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Climatic deviations across a transect of South Africa during El Niño and La Niña years

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Abstract

South Africa is a water-scarce country that is highly dependent on agriculture. This means that the local impacts of climate altering phenomenon, such as the El Niño-Southern Oscillation (ENSO), are critical to understand. At a broad scale, these systems are known to affect rainfall distribution, resulting in drought (flood) conditions during El Niño (La Niña) events in the majority of the country, and the converse in the southwestern Cape. However, fine resolution analyses of local impacts of these events have been restricted to the coastal zone, and little is known for the interior. We explore the uniformity in the transition of the climatic deviations [for minimum temperature (T_{min}) and maximum temperature (T_{max}), and rainfall] along a 12-site transect spanning the South African interior. The majority of the deviations determined were not statistically significant which suggests that the common understanding of the climatic impacts of ENSO events in South Africa is not well understood. However, it should be acknowledged that all the locations used in this research, aside from Hermanus, were located inland which may be the reason the deviations at these locations were not statistically significant.

Introduction

The El Niño-Southern Oscillation (ENSO) is an extensive, multidimensional oceanic and atmospheric climatic phenomenon (Anderson et al. 2017; Kogan and Guo 2017). It is arguably one of the strongest interannual climatic phenomenon (Fan et al. 2017; Hu and Fedorov 2017). ENSO events are expressed through semi-periodic (Baudoin et al. 2017) abnormal sea-surface temperature variations in the equatorial region of the Pacific Ocean which influences the state of the atmosphere (Camberlin et al. 2001; Gaughan and Waylen 2012). Ocean-atmospheric variations result in changes in the normal Walker Circulation which causes shifts in the interannual precipitation received in tropical areas (Anyamba et al. 2002; Gaughan and Waylen 2012); as well as shifts in temperature (Anderson et al. 2017). This results in fluctuations in the amount of precipitation received both in this region (Anyamba et al. 2002), and with global influence (Kovats 2000; Guilyardi 2006; Kogan and Guo 2017), as with varying impacts regionally (Hanley et al. 2003; Gizaw and Gan 2016; L'Heureux et al. 2016).

In many regions, El Niño events are associated with hot and dry conditions. An example of a severe El Niño induced drought is the 1876/1878 event which impacted on many countries around the world including Brazil, China, Egypt, Ethiopia, India, Java, South Africa and Sudan (Kovats et al. 2003). Many of these regions were similarly affected by drought during the 2015/2016 El Niño event which caused severe food insecurity and even forest fires (Caminade et al. 2017). In other regions, including Bolivia, Colombia, Ecuador and Peru, El Niño is linked to flooding (Kovats et al. 2003; Smith and Ubilava 2017). ENSO events have a significant impact on human health (Kovats 2000; Kovats et al. 2003; Kogan and Guo 2017), especially as these events are often irregular (Kovats et al. 2003). The Zika virus (mosquito-borne) outbreak, which originated in South America, and a Yellow Fever outbreak in Angola, both of which occurred in 2015, are argued to have been influenced by the climatic conditions caused by the 2015/2016 El Niño event (Caminade et al. 2017). ENSO is also said to have influenced the number of incidences of cholera (Moore et al. 2017). The effects of La Niña events on climate are often the reverse of the effects of El Niño events (Kovats 2000; Kovats et al. 2003; Miralles et al. 2014; Hirons and Klingaman 2016a; Cashin et al. 2017).

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Despite the ENSO phenomenon originating far from Africa (Camberlin et al. 2001), it is said to be important in influencing the climate of this continent both now and in future (Hulme et al. 2001; Collins 2011). As it is a semi-arid region, southern Africa experiences most of its precipitation during the southern hemisphere (austral) summer, with the exception of the southwestern tip which receives winter rainfall (Roffe et al. 2019**)**. Rainfall variability in South Africa, and particularly the summer rainfall zone, is argued to be significantly influenced by ENSO events (Crétat et al. 2012; Landman and Beraki 2012; Lakhraj-Govender and Grab 2019). These events affect precipitation variation in this country as it is broadly understood that El Niño events give rise to droughts (Camberlin et al. 2001; Anyamba et al. 2002; Nash and Grab 2010; Crétat et al. 2012; Gaughan and Waylen 2012; Ratnam et al. 2014; Meque and Abiodun 2015; Baudoin et al. 2017) and warm conditions (Jury 2002) while La Niña events give rise to wet conditions (Crétat et al. 2012; Gaughan and Waylen 2012; Meque and Abiodun 2015) and cooler maximum temperatures (Arblaster and Alexander 2012; Lakhraj-Govender and Grab 2019).

The ENSO signal can be communicated into the precipitation field of southern Africa in two ways: (1) solely through the atmosphere (this occurs through the generation of Rossby waves) as seen from General Circulation Model simulations; (2) through ocean-atmospheric interactions (for example, atmospheric responses to east Pacific Ocean anomalies in sea-surface temperature results in the Indian Ocean warming; Cook 2000). The model used by Cook (2000) proposes that the reaction of the atmosphere to the eastern Pacific Ocean warming during ENSO causes drying in southern Africa. The peak of the southern African summer rainfall zone rainy season (December to March) coincides with the period where the region is most likely to be affected by ENSO events (Mason 2001; Crétat et al. 2012; Hirons and Klingaman 2016b; Hoell and Cheng 2017; Manatsa et al. 2015 in Hoell et al. 2017) as anomalies in the atmosphere, ocean and precipitation linked to these events reach their peak in this period (Crétat et al. 2012; Archer et al. 2017). In this season, the Walker Circulation is influenced by ENSO events which affects the convection over the middle and western regions of the Indian Ocean (Hoell et al. 2015). Dry conditions in southern Africa that are caused by El Niño events occur as westerly winds result in increasing evaporation (Jury 2002). El Niño events are linked to a high pressure located over southern Africa which results in abnormal mid-tropospheric descent and below-normal rainfall (Hoell and Cheng 2017; Hoell et al. 2017). La Niña events are linked to a low pressure over southern Africa which results in abnormal mid-tropospheric ascent and above-normal rainfall (Abdi et al. 2016; Hoell and Cheng 2017; Hoell et al. 2017). Since 1970, interannual variability in precipitation in southern Africa has increased (Jury 2013).

This is local climate response to ENSO does not uniformly occur. For example, the during the1997/1998 El Niño event, South Africa experienced precipitation within the range of normal conditions (Camberlin et al. 2001; Anyamba et al. 2002; Philippon et al. 2012; Crétat et al. 2012; Hoell et al. 2015; Funk et al. 2016). This may be as the correlation between ENSO events and precipitation variation in this country are said to be weak (Crétat et al. 2012) and non-linear (Meque and Abiodun 2015). As the mean climatic conditions experienced by South Africa during ENSO events are not always uniform, more quantitative data is needed to understand the climatic deviations during ENSO events at a higher spatial and temporal resolution. We therefore explore the deviations in South African climate for 12 stations along a transect spanning the interior, relative to the long term climatic conditions.

Methods

This study uses a 12-location transect, comprising 16 named weather stations (Figure 1), to explore differences between the summer rainfall zone (the north-eastern region) and winter rainfall zones (the southwestern region) (Roffe et al. 2019) and conditions between the southwestern and north-eastern regions of South Africa which experiences varying temperatures and rainfall amounts. A similar transect was used by Chase and Meadows (2007). The selected locations are said to experience varying conditions during El Niño and La Niña events, depending on which rainfall zone they are located in which makes the selected transect useful when determining the deviations in climatic conditions of South Africa during these events; for example, the summer rainfall zone is said to receive below normal rainfall during El Niño events, while the winter rainfall zone is said to receive above normal rainfall during these events (Philippon et al. 2012).

For the 12 locations, average daily climate data for three variables, T_{max}, T_{min} and rainfall, from 16 weather stations were acquired from the South African Weather Service (Table 1). The inaccurate average daily climate data (average values where daily values were missing) were excluded from the statistical analysis conducted in this research. The mean climatic conditions, including El Niño and La Niña events, for the study period were calculated on a monthly and an annual scale for each climate variable for each location along the transect.

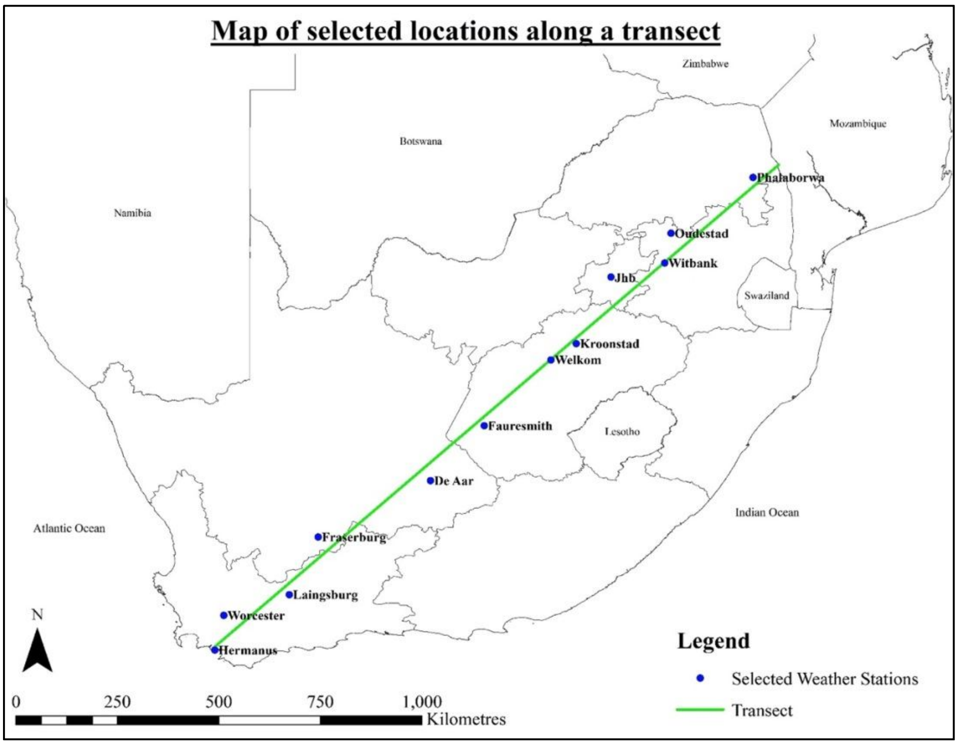

Figure 1. Map of the location of weather stations along the transect line.

