the world's deserts are found. Whereas, the higher latitudes and mostly in the northern hemisphere the rate of change is assumed to be closer to the global average.

### **1.3. Ecological consequences of climate change on Marion Island's landscape**

An increase in global temperatures has been seen as results of anthropogenic activities which have effects on global climatic conditions (Karl and Trenberth, 2003; IPCC 2007). The mean global temperature has risen by 0.74 °C over the last 100 years (IPCC, 2007), which led to a significant change in oceanic and atmospheric circulation (Fowler and Kilsbayl, 2002). In turn, different regions are experiencing different changes in terms of precipitation and wind patterns (Zhang et al., 2007). Some area will receive low rain fall while other areas will receive intensive and long lasting precipitations that are associated with heavy storm and high floods which will have tremendously impact on the landscape. Marion Island is characterised by maritime climate and has been experiencing continues climate change for the past years.

The climate of Marion Island has changed significantly over the last forty years. Records from the meteorological station on the eastern side of Marion Island show a marked increase in sunshine hours, pressure and temperature, together with a reduction in rainfall (Smith, 2002; Rouault et al., 2005). Smith (2002) reports an increase in air temperature of 1.2°C recorded between 1969 and 1999 which is more than twice the mean global rate of temperature increase (le Roux, 2008). It has been shown that under a changing climate, Marion Island experiences less cloud cover and more direct sunlight (Smith, 2002). The pressure increase in summer measured on Marion Island corresponds to a decrease in rainfall, an increase in the number of days without precipitation and a northward shift in the wind direction (Rouault et al., 2005).

The current changes in the climate of Marion Island are driven by changes in the synoptic weather systems (Smith and Steenkamp, 1990; Rouault et al., 2005; le Roux, 2008). Smith and Steenkamp (1990) propose that the observed radiation and air temperature increases on Marion Island can be explained by the relative positions of cyclone tracks. In warmer years the cyclonic centres pass, on average, further to the south of the island (Smith and Steenkamp, 1990). The island could then experience longer periods subjected to the north-westerly winds of the warmer sector of the cyclones and less exposure to the cold south-westerly winds of the post-cold front sector (Smith and Steenkamp, 1990). Rouault et al., (2005) correlate the air pressure increase in summer measured on Marion Island with the observed changes in rainfall and a northward shift in the wind direction. This could imply either a reduction in low pressures affecting the island in summer or relatively more anticyclonic conditions prevailing (Rouault et al., 2005).

The increase in air temperatures accompanied by a decrease rainfall has a tremendous impact on the island biodiversity. According to Smith (2002), change in temperature, sunshine, and humidity conditions can have a direct impact on the fauna and flora. According to McCarthy (2001), climate change can alter the composition and functioning of communities and ecosystems. The change in climate at Marion Island for the past years has also affected the ecology of the area by affecting the distribution and abundance of species. This can be seen in the Island's vegetation assemblages where two types of invasive plants (*A. stolonifera* and *Sagina Procumbers*) are wide spread in almost all type of habitats. In addition, *Festuca rubra* and *Agropyron repens* which are grass species that form a dense stands which smother the native plants has invaded and become dominant on few habitat at the localities where they occur (Gremmen, 1997).

Researchers have indicated that the change in climate at Marion Island could pose a threat to the indigenous populations of weevils (Gremmen and Smith 2004; le Roux 2004). In addition, continuous increase of the warming trend along with a decrease in precipitation could also negatively impact the larvae of the Marion flightless moth (*Pringleophaga marioni*). The changes in climatic conditions will not only affect vegetation rather it will also affect animal species. Increases in high temperatures create favourable conditions for invasive species that will negatively affect native species. For example, the increase in temperatures will favour the growth of mice population which is currently limited due to cold temperatures (Smith 2002). The house mouse (*Mus musculus*) is an introduced species in the island which feeds mainly on adult fly, weevil, snail, and earthworm individuals and the larvae of the above-mentioned insects. According to Smith (2004), mice can consume up to 194 g (dry matter) of invertebrates per hectare per day, therefore an increase in mice population will mean an increase in mice intake that will negatively affect indigenous species. Consequently, this will affect other species such as the black-faced sheathbill (*Chionis minor*) a migratory bird that depend on macro-invertebrates for its winter food source. It was already observed in the 1980s and 1990s that the populations of lesser sheathbills had declined in the northern and eastern parts of Marion Island (Bergstrom and Chown 1999).

The changing climate at the Island might influence the distribution of seabirds and seal population due to change of their feeding grounds which is caused by the changing position and frequencies of the atmospheric frontal systems that enables birds to reach their feeding grounds (Ryan and Bester, 2008). The drying and warming for past 35 years (Smith 2002; Sumner et al., 2004) will affect the vegetation. Vegetation will be affected indirectly through the alterations of the trophic dynamics of the islands. The change in atmospheric and oceanic circulation patterns which affects feeding grounds for seal and seabird population might result in a change in the amount of nutrients transferred from the ocean to the terrestrial ecosystem.

Transfer of nutrients from the ocean to the terrestrial environment plays a major role for both structure and function of the island vegetation (Chown and Fronneman, 2008; Smith 2002).

The increase in easterly winds might increase salt spray dominated habitats on the eastern side of the Island. Previous studies indicates that ongoing drying of the island will increase stem senescence and interact with wind patterns that will results in die back and degradation of cushions species (Le Roux, 2004; Le Roux et al., 2005). The assumption is that if climate change continues to bring about an increase in the shading of cushions at the island by rapid growing vascular species while slow growing *A. selago* is likely to be negatively affected (Le Roux, 2004).

The change in local climate of the island has both biological and geomorphological consequences. There has been a significant increase in the effect of invasive species on the local communities and species (Bergstrom and Chown 1999, Chown and smith 1993) whilst the increase in temperatures is responsible for the melting of the island's ice plateau (Sumner et al, 2004). Furthermore, clearly any decrease in the top predators on the island coupled with the expected decrease in rainfall resulting from global climate change will alter the delivery of nutrients from the terrestrial to the marine environment which will have a major implication on the island ecological system. For the past years heavy rainfall events have become a major source of meteorological disasters around the globe. Currently there is a relatively low forecast skill for heavy rain events which poses a serious challenge for scientific research and operational forecasting (Chyi et al., 2003). Some of the previous research has established links between heavy rainfall and a wide variety of synoptic features and parameters (Konrad II, 1997).

#### **1.4. Synoptic forcing of heavy rainfall**

Recent studies demonstrate that intensive rainfall can originate from deep convective clouds known as Cumulonimbus (Chappell 1998, Bathurst et al., 2011). However it has also been shown that synoptically forced systems produce extreme rainfall events (Maddox et al., 1979; Branick et al., 1988; Heideman and Fritsch 1988; Bradley and Smith 1994). Organized convective systems, with embedded severe weather and associated heavy rainfall, are often linked with frontal boundaries that help focus convection (Maddox et al., 1979). For instance at mid-latitudes the development of severe convective systems are mostly associated with synoptic forcing and with convective potential instability. In the eastern part of the United States, Heideman and Fritsch (1988) demonstrated that 80% of the synoptically forced events are produced through convection during the warm seasons. In addition, Schumacher and Johnson (2006) demonstrated that 93% of synoptic events were convective and only 25% of the heavy-rain events was primarily of synoptic forcing and normally occurred during the cool season in the eastern United States.

Studies on heavy rainfall events have previously recognized several patterns and mechanisms at the synoptic and mesoscale that are linked to the development of heavy rain. In addition, synoptic climatologically studies have shown suites of atmospheric features allied with intensive heavy rain events (Kunkel et al., 2003). According to Chappell (1998) convective cell develop and interact with one another on the mesoscale (10-100 km) in ways that can promote heavy rainfall. The interaction takes place at the scale of 100-1000 km where thermodynamics parameters such as temperature and moisture show high values. For instance, high values of perceptible water, instability and lower-tropospheric moisture are connected to heavy rain. In addition, heavy rainfall is related to large values of positive equivalent potential temperature and moisture advection in the lower troposphere. As such, interaction of synoptic systems such as cold front and upper level troughs with local topography often results in heavy rainfall

events that cause damage to the landscape (Chyi et al., 2003). Synoptic assessment plays a crucial role in linking time-patterns of precipitation with atmospheric circulations (Bathurst et al., 2011). The analysis of synoptic weather charts provide a better understanding of precipitation development mechanisms and their efficiency as well as the knowledge about time of a day when rainfall occurs or increases (Fujibe et al. 2005).

### **1.5. Marion Island synoptic weather conditions and rainfall events**

Although studies of synoptic assessment on extreme rainfall events are conducted worldwide, literature on synoptic climatology has mostly dealt with individual rainfall events, specific seasons or a limited number of years (Chappell, 1998). Characteristics of weather types and its relation to hourly rainfall are lacking worldwide. On Marion Island, no studies have been conducted in identifying synoptic patterns in relation to observed hourly rainfall events. Literature reveals that further studies is needed to investigate synoptically forced frontal extreme precipitation events in order to better forecast such occurrences and its implications (Fujibe et al., 2005). Hence the main objective in this research is to link intensive rainfall to the prevalent synoptic weather for the days that indicate highest hours of intensive rainfall. Furthermore an assessment of rainfall below certain thresholds will be assessed over time to investigate the possible changes and trends in rainfall patterns. Unfortunately, to obtain long-term data of hourly rainfall is a challenge and few studies on comprehensive hourly rainfall intensity data exist. Those that do exist are mostly after collecting data from analog media such as micro-films (IPCC, 2001). On Marion Island, observational evidence of long-term precipitation intensity has been limited to daily rainfall up to the 1990's.

## **1.6. Research Aim and Objectives**

### **1.6.1. Research Aim**

Few studies have been conducted on hourly rainfall intensity worldwide and on Marion Island there has never been a study on intensive hourly rainfall events which makes it difficult for scientist to predict future climatic change and its impact on the landscape. It is against this backdrop that this study seeks to assess synoptic weather charts and trend of rainfall intensity using data collected from 1995 to 2009 and attempt to predict future changes on rainfall climate and its associated impact on the landscape. Therefore, the main purpose of this research is to investigate the trend on intensive hourly rainfall at the island for the past two decades in relation to climate change and assess possible climate change implications.

### **1.6.2. Objectives**

To achieve the main purpose of this research, the study will also be guided by specific objectives that are divided in to four categories:

- Identifying intensive rainfall on Marion Island
- Investigating the trend from 1995-2009 of intensive rainfall
- Linking intensive rainfall to synoptic weather conditions
- Predicting future trends of intensive rainfall

## 1.7. Research questions

In order to address the above Objectives, research questions are formulated as follows:

Table 1: List of research questions

<b>Research objectives</b>	<b>Research questions</b>
To identify intensive rainfall by defining threshold for extreme events,	What is the highest repeated threshold in the four identified categories?
To investigating intensive rainfall trend (from 1995-2009 hourly data)	What is the temporal trend or characteristics of intensive rainfall events over Marion Island?
To identifying possible landscape and ecosystem responses to intensive rainfall	What are the possible changes on the landscape? How will the ecosystem respond to the intensive rainfall?
To link intensive rainfall to synoptic weather conditions	What is the relationship of synoptic weather systems and intensive rainfall?
To predict future trends of intensive rainfall	What could the future trend be of rainfall intensity in the island?

