Agricultural Perspectives on the 2015-2018 Western Cape Drought, South Africa: Characteristics and Spatial Variability in the Core Wheat Growing Regions.

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Abstract

Between 2015 and 2018, the Western Cape Province of South Africa experienced a multi-year severe drought, which negatively impacted major economic sectors. The province serves as an important producer of wheat in South Africa among other agricultural commodities. This study aims to analyze the 2015-2018 drought and its impacts on wheat production in the winter rainfall region of the Western Cape, South Africa. The central focus is to place the drought in both a historical and future context while emphasising the differences between the two core wheat growing regions. We present an analysis of the drought, as well as climate trends computed from weather data sets (1988–2018) from six weather stations across the two core wheat-growing. We first present a meteorological drought analysis of mean annual and seasonal rainfall and temperatures, subsequently providing an agricultural lens by computing Standardised Precipitation and Evapotranspiration Index (SPEI) accumulated over 12- and 36-month timescales, self-calibrated Palmer Drought Severity Index (sc-PDSI), changes to the start and end of the rainfall season, and their effects on wheat yields. Trend analysis was conducted to determine if drought observations form part of the longer-term trends in the region. Finally, we show how the drought varied spatially across the two regions. Results show that between 1988 and 2018, the wheat growing areas of the Western Cape experienced persistent drought with high spatial-temporal variability. The 2015-2018 drought, however, was the most severe experienced in the 30-year study period at five of the six stations. These results are consistent with conditions that can be expected under future climate change. Moreover, results can be useful for the development of early warning systems since they place the drought in the context of past drought conditions.

Keywords: Drought, Agriculture, wheat, SPEI, PDSI

1. Introduction

Drought is one of the most significant aspects of climate variability, particularly in semi-arid regions, such as large parts of southern Africa. Due to the inherent complexity of its interaction with socio-economic dimensions, as well as the region's reliance on climate-sensitive sectors such as agriculture, drought is one of the most damaging natural hazards in Africa (Botai, et al., 2017). Drought may manifest through four main stages, though not all droughts will propagate through all four stages. Drought first begins as a meteorological drought, brought about through below-normal precipitation over a period of one to three months. Secondly, if drought conditions continue, which result in insufficient soil and subsoil moisture, or if it occurs at a critical phase in the crop cycle - affecting crop growth, it can be defined as an agricultural drought. The third phase is referred to as hydrological drought, which develops when persistent drought conditions (> 36 months) affect run-off, manifesting through reduced streamflow and reservoirs storage. Finally, when the physical water shortage affects people, a socio-economic drought arises (Van Loon 2015; Wang et al., 2016; Botai et al., 2017, Ma et al., 2019).

Between 2015 and 2018, the Western Cape Province in South Africa, a winter rainfall region, experienced a multi-year severe drought (Archer et al., 2019; Ziervogel, 2019). The drought began in 2015, with below normal rainfall but, after three cycles of low precipitation, it had manifested as a socio-economic drought, affecting key economic sectors. Cape Town, the major metropole in the province, was threatened with the possibility of Day Zero (the day city taps were projected to run dry) (Archer et al., 2019; Ziervogel 2019). Aggravating these conditions, three of the four warmest years since 1977 had occurred at the time of the drought - including 2015, 2016, and 2017, moreover 2017 was the warmest year on record not influenced by an El Niño event (Climate System Analysis Group, 2017; World

Meteorological Organization, 2017). The rarity of such a drought occurring is indisputable, with a return period of more than 100 years (Otto et al., 2018).

Winter rain, which falls from June-August, is of great importance to the Western Cape, and the 2015-2018 drought had severe implications for the agricultural sector (Archer et al., 2019). The province is one of South Africa's largest producers of rainfed wheat, with 326 000 hectares planted in 2017, as well as high-value export crops such as deciduous, citrus, and stone fruit (BFAP, 2018). Climate risks for wheat production include rainfall variability; late and/or inadequate start of the rainfall season in April–May–June; droughts; warm and rainy conditions during the harvest period; localized flooding; heat waves and strong winds (Midgley et al., 2016). Crop losses due to climate variability are a cause for concern, as they weaken the financial sustainability of agricultural production (Kath et al., 2019). The agricultural value chain in the province is a critical economic sector, contributing 23% to South Africa's total agricultural Gross Domestic Product (Kuschke & Cassim, 2019; Western Cape Government, 2019). Furthermore, the importance of the agricultural sector as a major employer is undisputed, as agriculture and agro-processing comprise 18% of all formal employment. These jobs make up 71% and 25% of unskilled and semi-skilled occupations respectively (Pienaar and Boonzaaier, 2018; Kuschke & Cassim, 2019). Within the context of drought, there is very little opportunity for such workers to find employment elsewhere in the economy (Adams, 2019). Moreover, climate change and potentially increased drought frequency is likely to further constrain economic development, especially in the Western Cape, whose economy and employment rates depend on climate sensitive sectors such as agriculture (Midgley et al., 2005; Acquah, 2011).