Table 1. List of the stations used

City/Town	Station	Co-ordinates	Time range	Rainfall zone*	Mean annual rainfall(mm)**
Hermanus	Hermanus - 0006386A7	-34.43° S; 19.22° E	1996-2016	Winter	40.7
Worcester	Worcester-Aws - 0022729 X	-33.66° S; 19.42° E	1998-2016	Winter	23.4
Laingsburg	Laingsburg - 0045642 0	-33.2° S; 20.87° E	1995-2016	Summer/ Autumn	10.9
Fraserburg	Fraserburg - 0113025A2	-31.92° S; 21.51° E	1986-2016	Summer	16.6
De Aar	De Aar Wo - 0169880 1 De Aar - Mun - 0170009CX	-30.67° S; 24° E	1993-2016 1986-1993	Summer	28.1
Fauresmith	Fauresmith - 0291570 1	-29.45° S; 25.19° E	2001-2016	Summer	35.8
Welkom	Welkom - 0364300 1 Welkom - 0364300A6	-27.99° S; 26.67° E	1990-2016 (for T_{max} and T_{min}); 1993-2016 (for Rainfall) 1986-1992	Summer	36.4
Kroonstad	Kroonstad - 0365398 8	-27.63° S; 27.23° E	1986-2016 (for T_{max} and T_{min}); 1993-2016 (for Rainfall)	Summer	37.8
Johannesburg	Jhb Bot Tuine - 0475879 0	-26.15° S; 28° E	1986-2016	Summer	54.7
Witbank	Witbank - 0515320 8	-25.84° S; 29.19° E	1993-2016	Summer	56.8
Oudestad	Oudestad - 0552581 7	-25.18° S; 29.33° E	1986-2016	Summer	43.2
Phalaborwa	Phalaborwa Airport Aws - 0681266D1 Phalaborwa - 0681266C7 Phalaborwa - 0681266 3	-23.94° S; 31.15° E	2008-2014 1988-1990 1993-2008	Summer	35

*determined from datasets from the South African Weather Service. **calculated from datasets from the South African Weather Service

The El Niño and La Niña years were identified using the Oceanic Niño Index (NOAA 2017) and ranked for all locations along the transect, for all climate variables. These years were isolated and the monthly and annual mean were calculated for the El Niño and La Niña years identified to determine the average climate experienced in South Africa during these events. A statistical t-test was then conducted

(Kruger and Shongwe 2004) to compare the mean El Niño or La Niña climatic conditions to the long-term mean climatic conditions of each location along the transect.

The long-term climatic conditions (including El Niño and La Niña events), as well as the mean climatic conditions experienced during El Niño and La Niña events, were used to compare the overall deviations in the T_{min}, T_{max}, and rainfall for all 12 locations along the transect, combined. The minimum and maximum deviations both above and below the long-term mean were calculated by subtracting individual El Niño and La Niña events for each location from the long-term mean of that location to identify which events had the greatest impact on the climate of South Africa. The deviations were calculated by subtracting the event average for each climate variable at each location from the long-term mean of each location. These deviations at each location were then ranked according to the greatest and the least divergence. This was done through conducting a cluster analysis to classify regions which experienced the greatest or the least divergence. These findings were then graphed and mapped to identify the degree of variation in South African climate experienced during El Niño and La Niña events at each location and whether there was a gradual transition in these climatic divergences. The outcome of this research may assist in improving the understanding of the climatic impacts of El Niño and La Niña events as well as in improving the adaptive capacity of South Africa when it comes to managing and alleviating the adverse impacts of these events.

Results

Exploratory data analysis

The time span of the data from the 16 stations varied from 16-31 years. Each of the 16 stations had missing data, either due to the date that the station opened (for example if the station opened in August, the data from the previous months were missing) or technical faults, such as equipment malfunctioning. Incorrect data was highlighted by the South African Weather Service as averages that were calculated with missing data. This incorrect data was excluded from this research.

Examples of some of the locations where major inconsistencies in terms of the data provided by the stations were identified included Kroonstad, for which a 31-year dataset was available, but much of the data for the first seven years (1986–1992) could not be used due to the large amounts of missing data and the inaccuracies marked by the South African Weather Service, and the rainfall data for this location only spanned the period 1993–present. Data for Phalaborwa was similarly problematic. This was most likely due to the three weather stations at this location, as the gap of missing data for two years (1991 and 1992) for all three climate variables was possibly due to no active stations during this period. The climate record for Phalaborwa terminated in 2014. For Welkom, T_{min} and T_{max} data overlapped for the period 1990–1993 due to two stations operating concurrently at this location. This overlapping data was included in this research as this data did not contain significant inaccuracies identified by the South African Weather Service, and would have contributed to the understanding of the climate experienced in this location.

Long-term mean climatic conditions

The long-term climatic conditions that are experienced in each of the 12 locations were calculated for each climate variable (T_{min} and T_{max} and rainfall) (Table 2). On average, the highest T_{min} and T_{max} (15.8°C and 29.0°C respectively) are experienced in Phalaborwa (located in north-eastern South Africa), while the lowest T_{max} (20.8°C) are experienced in Hermanus (located on the southwestern coast), and the lowest T_{min} (7.4°C) are experienced in Fraserburg, located in the southwestern region (Table 2). The greatest temperature difference between T_{min} and T_{max} is experienced in Fauresmith, located in central South Africa (T_{min} = 7.6°C, T_{max} = 25.2°C, 17.6°C mean diurnal temperature difference), while the mean diurnal range is experienced at Hermanus (T_{min} is 13°C and T_{max} is 20°C, therefore the temperature difference is 7.0°C; Table 2). This may be due to the continental climate and maritime climate experienced at each of these locations respectively. In terms of rainfall it was found that, on average, Laingsburg (in the southwestern region) receives the least amount (130.9mm), while Witbank (in the northeast of the country) receives the highest (682.2mm; Table 2).

Climatic conditions over the long-term, El Niño and La Niña events

Over the 31-year study period used in this research, 10 El Niño events and nine La Niña events occurred varying in severity and duration (Table 3). Of the 10 El Niño events, six lasted a year or longer, with the longest being the 2015/2016 event which lasted for 17 months (Table 3). Three El Niño events lasted for a year, and the remaining four events lasted between seven and 11 months (Table 3). Between 2002 and 2007, four El Niño events occurred (Table 3). The strongest El Niño event, according to the ONI, was the 1997/1998 event (which had a mean strength of 1.6°C), while the weakest was the 2004/2005 event, with a mean strength of 0.6°C (NOAA 2017; Table 3).

Five of the nine La Niña events lasted for a year or longer, with the remaining four lasting for six months or longer (Table 3). The longest of these was the 1988/1989 event which lasted 15 months, and the shortest was the 2016/2017 event which lasted only six months (Table 3). In the period 1998-2001, three consecutive La Niña events occurred (Table 3). The strongest La Niña event was the 1988/1989 event, with a mean strength of -1.2°C, while the two weakest events were the 2000/2001 and 2016/2017 events, both with a mean strength of -0.7°C (NOAA 2017; Table 3).

Table 2. Average Climatic Conditions of South Africa

Location	Average maximum temperature (°C)	Average minimum temperature (°C)	Annual total Rainfall (mm)
Hermanus	20.8	13.8	488.2
Worcester	25.5	11.5	280.5
Laingsburg	25.5	11.0	130.9
Fraserburg	23.9	7.4	199.4
De Aar	25.0	9.7	337.1
Fauresmith	25.2	7.6	429.4
Welkom	26.0	10.3	437.3
Kroonstad	25.0	9.8	453.0
Johannesburg	23.6	9.9	656.3
Witbank	23.7	10.5	682.2
Oudestad	28.1	12.0	518.8
Phalaborwa	29.0	15.8	419.6

Table 3. El Niño and La Niña events that occurred between 1986 and 2016, their durations and mean strengths, as per the ONI (NOAA, 2017)

El Niño event	Duration (months)	Mean strength (°C)	La Niña event	Duration (months)	Mean strength (°C)
1986/1987	12	1.0	1988/1989	15	-1.2
1987/1988	8	1.2	1995/1996	10	-0.8
1991/1992	16	1.0	1998/1999	12	-1.1
1994/1995	8	0.8	1999/2000	12	-1.1
1997/1998	15	1.6	2000/2001	9	-0.7
2002/2003	11	0.9	2007/2008	13	-1.0
2004/2005	12	0.6	2010/2011	12	-1.1
2006/2007	7	0.7	2011/2012	9	-0.8
2009/2010	12	0.9	2016/2017	6	-0.7
2015/2016	17	1.4			

No statistically significant variability is observed when comparing the means of the long-term, El Niño and La Niña T_{max} conditions, and the variability for El Niño and La Niña years fall within the bracket of the variability of the long-term conditions (Figure 2). However, the long-term T_{max} mean is noticeably lower than that of El Niño and La Niña events (Figure 2). An even smaller degree of variability can be identified when comparing the means of the T_{max} conditions for El Niño and La Niña events, with the mean T_{max} for El Niño events being only slightly higher than that of La Niña events (Figure 2).