## CHAPTER TWO: LITERATURE REVIEW

### 2.1 A synoptic assessment of intensive rainfall

Rainfall events depend, among other factors, on the large scale atmospheric fields. Atmospheric circulation structures and knowledge of their main properties and links with surface variables are basic elements for diagnosis and forecasting (Winkler, 1988). The advantage of a synoptic assessment is that it provides a tool that could be introduced as a potential diagnostic and monitoring element to be incorporated in impact models necessary for planning of landscape activities and decision-making (Bettolli et al., 2010). In addition, a first step in estimating possible future climatic changes and their impacts, it is necessary to carefully determine the current rainfall variability basing on a careful scrutinising of the atmospheric circulations which form the main forcing factors for controlling variability. Scientist also suggests that atmospheric circulation analyses may give more robust indication of occurrence and change in extreme events (Winkler, 1988). In addition, studies on heavy rainfall have identified several patterns and mechanisms on the synoptic and meso-scale that are connected with or influence heavy rainfall development. Studies (e.g., Bosart and Carr 1978; Schwartz and Karl, 1990) have provided detailed information on the evolution of the storm environment during extremely heavy rainfall events in their respective case study analyses.

In order to understand the effects of intensive rainfall on the landscape it is important to link time-patterns of precipitation with atmospheric circulations (Bathurst et al., 2011). Synoptic weather charts, gives better understanding on precipitation development mechanisms and their efficiency in addition to the knowledge about time of a day in which rainfall occurs or increases. According to Doswell et al., (1996) atmospheric indicators associated with extreme precipitation producing damage on the landscape are derived from synoptic and mesoscale

processes. Hence an assessment of synoptic conditions leading to the formation of extreme precipitation events in other parts of the world has been conducted for the past years.

According to Vaghetti et al., (2008), major rainfall amounts occur in prefrontal conditions, this was demonstrated on a study about the favourable synoptic conditions to the occurrence of an intense rainfall situation in Pelotas (Brazil), in 2007. This was evident in the presence of a low pressure system over Argentina, with a trough extended over Rio Grande do Sul, wherein the divergence field showed convergence on the studied region, at the 925 hPa level. Bairy and Teixeira, (2009) investigate the synoptic conditions favourable to the occurrence of extreme precipitation in Southern Brazil. Many favourable aspects were found, as mass convergence in lower tropospheric levels, heat and moist transport from the Amazon region and the Atlantic Ocean. The advance of a low pressure region on surface and a trough in the middle troposphere advecting negative vorticity over the region. This condition presents significant relationship between the synoptic scale and mesoscale in the formation and development of extreme rainfall events.

In Pakistan, Muhammad et al., (2009) conducted a diagnostic study of intensive rainfall in the central part of the country. Results suggest that heavy rainfall events over the study area were under the influence of two synoptic scale weather systems and a mesoscale low. The approach of a monsoon depression and westerly wave were the synoptic scale systems. While the presence of mesoscale low slightly northeast of the study area and an intensified ridge penetrating from the northeast up to west of the study area enhanced the moisture accumulation and holding in atmosphere during the day time. In Southern Brazil, Bairy and Teixeira., (2009) analysed the main flow patterns over the three days before intense rainfall events. The results show that atmospheric phenomenon played a major role in the event. The most relevant features were the following: deepening of a mid-tropospheric trough by the west

of Southern Pacific on the three days before the event; a low pressure centre over northern Argentina one day before; Low Level Jet from the north over Paraguay two days before and strong moisture convergence over the southern Brazil one day before the event. A study on intense rainfall events over the west coast of the Indian peninsula show that, during the summer monsoon, copious rainfall occurs over the west coast of the Indian peninsula (Peterson et al., 2002). On occasions, the rainfall is exceptionally heavy, exceeding 20cm per day at some stations. These intense rainfall events are attributed to meso-scale systems which are generally embedded in synoptic or larger scale convective systems over the Arabian Sea. It is believed that these intense rainfall events are often associated with offshore troughs.

Changes in rainfall are typically harder to detect due to its greater variability, both in time and space. Even so, changing rainfall patterns have been detected for many parts of the globe (Solomon et al., 2007). Most of the regional studies that have been done in other parts of the world shows trends for increasing length of dry season and increase in average rainfall intensity associated with global climate change (Goswami et al., 2006). Other studies indicate that precipitation amount have generally increased over the past years in some parts of the world and the increase is primarily due to increase in the number of low intensity (small to moderate) events. For example, regional studies that are done in Canada indicate a general increased over the most parts of the country due to increase in the number of small to moderate events with no identifiable trend in extreme precipitation events (Bettolli et al., 2010).

The European Union examined changes in precipitation between the control period, 1961–1990, and the predicted 2070–2099 period, using climate models, HadCM3 and HadRM3. According to these climate models, it is projected that in most of Europe intense precipitation will increase, even over vast areas where decrease of mean precipitation is expected (Kharin and Zwiers., 2000). This prediction supports the findings of Christensen and Christensen

(2003) that used another regional climate model (HIRHAM4) and concluded that the amount of summer precipitation exceeding the 95th percentile is very likely to grow in many areas of Europe, even if the mean summer precipitation may decrease over a substantial part of the European continent. In addition, in Siberia they also found cases of increasing rainfall intensity while the total precipitation decreased (Semenov and Bengtsson, 2002).

In the Hawaiian Islands, Chyi et al., (2003) studied extremes precipitation events under changing climate and one of their main objectives was to assess the trends of intensive rainfall and projection of future heavy rainfall events using historical data 1905 and 2009. Their results revealed that between 1950s and 2007, Kauai and Maui islands experienced downward trends in rainfall intensity (rainfall become less intense), however the bigger island Hawaii experienced upward trends in rainfall intensity (more intense rainfall). According to Kunkel et al., (1999) intensive rainfall from 1931 to 1996 in the United States indicated an increasing trend at a rate of 3% per decade with no significant trend during 1951–1993 in Canada. In addition, Kunkel et al., (2003) reported a sizeable increase in the frequency of extreme precipitation events since the 1920s/1930s in the U.S.

In the Alpine region of Switzerland (Frei and Schär , 2005) discovers an increase in the frequency of intensive rainfall during 1901-1994 .While in the central India from 1951 to 2000 Goswami et al., (2006) found a significant increasing trend in both the frequency and the magnitude of intensive rainfall events. In addition, Alexander et al., (2006) also noted a general increase in the precipitation indices at a global scale. For example, Frich et al. (2002) using global daily station data their results indicate an increase in the number of warm summer nights, a decrease in the annual number of frost days, and a significant increase in the total wet day rainfall. While Jones et al. (2004) reported significant increase in precipitation trends

over the twentieth century in winter for both average precipitation intensity and moderately strong events in central and Western Europe.

Globally, larger changes in extreme precipitation relative to changes in mean precipitation are shown. Using a multimodel analysis, Tebaldi et al., (2005) analysed global average time series of extremes and found that the simulated increases in precipitation intensity during the twentieth century continue through the twenty-first century. On the other hand, in all scenarios, the dry periods between precipitation events display a somewhat weaker and less consistent increasing trend. The above scenarios have important implications for the seasonality of the future rainfall intensity and together it may suggest a short but more intensive rainfall seasons that will have implication on the landscape.

## **2.2. Global view on the effects of intensive rainfall and future implications**

Scientific studies suggest a significant future increase in intensive rainfall events in many regions, including regions in which the mean rainfall is projected to decrease (IPCC, 2001). Increases in the frequency and severity of rainfall are projected to adversely affect the landscape and it will further affect the physical, chemical and biological properties of soil with predominantly adverse impacts on vegetation (Easterling et al., 2000). Changes in precipitation and temperature lead to changes in runoff and water availability. Runoff is projected with high confidence to increase by 10 to 40% by mid-century at higher latitudes and in some wet tropical areas, including populous areas in East and South-East Asia, and decrease by 10 to 30% over some dry regions at mid-latitudes and dry tropics, due to decreases in rainfall and higher rates of evapotranspiration (IPCC, 2001). Areas in which runoff is projected to decline face a reduction in the value of ecological services provided by water resources. Previous research indicates that the beneficial impacts of increased annual runoff in some areas are likely to be tempered by negative effects of increased precipitation

variability and seasonal runoff shifts on water supply. According to the IPCC (2001), more intense precipitation events which are very likely to occur in the future would lead to multiple adverse consequences, such as; increased flood, landslide, avalanche, and mudslide damage; increased soil erosion; increased pressure on government and private flood insurance systems and disaster relief.

The amount of soil detached, as well as other key processes in water erosion is related to rainfall intensity (Nel and Sumner, 2007). Burnett and McNicoll (2000) in Italy found out that increase rainfall intensity with the decrease in total rain fall has strong implication for the natural climate of the region. Srikantha and Ritnayake (2004) reported that although high intensity rainfall can occurs within a short period of rainy season it will cause more land degradation and flash floods. Degradation of the landscape especially through soil erosion and change in land cover is dependent on the relative magnitude of rainfall intensities compare to other rainfall physical characteristic. The conventional wisdom has been to assume that surface roughness increases the resistance of soil to detachment by raindrop impact, reduces the flow velocity and erosive power of runoff (Srikantha and Ritnayake, 2004). On the other hand, on rough surfaces the potential for scouring action, headcut development and rilling increases with an increase in rainfall intensity.

Just like many other regions of the world, studies on intensive rainfall on Marion Island do not exist. It is against this backdrop that this study seeks to investigate trend of rainfall intensity using data collected from 1995 to 2009 and try to understand the effects of intensive rainfall on the landscape and make predictions on the future landscape/rainfall interactions.

### CHAPTER THREE: RESEARCH METHODOLOGY

This chapter discuss the various methods and procedures used in data collection and data analysis. In order to achieve the aim and objective of this research, secondary data from the South African Weather Services were the main source of information.

Hourly rainfall data, and synoptic charts for Marion Island (1995-2009) were obtained from the South African Weather Service for the meteorological station on the eastern side of Marion Island. However, since the quality of the digitalized data is not always perfect, the record does have some missing data. The hourly rainfall data ( $I_{60}$ ) was divided into five different intensity categories (thresholds) to derive a temporal trend of rainfall intensity and identify the highest recurrence of rainfall intensity. The five categories are: 0 mm; 01 mm -1.99 mm; 2 mm-4.99 mm; 5 mm-9.99 mm as well as 10 mm and above.

The rainfall intensity distribution graphs was drawn based on the above mention five intensity groups. In addition, in order to analyse the average rainfall quantity in the range of categories the threshold will be defined as follows:

- 0 mm – hours of zero rainfall
- 0,1 mm – 1,99 mm, low intensive rainfall
- 2 mm – 4,99 mm, moderate intensive rainfall
- 5 mm – 9,99 mm, high intensive rainfall
- 10 mm and above, extreme event

Category one is considered as hours with no rainfall. The second category is considered as low intensity rainfall hours and the third category is considered as moderate rainfall per hour. The fourth category is considered as the high intensity rainfall hours while category five is considered as extreme rainfall per hour. In order to link intensive rainfall to synoptic weather

conditions, the highest reoccurrence of intensive rainfall at the extreme category (10 mm and above) was identified and synoptic weather charts for that day was analysed. The parameters to be assessed to assist with the synoptic assessment of heavy rainfall include atmospheric pressure, air temperature and wind direction as well as wind speed. Time series analysis as well as linear regression statistics were employed to see if any of the trends are significant at the 95% confidence level. From these assessments the literature was perused to investigate the possible future climate change and relationship with intense rainfall its impact on the landscape.

## CHAPTER FOUR: RESULTS

### 4.1 Temporal trend of hourly rainfall intensity

The temporal trend of the intensity of hourly rainfall ( $I_{60}$ ) was analysed. The analysis was based on the five categories that have been defined.

