

**A METEOROLOGICAL ANALYSIS OF EXTREME FLOOD EVENTS IN  
THE SOUTHERN PARTS OF THE EASTERN CAPE, SOUTH AFRICA**

A thesis submitted in fulfilment of the requirements for the degree of

MASTER OF SCIENCE

AT

RHODES UNIVERSITY

By

TENNIELLE LINDSAY JACOBS

April 2017

## **Abstract**

Extreme flood events have been found to occur in the Eastern Cape Province of South Africa. The southern and south-eastern coastal regions are particularly susceptible to floods with daily rainfall records of up to 490 mm having been recorded here. In order to gain a better understanding of these floods, historical floods in the southern parts of the Eastern Cape have been analysed in this study. This study aimed to investigate the most extreme flood events in the history of the area and to analyse the surface observational data during the heavy rainfall events found, to contribute to the understanding of these heavy rainfall events. Seven case studies were investigated using NCEP/NCAR Reanalysis 1 data and surface observational data, to analysis the synoptic circulation and surface data tendencies during heavy rainfall events. All of the case studies that had synoptic data available showed to have a COL system present with the upper air low lying westward of the flood area. The surface synoptic situation presented an intense high pressure system lying south west or south of the country in the Atlantic Ocean between 35-45°S. Another key factor was a surface trough over the interior of the country, due to the COL, extending southwards to protrude off of the south or south eastern coastline east of the flood areas. The combination of these three systems colloquially referred to as a “Black South-Easter”, produced dangerous rainfall intensities when the winds were perpendicular to the coast.

The results of the surface observations revealed temperatures increasing at night (against diurnal cycles) with increasing relative humidity preceding the heavy rainfall events. The pressure showed both increasing and decreasing trends during heavy rainfall events however in five of six cases a tight pressure gradient was present producing an influx of moist air into the flood area. Onshore winds were found to be of high importance in heavy rainfall events to bring moist air into the area. Wind speeds greater than 5m/s occurred during times of high rainfall intensities.

## **Declaration**

The author hereby declares that this study is not plagiarised and is the researchers own work unless otherwise stated. This is in accordance with the plagiarism policy of Rhodes University. The work submitted here has not been submitted at any other university.

# Table of Contents

<b>ABSTRACT</b> .....	<b>I</b>
<b>DECLARATION</b> .....	<b>II</b>
<b>TABLE OF CONTENTS</b> .....	<b>III</b>
<b>LIST OF TABLES</b> .....	<b>VI</b>
<b>LIST OF FIGURES</b> .....	<b>VII</b>
<b>ACKNOWLEDGEMENTS</b> .....	<b>XI</b>
<b>ACRONYMS AND TERMS</b> .....	<b>XII</b>
<b>CHAPTER 1 GENERAL INTRODUCTION</b> .....	<b>1</b>
1.1. INTRODUCTION .....	1
1.2. OVERVIEW OF THE STUDY AREA .....	1
1.3. MOTIVATION AND AIM .....	3
1.4. OBJECTIVES AND RESEARCH QUESTIONS .....	4
1.5. RESEARCH OUTLINE .....	5
<b>CHAPTER 2 LITERATURE REVIEW</b> .....	<b>6</b>
2.1. INTRODUCTION .....	6
2.2. DEFINING FLOODS AND RISK .....	6
2.2.1. <i>Floods</i> .....	6
2.2.2. <i>Hazard, Vulnerability and Risk</i> .....	7
2.3. FLOOD PRODUCING WEATHER SYSTEMS IN SOUTH AFRICA .....	8
2.3.1. <i>Tropical weather systems</i> .....	8
2.3.2. <i>Mid-latitude systems</i> .....	9
2.3.3. <i>Cut-Off low systems</i> .....	9
2.4. CUT-OFF LOWS AS FLOOD PRODUCING SYSTEMS IN THE STUDY AREA .....	11
2.4.1. <i>COL's within the study area</i> .....	11
2.4.2. <i>COL's with a ridging high pressure system at the surface</i> .....	12
2.5. RISK REDUCTION APPROACH TO DISASTER MANAGEMENT .....	13
2.6. METHODOLOGY REVIEW .....	15
2.6.1. <i>Statistical and standardized methods</i> .....	15
2.6.2. <i>Flood risk assessment</i> .....	16
2.7. CONCLUSION .....	17
<b>CHAPTER 3 STUDY AREA</b> .....	<b>18</b>
3.1. INTRODUCTION .....	18
3.2. THE STUDY AREA .....	18
3.2.1 <i>Factors that determined the selection of the study area</i> .....	18
3.2.1.1 Factor 1: Climate variability .....	18
3.2.1.2 Factor 2: Population distribution .....	19
3.2.1.3 Factor 3: Water management areas .....	19
3.2.2. <i>Rainfall and climate of the study area</i> .....	21
3.2.3. <i>Rivers within the study area</i> .....	22

3.2.4.	<i>Topography of the study area</i> .....	23
3.3.	CONCLUSION.....	24
<b>CHAPTER 4</b>	<b>METHODS</b> .....	<b>25</b>
4.1	INTRODUCTION.....	25
4.2	OBJECTIVE 1: IDENTIFY EXTREME HISTORICAL FLOOD EVENTS .....	25
4.2.1	<i>Introduction</i> .....	25
4.2.2	<i>Caelum</i> .....	25
4.2.3	<i>Rainfall data</i> .....	26
4.2.3.1	Rainfall data collection .....	26
4.2.3.2	Data quality control and troubleshooting .....	27
4.3	OBJECTIVE 2: CONDUCT AN ANALYSIS OF SURFACE OBSERVATIONAL DATA FROM HEAVY RAINFALL EVENTS. ....	29
4.3.1	<i>Introduction</i> .....	29
4.3.2	<i>Daily weather bulletins</i> .....	30
4.3.3	<i>NCEP/NCAR reanalysis data</i> .....	30
4.3.4	<i>Surface observational data</i> .....	31
4.4.	CONCLUSION.....	32
<b>CHAPTER 5</b>	<b>RESULTS AND DISCUSSION</b> .....	<b>33</b>
5.1	INTRODUCTION.....	33
5.2	RAINFALL DATA RESULTS .....	33
5.3	CASE STUDIES.....	35
5.3.1.	<i>Case 1: East London 24-28 August 1970</i> .....	35
5.3.1.1	Case Overview.....	35
5.3.1.2.	Systems Analysis .....	36
5.3.1.3	Meteorological parameters analysis.....	44
5.2.1.4	Case discussion .....	53
5.3.2.	<i>Case 2: Port Elizabeth 01 September 1968</i> .....	54
5.3.2.1	Case overview .....	54
5.3.2.2	Systems analysis.....	54
5.3.2.3	Meteorological parameters analysis.....	59
5.3.2.4	Case Discussion .....	65
5.3.3.	<i>Case 3: East London 15-16 August 2002</i> .....	66
5.3.3.1	Case overview .....	66
5.3.3.2	Systems Analysis .....	66
5.3.3.3	Meteorological parameters analysis.....	71
5.3.3.4	Case Discussion .....	76
5.3.4.	<i>Case 4: Port Elizabeth 24-26 March 1981</i> .....	76
5.3.4.1	Case overview .....	76
5.3.4.2	Systems analysis.....	76
5.3.4.3	Meteorological parameters analysis.....	81
5.3.4.4	Case Discussion .....	86
5.3.5.	<i>Case 5: East London 05-07 November 2005</i> .....	87
5.3.5.1	Case overview .....	87
5.3.5.2	Systems analysis.....	87
5.3.5.3	Meteorological parameters analysis.....	92
5.3.5.4	Case Discussion .....	97
5.3.6.	<i>Case 6: Gamtoos/Sunday's River 28-31 December 1931 – 01 January 1932</i> .....	98

5.3.6.1	Case overview .....	98
5.3.6.2	Synoptic Analysis.....	98
5.3.6.3	Meteorological parameters analysis.....	98
5.3.6.4	Case Discussion .....	101
5.3.7.	<i>Case 7: Patensie/ Port Elizabeth 24-27 July 1983</i> .....	101
5.3.7.1	Case overview .....	101
5.3.7.2	Synoptic analysis .....	102
5.3.7.3	Meteorological parameters analysis.....	108
5.3.7.4	Case Discussion .....	114
5.4.	DISCUSSION OF CASE STUDY RESULTS .....	115
5.4.1.	<i>Summary of case study results</i> .....	115
5.4.2.	<i>Discussion</i> .....	117
5.5.	CONCLUSION.....	120
<b>CHAPTER 6</b>	<b>CONCLUSIONS AND RECOMMENDATIONS.....</b>	<b>122</b>
6.1.	POSSIBLE CAVEATS .....	122
6.2.	CONCLUSIONS .....	123
6.3.	RECOMMENDATIONS .....	125
<b>APPENDICES.....</b>		<b>127</b>
APPENDIX 1 .....		127
APPENDIX 2 .....		127
APPENDIX 3 .....		128
APPENDIX 4 .....		128
APPENDIX 5 .....		129
<b>REFERENCES.....</b>		<b>130</b>

## List of Tables

Table 1.1: Research Matrix .....	4
Table 4.1: Wind descriptors (Adapted from the Beaufort scale) .....	32
Table 5.1: Top five flood events with the highest twenty-four-hour rainfall amounts in descending order. 34	
Table 5.2: Top five flood events with the highest event rainfall amounts in descending order of rainfall amounts. Dates marked with an asterisk also appear in Table 5.1. ....	34
Table 5.3: Daily rainfall amounts in millimetres at stations around East London for 24-28 August 1970 ..	44
Table 5.4: Wind direction and wind speed at Cape St Francis for 28 December 1931 to 01 January 1932 .....	99
Table 5.5: Daily rainfall amounts recorded at Port Elizabeth VRT station. ....	100
Table 5.6: Rainfall measured in millimetres at stations between Patensie and Port Elizabeth for 24-27 July 1983. ....	108

## List of Figures

Figure 1.1: Map of South Africa with the Eastern Cape Province, the area of interest, highlighted in purple. ....	2
Figure 1.2: The Agulhas current is shown along the east coast of South Africa. Source: Lutjeharms and Ansorge (2001). ....	2
Figure 2.1: An example of a westerly trough (left) and a cut-off low (right) with thicker lines representing the geopotential heights at 500hPa and thinner lines the isobars at mean sea level (hPa) over the oceans and contours of the 850hPa surface (gpm) over the land. Dotted lines are areas receiving precipitation. Source: Tyson and Preston-Whyte, (2000:196). ....	10
Figure 2.2: A schematic representation of the circulation associated with a cut-off low at the 500hPa and near-surface levels (Tyson and Preston-Whyte, 2000:197). ....	10
Figure 3.1: Mean Annual Precipitation over South Africa. Source: Schulze (1997:32) .....	19
Figure 3.2: Drainage regions of South Africa, Source: Department of Water Affairs (2017). ....	20
Figure 3.3: The Eastern Cape Province with the study area highlighted. ....	21
Figure 3.4: Rivers in the study area. ....	23
Figure 3.5: Topographical map of South Africa with elevation in metres. Mountain ranges of interest are: 1. Cape Fold Mountains, 2. Groot-winterhoek Mountains, 3. Amatola Mountains Source: Modified from Mapsof.net (2017). ....	24
Figure 4.1: Rainfall stations within the study area. ....	26
Figure 5.1: The five-day rainfall accumulation in East London on 24-28 August 1970. Source: Adamson (1981:25). ....	36
Figure 5.2: Synoptic chart of mean sea level pressure (hPa) at 00Z on 24 August 1970. ....	37
Figure 5.3: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 24 August 1970. ....	37
Figure 5.4: Synoptic chart of mean sea level pressure (hPa) at 00Z on 25 August 1970. ....	38
Figure 5.5 Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 25 August 1970. ....	39
Figure 5.6: Synoptic chart of mean sea level pressure (hPa) at 00Z on 26 August 1970. ....	40
Figure 5.7: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 26 August 1970. ....	40
Figure 5.8: Synoptic chart of mean sea level pressure (hPa) at 00Z on 27 August 1970. ....	41
Figure 5.9: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 27 August 1970. ....	42
Figure 5.10: Synoptic chart of mean sea level pressure (hPa) at 00Z on 28 August 1970. ....	43
Figure 5.11: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 27 August 1970. ....	43
Figure 5.12: Pressure at East London WK for 24-28 August 1970. ....	47
Figure 5.13: Temperature for 24-28 August 1970 at East London WK. ....	48
Figure 5.14: Relative humidity at East London WK for 24-28 August 1970. ....	48
Figure 5.15: Wind direction at East London WK for the 24-28 August 1970. ....	49
Figure 5.16: Wind speed at East London WK for 24-28 August 1970. ....	49

Figure 5.17: The autographic rainfall chart at B.J Schoeman Airport in East London for 27 August 1970. Source: Hayward and van den Berg (1970:130). .....	50
Figure 5.18: Daily Rainfall at East London WK for 24-28 August 1970. ....	51
Figure 5.19: Hourly rainfall intensity at East London WK for 24-28 August 1970.....	53
Figure 5.20: Synoptic chart of mean sea level pressure (hPa) at 18Z on 31 August 1968. ....	55
Figure 5.21: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 18:00Z on 31 August 1968. ....	55
Figure 5.22: Synoptic chart of mean sea level pressure (hPa) at 00Z on 1 September 1968. ....	56
Figure 5.23: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 1 September 1968.....	57
Figure 5.24: Synoptic chart of mean sea level pressure (hPa) at 00Z on 2 September 1968.....	58
Figure 5.25: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 1 September 1968.....	58
Figure 5.26: Pressure at Port Elizabeth WK for 31 August – 2 September 1968.....	60
Figure 5.27: Temperature at Port Elizabeth WK for 31 August – 2 September 1968.....	61
Figure 5.28: Relative Humidity at Port Elizabeth WK for 31 August – 2 September 1968. ....	61
Figure 5.29: Wind direction at Port Elizabeth WK for 31 August – 2 September 1968. ....	62
Figure 5.30: Wind Speed at Port Elizabeth WK for 31 August – 2 September 1968.....	62
Figure 5.31: Daily Rainfall at Port Elizabeth WK for 1 September 1968. ....	64
Figure 5.32: Hourly Rainfall Intensity at Port Elizabeth WK for 1 September 1968.....	64
Figure 5.33: Rainfall Intensity between 08:00 and 12:00SAST at Port Elizabeth WK on 1 September 1968. ....	65
Figure 5.34: Synoptic chart of mean sea level pressure (hPa) at 00Z on 14 August 2002. ....	67
Figure 5.35: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 14 August 2002. ....	67
Figure 5.36: Synoptic chart of mean sea level pressure (hPa) at 00Z on 15 August 2002. ....	68
Figure 5.37: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 15 August 2002. ....	69
Figure 5.38: Synoptic chart of mean sea level pressure (hPa) at 00Z on 16 August 2002. ....	70
Figure 5.39: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 16 August 2002. ....	70
Figure 5.40: Pressure at East London WO for 14 -16 August 2002. ....	72
Figure 5.41: Temperature at East London WO for 14-16 August 2002.....	72
Figure 5.42: Relative Humidity at East London WO for 14 -16 August 2002. ....	73
Figure 5.43: Wind Direction at East London WO for 14-16 August 2002. ....	73
Figure 5.44: Wind Speed at East London WO for 14-16 August 2002.....	74
Figure 5.45: Daily Rainfall at East London WO for 15 August 2002. ....	74
Figure 5.46: Hourly Rainfall Intensity at East London WO for 15 August 2002.....	75
Figure 5.47: Synoptic chart of mean sea level pressure (hPa) at 00Z on 24 March 1981. ....	77
Figure 5.48: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 24 March 1981. ....	77
Figure 5.49: Synoptic chart of mean sea level pressure (hPa) at 00Z on 25 March 1981. ....	78

Figure 5.50: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 25 March 1981. ....	79
Figure 5.51: Synoptic chart of mean sea level pressure (hPa) at 00Z on 26 March 1981. ....	80
Figure 5.52: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 26 March 1981. ....	80
Figure 5.53: Pressure at Port Elizabeth WK for 24 -26 March 1981.....	82
Figure 5.54: Temperature at Port Elizabeth WK for 24-26 March 1981. ....	83
Figure 5.55: Relative Humidity at Port Elizabeth WK for 24-26 March 1981.....	83
Figure 5.56: Wind Direction at Port Elizabeth WK for 24-26 March 1981. ....	84
Figure 5.57: Wind Speed at Port Elizabeth WK for 24-26 March 1981. ....	84
Figure 5.58: Daily rainfall at Port Elizabeth WK on 25 March 1981.....	86
Figure 5.59: Hourly rainfall intensity at Port Elizabeth WK for 25 March 1981.....	86
Figure 5.60: Synoptic chart of mean sea level pressure (hPa) at 18Z on 5 November 2005.....	88
Figure 5.61: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 18:00Z on 5 November 2005.....	88
Figure 5.62: Synoptic chart of mean sea level pressure (hPa) at 00Z on 6 November 2005.....	89
Figure 5.63: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 6 November 2005.....	90
Figure 5.64: Synoptic chart of mean sea level pressure (hPa) at 00Z on 7 November 2005.....	91
Figure 5.65: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 7 November 2005.....	91
Figure 5.66: Pressure at East London WO for 5-7 November 2005.....	93
Figure 5.67: Temperature at East London WO for 5-7 November 2005. ....	94
Figure 5.68: Relative humidity at East London WO for 5-7 November 2005.....	94
Figure 5.69: Wind direction at East London WO for 5-7 November 2005. ....	95
Figure 5.70: Wind speed at East London WO for 5-7 November 2005. ....	95
Figure 5.71: Daily rainfall at East London WO for 6 November 2005.....	96
Figure 5.72: Hourly rainfall intensity at East London WO for 6 November 2005. ....	97
Figure 5.73: Synoptic chart of mean sea level pressure (hPa) at 00Z on 24 July 1983.....	102
Figure 5.74: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 24 July 1983.....	103
Figure 5.75: Synoptic chart of mean sea level pressure (hPa) at 00Z on 25 July 1983. ....	104
Figure 5.76: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 25 July 1983.....	104
Figure 5.77: Synoptic chart of mean sea level pressure (hPa) at 00Z on 26 July 1983.....	105
Figure 5.78: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 26 July 1983.....	106
Figure 5.79: Synoptic chart of mean sea level pressure (hPa) at 00Z on 27 July 1983.....	107
Figure 5.80: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 27 July 1983.....	107

Figure 5.81: Pressure at Port Elizabeth WK for 24-27 July 1983. ....	110
Figure 5.82: Temperature at Port Elizabeth WK for 24-27 July 1983. ....	111
Figure 5.83: Relative humidity at Port Elizabeth WK for 24-27 July 1983. ....	111
Figure 5.84: Wind direction at Port Elizabeth WK for 24-27 July 1983. ....	112
Figure 5.85: Wind speed at Port Elizabeth WK for 24-27 July 1983. ....	112
Figure 5.86: Daily rainfall at Port Elizabeth WK for 24 -27 July 1983. ....	113
Figure 5.87: Hourly rainfall intensity at Port Elizabeth WK for 24 July 1983. ....	114

## **Acknowledgements**

I would firstly like to thank the South African Weather Service for the data provided and the support given. Thank you for providing me with finances to complete this degree so that I could gain knowledge on this topic and move forward in my career. To the staff of the Port Elizabeth Weather Office, thank you to each one of you for your support, advice and patience. A special thanks to my regional manager, Hugh Van Niekerk for a willingness to allow me to follow this path while working full time, to Brent Appel for your knowledge and for helping me understand the instruments that have recorded rainfall through the years and Garth Sampson for many hours of data collection and scientific interpolations. To those in the head office in Pretoria, Elsa de Jager thank you for help with the autographic data, Charlotte McBride for the upper air charts and to Karin Oxley for assistance with articles and literature. A special thanks to my friend and colleague Elizabeth Webster, who has walked this meteorological journey with me from my undergraduate degree.

I would also like to extend my thanks to my supervisor, Prof. Ian Meiklejohn, and my co-supervisor Dr. Desmond Pyle. To Ian, thank you for your patience and guidance especially when I felt confused and frustrated during my studies. To Des, thank you for your meteorological input and your kindness and understanding you showed me.

To my amazing family, thank you for your encouragement to keep me going and for your prayers. To my Oxygen Life friends in Port Elizabeth: no words can explain my gratitude to all of you for your prayers and help along the way. Thank you for your meals that sustained me and for always keeping me focused. A special thanks to Brigitte Melly and Catherine Lochhead, friends that have stood by my side during the good days and the bad days.

I would like to acknowledge my husband, Grant, who always tried to understand, always encouraged me and who walked with me to the end. Lastly to God the Father, who formed and created me and gave me a love for the power and awe of weather and nature. May this thesis be for His glory.

## Acronyms and Terms

SAWS – South African Weather Service

DM – Disaster management

NMBM- Nelson Mandela Bay Municipality

COL – Cut-off low

WMA- Water management area

WK – Weer Kantoor

WO – Weather Office

Z- Refers to Zulu time or UTC/GMT time

SAST- South African Standard Time

AGR- Agriculture

Amsl – Above mean sea level

hPa – Hectopascal (unit of measurement for pressure).

gpm – Geopotential metres

LLJ – Low level jet

SST – Sea surface temperature

NCEP – National Center for Environmental Prediction

NCAR – National Center for Atmospheric Research

Low pressure – A low pressure system which rotates clockwise in the southern hemisphere.

High pressure- A high pressure system which rotates anticlockwise in the southern hemisphere.

Trough – An extension of a low pressure system.

Ridge – An extension of a high pressure system.

# Chapter 1 General Introduction

## 1.1. Introduction

This chapter seeks to provide an introduction to the study of extreme floods in the southern parts of the Eastern Cape. The aim of the study will then be followed by the objectives and research questions and an outline of the study.

## 1.2. Overview of the study area

South Africa is located on the southern tip of Africa with a northern latitude of 22°S and a southern extreme of approximately 35°S. The country consists of nine provinces (Figure 1.1). The selected study area is within the Eastern Cape Province which is located in the south-eastern part of the country with the south-west Indian Ocean meeting the coastline. The Eastern Cape Province has the warm Agulhas Current running along the coastline (Figure 1.2). The Eastern Cape shares its border with the Northern Cape and Western Cape provinces in the west, the Free State province and Lesotho in the north and the Kwa-Zulu Natal province in the east. It has a total surface area of 168 966 km<sup>2</sup> and is the second-largest province in South Africa (Anon., 2016).

The Eastern Cape is the countries' third most populated province and contributed 8% to the GDP of South Africa in 2014/2015 (Makgetla, 2016). The province has two major metropolitan areas, namely the Nelson Mandela Bay Metropolitan (NMBM) and the Buffalo City Metropolitan. The city of Port Elizabeth, together with its port, lies within the Nelson Mandela Bay Metropolitan. The NMBM also has a second port called the Port of Ngqura. The city of East London lies within the Buffalo City Metropolitan and also has a port.

The Eastern Cape has the largest population of livestock in the country with specialties such as Mohair from the Karoo area (Young, 2013). Pineapples, chicory and dairy farms dominate the south-eastern parts of the province in the Alexandria- Grahamstown area (Republic of South Africa, 2014).

The study area falls within the south-eastern region of the Eastern Cape but will be more precisely defined in Chapter 3.

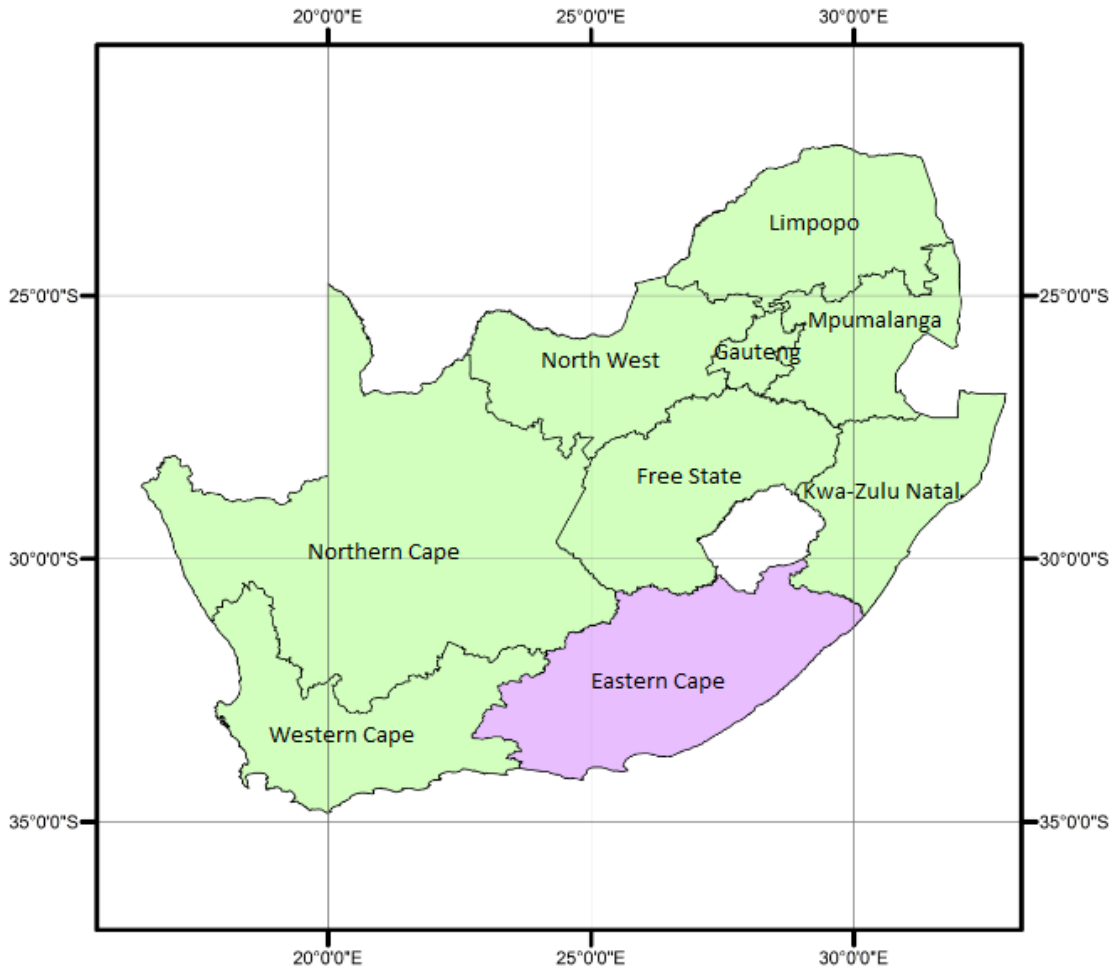


Figure 1.1: Map of South Africa with the Eastern Cape Province, the area of interest, highlighted in purple.

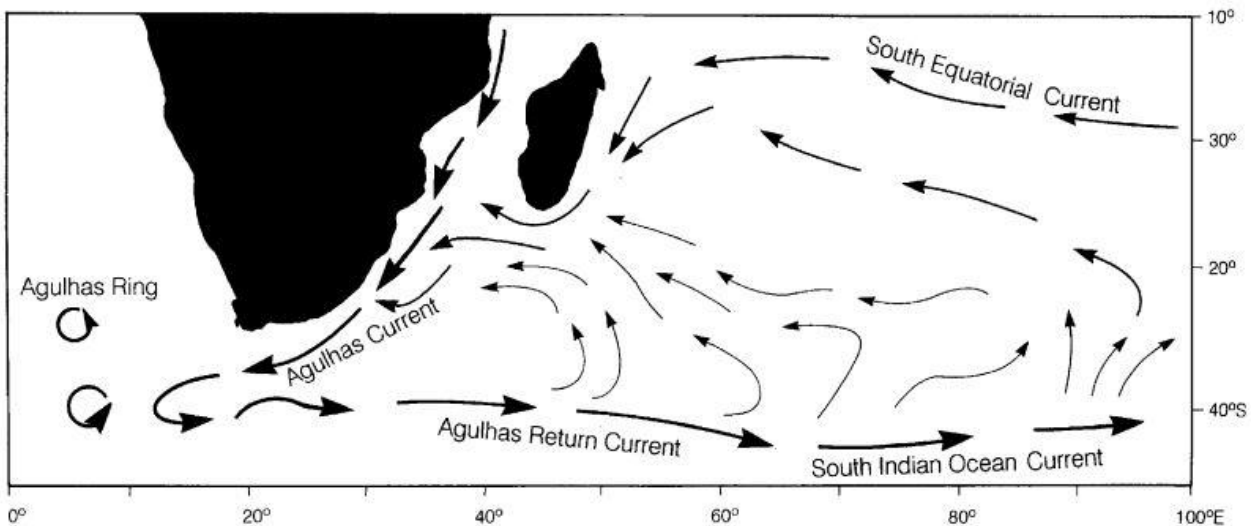


Figure 1.2: The Agulhas current is shown along the east coast of South Africa. Source: Lutjeharms and Ansong (2001).

### 1.3. Motivation and Aim

The Eastern Cape has in the past experienced extreme rainfall events, notably in Port Elizabeth in September 1968, East London in 1970 and more recently in 2002 (Hayward and van den Berg, 1968, 1970; Singleton & Reason, 2006, 2007a). The Port Elizabeth flood in September 1968 resulted in flooding that caused people to flee to rooftops as the waters rose to the window height of some houses due to intense rainfall of over 400 mm within four hours, which poured out over the city. (Hayward and van den Berg, 1968). Cars were washed into the sea and the airport was closed due to water on the runway (Hayward and van den Berg, 1968). Nine people lost their lives during the 1968 flood event (eight from drowning) (Hayward and van den Berg, 1968), while seven people lost their lives in the East London August 1970 event (Hayward and van den Berg, 1970). The 1970 East London event resulted in damage to roads and infrastructure as well as disruptions in communication as almost double the rainfall accumulation of the Port Elizabeth 1968 event fell over five days. The extreme rainfall event in East London 2002 produced over 300 mm of rain in twenty-four hours with a peak intensity of around 85 mm/h which resulted in the closure of the city's harbour (Singleton & Reason, 2006).

Extreme rainfall events within the Eastern Cape are attributed to cut-off lows, especially along the south and south-eastern coastal regions (Taljaard, 1985; Molekwa *et al.*, 2014; Engelbrecht *et al.*, 2015). Many studies have been conducted on synoptic circulation and the contribution to heavy rainfall in South Africa (Hart *et al.*, 2010; Molekwa *et al.*, 2014; Engelbrecht *et al.*, 2015; Engelbrecht and Landman, 2016). Molekwa *et al.* (2014) suggested that the amount of rainfall induced by a COL relies on the low-level processes and circulation. If these processes could be better understood then the distribution and amount of rainfall induced by a COL could potentially be better forecast. Meso-scale circulation systems also exist together with the synoptic circulation, due to the interaction of the mountainous terrain inland from the coastal areas and the moist air from the Agulhas current flowing into the Cape south coast (Engelbrecht *et al.*, 2015). Sea surface temperatures and local topography have been found to enhance rainfall amounts along the south and south east coast of the Eastern Cape (Singleton & Reason, 2006; Molekwa *et al.*, 2014). From this, an analysis of the surface observational data could result in a better understanding of the low-level circulations and processes involved in contributing to heavy rainfall events

Therefore, the aim of this study is to investigate extreme flood events in the southern parts of the Eastern Cape, particularly along the south and south-east coast and adjacent interior, and to analyse the surface observational data associated with these heavy rainfall events.

## 1.4. Objectives and Research Questions

**Objective 1:** To research and identify extreme historical flood events within the study area.

*Research question: Which historical events were the most severe in the study area?*

**Objective 2:** Conduct an analysis of surface observational data from heavy rainfall events.

*Research question: What does the surface observational data reveal in contributing to the heavy rainfall events?*

Each objective and research question, together with the data required and the methods used, is highlighted below in Table 1.1.

Table 1.1: Research Matrix

Objectives	Research Question/s	Data Required	Data Acquisition Tools	Method
1. To research and identify extreme historical flood events within the study area.	Which historical events were the most severe in the study area?	Rainfall data, event reports from disaster management (DM), newspaper articles and NCEP/NCAR Reanalysis 1 data.	Rainfall data retrieval from SAWS, visits to DM centres, Caelum. NCEP/NCAR Reanalysis 1 data.	Data analysis in Excel, research of events and obtaining of NCEP/NCAR Reanalysis 1 data.
2. Conduct an analysis of surface observational data from heavy rainfall events.	What does the surface observational data reveal in contributing to the heavy rainfall events?	Surface observational data from SAWS.	SAWS library and climate data information.	Rainfall data in Excel format and analysis of surface observational data

## **1.5. Research Outline**

Chapter one is the general introduction which presents the study and the aims of the study. The chapter then moves on to present the objectives and research questions as well as the data acquisition tools and the methods used in the study.

A literature review in chapter 2 elaborates on the importance of floods and their effects on daily living as well as the types of floods and the weather systems that produce floods. A brief look into the roles of disaster management is given as well as a methodology review.

Chapter three provides details on the study area. There were particular factors that influenced the choice of the study area and these are considered in this chapter. The study area climate, river systems and topography are also reviewed, which provide a clear idea of the environment in which the floods may occur.

Chapter four identifies the methods used to meet the objectives and answer the research questions. It details the acquisition of rainfall data and quality control methods used as well as the types of meteorological parameter data collected for the study.

Chapter five explores the results of the rainfall analysis from which a meteorological analysis was done on certain case studies that showed to be the most severe flood events.

Chapter six probes the possible shortfalls of the study and draws conclusions that meet the aim and objectives given in Chapter 1. Lastly, some recommendations for future studies are provided.

## **Chapter 2 Literature Review**

### **2.1. Introduction**

The scope of this study is on areas within the southern parts of the Eastern Cape that are highly susceptible to flooding. This literature review will provide an outline of the definitions of floods, the weather systems that cause flooding in South Africa and how the key role players in disaster management approach these disasters, specifically with regards to disaster risk reduction. A review of methods used to identify flood risk areas is also included.

### **2.2. Defining floods and risk**

#### **2.2.1. Floods**

Alexander (2000) defines a flood as the discharge of water that results in damage or that which overtops the river banks. A peak in discharge and then return to normal base flow or no flow is considered a flood (Alexander, 2000).

Cuny (1991) classifies 4 basic types of flooding: flash floods, standing floods, coastal flooding from storm surge and riverine floods. Below are some of Cuny's descriptions:

- Flash floods result from thunderstorms producing rainfall that accumulates very quickly which runs off over steep terrain or in mountainous areas. The waters run rapidly down narrow zones such as gullies, arroyos or wadis until they reach wider areas or streams where the flood waters can slow down as it spreads out.
- Standing floods are produced by rainfall that cannot be drained sufficiently or quickly enough due to poor drainage systems in urban areas, high runoff rates or poor absorption due to saturated soils.
- Coastal floods occur as a result of intense weather systems that cause storm surges. Tropical cyclones or deep low pressure systems are typical weather systems that produce storm surges along the coast.
- A riverine flood is the overflow of a river streambed when rainfall occurs in that river's particular watershed. This type of flooding is associated with heavy

rainfall in the watershed. Riverine flooding can be worsened when the river reaches the ocean as the oceans' tides can reduce the exit of water from the river into the ocean. During high tides, water can even be pushed back up along the river, which could cause further flooding over the wide, flat floodplains. Due to the extent of floodplains, which can be kilometres wide, flooding can be widespread and continue even when rainfall occurs far into the drainage basin.

The study area is susceptible to all the above types of flooding. Coastal flooding would, however, not be caused due to a tropical cyclone in the study area but rather by extra-tropical and mid-latitude weather systems such as cold fronts and deep surface lows associated with cut-off lows.

### **2.2.2. Hazard, Vulnerability and Risk**

Pyle (2006) mentions that the standardisation of key terms in the hazard field has been problematic due to various fields of knowledge contributing to the definition of the key terms.

The standardisation of these terms is taken from Pyle (2006). In order to define risk, one must first define hazard and vulnerability as risk is dependent on both of these.

Pyle (2006:16) defined hazard, vulnerability and risk as the following:

- **Hazard:** "A potentially damaging physical event, phenomenon or human activity that may cause the loss of life, or injury, property damage, social and economic disruption or environmental degradation."
- **Vulnerability:** "The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards."
- **Risk:** "The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions. Conventionally, risk is expressed by the equation  $\text{Risk} = \text{Hazard} \times \text{Vulnerability}$ ."

This study will focus on the hazard component of risk in the study area, namely, floods which cause large disruptions and loss of life in the study area.

### **2.3. Flood Producing Weather Systems in South Africa**

South Africa experiences floods of all types from flash floods to coastal flooding. The country is influenced by many different weather systems with tropical systems affecting the northern and eastern parts and mid-latitude systems in the west and south. The weather systems which contribute to floods over South Africa will now be discussed.

#### **2.3.1. Tropical weather systems**

The floods that occurred between December 1999 and March 2000 due to tropical easterly lows and tropical cyclones, documented in Dyson and van Heerden (2001), caused extensive damage across the north-eastern parts of southern Africa. The two most northern provinces of South Africa were severely affected, leaving a million people without adequate water (Alexander, 2002). Alexander (2002) discusses the damage to infrastructure and communication interruptions due to floods during this period. It was estimated, across Mozambique and South Africa, that it would cost R 1000 million to repair the damage to infrastructure.

De Coning *et al.* (1998) discuss the heavy rainfall that led to widespread flooding across the eastern parts of South Africa in February 1996. Stations in the summer rainfall region received up to 200% above normal rainfall for the month of February 1996. Flash floods from deep convective cells were the most damaging events. Significant heavy rain fell during 8-16 February with the most intense episode occurring from 12-14 February 1996. A characteristic cloud pattern known as a tropical-temperate-trough (TTT), lead to the heavy rainfall that occurred in February 1996. This is common during the months of January and February over the eastern parts of South Africa when the Inter-Tropical Convergence Zone (ITCZ) is at its southernmost point over Zambia. Tropical lows draw moisture into South Africa from the north. A TTT forms when a trough links convection over the tropical or sub-tropical areas of southern Africa to a mid-latitude depression south of the country (Dyson *et al.*, 2002). TTTs are associated with heavy rainfall when strong onshore flow exists along the south and south-eastern coastal regions of South Africa (Dyson *et al.*, 2002). Engelbrecht *et al.* (2015) found that 28% of the annual rainfall is attributed to TTT's along the Cape south coast of South Africa.

The Eastern Cape study area utilised in this research rarely, if ever, is affected by floods from tropical weather systems such as tropical cyclones or tropical easterly lows, as it is located in the westerly wind belt due to its latitude. However, TTT's do produce rainfall along the Cape south coast of the Eastern Cape and also interact with baroclinic mid-latitude systems (Engelbrecht *et al.*, 2015). In fact Dyson *et al.* (2002) categorise TTT's with having tropical, sub-tropical and mid-latitude weather system characteristics due to a combination of these systems that result in a TTT.

### **2.3.2. Mid-latitude systems**

Mid-latitude cold fronts are mostly associated with winter rainfall in the south-western parts of South Africa (Favre *et al.*, 2013). Heavy to extreme precipitation occurs in the western and southern parts of the country due to these cold fronts, more specifically in the south-west part of the Western Cape (Favre *et al.*, 2013). Cold fronts do contribute to the southern coastal annual rainfall, particularly in winter; however, these systems alone rarely result in intense rainfall (Singleton and Reason, 2007a).

Mid-latitude cold fronts can align with surface troughs over the land during summer periods, which extends moisture laden air from the tropics southwards into the country. Heavy precipitation occurred over the north-eastern parts of the country due to the lifting of the western edge of a moist plume over a cold front during the TTT event on 14 February 1996 as discussed in De Coning *et al.* (1998).

### **2.3.3. Cut-Off low systems**

A cut-off low (COL) is a cold cored low pressure system in the mid to upper troposphere (a local minimum in geopotential heights at 500hPa) that is "cut-off" from the basic westerly current and displaced equatorward. (Tyson and Preston-Whyte, 2000; Singleton and Reason, 2007b; Molekwa *et al.*, 2014; Engelbrecht *et al.*, 2015). A COL is a more intense form of a westerly trough (Figure 2.1), a trough in the upper westerlies that deepens and becomes a closed low which then continues to build down to the surface (Tyson and Preston-Whyte, 2000). COL's can be identified as closed contours of geopotential height with cyclonic circulation or on isentropic maps of high potential vorticity (Nieto *et al.*, 2008). COL's are unstable, baroclinic systems that lean westwards with height (Tyson and Preston-Whyte, 2000) and can produce deep convective thunderstorms and heavy showers due to the instability caused by the cold core of the system (Singleton and Reason, 2007a; Molekwa *et al.*, 2014). Instability can also be caused from the strong convergence and vertical motion in the system, especially east of the COL (Figure 2.2) (Tyson and Preston-Whyte, 2000).

Cut-off lows generally occur in the austral spring and autumn months (Singleton and Reason, 2007a).

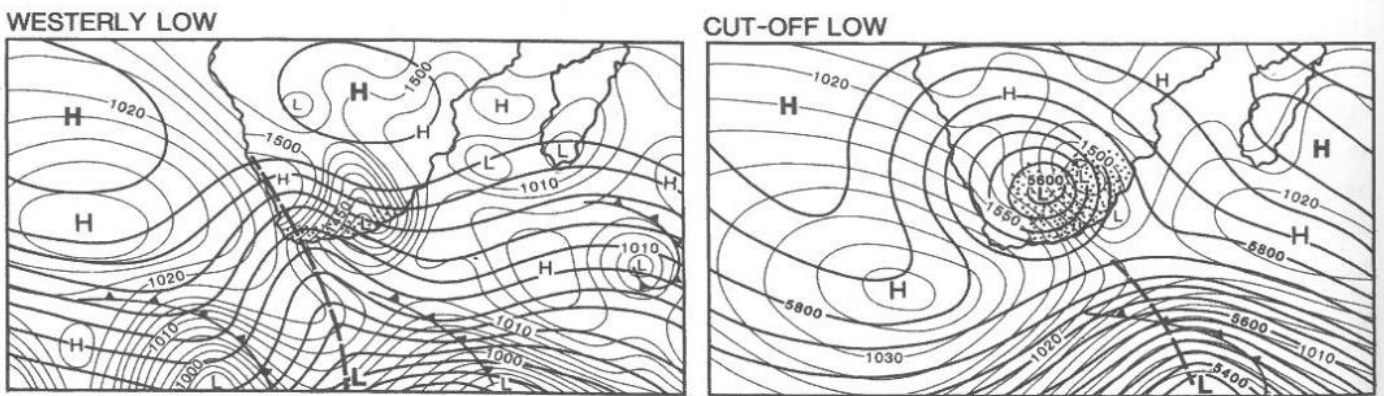


Figure 2.1: An example of a westerly trough (left) and a cut-off low (right) with thicker lines representing the geopotential heights at 500hPa and thinner lines the isobars at mean sea level (hPa) over the oceans and contours of the 850hPa surface (gpm) over the land. Dotted lines are areas receiving precipitation. Source: Tyson and Preston-Whyte, (2000:196).

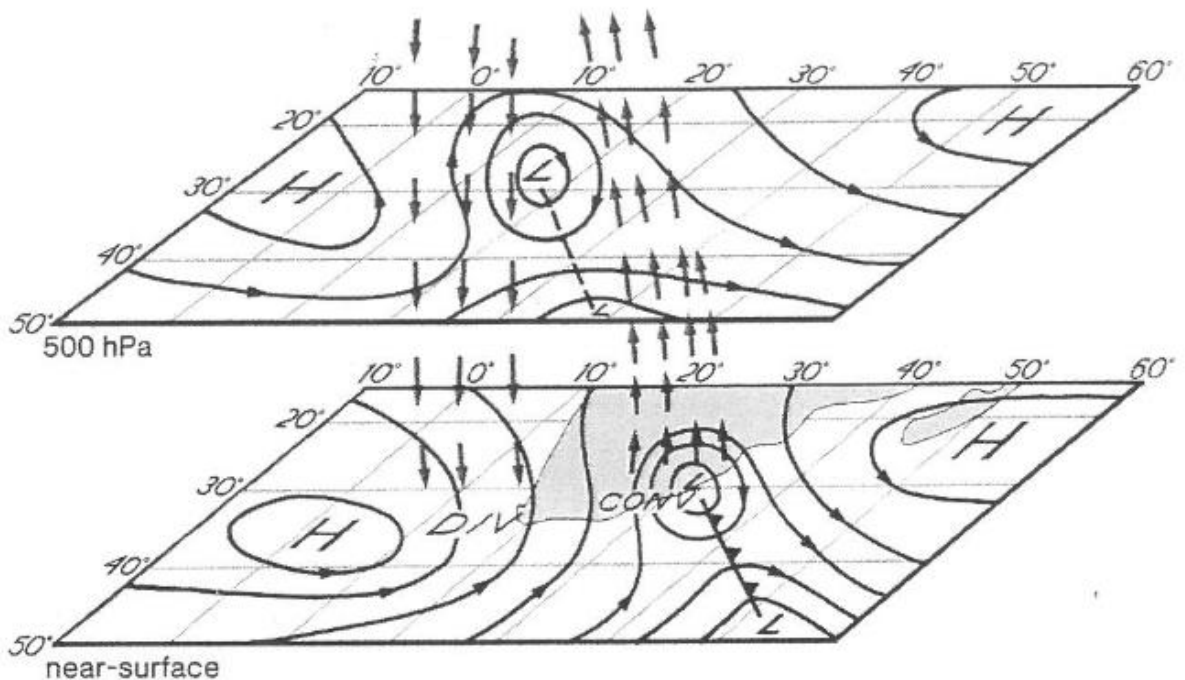


Figure 2.2: A schematic representation of the circulation associated with a cut-off low at the 500hPa and near-surface levels (Tyson and Preston-Whyte, 2000:197).

Favre *et al.* (2013) recently investigated the contribution of precipitation from COLs over South Africa. In this study, precipitation, outgoing long wave radiation and precipitable water datasets were analysed. It was found that in winter, which was

classified as July, August and September, most of the rainfall that occurred inland was due to COL's. The authors also found that in this period, any extremes of rainfall were 50 to 100% due to COL's. The precipitation amounts vary in different COLs; however, when a significant transport of moisture occurs, at low and mid-levels, larger amounts of precipitation may occur, especially over warm ocean regions (Nieto *et al.*, 2008).

Severe flood events caused by COL's, as noted in Alexander (2000), are the Port Elizabeth floods of 1968, East London in 1970, Laingsburg in 1981 and Natal floods in 1987. The Natal 1987 floods were South Africa's worst natural disaster with more than 300 deaths and total damage exceeding R1000 million. This disaster highlights the catastrophic possibilities of floods due to COL's.

## **2.4. Cut-off lows as flood producing systems in the study area**

### **2.4.1. COL's within the study area**

Taljaard (1985) determined that COLs are associated with widespread light to moderate rainfall, with 20% of COLs resulting in heavy rainfall. However, it was found that the rain producing potential of each individual system depends on various factors, including the direction of onshore wind flow, location of other weather systems and the effect of topography (Sampson, 2007). According to Sampson (2007), approximately 25% of COLs in South Africa result in flood-producing rains. Similarly, Molekwa *et al.*, (2014) found that one in five COL systems lead to heavy rain and flood events. Heavy rain events along the coastal regions can occur when a baroclinic system, such as a COL, is present with vertical motion through the mid tropospheric layers together with an influx of low level water vapour beneath the region of vertical motion (Dyson *et al.*, 2002). The vertical motion occurs east of the COL (Figure 2.2) and is the area where instability is found.

COLs have, in the past, caused extreme rainfall events to occur over the southern and south-eastern coastal regions and their adjacent interiors (Singleton and Reason, 2007a). Flash flooding from COLs in the study area have resulted in some cases. Most of these floods occur along the southern and eastern coastal areas and in the adjacent interior (Molekwa *et al.*, 2014). Favre *et al.* (2013) concluded that annual precipitation, the number of rainy days and extreme rain days, are most

frequent over the south-east coast of the country with COLs contributing to about 100-250 mm of the annual rainfall.

The southern and eastern coastal areas of South Africa have the potential to produce higher rainfall amounts during COL events, due to the effects of sea surface temperatures and topography (Singleton and Reason, 2006). Singleton and Reason (2007a) highlighted the importance of investigating South African cases of COL flooding. Although Northern Hemisphere studies have been conducted, the South African orographic landscape and the influence of the ocean, results in local effects triggering intense rainfall.

#### **2.4.2. COL's with a ridging high pressure system at the surface**

COLs may interact with different low-level circulation but the most common of these is a strong ridge of a surface high pressure system to the south (Singleton and Reason, 2007b; Engelbrecht *et al.*, 2015). Engelbrecht *et al.* (2015) found that ridging high pressure systems produce rainfall when further south rather than equatorward even with relatively similar pressure distributions. The Cape south coast's annual rainfall is largely attributed to ridging high pressure systems however, the occurrence of heavy rainfall events was largely due to COL's occurring with ridging high pressure systems in the low-level circulation (Engelbrecht *et al.*, 2015). Dyson *et al.* (2002) mention a surface high pressure system located south or southeast of the country with significant pressure gradients being maintained near the land as a key factor for significant rainfall to occur with COLs. A second factor that is required is a rapid influx of cool maritime air onto the land caused by the push of the high.

A COL event on 15-16 August 2002, led to rainfall exceeding 300 mm in a twenty-four-hour period in the East London area, causing the closure of the harbour (Singleton and Reason, 2006). A surface high pressure system was located south of the country, bringing moisture into the Eastern Cape with south-easterly (onshore) winds (Singleton and Reason, 2006). This combination of weather systems, a COL together with a surface ridging high pressure system, is colloquially referred to as a "Black South-Easter" along the southern coast of South Africa. However, Hayward and van den Berg (1970) add a third factor of a surface trough over the southern interior of the country which protrudes off the coast. A "Black South-Easter" produced the severe floods in Port Elizabeth on the 1st September 1968 where heavy downpours of rain resulted in nearly 500 mm in a four-hour period (Hayward and van

den Berg, 1970; Molekwa, 2013), as well as disastrous floods in East London on 27 August 1970.

What is of interest during heavy rainfall events is the effect that orography has on the amount of rainfall received, notably the eastern escarpment of South Africa (Dyson and van Heerden, 2001) and the coastal mountains along the east coast (Singleton and Reason, 2006). Orography can create an environment that is favourable for the development and organisation of convective cells (Nieto *et al.*, 2008). An influx of moisture perpendicular to orographic areas can greatly increase rainfall volumes. It was assessed that the 2002 East London event was greatly enhanced by the steep topographic coastal mountains. Onshore winds forced moist air up over the terrain, thereby increasing rainfall quantities (Singleton and Reason, 2006). Port Alfred experienced floods in October 2012, which caused extensive damage to the area (Pyle and Jacobs, 2016). Most of the rainfall fell upstream against the higher topography around Grahamstown and filtered downstream, resulting in floods in the Port Alfred area.

Although not within the study area, the Laingsburg flood of 1981 was also a noteworthy example of the effect of orography on rainfall amounts. A cut-off low system with a ridging high pressure system caused the devastating floods which swept away half of the town (Nieman *et al.*, 1981). The rivers in the Laingsburg area converge and then pass through a gorge which caused temporary damming of water upstream of the town and produced high velocities of water through the gorge (Nieman *et al.*, 1981). Laingsburg is situated in a “pocket floodplain” between two gorges each located upstream and downstream of the town. This highlights that orography not only increases rainfall amounts but can also amplify the effects of flood waters.

## **2.5. Risk reduction approach to disaster management**

In recent times, disaster management has progressed from disaster relief and moved towards disaster risk management and risk reduction (Pyle, 2006). The Republic of South Africa (2015:4) defined disaster risk reduction as goals, objectives or measures put in place for:

- anticipating future disaster risk;

- reducing existing exposure, hazard or vulnerability; and
- improving resilience.

The Disaster Management Amendment Act No. 16 of 2015 defines a disaster as any significant disruption of the life of a community (Republic of South Africa, 2015). Although rare large-scale systems, such as the Super typhoon Haiyan that hit the Philippines in 2013, gain much media attention, small-scale severe events are just as devastating to local communities and disaster risk management and mitigation processes are needed at a local community (or district) level (Pyle, 2006). The South African national disaster management framework is tasked with establishing prevention and mitigation plans for different disasters, including the magnitude and severity of these disasters and measures that can be taken to reduce vulnerability in disaster-prone or high-risk areas (Republic of South Africa, 2003).

Current international thinking is geared towards investing in proactive measures rather than relying on reactive measures (Pyle, 2006). Short-term relief responses prove to be expensive so government is more inclined to contribute financially towards long-term prevention and risk reduction, which will be more cost-effective in the long run (Pyle, 2006). However, most municipal districts cannot afford flood control measures in urban areas once urbanisation has already taken place (Campana and Tucci, 2001). Putting in drainage measures post-urbanisation is extremely expensive (Campana and Tucci, 2001). Developing countries also struggle to cope with developing flood control measures and these costs can be reduced by taking alternate approaches (Cuny, 1991).

An effective early warning severe weather system is dependent on various components working together (Pyle, 2006). Firstly, an indigenous response from people can enhance the benefits of floods and prevent large spread disaster, simply by educating the people on how to live with floods and develop self-reliance (Cuny, 1991). Capacity building, training and education in terms of disaster management, also forms part of the national disaster management framework (Republic of South Africa, 2003). Government would spend fewer resources on this type of approach while also speeding up protection of people at local levels (Cuny, 1991). However, there is a problem locally in the understanding of early warnings by hazard-prone communities and the consequent response to these warnings (Pyle, 2006). A shortcoming that the South African Weather Service (SAWS) and disaster management organisations also have is the dissemination of these warnings to rural communities that don't have access to media, such as SMS, email or television (Pyle, 2006).

*“It was indicated that if more warning could be given, floods might not be so destructive. This response implies a degree of indigenous local flood preparedness.”* - Fredrick C. Cuny on the floods in West Bengal, 1978 (Cuny, 1991:334).

Another approach is that of prevention and mitigation through research and identification of hazards and factors which make communities vulnerable. Risk and vulnerability assessments are a requirement by South African provinces. Provincial and local (small scale) areas that are at risk need to be identified (Pyle, 2006). The national disaster management framework also aims to promote disaster management research and is required to take indigenous knowledge into account regarding disaster management (Republic of South Africa, 2003).

In conducting an analysis of surface observational data during extreme flood events and getting a better understanding of meteorological factors that result in these disasters, a drive towards highlighting hazard-prone regions at a local level can take place.