The same can be said for the variability of the T_{min} experienced during long-term, El Niño and La Niña events (Figure 2). A small but noticeable variation is observed when comparing the long-term T_{min} conditions to the mean T_{min} conditions experienced during El Niño and La Niña events (Figure 2). The variation between the T_{min} for El Niño and La Niña events are even smaller than that of T_{max}, mentioned above, with little difference between the mean T_{min} experienced during these events (Figure 2). The variability in the mean rainfall received during long-term, El Niño and La Niña conditions is similarly small (Figure 2). La Niña events were found to experience slightlu greater mean rainfall when compared to the mean rainfall experienced under long-term and El Niño conditions (Figure 2).

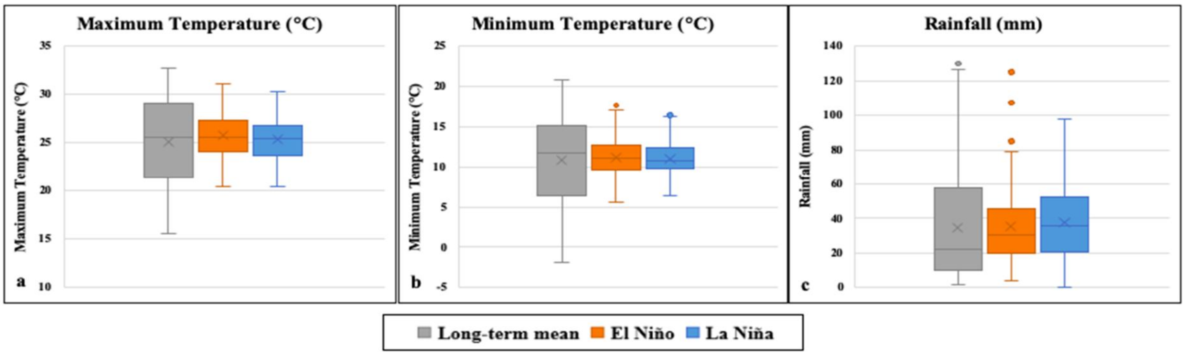

Figure 2. Comparison box plots for long-term conditions, average El Niño and average La Niña conditions

El Niño events

At all 12 locations, the T_{min} and T_{max} experienced during El Niño events are higher than the long-term mean conditions (Table 4). However, statistically significant deviations from the long-term mean were identified for only two of the 12 locations, Welkom ($p=0.049$) and Phalaborwa (one-tailed $p=0.013$; two-tailed $p=0.026$), during El Niño events for T_{max} only (Table 4). The deviations from the long-term mean at the remaining 10 locations were not statistically significant for T_{max}, and statistically significant deviations from the T_{min} long-term mean during El Niño events were not found at any of the locations.

Table 4. Average climatic conditions during El Niño events

Location	Maximum temperature (°C)	Minimum temperature (°C)	Rainfall (mm)
Hermanus	range: 20.5 - 21.5 t-statistic: 1.4 deviation: -0.2	range: 13.5 - 14.9 t-statistic: 1.3 deviation: -0.3	range: 31.9 - 61.1 t-statistic: 0.2 deviation: -0.9
Worcester	range: 25 - 27 t-statistic: 1.5 deviation: -0.5	range: 11 - 13 t-statistic: 1.2 deviation: -0.4	range: 11.5 - 22.8 t-statistic: -1.9 deviation: 4.5
Laingsburg	range: 25 - 27.5 t-statistic: 1 deviation: -0.4	range: 10.3 - 12.8 t-statistic: 1.1 deviation: -0.4	range: 3.9 - 13.1 t- statistic: -0.3 deviation: 0.4
Fraserburg	range: 21.6 - 27.2 t-statistic: 1.3 deviation: -0.7	range: 5.5 - 11 t-statistic: 1.2 deviation: -0.6	range: 6.2 - 28 t-statistic: -1.6 deviation: 2.9
De Aar	range: 23.5 - 28.6 t-statistic: 1.7 deviation: -0.9	range: 6.8 - 13.1 t-statistic: 1.3 deviation: -0.7	range: 16.3 - 64.3 t-statistic: 0 deviation: -0.1
Fauresmith	range: 23.7 - 28 t-statistic: 1.2 deviation: -0.8	range: 7.3 - 10.4 t-statistic: 1.3 deviation: -0.8	range: 22.6 - 58.8 t-statistic: 0.4 deviation: -2.6
Welkom	range: 25.3 - 29.3 t-statistic: 1.8** deviation: -0.7	range: 9.2 - 13.4 t-statistic: 1.7 deviation: -0.8	range: 20.9 - 107.2 t-statistic: 0.8 deviation: -6.2
Kroonstad	range: 24.2 - 28 t-statistic: 1.6 deviation: -0.9	range: 8.4 - 12.8 t-statistic: 1.4 deviation: -0.8	range: 24.5 - 42.5 t-statistic: -1.1 deviation: 3.1
Johannesburg	range: 22.8 - 26.1 t-statistic: 1.2 deviation: -0.5	range: 8.2 - 11.8 t-statistic: 1.1 deviation: -0.5	range: 22.1 - 124.9 t-statistic: 0.5 deviation: -5
Witbank	range: 22.7 - 25.7 t-statistic: 0.9 deviation: -0.4	range: 10.1 - 12.7 t-statistic: 1.2 deviation: -0.4	range: 29.9 - 77.6 t-statistic: -1.1 deviation: 6.7
Oudestad	range: 25.8 - 31.1 t-statistic: 0.9 deviation: -0.5	range: 8.3 - 15.8 t-statistic: 0.9 deviation: -0.6	range: 9.1 - 78.7 t-statistic: 0.1 deviation: -0.4
Phalaborwa	range: 29.2 - 31 t-statistic: 3.1** deviation: -0.9	range: 15.3 - 17.7 t-statistic: 1.6 deviation: -0.7	range: 13.7 - 38.5 t-statistic: -2** deviation: 8.2

The shades of red and blue indicate the amount of deviation in climatic conditions during El Niño events, with darker shades symbolising greater deviations while lighter shades and white symbolise smaller deviations. Negative values indicate above average conditions and positive values indicate below average conditions. **indicates statistical significance

The greatest deviation from the long-term mean for both T_{min} and T_{max} was at Hermanus, as T_{max} were on average 0.9°C higher than the long-term mean and T_{min} were on average 0.7°C higher than the long-term mean (Table 4). Despite this, the T_{max} deviation at Phalaborwa and Welkom, were statistically significant, as stated above. The T_{min} and T_{max} deviations during El Niño events in the southwestern region of the country (Hermanus, Worcester, Laingsburg and Fraserburg) were small as T_{max} was higher than the long-term mean by between 0.2°C (at Hermanus) and 0.7°C (at Fraserburg), and T_{min} was higher than the long-term mean by between 0.3°C (at Hermanus) and 0.6°C (at Fraserburg) (Table 4). For the locations in the north-eastern region of the country (Johannesburg, Witbank and Oudestad), slightly greater deviations from the long-term T_{min} and T_{max} means are observed. In this region, T_{max} is higher by between 0.4°C (at Witbank) and 0.5°C (at Johannesburg and Oudestad) relative to the long-term mean, and T_{min} is between 0.4°C (at Witbank) and 0.6°C (at Oudestad) higher than the long-term mean (Table 4). On the other hand, the locations where greater deviations from the long-term T_{min} and T_{max} mean during El Niño events were identified were located in central South Africa (Table 4). A greater deviation from the long-term mean for T_{min} and T_{max} was observed for De Aar, Fauresmith, Welkom and Kroonstad as, for these locations, T_{max} was between 0.7°C (at Welkom) and 0.9°C (at De Aar and Kroonstad) higher than the mean, and 0.7°C (at De Aar) and 0.8°C (at Fauresmith, Welkom and Kroonstad) higher than the long-term mean for T_{min} (Table 4).

This demonstrates that across South Africa, the variations in the temperature experienced during El Nino events are not uniform with a smaller increase in temperature from the long-term mean being observed in the southwestern region and part of the north-eastern region of the country (aside from Phalaborwa). A greater increase in temperature during El Niño events when compared to the long-term mean conditions, on the other hand, is identified for the central region of the country and Phalaborwa in the extreme northeast (Table 4).

For rainfall, statistically significant deviations from the long-term mean were identified at Phalaborwa (p-=0.049), only for El Niño events (Table 4), with deviations at the remaining 11 locations not being statistically significant. The deviations in the rainfall received at each location during El Niño events is more heterogeneous than that of T_{min} and T_{max}. This deviation is not characterised by the summer rainfall zone-winter rainfall zone divide.

During El Niño events, six of the 12 locations receive above average rainfall, while the remaining six receive below average rainfall (Table 4). A decrease in the amount of rainfall received during El Niño events, when compared to the long-term mean, is found for the southwestern region of the country (Worcester, Laingsburg and Fraserburg) where rainfall is between 0.4mm (at Laingsburg) and 4.5mm (at Worcester) lower than the long-term mean (Table 4). The only location in this region where the opposite is observed is Hermanus, which receives 0.9mm above average rainfall during El Niño events (Table 4). An increase in the amount of rainfall received compared to the long-term mean, is observed in central South Africa (De Aar, Fauresmith and Welkom). Here rainfall was between 0.1mm (at De Aar) and 6.2mm (at Welkom) higher than the long-term mean (Table 4). At the remaining locations in the north-eastern region (Kroonstad, Johannesburg, Witbank, Oudestad and Phalaborwa), different conditions are observed with every other location (Table 4). In other words, similar rainfall conditions were identified at every second location. Kroonstad (3.1mm less than average), Witbank (6.7mm less than average) and Phalaborwa (8.2mm less than average) receive below average rainfall during El Niño events, while Johannesburg (5mm more than average) and Oudestad (0.4mm more than average) receive above average rainfall during these events (Table 4).