Table 2: Frequency of annual hourly rainfall for each category at Marion Island

Year	Annual Rainfall (mm)	0 mm	0.1-1.99 mm	2-4.99 mm	5- 9.99 mm	10 mm and above
1995	1913.6	7164	1294	240	60	3
1996	1924.6	7096	1387	246	47	8
1997	2403.6	7032	1342	290	88	10
1998	2017.6	7007	1423	271	52	5
1999	1737.2	7104	1371	249	34	2
2000	1843.6	6400	1369	245	43	7
2001	1513.1	6047	1014	182	45	8
2002	2116.4	6257	1416	283	49	10
2003	2141.6	6922	1509	271	53	8
2005	1594.4	4897	1158	206	39	3
2006	2250.2	6922	1460	312	60	6
2007	2002.2	7085	1360	261	45	9
2008	2011.4	7155	1297	261	64	7
2009	1824.6	7169	1305	223	57	7
<b>Mean</b>	<b>1949.6</b>	<b>6732.6</b>	<b>1336.1</b>	<b>252.9</b>	<b>52.6</b>	<b>6.6</b>
<b>Stdev</b>	<b>242.3</b>	<b>642.2</b>	<b>125.4</b>	<b>33.9</b>	<b>13.3</b>	<b>2.6</b>
<b>CV (%)</b>	<b>12.4</b>	<b>9.5</b>	<b>9.4</b>	<b>13.4</b>	<b>25.3</b>	<b>38.5</b>
<b>Linear regression</b>	<b>r</b>	<b>0.05</b>	<b>0.12</b>	<b>0.05</b>	<b>0.02</b>	<b>0.09</b>
	<b>P</b>	<b>0.86</b>	<b>0.67</b>	<b>0.87</b>	<b>0.95</b>	<b>0.77</b>
<b>Correlation with rainfall amount</b>	<b>R</b>	<b>0.52</b>	<b>0.73</b>	<b>0.93</b>	<b>0.73</b>	<b>0.48</b>
	<b>P</b>	<b>0.06</b>	<b>&lt;0.01</b>	<b>&lt;0.01</b>	<b>&lt;0.01</b>	<b>0.8</b>

Table 2 shows the frequency of the annual hourly rainfall received for each category (1995 to 2009) as well as the total amount of rainfall received annually. Table 2 also present the mean and standard deviation for each category as well as the Coefficient of Variation (CV) as a percentage. The linear trend over time is given with the level of significance. Also through the Pearson Product Moment Correlation Coefficient the correlation ( $r$ ) between each of the categories and the annual rainfall is also given. For further analyses the temporal trend for

each category was graphed and the graphs in Figure 2. For all categories the annual frequency of hourly rainfall for each category shows no statistically significant increase or decrease over the recording period (Table 2).

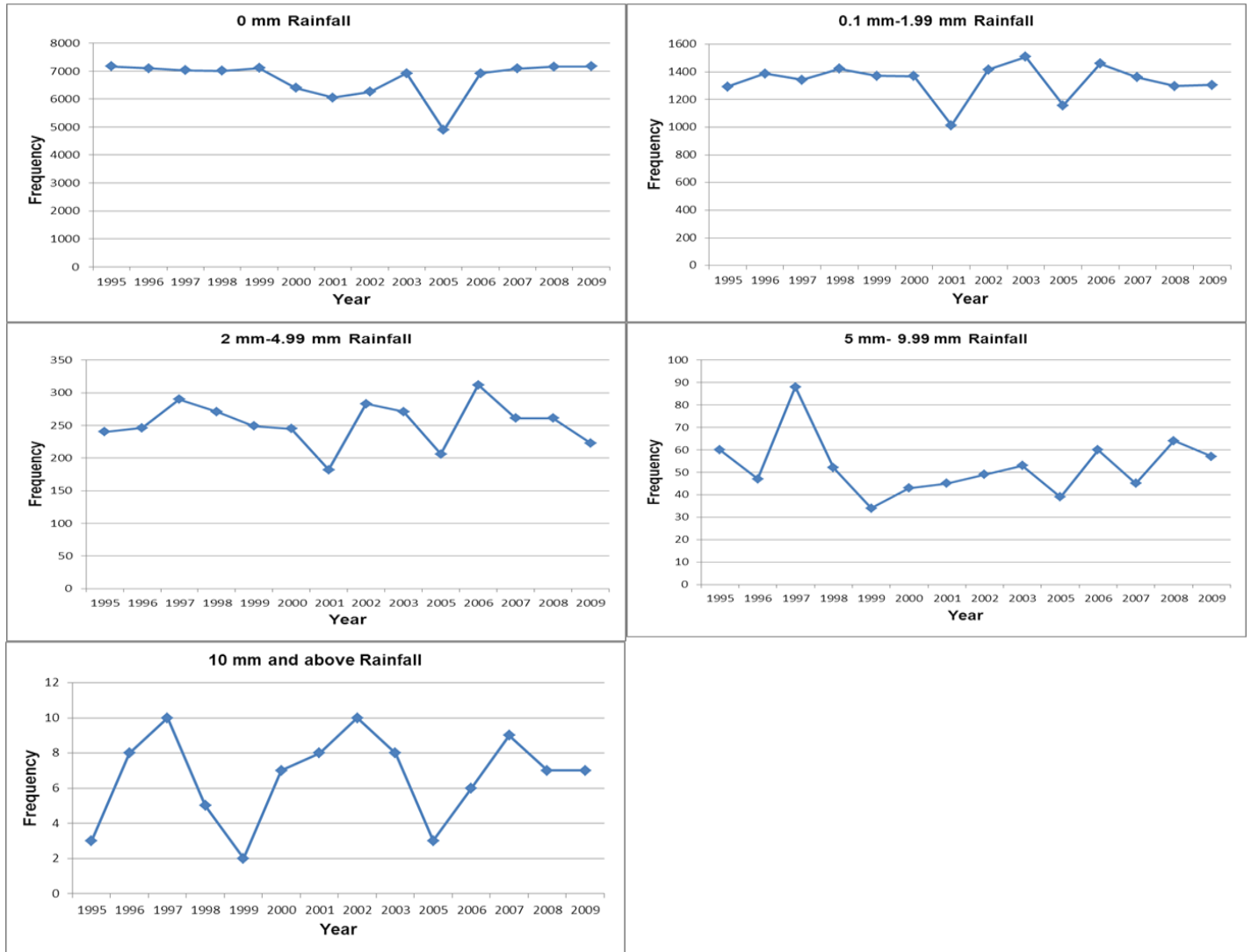


Figure 2: Annual frequency of hourly rainfall of the five categories (1995-2009)

From Table 2 it can be seen that mean rainfall for Marion Island over the recording period was 1949.6 mm. Also no linear trend in annual rainfall is seen with a very low  $r$  coefficient of 0.05 (Table 2; Fig. 2). Inter-annual rainfall variability over the recording period was very low with a CV of only 12.4%. For category one (0 mm of rainfall) the frequency of hours with no rainfall for the recording period shows no linear temporal trend ( $r=0.05$ ;  $P=0.86$ ). The annual frequency is closely represented by the mean (6732.6 mm). Furthermore the CV is low (9.5%)

showing very little temporal variability (Table 2). From the Pearson Correlation it can be seen that this category of no rainfall is poorly correlated with amount of rainfall received ( $r=0.52$ ;  $P=0.06$ ) (Table 2). From Figure 3 it is clear that the amount of hours of no rainfall is very closely represented by the mean and that the frequency is not related to amount of rainfall.

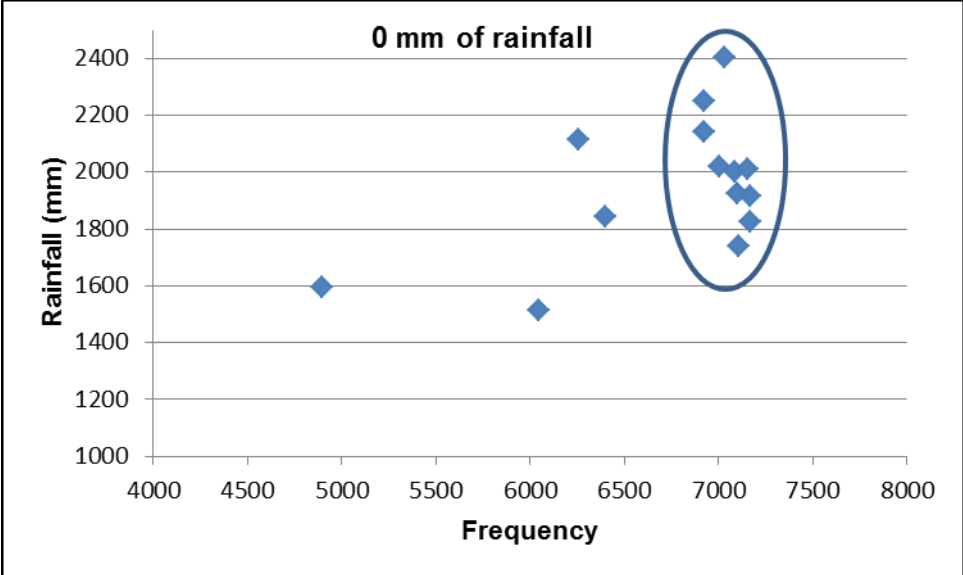


Figure 3: Frequency of 0 mm of rainfall against annual rainfall total

For hourly rainfall between 0.1 mm- 1.99 mm no linear trend over the recording period is discerned ( $r=0.15$ ;  $P=0.87$ ) (Table 2; Fig. 2). As with category one, the annual frequency is closely represented by the mean and inter-annual temporal variability is low with a CV of only 9.4%. However from the Pearson Correlation it can be seen that this category of hourly rainfall is statistically significantly correlated with amount of rainfall received ( $r=0.73$ ;  $P<0.01$ ) (Table 2).

For the frequency of hourly rainfall between 2 mm-4.99 mm again no linear trend over the recording period is discerned ( $r=0.05$ ;  $P=0.87$ ) (Table 2; Fig. 2). However inter-annual temporal variability as described by the CV is higher than the previous categories (13.4 %).

Furthermore, from the Pearson Correlation it can be seen that this category of hourly rainfall is statistically significantly and strongly correlated with amount of rainfall received ( $r=0.93$ ;  $P<0.01$ ) (Table 2). This indicates that the bulk of annual rainfall received on Marion Island is from hourly rainfall between 2 and 4.99 mm.

Hourly rainfall received between 5 mm- 9.99 mm again shows no linear trend over the recording period (Table 2; Fig. 2). However inter-annual temporal variability as described by the CV is again higher than the previous categories (25.3 %). Also from the Pearson Correlation it can be seen that this category of hourly rainfall is statistically significantly correlated with amount of annual rainfall received ( $r=0.73$ ;  $P<0.01$ ) (Table 2).

Extreme intensive hourly rainfall events (10mm and above) also show no linear temporal trend over the recording period. However from Figure 2 and Table 2 it can be seen that the trend is highly variable (CV = 38.5%) and show a quasi-oscillation of approximately 5 years. Intensive hourly rainfall is poorly correlated with annual rainfall amount. Given that none of the categories show an annual linear temporal trend over time the hourly rainfall was analysed for each month. For functionality each category has therefore been divided into months and each category is presented in 6 months increments (Jan-Jun and Jul-Dec).

#### **4.1.1 No rainfall**

All months indicate different temporal trends over time for this category. However the most significant changes in hours with no rainfall occurred during the month of January and April (Figs 4 and 5). Hours with no rainfall increased during January ( $R^2=0.1$ ) for the recording period and with the increasing trend being observed also during December and February. This show a significant increase of hours with no rainfall during most of the summer period. Conversely, the same is true for the winter months of June and July. Both these months show a significant increase in hours with no rainfall. However the increase in hours with no rainfall during summer and winter is offset by the decrease in hours with no rainfall observed during April, March and May (Fig. 4) and September and October (Fig. 5).