## **2.6. Methodology review**

### **2.6.1. Statistical and standardized methods**

Alexander (2002) looked at applying different statistical approaches to predict flood magnitude. Due to the complication of processes that result in floods, an upper limit is near impossible to predict with statistical models underestimating the occurrence of severe events, especially with a return period greater than 50 years (Alexander, 2002). The current study looks at extreme historical events that have return periods greater than 50 years and therefore, a statistical approach was decided against.

Seiler *et al.* (2002) introduced the Standardized Precipitation Index (SPI) as a method of identifying flood risk areas. The SPI was initially used for drought detection but due to its characteristics was adapted to identify above normal precipitation events (Seiler *et al.*, 2002). The flood risk assessment, using the SPI, was conducted in the southern Cordoba Province in Argentina. The SPI was used to anticipate flood events through the development of soil-saturation levels using short-term soil water and long-term groundwater availability. Soil saturation levels are a key influence in flood occurrence. A period length of 25 years was analysed using the SPI method (Seiler *et al.*, 2002). The outcome, however, results in identifying flood years in an already known flood zone. The SPI takes soil saturation and groundwater availability into account. These represent hydrological and geological processes whereas the current study has a focus on meteorological processes.

### **2.6.2. Flood risk assessment**

Bouchard *et al.* (2007) conducted a study on improving flood risk management in flood prone informal settlements of Cape Town, South Africa. It was found that social, political and technical factors are all relevant in assessing flood risk management. This research conducted a flood risk index pilot study in which different methods were assessed, which involved looking at historical flood events and mapping of high-risk areas. A similar approach of identifying historical flood events and where they occurred will be used in this study. Other methods of flood management, which were found, included structural improvements, effective communication methods and recommendations for the improvement for the City of Cape Town's flood risk management strategies. Bouchard *et al.* (2007) used GIS to map high-risk areas by considering the topographical layout of the settlements. The lowest lying areas and subsequent "high-risk" for pooling and flooding were mapped. The historical flood events were analysed through evaluating trends in rainfall data and incident reports. GIS data was also evaluated but in the four-year period assessed, they were found to be limited in their application due to inconsistent flood records (Bouchard *et al.*, 2007).

In conducting a severe storm risk assessment of the Eastern Cape, Pyle (2006), found that GIS was an effective tool in assessing risk but was not a method to be used in isolation due to various problems such as a lack of having been in the area to ground-truth data. GIS, is, however, beneficial in undertaking a multi-hazard analysis that incorporates both scientific data and socio-economic data by overlaying information. This simply cannot be done by hand drawn maps or other conventional mapping techniques, especially when analysing risk that has multiple elements. Pyle (2006) used the National Disaster Management Framework, established by South African legislation, to examine disaster risk. The framework was used to examine hazard threats, as the term disaster can be limiting (Pyle, 2006) and identifies a risk factor by considering hazards together with vulnerabilities, with the outcome to estimate a level of disaster risk. Hazards include historical information, probability, frequency, intensity, exposure, *etc.* while vulnerability encompasses economic, social, physical and environmental susceptibility and capacity (Pyle, 2006).

Ologunorisa and Abawua (2005) reviewed flood risk assessment by looking at various techniques used in case studies across the world. Five risk assessment techniques were classified. These were: meteorological parameters, hydrological parameters, socio-economic factors, a combination of hydro-meteorological and socio-economic factors and the use of Geographical Information Systems

(Ologunorisa and Abawua, 2005). The most used technique was that of meteorological parameters to assess flood risk specifically using rainfall parameters. The study concluded that the use of GIS as a flood risk assessment should be encouraged as it is able to integrate all the techniques into one output.

## **2.7. Conclusion**

It is clear that a variety of floods of all types can cause extensive damage as well as the loss of lives and property. COL's with a ridging high pressure at the surface seems to be the main flood producing weather system to affect the study area. Rainfall amounts can be augmented when moist air meets with orography at perpendicular angles. Rainfall data is the key meteorological source for flood analysis.

Government policy and practice tends towards risk reduction, rather than disaster response and relief. This proves to be better suited to key role players by being more prepared in disaster situations as well as having a financial benefit in the long run. Another option could be to capitalise on peoples' self-reliance by emphasising flood awareness. Disaster management legislation requires that risk/vulnerability assessments are conducted at provincial, municipal and community (local) levels in order to identify at-risk areas (Pyle, 2006). GIS is an effective tool used in conjunction with other methods to map risk areas. By definition, risk involves not only hazard but vulnerability as well, which involves factors which are beyond the scope of this study, which has a meteorological focus rather than a socio-economic focus. Therefore, the emphasis of this study will be on the meteorological parameters that lead to severe flood events.

## Chapter 3 Study Area

### 3.1. Introduction

This chapter presents the study area that was selected and the criteria that were utilised for the selection. As mentioned in chapter 1, the study area lies within the southern parts of the Eastern Cape Province in South Africa. After reviewing how the study area was selected, specific details of the study area are provided that cover climate, drainage and topography.

### 3.2. The study area

#### 3.2.1 Factors that determined the selection of the study area

In order to define the study area, three factors were taken into consideration, namely climate variability, local population distributions and water management areas (WMA's).

##### 3.2.1.1 Factor 1: Climate variability

The Eastern Cape Province has high climate variability with summer and winter rainfall systems affecting the province (Molekwa, 2013). The extent of the province is influenced by vastly different climates. The eastern extremes of the Great Karoo, which are located in the western parts of the Eastern Cape, are associated with dry, semi-arid conditions (Desmet and Cowling, 1999). The eastern parts of the Eastern Cape have higher rainfall than in the western parts (Figure 3.1). Higher rainfall is also received along the south coast areas (Molekwa, 2013) where annual rainfall is experienced (Engelbrecht *et al.*, 2015). Severe floods have occurred along the south-eastern coastline in the past (Molekwa *et al.*, 2014). Singleton and Reason (2006) suggest that the warm Agulhas Current provides higher moisture availability in severe rainfall events along the eastern coastline of the Eastern Cape. Therefore, the south eastern coastline of the Eastern Cape Province is highlighted as a higher rainfall area which experiences heavy rainfall events and consequent floods.

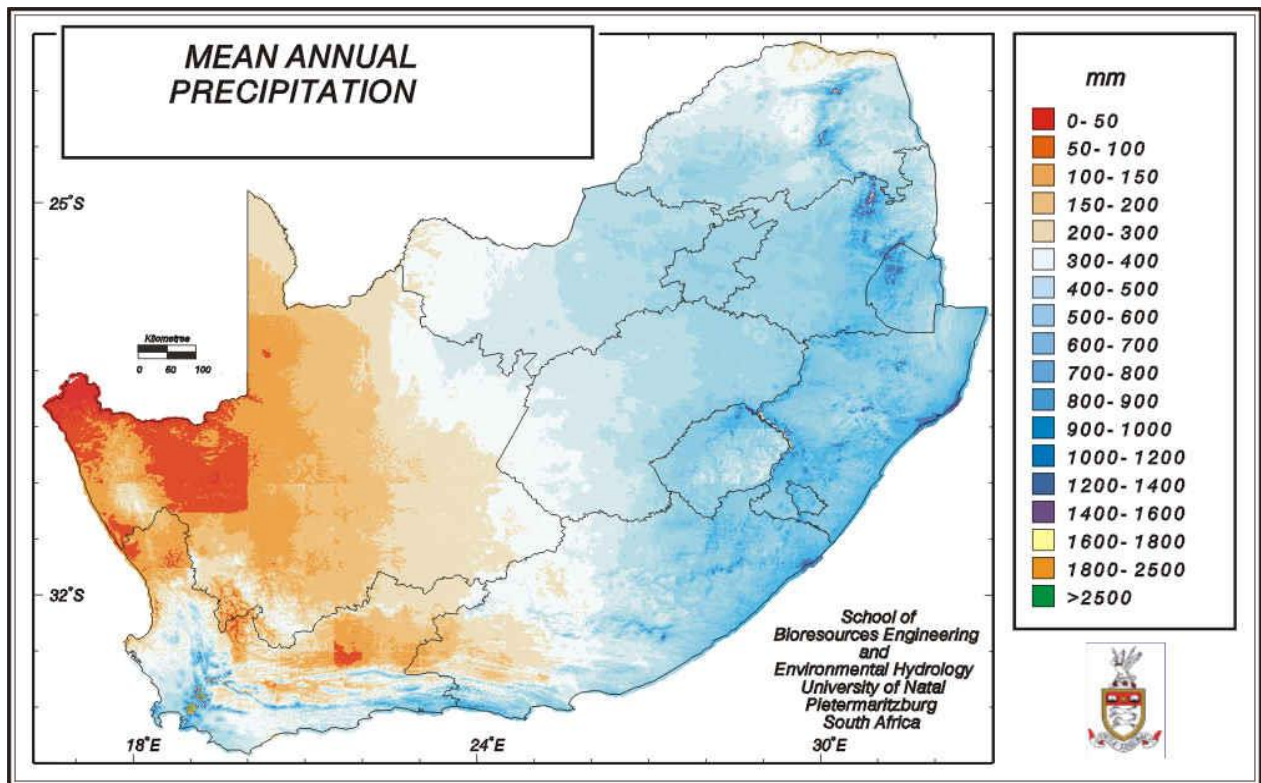


Figure 3.1: Mean Annual Precipitation over South Africa. Source: Schulze (1997:32)

### 3.2.1.2 Factor 2: Population distribution

A consideration in selecting the study area is that of population. Floods that have little effect on people have a reduced risk. Therefore, areas that are highly vulnerable to floods would be areas of higher population density. The two metropolitan areas of Port Elizabeth and East London would potentially be greatly affected by floods. In the case of a major flood, transportation routes could become inaccessible, diseases could spread from stagnant water and millions of people could be displaced. In terms of flood and disaster management, this study would shed some light on hazard threat areas.

### 3.2.1.3 Factor 3: Water management areas

Water management areas (WMAs) and drainage regions in the Eastern Cape were considered for demarcating the study area as they define existing management divisions. South Africa has 22 drainage regions, of which ten fall within the Eastern Cape (Figure 3.2).

The specific study area includes drainage regions M, P, R, eastern parts of K and southern parts of Q and N (Figure 3.2). These areas fall under the Tsitsikamma to Fish WMA (No. 15) and the western most part of the Mzimvubu to Keiskamma WMA (No. 12) to include the East London area (Department of Water Affairs, 2017). More

specifically, the sub-WMAs to be included are: Tsitsikamma, Algoa, Bushmans, Amatola and the extreme southern parts of the Fish and Sunday's sub-WMAs (south of Fort Beaufort). The northern basins of the Fish River and Sundays River sub-areas fall within the Karoo area with arid climatic conditions dominating the rainfall in this area (Shand, 2005) and will, therefore, be excluded.

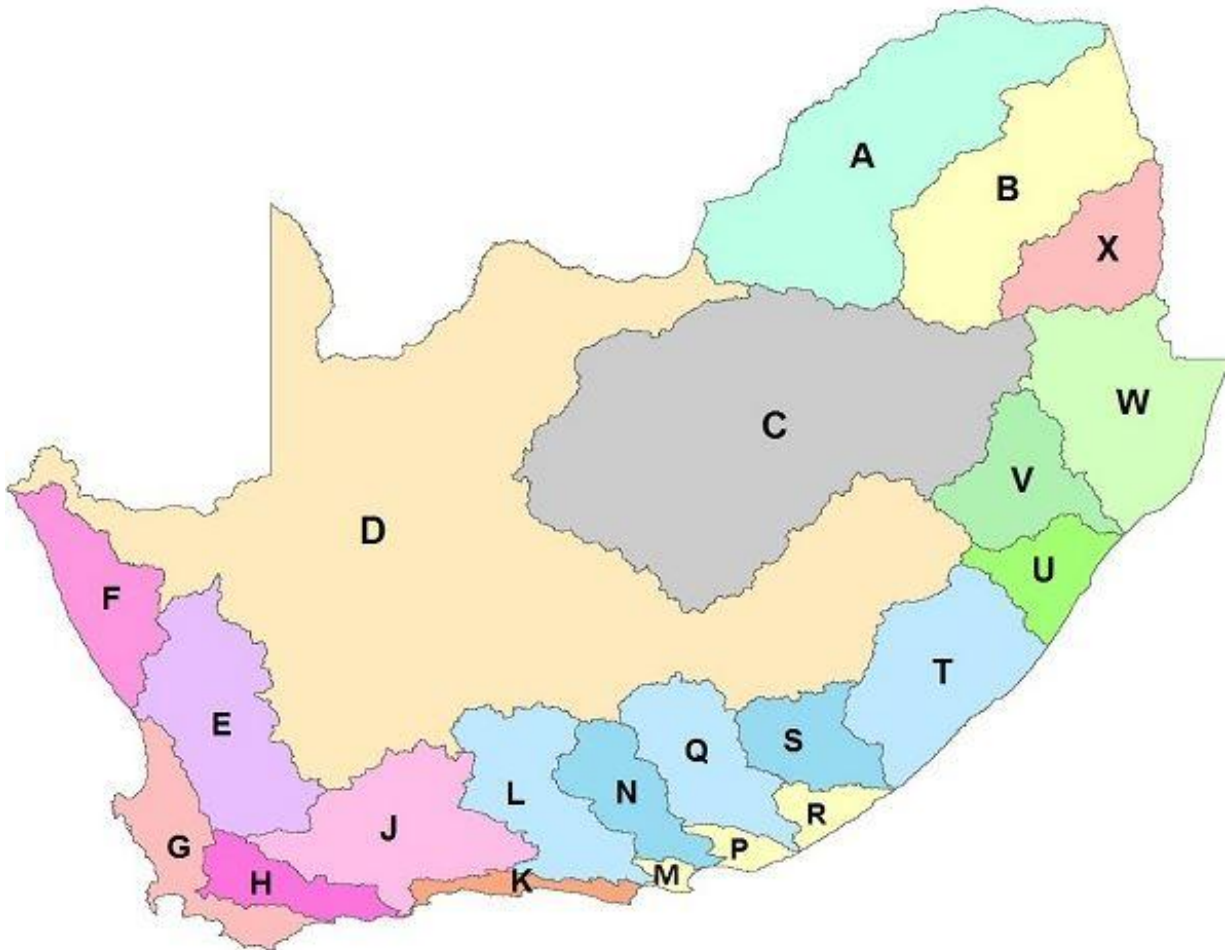


Figure 3.2: Drainage regions of South Africa, Source: Department of Water Affairs (2017).

The study area is from Gamtoos River to the Great Kei River Mouth but does not include the lower parts of the lower Great Kei River catchment or the Gamtoos catchment itself. Quaternary catchments were selected that fit into this region. The northern boundaries were restricted by higher topography as will be seen in section 3.2.4. The study area is highlighted in Figure 3.3 below.

The main cities and towns that fall within this study area are: Port Elizabeth, Uitenhage, Port Alfred, Grahamstown, Bisho and East London.

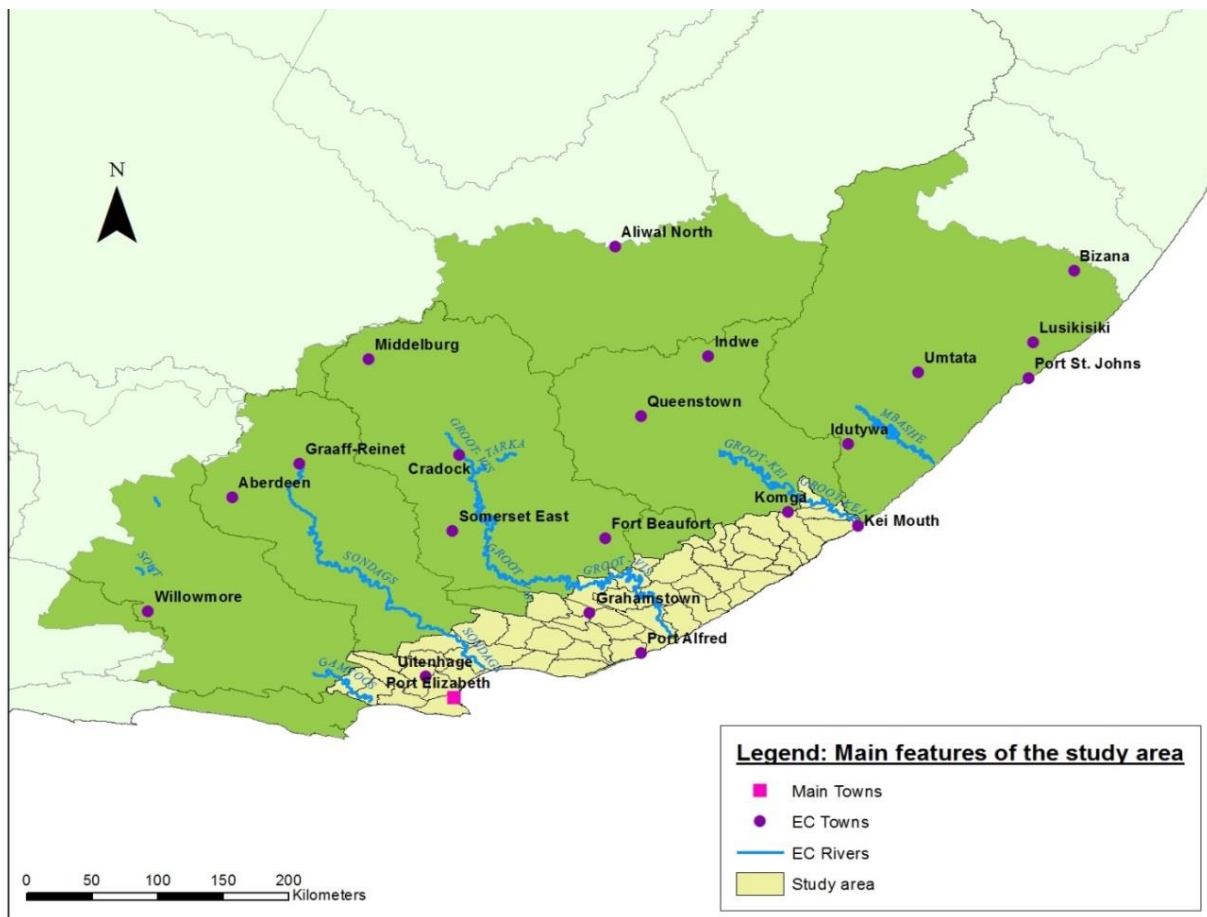


Figure 3.3: The Eastern Cape Province with the study area highlighted.

### 3.2.2. Rainfall and climate of the study area

Most of the study area, especially the south-eastern coastal belt, is strongly influenced by the warm ocean currents from the Indian Ocean (Shand, 2005). The warm Agulhas current runs parallel to the Eastern Cape coastline (Walker, 1990). The majority of the area receives rainfall throughout the year with a higher volume in summer. Rainfall amounts vary from 400 mm in the interior to 700 mm at the Fish River and 700 to 800 mm mean annual precipitation at Bushmans River (Boesmans) (Shand, 2005). The Internal Strategic Perspective for the Amatola-Kei area (drainage regions R and S) differentiates rainfall and climate according to the proximity to the coast. The coastal areas have a more temperate climate and rainfall here ranges from between 500 mm in the west at the Keiskamma River to 1000 mm at Great Kei River Mouth in the east. The Amatola Mountains receive around 1200 mm annually (Anon., 2004).

### **3.2.3. Rivers within the study area**

There are numerous large rivers within this area (Figure 3.4). The Gamtoos River forms the western boundary of the area and flows into St Francis Bay. In the Algoa sub-area (Van Stadens River to Coega River), the Swartkops River is the main river of influence (even though it isn't as long as the Coega River) and flows into Algoa Bay (Klages *et al.*, 2011). The Sunday's River has its headwaters near Nqweba Dam at Graaff-Reinet but flows southwards towards Algoa Bay where it exits near Cannonvale (Shand, 2005). Moving eastwards, the Bushmans River, Kariega and Kowie Rivers are the main rivers that form part of the Albany Coast sub-area (Shand, 2005). The Great Fish River supplies water to the Grahamstown area via pipelines. This river has its mouth in an estuary 25 km east of Port Alfred along the Albany Coast or drainage region P (Shand, 2005). The Orange River Development Project, developed in the 1970s, supplies water to the Fish and Sundays WMAs (Shand, 2005). The Amatola coastal catchments consist of the Keiskamma, Buffalo and Nahoon Rivers. These rivers drain the Amatola mountain range at 1960m above mean sea level to flow south-eastwards into the Indian Ocean either side of East London (Anon., 2004). The Amatole catchment has a mean annual run-off rate of 559 million m<sup>3</sup>/a (Anon., 2004).

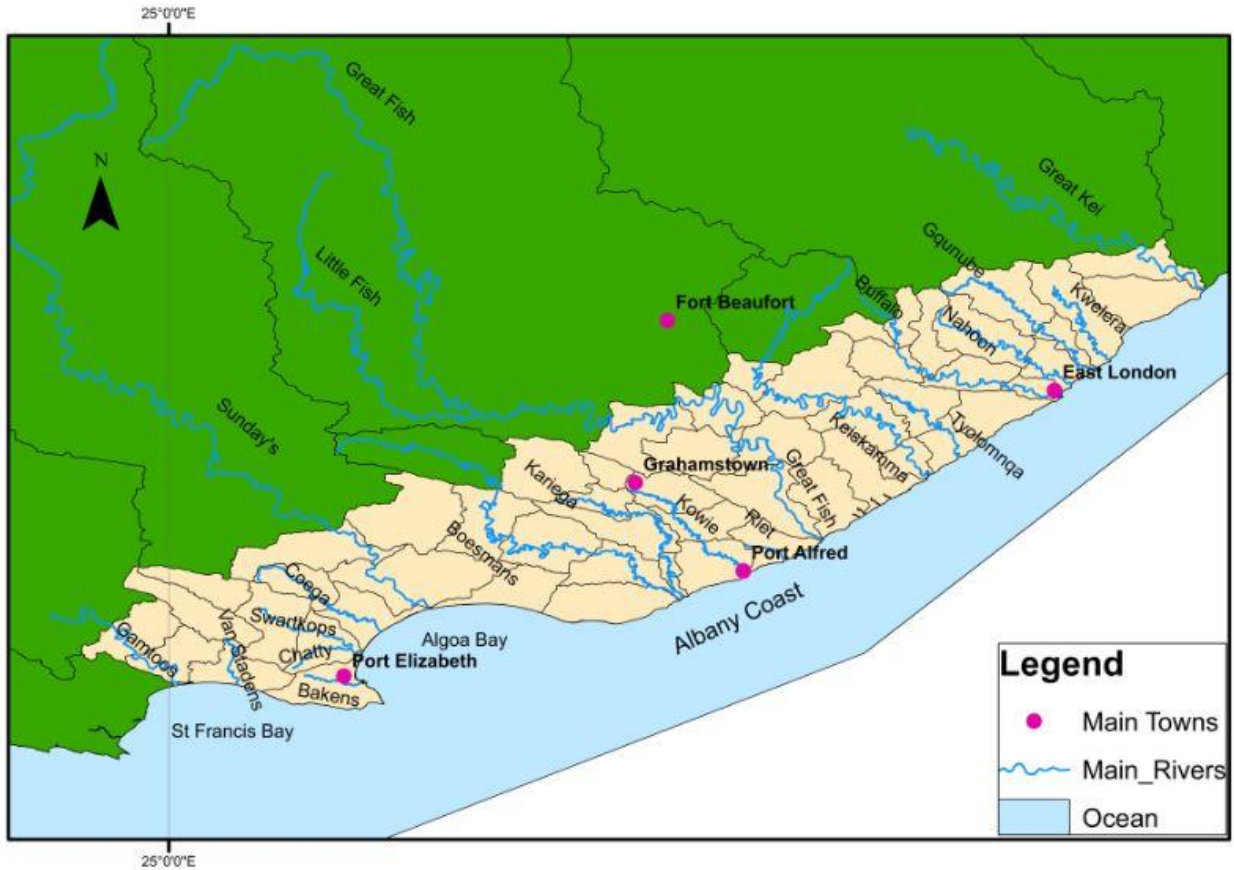


Figure 3.4: Rivers in the study area.

### 3.2.4. Topography of the study area

Most of the study area consists of relatively higher rainfall coastal catchment areas and the topography reflects increasing altitudes with distance from the coast (Figure 3.5). The most western part of the area has numerous mountain ranges running parallel to the coast, namely the Baviaanskloof Mountains, Tsitsikamma Mountains and the Groot-winterhoek Mountains (Shand, 2004). The Nelson Mandela Bay Metropolitan area, between the Van Standens River and Sunday's River, is fairly flat with the coastal plain sloping toward the sea and averaging around 75m above mean sea level (Klages *et al.*, 2011). The north-western parts of the NMBM are intruded by the Groot-winterhoek Mountains, part of the Cape fold mountain range (Klages *et al.*, 2011). The Albany Coast comprises steep, well incised river valleys in bush covered hills (Shand, 2005). Coastal catchments have significant runoff with less than average in the northern parts of the study area. Higher percentages of runoff occur during years in which floods occur (Shand, 2005). The Amatole- Kei area exists along the coastline between the Keiskamma River and the Great Kei River, then progresses inland to the Amatola mountain range at a height of 1960m above mean sea level (amsl) (Anon., 2004).

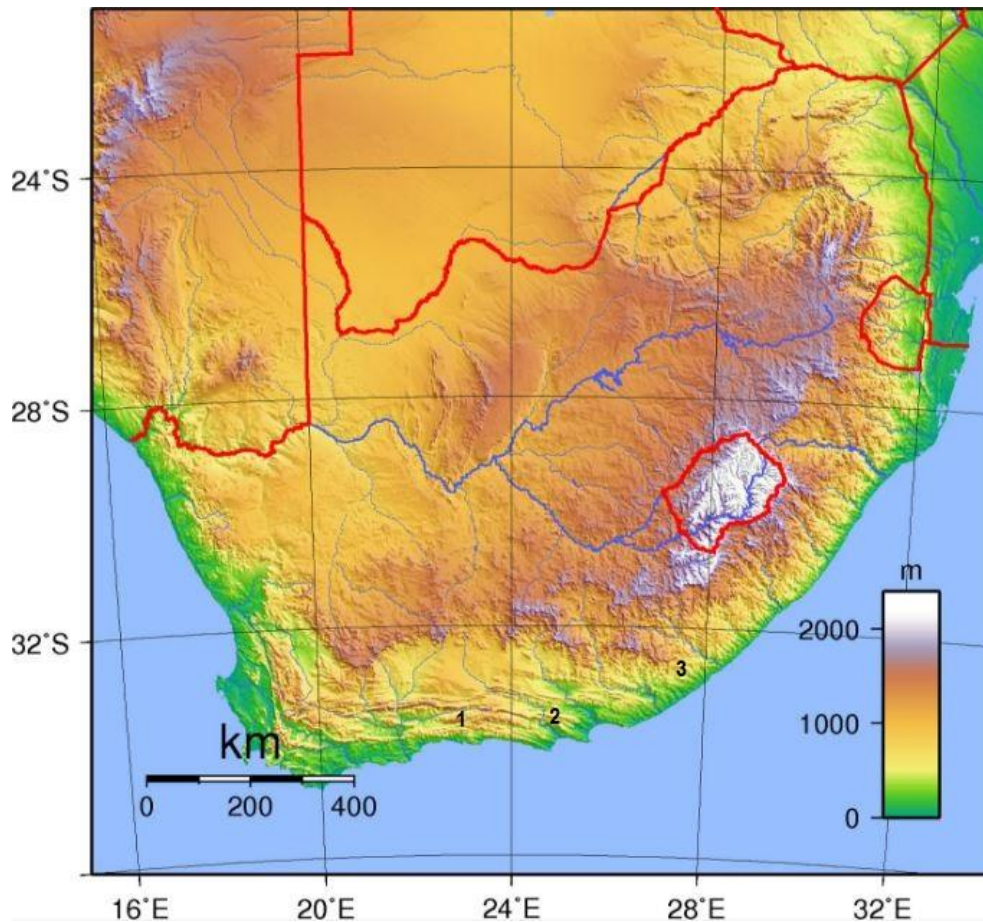


Figure 3.5: Topographical map of South Africa with elevation in metres. Mountain ranges of interest are: 1. Cape Fold Mountains, 2. Groot-winterhoek Mountains, 3. Amatola Mountains Source: Modified from Mapsof.net (2017).

### 3.3. Conclusion

The study area has been detailed with the western boundary along the Gamtoos River and the eastern boundary along the Great Kei River. The coastal areas have a temperate climate with annual rainfall, which peaks slightly in the summer season. The study area has many large rivers which drain the higher lying areas inland with the Amatola coastal mountains being the highest range in the study area.

## **Chapter 4 Methods**

### **4.1 Introduction**

The methods, techniques and tools used to achieve the aim of this research are presented. A fundamental intention of this study is to conduct a meteorological analysis of extreme flood events in the southern parts of the Eastern Cape between the Gamtoos and Great Kei Rivers.

In the research matrix, indicated in Table 1.1, each objective and research question was identified. Each objective of the study will now be given in greater detail and the corresponding methods and tools used to achieve these objectives will be highlighted.

### **4.2 Objective 1: Identify extreme historical flood events**

#### **4.2.1 Introduction**

The first objective was to conduct research and identify extreme historical flood events within the study area and to investigate which flood events were the most severe. First, severe weather events were identified through correspondence with the South African Weather Service. All severe weather events were reported in a published book by the SAWS, named Caelum and is discussed in detail below. Newspaper articles were then collected for extra information using the dates identified in Caelum as well as any disaster management reports.

#### **4.2.2 Caelum**

Caelum lists, in chronological order, the history of notable weather events in South Africa. The published hard copy reviews the years 1500-1990 and a digital copy in a Microsoft excel format was obtained for the dates from 1647 to 2013. Caelum was produced by sourcing newspaper articles, weather related articles as well as meteorological reports and publications from the then "Weather Bureau", with the aim of documenting "significant weather events" (Weather Bureau, 1991). Only events that were reported were able to be published in Caelum and this could show an inconsistency in the data as some events may have been unavoidably omitted. However, as this study concentrates on significant severe events, most of these events are recorded due to the impacts in terms of their damage and/or loss of life. It was decided that only severe events that occurred after 1900 were to be considered

as urban expansion and land use change can have a large impact on run-off and therefore, floods in an area. Reporting of events was also more improved in the 1900s with limited historical evidence before this time.

The printed version of Caelum gives the date, area and a brief description of the event in a few sentences. The digital format of Caelum includes the date, the type of event, where the event occurred, GPS coordinates of the location, height of the station and comments which range from damage recorded to the number of deaths. Meteorological data for each event is not recorded in the digital format of Caelum. Therefore, rainfall data was collected, from the SAWS, for the flood events recorded in Caelum that fell within the study area.

### 4.2.3 Rainfall data

#### 4.2.3.1 Rainfall data collection

Rainfall data from 187 rainfall stations in the Eastern Cape was collected, of which 94 fell within the study area (Figure 4.1).

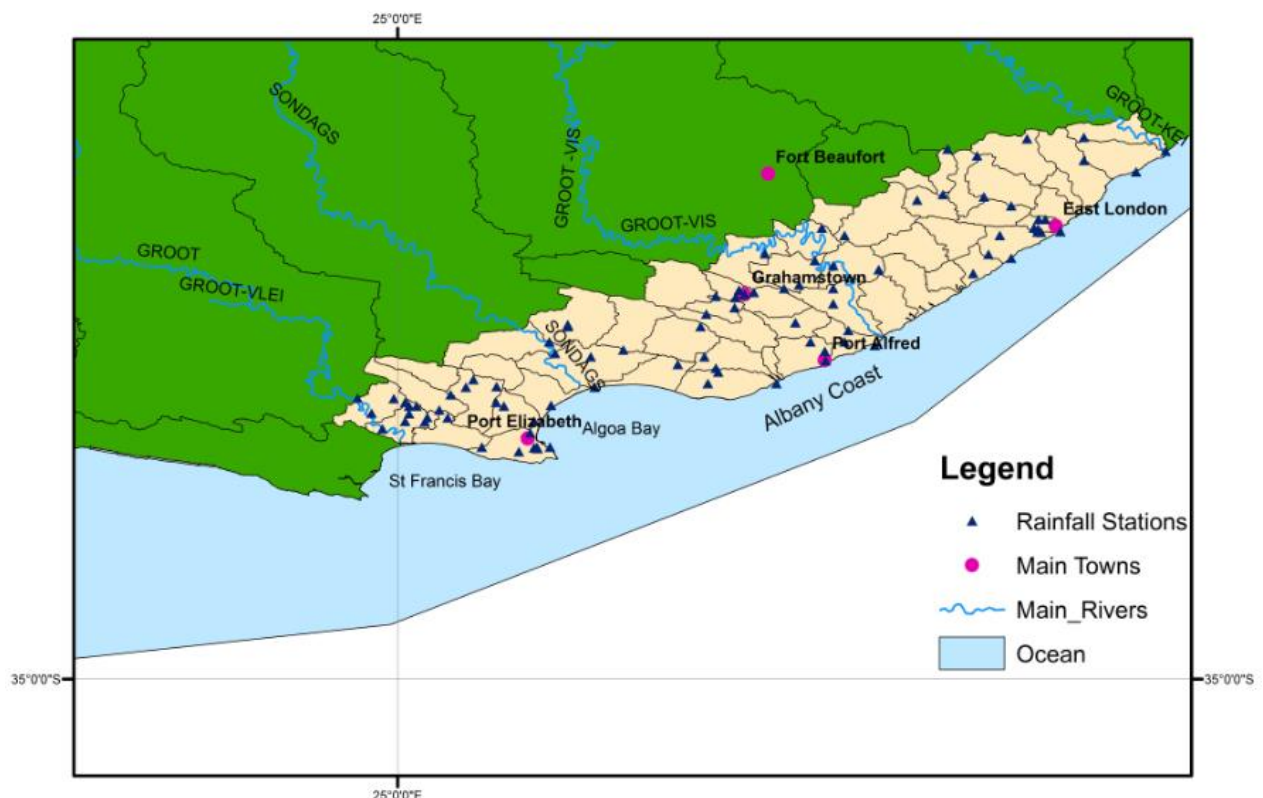


Figure 4.1: Rainfall stations within the study area.

The rainfall data was filtered according to the flood event dates acquired from Caelum. For each flood event, the rainfall station that received the highest twenty-four-hour rainfall was recorded.

In order to obtain realistic rainfall values that would have contributed to the flood, all the stations within the flood area were looked at. For example, if Caelum stated that the flood occurred in Port Elizabeth, all the rainfall stations around the area and upstream of the city were considered and analysed and not just the closest rainfall station to the city centre or the flood area. This was done in order to consider events where rainfall fell in the watershed areas upstream of the affected area and perhaps not necessarily in the flood area itself.

In some instances the highest twenty-four-hour rainfall at a rainfall station was excluded and the next highest rainfall used. These instances occurred when the highest twenty-four-hour rainfall at a rainfall station was too far away to have been able to contribute to the flood or contributed to runoff into a different catchment area than from where the flood occurred. While there are many socio-economic as well as hydrological factors that contribute to a flood, in terms of a meteorological analysis, classifying the severity of flood events according to the amount of rain recorded, was found to be the most pragmatic approach.

Flash flood events tend to occur when heavy rainfall occurs in short periods of time, with high rainfall rates while riverine flooding tends to occur over a number of days of consistent rainfall (Doswell *et al.*, 1996). Therefore, the maximum event rainfall was also collected as some flood events had rainfall occurring for more than 24 hours adding to or exacerbating the flooding.

The events that had the highest twenty-four-hour rainfall amounts were organised in descending order. The same was done for the event rainfall category. The top five for each category were then identified and analysed.

#### *4.2.3.2 Data quality control and troubleshooting*

The SAWS rainfall data was used to retrieve rainfall values. The SAWS ensures strict quality control of rainfall values from various weather stations around the country. Therefore, due to these quality control measures already taken, the SAWS values were trusted. SAWS rainfall values were selected above values reported in the Caelum, as Caelum uses newspaper reports in conjunction with reported rainfall values from other sources, such as municipal or private stations. These other sources were not as reliable due to lower quality control measures.

Due to the study ranging over a long period of time, rainfall was measured using different instruments throughout the history of the South African Weather Service. The following instrument details were collected from B. Appel (2016, *pers.comm*).

Before 1990, standard rain gauges were used to record daily rainfall, which was used in conjunction with autographic rain gauges. Autographic rain gauges were used primarily to record hourly rainfall intensity. Standard rain gauges record daily rainfall up to a maximum of 300 mm at a time. The rain gauge allows rain to fall into a container with a funnel at the top, which collects and is then measured by SAWS personnel by being poured into a measuring glass. This was done at 08:00 SAST every morning. The measurement recorded by the standard rain gauge was the official amount used in the data captured. The official daily measurement was used to compare the autographic recordings. The autographic rain gauge allows rain to fall into a funnel which filters the rain through a pipe and into a cylindrical canister. The canister has a float in it which has a pen attached to it. As the float rises, when the rain fills the canister, the pen draws a line on a graph which is attached to a rotating drum that has a clock in it. The clock was wound once a week. The graph paper stays dry and is protected by the funnel above. This method entails a graph being drawn in 10 mm peaks on graph paper. If the time taken for a 10 mm fill to be reached is short, then the graph will have a steep gradient; if it takes longer, the graph has a more gradual slope. Once 10 mm was reached, an outflow pipe allowed the water to be syphoned out and the graph returns back to 0 mm. The autographic rain gauges were used primarily to see rainfall intensity per hour as many peaks close together indicated high intensities. The problem with the standard rain gauge is that when heavy rains fell in excess of 300 mm, the SAWS personnel had to be on hand to empty the bucket to allow it to refill. This was likely during very heavy rainfall intensities and small amounts of rain may have been unrecorded during the changeover. The problem with autographic rain gauges is the time it takes for the water to be syphoned out to empty versus the rate of it filling up again. This would again lead to a small loss of rainfall during very intense rainfall periods. The autographic rain gauges were gradually phased out across South Africa in the early 1990's and were replaced with tipping-bucket rain gauges, which are still in use today. Some private farms still have standard rain gauges that require people to measure out the rainfall (Appel, 2016, *pers.comm*).

The tipping bucket rain gauge has a funnel with a pipe which leads the rainfall to fall into one of two tipping buckets, which tips when the weight of water equals 0.2 mm of rain. Once it tips the water out from the first bucket, the next bucket is ready to collect

the rainfall. A reed switch is wired to a logger which counts the tips and records the amount of tips multiplied by 0.2 and the data is then downloaded in a digital format. Fewer problems exist then in capturing high intensity periods (Appel, 2016, *pers.comm.*).

The SAWS rainfall data also contained some discrepancies. The collection of rainfall amounts needs to be conducted every day in order to have accurate daily rainfall data. However, due to some of the rainfall stations being on private farm lands, the onus is on the farmer/s to measure and record the rainfall. This has resulted in daily readings occasionally not being recorded. Instead, the recording may be taken after a few days or in some instances, even after an entire month. This makes identifying high rainfall events by twenty-four-hour rainfall very difficult. Thus, it was decided that rainfall that had accumulated over a few days could not be used to analyse the highest daily rainfall. The SAWS rainfall data had three different codes for errors in the rainfall collection. These were indicated as 'A', 'C' or '\*\*\*'. The 'A' indicated that the rainfall was not recorded that day and was accumulating. The 'C' indicated the rainfall value shown had accumulated over a number of days. In these instances, the twenty-four-hour rainfall could not be confirmed and was therefore, not used. '\*\*\*' indicated missing rainfall data while blank cells in the excel format indicated no rainfall fell for that particular day. Accumulated data was, however, used in identifying the flood event totals, where possible. Even in light of these challenges, the SAWS data still had the largest amount of consistent and quality controlled data over a long period compared to any other source.

The resulting data was then sorted from largest to smallest and the top five twenty-four-hour rainfall events and the top five event rainfall dates were chosen to be analysed.

### **4.3 Objective 2: Conduct an analysis of surface observational data from heavy rainfall events.**

#### **4.3.1 Introduction**

Once the top five twenty-four-hour rainfall and event rainfall dates were identified, the meteorological analysis could then be conducted.

For each of the dates identified, the surface synoptic charts and upper air charts were collected to identify which weather systems contributed to or caused the heavy

rainfall and associated floods. The surface synoptic charts and upper air charts were collected using NCEP/NCAR Reanalysis 1 data. Daily weather bulletins were collected from SAWS as a starting point for the dates identified. Lastly, meteorological data such as hourly rainfall, pressure, temperature, humidity, wind direction and wind speed was used to analyse the surface observational data that occurred during the heavy rainfall events.

#### **4.3.2 Daily weather bulletins**

Daily weather bulletins were available from the SAWS website and Port Elizabeth Weather office archives. These bulletins consist of a surface synoptic chart and a basic summary of the weather systems of the day (both surface and upper air) and any significant events that occurred such as cloudbursts, floods or severe thunderstorms.

The daily weather bulletins were collected for the flood event dates where available to get information of the main weather systems and occurrences of severe weather on the day.

#### **4.3.3 NCEP/NCAR reanalysis data**

The NCEP/NCAR reanalysis 1 data (Kalnay *et al.*, 1996) was used to retrieve surface and upper air data to see the location of weather systems in circulation for the selected flood dates. The NCEP/NCAR reanalysis 1 project is an analysis/forecast system that performs data assimilation using past data. The NCEP/NCAR reanalysis 1 data was used as it starts from 1948 whereas the NCEP/NCAR reanalysis 2 data only starts from 1979. Mention must be made here that using NCEP/NCAR reanalysis 1 data does not include satellite data for the southern hemisphere in the reanalysis procedure whereas NCEP/NCAR reanalysis 2 data does (Engelbrecht *et al.*, 2015). NCEP/NCAR reanalysis data has a vertical resolution of 17 pressure levels available at four times daily intervals.

Surface synoptic charts are an analysis of the state of the atmosphere at surface level over a certain area at a given time. Synoptic scale ranges from several hundred kilometres to several thousand (American Meteorological Society, 2015). The surface synoptic charts used in this study were pressure charts depicting the location of high and low pressure systems over the country of South Africa and the country's bordering oceans. The NCEP Reanalysis 1 data (Kalnay *et al.*, 1996) was used to retrieve mean sea level pressure charts of an area from 10°S to 45°S and from 05°E to 45°E.

Upper air charts are charts that depict parameters (geopotential heights, temperature, potential vorticity etc.) on a constant pressure level e.g. 500hPa. Geopotential height charts were collected at 500hPa, as a local minimum in geopotential heights occurs at this level during COLs (Molekwa *et al.*, 2014; Engelbrecht *et al.*, 2015), to see the location of upper air low and high pressure systems between 10°S to 45°S and from 05°E to 45°E. The temperature charts at 500hPa were then overlaid on the geopotential height charts to see potential cold core systems such as in the case of COLs.

#### **4.3.4 Surface observational data**

Surface observational data was collected for the events identified. This included pressure (reduced to sea level), temperature, humidity, wind direction, wind speed and hourly rainfall data which were obtained from the SAWS, Port Elizabeth and Pretoria offices. This data was then analysed to look for patterns or correlations that may have occurred between the different events. The data is presented in chapter 5 in graphical format with hours in SAST. Hourly rainfall data was analysed in order to look at rainfall intensity and to conclude whether the rainfall fell in a short space of time, or if it was over longer periods. Rainfall that falls heavily in a short space of time is more likely to contribute to flash flooding.

Pressure can be used to identify a change in synoptic systems by the pressure increasing for high pressure systems and a decreasing pressure for low pressure systems. The pressure, reduced to sea level, was measured in the standard of hectopascals (hPa). Relative humidity was analysed to assess the moisture near the surface to understand the environment in which the heavy rainfall events took place and what preceded these events. Relative humidity was in percentage. Surface temperature was included to understand the air masses in circulation prior to and during, the heavy rainfall events. This is especially important when a ridging high pressure system pushes in cold air from behind a cold front. Temperature was measured in degrees Celsius. The importance of onshore flow was mentioned in the literature review and therefore, wind direction and wind speed were measured to see if onshore winds were present in the flood events. Wind direction was measured in degrees from north (0°) in a clockwise direction. Wind speed was measured in metres per second. Wind descriptors were used in the surface data analysis as defined by the South African Weather Service, found in Table 4.1 below. A common term not found in Table 4.1 is the term for a wind which is light and variable. This refers to a wind that is light in speed with varying wind directions.

Table 4.1: Wind descriptors (Adapted from the Beaufort scale)

Descriptor	Knots	Km/h	m/s (rounded off values)
Light	1-9	1-16	1-4
Moderate	10-13	17-24	5-7
Fresh	14-19	25-35	8-10
Strong	20-34	36-61	11-17
Gale	35-40	62-74	18-20
Strong gale	41-47	75-87	21-24

#### 4.4. Conclusion

This chapter looked at the methods used to conduct this study and to meet the objectives outlined in chapter 1. Using these methods, the results for the rainfall analysis and surface data analysis follow in the next chapter.

# Chapter 5 Results and Discussion

## 5.1 Introduction

This chapter discusses the results found in the rainfall data analysis as well as the results of the meteorological assessment of severe historical flood events that occurred within the study area. Seven case studies were analysed with a case discussion at the end of each case study to highlight the important factors. This chapter, thereafter, includes a discussion of all the results pertaining to all seven cases. The chapter is then concluded with the final remarks from the results.

## 5.2 Rainfall Data Results

Using Caelum as a source, 45 flood events were identified to have occurred in the study area between 1902 and 2013. The rainfall data from all the rainfall stations available were collected for each event. The previous chapter discussed how the rainfall data was analysed, quality controlled and categorized by highest rainfall in twenty-four hours and event rainfall respectively. From these results, it was able to be established which historical flood events were the most severe in the study area.

Table 5.1 displays the five highest twenty-four-hour rainfall flood events. The most severe event occurred in the East London area with 490 mm as the highest twenty-four-hour rainfall amount recorded which was measured at the East London Agriculture (AGR) station. This rainfall amount was recorded on 27 August 1970. This occurred during the flood event that took place between 24 and 28 August 1970 which had an event total of 1101.4 mm. In Table 5.2, it can be seen that this was also the highest event total of all the floods recorded. From Table 5.1, the next highest twenty-four-hour rainfall was at Port Elizabeth with a total of 429 mm. However, in Table 5.2, this event came in only at fourth. Another interesting mention is that the second highest event total of 528 mm for the flood in the Gamtoos River area does not feature in the top five highest twenty-four-hour rainfall. This implies more consistent heavy rainfall days over a longer period rather than one significant day contributing to the event total.

Table 5.1: Top five flood events with the highest twenty-four-hour rainfall amounts in descending order.

Date	Flood Location	Rainfall station	Amount (mm)	Date recorded	Event total (mm)
24-28/08/1970	East London	East London AGR	490	27/08/1970	1101.4
31/08/1968 01-02/09/1968	Port Elizabeth	Port Elizabeth WK	429	01/09/1968	455
15/08/2002	East London	East London WO	317.2	15/08/2002	317.2
24-26/03/1981	Port Elizabeth	Groendal Bos	274	25/03/1981	316
05-06/11/2005	East London	Umzoniana	261.5	06/11/2005	273

Table 5.2: Top five flood events with the highest event rainfall amounts in descending order of rainfall amounts. Dates marked with an asterisk also appear in Table 5.1.

Date	Flood Location	Rainfall Station	Event Rainfall Amount (mm)
*24-28/08/1970	East London	East London AGR	1101.4
28-31/12/1931 01/01/1932	Gamtoos and Sunday's River	Otterford Bos	578
*24-26/03/1981	Port Elizabeth	Port Elizabeth Cotswold	460
*31/08/1968 01-02/09/1968	Port Elizabeth	Port Elizabeth WK	455
24-27/07/1983	Patensie/Port Elizabeth and Gamtoos	Otterford Bos	428

Some flood events occur both in the top five for twenty-four-hour rainfall and in the top five for event rainfall as indicated by an asterisks in Table 5.2. These cases are 24-28 August 1970, 1 September 1968 and 24-26 March 1981. Therefore, instead of ten case studies, only

seven remain due to the recurrences of the events. The seven case studies will therefore be investigated and an analysis of surface observational data conducted for each.

### **5.3 Case Studies**

#### **5.3.1. Case 1: East London 24-28 August 1970**

##### *5.3.1.1 Case Overview*

This flood event represents the most severe event according to rainfall data to occur in the study area. This remarkable event obtained both the highest twenty-four-hour rainfall and the highest event rainfall. The highest twenty-four-hour rainfall occurred at the East London Agriculture rainfall station which recorded 490 mm ending at 08:00 SAST on 28 August 1970. The event totalled 1101.4 mm at the same station for the five-day period from 24-28 August 1970. The five-day rainfall accumulation can be seen in Figure 5.1 with the concentration of the heaviest rainfall just inland from East London city. This resulted in extensive flooding and damage to roads and properties as well as communication disruptions. Unfortunately, seven lives were lost due to the flooding.

The synoptic analysis is given in the next section to identify which weather systems were responsible for the devastation caused in East London.

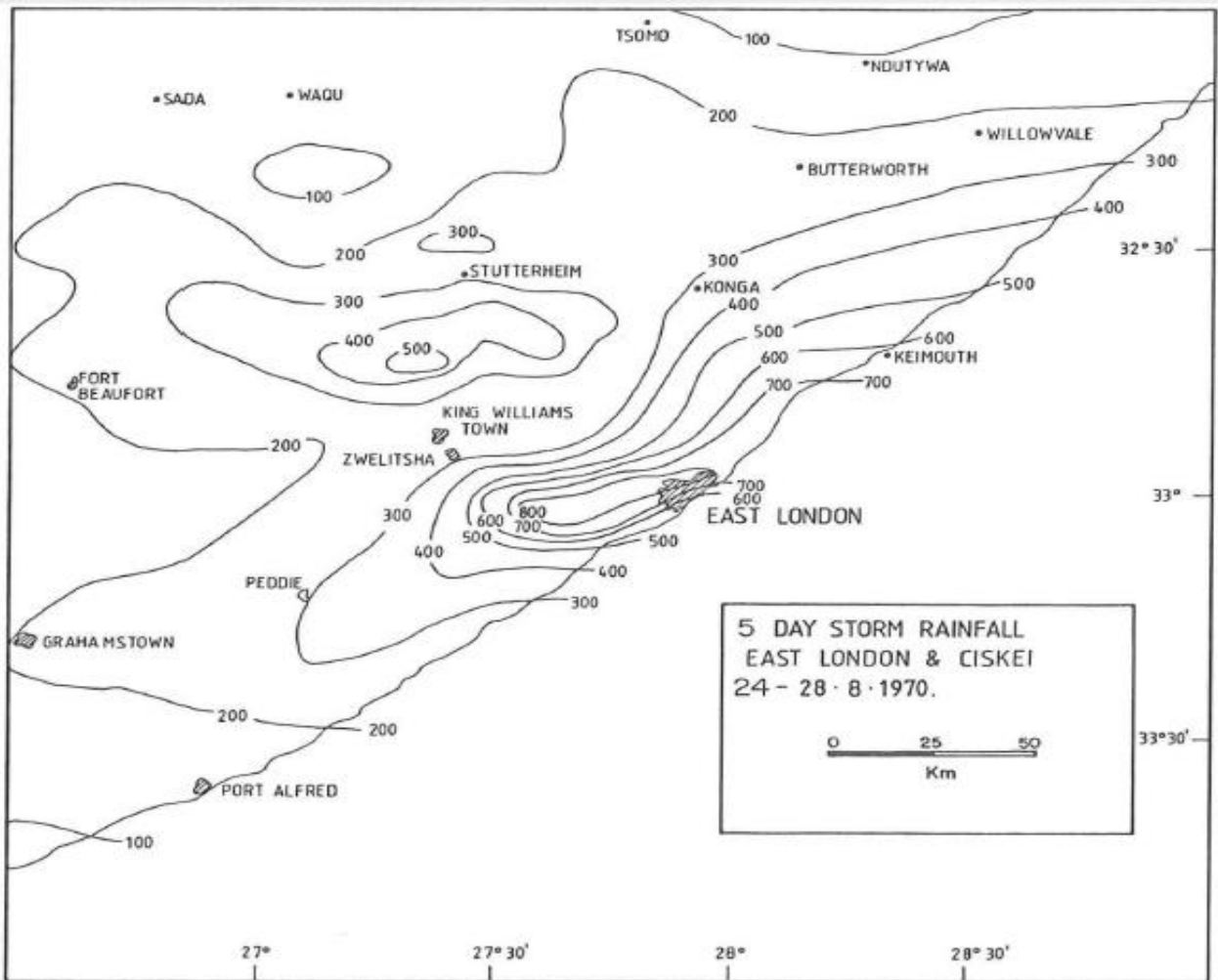


Figure 5.1: The five-day rainfall accumulation in East London on 24-28 August 1970. Source: Adamson (1981:25).

### 5.3.1.2. Systems Analysis

The synoptic overview looks at the synoptic scale systems that may have contributed to the heavy rainfall. This section is categorized into days to better follow what happened in a consecutive time series.

**Monday 24 August 1970:** A cold front moved through South Africa, with the low pressure system located south of Port Alfred at 00:00Z (Figure 5.2). The Atlantic Ocean high pressure system can be seen south-west of the country pushing in behind the cold front. The upper air analysis (Figure 5.3) revealed a broad upper air trough over the western part of the country at 00:00Z with a temperature trough just south of Cape Agulhas.

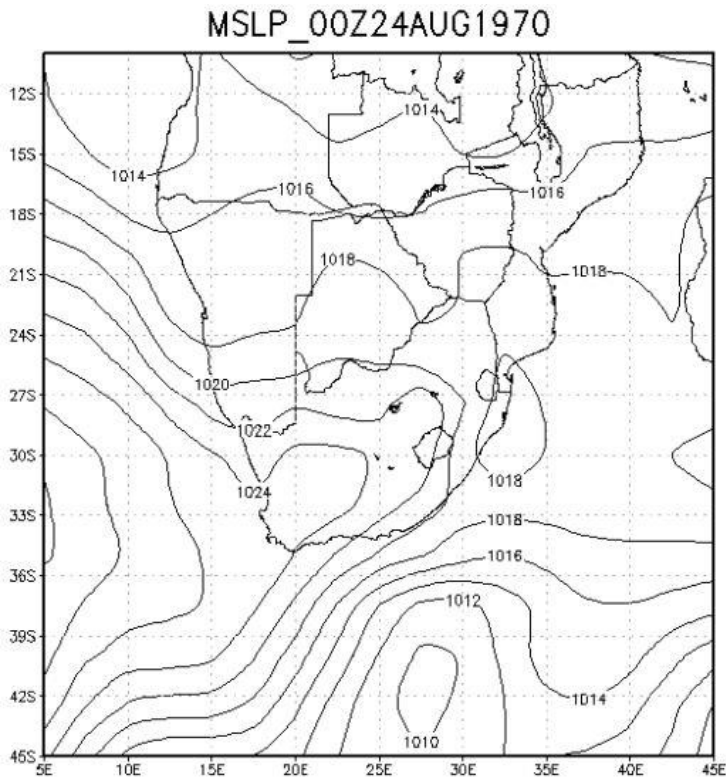


Figure 5.2: Synoptic chart of mean sea level pressure (hPa) at 00Z on 24 August 1970.