La Niña

Statistically significant deviations from the long-term mean were observed at Kroonstad (for T_{min}) and Hermanus and Witbank (for rainfall) for La Niña events. Deviations in T_{max} were not significant at any of the 12 locations for these events.

The statistically significant T_{min} deviation for Kroonstad (one-tailed p=0.014; two-tailed p=0.027) was 0.7°C higher than the long-term mean. Non-statistically significant deviations for the stations. involved T_{max} higher than the long-term mean by 0.4°C, and 8.8mm more rainfall compared to the long-term mean (Table 5).

Unlike El Niño events, for which the T_{min} and T_{max} were consistently above average, these two variables are more heterogeneous in La Niña events. This is due to the T_{min} and T_{max} being above average in some locations and below average in others during La Niña events, with varying degrees of deviation from the long-term mean at each location. Eight of the 12 locations experienced higher T_{max} during La Niña events, and 10 experienced higher T_{min} during these events (Table 5).

Table 5. Average climatic conditions during La Niña events.

Location	Maximum temperature (°C)	Minimum temperature (°C)	Rainfall (mm)
Hermanus	range: 20.5 - 21.3 t-statistic: -0.3 deviation: 0	range: 13.4 - 14.5 t-statistic: -0.3 deviation: 0	range: 21.1 - 47.3 t-statistic: -2.3** deviation: 7.9
Worcester	range: 24.5 - 27.8 t-statistic: 1.3 deviation: -0.6	range: 10.8 - 13.8 t-statistic: 0.85 deviation: -0.4	range: 9 - 40.1 t-statistic: -1.1 deviation: 4.1
Laingsburg	range: 24.9 - 29.2 t-statistic: 1.7 deviation: -0.8	range: 9.8 - 15.2 t-statistic: 0.9 deviation: -0.5	range: 3.1 - 19.1 t-statistic: -0.8 deviation: 1.5
Fraserburg	range: 22.7 - 26.7 t-statistic: 1 deviation: -0.4	range: 7 - 9.1 t-statistic: 1.2 deviation: -0.3	range: 8.3 - 33.8 t-statistic: 1.1 deviation: -3.2
De Aar	range: 21.9 - 26.8 t-statistic: 0.1 deviation: -0	range: 6.4 - 11.1 t-statistic: 0.2 deviation: -0.1	range: 8.6 - 47.6 t-statistic: 0.1 deviation: -0.2
Fauresmith	range: 23.6 - 26.6 t-statistic: -0 deviation: 0	range: 6.7 - 8.5 t-statistic: -0.1 deviation: 0	range: 18.6 - 42.8 t-statistic: -0.4 deviation: 2.2
Welkom	range: 23.1 - 28.1 t-statistic: 0.2 deviation: -0.1	range: 8.7 - 11.9 t-statistic: 0.5 deviation: -0.2	range: 8.2 - 62.7 t-statistic: 0.3 deviation: -1.9
Kroonstad	range: 24 - 26.8 t-statistic: 1.1 deviation: -0.4	range: 9.9 - 12 t-statistic: 2.8** deviation: -0.7	range: 22.6 - 88.4 t-statistic: 1.3 deviation: -8.8
Johannesburg	range: 21.1 - 25.7 t-statistic: -0.1 deviation: 0.1	range: 8.1 - 11.5 t-statistic: 0.1 deviation: -0	range: 31.2 - 94.9 t-statistic: 0.8 deviation: -4.5
Witbank	range: 22.2 - 28.5 t-statistic: 0.3 deviation: -0.2	range: 9.8 - 14.5 t-statistic: 0.8 deviation: -0.4	range: 67.8 - 97.9 t-statistic: 4.7** deviation: -18
Oudestad	range: 26.4 - 30.3 t-statistic: 0.1 deviation: -0.1	range: 9.8 - 13.9 t-statistic: 0.3 deviation: -0.1	range: 0 - 72.6 t-statistic: 0.3 deviation: -2
Phalaborwa	range: 27.5 - 29.9 t-statistic: -0.8 deviation: 0.2	range: 14.5 - 16.9 t-statistic: 0.7 deviation: -0.2	range: 26.7 - 73.3 t-statistic: 1.6 deviation: -8.8

The shades of red and blue indicate the amount of deviation in climatic conditions during La Niña events, with darker shades symbolising greater deviations while lighter shades and white symbolise smaller deviations. Negative values indicate above average conditions and positive values indicate below average conditions. **statistically significant

During La Niña events, no change in the long-term mean were found for Hermanus and Fauresmith for both T_{max} and T_{min} (Table 5). Above average T_{max} and below average T_{min} were not recorded for any of the 12 locations. However, below average T_{max} and above average T_{min} are recorded at both Johannesburg and Phalaborwa during La Niña events (Table 5). The T_{max} for Johannesburg is 0.1°C lower than the long-term mean with no change in the T_{min} (Table 5). At Phalaborwa, the T_{max} are 0.2°C lower than the long-term mean while the T_{min} at this location are 0.2°C higher than the long-term mean (Table 5).

Statistically significant deviations for rainfall were only found at two of the 12 locations (Table 5). These locations are Hermanus (p=0.03), which received 7.9mm less rainfall during La Niña events when compared to the long-term mean; and Witbank (one-tailed p=0.001; two-tailed p=0.002), where the rainfall received was 18mm higher than the long-term mean (Table 5).

During La Niña events, above average rainfall was observed at eight of the 12 locations, while below average rainfall was observed at the remaining four (Table 5). The four locations where below average rainfall was recorded all lie within the southwestern region [Hermanus (see paragraph above), Worcester and Laingsburg] and the centre of the country (Fauresmith) (Table 5). 4.1mm less rain compared to the long-term mean, was observed at Worcester, while Laingsburg received 1.5mm below average during La Niña events. At Fauresmith 2.2mm less rainfall occurred compared to the long-term mean during these events (Table 5).

Above average rainfall was observed at Fraserburg, De Aar, Welkom, Kroonstad, Johannesburg, Witbank (see above), Oudestad and Phalaborwa (Table 5). In Fraserburg, the rainfall received during La Niña events is on average 3.2mm higher than the long-term mean, while at De Aar rainfall was 0.2mm higher than the long-term mean (Table 5). A 1.9mm increase in rainfall compared to the long-term mean was observed at Welkom, while both Kroonstad and Phalaborwa received rainfall that was 8.8mm higher than the long-term mean (Table 5). At Johannesburg 4.5mm more rain than that of the long-term mean was observed for La Niña events (Table 5).

For La Niña events, the rainfall deviations are consistent with the differences in rainfall zones. This is supported by the below normal rainfall recorded at the locations in the winter rainfall zone including, Hermanus (the only location with a statistically significant rainfall deviation in this rainfall zone) and Worcester; and Laingsburg (which is on the border of the winter and summer rainfall zones) (Table 5). Aside from Fauresmith, the locations in the summer rainfall zone (Fraserburg, De Aar, Welkom, Kroonstad, Johannesburg, Witbank, Oudestad and Phalaborwa) receive above normal rainfall, with Witbank being the only location in this rainfall zone with a statistically significant deviation (Table 5). However, the above average rainfall recorded at the locations in the summer rainfall zone is varied as greater increases (greater deviations) occur in some locations, while smaller increases (smaller deviations) occur at the others.

Comparing the climatic conditions of El Niño and La Niña events

Lower temperatures are observed during La Niña conditions compared to El Niño conditions (Figureure 3). However, the average T_{max} experienced during these events overlap for each of the 12 locations (Figureure 3). During La Niña events, Worcester and Laingsburg, slightly higher average T_{max} are recorded, compared to the other locations; a greater variability is also observed for average T_{max} during La Niña events (Figureure 3). The average T_{max} distribution for El Niño events at Worcester is skewed below the median while for La Niña events, the distribution is skewed above the median (Figureure 3). However, the deviations identified at Worcester, where La Niña was more variable, were skewed above the median for both El Niño and La Niña events which would suggest a decrease in the average T_{max}.

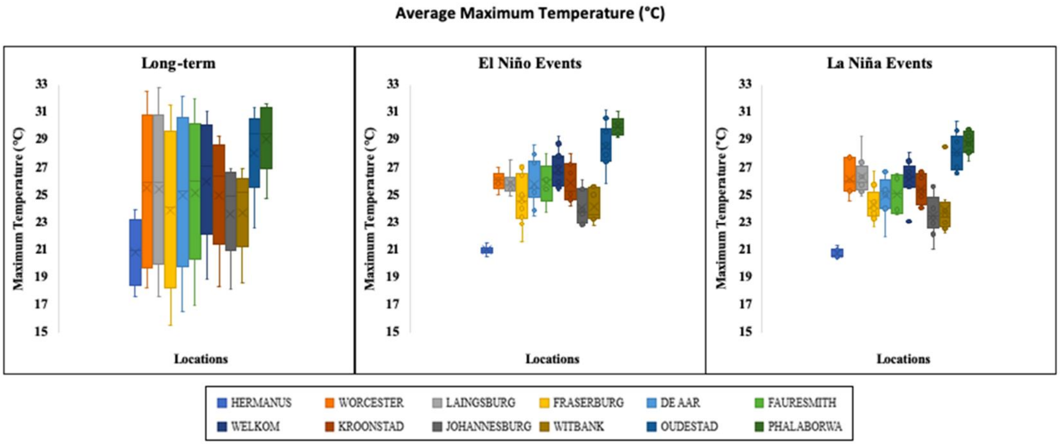

Figure 3. Box plot showing variations in maximum temperature (°C) for each location for long-term mean, average El Niño and average La Niña conditions.