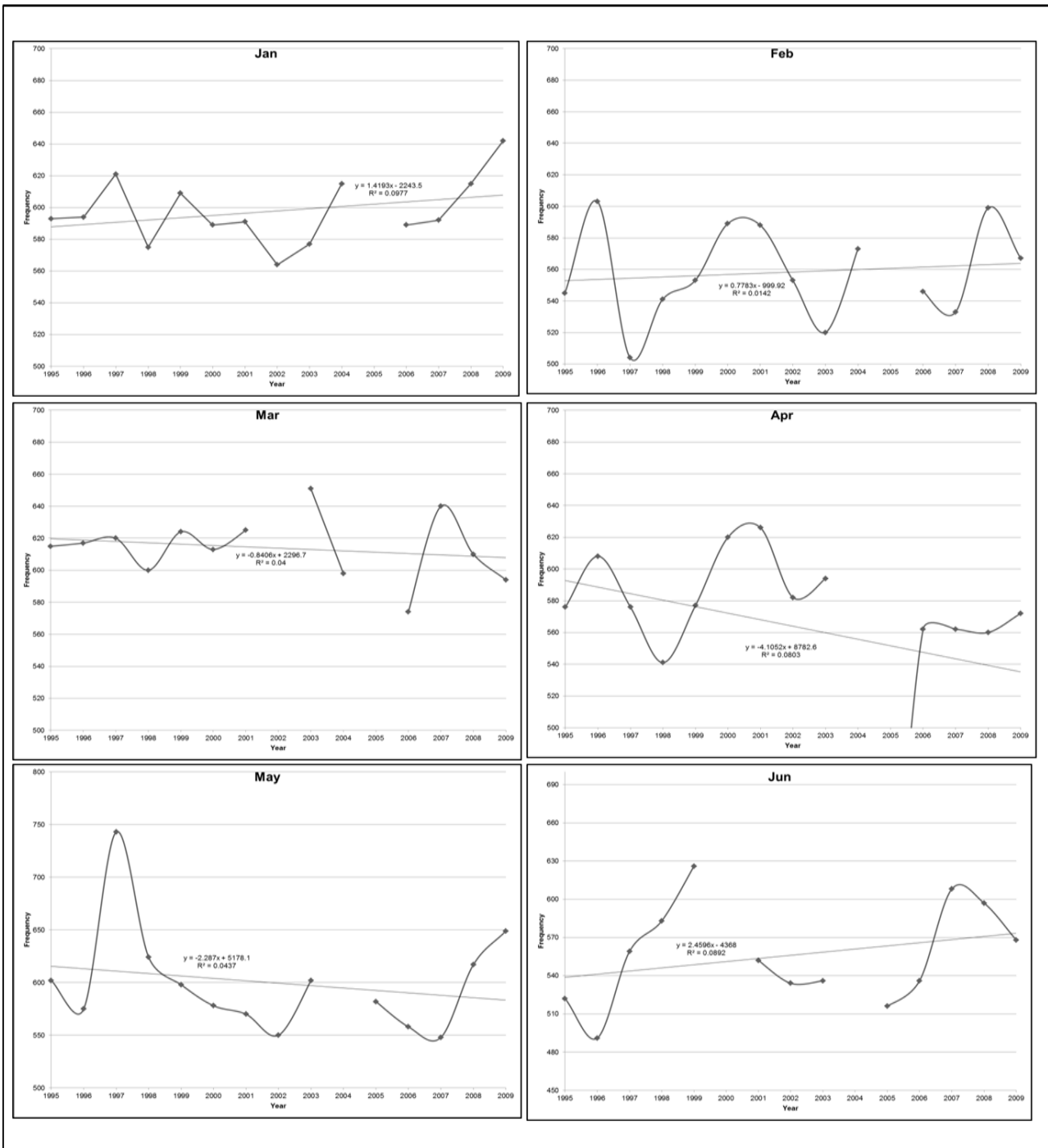


Figure 4: Frequency of hourly rainfall of 0 mm (January to June)

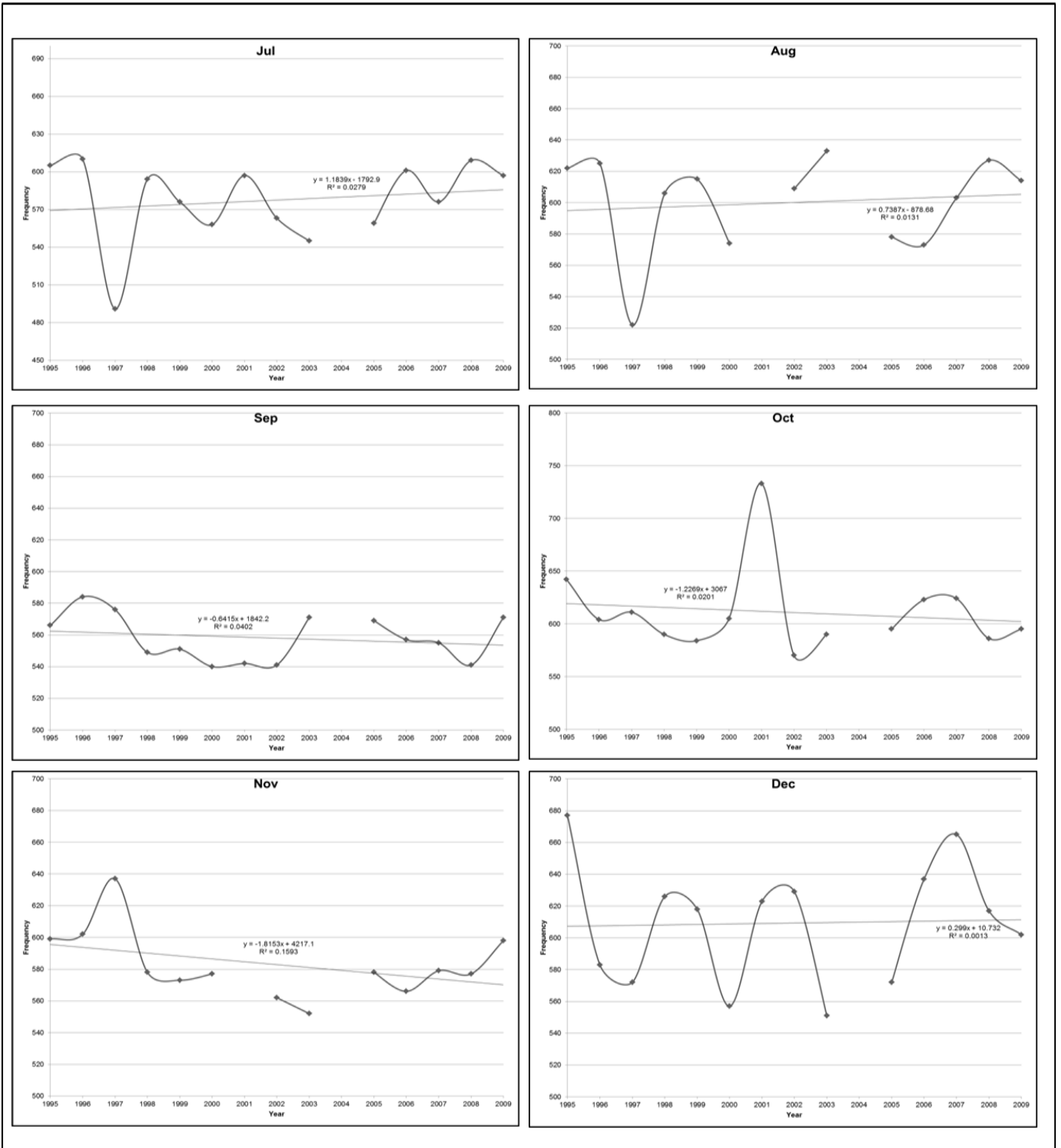


Figure 5: Frequency of hourly rainfall of 0mm (July to December)

### 4.1.2 Low intensity rainfall

Figure 6 and 7 show the monthly frequency of hourly rainfall of between 0.1 mm and 1.99 mm. Results indicate that December, January, February and March all show a decreasing trend over time. This decrease in low intensity rainfall during these months is offset by an increase in rainfall within this category during April and May and September and October. The winter months also show a decreasing trend of low intensity rainfall.

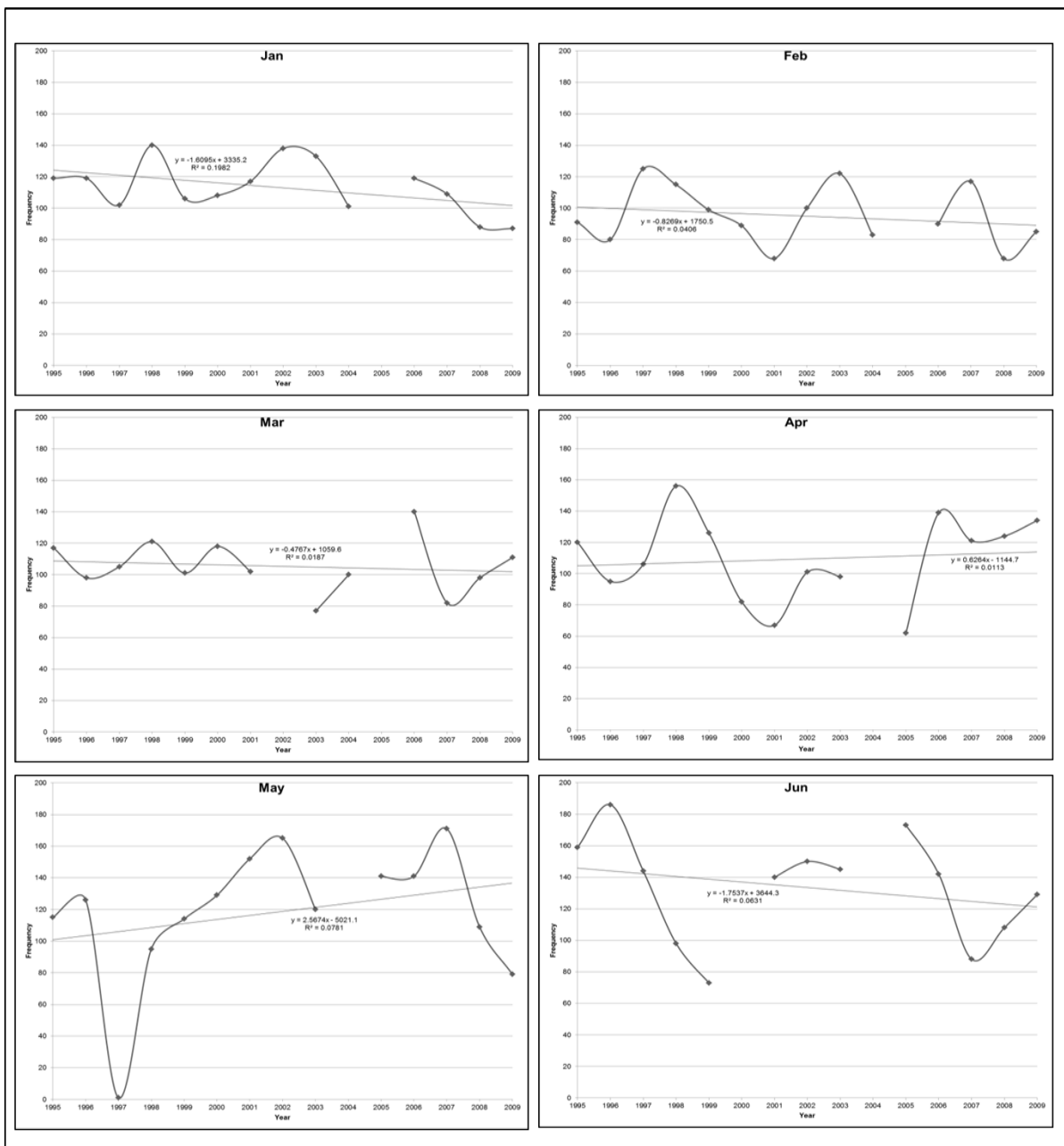


Figure 6: Frequency of hourly rainfall of between 0.1 mm and 1.99 mm (January to June)