Rainfall in southern Africa is typical of semi-arid, sub-humid, and Mediterranean type climates, with a pronounced dry season in part of the year. Rainfall variability is, thus, concentrated in relatively short periods. A range of studies show that several dynamics may affect rainfall in the Western Cape. Reason and Rouault (2005), found most dry winters over western South Africa are associated with the positive phase of the Antarctic Oscillation (AAO) or Southern Annular Mode (SAM). Archer et al. (2019) observed that during the drought, for the first time since at least 1979, SAM was positive in all three parts of the winter rainfall season for multiple consecutive years (2015, 2016, 2017). The cumulative effects of the three-year drought period (2015–2017) may thus be related to this consistent positive anomaly (Archer et al., 2019). Philippon et al. (2011) found winter rainfall (May- June- July) to be positively correlated with El Niño events - however, their findings feature a strong decadal component and appear restricted to the recent decades since 1979.

Studies focused on drought in South Africa have tended to focus more on the summer rainfall regions (for example, Oxfam 2017; Archer et al., 2017), and fewer studies have analyzed drought affecting the winter rainfall region of the Western Cape (Reason & Rouault, 2005). Due to the severity and wide-ranging impacts of the 2015-2018 drought, a range of studies seeking to understand and explain the drought have emerged (and continue to do so). Throughout the drought, the Climate Systems Analysis Group at the University of Cape Town published numerous drought analyses on their blog, including Wolski et al., (2017); Wolski (2017), and Johnston (2018), among others. Ziervogel (2019) published an in-depth analysis of the 2015-2018 drought from an urban water management perspective, including lessons learned and key areas for improved governance. Midgley and Methner (2016) considered lessons learned for governance and drought response in the agricultural sector. Botai, et al. (2017) examined the drought in the Western Cape (including the summer rainfall region) up to mid-2017, using the SPI (Standardized Precipitation Index). The study found that the province experiences frequent mild drought at the 3- and 6-month timescales. Otto et al. (2018) analyzed the impact of climate change on the rainfall deficit between 2015-2017, finding that anthropogenic climate change tripled drought likelihood. Kam et al., (2021) found that the recent Cape Town drought was the longest (according to a CRU dataset) and third longest (according to a GPCC dataset) drought on record since at least 1901. The study further found that anthropogenic climate change likely increased the probability of a long-lasting drought by at least a factor of 2. As mentioned earlier, Archer et al. (2019) examined the progression of the drought and its relationship with SAM, considering impacts on two major agricultural commodities (apples and wheat) in the region and discussing potential adaptation options. This research paper seeks to enhance the current discussion on drought in this region, expanding on the work already undertaken, through considering the drought from an agricultural perspective and its impacts specifically on the wheat growing regions.

This study aims to analyse the 2015-2018 drought and its impacts on wheat production in the winter rainfall region of the Western Cape, South Africa. The central focus is to place the drought in both a historical and future context while emphasising the differences between the two core wheat-growing regions. The aim was met through three main objectives: first, for the historical context, time series analysis of several drought indicators was conducted; second, trend analysis was performed to understand whether these observations form part of a long-term trend and give an indication of potential future conditions. Finally, the relationship between wheat yield and climate variability was analysed. Insight gained from this detailed analysis can better support drought management planning at the municipal or provincial level (Masih et al., 2014).

2. Methodology

Drought is a dynamic phenomenon, which necessitates the study of both its temporal and spatial extents and developments (Shahid, 2008). Thus, this study analyses how the 2015-2018 drought developed temporally and spatially, as well as how it differed between the two core wheat-growing areas in the Western Cape.

2.1. Study Area

The Western Cape is the south-westernmost province in South Africa. Cape Town, South Africa's second-largest city, is the capital and economic hub of the province. Wheat is grown in two main areas - namely the Swartland (incorporating Rooikaroo-Aurora and Sandveld-south), north of Cape Town, and the Rûens, east of Cape Town (Fig. 1). This study focuses on the western side of the Rûens (Rûens-west) since the climate gradually changes to year-round rainfall eastwards (Rûens-east) with a reduction in agricultural potential.