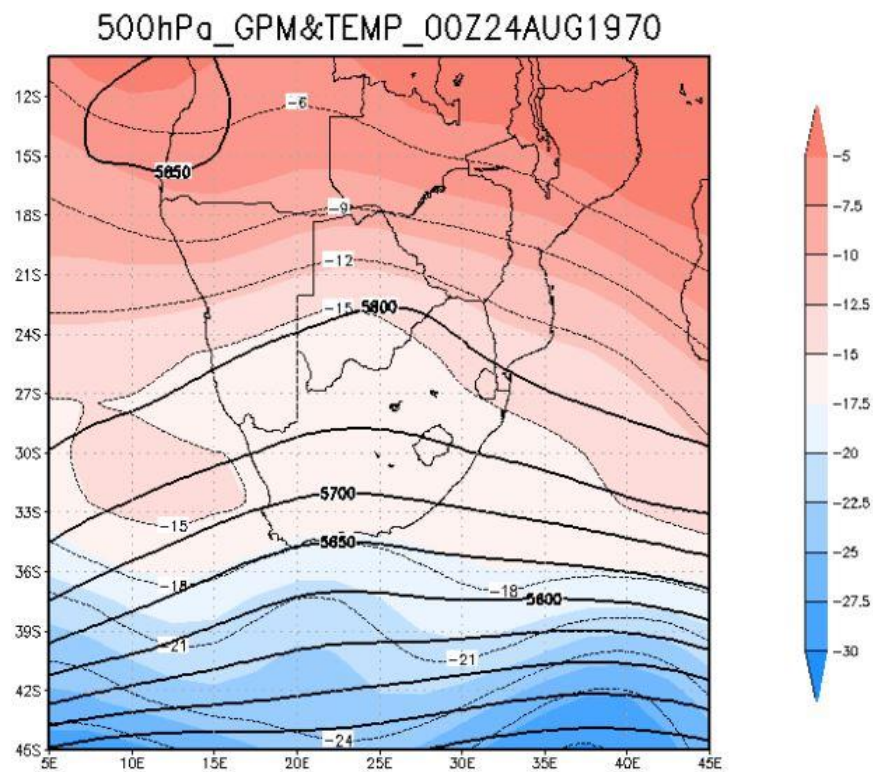


Figure 5.3: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 24 August 1970.

**Tuesday 25 August 1970:** The surface analysis (Figure 5.4) shows that the cold front from the previous day had moved to the south east and the high pressure system ridged in behind the cold front along the south coast of the country. A surface trough developed over the central interior of the country. The upper air chart (Figure 5.5) showed a steeper upper air trough off the south west Cape compared to the previous day as well as an intensification of the temperature trough which extended further north to be in similar proximity to the upper air trough.

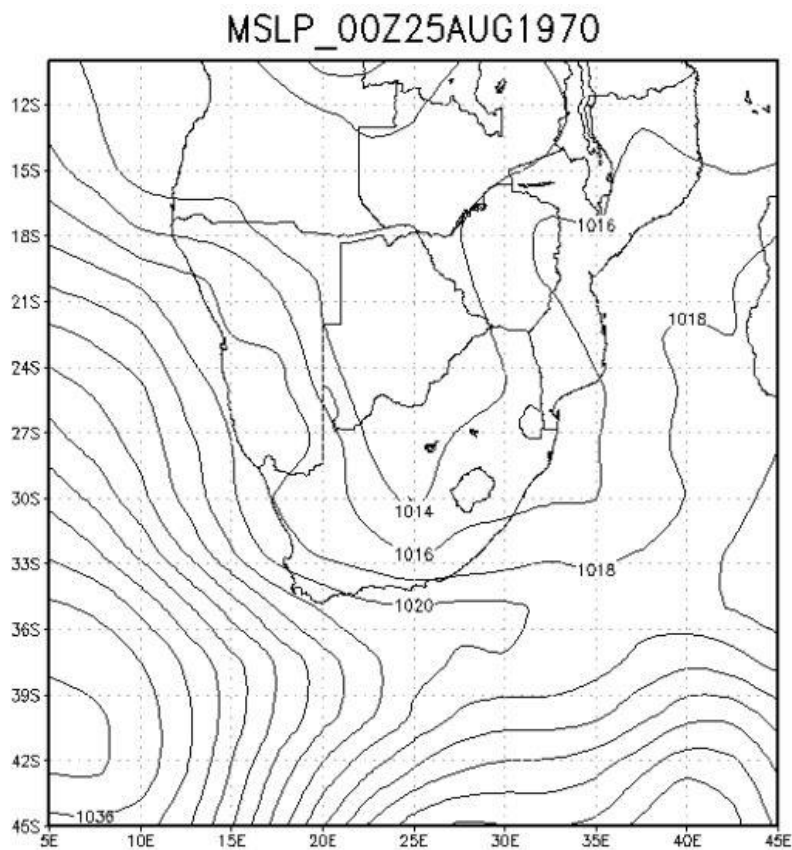


Figure 5.4: Synoptic chart of mean sea level pressure (hPa) at 00Z on 25 August 1970.

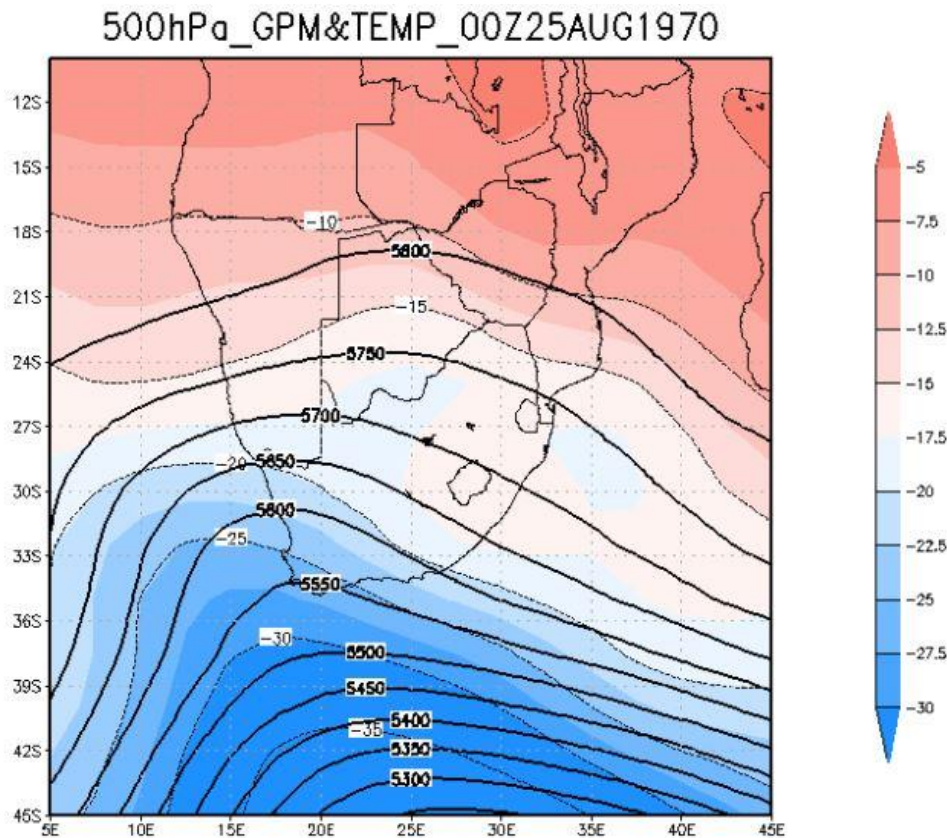


Figure 5.5 Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 25 August 1970.

**Wednesday 26 August 1970:** The Atlantic Ocean high pressure system moved northwards from approximately 40°S the previous day to be located around 36°S with a ridge extending along the south coast of the country (Figure 5.6). A tight pressure gradient can be seen between the ridge of the high pressure system and the surface trough which is extending off of the Kwa-Zulu Natal coastline. The upper air trough from the previous day had intensified into a COL, with a cold core, which was located over the western parts of the Northern Cape at 00:00Z (Figure 5.7).

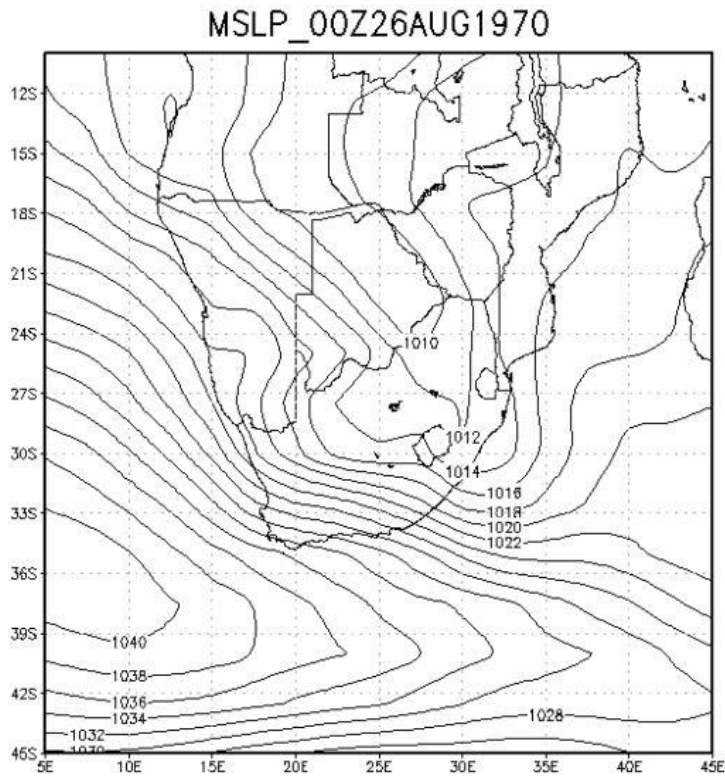


Figure 5.6: Synoptic chart of mean sea level pressure (hPa) at 00Z on 26 August 1970.

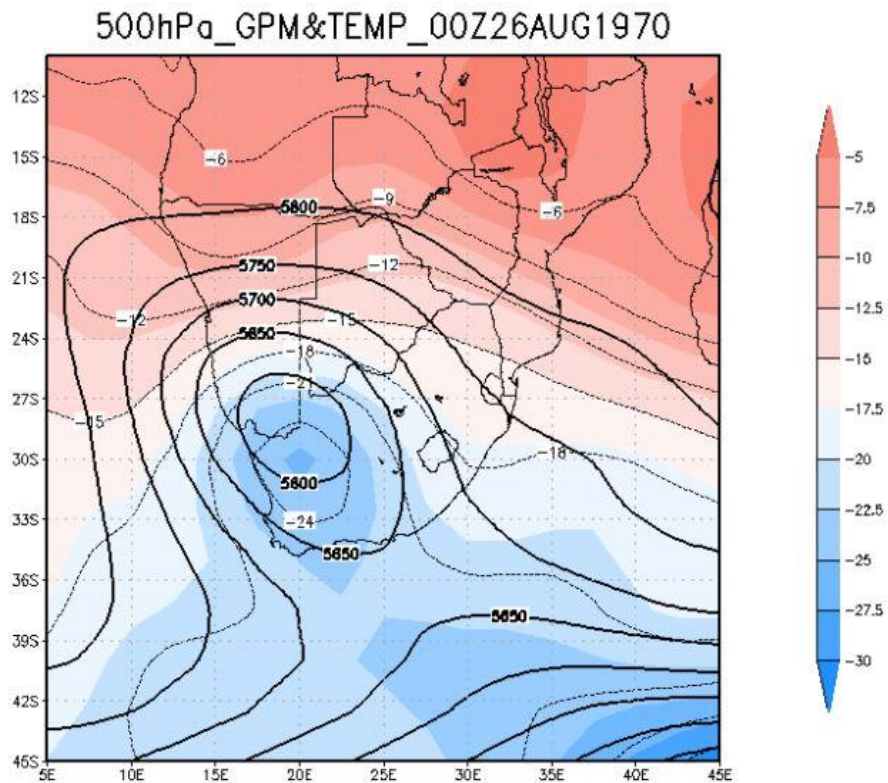


Figure 5.7: Geopotential heights at 500hPa in black contours with 500hPa temperature in shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 26 August 1970.

**Thursday 27 August 1970:** The high pressure system to the south west of the country again moved further north to be located around 35°S and still extended a ridge along the south coast (Figure 5.8). A surface trough extended off of the Kwa-Zulu Natal coastline once again and a surface low pressure is located over the eastern interior of the country. The COL had moved slightly north eastwards (Figure 5.9) to be located over the central parts of the Northern Cape although slightly weaker (5650gpm and temp < -20°C) compared to the previous day (5600gpm temp < -24°C).

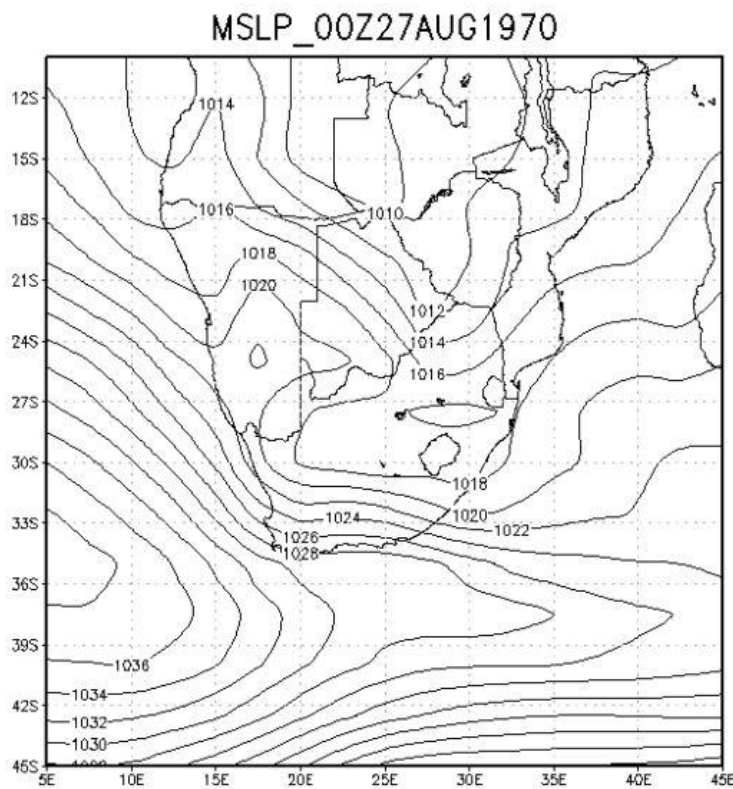


Figure 5.8: Synoptic chart of mean sea level pressure (hPa) at 00Z on 27 August 1970.

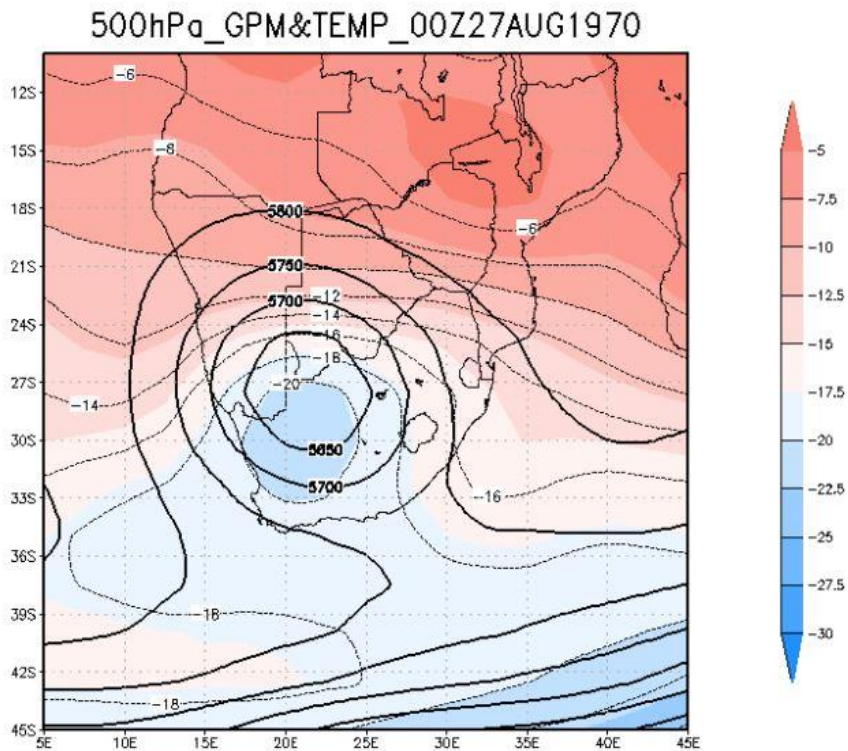


Figure 5.9: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 27 August 1970.

**Friday 28 August 1970:** The surface high pressure system had weakened substantially from the previous day from 1038hPa to 1030hPa (Figure 5.10). Although the ridge still extended along the south coast the pressure gradient was weaker than in previous days. A surface low pressure system existed along the Kwa-Zulu Natal coastline. The COL had progressed slowly eastwards to be located over the central interior of South Africa (Figure 5.11) with a temperature core of -18 °C.

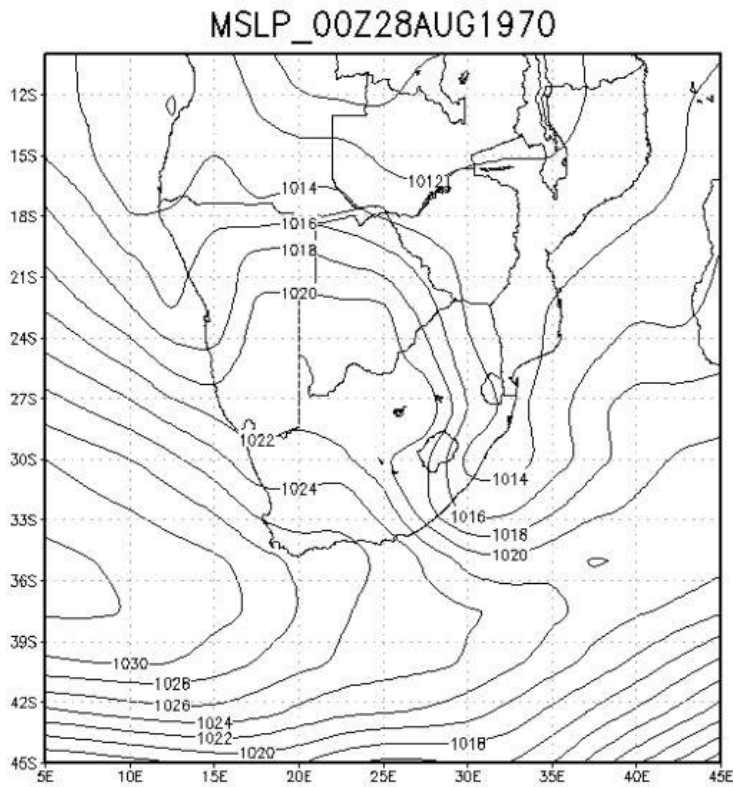


Figure 5.10: Synoptic chart of mean sea level pressure (hPa) at 00Z on 28 August 1970.

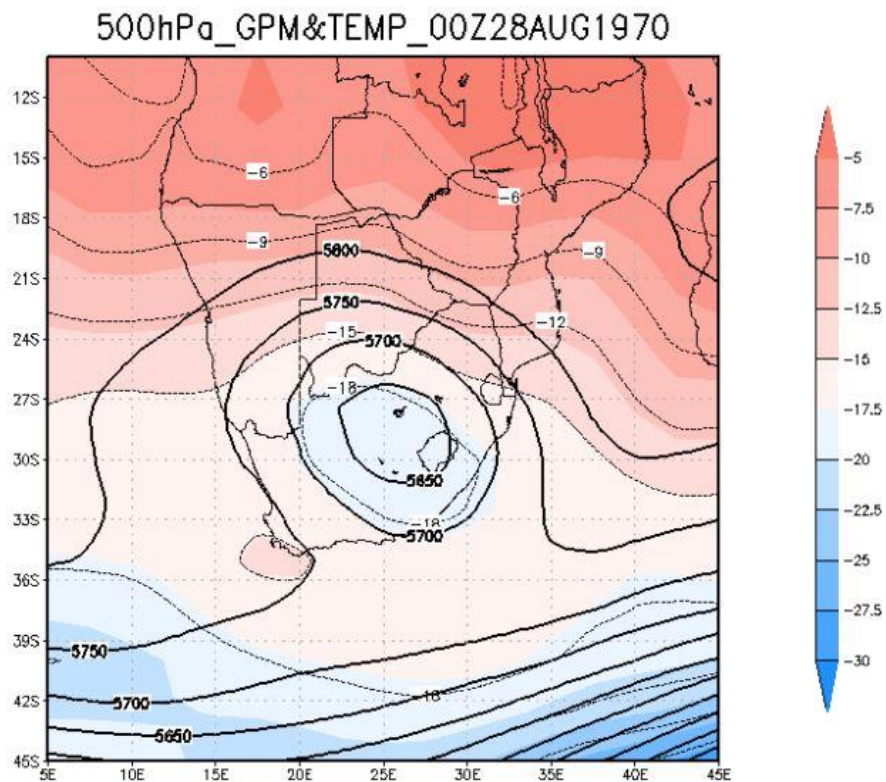


Figure 5.11: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 27 August 1970.

### 5.3.1.3 Meteorological parameters analysis

The single day with the highest rainfall for this event occurred on the 27 August 1970 which started at 08:00 SAST on 27 August and ended at 08:00 SAST on 28 August 1970. The daily rainfall for 27 August was 447 mm at East London WK and 490 mm at East London AGR station. The daily rainfall accumulation can be seen in Table 5.3 for different stations surrounding East London.

Table 5.3: Daily rainfall amounts in millimetres at stations around East London for 24-28 August 1970

Date	East London WK	East London AGR	East London Signal
24 August 1970	29	21.7	18.5
25 August 1970	155.3	220.7	98
26 August 1970	70.8	125	37
27 August 1970	447	490	405.3
28 August 1970	152.4	244	118

The SAWS has a threshold for classifying heavy rainfall. This threshold is 50 mm or greater. During this event, this threshold was not only reached for four consecutive days at East London WK and East London AGR rainfall stations but in some instances, it was almost ten times this threshold. The first significant rainfall was recorded on 25 August 1970, which coincided with a cut-off low over the western parts of the Northern Cape and the ridging of the high pressure system along the south coast. A key contributor to the heavy rainfall in East London was the presence of the surface low over the interior. The clockwise rotation around this low resulted in the inflow of moist, warm air from the Indian Ocean into the East London area (Hayward and van den Berg, 1970). This caused a marked contrast in air mass as a warmer, moister air mass from the north east met a cooler air mass from the south-west as the high pressure ridged in behind the low.

For the meteorological analysis, the East London WK station will be used as the data was recorded hourly whereas at the East London AGR station, recordings were only

taken twice daily. Each individual day will be analysed with all the applicable meteorological parameters.

Looking at the 24th August 1970, the pressure (Figure 5.12) started gradually increasing after about 04:00 to reach a peak at 09:00 but remained between about 1020 and 1022 hPa for the day. The temperature (Figure 5.13) started off at the lowest minimum compared to all the other days at 9.5 °C at 06:00 on the 24th and increased rapidly to a maximum at 11:00 of 17.6 °C. This was the highest temperature for the five-day period. The temperature then began to gradually decrease. The relative humidity, in Figure 5.14, indicated the driest profile for the five-day period on the 24<sup>th</sup>, with a minimum relative humidity at 51% at 10:00. The relative humidity began to increase rapidly after this until 14:00 when it stabilised for a short time until another rapid increase at 18:00 into the evening. The wind direction, in Figure 5.15, started off south-westerly until around 08:00 after which the wind direction began turning towards a south-south-easterly direction. After 18:00, the wind began to vary between a northerly and easterly wind for most of the night. The wind speed (Figure 5.16) started off fairly light and began to increase after 06:00 to reach a peak for the day at 7.6 m/s at 10:00. The wind speed remained in the “fresh” category until about 13:00, after which the speed began to decrease to 18:00 when the wind was less than 2 m/s which explains the rapid changes between northerly and easterly wind. A wind that is very light can tend to vary in direction and is regarded as a light (speed) and variable (direction) wind.

The pressure decreased through the morning of the 25th August but rose sharply after 14:00 from 1013.7 hPa to 1023.8 hPa by 23:00. The temperature in Figure 5.13 dropped sharply around 14:00 from 16.4 °C to 13.2 °C at 16:00. After this, the temperature remained fairly stable for the rest of the evening. The relative humidity was high for most of the day between 90 and 100% with a decrease between 10:00 and 14:00 and between 17:00 and 19:00. The wind direction started off as a northerly wind and changed to an easterly wind by 03:00 and remained easterly until 15:00 at which point the wind changed to a south easterly and remained that way for the rest of the day. The wind speed started off light and increased gradually throughout the morning. A sharp increase occurred between 07:00 and 09:00 from 4.5 to 9.8 m/s. The wind speed then decreased after 09:00 to 12:00 when the wind moderated at around 5 m/s until 16:00 when the wind suddenly spiked from 5.8 m/s to reach 13 m/s by 19:00. After this, the wind speed decreased to 5.8 m/s by 23:00.

On the 26th August, the pressure continued to increase from the previous day to reach the highest pressure in the five-day period at 1026.7 hPa at 09:00. The pressure then decreased throughout the afternoon to 1022.5 hPa by 15:00 after which it increased slightly to 1024 hPa for the rest of the night. The temperature had a minimum of 13.2 °C at 03:00 and had an increasing trend throughout the morning to reach a peak at 16.4 °C at 14:00. The temperature dropped after 14:00 to 15.5 °C but then began to increase again with the maximum of the day occurring at 19:00 at 16.6 °C. The relative humidity was high throughout the morning but continued to increase with a peak at 100% at 12:00. After 12:00 the relative humidity began to decrease with a minimum at 19:00 of 78%. The relative humidity then increased to another peak at 95% at 22:00. The wind direction averaged on a south-easterly wind direction for the entire day. The wind speed ranged between 6 and 8 m/s for the whole day with a minimum at 22:00 of 5.8 m/s.

The 27th August was the day that recorded the highest rainfall in twenty-four hours. The pressure on this day decreased throughout the morning to a minimum at 11:00 of 1017.7 hPa but then increased after this with the maximum at 22:00 of 1022.5 hPa. The temperature had a morning minimum at 06:00 of 14.4 °C, after which the temperature increased rapidly to 16.4 °C at 08:00 and then stabilised until a rapid decrease in the temperature occurred after 11:00. The temperature continued to decrease until reaching a minimum of 10.3 °C at 18:00 for the day. The temperature hovered around the 11 °C point for the rest of the night. The relative humidity was the highest for this day than for any other in the period and averaged just under 100% for the day. The lowest relative humidity was between 01:00 and 03:00 at 95%. The wind direction was south-easterly until 12:00, after which the wind changed to a southerly direction until 15:00. The wind direction then moved to a south-south-westerly wind averaging around 200° for the rest of the evening. The wind speed averaged around 6 m/s until 06:00 after which the wind speed increased rapidly to 11.2 m/s at 10:00 but then decreased. An extreme minimum occurred at 13:00 with a wind speed of 2 m/s but then increased rapidly to average around 5-6 m/s for the rest of the evening.

On the 28th August, the pressure decreased gradually for most of the first half of the day with a sharp decrease between 13:00 and 14:00 where the pressure dropped from 1018 hPa to 1015.8 hPa. The pressure then increased gradually to 1017.6 hPa by 18:00, after which it stabilised for the rest of the night. The temperature had a minimum of 10.2 °C at 02:00 and the temperature increased with a maximum of 15.2 °C reached at 11:00 and 14:00 with a minimum in between of 13.6 °C at 13:00. The

temperature decreased sharply after 14:00 to reach 12.2 °C at 15:00 with a second minimum of 11.3 °C at 18:00 but then the temperature increased gradually after this. The relative humidity was very high for most of the day with the minimum occurring at 22:00 at 94%. The wind direction started off south-westerly until 05:00 then turned south-easterly. The wind changed to a westerly at 15:00 but then changed back to a south westerly by 17:00 for the rest of the evening. The wind speed averaged about 5 m/s for the morning with a peak between 08:00 and 10:00 averaging about 7 m/s. The wind speed decreased sharply between 10:00 and 12:00 from 7.6 to 1.8 m/s. After 12:00, the wind speed increased gradually to reach 8.9 m/s for the maximum of the day at 19:00 and then decreased slowly in the evening but averaged around 7 m/s.

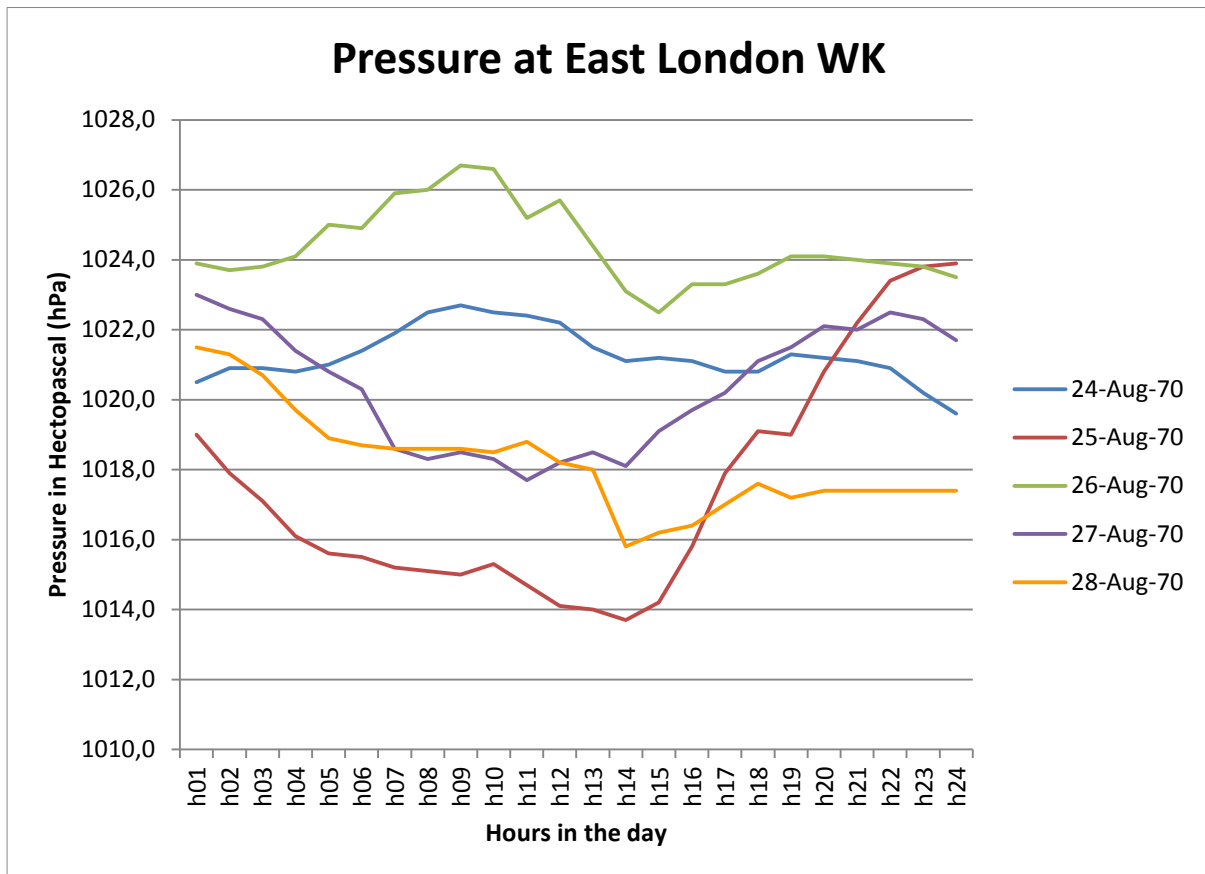


Figure 5.12: Pressure at East London WK for 24-28 August 1970.

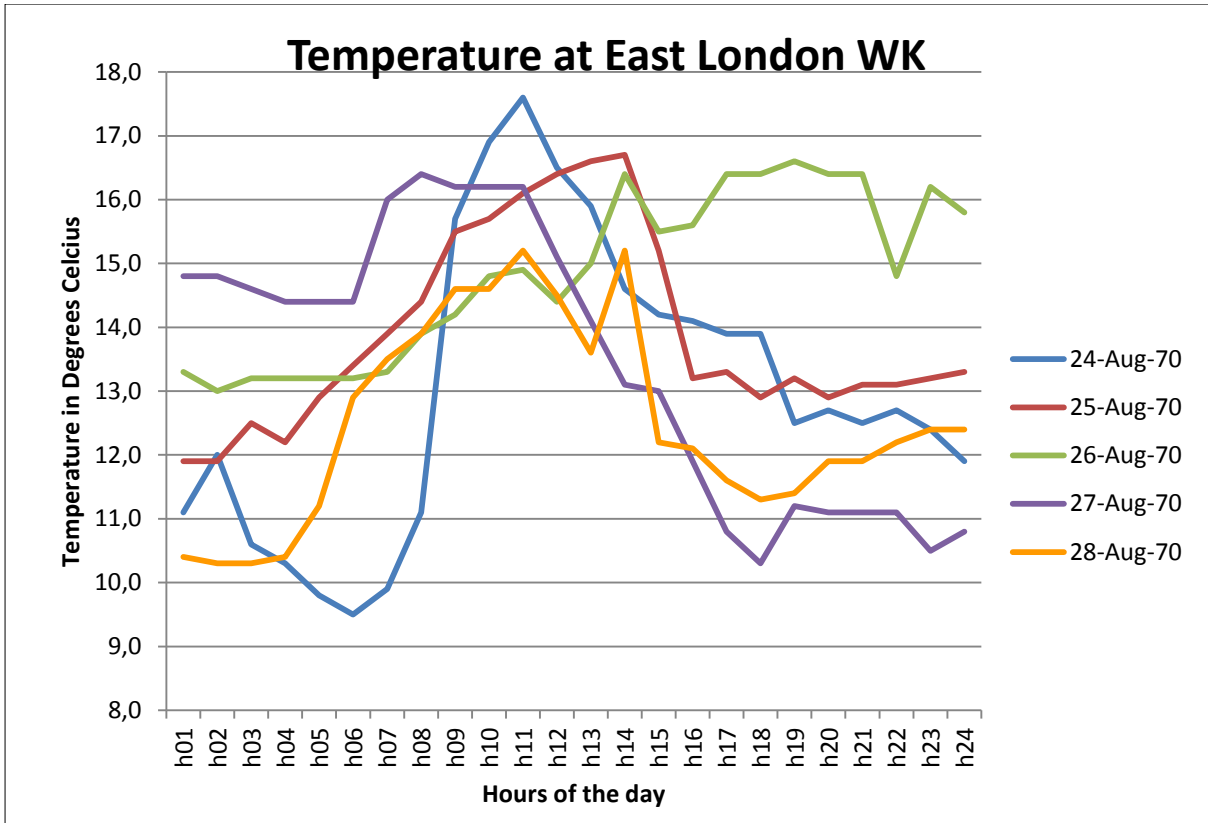


Figure 5.13: Temperature for 24-28 August 1970 at East London WK.

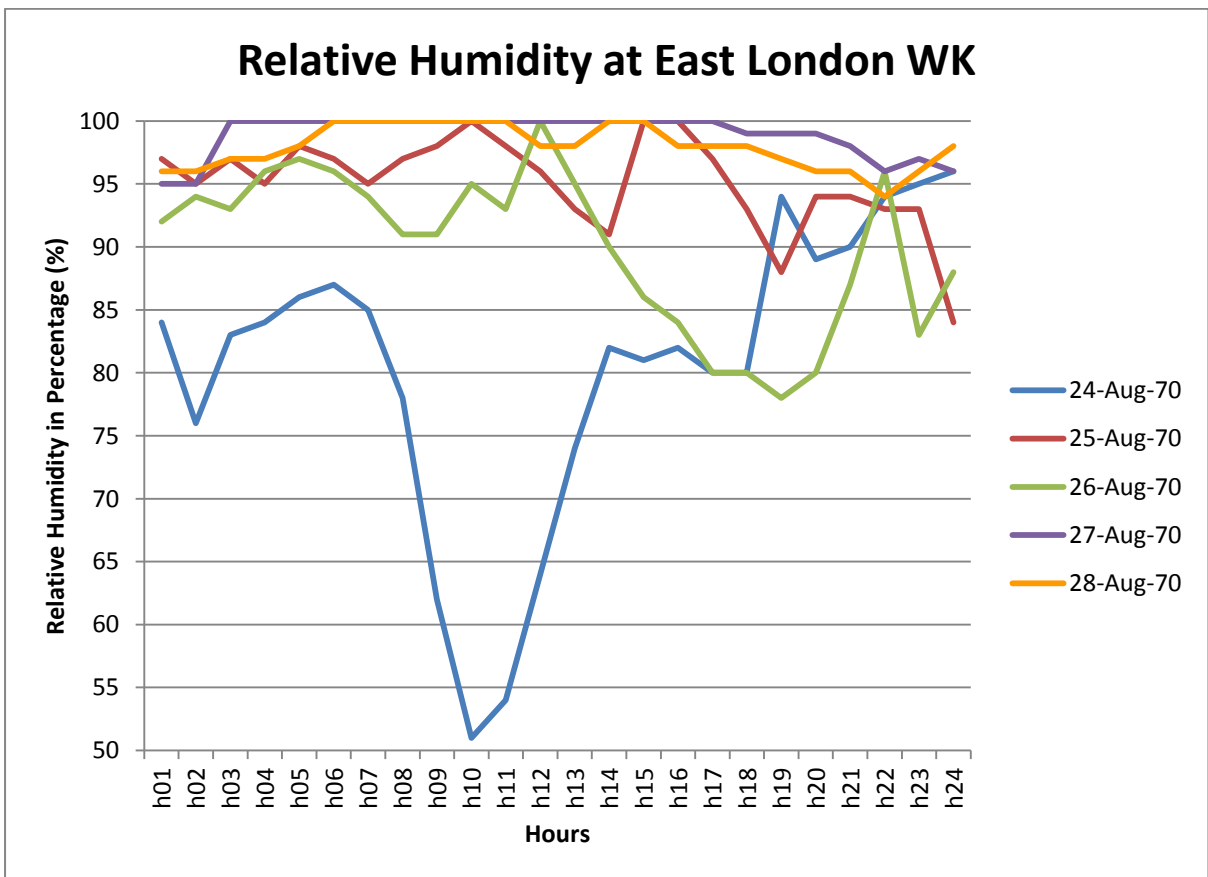


Figure 5.14: Relative humidity at East London WK for 24-28 August 1970.

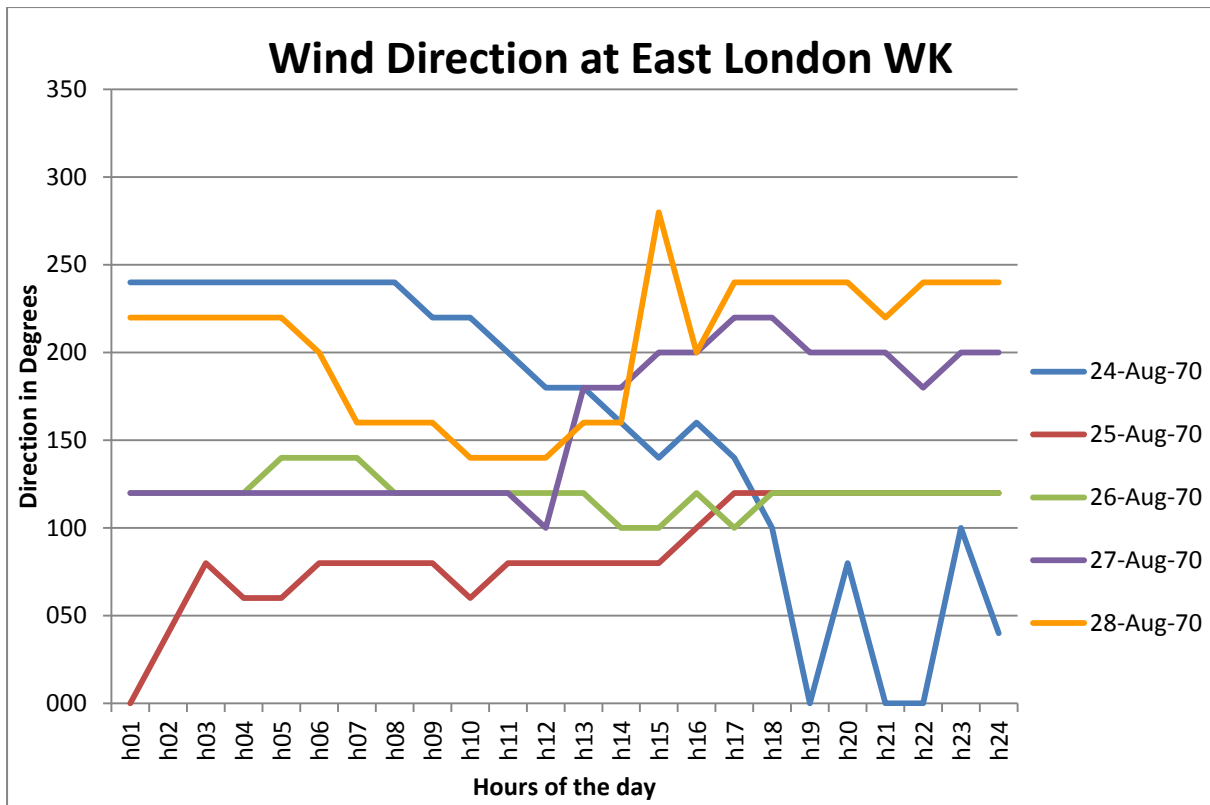


Figure 5.15: Wind direction at East London WK for the 24-28 August 1970.

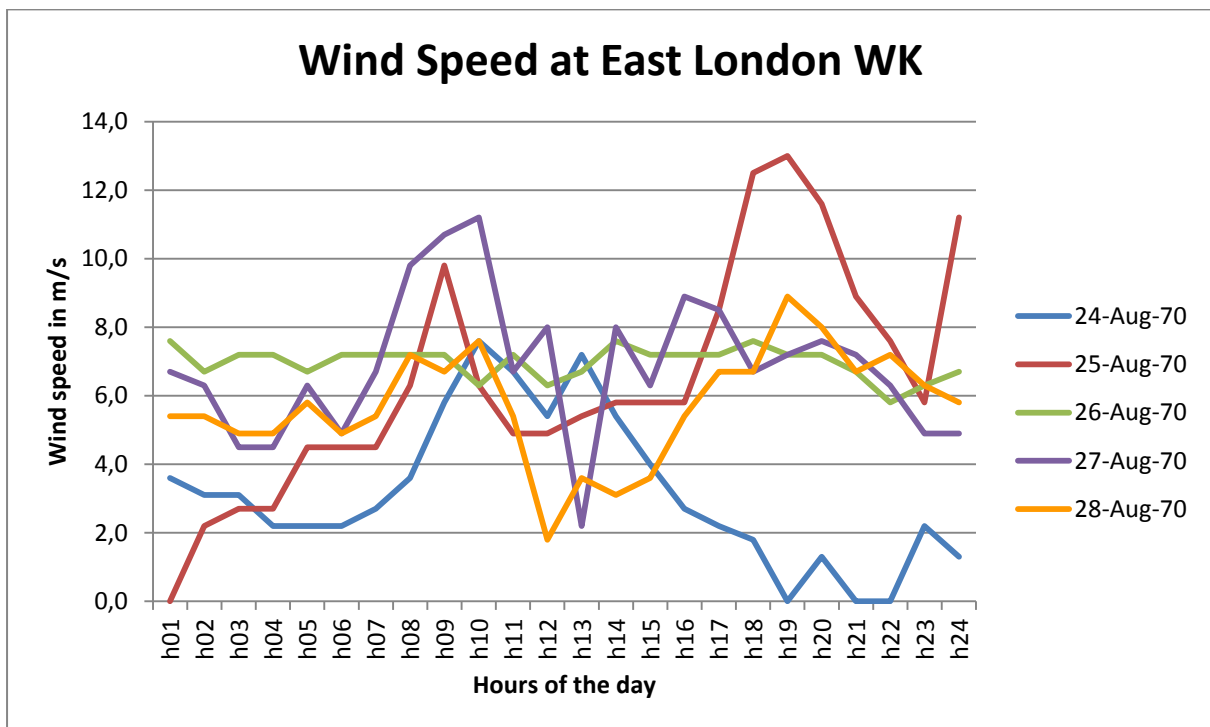


Figure 5.16: Wind speed at East London WK for 24-28 August 1970.

Table 5.3 showed daily rainfall accumulations at various stations surrounding East London. The rainfall figures in Table 5.3 are regarded as the correct, quality controlled measurements, however, daily rainfall and hourly rainfall intensity graphs

require hourly rainfall data, which was not available in a SAWS quality controlled format. Thus, the hourly rainfall figures were retrieved using the autographic rainfall charts from East London WK. It is important to note that autographic data has faults, which were discussed in chapter 4. The autographic charts themselves were not available in a hard copy for this period but the data was digitized by the Climate Centre for Water Research. The digitized data had missing amounts, especially for the 27 August 1970 which was then added from the autographic chart for that day, published by Hayward and Van den Berg (1970), as seen in Figure 5.17. The day that had significant challenges in the rainfall collection was the 28 August 1970. The other days' autographic data came to the correct daily totals, recorded by the standard rain gauges; however, a large difference occurred on the 28th in that no rainfall was recorded in the digitized data but 152.4 mm was recorded by the standard rain gauge, thus using synoptic messages issued at 08:00, 14:00 and 20:00 and an interpretation of the synopsis, it was projected that the rain fell predominantly in the morning period. Scientific interpolation was thus conducted for hourly rainfall for the 28th August.

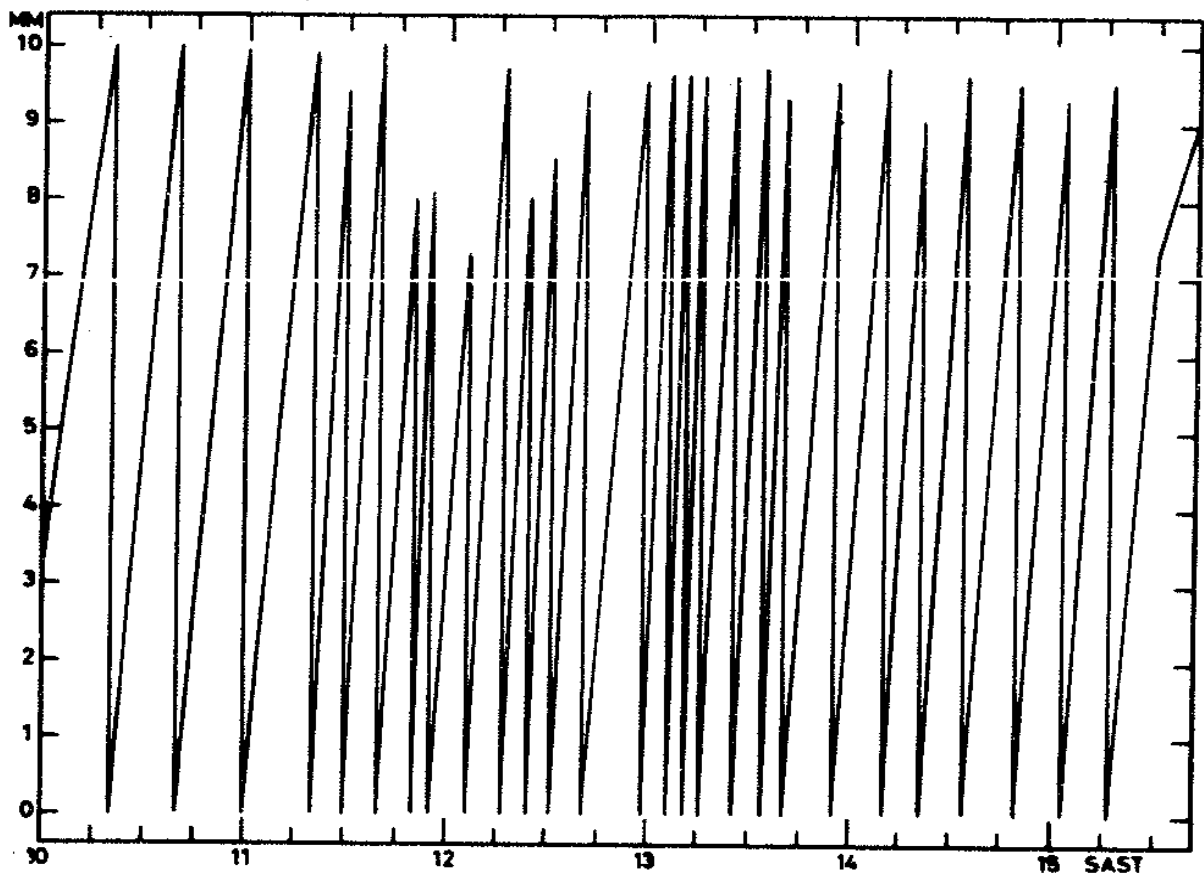


Figure 5.17: The autographic rainfall chart at B.J. Schoeman Airport in East London for 27 August 1970. Source: Hayward and van den Berg (1970:130).

The daily rainfall, in Figure 5.18, clearly shows the largest rainfall accumulation occurred on the 27 August, with just under 450 mm. The daily rainfall for the 28th and 25th August ended closely together at around 150 mm each. The lowest recording days were the 26th and 24th August respectively.

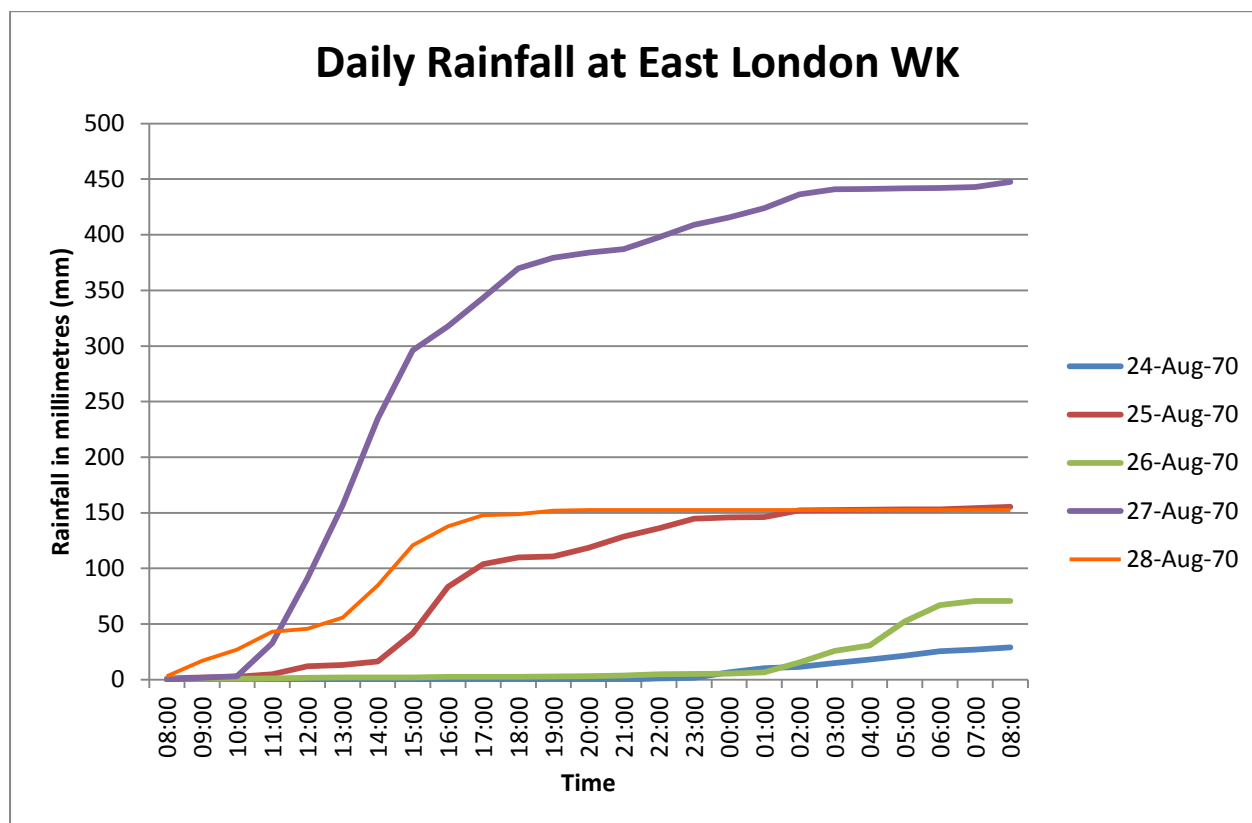


Figure 5.18: Daily Rainfall at East London WK for 24-28 August 1970.

Figure 5.19 helps to identify the highest rainfall intensity period between the 24 and 28th of August. The very noticeable highest rainfall intensity per hour occurred on the 27th August at 14:00 with an intensity of just under 80 mm/h. The next day with high rainfall intensities is for the 25th August at 40 mm/h, closely followed by the 28th August with an intensity of around 35 mm/h. These were the maximum intensities recorded for these days. The 24th and 26th indisputably had much lower rainfall intensities with the highest intensity for both days occurring in the early hours of 27th August, which was before 08:00 so still officially fell into rainfall for the 26th August.

The 24th August had rainfall occurring mainly in the evening starting at around 22:00 with the highest rainfall intensity at 00:00 of about 5 mm/h. The pressure decreased slightly during this period with the relative humidity increasing. The wind direction was varying between a northerly and an easterly wind but with very low wind speeds. At the hour of the highest rainfall intensity, the wind was a light north easterly.