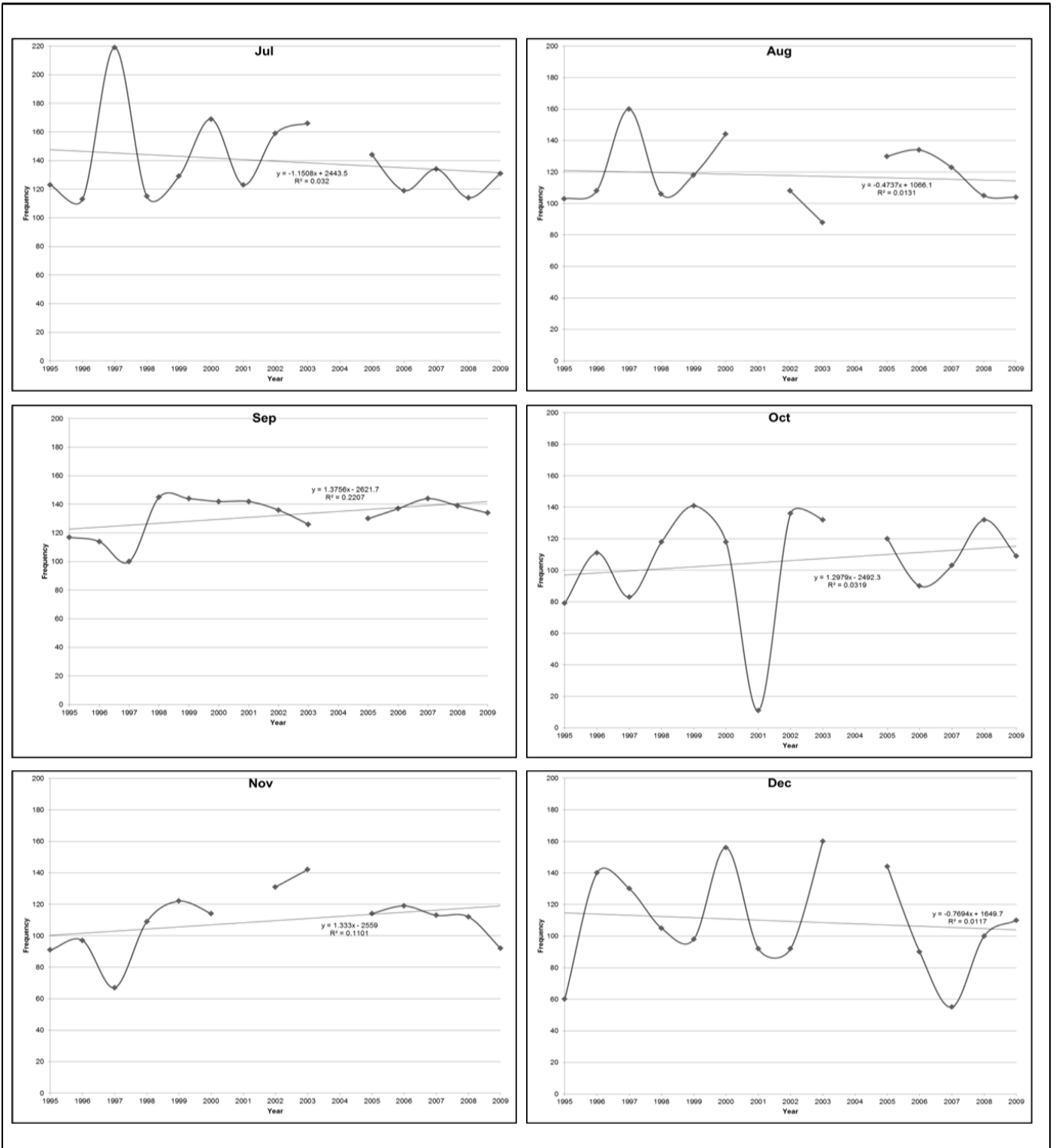


Figure 7: Frequency of hourly rainfall of between 0.1 mm and 1.99 mm (July to December)

### 4.1.3 Moderate rainfall intensity

The months of November, December, January and February all show an increase in hours with rainfall between 2 and 4.99mm (Figs. 8 and 9). This increase in hourly rainfall is offset by the decrease observed during the months of May, June and September.

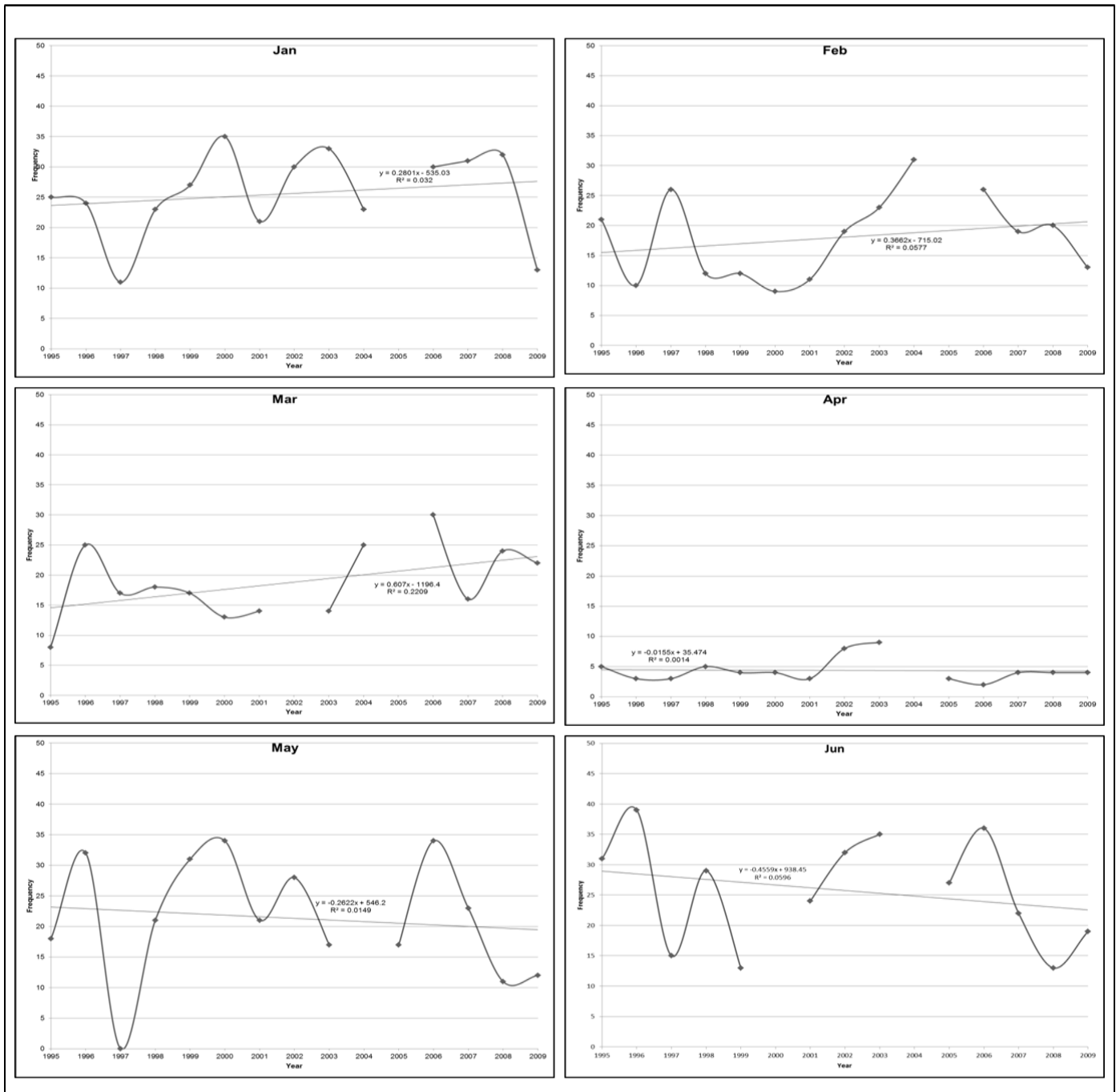


Figure 8: Frequency of hourly rainfall of between 2.0 mm and 4.99 mm (January to June)

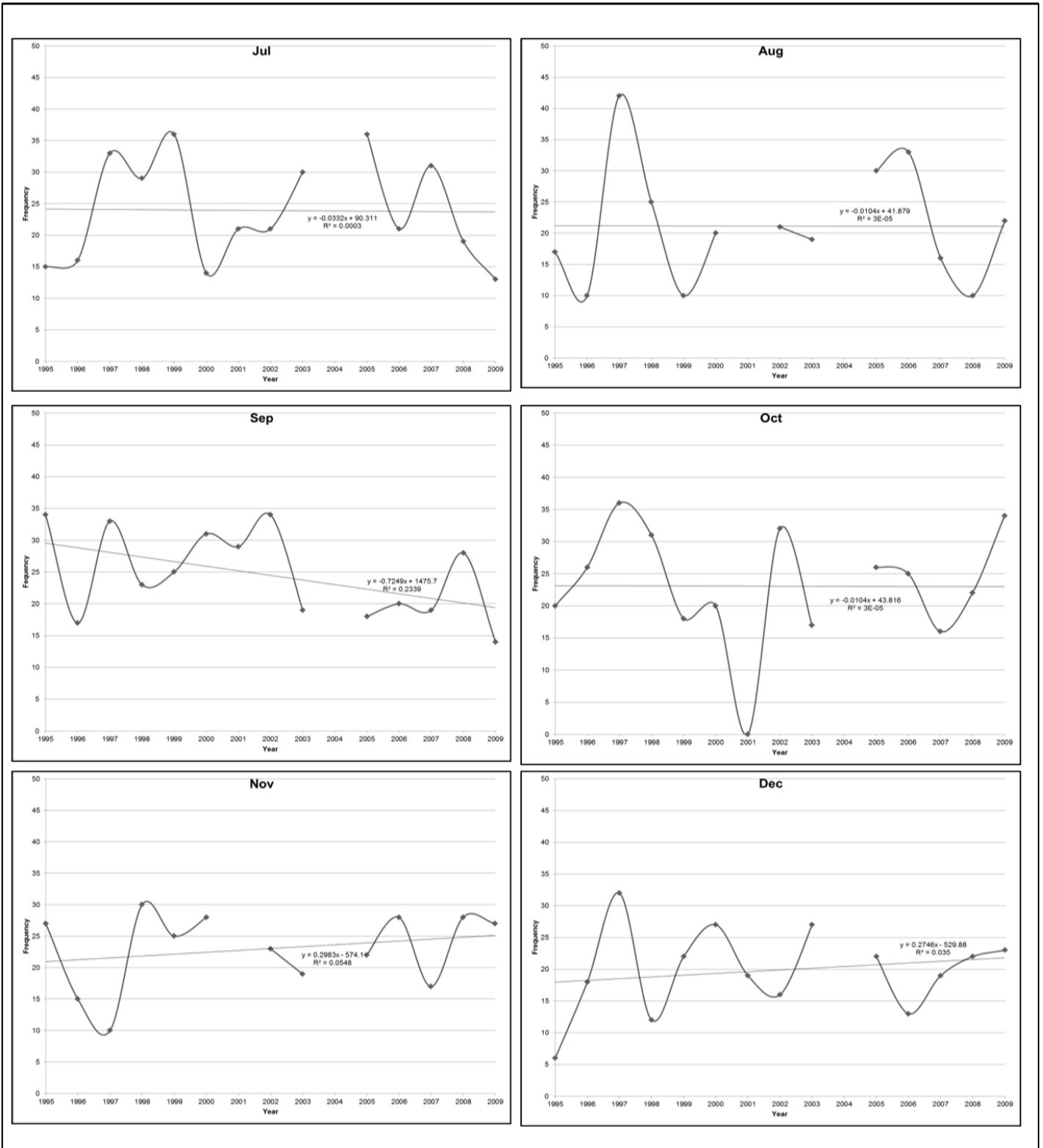


Figure 9: Frequency of hourly rainfall of between 2.0 mm and 4.99 mm (July to December)

#### 4.1.4 High rainfall intensity

Figures 10 and 11 show the frequency of hourly rainfall of between 5 mm- 9.99 mm. Rainfall events of 5 mm-5.99 mm per hour fall under category three and based on the defined threshold they are regarded as heavy rainfall events. November and December show an increase in high rainfall events measured, but the frequency is low. It can be seen that during June hourly high rainfall events decreased.