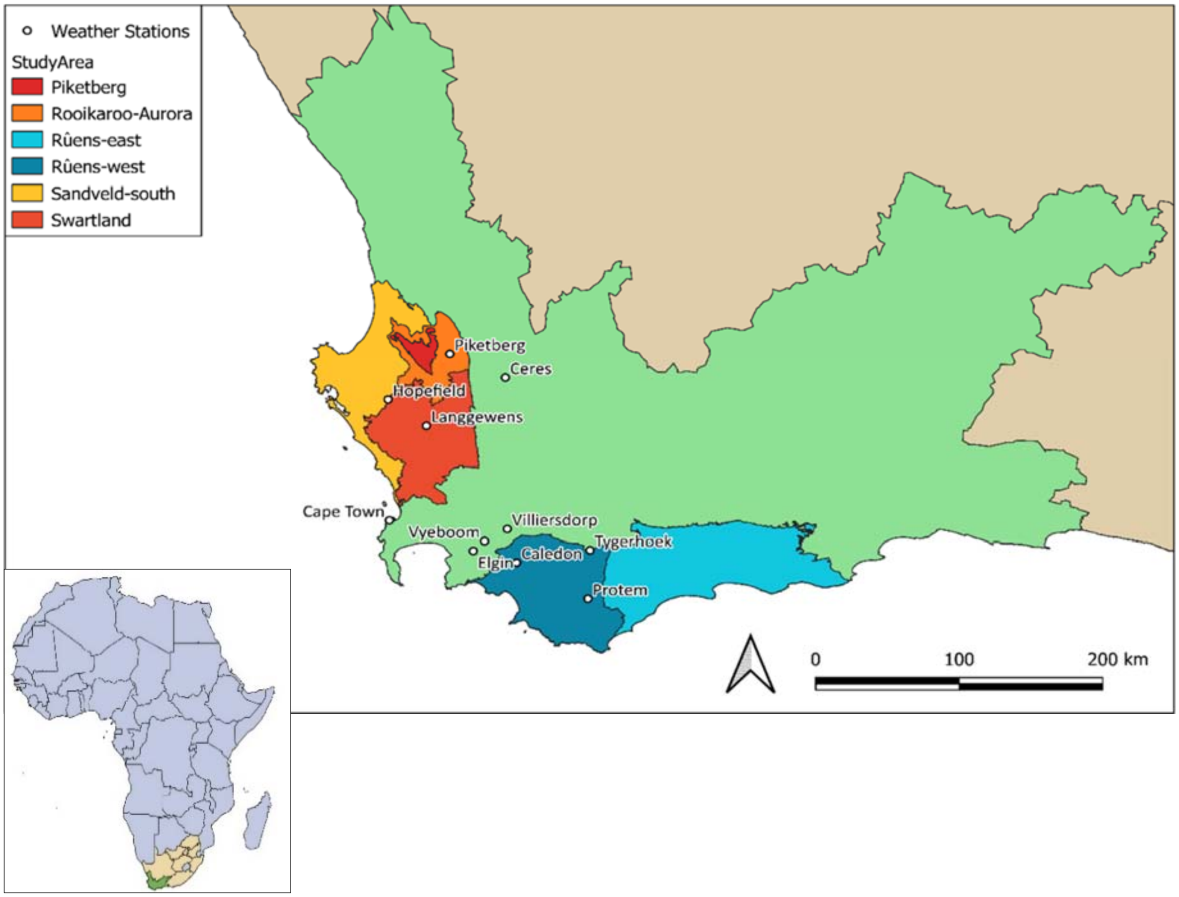

Fig. 1. A map of the Western Cape Province, South Africa, showing the geographic locations of the weather stations used in the two core wheat-growing regions, the Swartland (incorporating Rooikaroo-Aurora and Sandveld-south and Piketberg) and the Rûens. Three weather stations were located within each study area, but an additional three stations just west of the Rûens (Elgin, Vyeboom and Villiersdorp) and one additional station just east of the Swartland (Ceres) were included for analytical purposes. Insert: Map of Africa showing the Western Cape Province within South Africa.

The wheat-growing regions experience a Mediterranean-type climate, with hot dry summers and cool wet winters (Archer et al., 2019). The long-term mean climate for the two wheat regions is summarized in Table 1. The mean annual precipitation in the province varies from ~300 mm to more than 1500 mm (Botai et al., 2017). Wet winters are caused by an equatorward shift, and stronger mid-latitude storm track in the South African sector (Reason & Rouault, 2005; Midgley et al., 2005).

Table 1

The typical climate in the two core wheat-producing areas of the winter rainfall region, Western Cape Province, South Africa (Agricultural Research Council Agromet Climate Database, 2018).

Area	Mean Annual Rainfall	Mean Annual Maximum Temperature	Mean Annual Minimum Temperature
Swartland (n=3)	364 mm	25.3°C	15.2°C
Rûens (n=3)	334 mm	21.8°C	11.8°C

2.2. Data and Analysis

Daily maximum and minimum temperature (hereafter referred to as Tmax, Tmin respectively) and rainfall data from 1988-2018 for ten stations across the region were obtained from the Agricultural Research Council – Soil, Climate and Water Agrometeorology Programme Database (Agricultural Research Council Agromet Climate Database, 2018). Characteristics of the selected stations are summarised and listed in Table 2. Stations were chosen based on a continuous length of records for both rainfall and temperature data with good distribution to cover the study regions. In this study, complete data was defined as missing less than 5 days of data per month. Only Langgewens and Tygerhoek had complete station data for the entire study period (1988-2018). Data from the four additional stations not located in the Rûens or Swartland areas (Fig. 1) were used as additional data to improve the kriging calculations (as described in more detail below).

Table 2

Geographic positions, elevations, and data availability (numbers in brackets indicate month of the year) of the ten weather stations used in the study.