The average T_{max} distribution at Laingsburg, by contrast, is skewed above the median for both events (Figure 3); this is supported by the deviations (with a greater variability for La Niña events) that occurred during these events at this location as the distribution is skewed below the median for both, which indicates an increase in average T_{max} for El Niño and La Niña events. The opposite is the case for Fraserburg, De Aar, Welkom, Kroonstad and Witbank where the greatest variations in the average T_{max} were identified for El Niño events (Figure 3). At all five locations the average T_{max} were skewed above the median (Figure 3). This is supported by the deviations of the events (of which the greatest variability was for El Niño events at three of the five locations, Fraserburg, De Aar and Kroonstad, while the greatest variability of the remaining two, Welkom and Witbank, were more variable for La Niña events), as the distribution of the deviations for all five locations were skewed below the median for El Niño events suggesting that the average T_{max} at these locations increase during El Niño conditions. Little difference was found between the average T_{max} of El Niño and La Niña events at the remaining five locations, Hermanus, Fauresmith, Johannesburg, Oudestad, and Phalaborwa (Figure 3), despite the deviations at these locations being more variable during El Niño events. Of these five locations, the skewedness of the average T_{max}

distribution is opposite for El Niño and La Niña events at Hermanus (skewed below the median for El Niño and above the median for La Niña) and Oudestad (skewed above the median for El Niño and below the median for La Niña; Figure 3).

As with T_{max}, the average T_{min} recorded during El Niño events are higher than that of La Niña events (Figure 4). There is also not much difference between the average T_{min} recorded for El Niño and La Niña events with the ranges of these events overlapping at all 12 locations (Figure 4). There are three locations, Laingsburg, De Aar and Witbank, where outliers are identified for La Niña events; these outliers do not overlap with the El Niño average T_{min} range (Figure 4). At Laingsburg and Witbank, these outliers are higher than the El Niño range while at De Aar, the outlier is lower than this range (Figure 4).

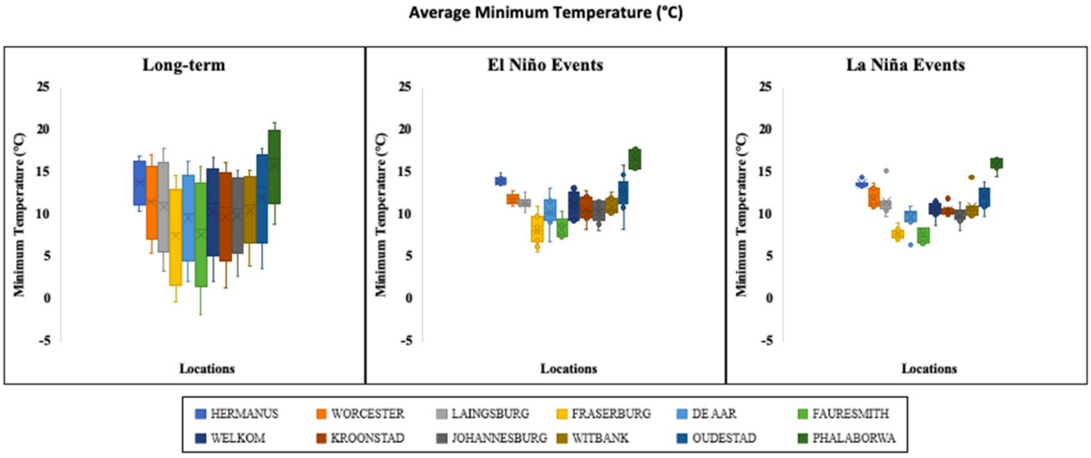

Figure 4. Box plot showing variations in minimum temperature for each location for long-term mean, El Niño and La Niña condition.

Similar to the average T_{max} mentioned above, the greatest variability in the average T_{min} during La Niña events is identified for Worcester (Figure 4). It is the only location of the 12 where greater variability is observed for La Niña events in terms of average T_{min}. For Worcester, the average T_{min} distribution for El Niño is symmetrical while it is skewed above the median for La Niña events (Figure 4). This is reflected in the deviations identified at this location; for El Niño the distribution is skewed above the median while for La Niña, where the greatest variability was identified, the distribution is skewed below the median which suggests an increase in T_{min}. No statistically significant difference was found between the average T_{min} for El Niño events relative to La Niña events in Laingsburg. At this location, the average T_{min} distributions for both events were skewed above the median (Figure 4) as are the deviations identified at this location; with the greatest variability in deviations being identified for La Niña events; this is most likely the reason why there is no noticeable difference in the average T_{min} recorded for El Niño and La Niña events.

At the remaining 10 locations, Hermanus, Fraserburg, De, Aar, Fauresmith, Welkom, Kroonstad, Johannesburg, Witbank, Oudestad and Phalaborwa, a greater average T_{min} variability was found for El Niño events (Figure 4), with the greatest variability in the deviations for El Niño events being observed at nine locations (aside from Witbank). For these events, average T_{min} distributions are skewed above the median at, Hermanus, Fraserburg, De Aar, Fauresmith, Kroonstad and Witbank, while Welkom, Oudestad and Phalaborwa have a relatively symmetrical distribution. Johannesburg is the only location where the distribution is skewed below the median (Figure 9). For La Niña events, Hermanus, De Aar, Welkom, Witbank, and Oudestad have a below-median skewed average T_{min} distribution, while Fraserburg and Phalaborwa have symmetrical distributions; and the distributions at Fauresmith, Kroonstad, and Johannesburg are skewed above the median (Figure 4). This variability can only be supported by the deviations recorded at some locations. This is argued as an increase in T_{min} is indicated at the locations where the deviation distribution is skewed below the median for El Niño events, such as Hermanus, Fauresmith, Welkom, Kroonstad, Witbank and Phalaborwa. The deviations in the average T_{min} for El Niño at the remaining four locations were either symmetrical (at Fraserburg and Oudestad), or skewed above the median (at De Aar and Johannesburg) which indicates a decrease in T_{min} (Figure 4). However, greater variability was still observed for El Niño events at these locations (Figure 4).

As was seen with average T_{max} above, El Niño events appear to be more variable in terms of average T_{min} than La Niña events. Greater variability is observed during El Niño events at 10 of the 12 locations, with little or no difference being occurring at one location; and a greater variability during La Niña events being observed for only one location (Figure 4).

When looking at the average rainfall received during El Niño and La Niña events a greater number of outliers are identified for both events (Figure 5), which was not the case with T_{max} and T_{min}, as seen above. There are some overlaps in average rainfall received during El Niño and La Niña events at the 12 locations; however, the overlap is not as great as that of T_{max} and T_{min} (Figure 5).

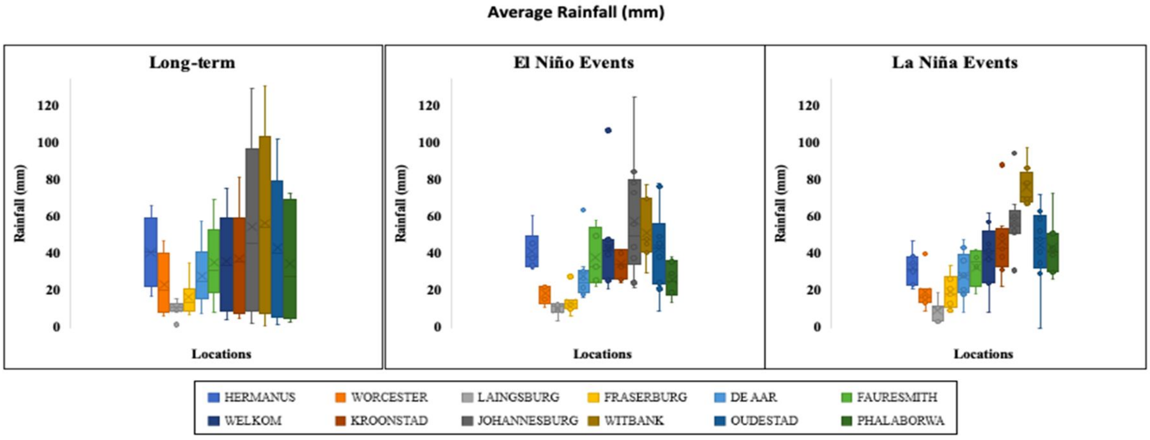

Figure 5. Box plot showing variations in rainfall per location for long-term mean, El Niño and La Niña.

Hermanus was the only location, of the 12, where a great difference in the variability of average rainfall received during El Niño and La Niña events was not observed; with the distribution being symmetrical for both events (Figure 5). However, the deviations at this location is skewed below the median for both events. A greater average rainfall variability for El Niño events was identified at five of the 12 locations used in this research; these locations include Worcester, Fauresmith, Johannesburg, Witbank and Oudestad (Figure 5). Of these five locations, the greatest difference between the average rainfall received during El Niño and La Niña events occurred at Witbank, where the distribution of average rainfall for both events is skewed above the median (Figure 5). A great difference between the deviations for El Niño and La Niña events are also identified at Witbank, with El Niño having a greater variability. At Witbank the distribution of the deviations in average rainfall is skewed below the median for both ENSO events, consistent with an increase in the amount of rainfall received during both events. The distribution of the average rainfall received, at Johannesburg, is skewed above the median for both El Niño and La Niña events (Figure 5); this is supported by the skewedness of the distribution of the deviations (where the greatest variability was identified for El Niño events) at this location which is skewed below the median for both events, indicating an increase in rainfall during both events.