The 25th August saw substantially greater rainfall amounts than the 24th with rainfall occurring through most of the day. The highest intensities, however, occurred in the afternoon period with the highest hourly intensity taking place at 16:00 with just over 40 mm/h. The morning period had decreasing pressure while the afternoon had rapidly increasing pressure. A sharp decrease in temperature occurred as the pressure started rising in the afternoon. The relative humidity also increased in the afternoon. The wind direction changed from an easterly to a south-easterly at 16:00 and the wind speed started rapidly increasing. Between 16:00 and 17:00, the wind direction was south-easterly with a wind speed increasing from less than 6 m/s to over 12 m/s.

On the 26th August, the rainfall amount decreased from the previous day with no rain occurring for most of the day. The rainfall started late in the evening around 21:00 and continued into the early hours of the 27th August. The higher rainfall intensities occurred between 02:00 and 06:00 on the 27th August. The pressure started decreasing in this period with the relative humidity being at 100%. The winds were mainly south-easterly throughout the entire day and continued into the morning of the 27th averaging about 120°. However, the wind speed was stronger through the 26th August and started decreasing into the early hours of the 27th. Small spikes in the wind speed seemed to result in higher rainfall intensities.

The rainfall continued to increase into the 27th with the highest rainfall intensities of the entire five-day period occurring between 11:00 and 15:00 with high rainfall intensities continuing to 18:00. The pressure had a decreasing tendency during this period but with slight pressure increases after 11:00. The pressure started to take on an increasing trend after 15:00. The temperature decreased rapidly after 11:00 and the relative humidity remained at 100% until after 18:00 when it decreased slightly. The wind direction changed at 11:00 from a south-easterly to a southerly wind and then moved to a south-south-westerly direction for the rest of the afternoon, averaging around 200°. The wind speed was strong for most of the day with a peak at around 09:00 in the morning. The wind speed, however, began to decrease after this but with a slight peak occurring between 11:00 and 12:00 to fall rapidly to a minimum at 13:00. After 13:00, the wind speed increased rapidly again to become fresh southerly. The highest rainfall intensity took place at 14:00 just as the wind speed increased and the wind direction changed.

The hourly rainfall intensities are displayed in Figure 5.19 but in order to maintain the integrity of the study, an analysis will not be conducted for the day of the 28<sup>th</sup> August

due to the discrepancies in the data. The scientific interpolation used was to get a general idea of the rainfall distribution, specifically for the daily rainfall totals but at an hourly scale range, the data is not suitable to be analysed.

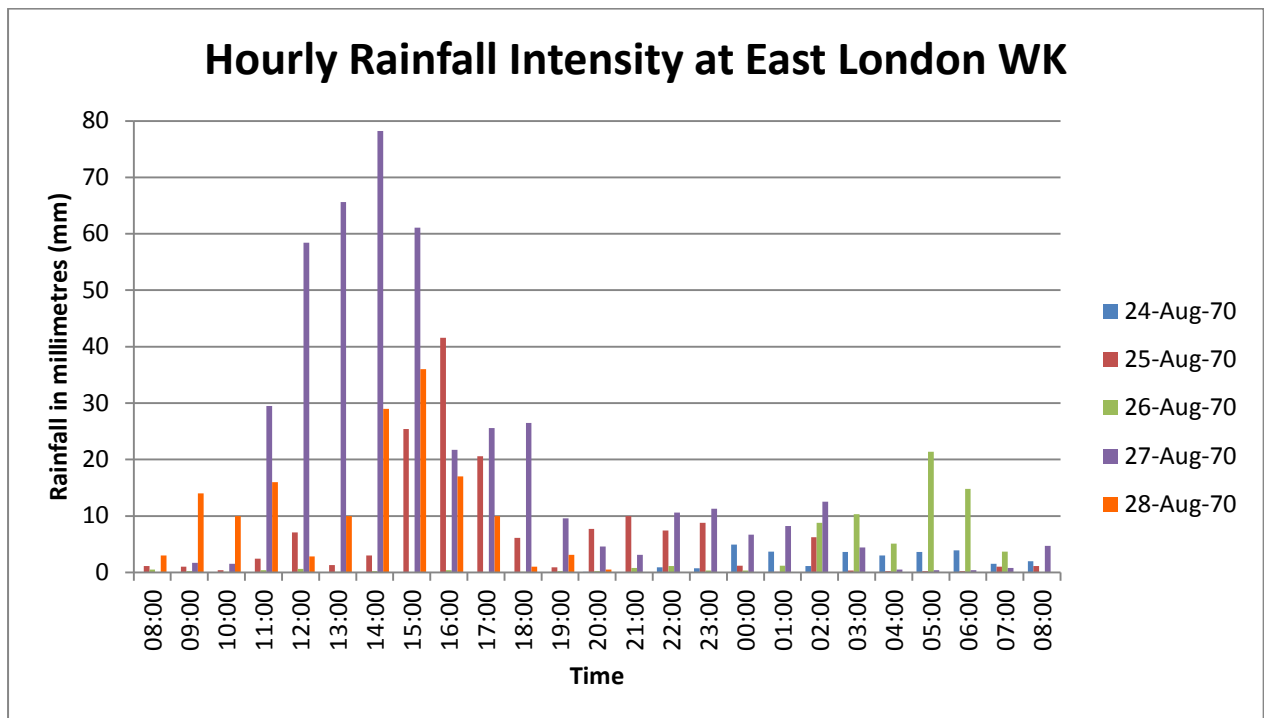


Figure 5.19: Hourly rainfall intensity at East London WK for 24-28 August 1970.

#### 5.2.1.4 Case discussion

This case had three distinctive synoptic patterns, which contributed to the heavy rainfall over the period. These were (1) a strong high pressure system to the south-west of the country which extended a ridge along the south coast region, (2) a surface low pressure system over the southern interior which protruded over the coast and (3) a cold-cored upper air low pressure system over the central interior. These patterns working together are colloquially referred to as a Black South-Easter.

The two days with the highest rainfall, namely the 25<sup>th</sup> and the 27<sup>th</sup>, both had pressures decreasing in the morning and then increasing in the afternoon; indeed their pressure signatures were very similar. The highest rainfall intensities on these days occurred at a wind direction change in a clockwise direction of easterly to south-easterly or south- easterly to southerly. Both also occurred as the pressure started increasing together with a temperature decrease and wind speed increase. This would indicate then that an onshore flow, either south-easterly, southerly or south-south-westerly at a moderate or higher wind speed, would imply high rainfall intensities but the 26<sup>th</sup> of August had both of these components and although rainfall

did occur throughout the day with a total of 70 mm, the intensities aren't like those seen on the 25<sup>th</sup> and 27<sup>th</sup>. Looking at the 12:00Z mslp maps for the 25<sup>th</sup> (Appendix 1a) the surface trough deepened on the 25<sup>th</sup> and extended off of the coastline around Port Edward. On the 27<sup>th</sup> the 12:00Z mslp map (Appendix 1b) revealed that the surface trough extended off the coast around Durban. The key indicator then seems to be a wind direction change created by a synoptic forcing such as a low pressure system moving through the area. On the 25<sup>th</sup>, the surface low pressure extended a trough just off of the coast towards Port Edward, resulting in a south easterly wind into the East London area. This occurred with the high ridging along the south coast with the upper low still west of East London. On the 26<sup>th</sup> of August, the surface low was located north of Durban. A surface low moved out over the coastline near the Durban area on the 27<sup>th</sup> with the upper low just north-west of the East London area. The 28<sup>th</sup> also showed significantly high rainfall values and although an hourly rainfall analysis couldn't be done, the synoptic analysis shows a similar pattern to the surface low pressure position of the 25<sup>th</sup> and 27<sup>th</sup> of August being around the Durban area, resulting in onshore flow behind the low pressure. The 28<sup>th</sup> also had a wind direction change from south-westerly to south- easterly at a moderate to fresh wind speed.

### **5.3.2. Case 2: Port Elizabeth 01 September 1968**

#### *5.3.2.1 Case overview*

The flood of Sunday, 1 September 1968 is a noteworthy flood in Port Elizabeth with the highest twenty-four-hour rainfall for the city in its history. The twenty-four-hour rainfall recorded at the Port Elizabeth airport reached 429 mm with an event total of 455 mm from 31 August to 2 September 1968. This event was different to the East London 1970 case in that it was a single day event with extremely intense rainfall in a short period of time, rather than over a few days. Unfortunately, 11 people lost their lives during this flood but it is supposed that had such an event occurred on a working day, the death toll would have been substantially greater.

#### *5.3.2.2 Systems analysis*

**Saturday 31/08/1968:** The surface analysis (Figure 5.20) shows a surface trough over the north eastern parts of South Africa at 18:00Z with a high pressure system to the south west of the country. The upper air analysis (Figure 5.21) shows an upper air trough lying over the south west Cape with a temperature trough also present in association with the upper air trough.

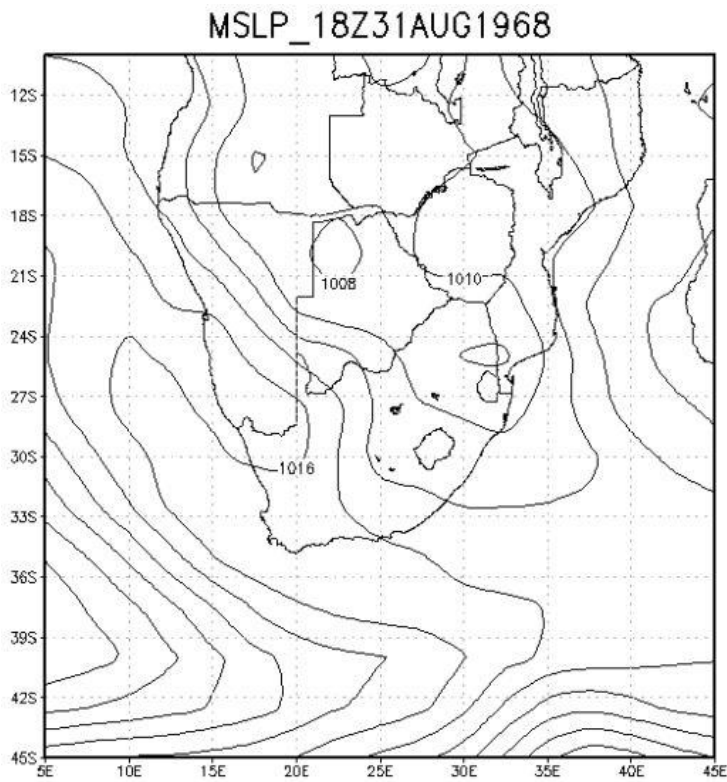


Figure 5.20: Synoptic chart of mean sea level pressure (hPa) at 18Z on 31 August 1968.

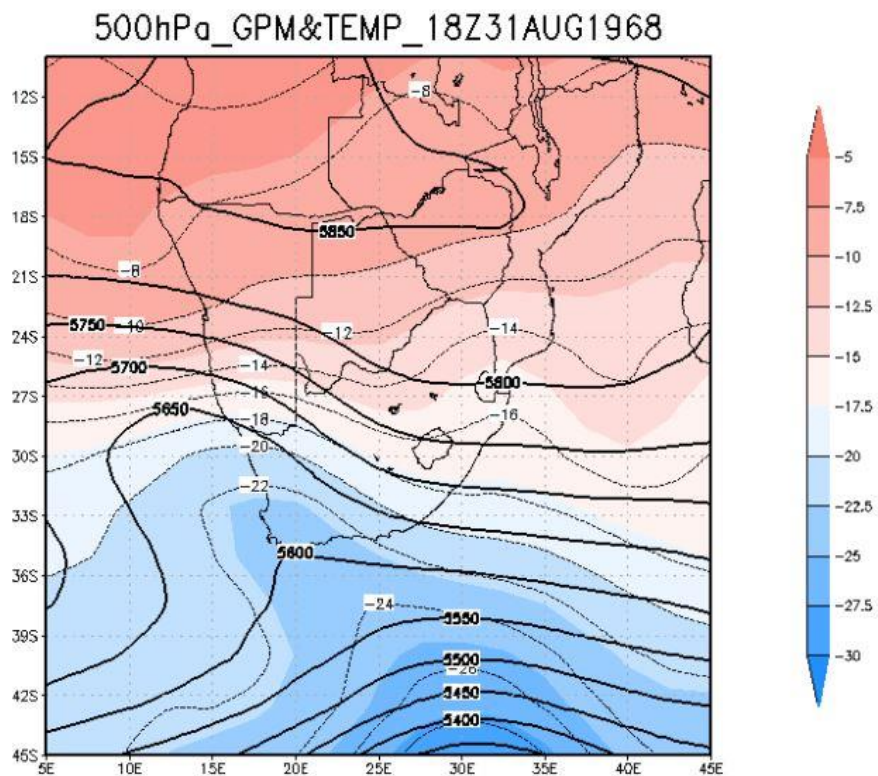


Figure 5.21: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 18:00Z on 31 August 1968.

**Sunday 01/09/1968:** In Figure 5.22, the surface analysis reveals a surface trough through the extreme north eastern parts of South Africa extending down to Mozambique. A separate low pressure system is seen on the west coast of the Western Cape with a high pressure lying to the south west of the country extending a ridge eastwards, south of the country. In the upper air (Figure 5.23) a closed low can be seen with a cold core thus a COL had developed over the south west Cape and had extended down to form the surface low there.

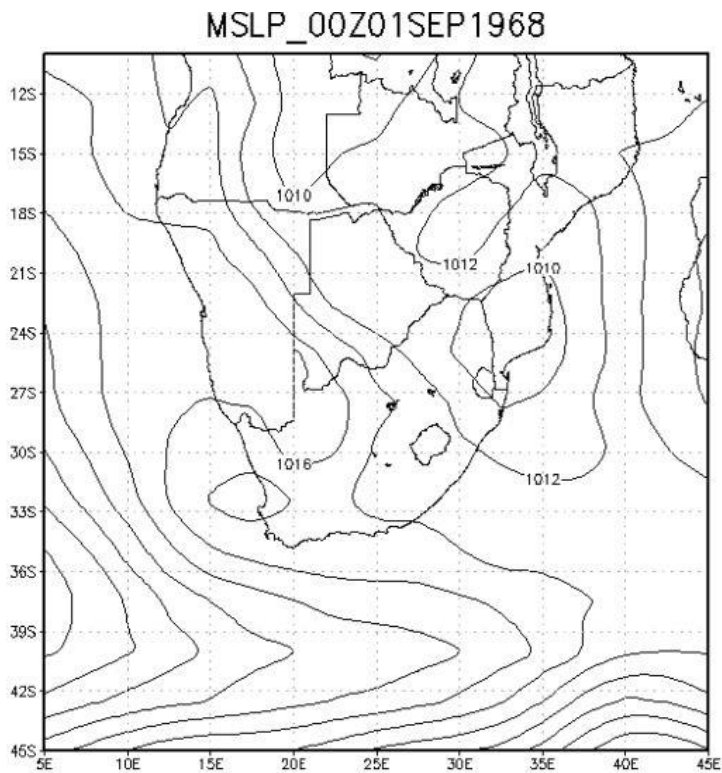


Figure 5.22: Synoptic chart of mean sea level pressure (hPa) at 00Z on 1 September 1968.

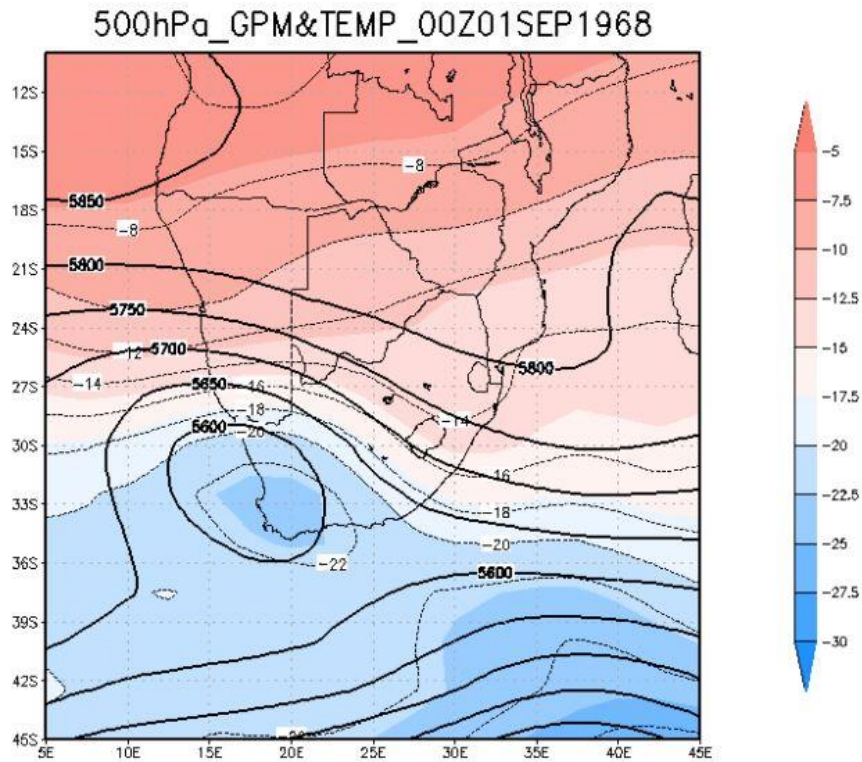


Figure 5.23: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 1 September 1968.

**Monday 02/09/1968:** The COL system had moved eastwards with the surface low located off of the Kwa-Zulu Natal coastline (Figure 5.24). The closed low at 500hPa (Figure 5.25) was located over the Eastern Cape maintaining its cold core.

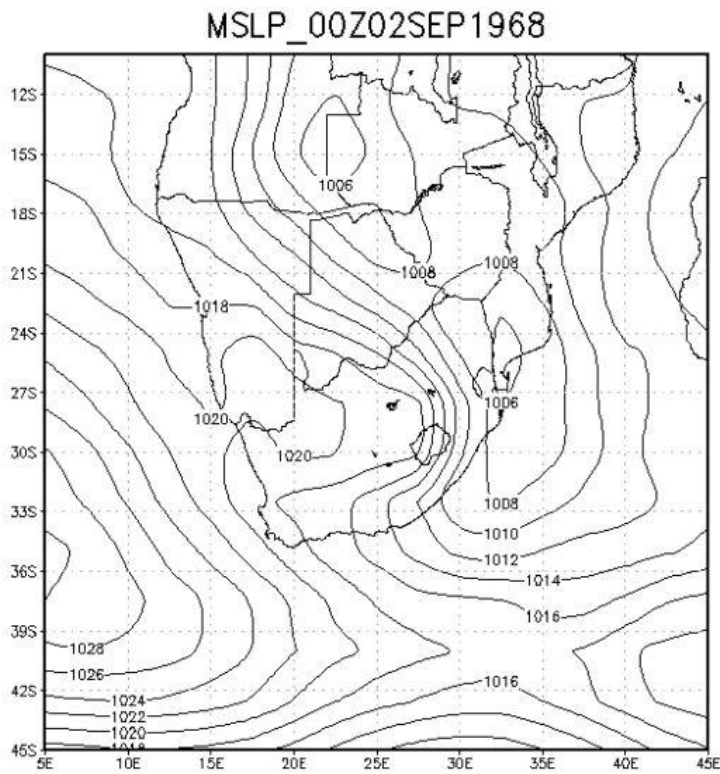


Figure 5.24: Synoptic chart of mean sea level pressure (hPa) at 00Z on 2 September 1968.

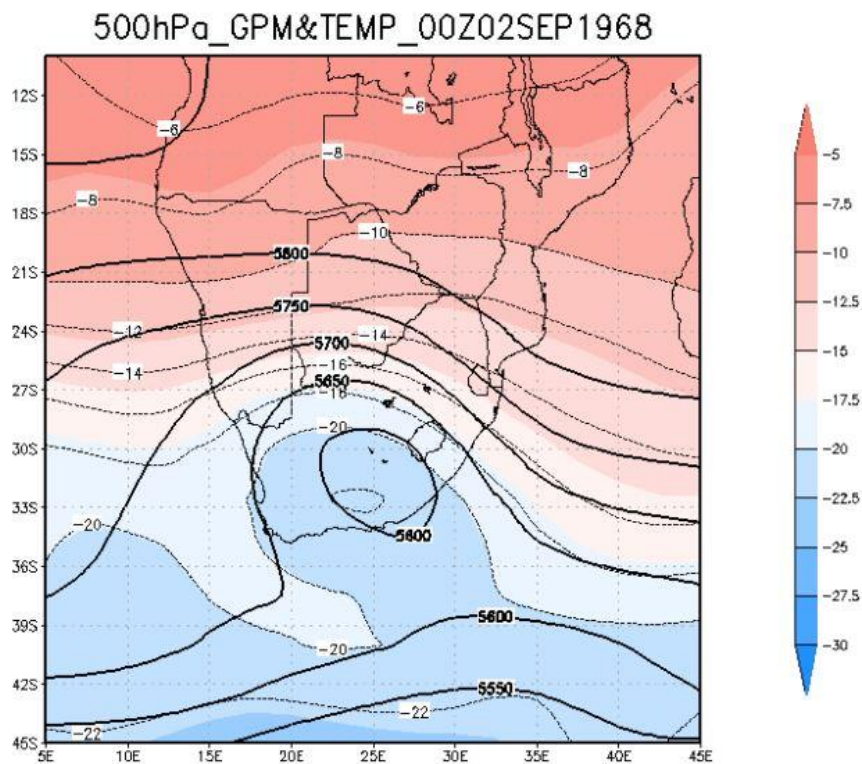


Figure 5.25: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 1 September 1968.

### 5.3.2.3 *Meteorological parameters analysis*

The pressure on 31 August 1968 (Figure 5.26) shows two periods of slight decrease in the morning and the afternoon respectively, with a mild increase in-between these periods. The pressure for the day varied only slightly overall. A temperature analysis using Figure 5.27, showed the minimum for the entire three-day period (31 August to 2 September) at 10 °C on the morning of 31 August. The temperature then rose to a maximum of 18.3 °C to also be the maximum for the entire period. The temperature then followed a normal diurnal cycle with a decrease towards the evening but the temperature started to rise again after 20:00 from 14.6 °C to 16.3 °C by hour 24. The relative humidity (Figure 5.28) showed a decreasing trend to a minimum of around 75% at 11:00. It then increased into the evening as onshore south-easterly winds (Figure 5.29) occurred with light northerly winds preceding this. Coastal areas generally report higher relative humidity when the winds are onshore (moving from the coast onto the land). The south- easterly moved into the area at around 14:00 SAST and the wind speed increased slightly (Figure 5.30). However, relatively light winds were recorded throughout the day. The pressure showed a slight increase at the same time that the wind turned south- easterly but began to fall between 22:00 to 23:00 SAST, with a rising temperature, on the night of 31 August 1968.

The pressures for the 31 August 1968 and 1 September are near identical. The decreasing pressure trend from the evening of 31 August continued into the early hours of 1 September but the pressure began to rise gradually after 04:00 and more rapidly after 08:00. The pressure on 1 September also showed marginal fluctuations throughout the day, similar to the day before. The temperature was fairly warm throughout the early morning hours, especially for spring. The overall maximum for the day was recorded at 16.1 °C between 04:00 and 05:00. The temperature dropped by about 2 °C between 07:00 and 08:00 on the 1<sup>st</sup> but then rose to a small peak at 11:00, after which the temperature decreased slightly but showed a fairly steady trend for the rest of the evening. The relative humidity profile for 1 September remains humid throughout the day with a very slight decrease in relative humidity towards midday while the previous days' profile has a marked decrease in the warmest part of the day. The wind was relatively light throughout the late hours of 31 August but changed rapidly from calm conditions to a moderate easterly around 04:00 then reverted to a light north-westerly around 06:00 am. A rapid change occurred between 07:00 and 08:00 as the wind turned from 320° (NW) to 120° (SE) and picked up from a light to a moderate wind. The temperature simultaneously decreased by 2 °C. The indication of wind direction changes with a northerly

component to a more easterly or south-easterly wind, together with slight pressure falls and then gradual increases. The inflow of moist south-easterly flow at the surface created a deep layer of moisture. From the mean sea level pressure chart at 08:00 SAST on 1 September (Appendix 2), the surface low pressure system had just moved through the Port Elizabeth area. The change in the wind direction and the slight increase in pressure also agree that this surface low pressure moved through the area between 07:00 and 08:00.

The 2<sup>nd</sup> of September saw a large pressure rise throughout the day from 1012.6 hPa at 01:00 to 1021.9 hPa at hour 24. Looking at the synoptic analysis, this is when the high pressure system, to the south west, pushed onto the coastline. The temperature rose gradually in the morning of the 2<sup>nd</sup> until 11:00, after which a sharp rise occurred to a peak for the day at 13:00 of 17.2 °C. The relative humidity also decreased throughout the morning with a minimum around mid-afternoon but increased towards the evening. The wind direction averaged 200° in the morning but turned to 160° at around 10:00 with a moderate wind but increasing to a strong wind around 13:00.

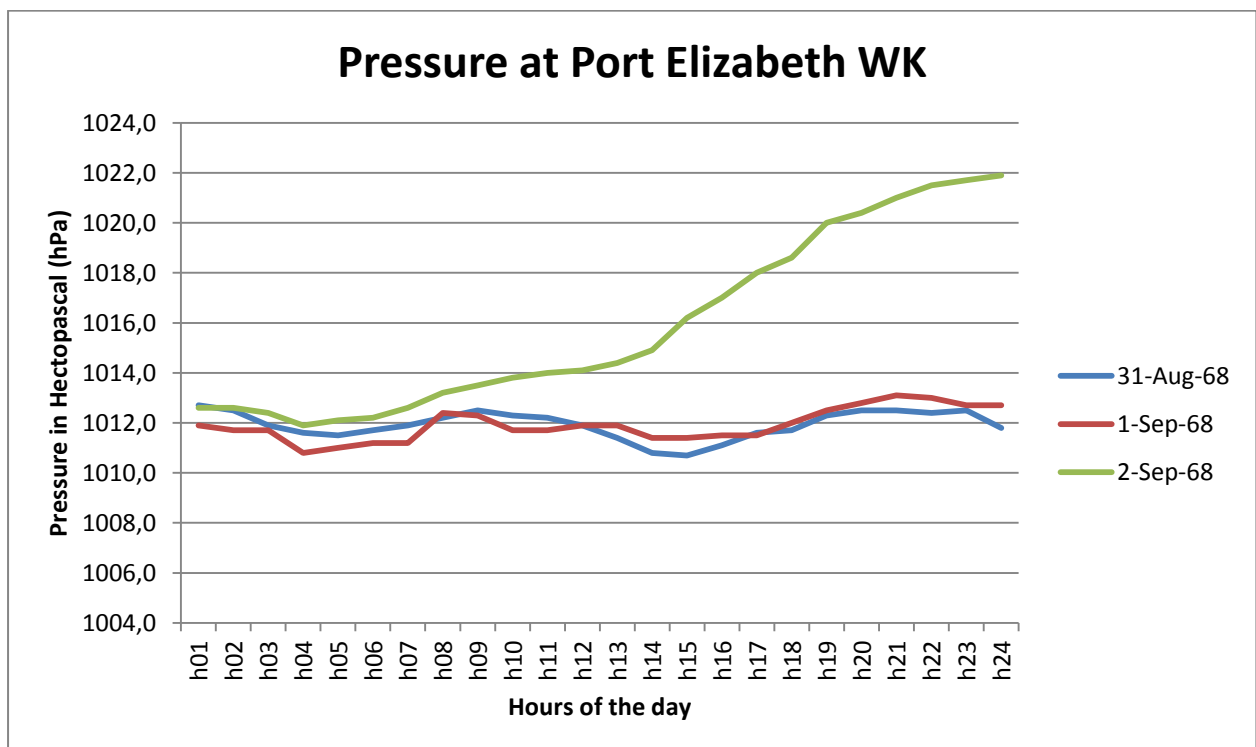


Figure 5.26: Pressure at Port Elizabeth WK for 31 August – 2 September 1968.

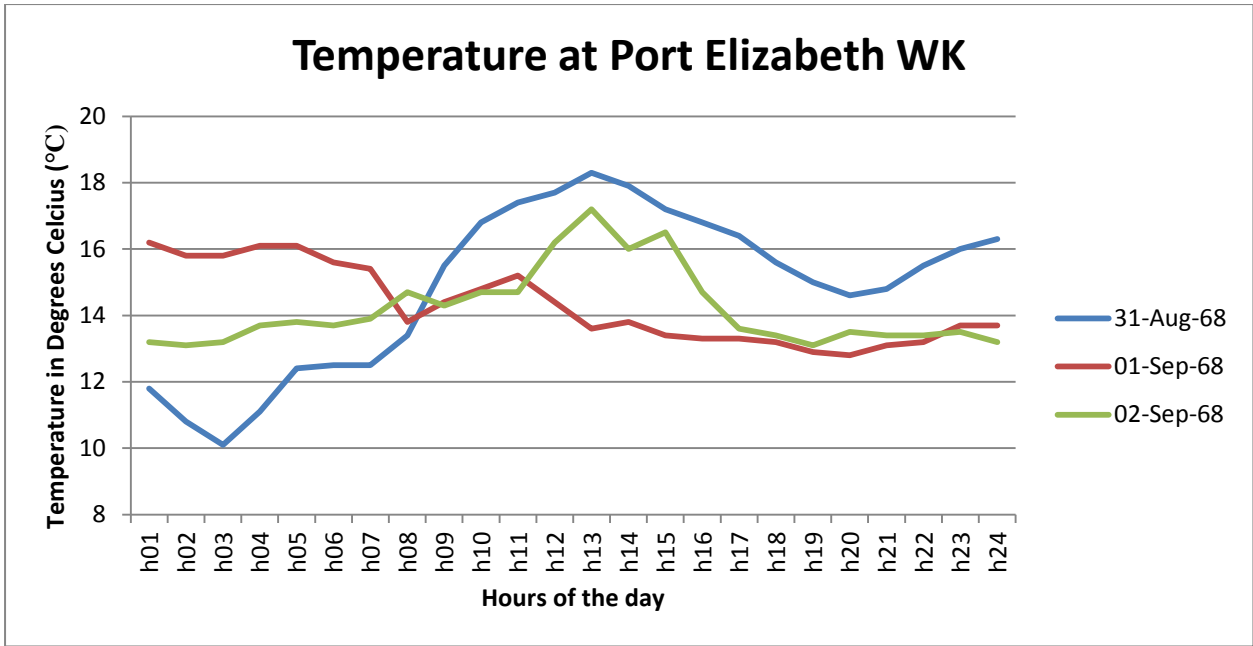


Figure 5.27: Temperature at Port Elizabeth WK for 31 August – 2 September 1968.

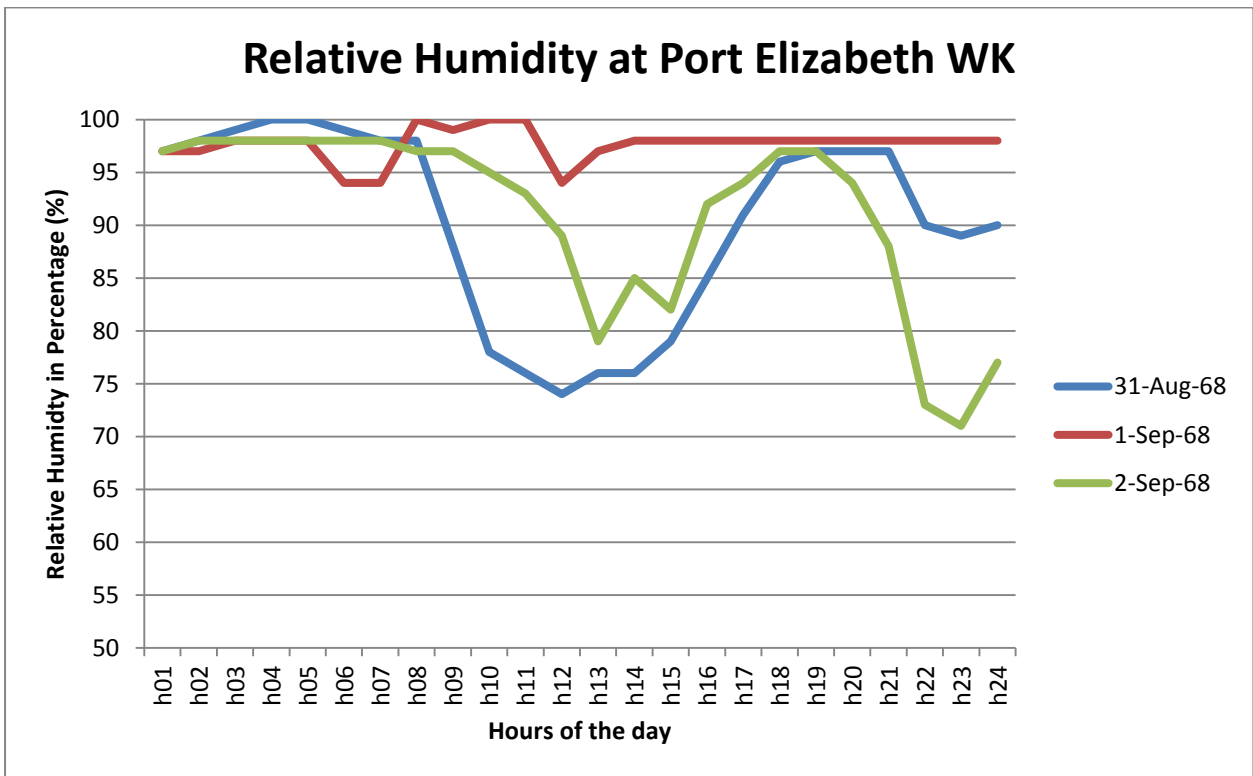


Figure 5.28: Relative Humidity at Port Elizabeth WK for 31 August – 2 September 1968.

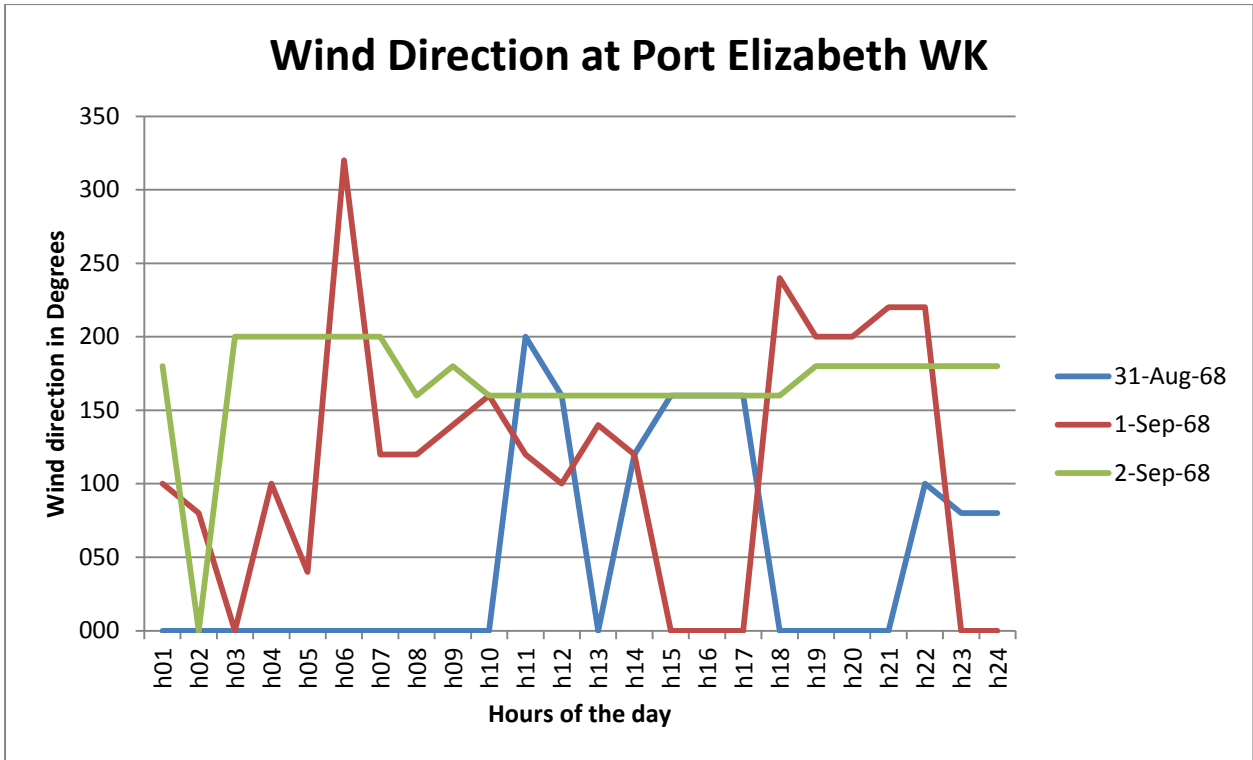


Figure 5.29: Wind direction at Port Elizabeth WK for 31 August – 2 September 1968.

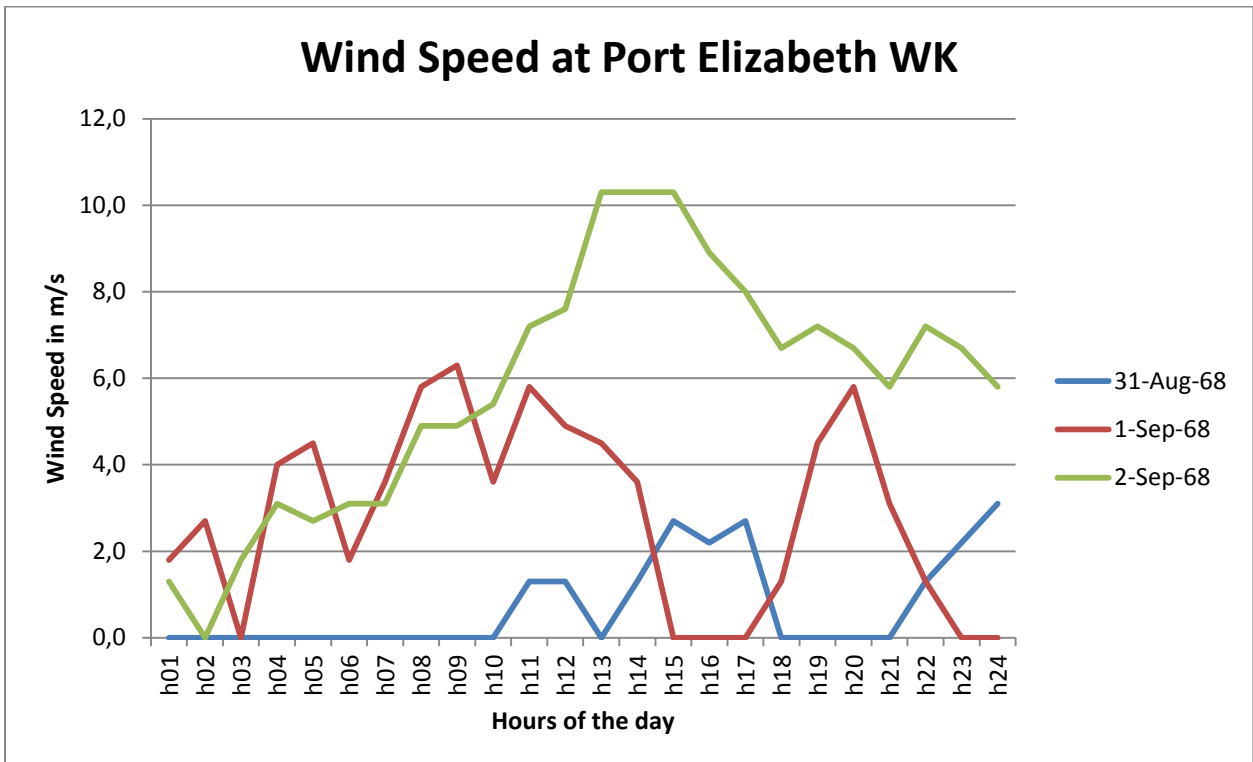


Figure 5.30: Wind Speed at Port Elizabeth WK for 31 August – 2 September 1968.

A commercial pilot reported a “peculiar feel” to the air on the evening of 31 August 1968 when he landed at Port Elizabeth airport (City of Port Elizabeth Engineer’s Department, 1968). The City Engineer’s Department report confirmed that a deep

blanket of moisture from the warm Agulhas current moved into the Port Elizabeth area from the south-east. Loud claps of thunder occurred during the night of 31 August with a few downpours but the heaviest rain period occurred after 8 am on 1 September 1968 (City of Port Elizabeth Engineer's Department, 1968).

The daily rainfall recorded at Port Elizabeth airport can be seen in Figure 5.31 from 08:00 SAST on 1 September 1968 to 08:00 SAST the next day. The greatest peak occurred in a short space of time on the morning of 1 September 1968 just after 8:00 SAST, as seen in Figure 5.32. Of the 429 mm recorded this day, 355 mm was recorded between 08:00 and 12:00 SAST. That equates to an average rainfall rate of 88.75 mm per hour, or 22.2 mm every 15 minutes. The hourly rainfall intensity chart in Figure 5.32 indicates high intensities of rainfall between 08:00 and 12:00 SAST with lower intensities until 00:00, after which the rain ceased. The commencement of heavy downpours at 08:00 corresponds with the wind direction change to south easterly at which time it is thought that the surface low pressure moved through the Port Elizabeth area. During the period between 08:00 and 12:00, the winds remained south-easterly when the rainfall was the most intense and the wind speed began to decrease as the winds changed to a northerly wind towards 15:00. Between 15:00 and 17:00, the wind remained a light northerly and the rainfall intensities decreased. After 17:00, the winds turned to a south- westerly, at which point the rainfall intensity increased again but at a much gradual pace compared to the morning's rain.

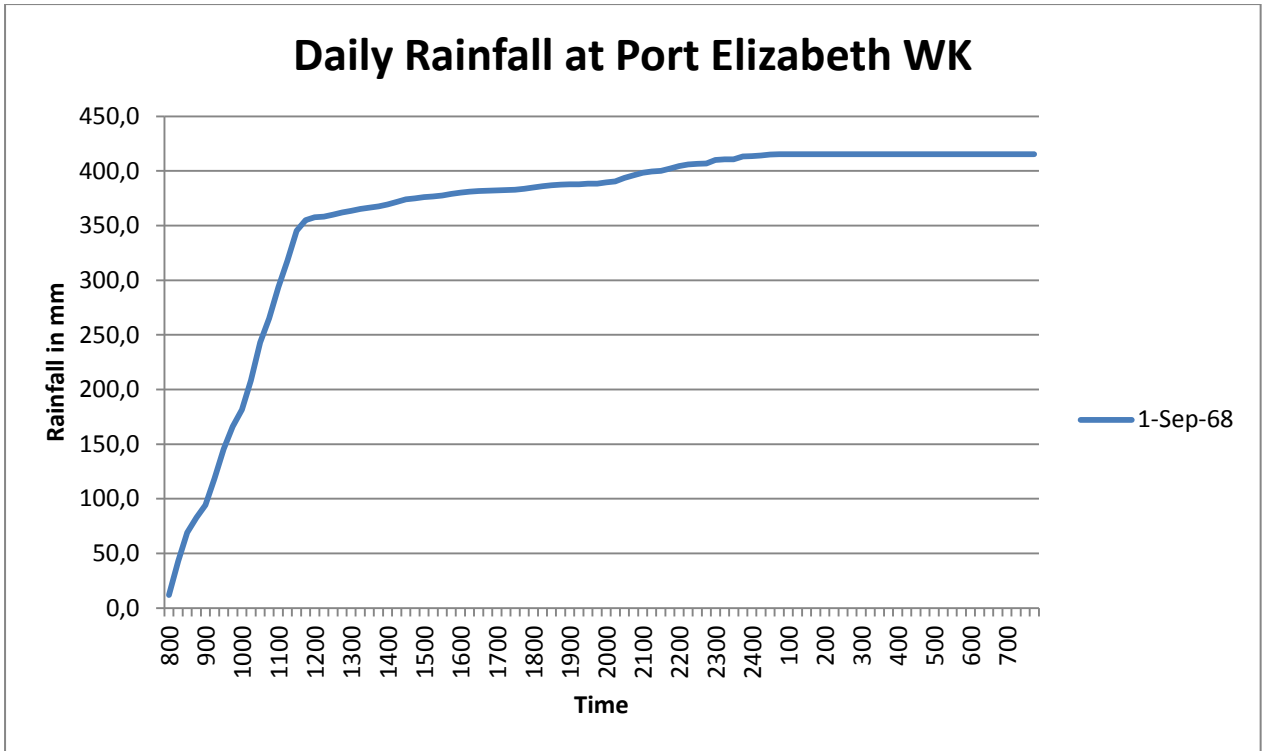


Figure 5.31: Daily Rainfall at Port Elizabeth WK for 1 September 1968.

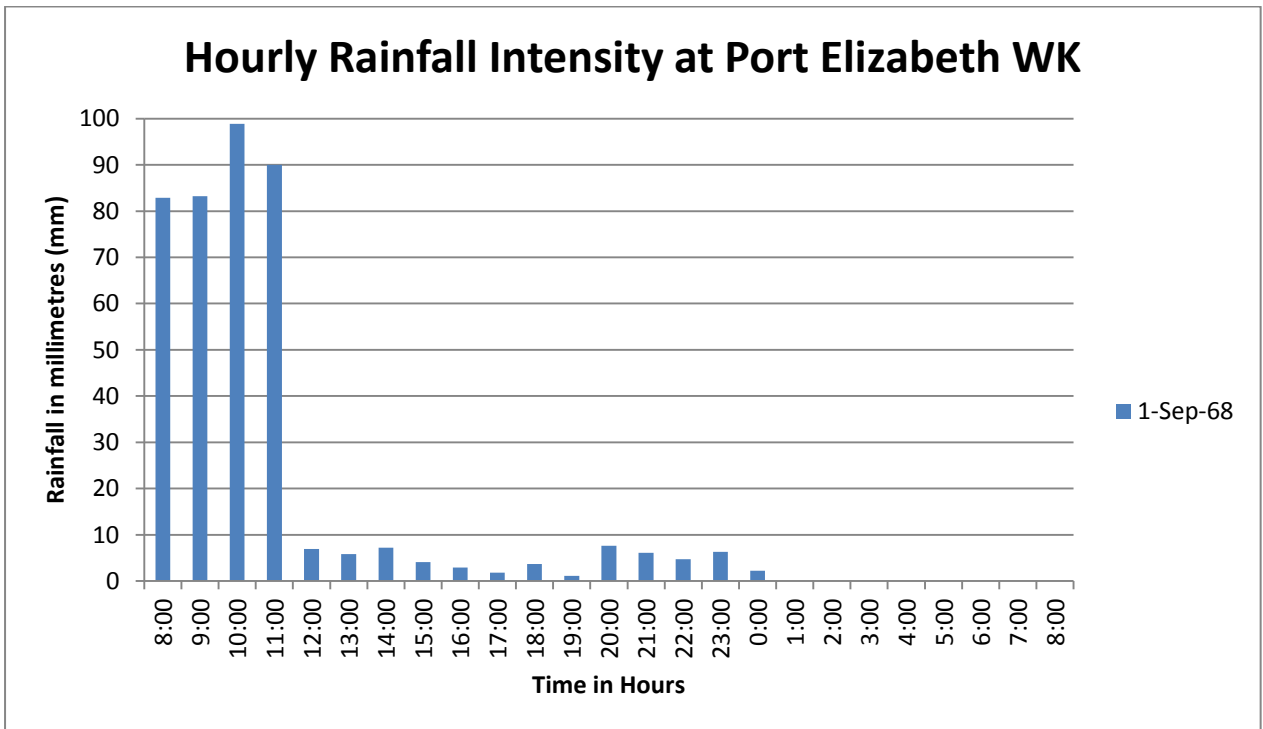


Figure 5.32: Hourly Rainfall Intensity at Port Elizabeth WK for 1 September 1968.

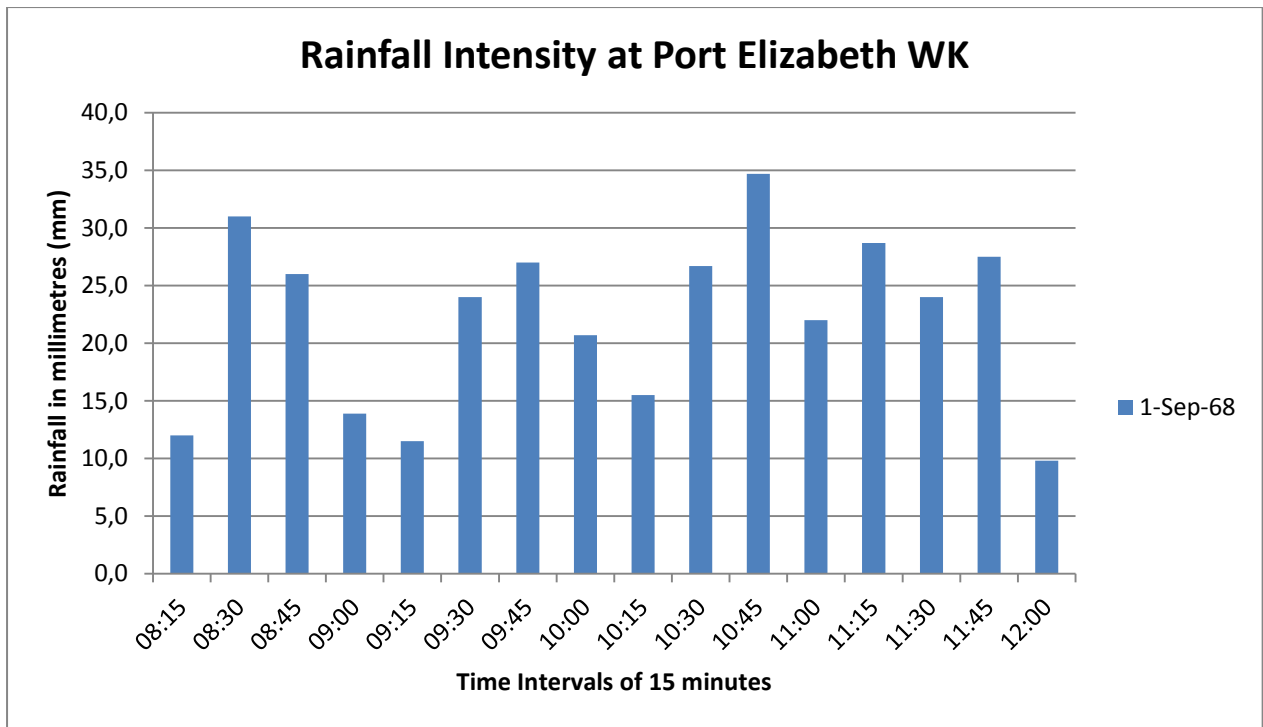


Figure 5.33: Rainfall Intensity between 08:00 and 12:00SAST at Port Elizabeth WK on 1 September 1968.

In Figure 5.33, the 15 min intervals of rainfall intensity are given in the period of the heaviest rain between 08:00 and 12:00 on 1 September 1968. The two highest peaks of rainfall intensity around 08:30 and 10:45 coincide with two peaks of wind speed increase in Figure 5.30. Both occur during a south-easterly wind but the highest intensity peak at 10:45 occurs when the wind was slightly more south-south-easterly, around 160° compared with 120° at 08:30. This represents an onshore flow component of winds coming straight from the ocean onto Port Elizabeth.

#### 5.3.2.4 Case Discussion

The 1<sup>st</sup> September 1968 flood in Port Elizabeth is a notorious flood event in the city, especially due to the unexpected heavy rains that fell that day. The City of Port Elizabeth Engineer's Department (1968) mentioned that the downpours could not have been predicted due to the small scale of the convective cell that produced the heavy rain. This convective cell size is too small to have been seen on normal weather charts at the time (City of Port Elizabeth Engineer's Department, 1968).

This event had the three synoptic patterns that the previous case had, namely; a relatively strong ridging high along the south coast with a surface interior low pressure system over the central interior together with a cut-off low, located over the southern interior of the country. However, the ridging high indicated by a strong pressure increase only occurred on 2 September. Therefore, in this case, the

significance of the heavy rainfall on 1 September was due to the positioning of the surface low pressure from the interior and the upper low still being west of Port Elizabeth. The high rainfall intensity also resulted in flash flood conditions due to the short period of time that the rainfall occurred, whereas the East London 1970 case had consistent heavy rainfall over a few days.

Interestingly, the 2<sup>nd</sup> September had southerly winds representing an onshore wind with a fresh to strong wind speed but very little rainfall occurred. The high pressure system at the surface had ridged along the coast but the COL was now to the east of Port Elizabeth. This removes the possibility of thunderstorms due to a lack of instability because of the positioning of the COL but heavy rain is still possible.

Although this event was difficult to forecast, it was fortunate to have occurred on a Sunday when people were mostly at home. Had this event occurred on a work day, the fatalities would have likely been higher.

### **5.3.3. Case 3: East London 15-16 August 2002**

#### *5.3.3.1 Case overview*

This event occurred more recently and features as the third highest twenty-four-hour rainfall event for the 15th August 2002. It does not, however, appear in Table 5.2 of the top five heaviest event rainfalls. This flood caused extensive damage to the East London area. A rainfall amount of 317.2 mm was recorded from 08:00 on 15 August 2002 to 08:00 on 16 August 2002. The harbour flooded and had to be closed.

#### *5.3.3.2 Systems Analysis*

**Wednesday 14/08/2002:** A cold front moved south of the country with a high pressure system located south west of the country with the high extending a ridge across the southern parts of the country (Figure 5.34). In the upper air (Figure 5.35) an upper air trough was located on the south west Cape coastline with an upper air temperature trough.