Station	Latitude (S)	Longitude (E)	Elevation (masl)	Data Availability
		Swartland		
Langgewens	-33.28	18.70	177	1967- 2018
Hopefield	-33.10	18.42	71	1997- 2018
Piketberg	-32.78	18.89	171	1988-2007 (7) & 2007 (9)-2018
		Rûens		
Tygerhoek	-34.13	19.9	331	1964-2018
Protem	-34.47	19.90	283	1924-2009 (2) & 2009 (3)-2018
Caledon	-34.22	19.36	191	1920-2004 & 2006-2018
		Additional Stations		
Vyeboom	-34.13	19.03	394	1973-2015 (6) & 2015 (8)-2018
Villiersdorp	-34.07	19.12	308	1991-2012 (7) & 2012 (9)-2018
Elgin	-33.99	19.29	305	1964-1997 & 2004-2018
Ceres	-32.97	19.30	945	1942-1995, 2000-2018

Data analyses were conducted in R, using the packages: Climdex version 1.1-9.1, SPEI version 1.7, ScPDSI version 0.1.3, Pracma version 2.2.9, and Kendall version 2.2. Drought years (2015-2018) were compared with the long-term mean (1988-2014, 26y). Seasons were divided as follows: summer = December, January, February (DJF); autumn = March, April, May (MAM); winter = June, July, August (JJA) and spring = September, October, November (SON). It is acknowledged that two previous significant droughts in the Western Cape occurred in 2002-2003 and 2009-2010 (WCDoA, 2017). According to Botai et al. (2017) on the 3- and 6-month SPI timescales, these droughts were mild - other such drought events occurred in the years 1987–1988, 1993–1994, 1997–2000, and 2008–2011. It is noted that Botai et al. (2017) did evaluate 12-month SPI timescales, and only the 2009-2011 drought was recorded at this SPI time interval. The 2015-2018 drought is more comparable to the extended drought of 1926-1933 and can be considered as a 1-in-100-year drought (Otto et al., 2018).

The standardised precipitation evapotranspiration index (SPEI) is one of the most widely used indices for drought assessment (Labudová et al., 2017). Its main function is to capture drought intensity, but it can also indicate drought length and return periods (Rouault and Reason, 2003). SPEI is defined as the difference between precipitation and potential evapotranspiration. SPEI uses the basis of SPI but includes temperature as a factor - this may include daily Tmax and Tmin or a median, allowing the index to account for the effect of evapotranspiration on drought development through a basic water balance calculation (Arujo et al., 2016). SPEI is also applicable for all climate regimes, with the results being comparable, since they are standardised (Integrated Drought Management, 2018). For all calculations, the R-SPEI package was used, which allows different options for the SPEI assessment. The SPEI index was calculated for both regions using the Hargreaves ETo equation at the 6-, 12- and 36-month intervals. These intervals can capture agricultural and hydrological drought. A 6-month SPEI with a start time of May taken in October was used to evaluate the drought over the wheat growing season for the four drought years 2015-2018. SPEI values were interpreted using the values in Table 3 from McKee et al. (1993).

Table 3

SPEI values and drought severity from to McKee et al., (1993).

Description	Criteria
Extremely Wet	SPEI > 2
Severely Wet	1.5 < SPEI < 1.99
Moderately Wet	1 < SPEI < 1.49
Mildly Wet	0 < SPEI< 0.99
Mild Drought	-0.99 < SPEI < 0
Moderate Drought	-1.49 < SPEI < -1
Severe Drought	-1.99 < SPEI < -1.5
Extreme Drought	SPEI < -2

SPEI was expressed spatially by converting the SPEI values at the geographic location of each station to point values. The points were then interpolated using kriging in SAGA. Kriging is a widely used geostatistical interpolation method that uses known values and a semi-variogram to determine unknown values. Kriging assumes that the spatial variation is neither totally random nor deterministic. Based on the semi-variogram, optimal weights are assigned to known values to calculate unknown ones. The variogram changes with distance, and the weights depend on the known sample distribution (Singh and Verma, 2019). Percentage of long-term mean rainfall was also spatially expressed in the same way in SAGA. The period used for long-term mean for temperature and rainfall means was from 1988-2014 - these were then compared to each of the currently considered drought years, 2015, 2016, 2017, 2018, to visualise the temporal and spatial development of the drought.

R-ScPDSI package was also run to calculate the Palmer Drought Severity Index (PDSI). PDSI is calculated using monthly temperature and precipitation data, along with the water-holding capacity of soils (Integrated Drought Management, 2018). Sc-PDSI is the self-calibrating PDSI run in R, and it allows for the comparison of results from various regions. Several studies have proven that the sc-PDSI performs better in spatial comparison than the conventional PDSI (R-ScPDSI Documentation, Nd). Information on soil water-holding capacity for the soil properties prevalent in each region was obtained from Wallace (2013).

For the R-Climdex analysis, the two stations, Langgewens and Tygerhoek, were used as representatives, as they were the two stations with the most complete dataset for the 30-year study period. R-package Kendall was used to run the Mann-Kendall test to assess trends over time. Kendall rank correlation coefficient was chosen as it is frequently used in climate sciences and for smaller sample sizes ($n < 30$) (Hennemuth et al., 2013). Trend analysis conducted on the rainfall data included seasonal and annual rainfall, as well as rainfall characteristics and extremes. Rainfall characteristics and extremes indices used were developed by the ETCCDI (Expert Team on Climate Change Detection and Indices), such as rainfall intensity, rainfall events >1 mm, > 10 mm, greater than 20 mm, consecutive wet days (CWD) and consecutive dry days (CDD) and are available in the R-Climdex package (Alexander, et al., 2019). For the temperature data, trend analysis was conducted on annual and seasonal minimum and maximum values. Trends were considered significant if the $p\text{-value} < 0.05$. Positive tau (τ) values indicate an increasing trend, while negative τ values indicate a decreasing trend. Finally, to determine if conditions experienced during the drought were significantly different from pre-drought conditions, a two-sample T-test, assuming unequal variances, was performed. While it is acknowledged that a 30-year period is short for trend analysis, especially when the final years show a significant decrease in rainfall, weather data in this region is often incomplete. Thus, a balance was made to obtain the most complete sets of data (including Tmax, Tmin and rainfall) over the timeseries.