At Worcester, the distribution of average rainfall was skewed below the median for El Niño events and above the median for La Niña events (Figure 5), with the skewedness of the deviations at this location being above the median for El Niño events and below the median for La Niña events indicating that rainfall decreases during El Niño events and increases during La Niña events. The greatest variability for El Niño events was observed for Fauresmith; the distribution of average rainfall at this location was skewed above the median for El Niño events and below the median for La Niña events (Figure 5). The deviations at Fauresmith, for which El Niño has the greatest variability, are symmetrical for La Niña events but is skewed below the median for El Niño events indicating an increase in rainfall at this location during El Niño events. The average rainfall distribution at Oudestad is skewed below the median for both ENSO events (Figure 5) and the deviations at this location is skewed below the median for El Niño events and above the median for La Niña events, which indicates that, at Oudestad, rainfall increases during La Niña events and decreased during El Niño events.

There are six locations where a greater average rainfall variability for La Niña events is observed, Laingsburg, Fraserburg, De Aar, Welkom, Kroonstad and Phalaborwa (Figure 5). The rainfall distribution at both Laingsburg, and Welkom are skewed below the median (Figure 5). The deviations at these locations however, do not have the same skewedness. Laingsburg, where the greatest variability of average rainfall deviations was found for La Niña events, has a deviation distribution that is skewed above the median for both ENSO events, indicating a decrease in the amount of rainfall received at this location during both events. On the other hand, the deviations at Welkom are skewed below the median for El Niño events and above the median for La Niña events, indicating that rainfall increases during El Niño events and decreased during La Niña events at this location. Kroonstad, it can also be said, receives an increased amount of rainfall for both ENSO events as, while the average rainfall distribution at this location is symmetrical (Figure 5), the deviations at this location are skewed below the median for both events, with more variability being observed for La Niña events. The same skewedness for El Niño and La Niña events is also identified at De Aar with the average rainfall being skewed above the median (Figure 5). The deviations at this location are skewed below the median for El Niño events and above the median for La Niña events. At Fraserburg, the average rainfall distribution was skewed below the median during El Niño events and above the median during La Niña events (Figure 5); with the deviations at this location being skewed below the median for both events. Phalaborwa was another location where the greatest variability for both the average rainfall (Figure 5) and the deviation were observed for La Niña events. The average rainfall distribution at this location is skewed above the median for El Niño events and is symmetrical for La Niña events (Figure 5). In terms of the deviation experienced at Phalaborwa, the distribution is skewed to above the median for El Niño events and below the median for La Niña events.

Discussion

While previous studies have stated that the climate of South Africa is greatly affected by El Niño and La Niña events (Tyson and Preston-Whyte 2000; Crétat et al. 2012; Meque and Abiodun 2015; Engelbrecht et al. 2017; Fan et al. 2017), the findings presented in this report suggest otherwise. This is argued as, out of all the deviations observed at each of the 12 locations, for all three climate variables (T_{min}, T_{max} and rainfall), during both El Niño and La Niña events, very few were statistically significant.

While the transition of the climatic impacts caused by El Niño events is not uniform along the transect (Figureure 6), temperatures (both T_{min} and T_{max}) are, to varying degrees, warmer during El Niño events (Table 4) at all 12 locations, while six locations, (Worcester, Laingsburg, Fraserburg, Kroonstad, Witbank and Phalaborwa), experience below average rainfall during these events (Figure 6). This may be why El Niño events are commonly associated with drought conditions in South Africa. However, it is also observed that the six remaining locations (Hermanus, De Aar, Fauresmith, Welkom, Johannesburg and Oudestad) receive above normal rainfall during these events (Figure 6). Notably, there is no apparent pattern to the division of locations. It is commonly understood that under El Nino conditions dry regions become drier while wet regions become wetter, yet this is not supported by these results. Moreover, the results are not discriminated by the rainfall seasonality of the location.

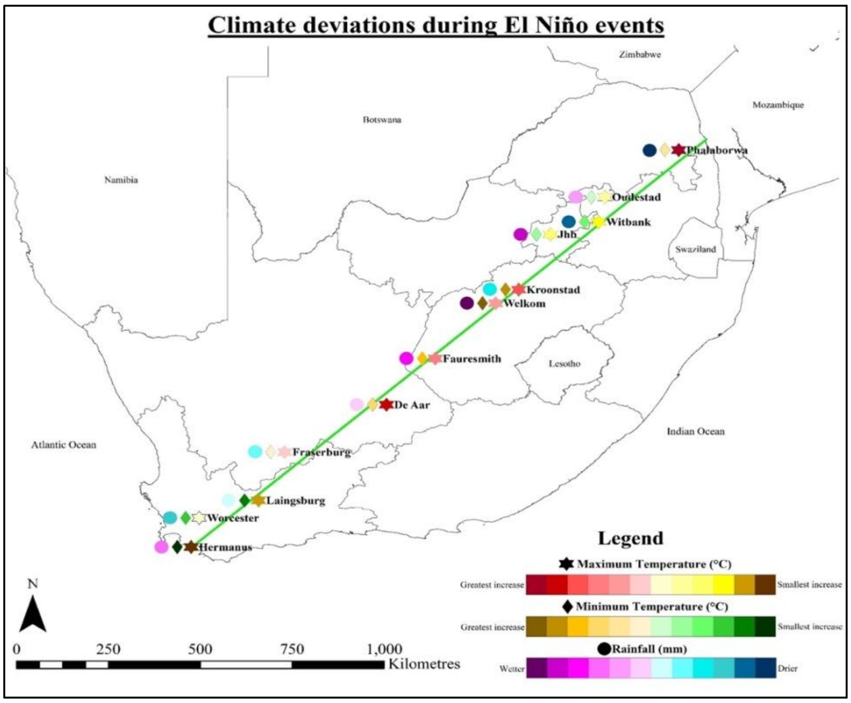

Figure 6, Map of the climate deviations observed during El Niño events'

The Pacific Ocean is said to have an influence on the summer rainfall received in South Africa (Landman and Beraki 2012); despite the distal location (Camberlin et al. 2001). The regions that were found to receive rainfall that is influenced by El Niño and La Niña events were north-eastern region of the country (Nash and Grab, 2010), including the Limpopo Province (Meque and Abiodun 2015) and the south coast of South Africa, where summer rainfall is influenced more greatly (Engelbrecht et al. 2017) with rainfall being above average during La Niña events (Weldon and Reason 2014), and the southwestern Cape (Engelbrecht et al. 2017). However, both Reason and Rouault (2005) and Philippon et al. (2012) state that the relationship between ENSO events and the rainfall received in the winter rainfall zone of the country (the southwestern region as was found in this study) is not clear and that the rainfall received in this region is influenced more by the Antarctic Oscillation than ENSO. This Oscillation is not greatly affected by ENSO (Reason and Rouault 2005; Philippon et al. 2012). However, it has also been stated that the summer of the southwestern region of South Africa is influenced by ENSO events (Rouault et al. 2010; Philippon et al. 2012).

It is commonly believed that, in South Africa, El Niño events cause an increase in temperatures and a decrease in rainfall (Mason 2001; Rouault et al. 2010; Archer et al. 2017), especially in summer (Cashin et al. 2017; Kruger 1999) when majority of the country receives rainfall (Mason 2001; Richard et al., 2000 in Ratnam et al., 2014; Jury, 2015). The winter rainfall zone, on the other hand, receives more rainfall during El Niño events (Philippon et al. 2012). From the results presented in this report, the understood climatic impacts of El Niño events (large increases in temperature and great decreases in rainfall in the summer rainfall zone and the inverse for the winter rainfall zone) are observed at six of the 12 locations: Hermanus, Laingsburg, Fraserburg, Kroonstad, Witbank and Phalaborwa (Figure 6). Despite the small increase in T_{min} and T_{max}, a slight increase in rainfall is observed at Hermanus, a location in the winter rainfall zone (Figure 6). This rainfall zone is said to receive higher amounts of rainfall during El Niño events, as mentioned above (Philippon et al. 2012). At Laingsburg (a location on the winter rainfall zone-summer rainfall zone border), it can be observed, receives slightly less rainfall during these events, as is usually the case in the summer rainfall zone; however, the temperatures at this location are observed to be slightly above average, similar to Hermanus (Figure 6). This is an interesting observation as the temperatures at this location appear to respond to El Niño events in a manner similar to that of Hermanus in the winter rainfall zone, while the rainfall at this location appears to respond to these events in a manner that is similar to locations in the summer rainfall zone. Fraserburg, Kroonstad, Witbank and Phalaborwa all lie within the summer rainfall zone. Greater increases in temperature are observed at Fraserburg, Kroonstad and Phalaborwa, with all three locations also receiving less rainfall than average (Figure 6); However, of these three locations, the commonly understood impacts of El Niño events can be observed most clearly at Kroonstad and Phalaborwa (Figure 6). The observation made at Phalaborwa is supported (Figure 13) by a finding of Meque and Abiodun (2015) who find that there is strong relationship between the temperatures in the north-eastern region of the country and ENSO events, while the relationship between rainfall and ENSO is not as strong. However, they argue that the drought that is often observed at this location during El Niño events is most likely the result of increased evapotranspiration along with the below normal rainfall (Meque and Abiodun 2015). On the other hand, Witbank differs slightly as the increase in both T_{min} and T_{max} is small, but the there is a great decrease in rainfall (Figure 6). However, the observed climatic changes at these locations agree with the commonly understood climatic impacts of El Niño events that temperature increased during these events while rainfall decreases (Mason 2001; Rouault et al. 2010; Archer et al. 2017) especially during the summer months (Cashin et al. 2017; Kruger, 1999) when ENSO events are said to reach their peak strengths (Mason 2001; Richard et al. 2000 in Ratnam et al. 2014).