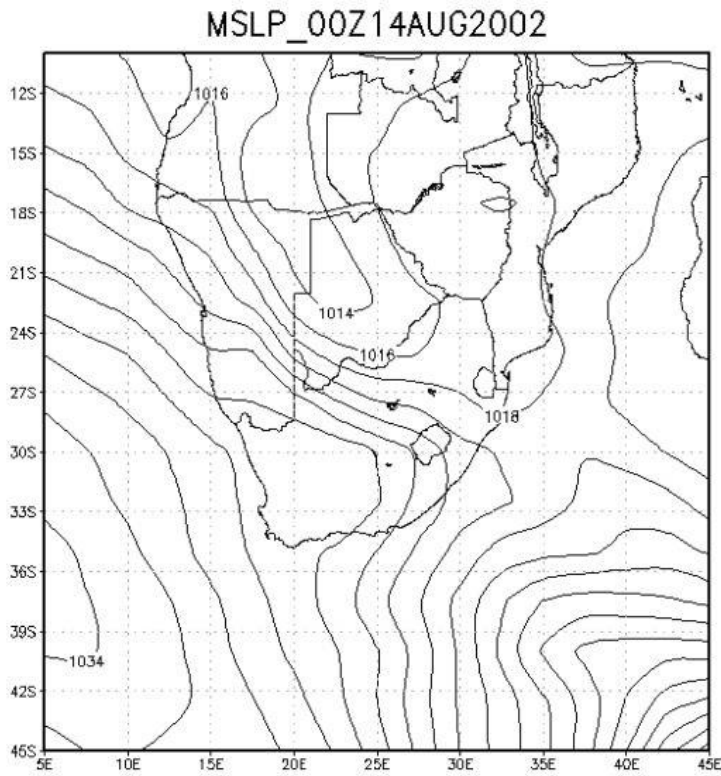


Figure 5.34: Synoptic chart of mean sea level pressure (hPa) at 00Z on 14 August 2002.

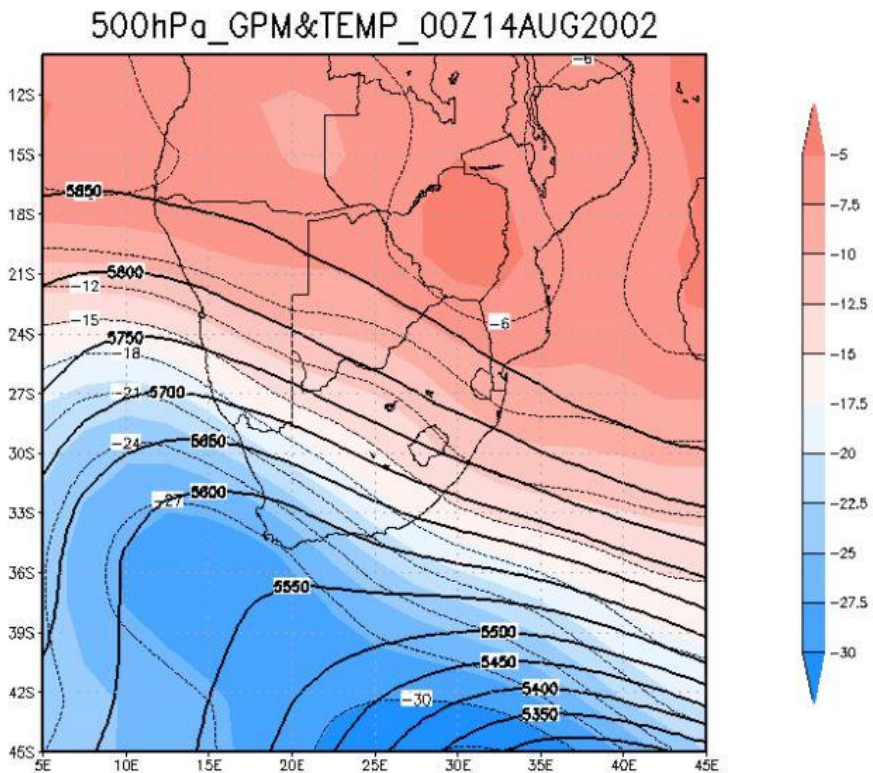


Figure 5.35: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 14 August 2002.

**Thursday 15/08/2002:** The surface analysis showed the high pressure system intensified to 1040hPa and had moved to the south of the country around 43°S (Figure 5.36). The surface trough was located over the extreme north eastern parts of the country. The upper air trough had intensified to be almost cut-off on the south west Cape (Figure 5.37) with a cold core forming.

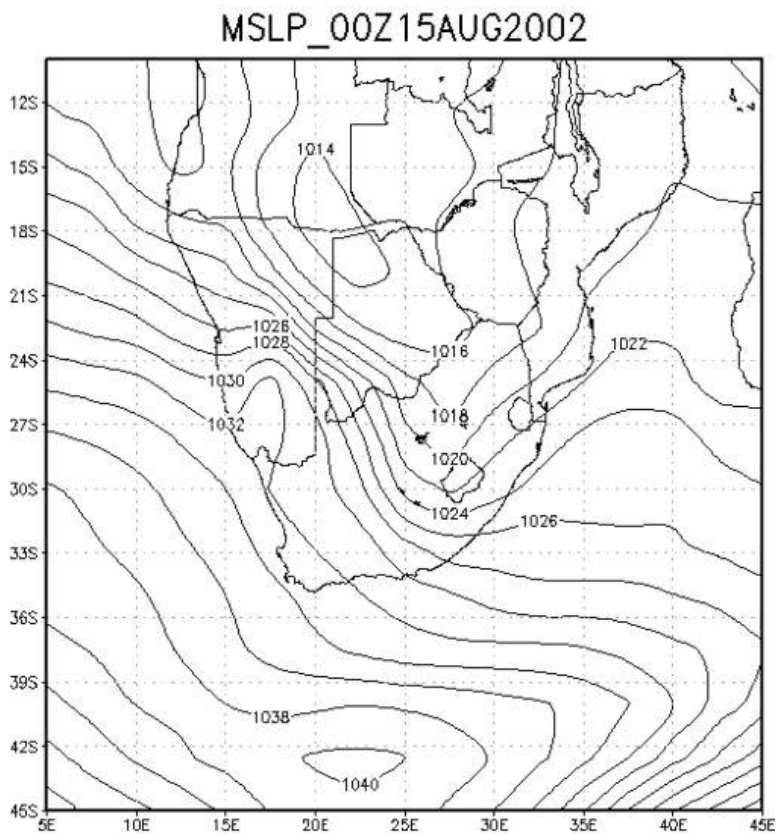


Figure 5.36: Synoptic chart of mean sea level pressure (hPa) at 00Z on 15 August 2002.

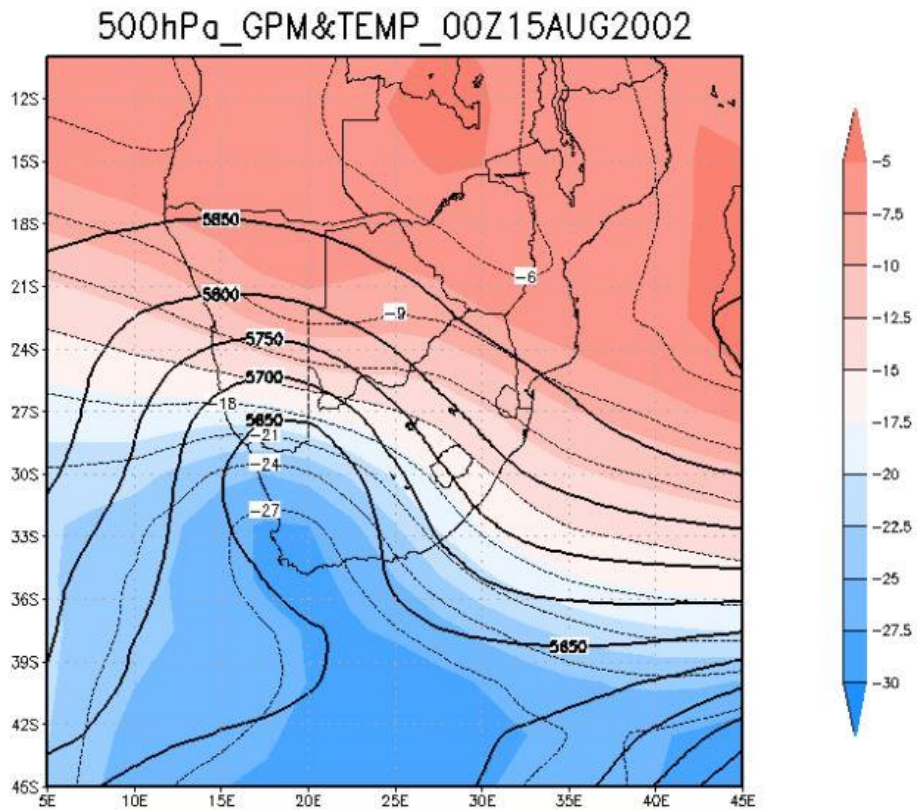


Figure 5.37: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 15 August 2002.

**Friday 16 August 2002:** The high pressure system south of the country had moved to the west (Figure 5.38) with a low pressure system located off of the Kwa-Zulu Natal coastline. A COL had developed and was located on the west coast of the Northern Cape with a temperature trough in a similar position (Figure 5.39).

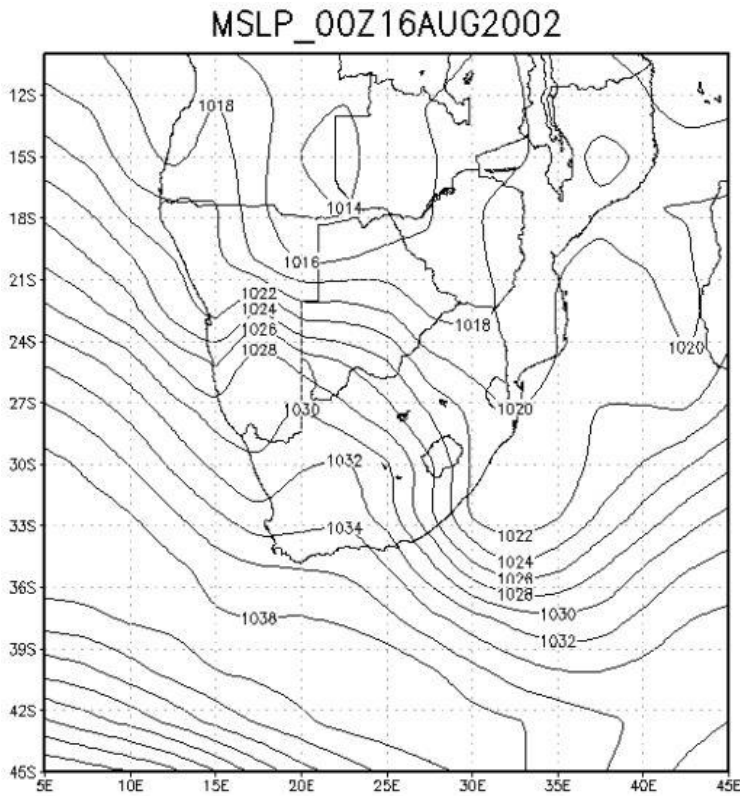


Figure 5.38: Synoptic chart of mean sea level pressure (hPa) at 00Z on 16 August 2002.

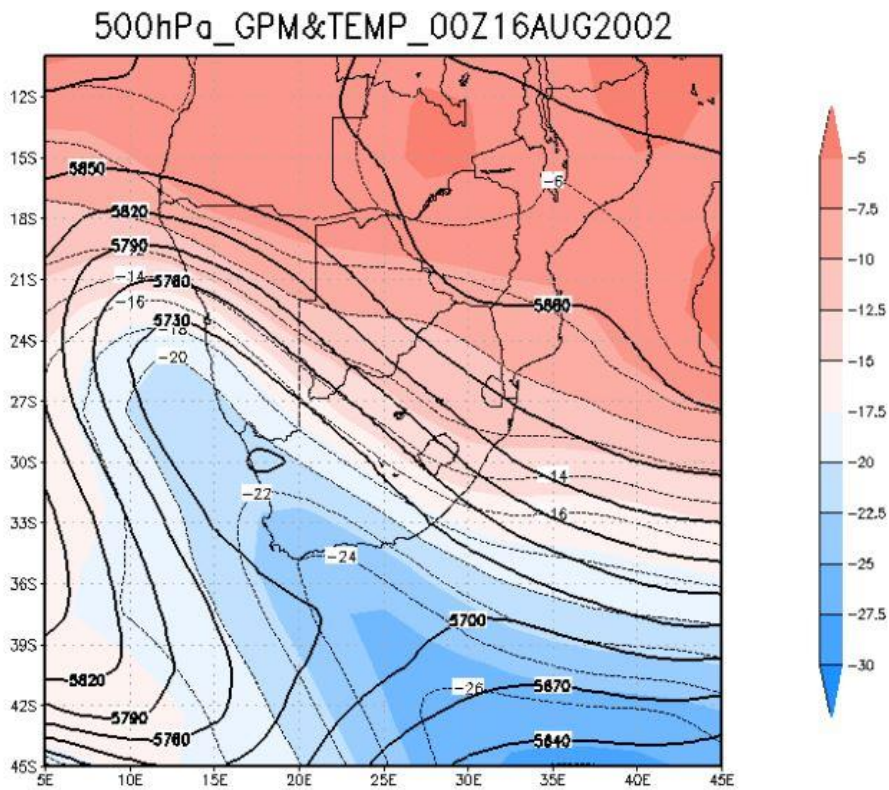


Figure 5.39: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 16 August 2002.

### *5.3.3.3 Meteorological parameters analysis*

The pressure (Figure 5.40) on 14 August 2002 rose gradually throughout the day as the Atlantic high pressure system ridged in behind the initial cold front. The temperature on the 14<sup>th</sup> August had a minimum of 9.5 °C at 03:00 then rose slightly but decreased again towards 06:00 to reach 9.6 °C (Figure 5.41). After this, the temperature increased to 14.6 °C at 14:00 and had a decreasing trend into the evening. The relative humidity was lowest during the day but increased rapidly into the evening after 15:00, as seen in Figure 5.42, which correlates with a wind direction change, seen in Figure 5.43, from westerly to a south-easterly/easterly wind which is onshore for East London.

On 15 August, the pressure remained near steady in the early morning but began to decrease around 08:00 to reach a minimum pressure of 1022.9 hPa at 15:00. This indicates a low pressure approaching the area. The pressure then began to rise rapidly into the evening of 15 August and continued into mid-morning of 16 August as the high pressure system ridged once again into the area following a low pressure system. The decreasing temperature trend from the previous night (14<sup>th</sup> August) continued into the morning of the 15<sup>th</sup> to be around 12 °C but had a 1 °C increase between 01:00 and 02:00 but then decreased to 11.3 °C at 03:00 and remained constant until 05:00. The temperature then increased gradually to a maximum at 15:00 of 15.1 °C. The temperature decreased slightly but remained around 14 °C for most of the evening and started decreasing more rapidly after 22:00. The relative humidity remained high around 95% throughout the day on the 15<sup>th</sup> of August. The average wind direction also remained easterly to south-easterly with two spikes of north-westerly winds but these winds were relatively light whereas the higher wind speeds were on easterly winds as seen in Figure 5.44. These light north-westerly winds didn't seem to have an impact on relative humidity as it remained high and didn't drop as is expected with an offshore wind. The low wind speed of this direction change seems to be the key to having little effect on the relative humidity.

The pressure rose rapidly in the morning hours of the 16<sup>th</sup> August until 09:00, after which it increased more slowly to reach a maximum of 1032.6 hPa by 20:00. The temperature decreased to 11.8 °C at 06:00 on the 16<sup>th</sup> and then increased to 15.3 °C at 12:00. The temperature dropped sharply between 12:00 and 13:00 to 13.5 °C. The temperature then remained relatively constant averaging around 13.5 °C until 17:00, after which the temperature began increasing to a peak at 20:00 of 14.5 °C. The temperature started decreasing rapidly after 21:00 to reach 12 °C by hour 24. The

relative humidity during 16 August remained high until around 11:00 where it dipped slightly. This corresponds with a wind direction change from a southerly wind (180°) to a south-westerly (250°) wind which changes from an onshore wind to an along shore wind (parallel to the coast). The wind speed was strongest in the early morning but decreased throughout the morning until about 08:00 after which point the average wind speed was light to moderate.

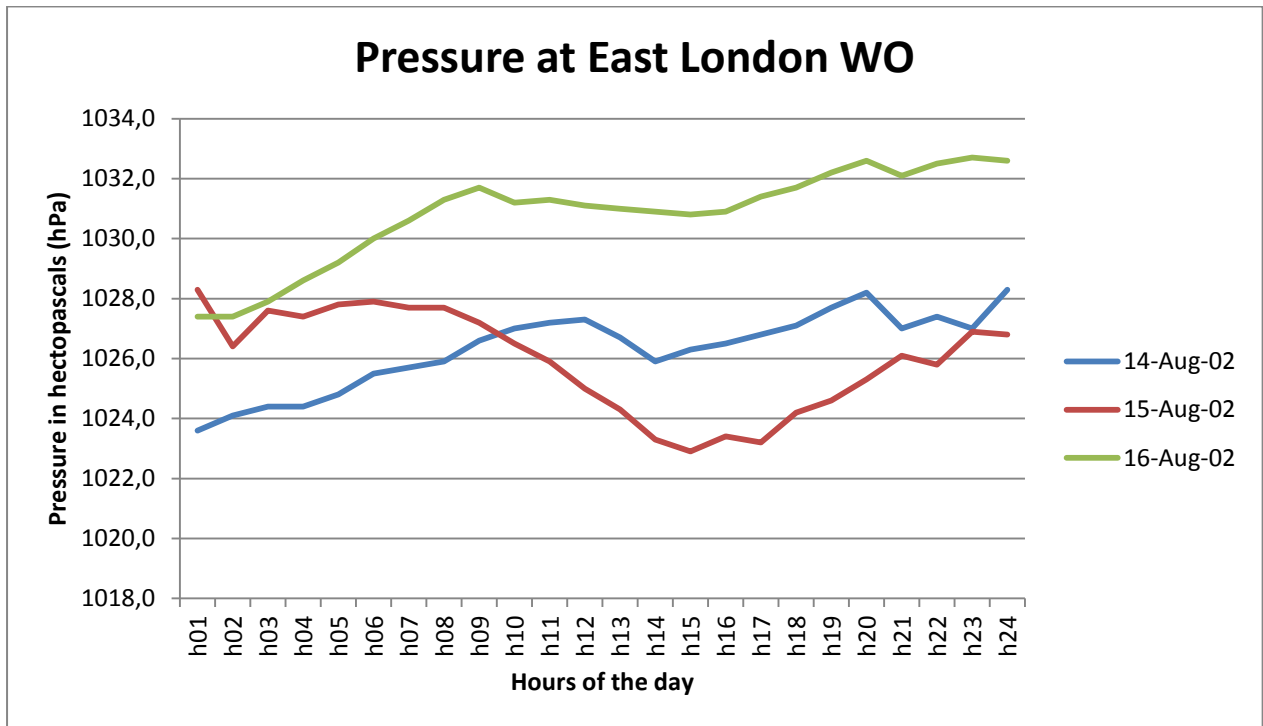


Figure 5.40: Pressure at East London WO for 14 -16 August 2002.

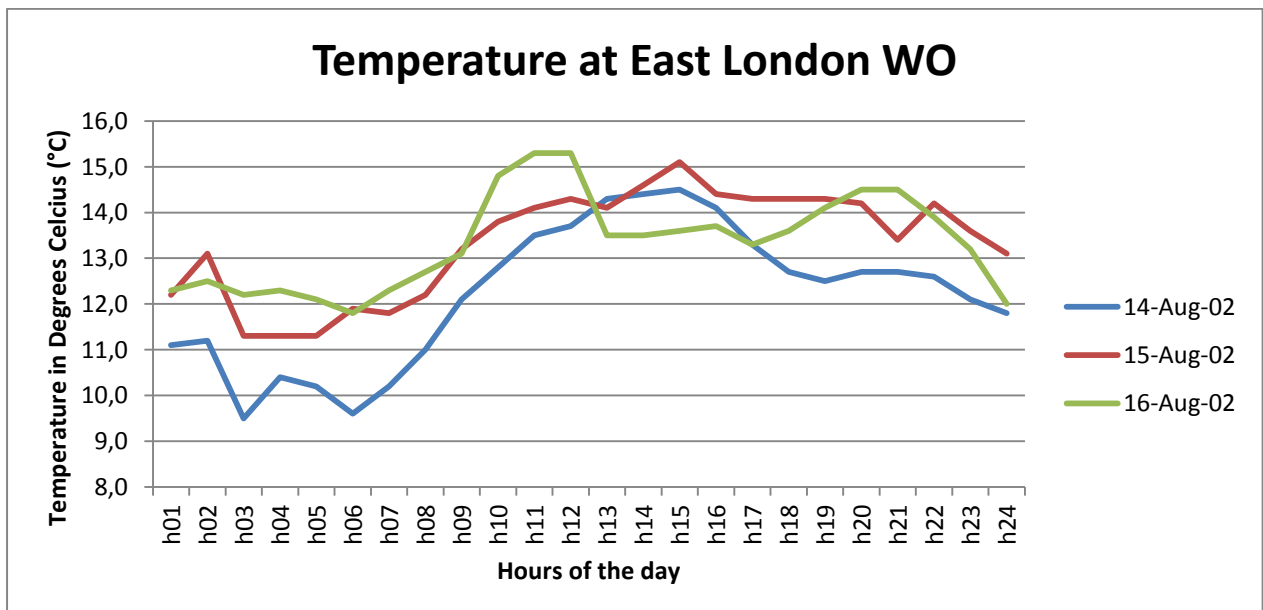


Figure 5.41: Temperature at East London WO for 14-16 August 2002.

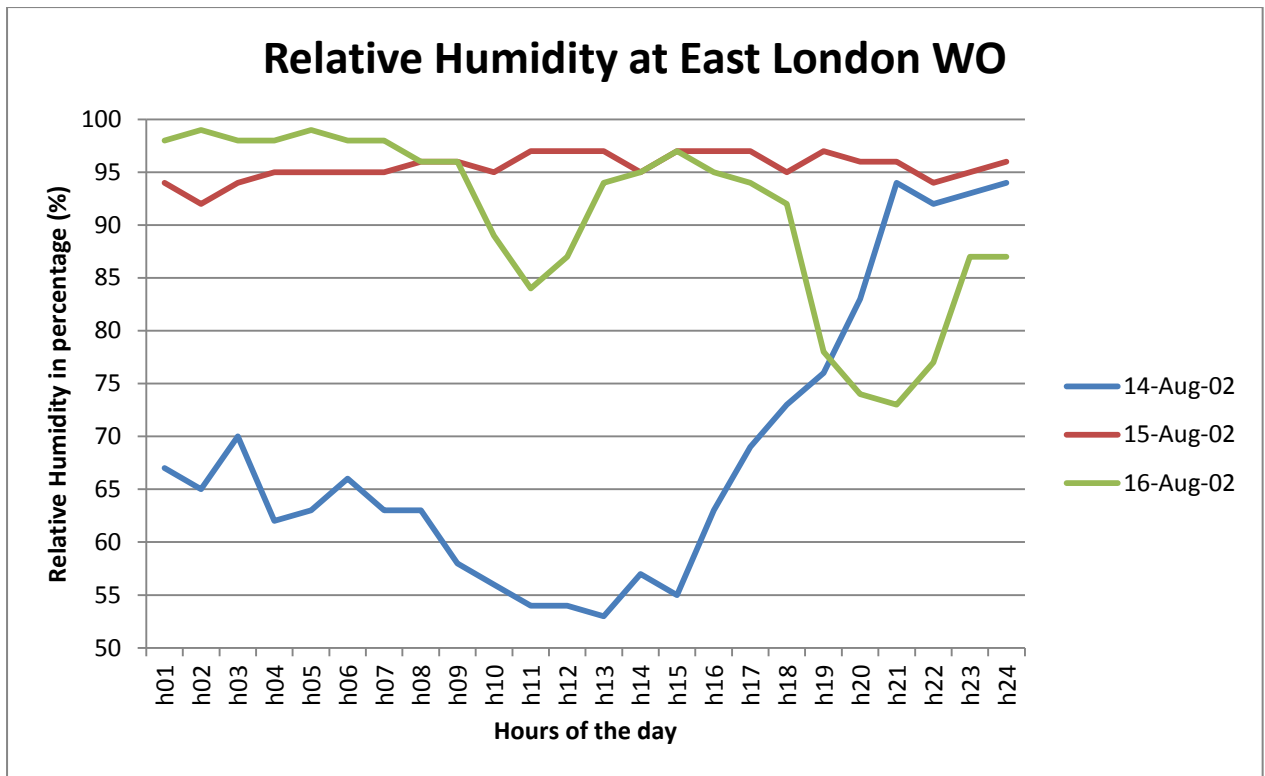


Figure 5.42: Relative Humidity at East London WO for 14 -16 August 2002.

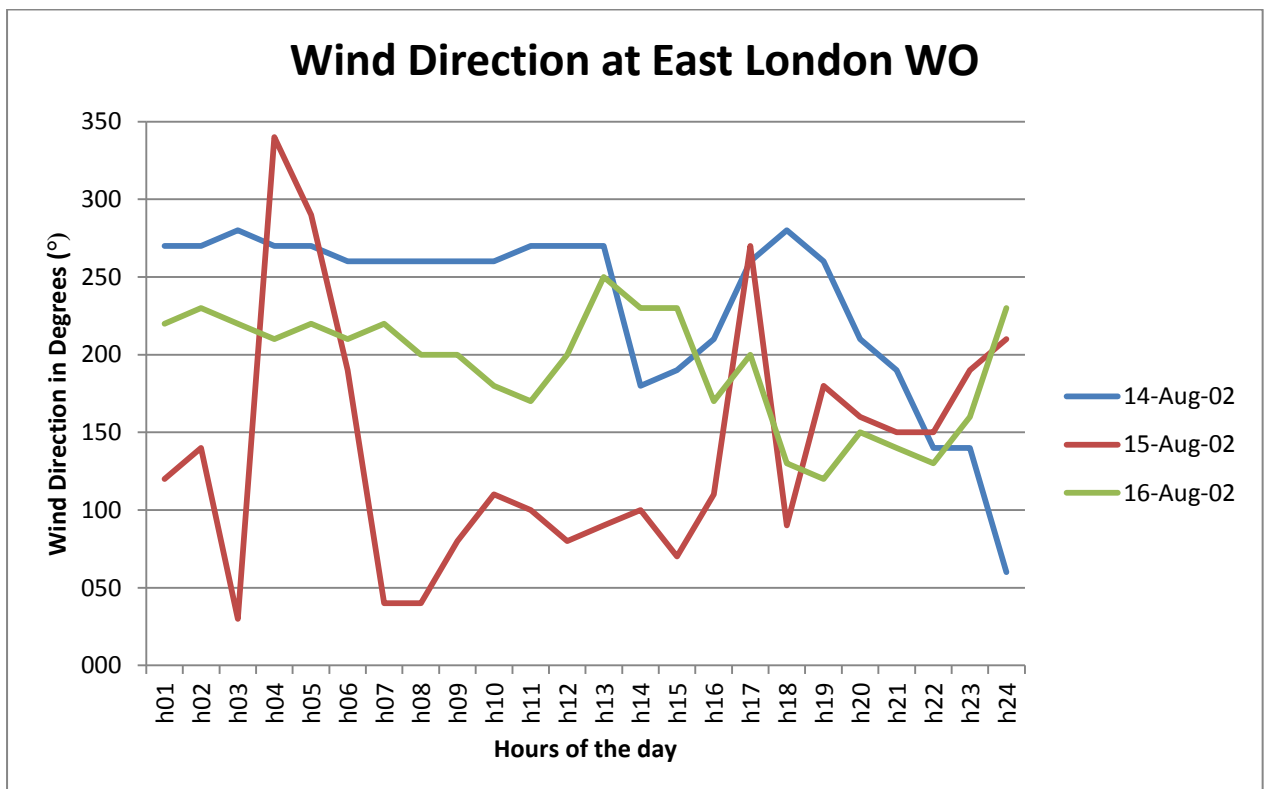


Figure 5.43: Wind Direction at East London WO for 14-16 August 2002.

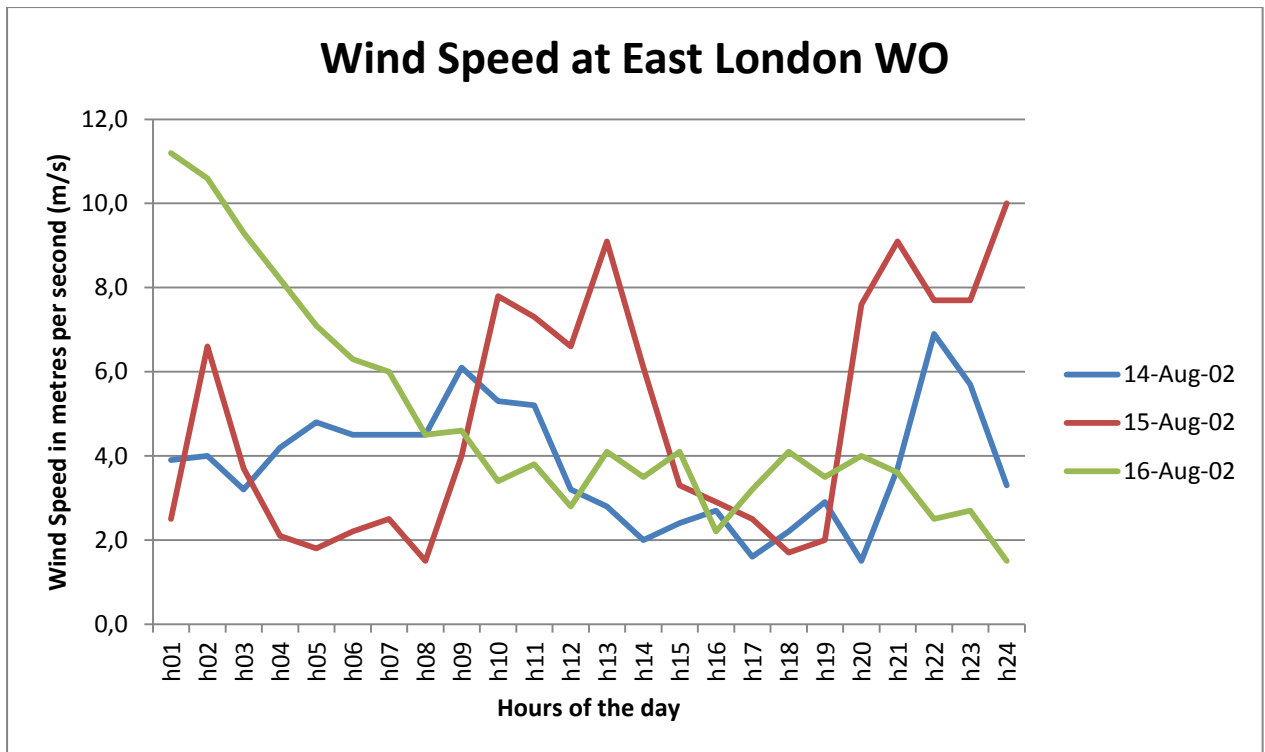


Figure 5.44: Wind Speed at East London WO for 14-16 August 2002.

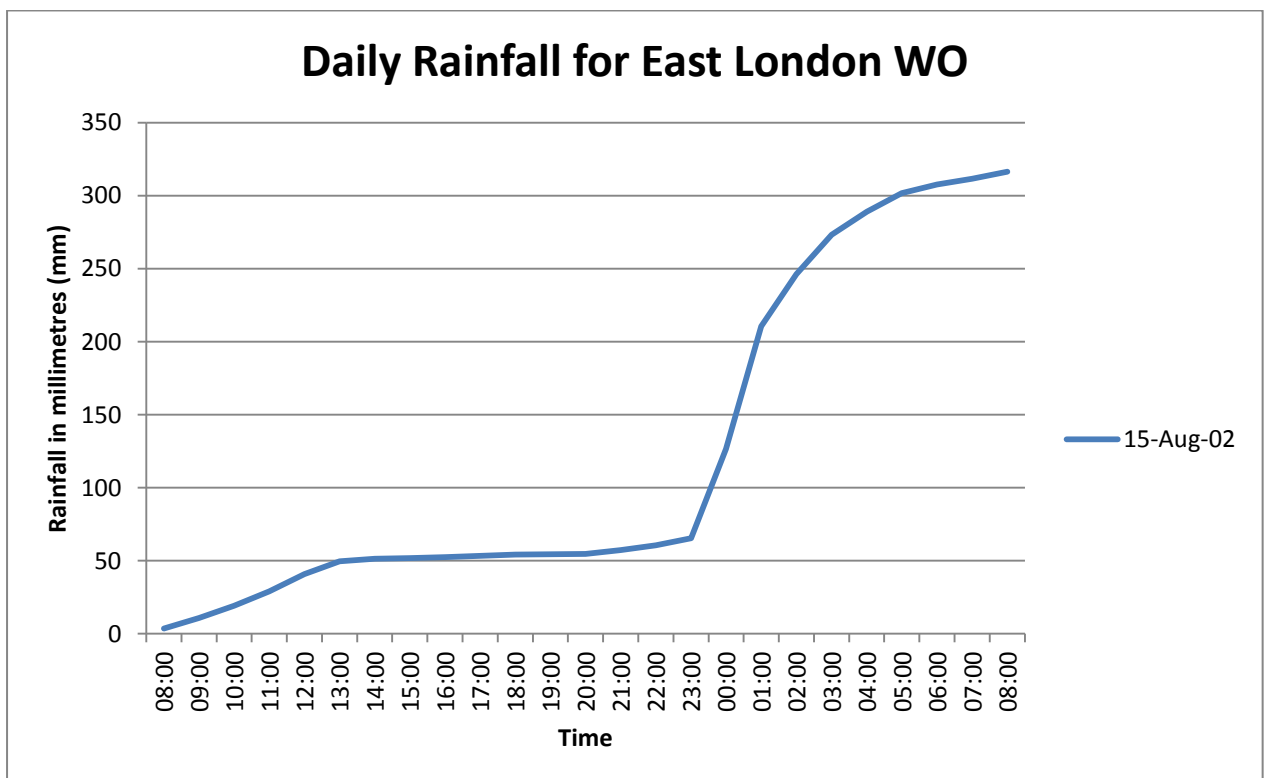


Figure 5.45: Daily Rainfall at East London WO for 15 August 2002.

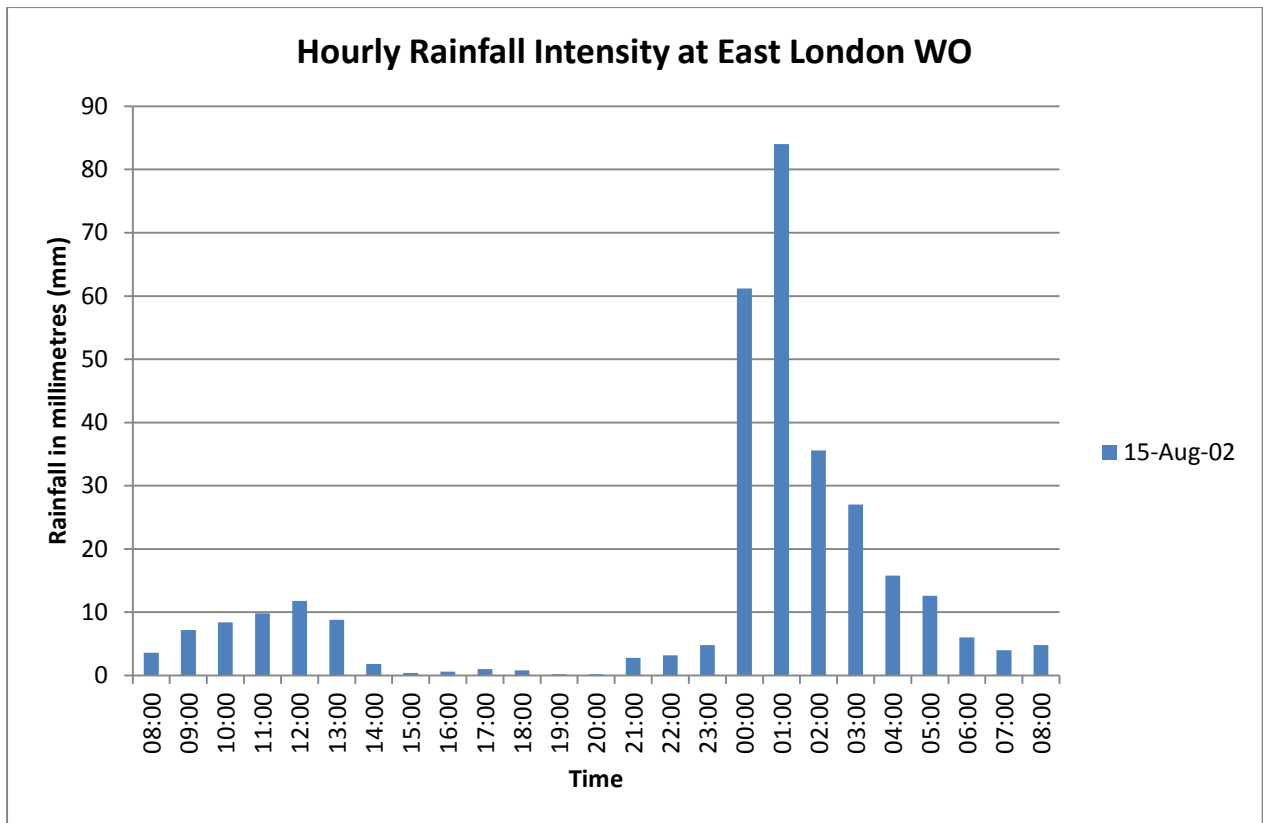


Figure 5.46: Hourly Rainfall Intensity at East London WO for 15 August 2002.

Light rain started to ensue around 21:00 on 14 August as the winds turned to a south- easterly direction after the pressure had already increased. On the morning of 15 August 2002, the rainfall began to fall more steadily with a peak towards 12:00 during which stage the pressure was decreasing and the wind had changed to an easterly direction. The wind speed (Figure 5.44) had also increased on the easterly wind. Around 15:00 to 20:00, very little rainfall was recorded, as seen in Figure 5.45 and Figure 5.46 and the pressure gradually rose during this period. The winds had changed direction in this period and spiked from a north-westerly wind to an easterly but with very low speeds which indicated the winds to likely be light and variable. When the wind began to pick up speed again and changed to a southerly to south- easterly wind, the rain started to increase again. A very large peak in the rainfall occurs in Figure 5.46 at 00:00 when the wind speed increased to around 11.5 m/s and changed from a south-easterly to a southerly flow but the temperature remained fairly constant. The wind also began rising after 00:00 and continued to rise into the early morning of 16 August. Between 00:00 and 06:00 on 16 August was the highest rainfall peak where around 240-250 mm fell. This averages at between 40-42 mm/h at which time the wind speed was the highest on a south-south- westerly direction around 210-220°.

#### *5.3.3.4 Case Discussion*

This event was also a flash flood case of high rainfall peaks occurring in a short period of time. The development of a surface low decreased the pressure on 15 August and caused a tight pressure gradient between the surface low and high pressure system in the late afternoon with onshore winds (Appendix 3). These onshore winds were of a stronger speed and therefore, moist air from the Indian Ocean was advected into the area during an already humid day. The heaviest rains occurred from 12:00 SAST on 15 August with high rainfall intensities at 00:00 SAST on 16 August. The upper air low was still located north-west of East London thereby being in the unstable area east of the upper air low pressure system.

### **5.3.4. Case 4: Port Elizabeth 24-26 March 1981**

#### *5.3.4.1 Case overview*

The event of 24-26 March 1981 resulted in flooding in the Port Elizabeth area. This event ranked fourth on the twenty-four-hour rainfall events in Table 5.1 with a twenty-four-hour rainfall of 274 mm measured at Groendal Bos. The event rainfall ranked third from the top in Table 5.2 with an event total of 460 mm recorded at Port Elizabeth Cotswold station. These floods were known as the biggest floods to hit Port Elizabeth since the 1968 floods.

#### *5.3.4.2 Systems analysis*

**Tuesday 24/03/1981:** A cold front system was approaching the Cape Town area with a coastal low moving along the east coast of the Eastern Cape (Figure 5.47). In the upper air (Figure 5.48) a steep trough was located south west of the country with a cold core coinciding with the trough.

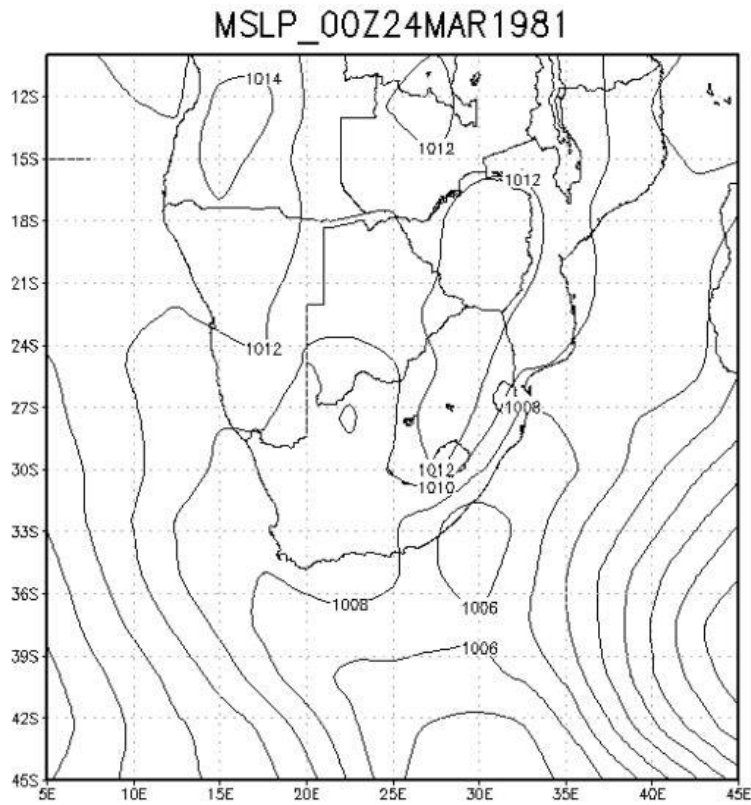


Figure 5.47: Synoptic chart of mean sea level pressure (hPa) at 00Z on 24 March 1981.

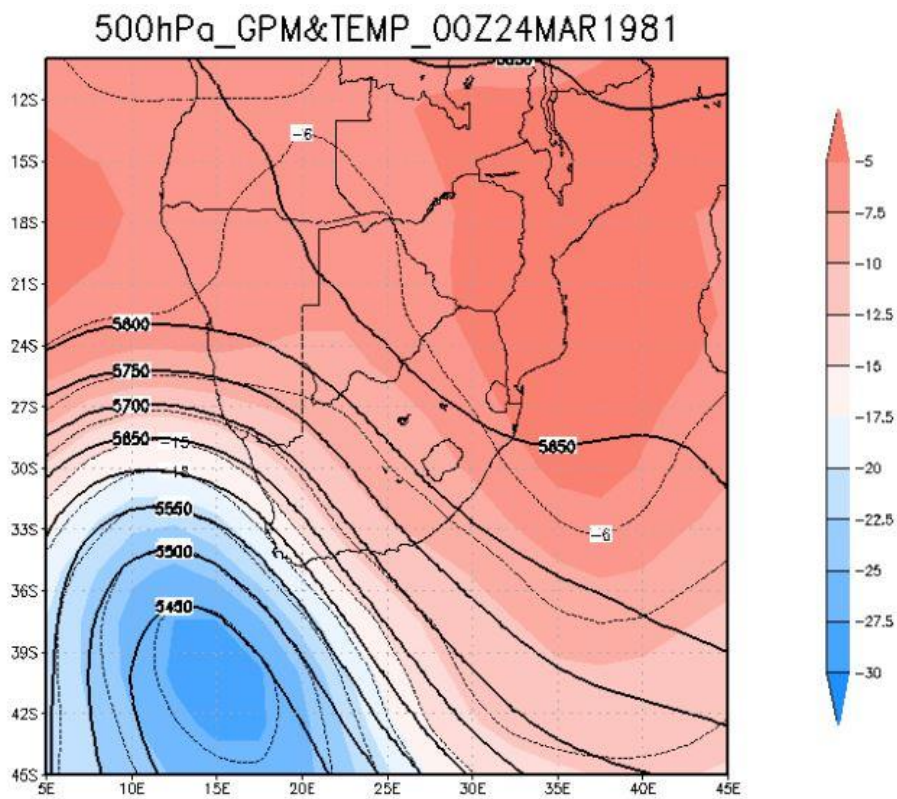


Figure 5.48: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 24 March 1981.

**Wednesday 25/03/1981:** The cold front moves eastwards away from the country with the Atlantic Ocean high pressure system moving in behind it to be located to the south west of the country (Figure 5.49). A low pressure system was located off of Port St Johns a 00:00Z. The upper air trough had become a cut-off low off of the west coast of the Western Cape (Figure 5.50).

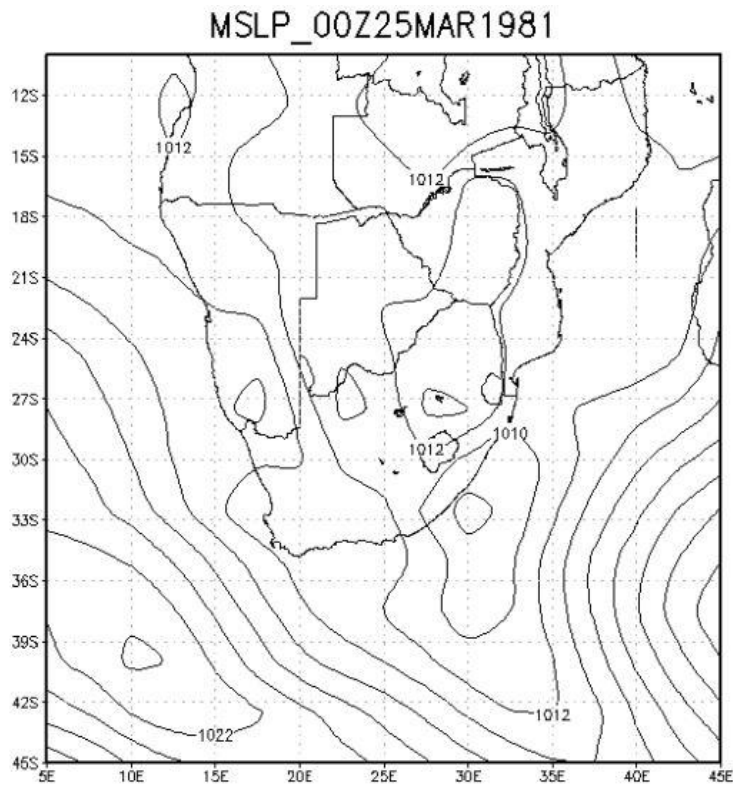


Figure 5.49: Synoptic chart of mean sea level pressure (hPa) at 00Z on 25 March 1981.

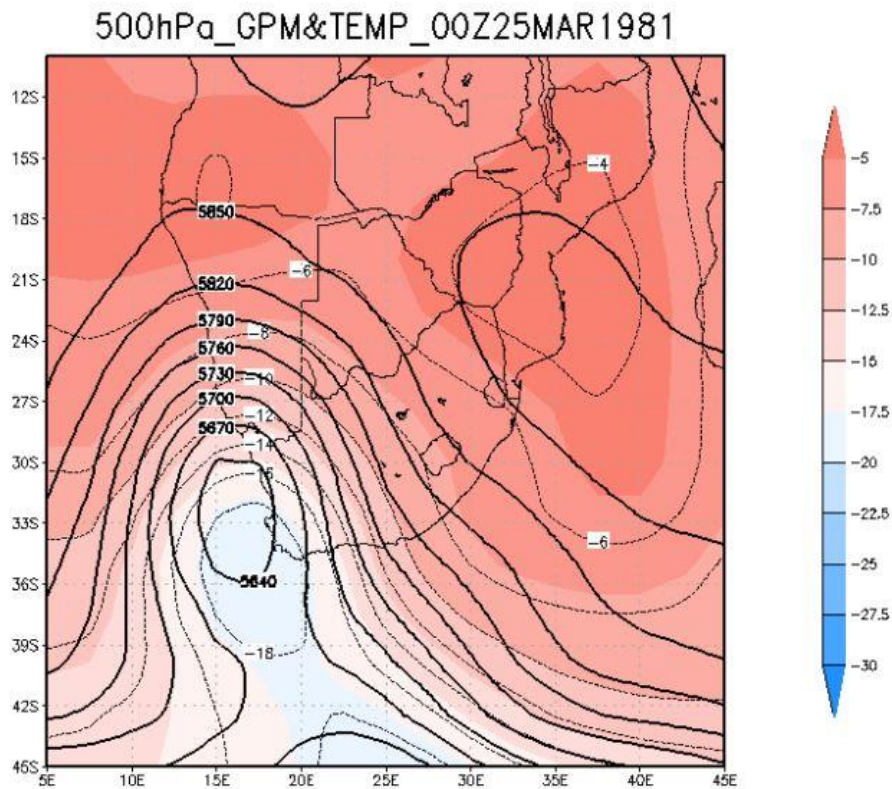


Figure 5.50: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 25 March 1981.

**Thursday 26/03/1981:** The surface analysis (Figure 5.51) shows that the Atlantic Ocean high pressure system was still located south west of the country but extended a ridge to the south east which increased the pressure gradient along the south coast. A low press system was located off of the East London coastline at 00:00Z. The COL was located over the central interior of the Northern Cape (Figure 5.52). The COL had weakened as is seen in the geopotential heights from a core of 5640gpm the previous day to 5730gpm. This weakening can also be seen in the increase of the upper air temperature at 500hPa from -18 °C to -15 °C.

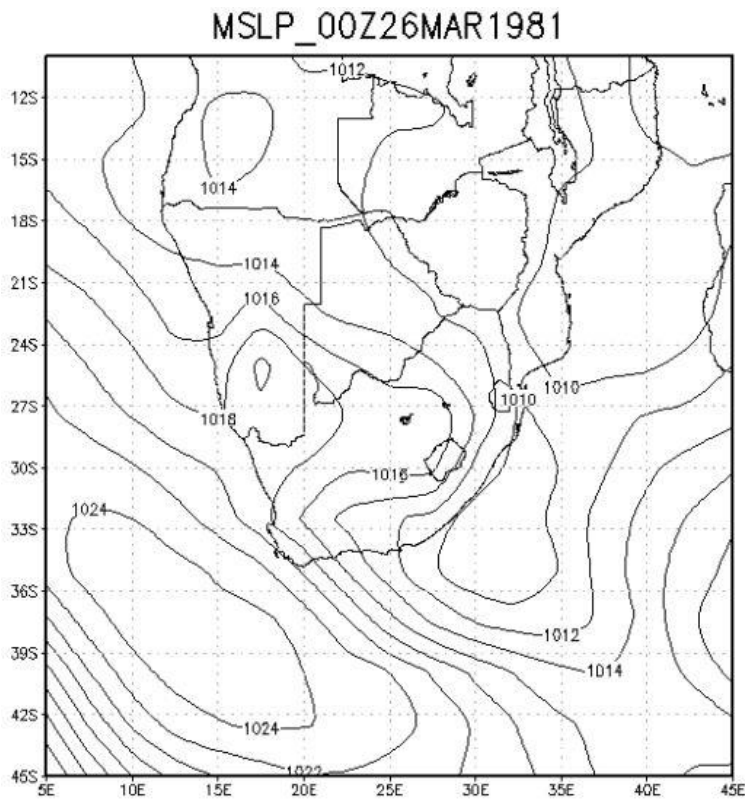


Figure 5.51: Synoptic chart of mean sea level pressure (hPa) at 00Z on 26 March 1981.

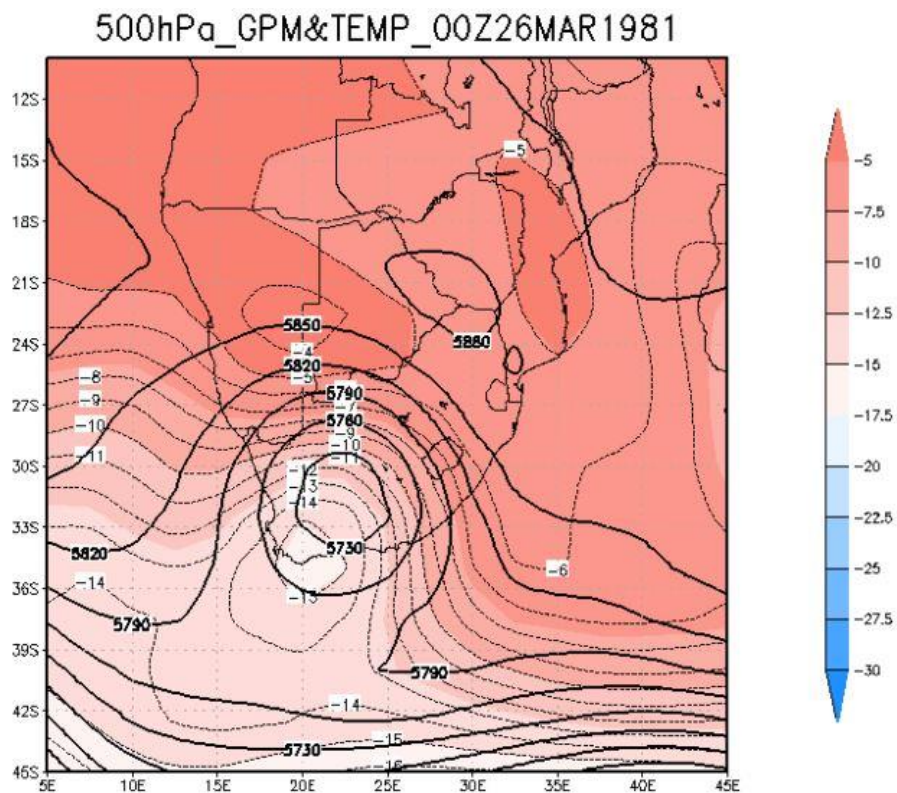


Figure 5.52: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 26 March 1981.

#### 5.3.4.3 Meteorological parameters analysis

On the 24<sup>th</sup> March 1981, the pressures increased gradually throughout the day (Figure 5.53). The temperature (Figure 5.54) started off fairly warm around 20 °C and decreased into the early morning to a minimum of 18.6 °C at 06:00. The temperature then gradually increased to 22.7 °C at 14:00 and then decreased slowly for the rest of the evening. The relative humidity at Port Elizabeth WK in Figure 5.55, followed a fairly normal decrease in relative humidity towards midday when it was the driest and then increased towards the evening but with a sharp increase after 15:00. The wind direction was a southerly wind between about 180-210° for most of the day on the 24<sup>th</sup> March (Figure 5.56). Around 19:00, the wind rapidly changed directions and the wind can be seen varying between northerly and southerly wind directions but in Figure 5.57, it can be seen that at the same time the winds are decreasing in strength and once again there was a light and variable situation. The wind speed, however, increased significantly at 22:00 on a south westerly wind.