Since wheat grown in the Western Cape is rainfed, the length of rainfall season governs the growing period and, thus, establishing the onset and end of the rainfall season is critical. In the Swartland rainfall is highly concentrated in the winter months (173 mm) with autumn receiving (81 mm). The Rûens receives a more even spread of rainfall across the autumn (93 mm) and winter (93 mm) months (totaling on average 186 mm). In the Rûens-west, the growing season of wheat requires between 110 and 135 days, while in the Swartland, the season ranges from 100-130 days, depending on the cultivar (Wallace, 2013). Autumn rainfall is important for wheat production as wheat is planted from late autumn (May) to the beginning of winter (June). If adequate rainfall has not been received by end of autumn farmers need to work within a shorter rainfall season or are forced to abandon planting altogether. The onset and end of the rainfall season vary depending on the crop type, and field management. For this study, the rainy season was defined as the period during which wheat can be sowed and supported through to maturity and successful harvest. Using the parameters set out by Kloppers (2014), rainfall onset was defined as the Julian date at which 10 mm of rain falls in a dekad, followed by 25 mm in the next four dekads. The end of the rainfall season was defined as the last date in which 25 mm rain is received in a four dekads period. A two-sample T-test, assuming unequal variances, was run on the results to determine if there was a significant difference (SD) between onset or cessation during drought conditions and pre-drought conditions.

Finally, the consequences of climate variability on wheat yield (t/ha) were determined. Production statistics from 1988-2018 were obtained for the province from the South African Grain Information Services (SA-GIS, 2018). The correlation between wheat yield and each of the values for annual, winter, and autumn rainfall, along with autumn Tmax and winter Tmax was calculated using the Kendall rank correlation coefficient. Wheat yields for the province show a steady increase from the 1980s, mostly attributed to the implementation of technology and improved crop management (such as the adoption of Conservation Agriculture) (Piesse & Thirtle, 2010; ARC-CO, 2014). Therefore, the wheat yield data were detrended with a first-order polynomial (linear) using the R-Pracma package, before running the correlation coefficient. R-Pracma's detrend function computes the least-squares fit of a straight line to the data and then subtracts the resulting function from the data.

3. Results

For the results, we first present the findings of the meteorological drought such as mean and seasonal averages, short-term SPEI; Climdex indices and the results of the Mann-Kendall tests. Then the findings from the agricultural drought indices such as sc-PDSI, 36-month SPEI, start/end of the rainfall season. We then present the spatial and temporal variability of the drought, finally concluding with the effects on wheat production.

3.1. Annual and Seasonal Means

During the drought, the Swartland received 71% of the long-term mean annual rainfall (Table 4). Autumn rainfall was 37% lower than the long-term mean during the 2015-2018 drought, from a mean of 78 mm to 50 mm. The winter rainfall was 20% lower from a mean of 170 mm to 135 mm. Rainfall deviations of σ-1 were experienced at most stations in 2015, 2017 and early 2018. During autumn 2017 all stations recorded a Tmax which exceeded σ-2.

The Rûens received overall 25% less rainfall than the long-term mean annual rainfall during the drought. Autumn rainfall was 55% lower from a mean of 114mm to 53mm. Winter rainfall was closer to normal with only a 5% decrease. Rainfall deviations of σ-2 were experienced in three winters in the Rûens (2015-Protem, 2016-Tygerhoek, 2017-Caledon). Like the Swartland, during autumn 2017 all stations recorded a Tmax which exceeded σ-2. Protem experienced higher (> σ-2) rainfall during winter 2015 and (> σ-1) during winter 2016. A more detailed analysis of climate variations during the drought period can be found in Appendix 1.

Table 4

Percentages of long-term rainfall, Tmax and Tmin per station for each of the drought years, cells highlighted in yellow and red show σ-1 and σ-2 respectively below normal for rainfall and above normal for temperature. Cells highlighted in light and dark blue show σ-1 and σ-2 respectively for below normal temperature. DJF = summer; MAM = autumn; JJA = winter; SON = spring, Ann = Annual.