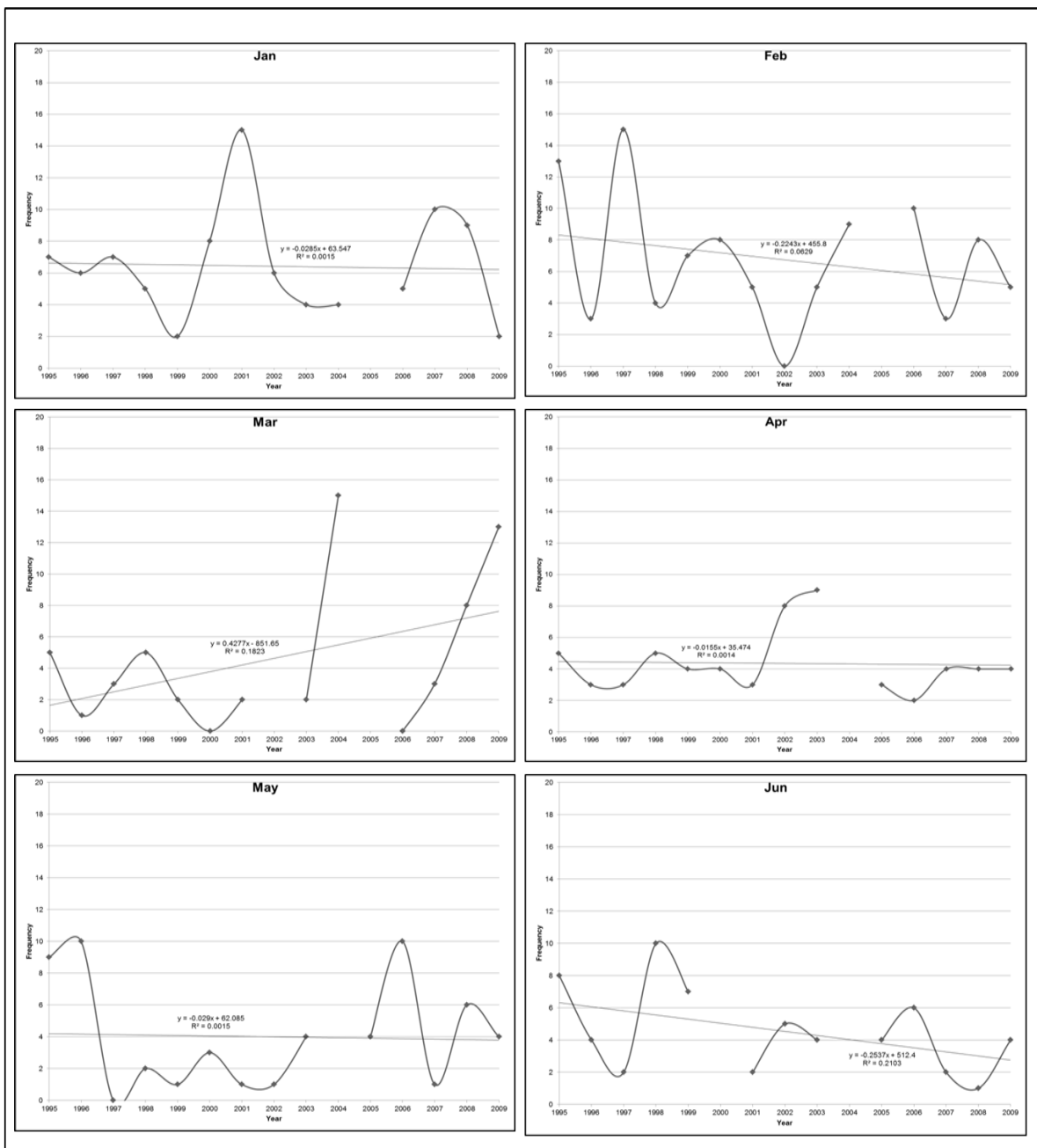


Figure 10: Frequency of hourly rainfall of between 5 mm- 9.99 mm (January to June)

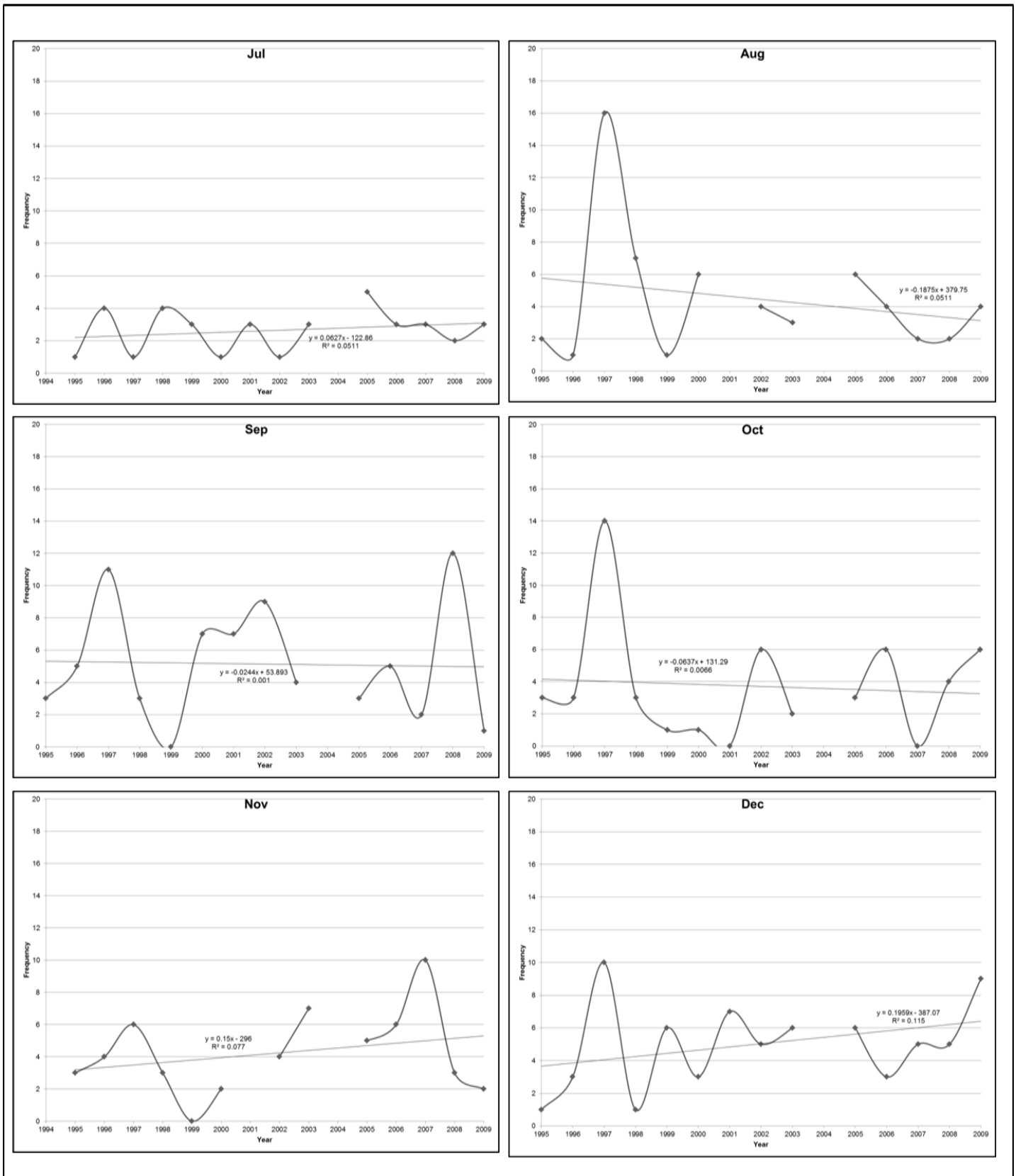


Figure 11: Frequency of hourly rainfall of between 5 mm- 9.99 mm (July to December)

#### **4.1.5 Severe rainfall intensity**

Figures 12 and 13 show the frequency of hourly rainfall of 10 mm and above and this category is regarded as severe rainfall intensity. It can be seen that January has the highest frequency of intensive rainfall events and it shows an overall decreasing trend. The other months have a very low frequency of high intensity events especially in winter (June and July)

The data indicate the following days that the island received the highest amount of hourly rainfall. On January the 12<sup>th</sup> 2002, hour 1 (17, 8 mm) and hour 23 (with 17.8 mm). January the 18<sup>th</sup>, 2002, hour 19 (11.4 mm) and January 2002 the 30<sup>th</sup>, hour 24 (10.2 mm) and hour 1 (10.8 mm) and hour 2 (10.4 mm). In total January 2002 had 6 events of hourly rainfall exceeding 10 mm threshold with the maximum of 17,8 mm. From the available data, 17,8mm rainfall per hour is considered to be the highest rainfall event recorded between 1995 and 2009. These dates were analysed further to investigate the synoptic conditions associated with extreme rainfall events on Marion Island.