On the 25<sup>th</sup> the pressure remained fairly constant, except towards the evening where the pressure started to decrease rapidly. The temperature started off at 17.1 °C and increased very slowly to a maximum at 21:00 and 22:00 at 20.2 °C. The late maximum doesn't follow diurnal cycles and other factors must be at play. The temperature did, however, start to decrease after 22:00 but marginally by about one degree in an hour. The relative humidity continued to increase from the previous day into the 25<sup>th</sup> and remained high at about 97% through most of the day. The wind gradually decreased in strength into the morning of the 25<sup>th</sup> and returned to a slightly more southerly wind. After about 14:00, there was a rapid wind direction change to a northerly wind again, where the wind became calmer, until about 16:00 at which point the wind speed increased and the wind direction changed to a north-westerly and then to a south-easterly wind. The wind through the evening then on the 25<sup>th</sup> was a moderate to fresh south-easterly wind. The pressure started decreasing between 18:00 and 20:00 when the wind was onshore. The pressure then spiked between 20:00 and 21:00 and then began to decrease again.

The trend of decreasing pressure continued into the morning of the 26<sup>th</sup> March until about 06:00 SAST, after which the pressure rose rapidly for the rest of the day. The temperature continued to decrease from the previous night into the early hours of the 26<sup>th</sup> when the minimum was reached at 05:00 at 12.9 °C. The temperature increased rapidly to 16.7 °C at 08:00, which was the maximum for the day and then decreased steadily for the remainder of the day. The relative humidity decreased slightly in the

early morning hours but increased again after 03:00. In the early hours of 26<sup>th</sup> March, the wind direction turned to a north westerly wind and the wind speed began to increase. Between 05:00 and 08:00, the wind direction changed from a westerly wind to a southerly wind. The wind speed also increased to be very strong on the southerly wind. This wind speed and direction change correlated with a sharp pressure rise as the high pressure system ridged in behind the surface low off of the coastline as seen in Figure 5.51.

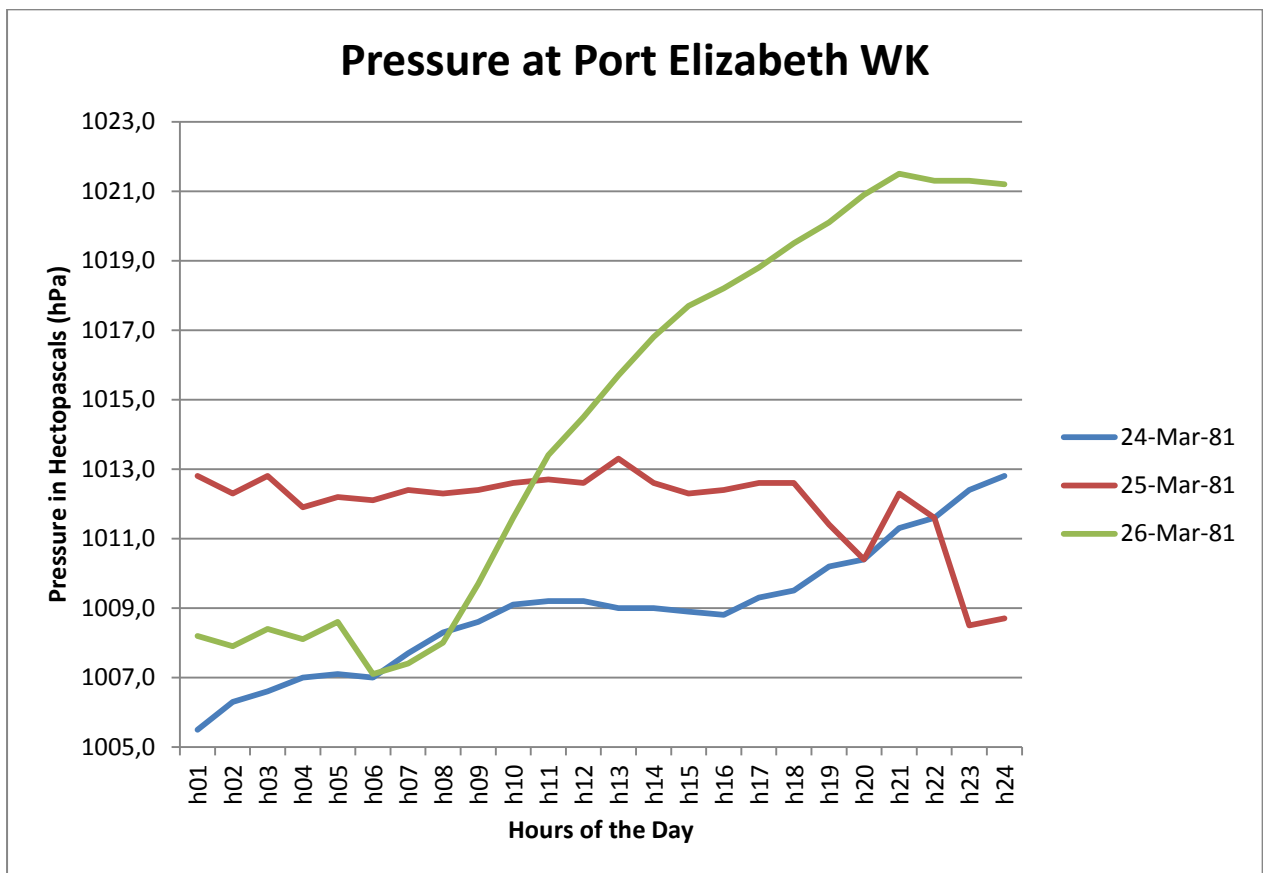


Figure 5.53: Pressure at Port Elizabeth WK for 24 -26 March 1981.

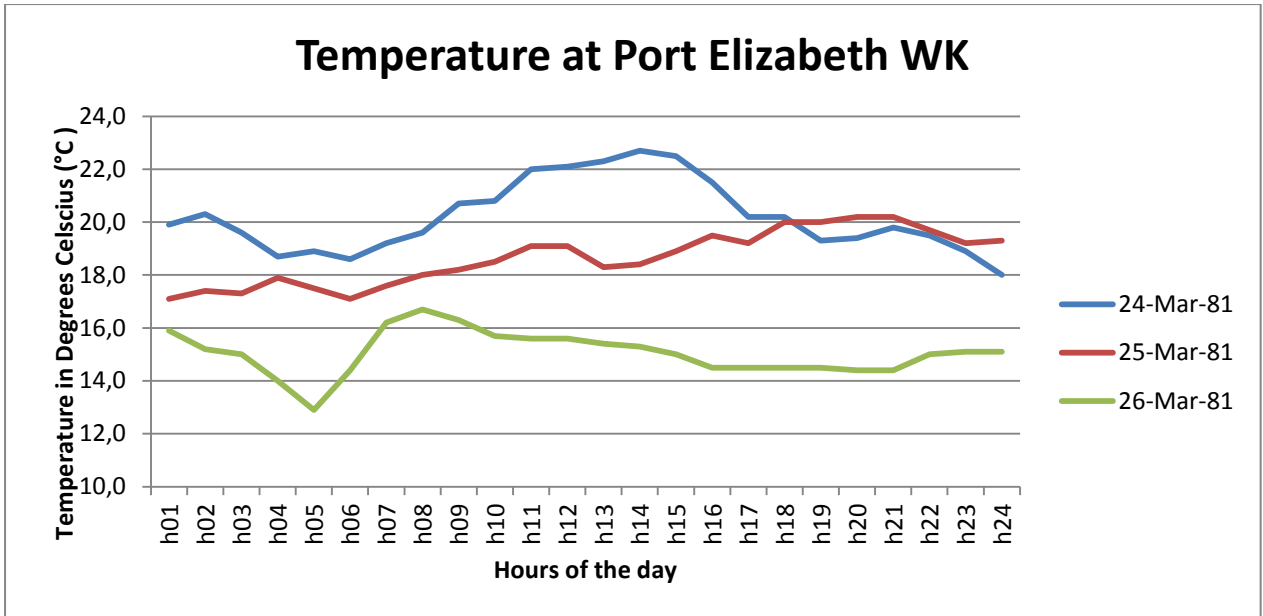


Figure 5.54: Temperature at Port Elizabeth WK for 24-26 March 1981.

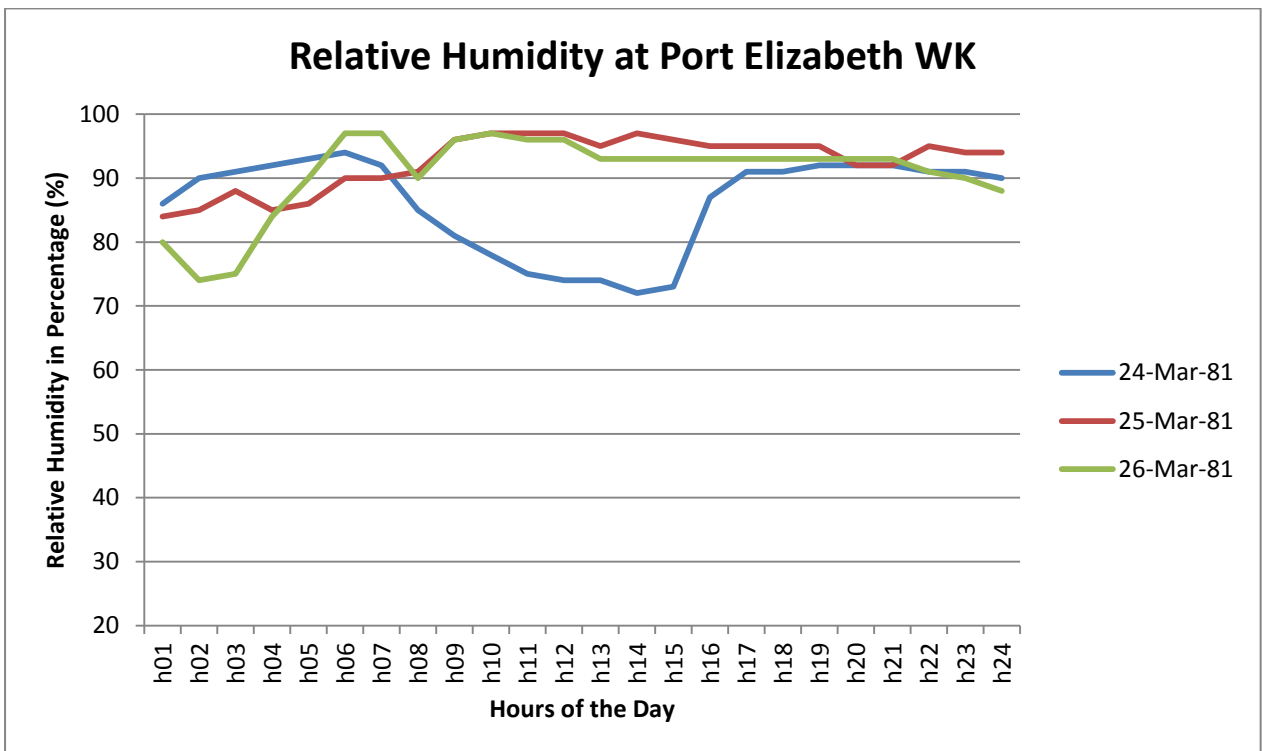


Figure 5.55: Relative Humidity at Port Elizabeth WK for 24-26 March 1981.

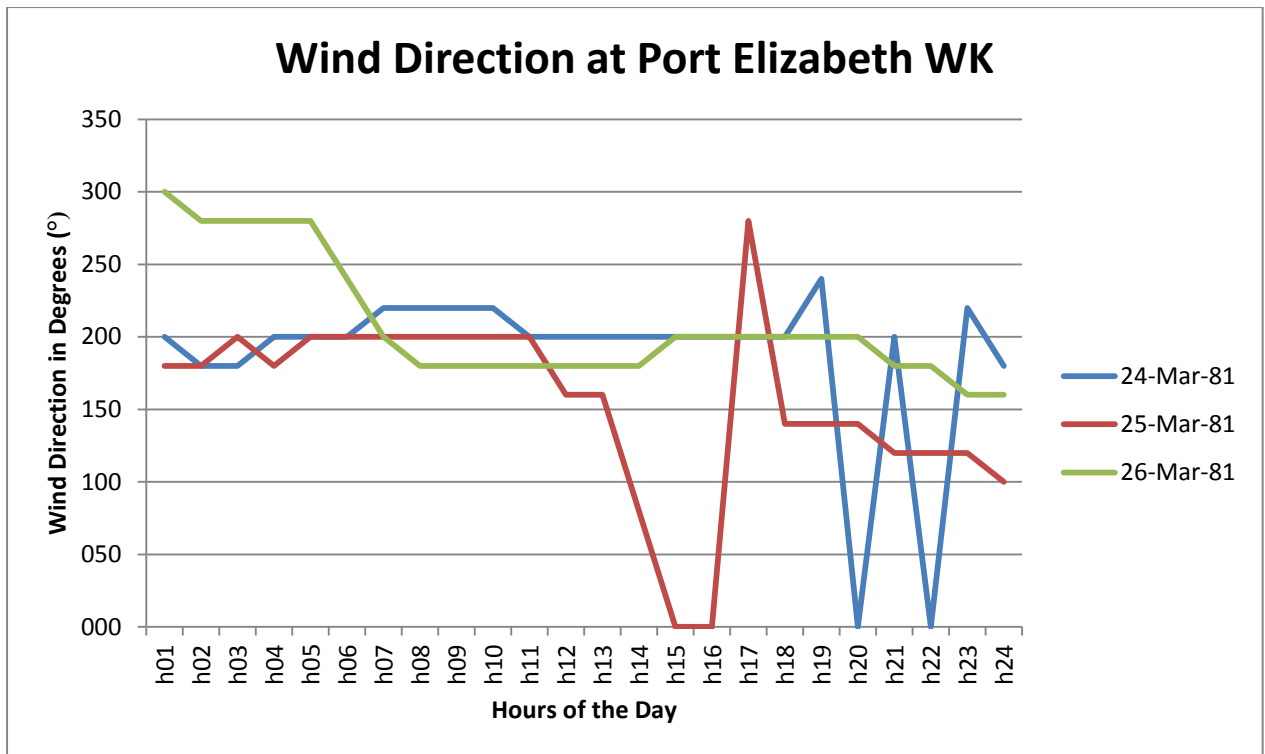


Figure 5.56: Wind Direction at Port Elizabeth WK for 24-26 March 1981.

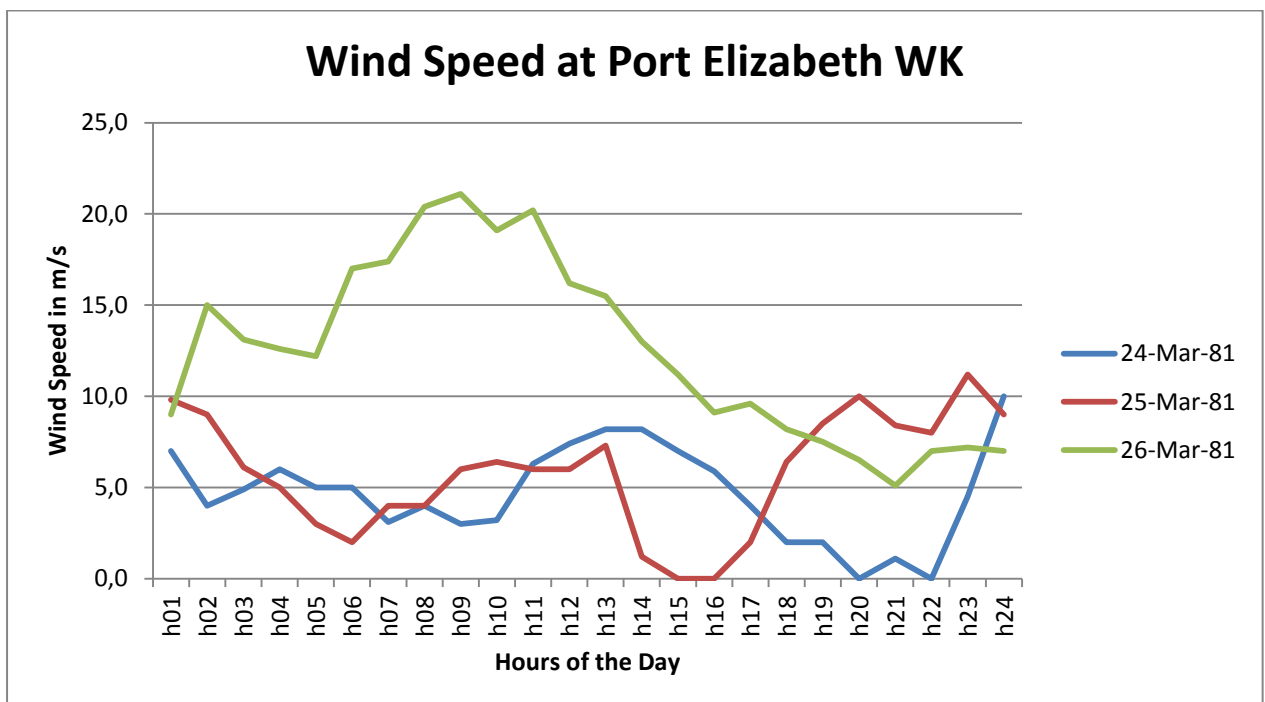


Figure 5.57: Wind Speed at Port Elizabeth WK for 24-26 March 1981.

Looking at the rainfall figures, light rain began to fall on the evening of the 24<sup>th</sup> March as the pressure rose and subsided into the morning of the 25<sup>th</sup> when the pressure stabilised. The day that recorded the heaviest rain during the period 24-26 March was the 25 March 1981, as seen in Table 5.1. The daily rainfall for 25 March 1981 is

shown in Figure 5.58. The largest increase in the rainfall is seen in the evening period after 20:00 into the early hours of the 26<sup>th</sup>.

Concerning the rainfall on the 25<sup>th</sup> of March, a notable increase can be seen throughout the morning after 08:00, as seen in Figure 5.59. The hourly rainfall intensity graph peaks in four different periods: firstly, between 08:00 and 14:00 where the rainfall gradually increased; secondly, between 17:00 and 19:00; thirdly, between 21:00 and 00:00 into the early morning of the 26<sup>th</sup> March and lastly, the period between 05:00 and 07:00.

During the first period between 08:00 and 14:00, the rainfall gradually increased per hour but the pressure remained fairly constant with minor changes between 1012 and 1013 hPa. The wind was southerly to south-easterly and fairly moderate in speed. The rainfall intensity decreased rapidly after 14:00 as the wind direction changed to a northerly wind.

The second period between 17:00 and 19:00 had a wind direction change from north-westerly to south-easterly. Once the wind changed direction to a south-easterly, the rainfall intensity increased rapidly. The south-easterly wind also increased in speed from the near calm north-westerly preceding this. The pressure remained steady between 17:00 and 18:00 and then began to decrease towards 20:00.

The pressure rose between 20:00 and 21:00 with a rise of nearly 2 hPa in the hour. But after 21:00 the pressures began to fall again. The temperature was at a maximum during this period which is peculiar at night. The wind direction was still south-easterly as the rain started and there wasn't a major change in wind direction as the rain ensued. The wind speed, however, spiked during the third period on the south-easterly wind. This wind speed increase would correspond with the rapid pressure increase and potential higher temperatures.

Lastly, the early morning period of the 26<sup>th</sup> March between 05:00 and 07:00, saw the largest increase with 56.5 mm recorded during the 05:00 to 06:00 hour. The pressure decreased during this period and began to rise after 07:00. The relative humidity had been rising rapidly from 03:00 before this period. The wind direction changed from westerly to a southerly wind during the rainfall period. The wind speed also increased from approximately 12.5 m/s to 18 m/s.

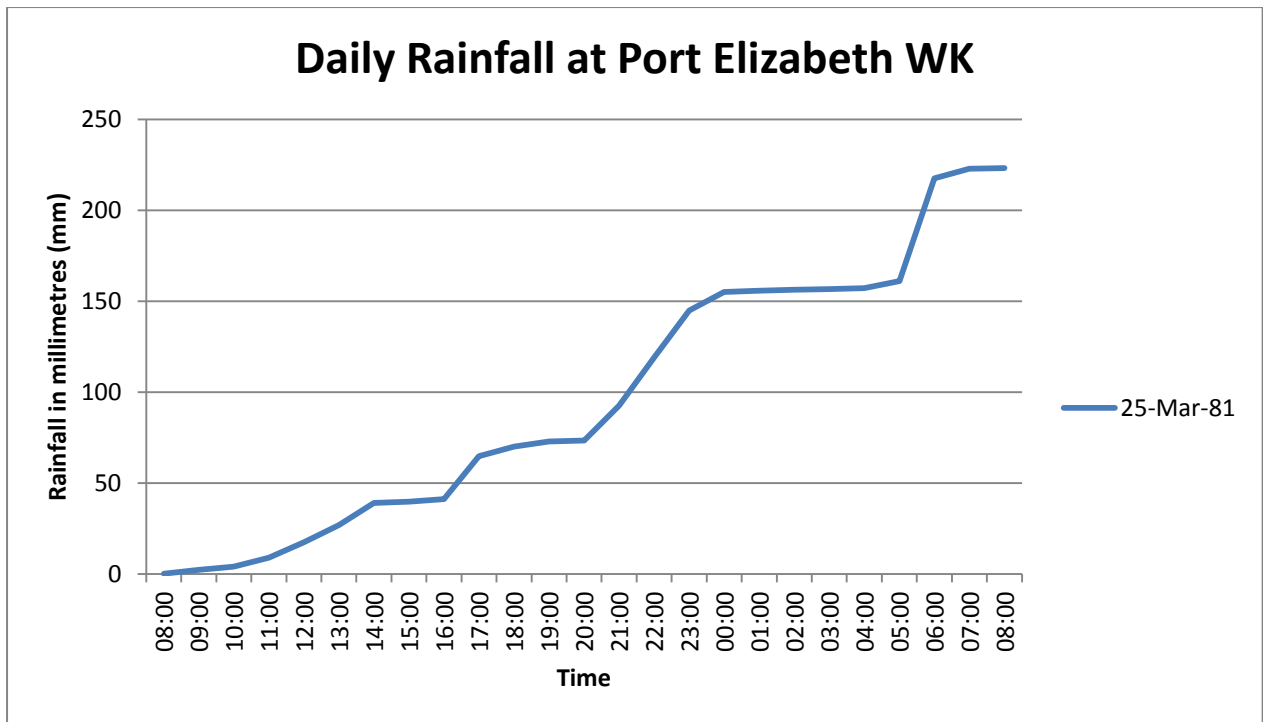


Figure 5.58: Daily rainfall at Port Elizabeth WK on 25 March 1981.

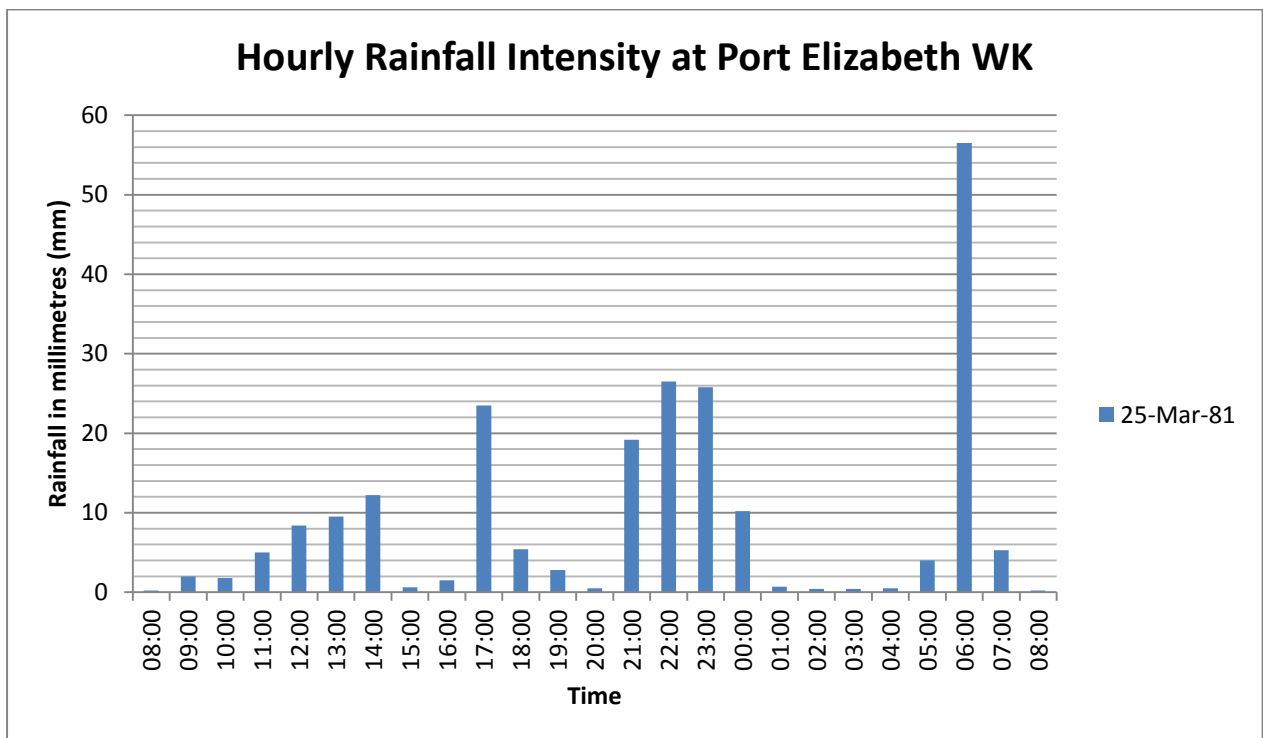


Figure 5.59: Hourly rainfall intensity at Port Elizabeth WK for 25 March 1981.

#### 5.3.4.4 Case Discussion

This case showed similarities to all the cases that have been discussed so far. The three key factors of an upper low lying west of the flood area, together with a ridging

high pressure system at the surface as well as a surface trough extending out onto the coastline are highlighted. The day that had the heaviest rainfall (25<sup>th</sup> March) was also the day when the surface trough extended onto the coastline to be north of East London (Appendix 4A), bringing moderate to fresh south-easterly winds into the area during the high rainfall intensity periods. When the wind was no longer south-easterly, a decrease in the rainfall intensity occurred. This event also saw high rainfall intensities occur before the pressure rose greatly and therefore, before the high pressure system ridged in. However, the last period between 05:00 and 07:00 was right on the cusp of the high ridging in as low level winds fed moisture onto the land to produce intense rainfall (Appendix 4B).

### **5.3.5. Case 5: East London 05-07 November 2005**

#### *5.3.5.1 Case overview*

This case is somewhat different from the other cases that have been analysed because it occurred in November. Most of the other cases were in the transitional seasons of autumn and spring, whereas this case is in early austral summer. Engelbrecht et al. (2015) noted November as the month that TTTs had the highest frequency together with COLs to produce rainfall along the Cape south coast. This case was the flooding event in Table 5.1 that had the fifth highest twenty-four-hour rainfall and did not feature in the top five heavy rainfall events in Table 5.2.

#### *5.3.5.2 Systems analysis*

**Saturday 05/11/2005:** The surface analysis reveals a TTT linking from the low pressure system over northern Botswana to a mid-latitude depression off of the east coast of Kwa-Zulu Natal (Figure 5.60). A high pressure system exists to the south west of the country extending a ridge eastwards. The upper air analysis (Figure 5.61) reveals a steep upper air trough located over the south western parts of the Western Cape in conjunction with a temperature trough at 500hPa.

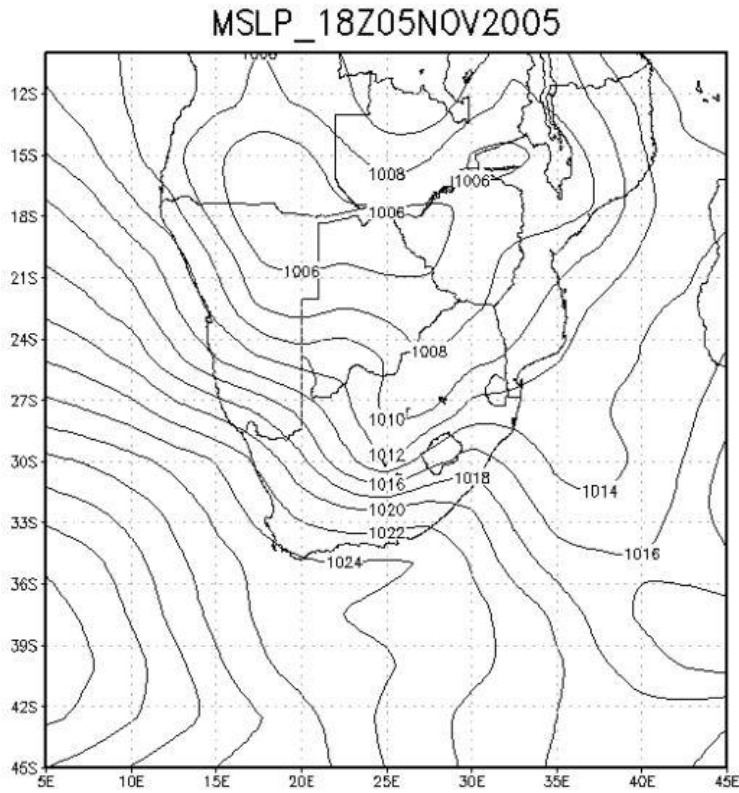


Figure 5.60: Synoptic chart of mean sea level pressure (hPa) at 18Z on 5 November 2005.

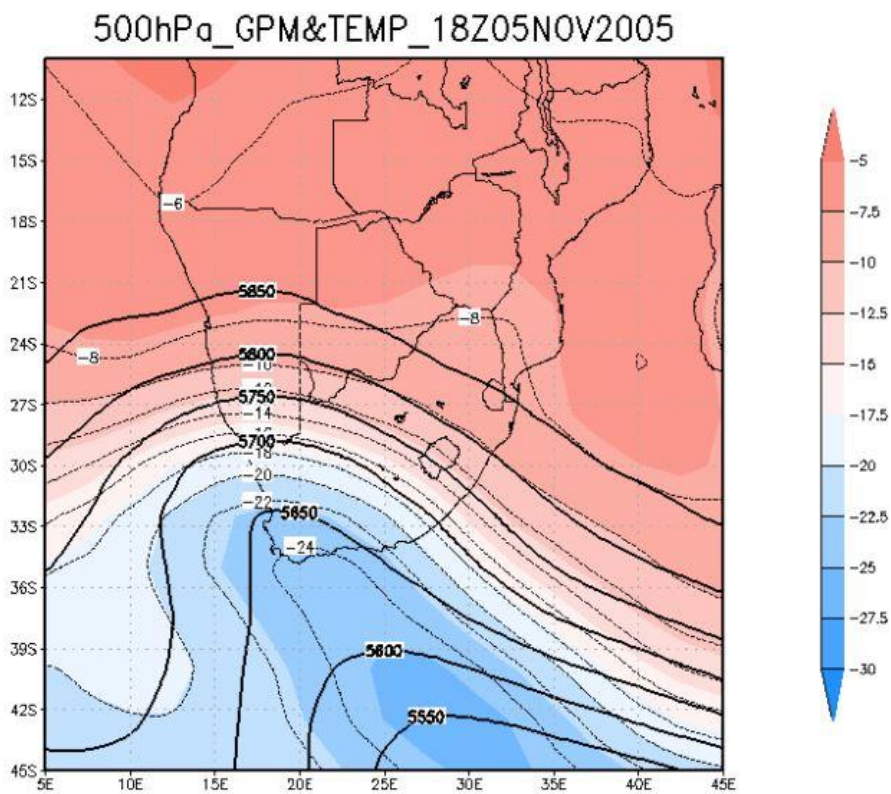


Figure 5.61: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 18:00Z on 5 November 2005.

**Sunday 06/11/2005:** The Atlantic Ocean high pressure system had ridged in along the south coast of the country with the TTT moving eastwards (Figure 5.62). The upper air analysis (Figure 5.63) shows the steep upper air trough to have remained stationary compared to the previous days analysis.

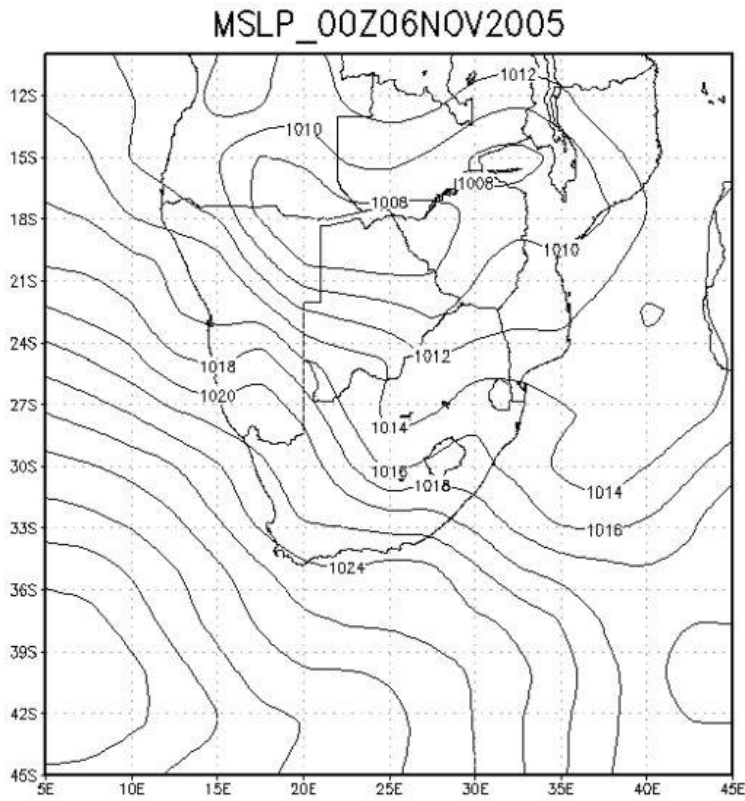


Figure 5.62: Synoptic chart of mean sea level pressure (hPa) at 00Z on 6 November 2005.

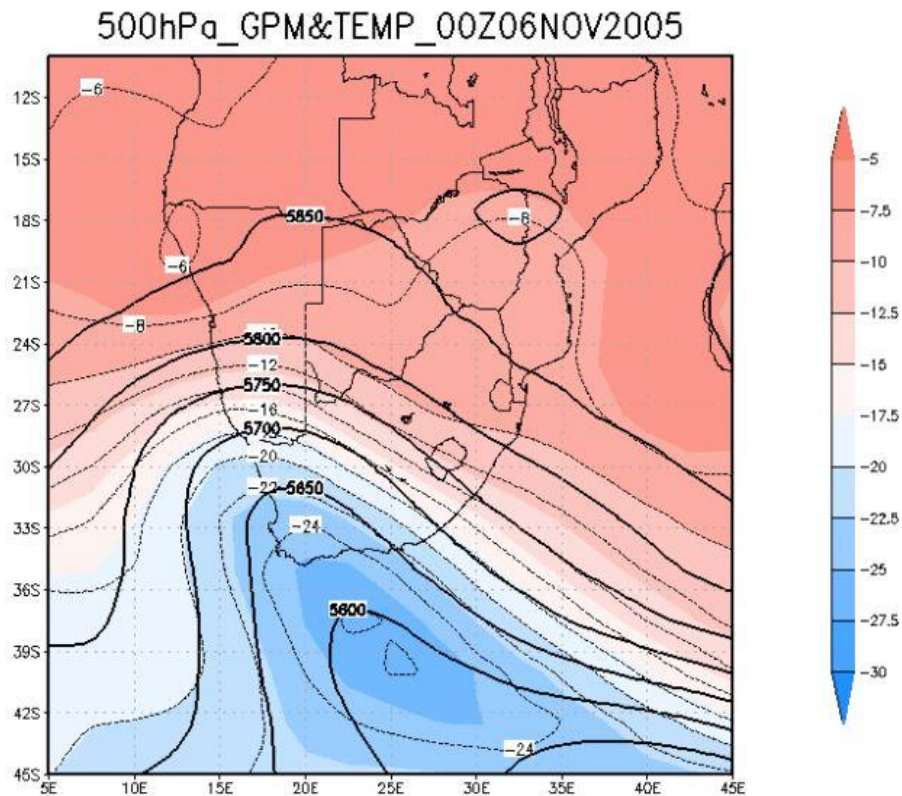


Figure 5.63: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 6 November 2005.

**Monday 07/11/2005:** The mean sea level pressure map (Figure 5.64) revealed the Atlantic Ocean high pressure system was still located far south west of the country but a low pressure system had formed off of the Kwa-Zulu Natal coastline thereby increasing the pressure gradient into the Eastern Cape. The upper air (Figure 5.65) showed a closed low at 500hPa with a cold core over the Port Elizabeth area and can be concluded as a COL.

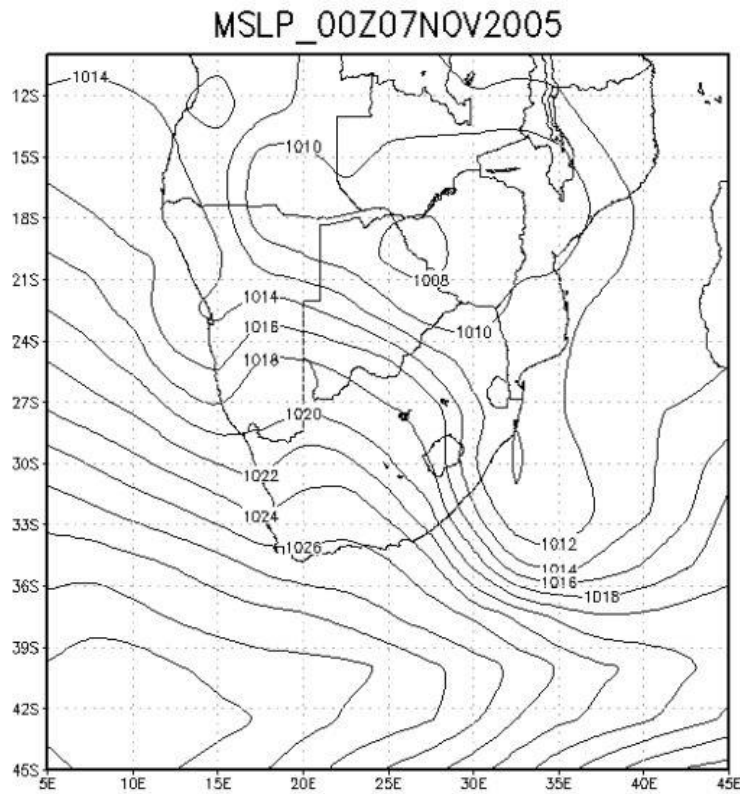


Figure 5.64: Synoptic chart of mean sea level pressure (hPa) at 00Z on 7 November 2005.

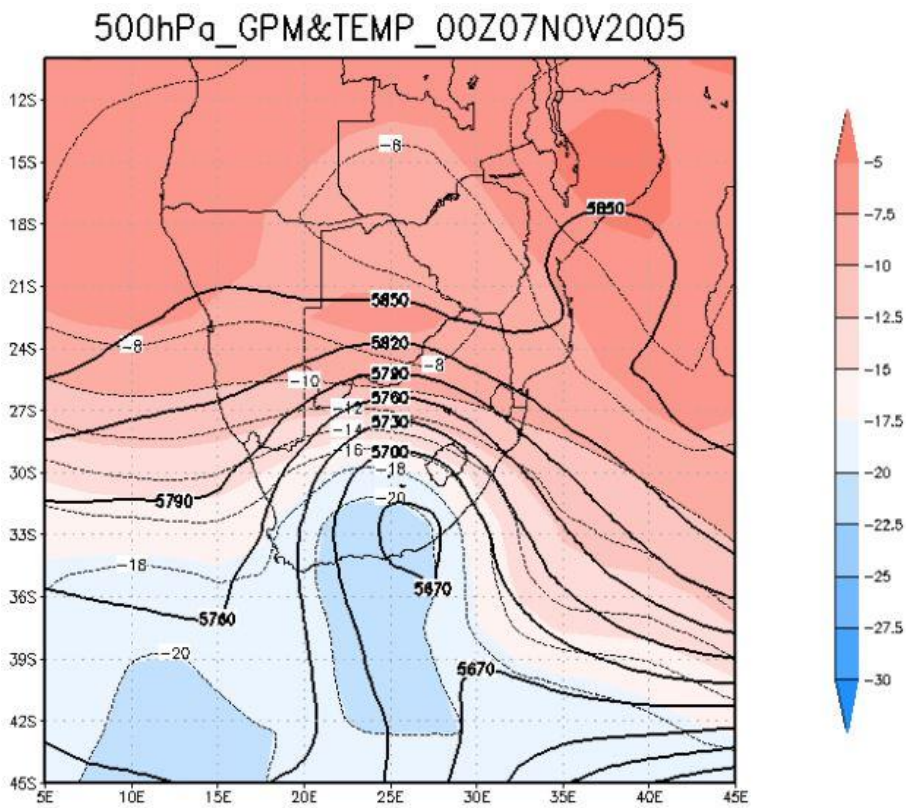


Figure 5.65: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 7 November 2005.

#### 5.3.5.3 Meteorological parameters analysis

The pressure graph (Figure 5.66) shows that the pressure rose substantially after 16:00 on the 5<sup>th</sup> November with a rise of three hectopascals. The pressure then remained high but stable throughout the evening. The temperature, in Figure 5.67, started off at around 12.5 °C and gradually increased for the day. The maximum was reached at 16:00 at 15.9 °C, after which the temperature decreased to about 13.8 °C by 18:00. The relative humidity rose rapidly after 16:00 by about 20%, as seen in Figure 5.68. This coincided with the pressure rise at the same time. The relative humidity then decreased after 21:00. The wind direction on 5 November 2005 went from a south-westerly to a south-easterly direction throughout the day but a sudden change occurred at 16:00 when the wind changed from south-easterly back to a south-westerly (Figure 5.69). This is the same time that the pressure rose and the relative humidity also increased. The wind then returned to a south-easterly direction for the remainder of the evening. The wind speed, seen in Figure 5.70, was relatively moderate throughout the day, varying between 2 and 4 m/s.

The pressure on the 6<sup>th</sup> November tended to decrease after 10:00. The pressure then rose again after 17:00 into the evening. The temperature continued to decrease from the previous night to 12.3 °C at 05:00 on the 6<sup>th</sup> November and then gradually increased to 14.9 °C at 16:00. The temperature then decreased but increased again at 19:00 to 15.0 °C. After 19:00, the temperature declined gradually. The relative humidity began to increase in the morning and remained between 90 and 95% for the majority of the day. The winds varied in direction in the early hours of the morning. After 06:00, the wind direction changed from a south-easterly to a south-westerly and the wind speed also increased on the south-westerly wind. The wind gradually changed direction to south- easterly and then to easterly at a moderate wind speed. The wind speed began to decrease after 15:00 up to 17:00 on a light north-easterly wind. However, after 17:00, the wind direction changed more than 180° from 50° (NE) to 240° (SW) between 17:00 and 18:00. The wind speed also started to pick up from 1.5 m/s at 17:00, reaching a peak of 9.5 m/s at 21:00.

The pressure decreased slightly into the early hours between 02:00 and 04:00 on the 7<sup>th</sup> of November but thereafter, began to rise and continued to rise for the rest of the day. Three temperature peaks occurred during the 7<sup>th</sup> of November. The temperature decreased to 12.7 °C at 05:00 on the 7<sup>th</sup> and then increased to 16.2 °C at 10:00 during the first peak. The first peak occurred at 10:00, as previously

mentioned, then at 12:00 with 18.0 °C and lastly at 16:00 with 18.4 °C. After 16:00, the temperature declined rapidly. These peaks are probably influenced by wind changes, which will be investigated later in this case. The relative humidity remained high into the early hours of the 7<sup>th</sup> of November. However, the relative humidity began to decrease after 08:00 and continued to decrease throughout the afternoon. The relative humidity rose sharply after 19:00 onwards. The wind remained fairly southerly throughout the early hours of the morning, varying between 210° and 180° at a wind speed between 4 and 6 m/s until 08:00. After 08:00, the wind changed direction to a westerly at 260° but returned back to a south-south-westerly at 10:00 and continued until 19:00. After 19:00, the wind direction gradually changed to a south-westerly and then to a north-westerly. It was mentioned earlier that the temperature fluctuated at 10:00, 12:00 and 16:00. The temperature probably increased to a peak at 10:00 as the wind was westerly before this, which is an offshore wind. The wind direction then changed to south-south-westerly after 10:00, which could have caused the temperature decrease as it's a more onshore wind which is naturally cooler off the ocean. The two other temperature peaks aren't really explained by the wind direction. The temperature peak at 12:00 coincided with a slightly lower wind speed but the 16:00 peak coincided with a wind speed increase.

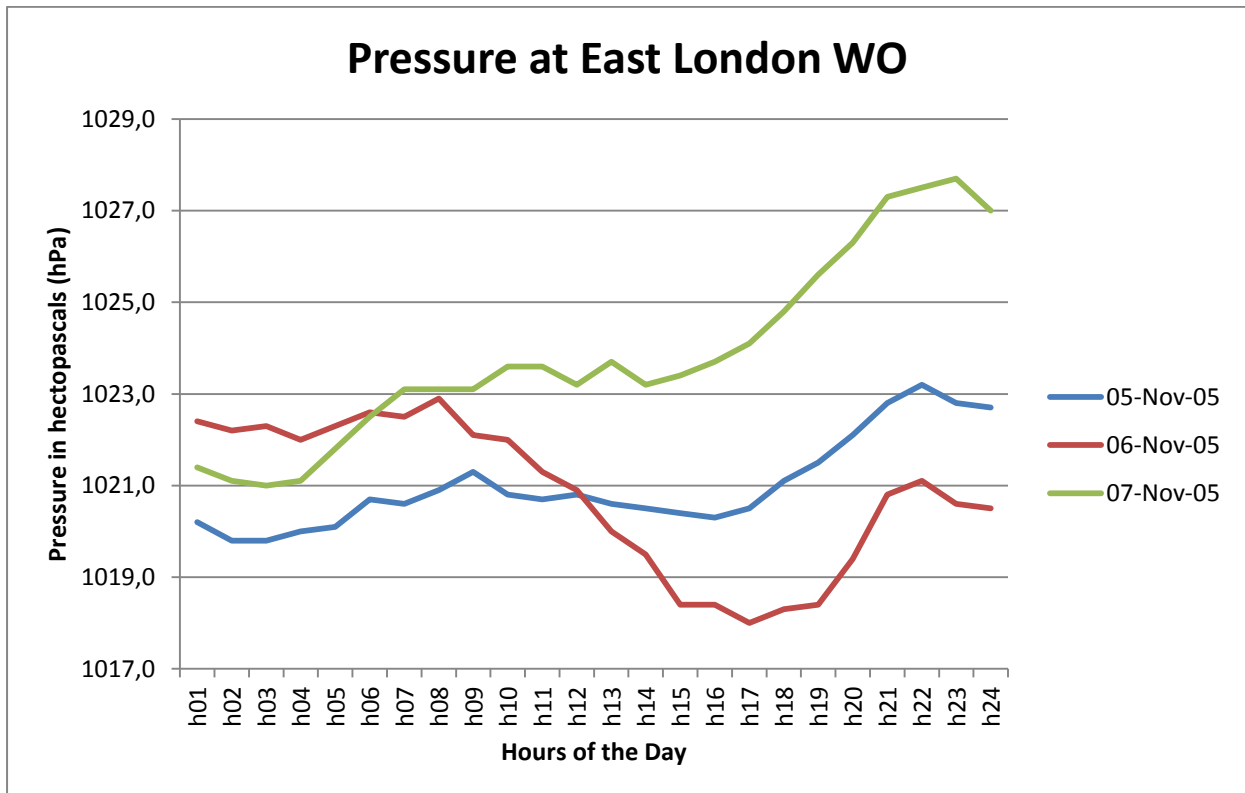


Figure 5.66: Pressure at East London WO for 5-7 November 2005.

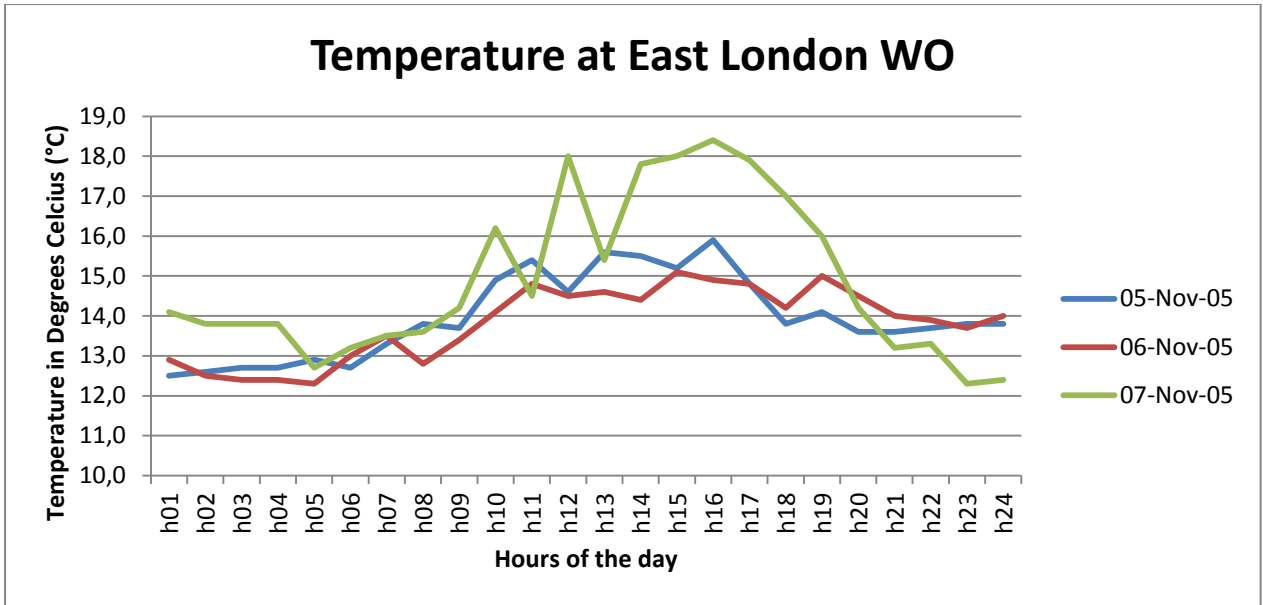


Figure 5.67: Temperature at East London WO for 5-7 November 2005.

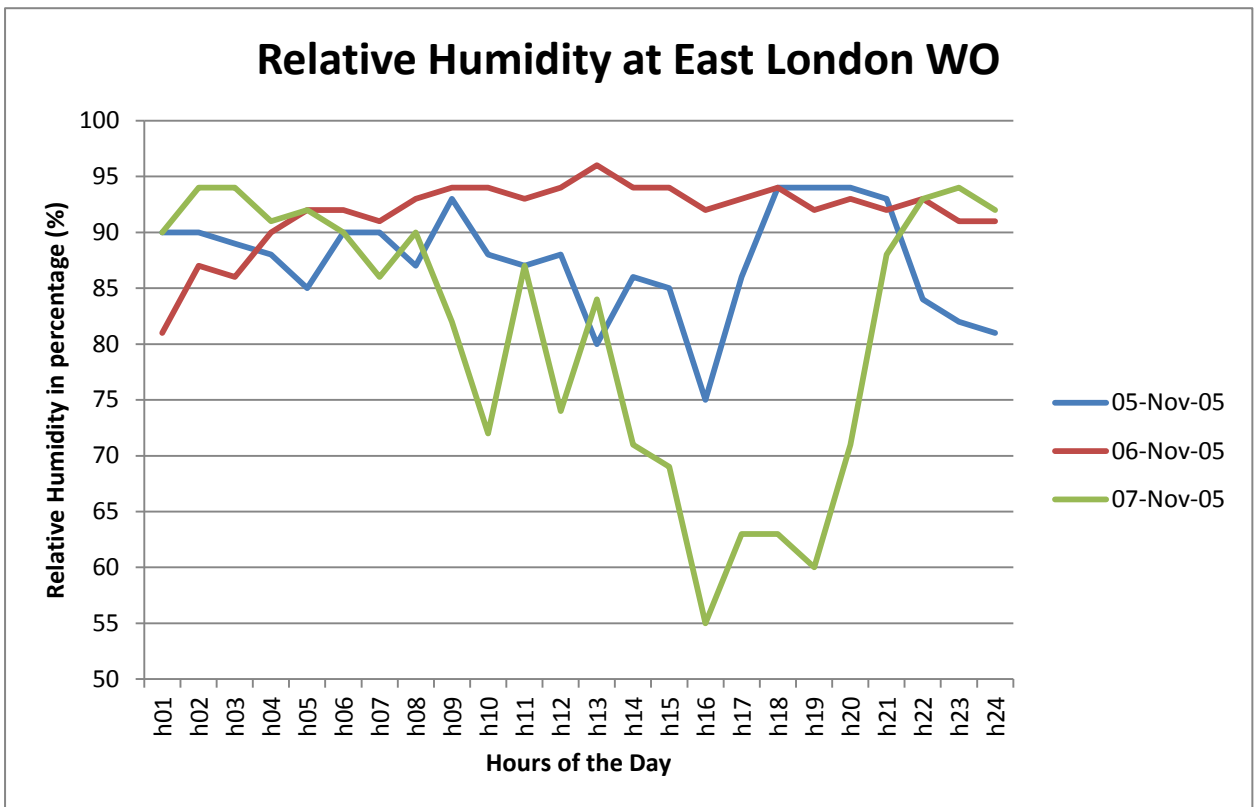


Figure 5.68: Relative humidity at East London WO for 5-7 November 2005.