		Rainfall (%)					Maximum Temperature (%)					Minimum Temperature (%)				
	Year	DJF	MAM	JJA	SON	Ann	DJF	MAM	JJA	SON	Ann	DJF	MAM	JJA	SON	Ann
Hopefield	2015	55	30	68	21	50	104	106	106	99	104	93	94	96	100	95
	2016	56	112	109	88	101	111	104	115	95	106	106	98	99	99	101
	2017	36	41	53	51	49	109	113	117	95	108	95	97	83	95	94
	2018	36	128	84	77	88	109	102	114	94	104	99	99	98	102	100
Piketberg	2015	61	8	84	30	54	99	105	106	99	102	94	98	99	101	97
	2016	45	67	74	96	75	106	102	114	95	104	106	98	103	94	101
	2017	41	21	60	55	48	103	111	116	95	106	98	99	89	99	97
	2018	11	81	72	80	73	103	100	114	93	102	102	99	98	96	100
Langgewens	2015	36	38	68	43	51	99	102	97	105	101	94	97	93	99	96
	2016	40	74	105	72	81	104	99	103	101	102	103	96	94	94	98
	2017	9	32	65	75	50	101	108	100	101	103	97	103	89	92	96
	2018	30	99	85	70	76	91	97	100	104	97	89	96	96	100	95
Protem	2015	103	49	175	104	108	103	107	104	99	103	100	100	96	105	100
	2016	130	79	134	61	96	107	103	110	99	104	105	99	105	102	103
	2017	116	21	74	83	65	105	111	115	97	107	99	102	98	96	99
	2018	85	34	78	74	64	103	107	120	97	106	99	101	107	101	101
Caledon	2015	83	32	136	71	91	99	103	98	109	102	104	111	135	118	113
	2016	92	63	112	35	87	109	105	111	110	108	113	111	135	116	116
	2017	160	36	44	78	56	107	114	105	98	106	106	112	117	102	109
	2018	100	67	96	80	85	98	97	100	102	99	101	104	115	106	105
Tygerhoek	2015	75	10	96	123	76	104	101	76	107	98	99	107	119	105	105
	2016	93	43	5	18	36	107	103	149	104	114	112	107	124	98	109
	2017	60	30	104	104	76	102	111	106	106	106	104	108	107	103	105
	2018	66	58	95	101	81	103	104	103	106	104	108	109	119	100	108

3.2.Climdex

Table 5 shows the results of the t-test and trend analysis of the rainfall characteristics for the drought vs pre-drought years. The results of the trend test illustrate whether the observations made during the drought may potentially be attributed to changes in long-term trends. Alternatively, the results of the t-test indicate whether the observations were unique to the drought years. Rainfall characteristics during the drought varied between the two regions. As expected, both regions experienced a significant decrease in rainfall during the drought. For Langgewens this was coupled with a significant increase in the number of CDD during the drought. Tygerhoek showed a significant difference in the increase in CWD during the drought.

In terms of the long-term trend analysis, Langgewens shows a decreasing trend in rainfall intensity and rainfall events > 20 mm, which both showed a statistically significant (p-value < 0.05) long-term negative trend. No significant long-term trends were observed for the 1 mm or 10 mm rainfall events at Langgewens. For the Rûens, no such long-term trends in rainfall characteristics emerged. These results are similar to those of the Department of Environmental Affairs (2013), who found a low consistency in trends across the Western Cape.

Table 5

Trend and T-test results for rainfall characteristics of drought vs pre-drought years for 1988-2018 for two stations, Langgewens and Tygerhoek. CWD= consecutive wet days CDD= consecutive dry days SD= standard deviation.

Station	CWD Trend	CWD test	CDD Trend	CDD t-test	Rainfall Trend	Rainfall t-test	Rainfall Intensity Trend	Rain> 1mm Trend	Rain> 10mm Trend	Rain> 20mm Trend
Langgewens	No Trend (τ= 0.02, p= 0.89)	No difference	No Trend (τ= -0.2, p= 0.13)	SD (p= 6.14e-12)	No Trend (τ= -0.01, p= 0.31)	SD (p= 0.03)	Decrease (τ= -0.43, p= 0.001)	No Trend (τ= 0.12, p= 0.37)	No Trend (τ= -0.34, p= 0.01)	Decrease (τ= -0.38, p= 0.007)
Tygerhoek	No Trend (τ= -0.13, p= 0.39)	SD (p=0.01)	No Trend (τ= -0.17, p= 0.24)	No difference	No Trend	SD (p= 0.03)	No Trend (τ= 0.18, p= 0.02)	No Trend (τ= -0.21, p= 0.13)	No Trend (τ= -0.03, p= 0.87)	No Trend (τ= 0.107, p= 0.47)

3.3. Long-Terms Seasonal Trends

Trend analysis was also conducted for seasonal changes using the Mann-Kendall test, results are shown in Table 6. Most of the trends are weak with the strongest trends evident in increasing winter temperatures. Noticeably, the Rûens display more long-term trends than the Swartland with only Piketberg in the Swartland recording any trends. The analysis also suggests increasing temperatures, mostly in Tmax, in all seasons particularly in the Rûens. There is also an indication of decreasing rainfall in the fringe seasons, autumn and spring.

Table 6

Seasonal trends per station (n=6) in rainfall, Tmax and Tmin for 1988-2018 in the core wheat-growing regions of the Western Cape, South Africa.