The other six locations do not agree with this commonly understood impact of El Niño events on the climate of South Africa. This is argued as Worcester, a location in the winter rainfall zone which should receive more rainfall during El Niño events, as stated by Philippon et al. (2012), is observed to receive less during these events and has higher temperatures (Figure 6). The remaining five locations (De Aar, Fauresmith, Welkom, Johannesburg and Oudestad) all lie within the summer rainfall zone and are expected to receive below average rainfall during these events; however, it is observed that these locations receive above average rainfall during El Niño events (Figure 6).

La Niña conditions in South Africa

As was the case with El Niño events, the transitions of the climate impacts of La Niña events are not uniform. From the results presented in this report, it was observed that above average rainfall was observed at eight of the 12 locations (De Aar, Welkom, Kroonstad, Johannesburg, Witbank, Oudestad and Phalaborwa), while below average rainfall was observed at the remaining four locations (Table 5).

Much of the literature concerning the ENSO phenomenon focus more on El Niño events than La Niña events. This may have contributed to the lack of understanding of these events (Hanley et al. 2003). The opposite of El Niño events (Cashin et al. 2017), La Niña events result in higher precipitation (Rouault et al. 2010) and cooler temperatures (Archer et al. 2017). The results presented here demonstrate that the climatic effects of El Niño events display more variability than La Niña events. This has been noted in literature previously where it has been stated that La Niña events tend to be less severe (Kovats 2000) and not as frequent as El Niño events (Cashin et al. 2017), as stated above. During La Niña events, it is said that the southwestern region of South Africa experiences less rainfall during the winter months (Philippon et al. 2012).

While it was observed that below average temperatures are experienced at Hermanus and above average temperatures are experienced at Worcester, both of these locations lie within the winter rainfall zone and received below average rainfall during La Niña events (Figure 7), as is expected in this rainfall zone (Philippon et al. 2012). At Laingsburg (on the border of the rainfall zones), conditions are similar to Worcester in the winter rainfall zone, with above average temperatures (both T_{min} and T_{max}) and below average rainfall being observed (Figure 7). This is once again an interesting finding as this location receives below average rainfall for both ENSO events.

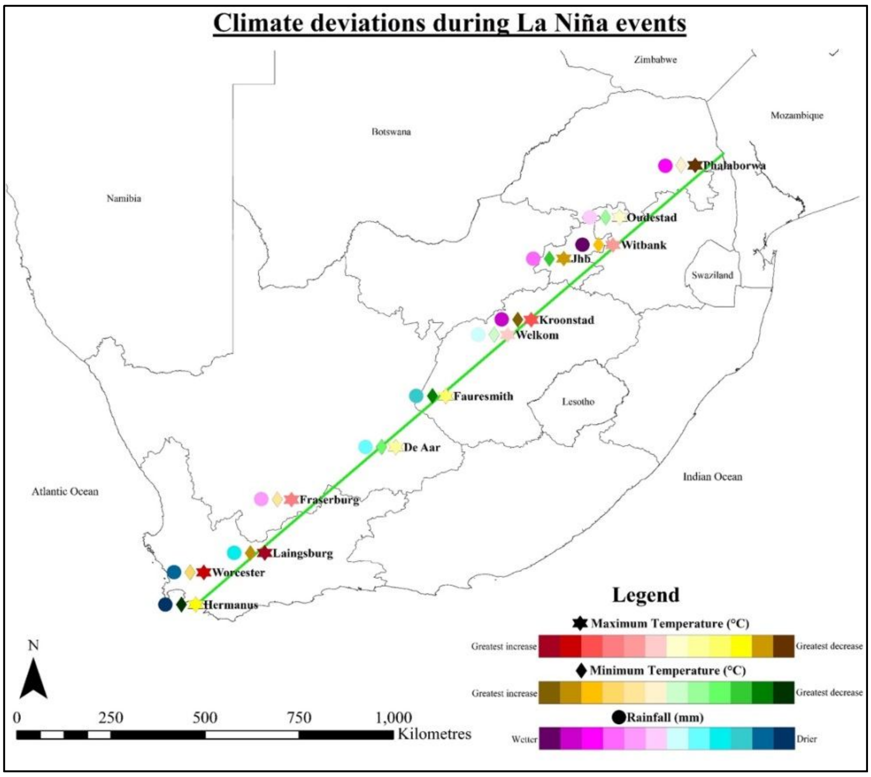

Figure 14. Map of the climate deviations observed during La Niña event.

In the summer rainfall zone, above average rainfall is observed Fraserburg, Kroonstad and Witbank as expected. However, the temperatures at these locations are all above average which does not agree with the common understanding of the climatic impacts of La Niña events (Figure 7). The commonly expected climatic impacts associated with La Niña events are observed at three locations (Johannesburg, Oudestad and Phalaborwa; Figure 7). However, at all three locations, temperatures (both T_{min} and T_{max}) are below average while rainfall is above average (Figure 17). Once again it can be observed that the north-eastern region of the country experienced the expected climatic conditions associated with an ENSO event, as suggested by Meque and Abiodun (2015) who state that there is a relationship between ENSO and the climate experienced in this region. However, the other locations in the summer rainfall zones (De Aar, Fauresmith and Welkom) exhibit below average rainfall during La Niña events (Figure 7).

External influences

The Pacific Ocean, where the ENSO phenomenon originates, it located far from Africa (Camberlin et al. 2001). However, it has been acknowledged the ENSO phenomenon is not a fixed dipole in the Pacific Ocean as it has a “travelling wave component” (Jury

2015, 227), which results in the sea-surface temperatures and atmospheric circulations being altered globally (Nicholson 2000). These global alterations are said to be one of the means in which ENSO influences the climate of Africa (Nicholson 2000). The thermohaline circulation is one of the means through which the ENSO signal is translated globally as it has been noted that changes in this circulation may have an impact on the amplitude of ENSO events (Timmermann et al. 2005). This circulation can be defined as a “buoyancy-driven flow field associated with water cooled (or heated) by contact with cold (warm) air, or modified by sources and sinks of fresh water” (Schmitz 1998, p. 159).

The sea-surface temperatures of the Atlantic Ocean and the Indian Ocean are said to influence the impact of ENSO events on the climate southern Africa (Gaughan and Waylen 2012; Hoell et al. 2015). ENSO events, are also said to influence the sea-surface temperatures of these two oceans which in turn influences the strength of the ENSO signal (Nash and Grab 2010). Within the Indian Ocean, the Indian Ocean Dipole (Hoell et al. 2017), Subtropical Indian Ocean Dipole (Archer et al. 2017; Hoell and Cheng 2017; Hoell et al. 2017) as well as the South Indian Convergence Zone (Cook 2000) all impact the climate of South Africa (Hoell et al. 2017). These climate forcing mechanisms are said to play a role in transporting interannual changes of the Indian Ocean sea-surface temperatures (Hoell et al. 2017). As mentioned previously, the rainfall received in South Africa is significantly altered depending on whether or not the Subtropical Indian Ocean Dipole and ENSO events are in phase (Hoell and Cheng 2017; Hoell et al. 2017). During El Niño events, the Indian Ocean is said to warm which plays a role in the teleconnections lining the Pacific Ocean and southern Africa (Mason 2001). Changes in the sea-surface temperature of the Indian Ocean during ENSO events is said to cause the atmospheric changes observed over southern Africa during these events (Mason 2001).

Conclusion

While it is commonly believed that the climate of South Africa is significantly affected by El Niño and La Niña events, it was found in the research presented here that this is not always the case. The research presented in this report attempted to determine the climatic impacts of El Niño and La Niña events on a finer scale. This was done by selecting a transect across South Africa along which twelve study sites were located. This transect extended from the southwestern region of the country to the north-eastern region of the country, thus extending across two different rainfall zones: winter and summer. The research aimed to determine whether there is a uniform transition along this transect in terms of the climatic deviations experienced during El Niño and La Niña events in order to improve the understanding of how these events affect the climate of South Africa. It was found that there is very little variation between El Niño and La Niña events in South Africa, with very few statistically significant deviations. This may possibly be the result of the majority of locations being situated inland, the potential influence of the microclimates of individual locations, or the external climate influences, such as the oceans bordering the country, oceanic dipoles (specifically the Indian Ocean Dipole and the Subtropical Indian Ocean Dipole), and the Quasi-Biennial Oscillation. It can be said that the aims and objectives set out at the beginning of this report were met as it was found that, compared to the general climatic conditions experiences across South Africa, El Niño and La Niña events do not affect these locations in a uniform manner, suggesting that the way in which the climate impacts of these events are understood may be flawed. By improving the understanding of the climatic impacts caused by ENSO events, the government would be able to better prepare for these events so that a water security crisis, such as that experienced in Cape Town between 2016 and 2017 (Baudoin et al. 2017). It is therefore acknowledged that this research only considered a small area of South Africa and did not address the possible uniformity of the climatic impacts of ENSO events as well as the understanding of these climatic impacts of for locations throughout South Africa. This proposes possible further research on this topic that aims to construct a full spatial understanding of the climatic impacts of ENSO events.

Reference

Abdi AM, Vrieling A, Yengoh GT, Anyamba A, Seaquist JW, Ummenhofer CC, Ardö J (2016) The El Niño – La Niña cycle and recent trends in supply and demand of net primary productivity in African drylands. Climate Change. 138(1-2):111-125.

Anderson W, Seager R, Baethgen W, Cane M (2017) Life cycle of agriculturally relevant ENSO teleconnections in North and South America. International Journal of Climatology. 37(8):3297-3318.

Anyamba A, Tucker CJ, Mahoney R (2002) From El Niño to La Niña: vegetation response patterns over east and southern Africa during the 1997-2000 period. Journal of Climate. 15(21):3096–3103.