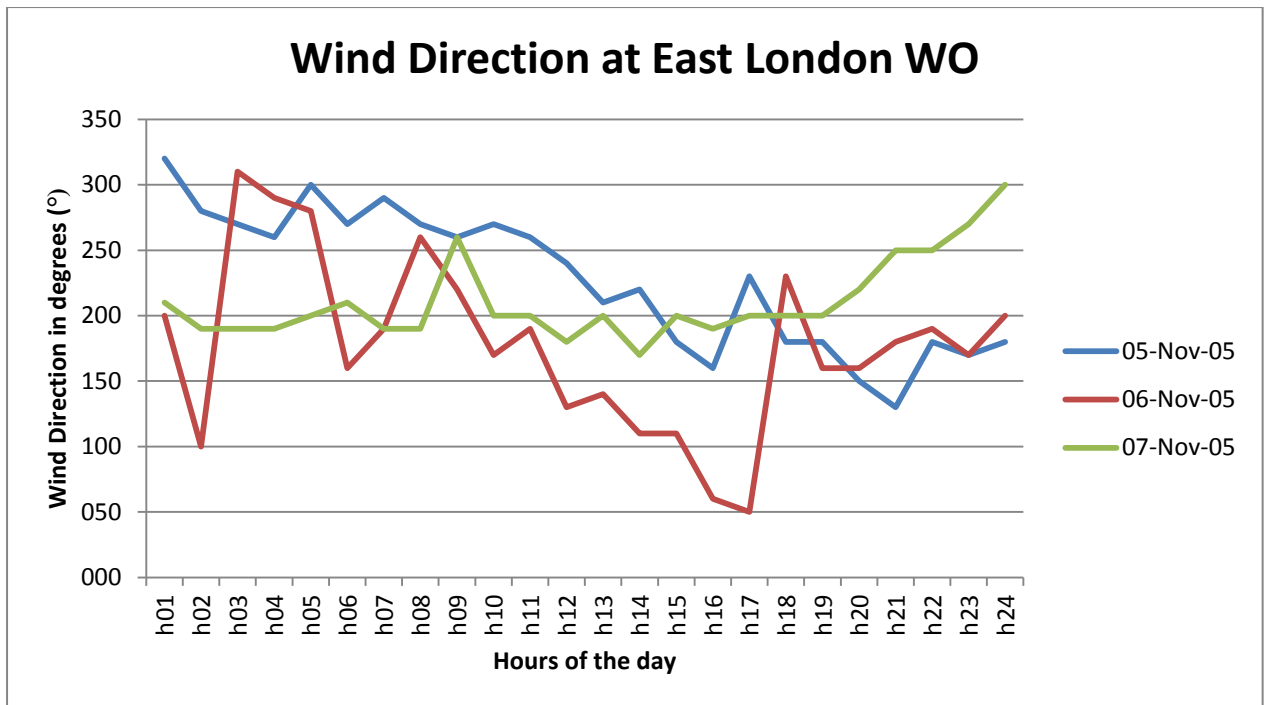


Figure 5.69: Wind direction at East London WO for 5-7 November 2005.

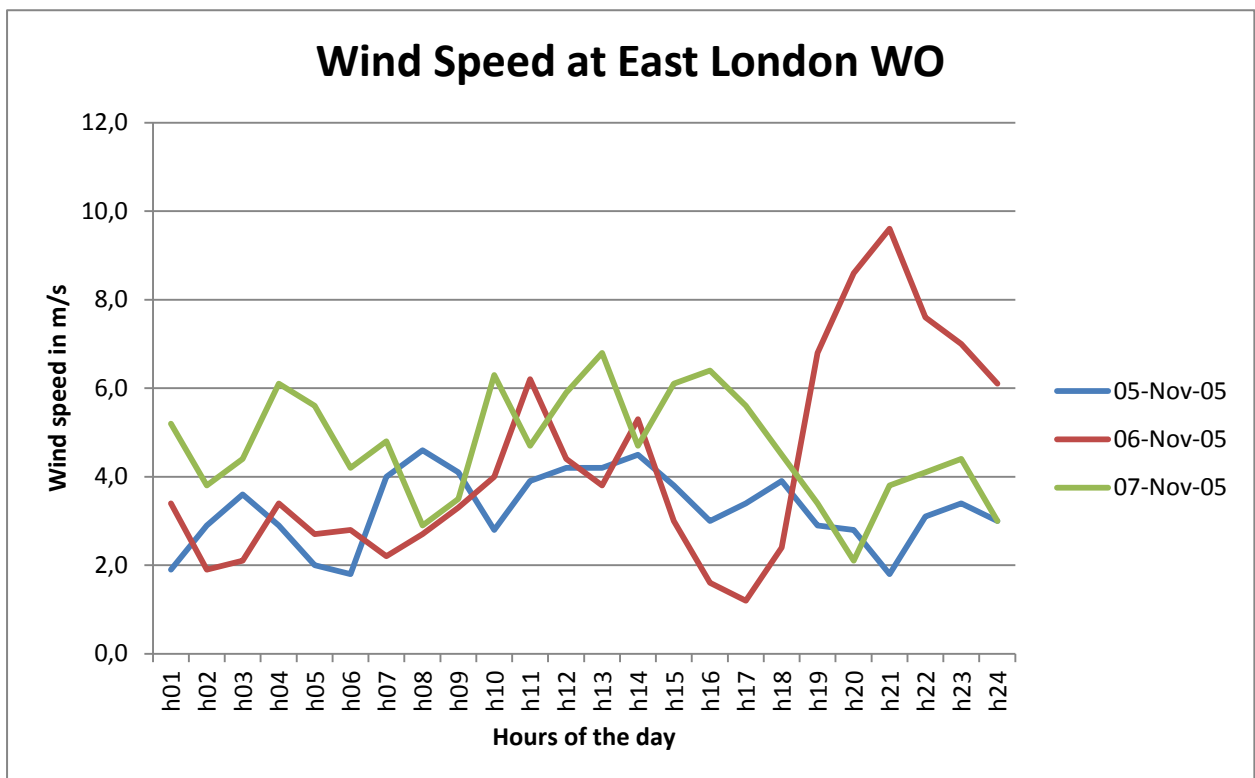


Figure 5.70: Wind speed at East London WO for 5-7 November 2005.

In Table 5.1, it can be seen that the day that recorded the highest twenty-four-hour rainfall was the 6 November 2005. The daily rainfall from 08:00 on 6 November to

08:00 on 7 November is shown in Figure 5.71. The daily rainfall recorded at East London WO was just over 160 mm in the twenty-four-hour period. The biggest accumulated increase in the daily rainfall occurred in the evening of 6 November into 7 November.

In Figure 5.72, the hourly rainfall intensity during the same period as the daily rainfall graph can be seen. The highest rainfall intensity hour was between 17:00 and 18:00 on 6 November with a peak at 30 mm. The temperature also decreased slightly in that time. The rain persisted but at a decreasing rate from 18:00 to 00:00. This high rainfall peak at 18:00 corresponded with a slight rise in pressure but more distinctly with a change in wind direction and speed. At that time the wind changed around from a north-easterly wind to a south-westerly wind of about 240°. The wind speed also began to increase after 18:00. The swing of the wind from a north-easterly to a south-westerly seems to imply a localized surface low pressure moving through the area.

Another peak was reached at 02:00 on 7 November of around 15 mm and the rain continued but tapered off towards 08:00. The pressure decreased slightly during this hour and wind speed also decreased slightly. The wind changed direction slightly from 210° at around 00:00 to 180° at 02:00 when the heavy rainfall intensity peaked again.

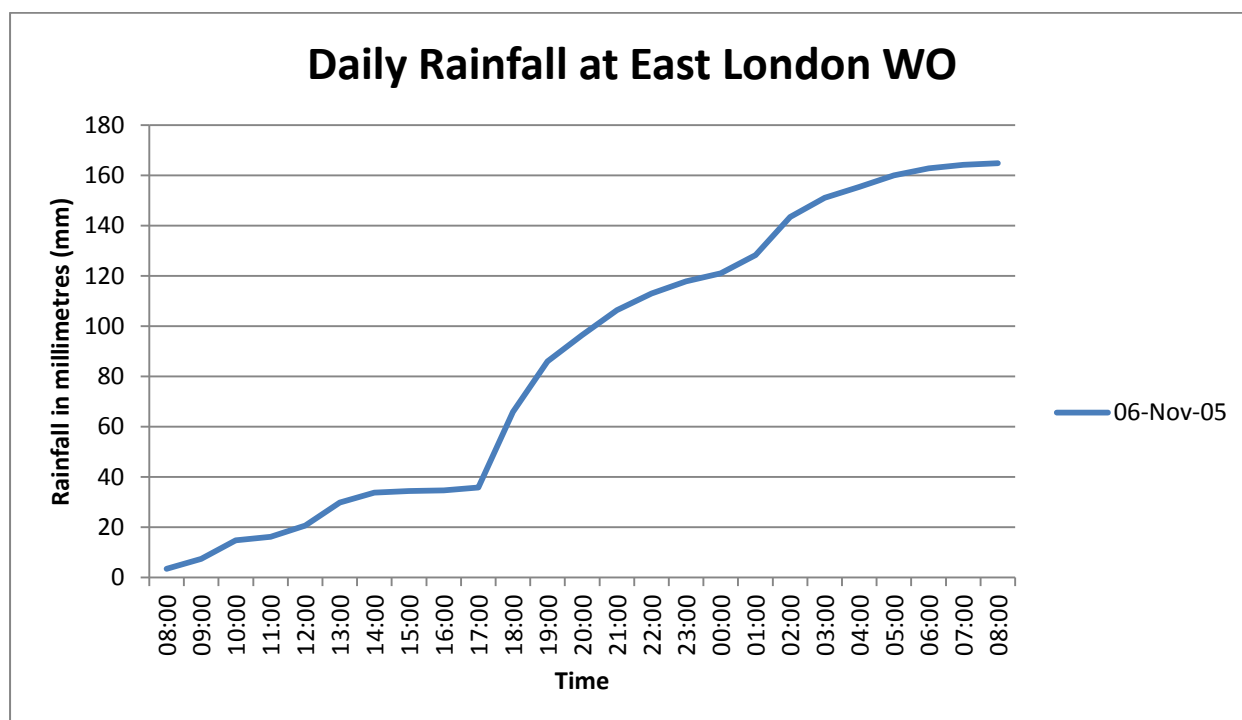


Figure 5.71: Daily rainfall at East London WO for 6 November 2005.

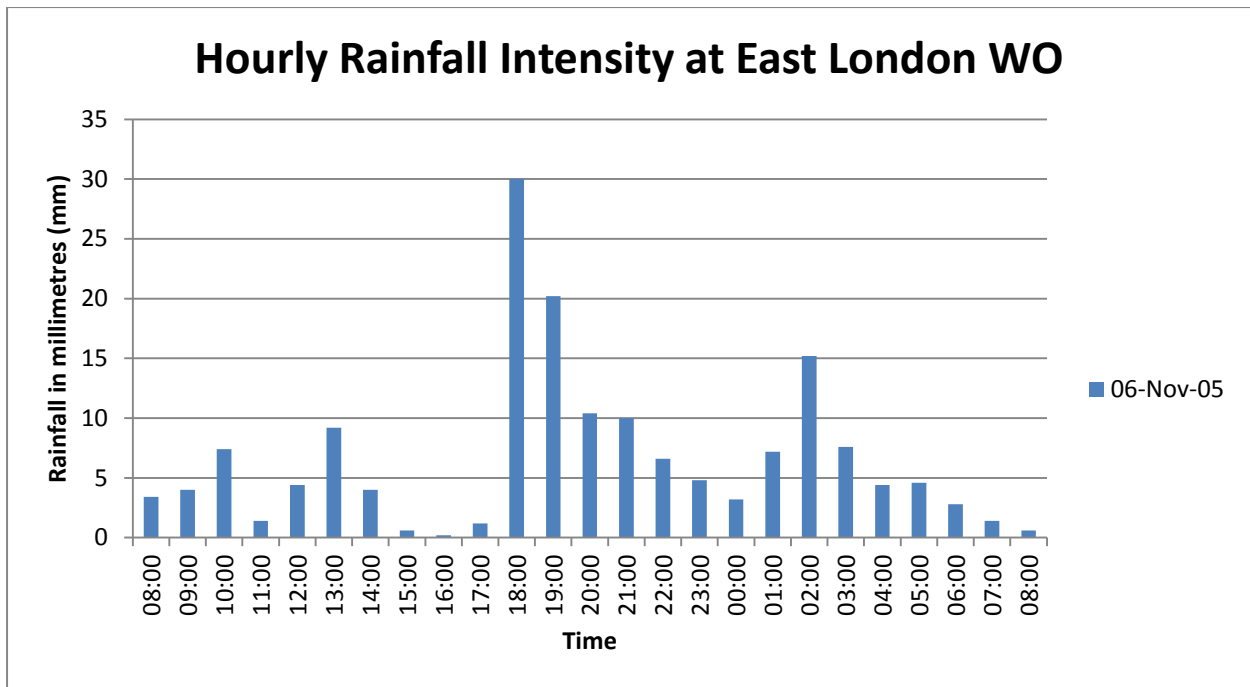


Figure 5.72: Hourly rainfall intensity at East London WO for 6 November 2005.

#### 5.3.5.4 Case Discussion

This case started off as a TTT and occurred with a steep upper air trough which later developed into a COL by 00:00Z on the 7<sup>th</sup> of November 2005. This COL existed west of the flood area with a ridging high pressure system along the south coast. The heaviest rainfall occurred in the evening of the 6<sup>th</sup> November at 18:00 SAST as the pressure gradient increased between a surface low off the Kwa-Zulu Natal coast and the high pressure system to the south west (Appendix 5). High rainfall intensities also occurred at 00:00Z on 7<sup>th</sup> November and similar tight pressure gradients are seen on the surface chart for that time (Figure 5.64). The timing of this system, in early summer, caused more tropical air to be in circulation, which could have increased the moisture availability and sea surface temperatures. The highest rainfall peak coincided with the gradual rise in pressure, however, most distinctly the higher intensity occurred at the same time as a wind direction change from north-easterly to south-westerly as a surface low pressure system seemed to have progressed through the area on the evening of the 6<sup>th</sup> of November.

### **5.3.6. Case 6: Gamtoos/Sunday's River 28-31 December 1931 – 01 January 1932**

#### *5.3.6.1 Case overview*

This case ranked second highest on the event rainfall table (Table 5.2) with an event total of 578 mm.

However, the case did not rank in Table 5.1 of the highest twenty-four-hour rainfall. This event seems to then have been a large amount of rain over a few days.

The report for the years 1931-1932 from the Meteorological office reported above normal rainfall for the southern coastal areas in excess of 25 percent above normal for the year 1931. This was to some extent due to the four days of heavy rainfall and floods experienced at the end of December 1931 (Union of South Africa, 1935).

“These floods deserve special mention here, as they were perhaps the heaviest and most disastrous yet experienced in South Africa over so extensive an area.” (Union of South Africa, 1935:vi).

According to the Union of South Africa (1935), the heaviest rainfall was recorded in the Western Cape south coast districts which fall outside of the study area but a significant amount of eight inches (203 mm) fell at Otterford Bos station, between Patensie and Port Elizabeth in the western parts of the study area, in a single day. The event total of 578 mm over five days was exceptional and resulted in damage to crops and bridges being washed away. The heaviest rainfall occurred on the slopes of the mountain ranges, especially the southern ranges near the coast.

#### *5.3.6.2 Synoptic Analysis*

Daily weather bulletins and synoptic chart analyses only began to be recorded, by the then South African Weather Bureau, from 1937 and were, therefore, unavailable for this case. NCEP/NCAR reanalysis 1 data was only available from 1948.

#### *5.3.6.3 Meteorological parameters analysis*

Due to this case being in the early 1930's, only daily wind and rainfall was recorded. Wind was only recorded in two points in the Eastern Cape. The first station was located at the Great Fish Point and the second station was located at Cape St Francis. Cape St Francis does not fall into the study area but the floods that occurred in this event occurred in the Gamtoos River valley and in the Sunday's River valley, therefore, Cape St Francis was the closest station available to the flood areas when compared to the station at the Great Fish Point. Daily winds and rainfall were

recorded at 08:00 SAST during the flood period. Having worked primarily with hourly data, it is understood that wind recorded on a daily basis reveals very little about the synoptic or even mesoscale dynamics, however, it has been seen in previous cases that the wind direction plays a significant role in the rainfall amounts and therefore, the daily wind can be seen in Table 5.4 below.

Table 5.4: Wind direction and wind speed at Cape St Francis for 28 December 1931 to 01 January 1932

Date	Average Wind Direction in Degrees	Average Wind Speed in m/s
28 December 1931	90	5.1
29 December 1931	270	8.2
30 December 1931	130	8.2
31 December 1931	130	1.5
01 January 1932	270	3.1

Table 5.4 reveals a predominantly easterly and south-easterly wind regime over the flood days in this event. The only days that showed westerly winds were on the 29<sup>th</sup> December and 1<sup>st</sup> January 1932. A theory that could be deduced is that a low pressure trough extended off of the south-east coast bringing in an easterly wind into Cape St Francis on the 28<sup>th</sup> December. The wind then changed westerly on the 29<sup>th</sup> December, implying a low approaching from the west such as a cold front or coastal low and the wind changing and maintaining a south-easterly flow for the 30<sup>th</sup> and 31<sup>st</sup> December could correspond with a low pressure system moving through the area and the high ridging in behind the cold front. The wind returned back to a westerly on the 1<sup>st</sup> January. While theories of the synoptic scale systems could be assumed, a lack of data renders these theories inadequate in this case.

Daily rainfall was recorded at Port Elizabeth VRT (vuurtoring – lighthouse) station during these years. Table 5.5 shows the daily rainfall recorded at the station for the period of 28 December 1931- 1 January 1932. The highest rainfall occurred on the 31<sup>st</sup> December 1931. This rainfall distribution shows fairly good rainfalls for four consecutive days, which may have led to the floods. This indicates that it was the accumulation of the rainfall that may have caused the floods.

Table 5.5: Daily rainfall amounts recorded at Port Elizabeth VRT station.

Date	Daily Rainfall (mm)
28 December 1931	1.8
29 December 1931	31
30 December 1931	38.1
31 December 1931	44.5
01 January 1932	34.3
Total	149.7

Taking both the wind and rainfall data into consideration may elude to some conclusions, however, both being recorded at different stations is perhaps inaccurate to compare. However, due to a lack of data, it is the only data the researcher can compare. Thus, conclusions will not be completely dependable.

On the 28th December 1931, 1.8 mm of rainfall was recorded with a moderate easterly wind. On the 29th December, 31 mm of rain was measured with a fresh westerly wind. The 30th December saw 38.1 mm with a fresh south-easterly wind. The heaviest rainfall was recorded on the 31st December when a light south-easterly wind occurred. Finally, on the 1st January 1932, 34.3 mm was recorded on a light westerly wind.

According to the Meteorological Report (Union of South Africa, 1935), heavy rains in the range of one to three inches (25-76 mm) were recorded for mainly the southern districts on the 28th December, west of Port Elizabeth. On the 29<sup>th</sup>, however, even heavier falls occurred with most stations recording 3 to 5 inches (76-127 mm) with Otterford Bos reaching the maximum of 8 inches (203.2 mm). Otterford Bos is in the western parts of the study area close to Patensie and near to the Gamtoos River.

By the 30th December, the rainfall was less intense but the heaviest rainfall of the entire period fell on the 31st of December with several stations in the south Cape receiving over ten inches (254 mm). These stations were, however, west of the study area. The rainfall intensity decreased again on the 1st January.

The days with the heaviest rainfall were the 29th December and the 31st December. This corresponds, from Table 5.4, to a westerly wind on the 29th and a south-easterly wind on the 31st. The westerly wind seems surprising to coincide with heavy

rainfall, however, the researcher would like to point out that the wind was westerly at 08:00 SAST and as previously mentioned, the wind direction could have changed as a low pressure system moved through. From the other cases, it has been seen that the high rainfall intensities occurred as the surface low pressure moved through an area on the leading edge of the high pressure system. Therefore, perhaps later in the day on the 29th December, a surface low moved through and resulted in high rainfall intensities. The wind was south-easterly on the 31st December which could have aided the heavier rainfall intensities.

#### *5.3.6.4 Case Discussion*

Interestingly, this case takes place very late in the year, in mid-summer, compared to the other cases. It is unfortunate that no synoptic analysis could be given. A pressure analysis would potentially also help greatly in trying to determine the surface synoptic systems. Only a very rudimentary discussion can then be drawn without the other meteorological parameters. This case had rain for approximately five days, which lead to a high event rainfall amount. The two days with the heaviest rainfall were the 29th and 31st December. No real conclusions can be made using a wind direction at a single time of the day as many factors could change throughout the day. Also there is no confirmation of any upper air systems in play due to a lack of upper air observations at this time.

### **5.3.7. Case 7: Patensie/ Port Elizabeth 24-27 July 1983**

#### *5.3.7.1 Case overview*

This case didn't feature in Table 5.1 with the highest twenty-four-hour rainfall but did feature at fifth place on the event rainfall table. The event had a total of 428 mm for the four-day period and this was recorded at Otterford Bos near Patensie. Floods were recorded in Patensie/ Gamtoos River, Port Elizabeth and East London. Several people died in these floods.

The surface data analysis could not be conducted at Otterford Bos where the highest event rainfall occurred as hourly data was not received from that station at the time. Therefore, the closest station to Otterford Bos that did record hourly data was Port Elizabeth WK. The surface data analysis will thus be conducted for Port Elizabeth WK for the four-day period.

### 5.3.7.2 Synoptic analysis

**Sunday 24/07/1983:** A surface trough existed through the central parts of South Africa at 00:00Z on 24 July 1983 (Figure 5.73). A strong high pressure system was located south of Cape Town with a centre at 42°S extending a ridge to the north east. The upper air analysis (Figure 5.74) revealed an upper air trough off of the west coast of the Western Cape. A temperature trough is also present in the upper air trough.

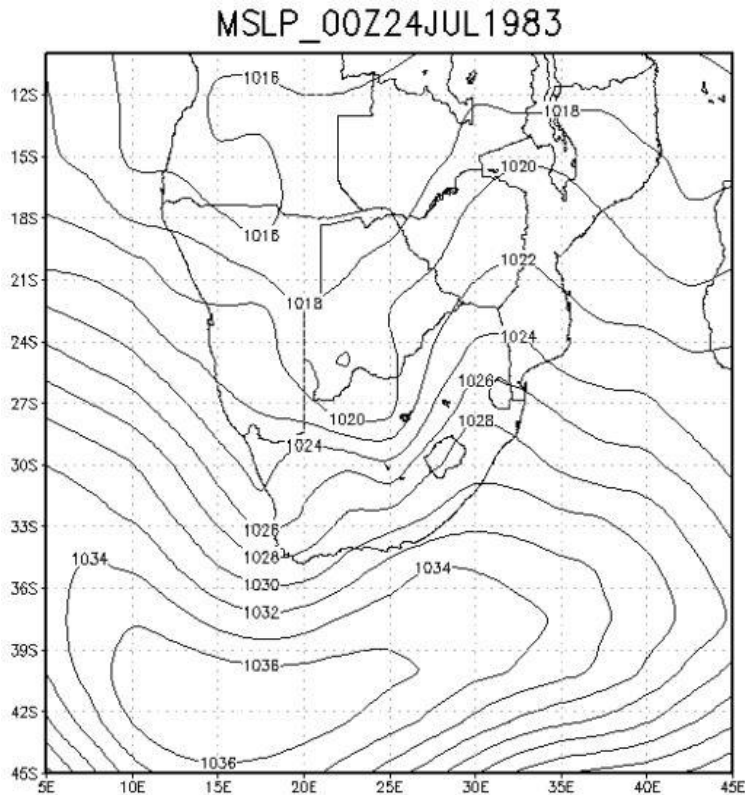


Figure 5.73: Synoptic chart of mean sea level pressure (hPa) at 00Z on 24 July 1983.

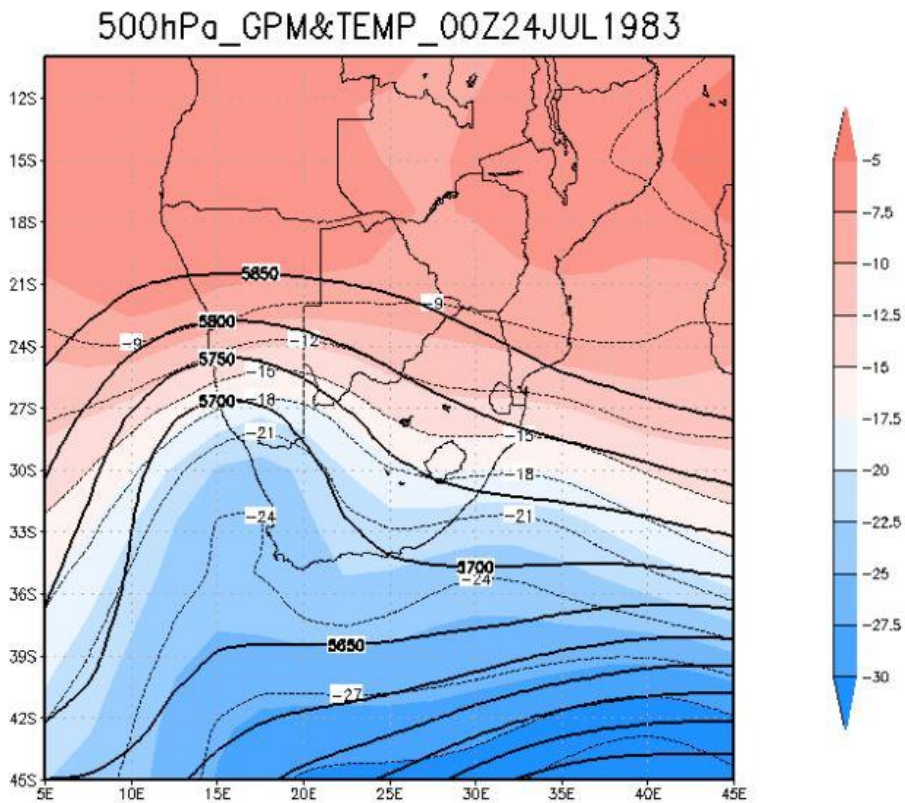


Figure 5.74: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 24 July 1983.

**Monday 25/07/1983:** A surface trough deepened through the central interior of the country with a low pressure system located over the Free State (Figure 5.75). The high pressure system intensified from 1036hPa the previous day to 1040hPa on the 25<sup>th</sup> of July at 00:00Z. This high pressure system also moved further eastwards to be located south of Port St Johns at 41°S. The upper air revealed a steep upper air trough over the Western Cape slightly further east compared to the previous day.

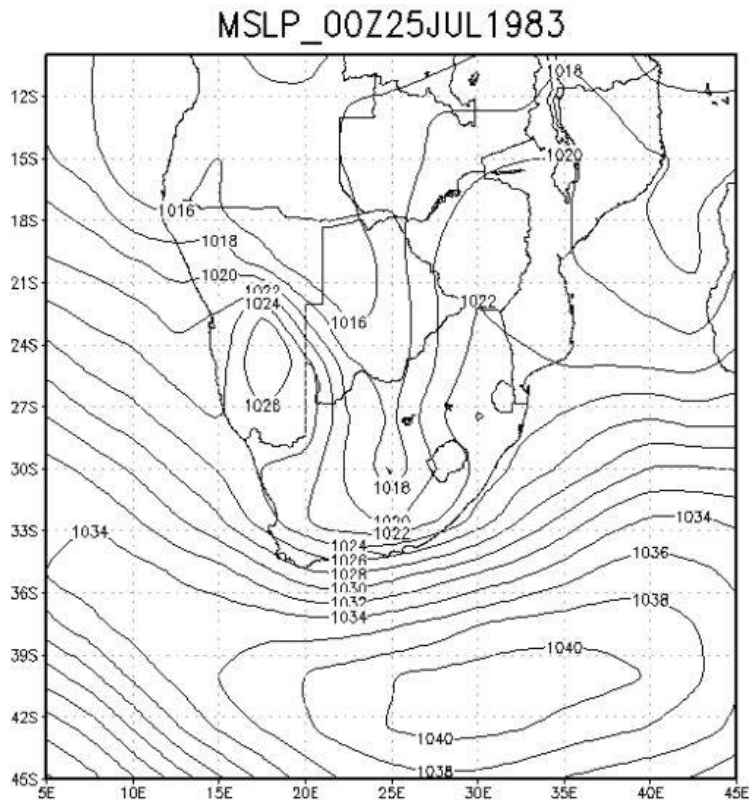


Figure 5.75: Synoptic chart of mean sea level pressure (hPa) at 00Z on 25 July 1983.

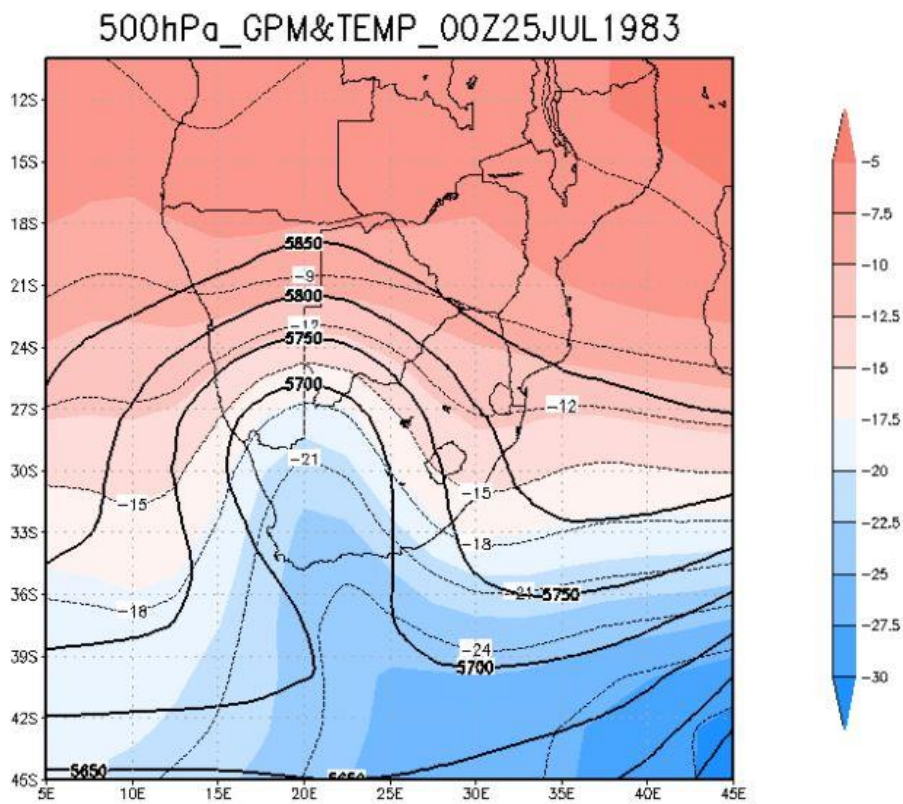


Figure 5.76: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 25 July 1983.

**Tuesday 26/07/1983:** A COL had developed from the deepening of the upper air trough and had moved off of the East London area at the surface (Figure 5.77) however the upper low was located over the northern parts of the Eastern Cape (Figure 5.78). The high pressure system had continued to move eastwards to be located in the Indian Ocean and had moved slightly further north to be at 40°S. The COL moving along the east coast of the Eastern Cape together with the high pressure system to the south east caused a tight pressure gradient at the surface to flow onto the south coast of the country.

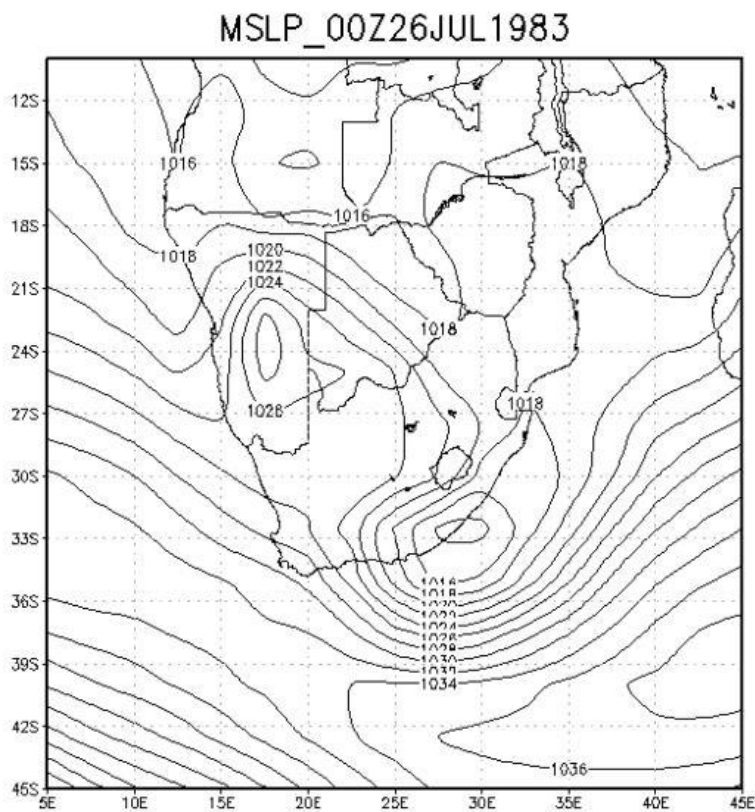


Figure 5.77: Synoptic chart of mean sea level pressure (hPa) at 00Z on 26 July 1983.

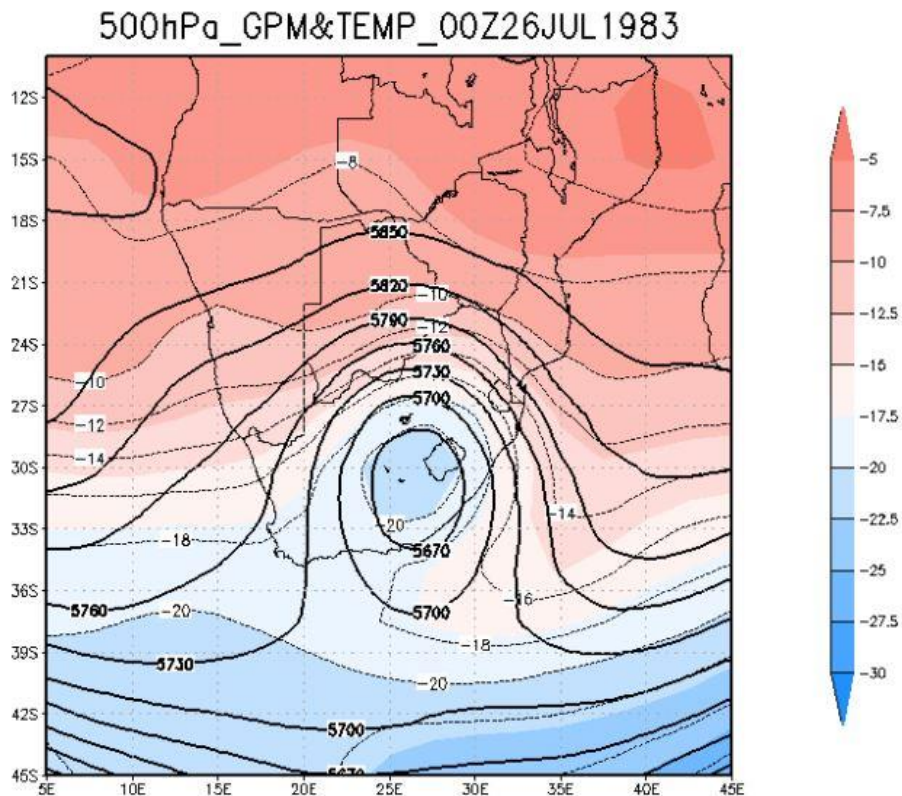


Figure 5.78: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 26 July 1983.

**Wednesday 27/07/1983:** The COL moved south eastwards with the surface low being extended off of the Wild Coast of the Eastern Cape (Figure 5.79). The COL has weakened as the core temperature had gotten slightly warmer compared to the previous day (Figure 5.80). The high pressure system over the Indian Ocean had moved further east and the Atlantic Ocean high pressure system was located south west of Cape Town. A tight pressure gradient can still be seen along the south coast of the country behind the COL.

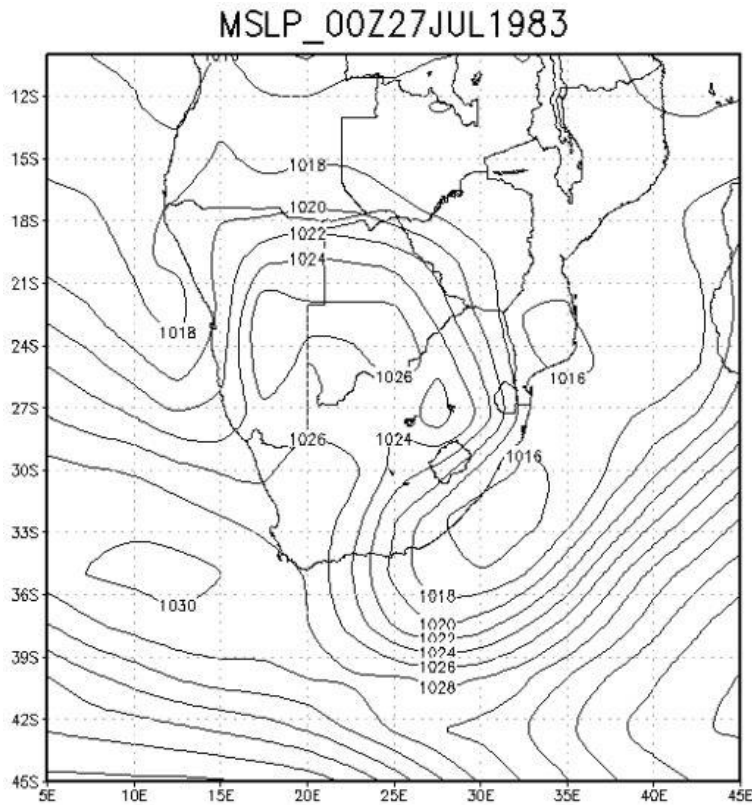


Figure 5.79: Synoptic chart of mean sea level pressure (hPa) at 00Z on 27 July 1983.

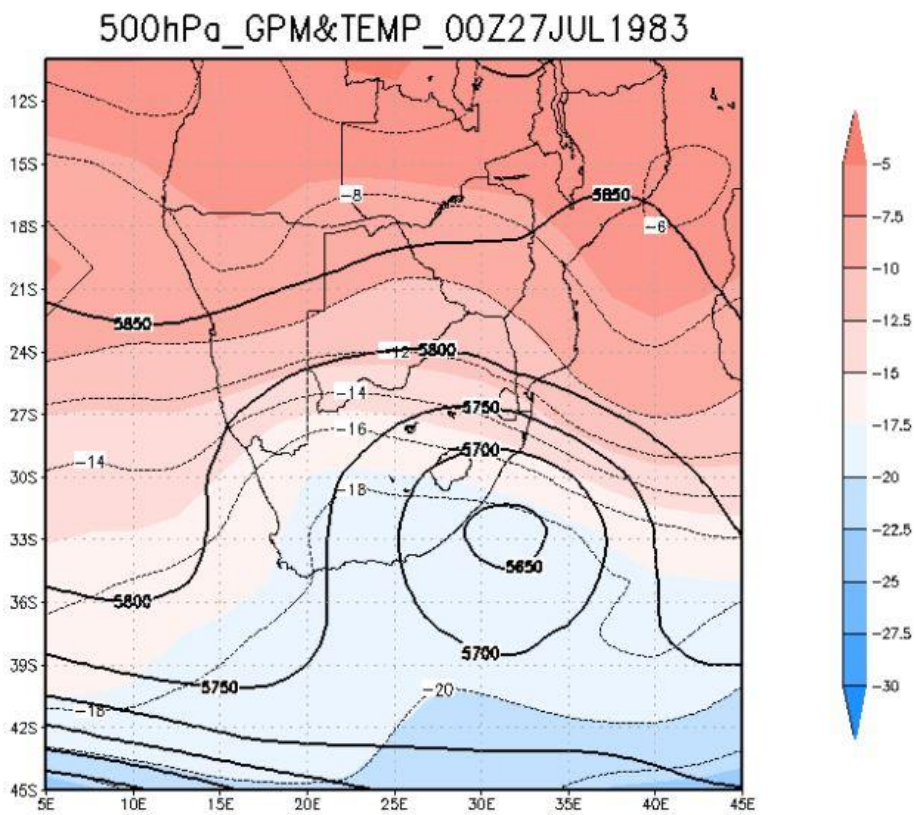


Figure 5.80: Geopotential heights at 500hPa in black contours with 500hPa temperature in dotted contours as well as shading with warmer temperatures in red and colder temperatures in blue at 00:00Z on 27 July 1983.

### 5.3.7.3 Meteorological parameters analysis

As mentioned above, the meteorological analysis will be conducted using the Port Elizabeth WK station and not Otterford Bos where the highest event rainfall occurred. However, Table 5.6 below shows the rainfall distribution across stations between Otterford Bos and surrounding Port Elizabeth. For three of the stations, excluding Otterford Bos, the two highest rainfall days were the 24th and 25th July but at Otterford Bos the highest rainfall days were 25th and 26th July. The rainfall amounts were also significantly higher at Otterford Bos on the 25th and 26<sup>th</sup>, compared to the rainfall received at any other station on any of the days.

Table 5.6: Rainfall measured in millimetres at stations between Patensie and Port Elizabeth for 24-27 July 1983.

Date	Port Elizabeth WK	Port Elizabeth Cotswold	Otterford Bos	Patensie
24 July 1983	52.7	83	72.5	23
25 July 1983	48	72.6	128	85
26 July 1983	29	32	157	22.5
27 July 1983	28.3	25	71	9.5

The pressure in Figure 5.81 on the 24 July showed a decreasing trend especially from mid-morning and stabilised after 14:00 into the evening until 18:00, at which stage the pressure rose slightly. The temperature increased gradually throughout the morning but then decreased to a local minimum at 09:00 (Figure 5.82). After this, the temperature increased to 16:00 with a maximum at 13.7 °C until another local minimum occurred at 20:00 at 12.9 °C. Interestingly, the temperature increased after this with the maximum of the day occurring at 23:00 at 13.9 °C. The relative humidity in Figure 5.83 started increasing after 06:00 while the pressure was decreasing. The relative humidity remained fairly high throughout the rest of the day, averaging around 95%. The wind direction (Figure 5.84) indicated the wind remained at a constant direction throughout the day. This direction was easterly and an onshore wind for Port Elizabeth, hence the high relative humidity. The wind speed in Figure 5.85 started off moderate but picked up in speed throughout the day reaching strong speeds with a peak at 00:00 on 25 July at 14 m/s.

The pressure began to decrease slightly into the morning of 25 July 1983 but stabilised until about 10:00, at which stage the pressure began to decrease more rapidly continuing throughout the day. The temperature on the 25th remained fairly steady throughout the day, remaining between 13 to 14 °C. The temperature did, however, decrease after 15:00 reaching a minimum at 12.6 °C at 18:00. The relative humidity remained between 90 and 95% most of the day with a decrease to 85% at 15:00 after which the relative humidity increased rapidly to be above 95% for most of the evening. The wind direction was still easterly throughout the morning of the 25th but after 08:00 the wind direction turned more south-easterly and remained between 100-150° for the rest of the day. The wind speed started decreasing throughout the early hours of the morning from the peak at 00:00 with a minimum at 08:00 at 8 m/s. After 08:00, the wind direction changed and the speed also began to increase but increased steadily until 17:00 at which point the wind speed increased rapidly to a maximum of 15 m/s. This was the highest wind speed recorded during the four-day period. At 20:00, the wind speed began to decrease.

The pressure which was decreasing on the 25th continued to decrease into the morning of the 26th until 09:00 where the pressure was about 1014 hPa. A slight rise in the pressure occurred between 09:00 and 12:00 but then began to decrease slightly to about 16:00 after which the pressure began to rise again slowly. The pressure was at a minimum for the four-day period at 1014 hPa at 14:00 on the 26th. The temperature increased throughout the morning to reach a local maximum at 10:00 at 16.0 °C but with a local minimum occurring at 11:00 at 15.1 °C after which the temperature increased again. The maximum for the day was reached at 15:00 at 17.1 °C after which the temperature decreased into the evening. Interestingly, the temperature started to rise after 19:00 and then steadied for the rest of the evening around 16.7 °C. The relative humidity averaged around 95% for the day but at 14:00 the relative humidity decreased slightly with a greater decrease after 20:00. The relative humidity decreased sharply between 20:00-23:00 but then increased rapidly between 23:00 and 24:00. The wind direction was southerly for the majority of the day but went northerly at 18:00 and returned back to a southerly to south-south-westerly at 19:00. The wind speed was decreasing until about 06:00 and then it increased from around 10 m/s to 14 m/s by 09:00 at the peak in the wind speed for the day. The wind speed decreased sharply in different time segments during the day until 18:00 at which point it was calm on the northerly wind. The wind direction change to southerly/south-south-westerly caused an increase in the wind speed again to reach 11 m/s at 24:00.

On the 27th July, the pressure began to rise after about 06:00 until 10:00 after which it remained relatively stable until 14:00. The pressure then continued to rise after 14:00 into the evening. The 27th had the warmest morning period for the entire four-day period with a morning minimum of 15.4 °C occurring at 03:00. The temperature increased to reach a maximum of 18.1 °C at 12:00 but then the temperature decreased rapidly until 19:00 after which it stabilised. The minimum at 19:00 was 15.1 °C. The relative humidity varied in the early morning hours but still remained fairly high until 08:00 after which the relative humidity decreased rapidly to a minimum of 76%, which was the minimum for the four-day period. After this minimum, the relative humidity increased to reach 90% by 11:00 and remained just above 90% for the rest of the day. The wind direction averaged about 210° which is a south-south-westerly wind direction. The only significant wind direction change occurred between 16:00 and 17:00 when the wind changed from 220° to 170°. The wind speed decreased between 00:00 and 03:00 but then began to increase rapidly between 03:00 and 06:00 from 4.2 m/s to 9.9 m/s, respectively. The maximum wind speed occurred at 08:00 at 10.2 m/s then decreased to 6.6 m/s by 11:00. After this, the wind speed increased again with another peak at 13:00. The wind speed then had a decreasing trend until about 19:00 after which the speed had a steady trend.

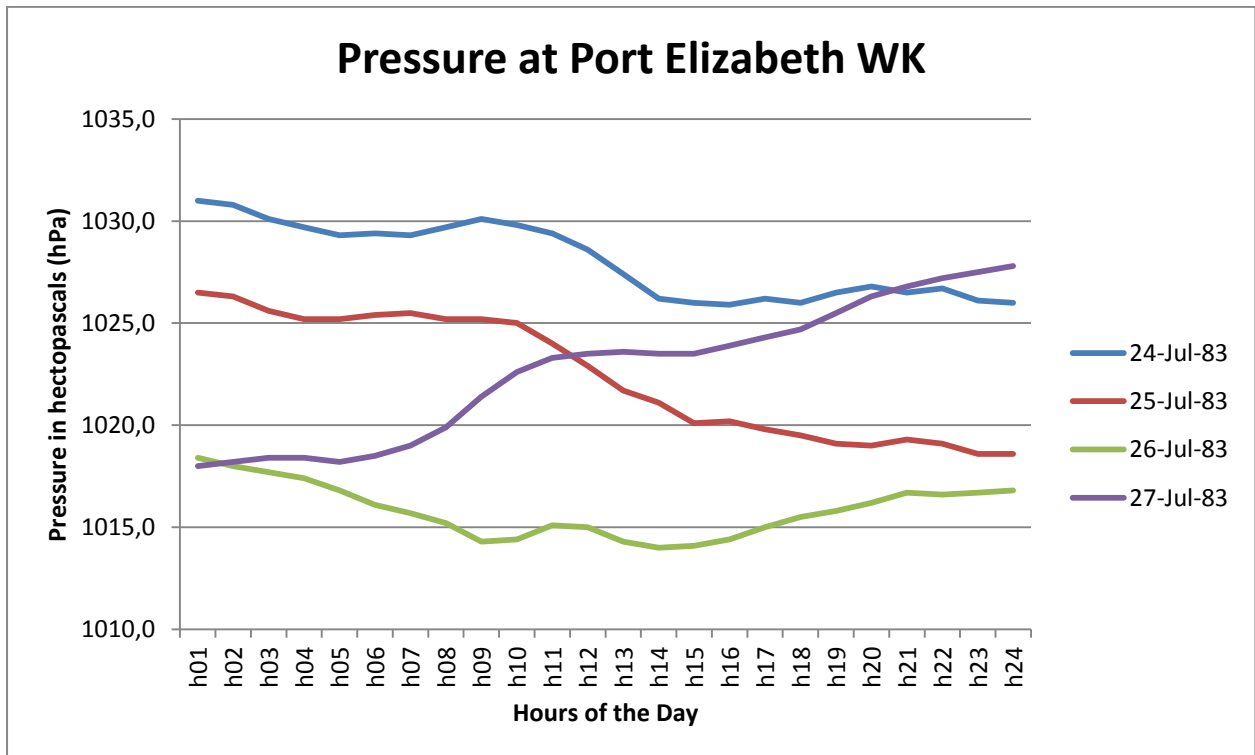


Figure 5.81: Pressure at Port Elizabeth WK for 24-27 July 1983.

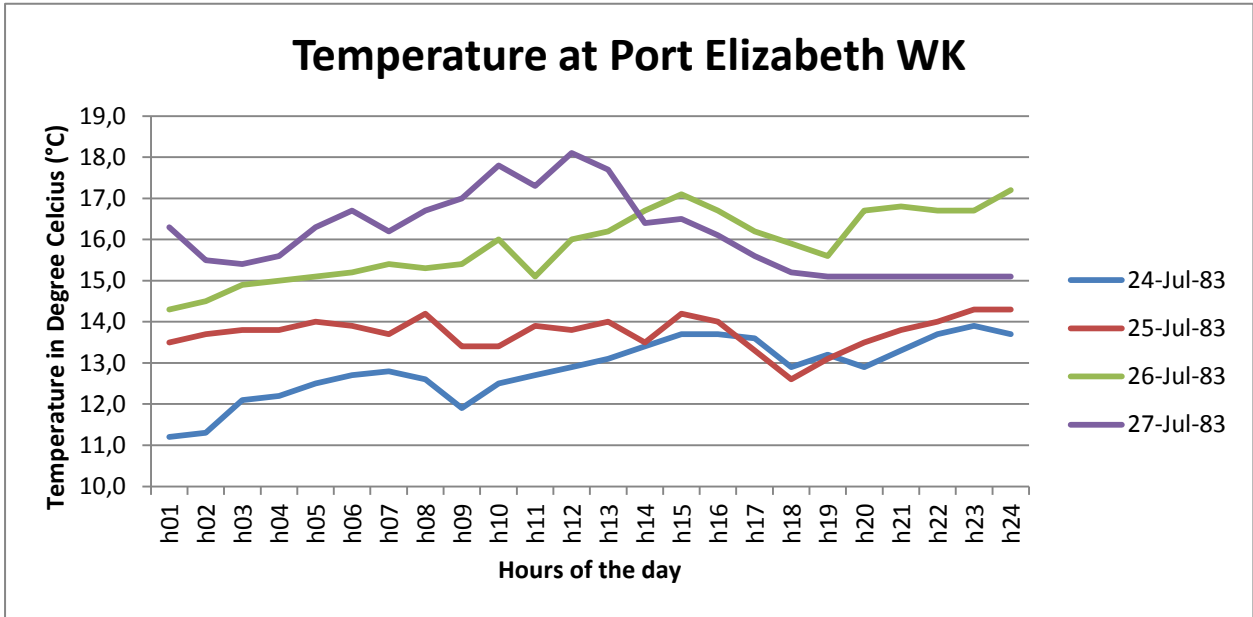


Figure 5.82: Temperature at Port Elizabeth WK for 24-27 July 1983.

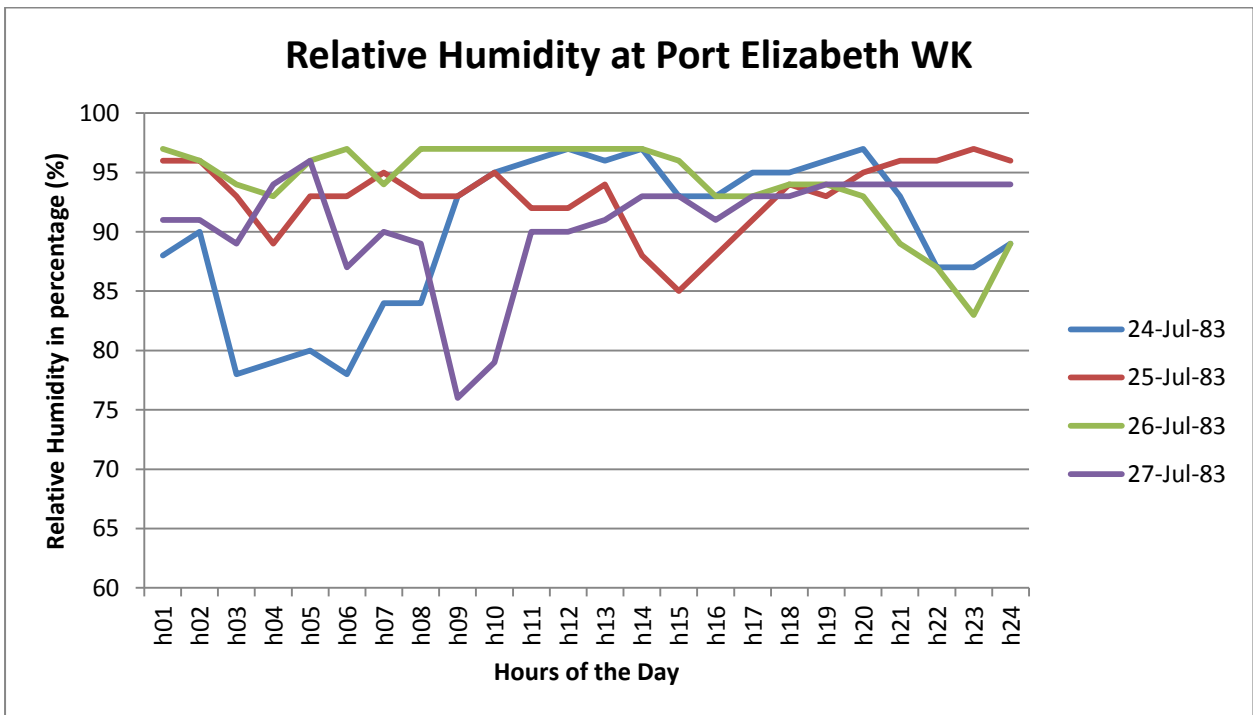


Figure 5.83: Relative humidity at Port Elizabeth WK for 24-27 July 1983.