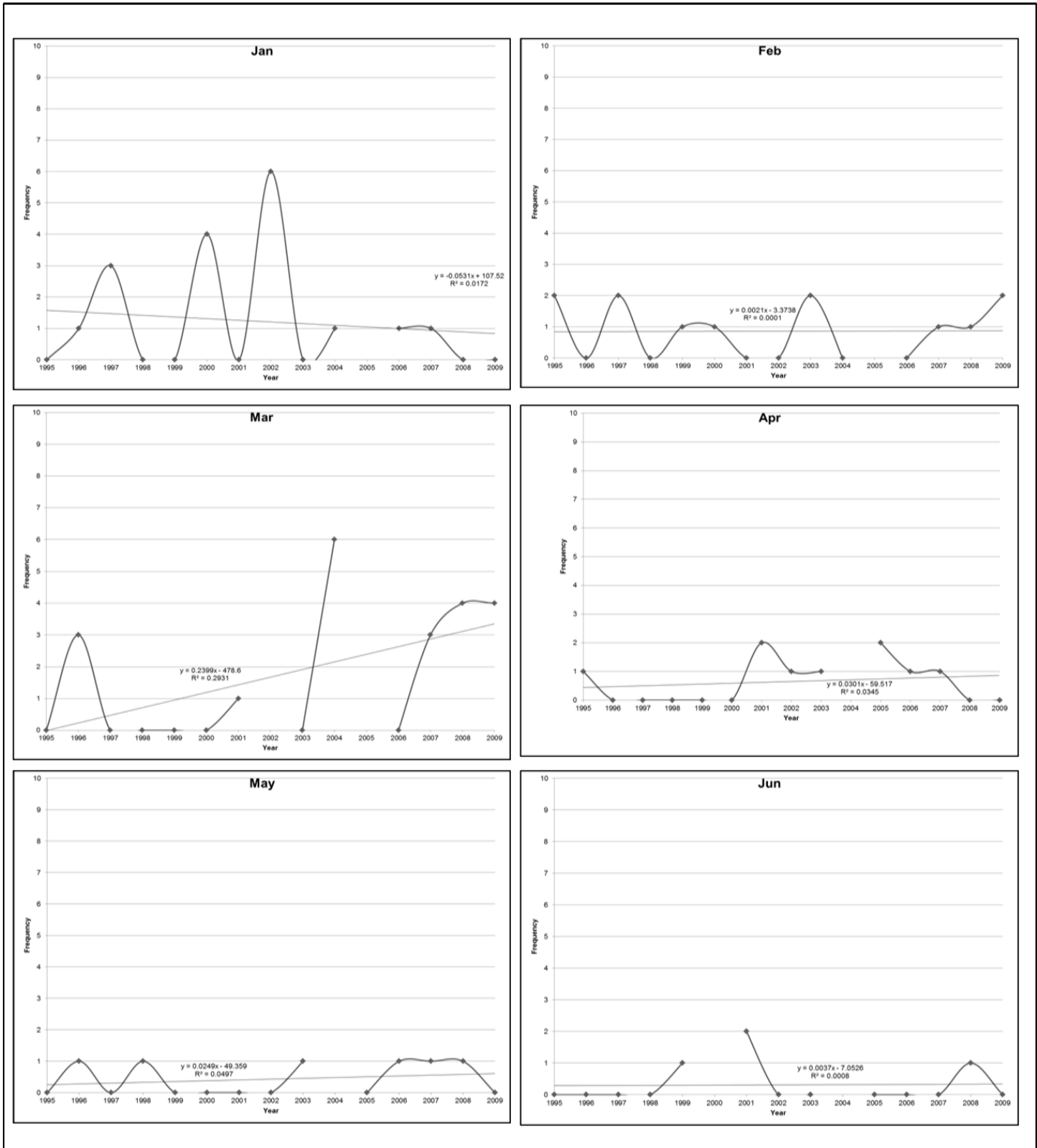


Figure 12: Frequency of hourly rainfall of 10 mm and above (January to June)

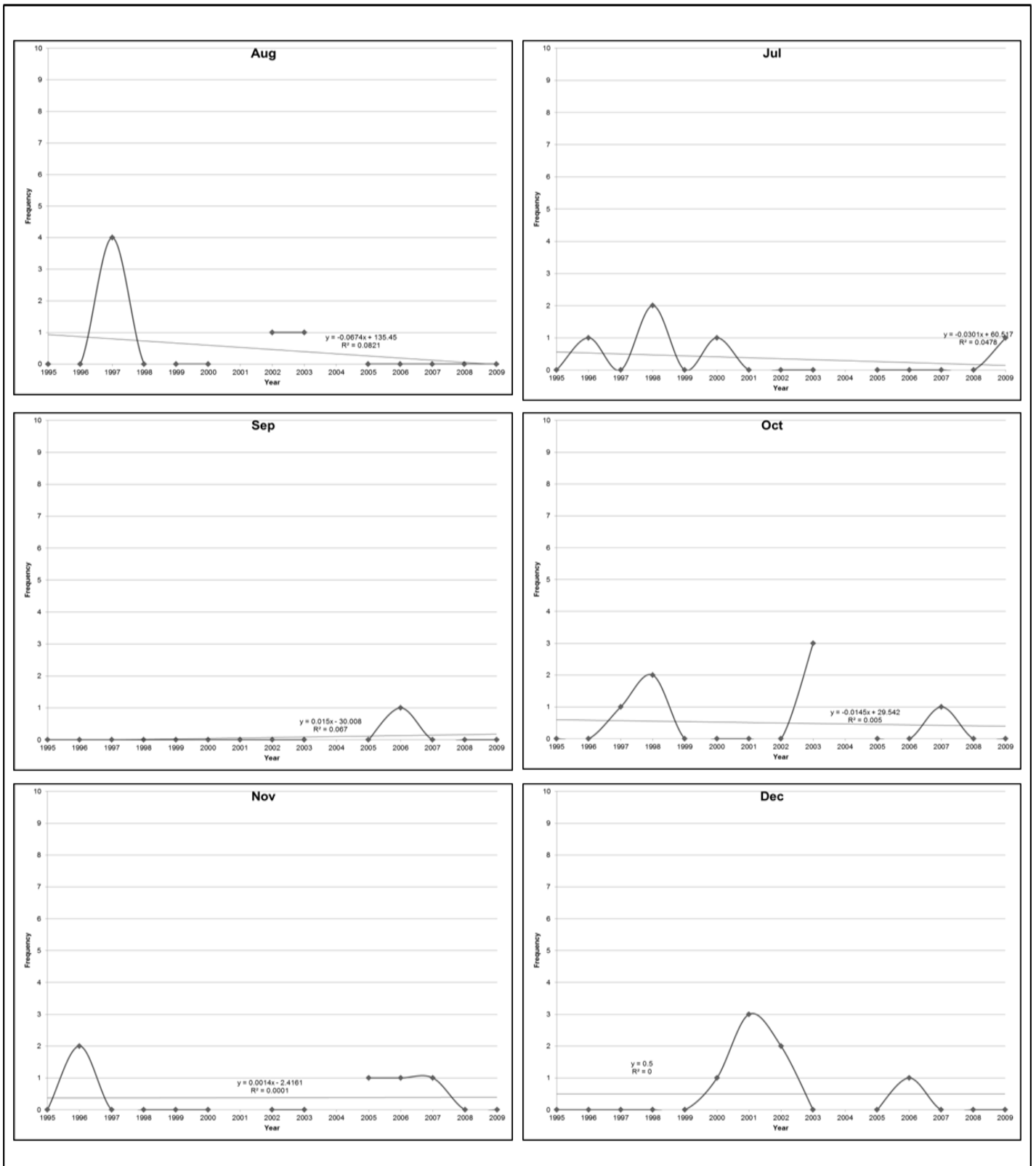


Figure 13: Frequency of hourly rainfall of 10 mm and above (July to December)

## 4.2 Linking Intensive rainfall to synoptic weather

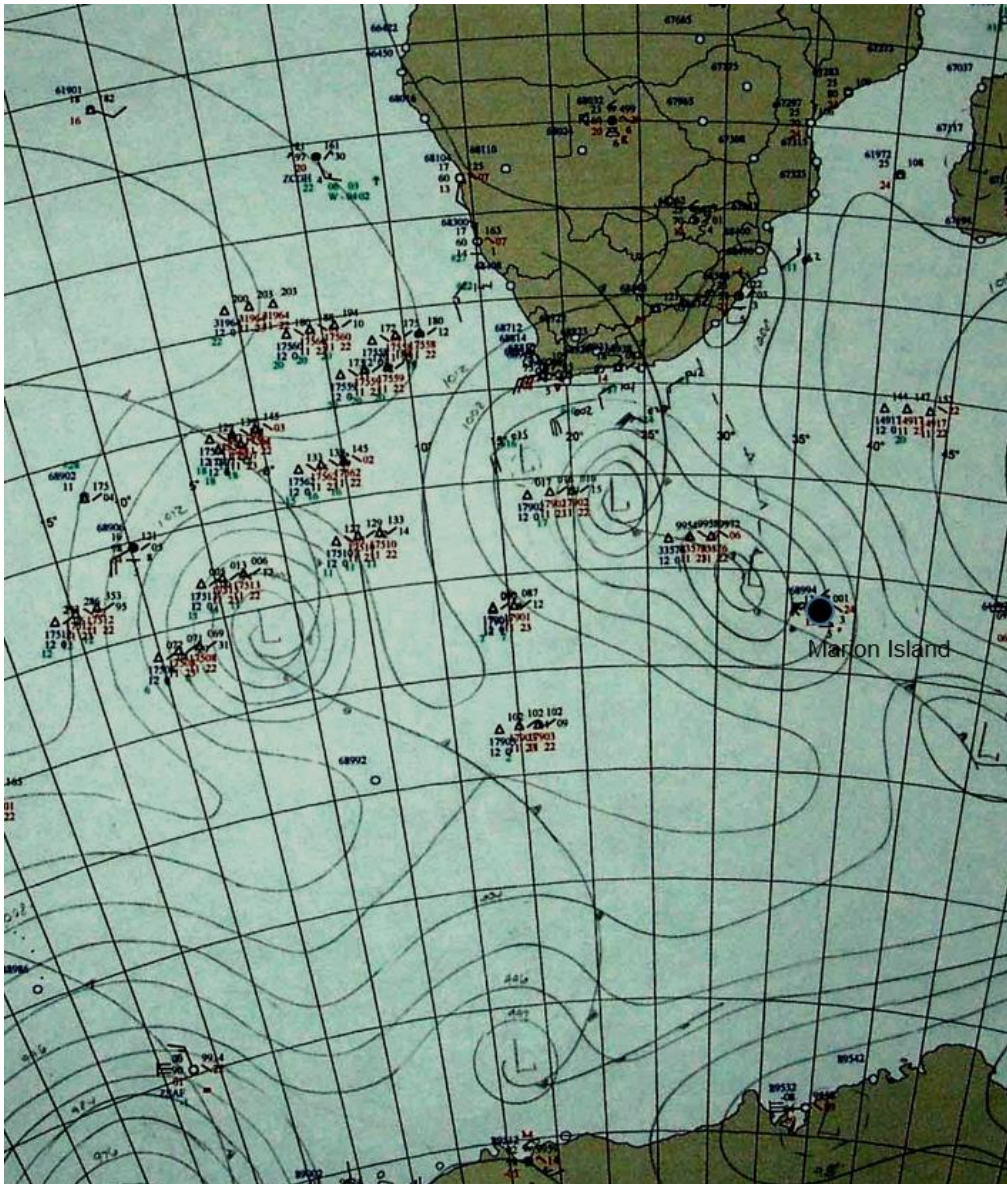


Figure 14: Synoptic shipping chart for the 12<sup>th</sup> January 2002 at 0 hours SAST.

From the synoptic chart drawn on the 12<sup>th</sup> of January 2002 for 0 hour SAST it can be seen that Marion Island is affected by a strong cut-off low pressure system over Marion Island extending meridionally in a north-westerly direction. Mean air pressure is 994hPa and the meridional

component in the dominant airflow explains the high humidity and suggests the potential to bring in a northerly maritime tropical air from lower latitudes west of the Island.



Figure 15: Synoptic shipping chart for the 18th January 2002 at 12 hours SAST.