Season	Increasing trends	Decreasing trends
Summer	- Piketberg Tmax (τ= 0.44, p= 0.0006) - Tygerhoek Tmax (τ= 0.27, p= 0.04) - Protem Tmax (τ= 0.36, p =0.004) - Protem Tmin (τ= 0.26, p =0.05) - Caledon Tmin (τ=0.5, p =9.3e-05)	
Autumn	- Piketberg Tmax (τ= 0.39, p=0.002) - Tygerhoek Tmax (τ= 0.37, p=0.005) - Protem Tmax (τ= 0.5, p=6.97e-05) - Caledon Tmin (τ= 0.57, p=1.14e-05)	- Caledon Rainfall (τ=-0.35, p=0.009) - Protem Rainfall (τ= -0.38, p=0.003)
Winter	- Piketberg Tmax (τ= 0.52, p=4.52e-05) - Caledon Tmin (τ= 0.6, p=4.17e-06) - Protem Tmax (τ= 0.63, p=8.3e-07)	
Spring	- Caledon Tmin (τ= 0.49, p=0.0001)	- Piketberg Tmax (τ= -0.37, p=0.004)

3.4. 12-Month SPEI

SPEI values (i.e. drought intensity over 12-month period) varied across regions and within regions as shown by the analysis of six stations (Fig. 2). It is clear that drought in the wheat-growing regions is a common occurrence. Two of the three stations in the Swartland recorded SPEI values of less than -2 during the 2015-2018 drought, which indicates severe drought. These values were experienced in 2017 in both Hopefield and Piketberg. These two stations also recorded a recovery in 2018. In the Rûens, drought varied in intensity - Tygerhoek and Protem showed moderate to severe drought, while Caledon experienced the most extreme drought of all the regions with a SPEI close to -4 in 2017 - yet it was the only area in the Rûens to show a small recovery in 2018. Protem experienced drought conditions from 2010, yet this drought briefly eased in 2015 as evident in the large (> σ-2) changes observed in Table 4. From 2016, however, Protem once again experienced drought conditions. Finally, Caledon and Piketberg are the most prone to drought conditions and experience mild drought (-1) regularly. Tygerhoek has the shortest drought periods.

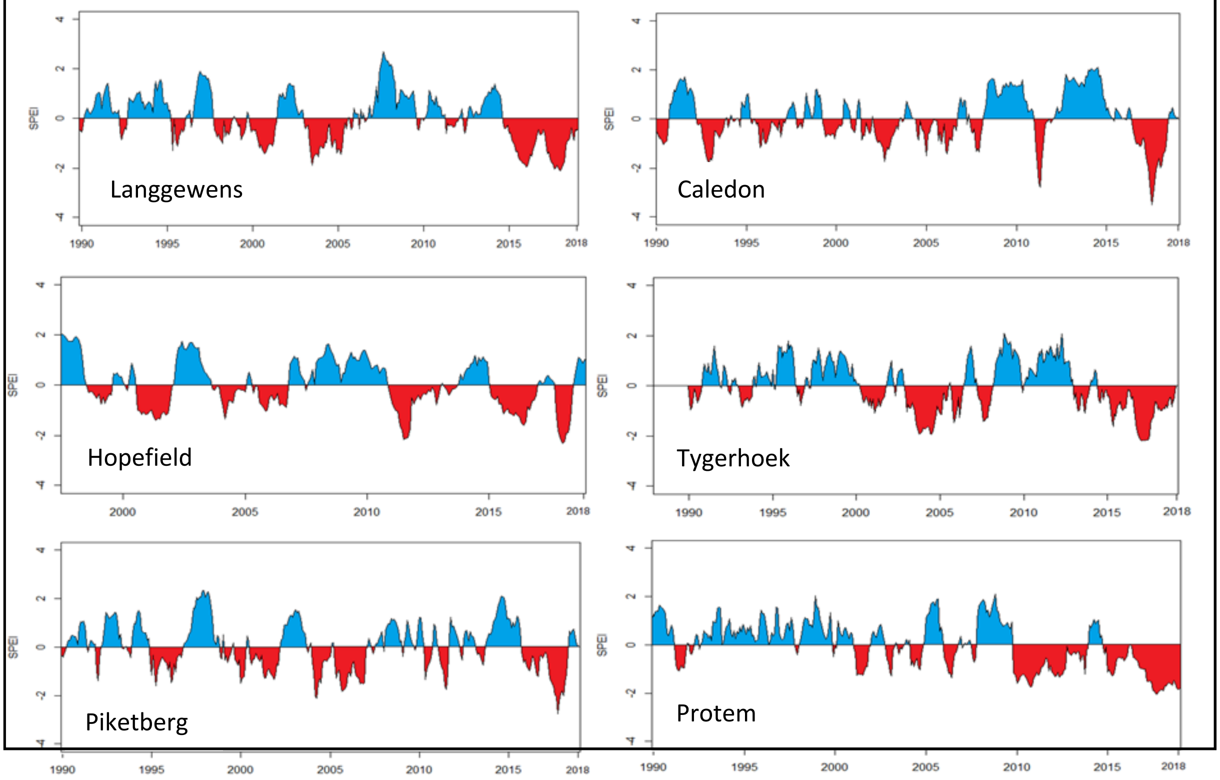

Fig. 2. 12-month SPEI for the period 1988-2018 for six stations (Langgewens, Piketberg, Hopefield, Tygerhoek, Caledon, Protem) in the wheat-growing areas, South-Western Cape, South Africa.