Arblaster J M, Alexander L V (2012) The impact of the El Niño-Southern Oscillation on maximum temperature extremes. Geophysical Research Letter. 39(20), DOI: 10.1029/2012GL053409.

Archer ERM, Landman WA, Tadross MA, Malherbe J, Wepener H, Maluleke P, Marumbwa FM (2017) Understanding the evolution of the 2014–2016 summer rainfall season in southern Africa: key lessons. Climate Risk Managemen. 16:22–28.

Baudoin M-A, Vogel C, Nortje K, Naik M (2017) Living with drought in South Africa: lessons learnt from the recent El Niño drought period. International Journal of Disaster Risk Reduction. 23:128–137.

Camberlin P, Janicot S, Poccard I (2001) Seasonality and atmospheric dynamics of the teleconnections between African rainfall and tropical sea-surface temperature: Atlantic vs. ENSO. International Journal of Climatology. 21(8):973–1005.

Caminade C, Turner J, Metelmann S, Hesson J C, Blagrove M S C, Solomon T, Morse A P, Baylis M (2017) Global risk model for vector-borne transmission of Zika virus reveals the role of El Niñ0 2015. PNAS. 114(1):119–124.

Cashin P, Mohaddes K, Raissi M (2017) Fair weather or foul? The macroeconomic effects of El Niño. Journal of International Economics. 106:37–54.

Chase BM, Meadows ME (2007) Late Quaternary dynamics of southern Africa's winter rainfall zone. Earth-Science Reviews.84(3):103–138.

Collins JM (2011) Temperature variability over Africa. Journal of Climate 24(14):3649–3666.

Cook KH (2000) The South Indian Convergence Zone and interannual rainfall variability over Southern Africa. Journal of Climate. 13(21):3789–3804.

Crétat J, Richard Y, Pohl B, Rouault M, Reason C, Fauchereau N (2012) Recurrent daily rainfall patterns over South Africa and associated dynamics during the core of the austral summer. International Journal of Climate. 32(2):261–273.

Engelbrecht CJ, Landman WA , Graham R, McLean, P (2017) Seasonal predictive skill of intraseasonal synoptic type variability over the Cape south coast of South Africa by making use of the Met Office Global Seasonal Forecast System 5. International Journal of Climatology. 37(4):1998–2012.

Fan J, Meng J, Ashkenazy Y, Havlin S, Schellnhuber HJ (2017) Network analysis reveals strongly localized impacts of El Niño. PNAS. 114(29):7543–7548.

Funk C, Harrison L, Shukla S, Hoell A, Korecha D, Magadzire T, Husak G, Galu G (2016) Assessing the contributions of local and east pacific warming to the 2015 droughts in Ethiopia and southern Africa. Bulletin of the American Meteorological Society. 97(12):75–80.

Gaughan AE, Waylen RP (2012) Spatial and temporal precipitation variability in the Okavango-Kwando-Zambezi catchment, southern Africa. Journal of Arid Environments. 82:19–30.

Gizaw M S, Gan TY (2016) Impact of climate change and El Niño episodes on droughts in sub-Saharan Africa. Climate Dynamics. 49(1–2):665–682.

Guilyardi E (2006) El Niño-mean state-seasonal cycle interactions in a multi-model ensemble. Climate Dynamics. 26(4):329–348.

Hanley DE, Bourassa MA, O'Brien J J, Smith SR, Spade ER (2003) A quantitative evaluation of ENSO indices. Journal of Climate. 16(8):1249–1258.

Hirons L, Klingaman N (2016a) El Niño 2015/2016: Impact Analysis, Monthly Outlook March 2016, National Centre for Atmospheric Science: Natural Environment Research Council, University of Reading. Accessed on 10 April 2017 from from: http://centaur.reading.ac.uk/61154/1/Monthly_Outlook_March2016.pdf

Hirons L. and Klingaman N. 2016b: La Niña 2016/2017 Historical Impact Analysis, Crown Copyright: University of Reading. Accessed on 8 May 2017 from: http://centaur.reading.ac.uk/58443/7/LaNina_Historical_Impact_report_Hirons.pdf

Hoell A, Cheng L (2017) Austral summer Southern Africa precipitation extremes forced by the El Niño-Southern oscillation and the subtropical Indian Ocean Dipole. Climate Dynamics. DOI: 10.1007/s00382-017-3801-z.

Hoell A, Funk C, Magadzire T, Zinke J, Husak G (2015) El Niño-Southern Oscillation diversity and southern Africa teleconnections during austral summer. Climate Dynamics. 45(5):1583–1599.

Hoell A, Funk C, Zinke J, Harrison L (2017) Modulation of the Southern Africa precipitation response to the El Niño Southern Oscillation by the subtropical Indian Ocean Dipole. Climate Dynamics. 48(7):2529–2540.

Hu S, Fedorov AV (2017) The extreme El Niño of 2015V2016 and the end of global warming hiatus. Geophysical Research Letters. 44(8):3816–3824.

Hulme M, Doherty R, Ngara T, New M, Lister D (2001) African climate change: 1900-2100. Climate Research. 17(2):145–168.

Jury MR (2002) Economic impacts of climate variability in South Africa and development of resource prediction models. Journal of Applied Meteorology. 41(1): 46–55.

Jury MR (2013) Climate trends in southern Africa. South African Journal of Science. 109(1-2):1–11.

Jury MR(2015) Factors contributing to a decadal oscillation in South African rainfall. Theoretical and Applied Climatology. 120(1-2):227–237.

Kogan F, Guo W (2017) Strong 2015–2016 El Niño and implication to global ecosystem from space data. International Journal of Remote Sensing. 38(1):161–178.

Kovats RS (2000) El Niño and human health. Bulletin of the World Health Organization. 78(9):1127–1135.

Kovats R-S, Bourma MJ, Hajat S, Worrall E, Haines A (2003) El Niño and health. The Lancet. 362(9394):1481–1489.

Kruger AC, Shongwe S (2004) Temperature trends in South Africa: 1960-2003. International Journal of Climatology. 24(15):1929–1945.

Kruger AC (1999) The influence of the decadal-scale variability of summer rainfall on the impact of El Niño and La Niña events in South Africa. International Journal of Climatology. 19(1): 59-68.

L'Heureux ML, Takahashi K, Watkins AB, Barnston AG, Becker EJ, Di Liberto TE, Gamble F, Gottschalck J, Halpert MS, Huang B, Mosquera-Vásquez K, Wittenberg AT (2016) Observing and predicting the 2015-16 El Niño. Bulletin of the American Meteorological Society. DOI: 10.1175/BAMS-D-16-0009.1.

Landman W A, Beraki A (2012) Multi-model forecast skill for mid-summer rainfall over southern Africa. International Journal of Climatology. 32(2):303–314.

Manatsa D, Mushore T, Lenouo A (2017) Improved predictability of droughts over southern Africa using the standardized precipitation evapotranspiration index and ENSO. Theoretical Applied Climatology. 127(1–2):259–274.

Mason SJ (2001) El Niño, climate change, and Southern African climate. Environmetrics. 12(4):327–345.

Meque A, Abiodun BJ (2015) Simulating the link between ENSO and summer drought in southern Africa using regional climate models. Climate Dynamics. 44(7):1881–1900.

Miralles DG, van den Berg MJ, Gash JH, Parinussa RM, de Jeu RAM, Beck HE, Holmes TRH, Jiménez C, Verhoest NEC, Dorigo WA, Teuling AJ, Dolman AJ (2014) El Niño – La Niña cycle and recent trends in continental evaporation. Nature Climate Change. 4(2):122–126.

Moore SM, Azman AS, Zaitchik BF, Mintz ED, Brunkard J, Legros D, Hill A, McKay H, Luquero FJ, Olson D, Lessler J (2017) El Niño and the shifting geography of cholera in Africa. PNAS. 114(17):4436–4441.

Nash DJ, Grab SW (2010) "A sky of brass and burning winds": documentary evidence of rainfall variability in the Kingdom of Lesotho, Southern Africa, 1824-1900. Climate Change. 101(3–4): 617–653.

Nicholson SE (2000) The nature of rainfall variability over Africa on time scales of decades to millenia. Global and Planetary Change. 26(1-3):137–158.

NOAA 2017. Cold and Warm Episodes by Season, NOAA. Accessed on 2 June 2017 from: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml.

Philippon N, Rouault M, Richard Y, Favre A (2012) The influence of ENSO on winter rainfall in South Africa. International Journal of Climatology. 32(15):2333–2347.

Ratnam JV, Behera SK, Masumoto Y, Yamagata T (2014) Remote effects of El Niño and Modoki events on the austral summer precipitation of southern Africa. Journal of Climate. 27(10):3802–3815.

Reason CJC, Rouault M (2005) Links between the Antarctic Oscillation and winter rainfall over western South Africa. Geophysical Research Letters. 32(7), DOI: 10.1029/2005GL022419.

Rouault M, Pohl B, Penven P (2010) Coastal oceanic climate change and variability from 1982 to 2009 around South Africa. African Journal of Marine Science. 32(2): 237–246.

Schmitz WJ (1998) On the interbasin-scale thermohaline circulation. Reviews of Geophysics. 33(2):151–173.

Smith SC, Ubilava D (2017) The El Niño Southern Oscillation and economic growth in the developing world. Economics Working Paper Series, 11, University of Sydney.

Timmermann A, An S-I, Krebs U, Goosse H (2005) ENSO suppression due to weakening of the North Atlantic thermohaline circulation. Journal of Climate. 18(16):3122–3139.

Tyson PD, Preston-Whyte RA (2000) The Weather and Climate of Southern Africa, Oxford University Press, Cape Town.

Weldon D, Reason CJC (2014) Variability of rainfall characteristics over the South Coast region of South Africa. Theoretical and Applied Climatology. 115(1):177–185.