From the synoptic chart drawn on the 18th of January 2002 for 12:00 SAST it can be seen that a similar situation exist as on the 12<sup>th</sup> with Marion Island being affected by a low pressure

system over and north of the island extending meridionally in a north-westerly direction with a following cold front. This system was also deemed a cut-off low pressure system and again the meridional component in the dominant airflow explains near 100% humidity and brought in northerly maritime tropical air from lower latitudes north-east of the island.

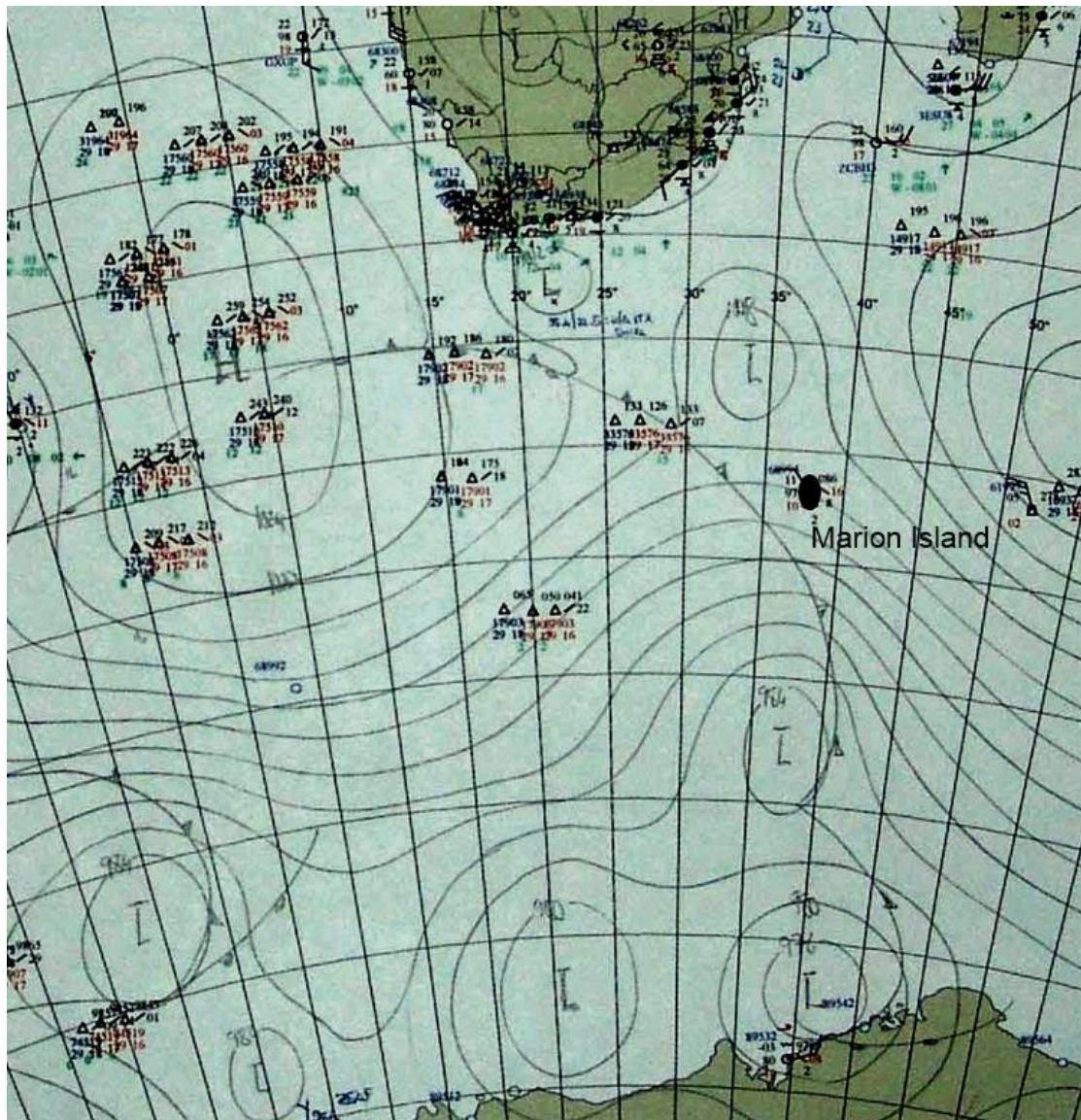


Figure 16: Synoptic shipping chart for the 29th January 2002 at 18 hours SAST.

Since the high hourly rainfall events occurred in the early hours of the 30<sup>th</sup> of January 2002, the shipping chart for the 29<sup>th</sup> was studied to ascertain the synoptic condition that existed. Again Marion is under a low pressure system with its centre north of Marion with a following cold front extending from a mid-latitudinal depression south of the island. This system was not

as strong as those on the 12 and 18<sup>th</sup> hence the rainfall was less. However, the meridional component in the dominant airflow again explains the high rainfall with the advection of maritime tropical air from the north.

## CHAPTER FIVE: DISCUSSION

From the data it was unexpected that for all categories the annual frequency of hourly rainfall shows no statistically significant increase or decrease over the recording period. Furthermore annual rainfall also shows no significant change. Furthermore, the inter-annual rainfall variability over the recording period was very low with a CV of only 12.4%. This is in contrast to long-term change over the last forty years where the climate of Marion Island has changed significantly. Records from the meteorological station on the eastern side of Marion Island show a marked increase in sunshine hours, pressure and temperature, together with a reduction in rainfall (Smith, 2002; Rouault et al., 2005). Smith (2002) also reports an increase in air temperature of 1.2°C recorded between 1969 and 1999 which is more than twice the mean global rate of temperature increase for the same period (le Roux, 2008). It has been suggested that under a changing climate, Marion Island experiences less cloud cover and more direct sunlight (Smith, 2002). The lack of change over the last 15 years may indicate a stabilisation with regards to annual rainfall. However, even though the frequency of hours with no rainfall for the recording period shows no linear temporal trend and that the annual frequency is closely represented by the mean significant changes in hours with no rainfall occurred during the summer months (increase). This concurs with long-term trends where Rouault et al. (2005) suggested that the pressure increase in summer measured on Marion Island corresponds to a decrease in rainfall and an increase in the number of days without precipitation.

As expected, the data indicate that as hourly rainfall for each category increase so does the inter-annual variability as well. Furthermore, a strong correlation exists with regards to annual rainfall and categories 0.1mm to 1.99mm, 2mm to 4.99mm and 5mm to 9.99mm. The bulk of annual rainfall comes from hourly rainfall in the category 2mm to 4.99mm. The data indicate that summer rainfall in this category increase over the last decade.

Extreme intensive hourly rainfall events (10mm and above) also show no linear temporal trend over the recording period and inter-annual rainfall is highly variable. Intensive hourly rainfall is poorly correlated with annual rainfall amount but from the limited data it does seem that a quasi-oscillation of approximately 5 years exists with regards to the frequency of extreme hourly rainfall. From the synoptic charts it seems that intense hourly rainfall is associated with a strong cut-off low pressure system over Marion Island extending meridionally in a north-westerly direction sometimes with a following cold front. Mean air pressure is low and the meridional component in the dominant airflow explains the high humidity and suggests the potential to bring in a northerly maritime tropical air from lower latitudes west or north-east of the island.

### **Climate change implications**

The climate of Marion Island has changed significantly over the last forty years with a marked increase in sunshine hours, pressure and temperature, together with a reduction in rainfall (Smith, 2002; Rouault et al., 2005). The current changes in the climate of Marion Island are driven by changes in the synoptic weather systems (Smith and Steenkamp, 1990; Rouault et al., 2005; le Roux, 2008). Smith and Steenkamp (1990) propose that the observed radiation and air temperature increases on Marion Island can be explained by the relative positions of cyclone tracks. In warmer years the cyclonic centres pass, on average, further to the south of the island (Smith and Steenkamp, 1990). The island could then experience longer periods subjected to the north-westerly winds of the warmer sector of the cyclones and less exposure to the cold south-westerly winds of the post-cold front sector (Smith and Steenkamp, 1990). Rouault et al. (2005) attributed the air pressure increase in summer measured on Marion Island with the observed changes in rainfall and a northward shift in the wind direction. This could imply either a reduction in low pressures affecting the island in summer or relatively more anticyclonic conditions prevailing (Rouault et al., 2005). If current climate trends do persist on

Marion Island, moisture availability could decline due to lower precipitation and higher temperatures driving faster evaporations according to le Roux (2008). A further southward shift in southern polar jet stream and the Antarctic Circumpolar current is also predicted; this will result in weakening atmospheric circulation on Marion Island. Numbers of cyclonic activity is due to decrease by 30% by 2100 (e.g. le Roux, 2008) and anti-cyclonic circulations is due to increase.

However, there are chances that Marion Island could actually become cooler and wetter again due to Antarctic warming with associated strengthening of westerly winds and weaker northerly winds (Le Roux, 2008). Le Roux (2008) admits that the outcome will depend on the balance of relative effects of warming temperatures, declining cyclone abundance, and changing storm tracks. Climate change implications for hourly rainfall on Marion Island therefore show various opposing trends. A decrease in low pressure systems and increase in anticyclonic conditions will increase the number of hours without rainfall (as seen from the data) especially in summer. A further decrease in the number of intensive hourly rainfall events could also be seen. However, the data from the last decade presented here do show a possible stabilisation in rainfall and that hourly rainfall between 2mm and 4.99mm increased during the summer months.

## CHAPTER SIX: CONCLUSION

To investigation of the trends in rainfall intensity hourly rainfall data from the South African Weather Service for the meteorological station on the eastern side of Marion Island was assessed (1995-2009). The hourly rainfall data ( $I_{60}$ ) was divided into five different intensity categories (thresholds) to derive a temporal trend of rainfall intensity and identify the highest recurrence of rainfall intensity. The five categories developed are: 0 mm; 01 mm -1.99 mm; 2 mm-4.99 mm; 5 mm-9.99 mm as well as 10 mm and above.

Several key findings are presented from the assessment of the temporal trend of rainfall intensity across all five categories:

- For all categories the annual frequency of hourly rainfall shows no statistically significant increase or decrease over the recording period.
- Annual rainfall also shows no significant change. Furthermore the inter-annual rainfall variability over the recording period was very low. This is in contrast to the long-term change over the last forty years where the climate of Marion Island was noted to have changed significantly.
- The lack of change over the last 15 years may indicate a stability with regards to annual rainfall. However, even though the frequency of hours with no rainfall for the recording period shows no linear temporal trend and that the annual frequency is closely represented by the mean. However, significant increase in hours with no rainfall occurred during the summer months. Contrastingly, the data from the last decade presented here do show that hourly rainfall between 2mm and 4.99mm (which is the bulk of annual rainfall) increased during the summer months.

- Extreme intensive hourly rainfall events show no linear temporal trend over the recording period and inter-annual rainfall is highly variable. Intensive hourly rainfall is poorly correlated with annual rainfall amount and a quasi-oscillation of approximately 5 years seems to exist.
- High intense hourly rainfall is associated with a strong cut-off low pressure system over Marion Island extending meridionally in a north-westerly direction. Sometimes followed by a cold front. Mean air pressure is low and the meridional component in the dominant airflow explains the high humidity and suggests the potential to bring in a northerly maritime tropical air from lower latitudes west or north-east of the island.
- Climate change implications for hourly rainfall on Marion Island show various opposing trends. A decrease in low pressure systems and increase in anticyclonic conditions will increase the number of hours without rainfall (as seen from the data) especially in summer. A further implication is that the number of intensive hourly rainfall events could also decrease. However the possibility exist that Marion Island is becoming wetter and the data indicate that hourly rainfall over the last decade show an increase during the summer months. Further research is needed to ascertain the current rainfall trends on Marion Island.

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