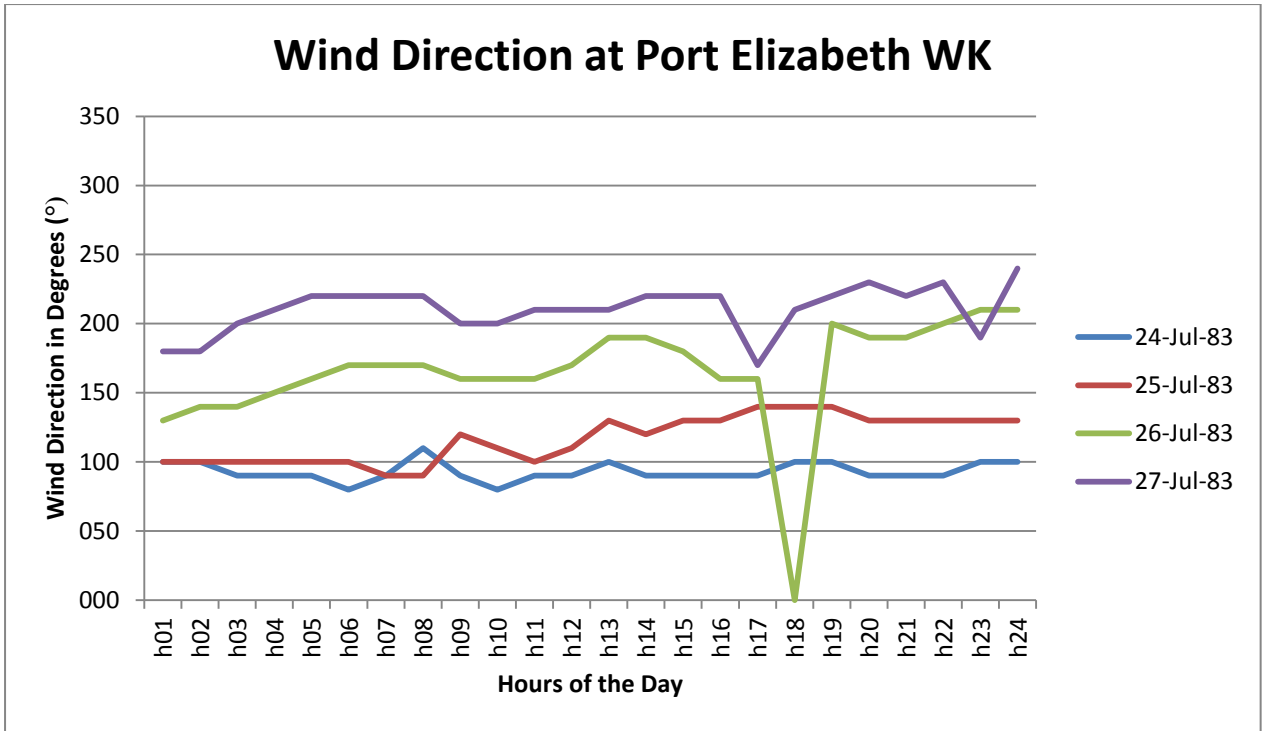


Figure 5.84: Wind direction at Port Elizabeth WK for 24-27 July 1983.

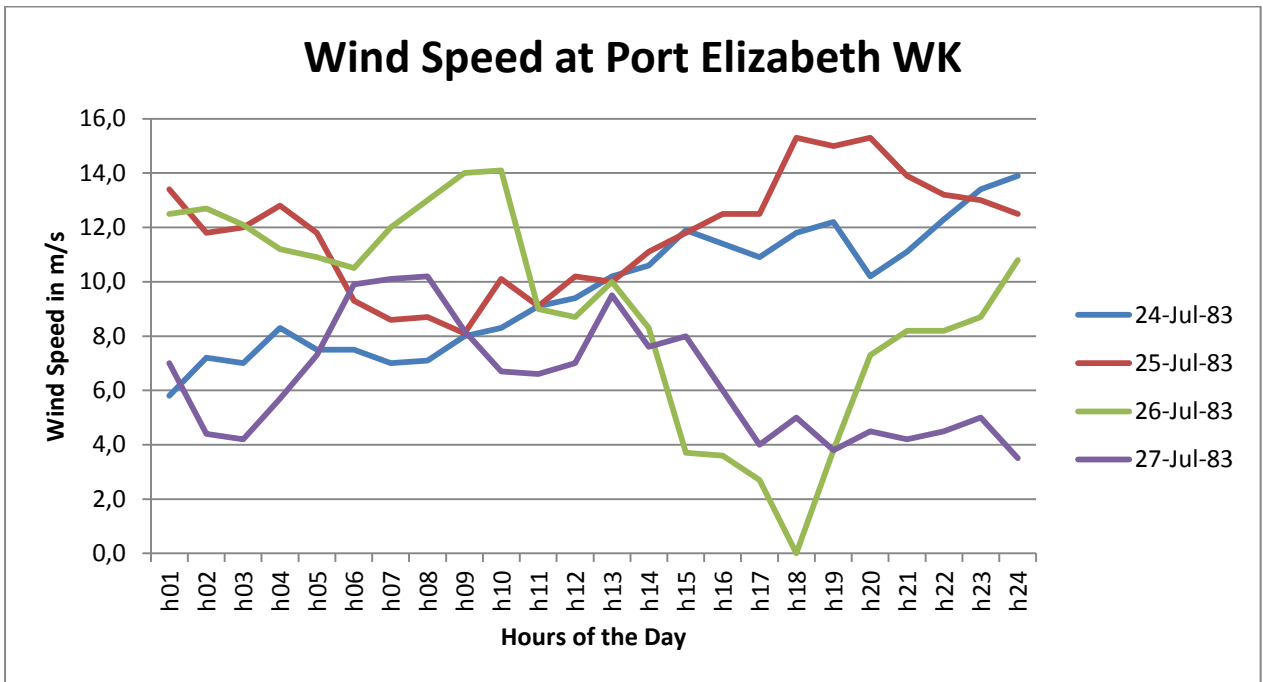


Figure 5.85: Wind speed at Port Elizabeth WK for 24-27 July 1983.

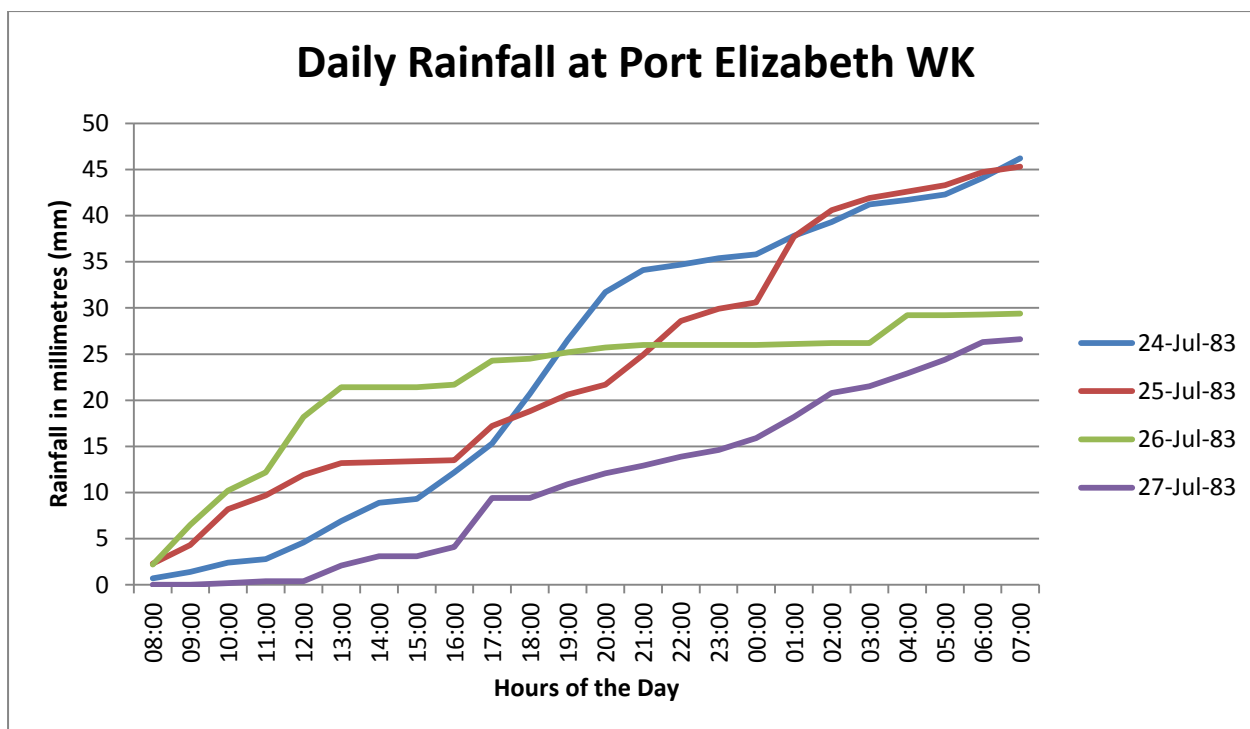


Figure 5.86: Daily rainfall at Port Elizabeth WK for 24 -27 July 1983.

In Figure 5.86, the rainfall for each day in the four-day period can be seen. The day with the highest rainfall occurred on the 24<sup>th</sup> of July, followed closely by the 25<sup>th</sup> of July. Although the 26<sup>th</sup> and 27<sup>th</sup> had substantial rainfall values, there was a large drop in the rainfall amount compared with the 24<sup>th</sup> and 25<sup>th</sup> of July. What is of interest is that all four days received good amounts of rainfall. This flood event didn't seem to occur due to one day receiving most of the rainfall as in some of the other cases.

The steepest gradient seems to have occurred on the 24<sup>th</sup> of July between 15:00 and 21:00 when the rainfall increased from just less than 10 mm to 34 mm. This can be confirmed in Figure 5.87 with the highest hourly rainfall intensities occurring just after 15:00. However, the highest peak in this period occurred between 18:00 and 20:00. During this period, the pressure rose slightly as did the temperature but the wind direction remained easterly, changing marginally from 90° to 100°. The wind speed increased slightly during this period from about 11 m/s to 12 m/s. Although not much seems to be revealed during this period, what is significant is that the wind did have an easterly (onshore) component as well as having a strong wind speed. The two days with the highest rainfall in this period seemed to have near identical pressure trends, similar wind direction and wind speeds. The trend in the pressures was one of decreasing while the wind direction remained onshore. The wind direction on the 24<sup>th</sup> was predominantly easterly and on the 25<sup>th</sup> was predominantly south-easterly. The

wind speed also remained fairly strong for both of these days. In comparison, the wind direction on the 26<sup>th</sup> and 27<sup>th</sup> was more southerly to south-westerly with varying wind speed, although with an average less than the previous days.

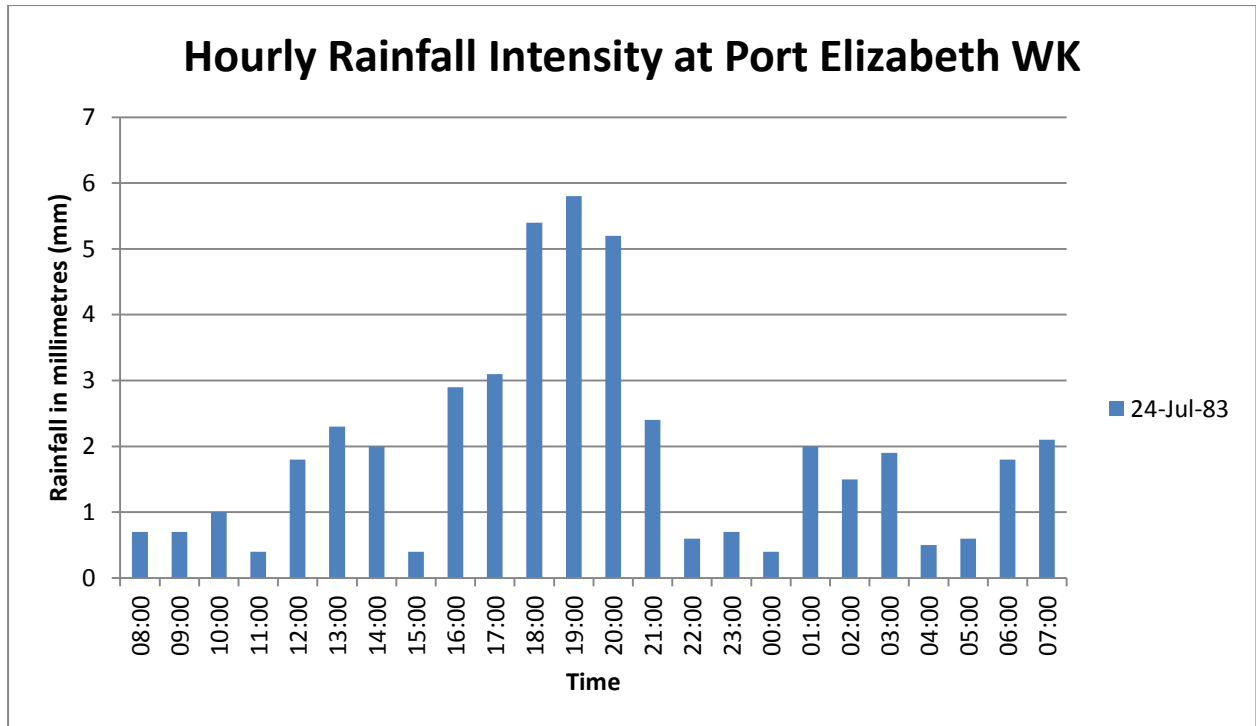


Figure 5.87: Hourly rainfall intensity at Port Elizabeth WK for 24 July 1983.

#### 5.3.7.4 Case Discussion

The difficulty with this case is the location of the station used, Port Elizabeth WK, compared to the flood location near Gamtoos River or Patensie. The Sunday's River, in the Port Elizabeth vicinity, did record floods; however, the event ranked in the top five due to the rainfall recorded at Otterford Bos, which is closer to Patensie. This is reflected in a great difference between the Port Elizabeth WK rainfall event total of 147.5 mm to 428 mm at Otterford Bos. However, Port Elizabeth WK was the closest station that recorded hourly values of the meteorological parameters. Otterford Bos only recorded daily rainfall values at the time. On a synoptic scale, the systems that contributed to the heavy rainfall would still be the same between Otterford Bos and Port Elizabeth but smaller features such as convective cells and meso-scale circulations, which may have added to the high rainfall values at Otterford Bos, would be missed.

Looking at the synoptic systems, the common features of an upper air low west of the flood area existed as well as the high pressure system with an extending ridge along the coastline. In this case, the high pressure system was south of the country rather than south-west of the country but the general circulation around the high pressure system still produced onshore winds into the flood areas. Interestingly, the low pressure trough at the surface seemed quite far north when compared to the other cases especially on the 24<sup>th</sup> of July. The COL only moved out off of the coastline on the 26<sup>th</sup> of July.

The two days with the highest rainfall at Port Elizabeth WK were the 24<sup>th</sup> and 25<sup>th</sup> July when the wind remained easterly to south-easterly, which was an onshore wind and as mentioned above, was a strong wind. When considering that the highest rainfall days at Otterford Bos were the 25<sup>th</sup> and the 26<sup>th</sup> the southward movement of the surface low pressure system from the 24<sup>th</sup> of July seemed to have a large impact on rainfall into the Otterford Bos area. The Otterford Bos area would have been on the leading edge of the surface high pressure system as the low pressure trough deepened and caused a stronger pressure gradient between the high pressure system and the low pressure system. This would have produced a strong onshore flow between the two systems into the Otterford Bos area, possibly even a low level jet.

## **5.4. Discussion of Case Study Results**

### **5.4.1. Summary of case study results**

Case study 1 took place in East London on 24-28 August 1970. The rainfall data for 28 August could not be analysed due to much of it having to be interpolated. The case had a cut-off low system with a surface ridging high pressure to the south-west. A surface trough was also present from the COL and produced onshore south-easterly flow and heavy rain on the 25<sup>th</sup> as the high pressure system ridged in. On the 27<sup>th</sup> the surface low created by the COL then developed and also moved out along the coastline north of East London, allowing the high pressure system to push in behind the low and resulting in the worst twenty-four-hour rainfall on record for the study area. The event rainfall was also the heaviest on record and resulted from four days of intensive heavy rain in the area.

Case study 2 occurred in Port Elizabeth on 1 September 1968 and was the most intense rainfall to occur in a short period. Notably, this case recorded the highest twenty-four-hour rainfall in the least amount of time. Synoptically, the interior surface low pressure system moved through the area causing the winds to turn south-east. The heavy rainfall that occurred resulted in flash floods. What is of interest is that the high pressure system didn't ridge into the area until the next day. However, a tight pressure gradient did occur between the COL moving off of the east coast and the high ridging behind it.

Case study 3 occurred in East London on 15-16 August 2002. This was also a flash flood incident that occurred in a short period of time. A surface low pressure system, associated with the COL, moved off the Kwa-Zulu Natal coastline on the 16<sup>th</sup> and resulted in the wind turning from south-easterly to south-south-westerly and the heaviest rainfall intensity occurred at the peak of the wind speed. The high pressure system had already ridged in around 15:00 on the 15<sup>th</sup> of August but the highest rainfall intensities only occurred around 00:00 and 01:00 of 16 August. The wind direction also didn't really change at that time but the wind speed increased.

Case study 4 occurred in Port Elizabeth from 24-26 March 1981 and was also a COL case which had four different periods of heavy rain. Three of them occurred before the high pressure system ridged in. The wind direction in these three periods was south-easterly. The fourth period, however, occurred at the leading edge of the surface high pressure system as the wind changed from a westerly wind to south-westerly and then a predominant south-easterly wind.

Case study 5 took place in East London during 5-7 November 2005. The heaviest rainfall occurred on the 6<sup>th</sup> of November with the highest intensity occurring around 17:00 as the wind changed direction from north-easterly to a south-westerly and then to a south-easterly for most of the night. At this time, the high pressure started to ridge in behind the surface low pressure system associated with the COL.

Case study 6 recorded floods in the Gamtoos River near Patensie and Sunday's River near Port Elizabeth. This event occurred in December of 1931 but could not be properly analysed due to the lack of synoptic analyses during this time. Since no synoptic analysis could be done, only rudimentary conclusions can be made. The wind direction on the day of the heaviest rainfall was south-easterly and again points to the importance of onshore winds. But winds alone cannot divulge much information about the state of the environment or the processes that resulted in the heavy rainfall.

Case study 7 produced floods in the Gamtoos River near Patensie, Sunday's River in Port Elizabeth and in East London. The biggest limitation with this event is that the event rainfall which allowed this study to be ranked in the top five was recorded at Otterford Bos station, while the analysis was conducted using data from Port Elizabeth WK station. This was the closest station to Otterford Bos that had hourly data in this event, which took place on 24-27 July 1983. The two days with the heaviest rainfall were the 24<sup>th</sup> and 25<sup>th</sup> when the surface trough was located through the central interior of the country. The pressure remained low and decreasing through these two days with the high only really ridging into the area on the 27<sup>th</sup> of July. The high rainfall intensities were produced east of the COL before it moved through the area in Port Elizabeth on the 24<sup>th</sup> and 25<sup>th</sup>. The winds in these high rainfall days were easterly to south-easterly. However, on the 25<sup>th</sup> and 26<sup>th</sup> when the heaviest rainfall occurred at Otterford Bos a steep pressure gradient can be seen in this area at the surface levels which may have caused the heavy rainfall.

#### **5.4.2. Discussion**

Each individual case study has been discussed above but this section now hopes to highlight the key factors that contributed to these extreme floods. Firstly, the synoptic analysis will be reviewed. Looking at the upper air systems (excluding Case 6 which did not have upper air data), all of the cases showed closed lows at the 500hPa level and all were cold cored. The location of all these upper air systems were north-west or west of the flood areas on the days that had heavy rainfall occurring. Most of the case studies started along the west coast of the country with two of the cases (Case study 2 and case study 5) having the COL's move through the Eastern Cape. Three of the case studies (Case study 1, 4 and 7) were located over the Northern Cape with case study 7 moving from the Northern Cape into the Free State.

Another factor is the location and depth of the surface low associated with the COL system as well as the surface high pressure system. All of the systems that had surface analysis available showed a high pressure system lying to the south-west or south of the country, extending a high pressure ridge eastwards along the south and south-east coast of South Africa. Only one of these systems, in case number 7, showed the high pressure system initially south of the country and then moving south-east of the country, extending a ridge, westwards along the south coast. All of the high pressure systems that occurred were located between 35 - 45°S.

Since all the case studies had a COL present the surface analysis showed low pressures over the interior of the country. Five of the six case studies showed a steep pressure gradient forming along the coastline into the areas that experienced heavy rainfall. The only case study that did not show a steep pressure gradient was in case study 2 where a surface low pressure system moved through the Port Elizabeth area at the time of the highest rainfall rates. The high pressure system to the south west of the country didn't ridge in at the time of the heaviest rainfall and thus a weak pressure gradient existed. The case studies in which heavy rainfall occurred in the East London area namely; case study 1, 3 and 5 all showed a surface low extending off of the Kwa-Zulu Natal coastline at the time of the heaviest rainfall. This would produce onshore winds and a tight pressure gradient between the surface low and high pressure system, to flow into the East London area. The case studies where the floods occurred in the Port Elizabeth area (case study 2 and 4) showed that a surface trough extended off of the east coast and down through Port Elizabeth (case study 2) and off of the Wild Coast of the Eastern Cape (case study 4). Case study 7 had the surface trough extending through the central interior of the country with a tight pressure gradient between the surface trough over the interior and the high pressure system south of the country.

The pressures showed mostly decreasing trends before the high rainfall intensities with the pressure rising after the rain began. On a larger scale, synoptically a surface trough would cause the pressure to decrease greatly and then increase rapidly as the surface trough moved through the area and the high pressure started to push in. The cases were therefore checked to see if the highest rainfall intensities occurred when slight pressure changes occurred, related to meso-scale circulations, or if the pressure showed synoptic (larger) increases and decreases with the heavy rain. At the time of the heaviest rainfall in the case studies, only two case studies (case study 2 and 7) were found to have slight pressure decreases and increases, indicating heavy rain occurring before the high pressure system ridged in. Another two cases (case study 1 and 5), showed the most intense rainfall occurring on the ridge of the high pressure. This leaves two more case studies that had heavy rainfall occurring before and after the high ridged in. In case study 3, the heaviest rainfall occurred well after the high had started ridging in and not on the leading edge as in the other cases. Case study 4 had high rainfall intensity periods occurring before the high pushed in as well as at the leading edge of the high ridging in. Although two of the case studies (2 and 7) had the highest rainfall intensities occurring before the high pressure system pushed in, the high rainfall intensities probably would not have

taken place if the high pressure had not been in the position it was either south-west or south of the country. So, although the heaviest rain didn't occur due to a high pressure rise, the wind rotating around the high pressure system would have produced a certain wind direction to move in the area.

The relative humidities were very high for all the heavy rainfall periods, which seems apparent but what is of interest is that the relative humidity increased for a few hours before the onset of the downpours. Five of the cases also showed warm nights where the temperature increased in the night, with increasing relative humidities before the downpours occurred. This illustrates an environment of warm, moist air in circulation before the heavy rain began. One of the cases (case study 5) showed no significant temperature changes from the natural diurnal cycle or no peaks occurring and coincided with relatively cool days with little difference between the diurnal temperature ranges.

All but one of the case studies (case study 4) showed rainfall occurring on moderate or higher wind speeds, in the range greater than 5 m/s. The heaviest rainfall also occurred as the wind changed from a lighter speed to stronger speed. However, the rainfall did not continue in intensity as the wind speed continued to increase but rather occurred on a marked change in wind speed increase. A light wind had little effect on rainfall intensity.

The wind direction showed predominantly south-easterly winds or southerly winds taking place with the heaviest rainfall. Two of the cases, namely 4 and 5, showed a wind direction change to a south-westerly on the heaviest rain but then turned to be predominantly south-easterly. The East London cases also revealed heavy rainfall occurring on a south-south-westerly wind. These winds are all onshore winds for the coastal stretch in the study area. However, a south-south-westerly in Port Elizabeth will have a slightly cooler source than in East London due to the different latitudes of the cities. Two of the three Port Elizabeth cases showed south-easterly winds during the heaviest rainfall periods and the third case showed south-easterly winds changing to southerly and then to south-south-westerly. Thus, an onshore wind seems to be a significant, if not the most important, factor. The temperature and relative humidity revealed a warm, moist environment prior to the heavy rain. The wind direction was either easterly or south-easterly in the hours prior to the commencement of the heavy rain in the case studies. This wind direction as mentioned is onshore which would produce high relative humidity as the moist air moves from the ocean onto the land.

Most of the cases had the heaviest rainfall intensities occurring at a wind direction change and a synoptic forcing such as a low pressure system moving through the area and the high pressure system ridging in behind it. A low level jet stream may occur between these two systems due to an increase in the pressure gradient between the systems as mentioned occurred in five of the six cases. This may result in a strong inflow of humid air. The upper air low could produce thunderstorms to the east of it and with this inflow of moist air feeding into the thunderstorms, high rainfall intensities could occur. However, convective development was not analysed in this study. What is to be highlighted is a time dependency of thunderstorms being present at the same time as the influx of moisture to produce high rainfall intensities. Onshore winds alone cannot cause thunderstorms to develop but the combination of the presence of thunderstorms from the synoptic systems (COL) meeting the influx of moist air at the surface could result in high rainfall intensities.

COLs occur in the interim seasons of austral autumn and spring. Four out of the seven cases occurred either in autumn or spring with one case occurring in summer and one case occurring in winter. Case study 6 also occurred in summer but no synoptic data was available to identify if a COL was present or not. Therefore, it seems that although these flood producing systems are more common in autumn and spring, they can occur in any season.

## **5.5. Conclusion**

This chapter showed the results of the rainfall analysis which resulted in seven case studies being analysed. Both a synoptic and meteorological parameter analysis of surface observations was conducted. From these case studies and subsequent discussions, it is concluded that: 1) COLs were present in all the case studies (excluding case study 6), 2) the position of the high pressure system should be south-west, south or south-east of the country extending a ridge along the south coast of the country; 3) a surface low pressure system due to the COL should be over the interior of the country with a trough extending off of the coastline east of the city that can expect floods.

Five of the six case studies that had synoptic charts revealed tight pressure gradients into the area where the floods occurred. The surface winds showed winds to be onshore during the times of heavy rainfall which for the study area is a south easterly, southerly or south-south-westerly wind. The surface wind speeds revealed moderate or higher speeds occurred

during times of heavy rain as well as a significant change in wind speed contributed to the heavy rainfall. Light winds were found to have little effect on rainfall intensities.

The pressure showed high rainfall intensities both on increasing and decreasing pressure trends. A surface temperature and relative humidity analysis showed four of six cases (excluding case 6) having warm evenings with increasing relative humidity preceding the heavy rainfall onset.

## Chapter 6 Conclusions and Recommendations

### 6.1. Possible Caveats

This study was conducted on the foundation of rainfall data collected from the SAWS. As mentioned in chapter 4, there were some problems with the data collected. Some of these problems included missing data and the requirement of using data interpolation such as those used in case study 1. Although this was the only method available to conduct a meteorological analysis in this case, some errors may be present, especially for the 28<sup>th</sup> of August 1970 rainfall data and intensities. In some cases, rainfall data couldn't be used or relied upon due to rainfall accumulating when the rainfall wasn't recorded daily. As mentioned, this usually occurs on privately owned farms or areas where people have volunteered to record rainfall readings. This highlights the importance of taking such readings on a daily basis.

Another caveat that needs to be mentioned is that of station location. Hourly data was sparsely collected in the more historical cases and therefore, some stations' data that was used doesn't fully display the characteristics of where the flood event occurred. The most common example of this is the distance between Otterford Bos station and Port Elizabeth WK station that occurred in cases 6 and 7. This could create a misinterpretation of the data and some events may have been missed such as convective development.

Convective cells in the form of thunderstorms have a very small scale of a few kilometres and can therefore be easily missed in using station data from another station rather than the station where the floods occurred. Another issue that can be raised is that of using hourly data rather than five-minute data, especially in a thunderstorm environment. Thunderstorms are usually short lived and affect a smaller region with minor pressure, temperature and wind variances occurring.

A possible bias with the data is that of looking first for areas where floods occurred rather than first looking at the rainfall amounts. It is known that floods can be area specific and that floods would most commonly occur in populated areas or where land use is such that runoff volumes are high. This leans the study towards towns or more populated areas, which were affected by the floods or which could have created a higher impact of the flood waters due to land use.

## 6.2. Conclusions

The motivation for this study existed in trying to better understand what low-level processes and circulations (Molekwa *et al.*, 2014) occur during heavy rainfall events by conducting an analysis of surface observational data. The aim of this study was to conduct an analysis of surface observational data during extreme flood events between the Gamtoos and Great Kei River areas of the Eastern Cape, South Africa. This was done by first identifying the most extreme flood events using twenty-four-hour and event rainfall totals. From this the top five twenty-four-hour rainfall events were identified as well as the top five event rainfalls. This resulted in seven selected case studies that were analysed. This meets objective one to identify the most extreme historical flood events in the study area. Objective two was to conduct an analysis of surface observational data during the severe event dates identified. This was met by identifying the weather systems that contributed to the extreme floods as well as an analysis of trends in each meteorological parameter of pressure, temperature, relative humidity, wind direction and wind speed and lastly, rainfall. It was found that cut-off lows, with the upper low lying west or north-west of the flood area, resulted in upper air instability and together with an interior surface trough and a strong high pressure system, lying either south or south-west of the country, the ingredients for high rainfall intensities was created. The combination of these three synoptic features is called a “Black South-Easter”. Strong high pressure systems, lying south or south-west of the country were present. This is in agreement with the synoptic circulations found by many other authors which lead to heavy rainfall (Hayward and van den Berg, 1968, 1970; Taljaard, 1985; Tyson and Preston-Whyte, 2000; Dyson *et al.*, 2002; Molekwa *et al.*, 2014; Engelbrecht *et al.*, 2015). An aspect found in this study is that of the surface trough protruding off of the coastline east of the flood area. This surface trough, extending from the interior of the country, causes a wind direction change and a warmer, moister air mass to flow onto the study area coastline from the Agulhas current.

Onshore winds circulating around the high pressure system meet with warm air circulating around the surface low pressure system and where these winds come together, a low level jet stream is thought to form and advect moist air onto the land from the ocean. These moist winds can feed into convective development in the area and result in heavy downpours. A time dependency of the location of thunderstorms and the timing of the influx of moist air into the area are highlighted. It was mentioned that in most of the cases the surface low, moving through the coastal area on the leading edge of the high pressure system, caused the influx of onshore winds. A tight pressure gradient between these two pressure systems could

result in a low level jet (Singleton and Reason,2007a) as is highlighted in five of the case studies.

What has also been considered is that onshore winds depend on the shape of the coastline. In this study, the shape of the South African coastline between Gamtoos River and Great Kei River Mouth allows for winds of a southerly component to be onshore. A wind with an easterly wind component was also found to be onshore but excluded a north-easterly wind. It was acknowledged in chapter 2 that topography results in higher rainfall amounts when the winds are onshore, thus, the local topography of the coastal mountains and ridges do play a role in the high rainfall intensities. The presence of the warm Agulhas current running along this stretch of coastline may also influence the type of air mass that gets advected into the area on an onshore wind. The highest rainfall intensities occurred on a south-easterly or southerly wind with moderate to strong wind speeds associated with a synoptic forcing such as a low pressure system moving through the area. It was mentioned that a strong onshore wind alone is unlikely to produce heavy rainfall but when the right weather systems are in place, heavy rainfall can occur.

The highest rainfall intensities occurred on both a pressure rise in some cases and a pressure decrease in other cases. While a large pressure increase caused by a ridging high pressure system did produce high rainfall intensities, there were also cases where the pressure had a decreasing trend with only slight pressure rises and still showed high rainfall intensities. Relative humidity was as to be expected, high in heavy rainfall events but the relative humidity tended to increase just before the onset of the heavy downpours. Warm nights, where the temperature increased at night, tended to precede heavy rainfall.

The latitude of the study area is what determines the presence of the synoptic systems required for the flood events to occur and the presence of the coastline with its topography and the shape of the coastline, determine the direction of the onshore winds and the important element they contribute to the intensity of the rainfall and therefore, the flood events.

This study has thus highlighted the study area as an area prone to flood events. The hazard of floods is a natural occurrence and cannot be changed; however, by knowing which weather systems interact to produce these floods, one can anticipate future disaster risks through improved weather forecasts and can, therefore, reduce vulnerability and exposure through early warning systems. One can also improve resilience by educating the public on this hazard.

### 6.3. Recommendations

Considering the caveats above and the conclusions made, some recommendations will be suggested.

As mentioned above, rainfall readings taking place daily will remove errors and data that can't be used in the SAWS database. Perhaps, educating the volunteers who take the rainfall data on the importance of taking daily readings could help.

When events occurred near to the hourly rainfall stations, perhaps five-minute data could be looked at if available. As technology has improved, more recent case study dates such as cases number 3 and 5 could be reanalysed, looking specifically at the five-minute data and the movement of convective cells through the area.

Local area studies could be conducted that concentrate on specific characteristics found in each local area or city such as Port Elizabeth or East London. This could incorporate the flood producing weather systems for the city, the local effects such as sea breezes, LLJ's or topographical influences. Which wind directions are onshore or offshore could also be of great importance. This could result in a city specific meteorological profile as it were.

An element that has not been researched in this study is that of sea surface temperature (SST) and the heat availability that is offered during onshore wind events. The warm Agulhas current has been seen to influence the rainfall intensities at East London during the 2002 event in case study 3 (Singleton and Reason, 2006). SST's can influence the source of moisture and temperature that affect coastal areas. SST data was less available during the historical dates but can be considered as a meteorological parameter in future studies.

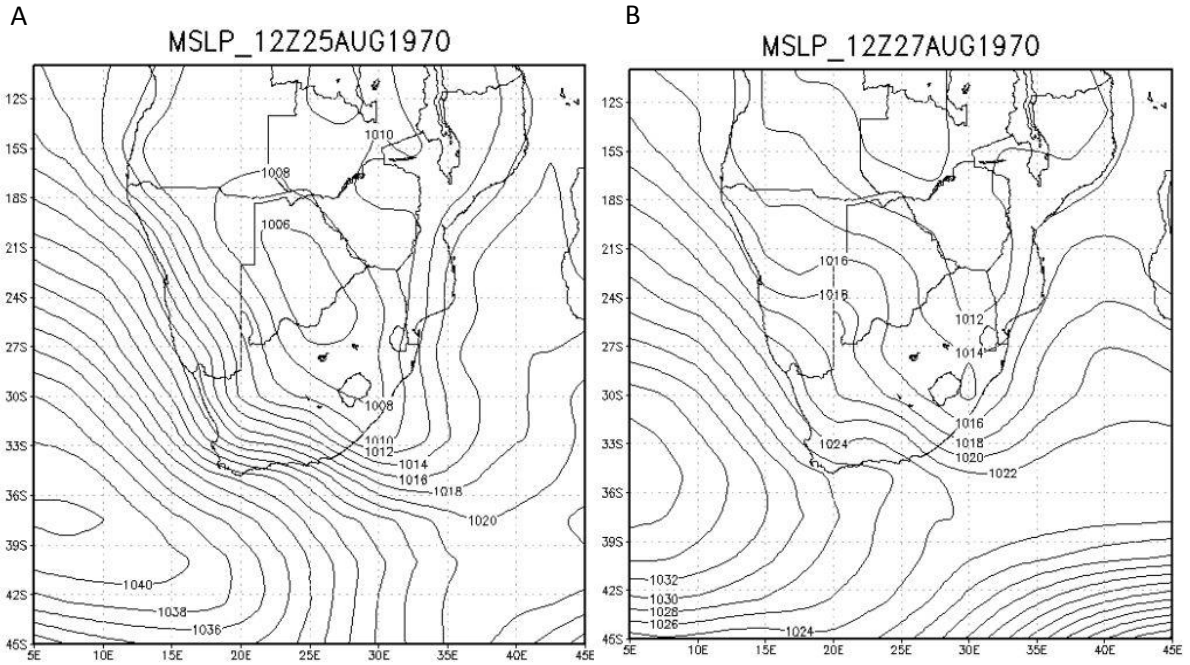
Also concerning the ocean dynamics, spring tides can influence the flood runoff into the ocean and create a lag in flood waters dispersing. This was thought to have influenced the 1968 floods in Port Elizabeth in case study 2. Spring tide influences on Black South-Easterly events could be further researched.

Finally, it was mentioned that this study was meteorologically based and that floods can be a hazard that influences risk. In this study, it was considered to add an element of risk by incorporating flood fatality maps, which would essentially be mapping the fatalities that occurred due to the floods. This could encourage comparisons between fatalities to land-use, proximity to the heaviest rainfall and potential land-use change over the years which could influence risk in future flood events. This path was not taken as it was felt that it would

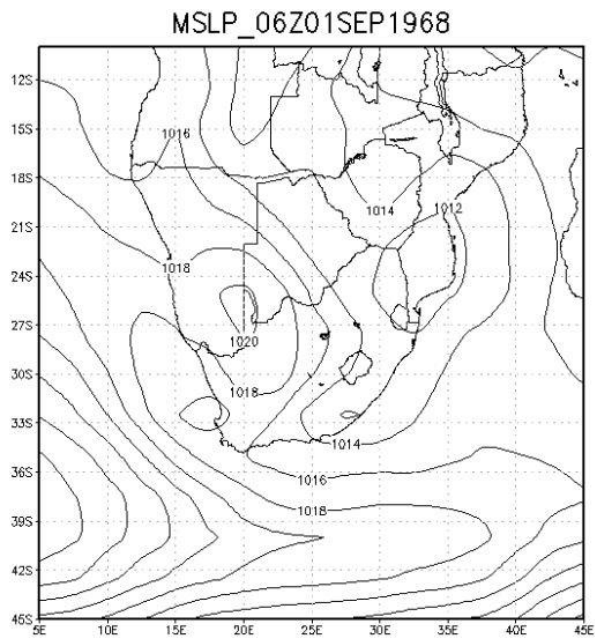
change the focus of the study from a meteorological one to that of risk and hydrological factors. Flood fatality maps from past extreme flood events could aid in the development of risk assessments or risk profiles for certain areas to aid disaster management.

# Appendices

## Appendix 1

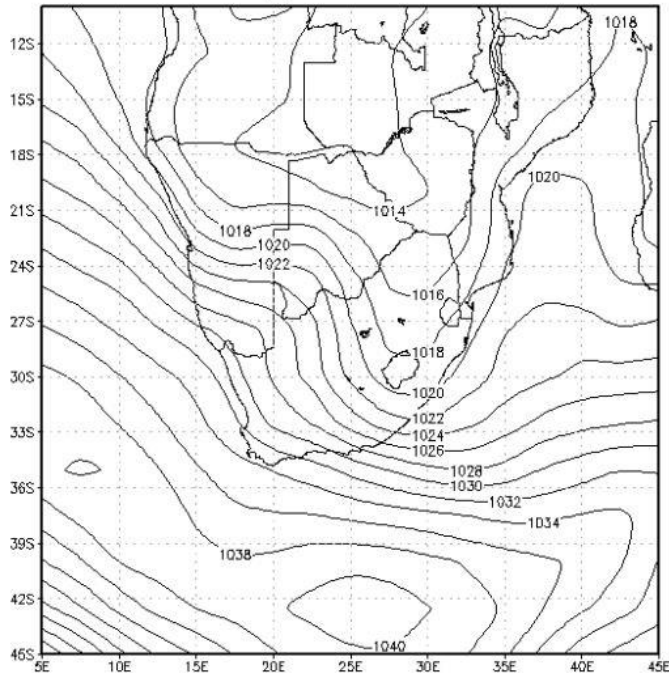


## Appendix 2



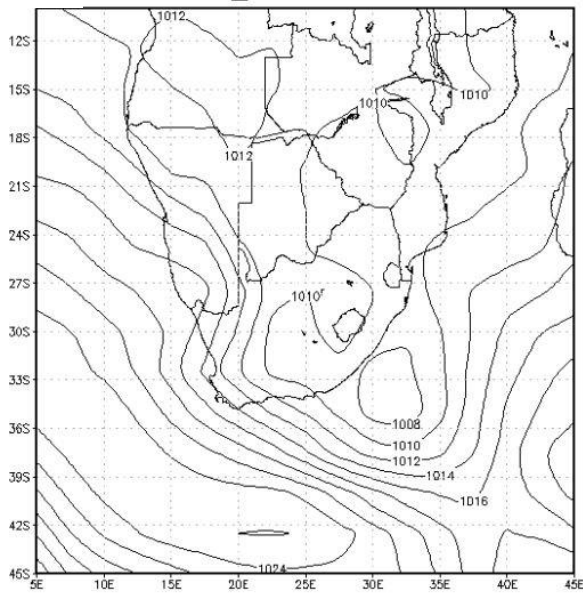
### Appendix 3

MSLP\_12Z15AUG2002

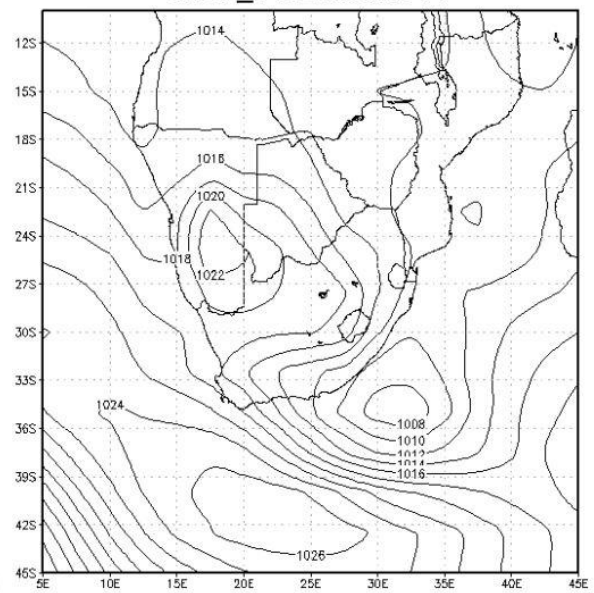


### Appendix 4

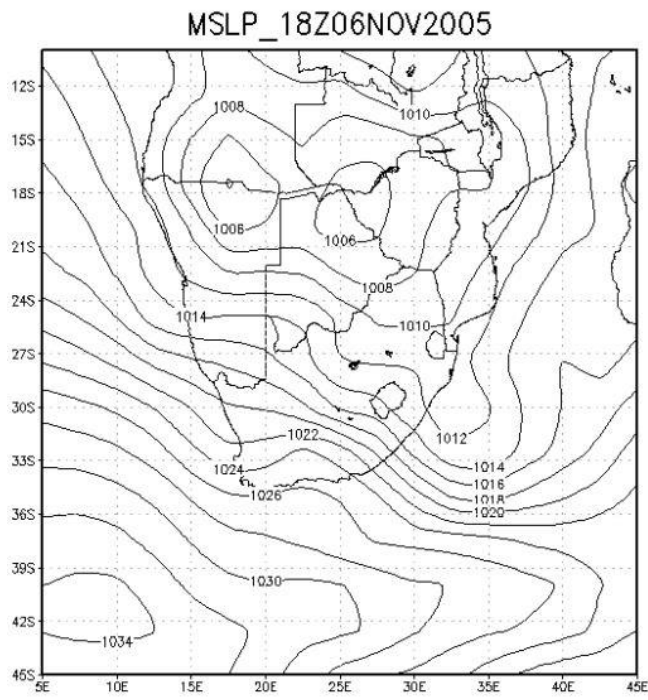
A MSLP\_18Z25MAR1981



B MSLP\_06Z26MAR1981



## Appendix 5



## References

- Adamson, P.T, 1981. *Southern African storm rainfall*. Unpublished report for Department of Environmental Affairs. Pretoria: Department of Environmental Affairs.
- Alexander, W.J.R. 2000. *Flood Risk Reduction Measures (Rev)*. Department of Civil Engineering. University of Pretoria.
- Alexander, W.R.J. 2002. Statistical analysis of extreme floods. *Journal of the South African Institution of Civil Engineering*, 44(1):20-25.
- American Meteorological Society, 2015: *Glossary of Meteorology*. [Online]. Available: <https://www.ametsoc.org/ams/index.cfm/publications/glossary-of-meteorology/> [05/08/2016].
- Anon., 2004. *Mzimvubu to Keiskamma Water Management Area: Amatole-Kei Internal Strategic Perspective*. [Online]. Available: <http://www.dwaf.gov.za/search.aspx> . [17/01/2014].
- Anon., 2016. *The Local Government Handbook: A complete guide to municipalities in South Africa*. [Online]. Available: [www.localgovernment.co.za](http://www.localgovernment.co.za). [October 2016]
- Appel, B., 2016. Technician, South African Weather Service. Personal Communication. 22 November
- Bouchard, B., Goncalo, A., Susienka, M. & Wilson, K. 2007. *Improving Flood Risk Management in Informal Settlements of Cape Town*. Worcester: Worcester Polytechnic Institute. (Project for Bachelor of Science) [pdf].
- Campana, N.A. & Tucci, C.E.M. 2001. Predicting floods from urban development scenarios: case study of the Dilúvio Basin, Porto Alegre, Brazil. *Urban Water*, 3:113-124.
- City of Port Elizabeth Engineer's Department, 1968. *Annual Report of the City Engineer for the Year Ended 31st December 1968*, Port Elizabeth: City Engineer's Department.
- Cuny, F.C. 1991. Living with floods. *Land Use Policy*, 8(4): 331-342.
- de Coning, E., Forbes, G.S. & Poolman, E. 1998. Heavy precipitation and flooding on 12-14 February 1996 over the summer rainfall regions of South Africa: Synoptic and isentropic analyses. *National Weather Digest*, 22(3):25-36.
- Department of Water Affairs, 2017: *Drainage Regions and Water Management Areas*. [Online]. Available: <http://www.dwaf.gov.za/Hydrology/Weekly/Drainage.aspx> . [08/04/2017].
- Desmet, P.G. and Cowling, R.M. 1999. Chapter 1 The climate of the Karoo-a functional approach. In Richard, W., Dean, J. & Milton, S.J. (eds), *The Karoo: Ecological patterns and processes*. Cambridge: Cambridge University Press. p. 3-16.
- Doswell, C. A., III, H. E. Brooks, and R. A. Maddox, 1996: Flash flood forecasting: An ingredients-based methodology. *Weather Forecasting*, 11:560–581.
- Dyson, L.L., van Heerden, J. 2001. The heavy rainfall and floods over the north-eastern interior of South Africa during February 2000. *South African Journal of Science*, 97:80-86.

- Dyson, L.L., van Heerden, J., Marx, H.G. 2002. Short term weather forecasting techniques for heavy rainfall. WRC report 1011/102.
- Engelbrecht, C.J. & Landman, W.A. 2016. Interannual variability of seasonal rainfall over the Cape south coast of South Africa and synoptic type association. *Climate Dynamics*, 47(1-2): 295-313.
- Engelbrecht, C.J., Landman, W.A., Engelbrecht, F.A., Malherbe, J. 2015. A synoptic decomposition of rainfall over the Cape south coast of South Africa. *Climate Dynamics*, 44(9-10): 2589-2607.
- Favre, A., Hewitson, B., Lennard, C., Cerezo-Mota, R. & Tadross, M., 2013. Cut-off lows in the South African region and their contribution to precipitation. *Climate Dynamics*, 41(9): 2331-2351.
- Hart, N.C.G., Reason, C.J.C., Fauchereau, N. 2010. Tropical-extratropical interactions over southern Africa: three cases of heavy summer season rainfall. *Monthly Weather Review*, 138(7): 2608-2623.
- Hayward, L.Q., van den Berg, H.J.C., 1968. *Die Port Elizabeth-Stortreens van 1 September 1968*, Newsletter No. 234, 157-169, Weather Bureau.
- Hayward, L.Q., van den Berg, H.J.C., 1970. *The Eastern Cape floods of 24 to 28 August 1970*, Newsletter No. 257, 129-141, Weather Bureau.
- Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Leetmaa, A., Reynolds, B., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K.C., Ropelewski, C., Wang, J., Jenne, R., Joseph, D. (1996). The NCEP/NCAR 40-year reanalysis project. *Bulletin of the American Meteorological Society*, 77:437–471.
- Klages, N., Jegels, J., Schovell, I., Vosloo, M., 2011: *Nelson Mandela Bay Municipality State of the environment report*. [Online]. Available: [http://www.nelsonmandelabay.gov.za/datarepository/documens/yVeEs\\_NMBM\\_SOER\\_Feb\\_2011.pdf](http://www.nelsonmandelabay.gov.za/datarepository/documens/yVeEs_NMBM_SOER_Feb_2011.pdf). [20/01/2014].
- Lutjeharms, J. R. E. and Anson, I. J. (2001). The Agulhas Return Current. *Journal of Marine Systems*, 30:115-138.
- Makgetla, 2016: The real economy bulletin - provincial review 2016. [Online]. Available: [www.tips.org.za/publications/the-real-economy-bulletin](http://www.tips.org.za/publications/the-real-economy-bulletin). [ 16 September 2016].
- Mapsof.net, 2017: South African Topography- South African Maps. [Online]. Available: <http://mapsof.net/south-africa/south-africa-topography>. [08 April 2017].
- Molekwa, S. 2013. *Cut-off lows over South Africa and their contribution to the total rainfall of the Eastern Cape Province*. Pretoria: University of Pretoria (MSc thesis) [pdf].
- Molekwa, S., Engelbrecht, C.J. & deW Rautenbach, C.J., 2014. Attributes of cut-off low induced rainfall over the Eastern Cape Province of South Africa. *Theoretical and applied climatology*, 118:307-318.

- Nieman, W.A., Harmse, J.T. & Ellmann, H.W.A. 1981. *Natuurkundige faktore wat aanleiding gegee het tot die Laingsburg vloedramp: implikasies vir beplanning*. Eenheid vir Toekomsnavorsing, Universiteit van Stellenbosch.
- Nieto, R., Sprenger, M., Wernli, H., Trigo, R.M. & Gimeno, L. 2008. Identification and Climatology of Cut-off Lows near the Tropopause. *Annals of the New York Academy of Science*, 1146:256-290. DOI: 10.1196/annals.1446.016
- Ologunorisa, T.E & Abawua, M.J. 2005. Flood Risk Assessment: A Review. *Journal of Applied Sciences and Environmental Management*, 9:57-63. DOI: 1119-8362
- Pyle, D.M. 2006. *Severe Convective Storm Risk in the Eastern Cape Province of South Africa*. Grahamstown: Rhodes University (PhD) [pdf].
- Pyle, D.M. & Jacobs, T.L. 2016. The Port Alfred floods of 17-23 October 2012: A case of disaster (mis)management?. *Jamba: Journal of Disaster Risk Studies*, 8(1):1-8.
- Republic of South Africa. 2003. Government Gazette: Act No. 57 of 2002: Disaster Management Act, Vol. 451, Republic of South Africa, Government Printer.
- Republic of South Africa. 2014. *South Africa's Provinces – Eastern Cape*. [Online]. Available: <http://www.info.gov.za/aboutsa/provinces.htm> [17/01/2014].
- Republic of South Africa. 2015. Government Gazette: Act No. 16 of 2015: Disaster Management Amendment Act, Vol. 606, Republic of South Africa, Government Printer.
- Sampson, G. 2007. *Meteorological Risk Assessment Nelson Mandela Metropolitan Municipal Area*. Unpublished report for the South African Weather Service. Port Elizabeth: South African Weather Service.
- Schulze, R.E. 1997. *South African atlas of agrohydrology and -climatology*. Pretoria: Water Research Commission
- Seiler, R.A., Hayes, M. & Bressan, L. 2002. Using the standardized precipitation index for flood risk monitoring. *International Journal of Climatology*, 22:1365-1376.
- Shand, N. 2004. *Fish to Tsitsikamma Water Management Area: Tsitsikamma to Coega Internal Strategic Perspective*. [Online]. Available: <http://www.dwaf.gov.za/search.aspx>. [18/01/2014].
- Shand, N. 2005. *Fish to Tsitsikamma Water Management Area: Fish to Sundays Internal Strategic Perspective*. [Online]. Available: <http://www.dwaf.gov.za/search.aspx>. [17/01/2014].
- Singleton, A.T. & Reason, C. 2006. Numerical simulations of a severe rainfall event over the Eastern Cape coast of South Africa: sensitivity to sea surface temperature and topography. *Tellus A*, 58(3):355-367.
- Singleton, A.T. & Reason, C. 2007a. A numerical model study of an intense cutoff low pressure system over South Africa. *Monthly Weather Review*, 135: 1128-1150.
- Singleton, A.T. & Reason, C. 2007b. Variability in the characteristics of cut-off low pressure systems over subtropical southern Africa. *International Journal of Climatology*, 27: 295-310.

- South African Weather Bureau, 1981. Daily Weather Bulletin for the month March 1981, pp. 47-51, Department of Transport, Republic of South Africa, Government Printer.
- South African Weather Bureau, 1983. Daily Weather Bulletin for the month July 1983, pp. 47-53, Department of Transport, Republic of South Africa, Government Printer.
- South African Weather Service, 2002. Daily Weather Bulletin August 2002, pp. 29-33. Pretoria. ISSN 0011-5517
- South African Weather Service, 2005. Daily Weather Bulletin November 2005, pp. 11-15. Pretoria. ISSN 0011-5517
- Taljaard, J.J. 1985. *Cut-off lows in the South African region*. Pretoria: Weather Bureau, Department of Transport.
- Tyson, P.D. & Preston-Whyte, R.A. 2000. The weather and climate of Southern Africa, Oxford University Press, Cape Town, South Africa, pp. 196-197.
- Union of South Africa. Department of Irrigation. 1935. *Meteorological Office: Report for the years 1931-32*. Pretoria: Government Printer.
- Walker, N.D. 1990. Links between South African summer rainfall and temperature variability of the Agulhas and Benguela current systems. *Journal of Geophysical Research*. 95(C3):3297-3319.
- Weather Bureau, 1991. *Caelum – A history of notable weather events in South Africa: 1500-1990*, Pretoria: Weather Bureau, Department of Environment Affairs.
- Young, J. 2013: *Investing in the Eastern Cape*. [Online]. Available: <http://www.southafrica.info/business/investing/opportunities/escape.htm#.Utkx6xX8LIU> [16/01/2014].