3.5. *36-Month SPEI*

Figure 3 shows the 2015-2018 drought followed a generally wet period for most stations. This wet period lasted up to a decade in some areas. On a 36-month time interval, the Rûens experienced more severe drought than the Swartland. Both Tygerhoek and Caledon experienced extreme drought (SPEI up to -4 in the case of Tygerhoek), and Protem showed values of -2 The Swartland, however, experienced less severe drought, and SPEI values remained around -2 and above. On a 36-month SPEI, the 2015-2018 drought was the most extreme drought experienced in the past 30 years for five of the six stations. Only Piketberg had previously experienced worse drought.

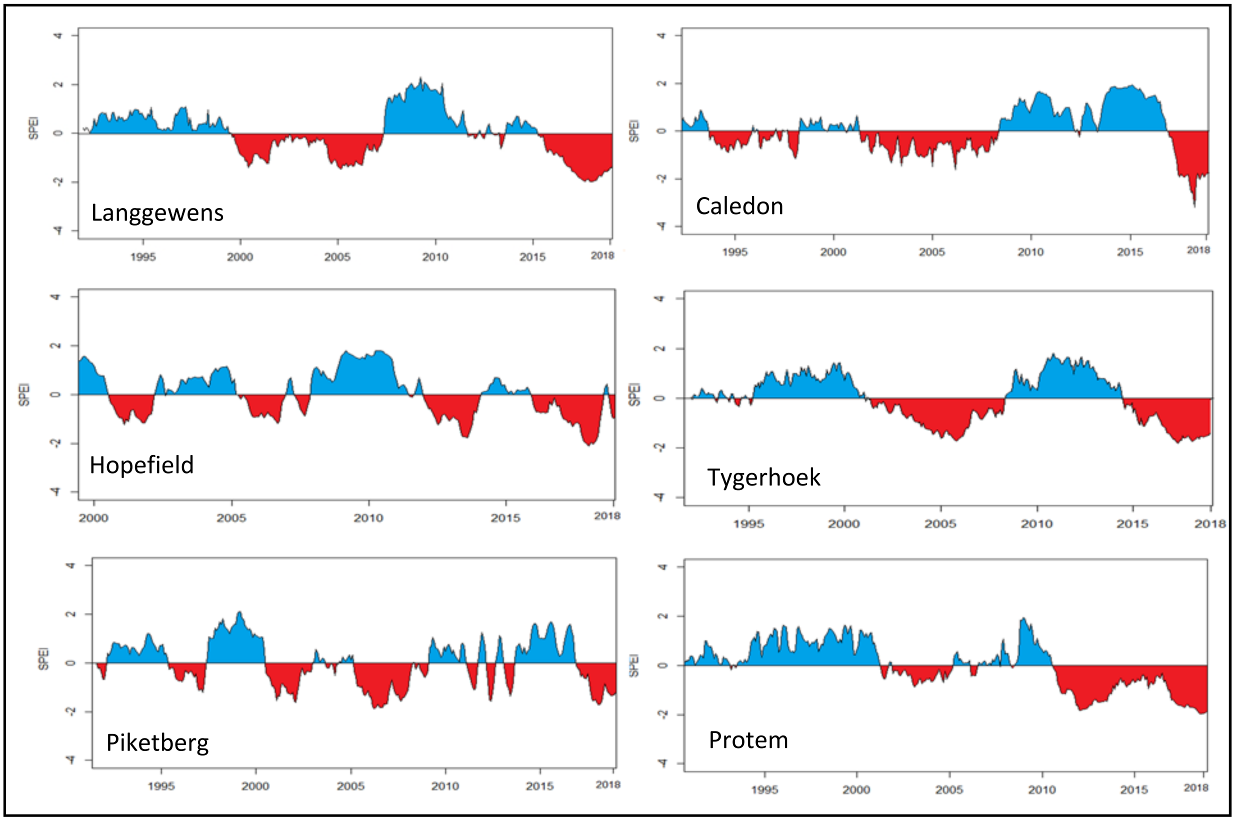

Fig. 3. 36-month SPEI for the period 1988-2018 for six stations (Langgewens, Piketberg, Hopefield, Tygerhoek, Caledon, Protem) in the wheat-growing areas, South-Western Cape, South Africa.

3.6. Sc-PDSI

Sc-PDSI varied across regions and within regions (Fig. 4). Sc-PDSI showed that the 2015-2018 drought was the most severe experienced since 1988 for five of the six stations (except Piketberg). In all regions, the PDSI was lower than – 4, which indicates severely dry conditions. Another point to note is that the low PDSI came after a generally high PDSI, an abnormally wet period for all stations (except for Protem). For Langgewens, Tygerhoek and Piketberg, this period of high PDSI was experienced for almost a decade beforehand. PSDI shows that the wheat areas have generally experienced shorter milder droughts in the past - in some regions, these droughts were regularly interspersed with wet periods. This drought seems to have been distinct in many areas - in that it was more severe (-4) and came after a long period of generally wet years.

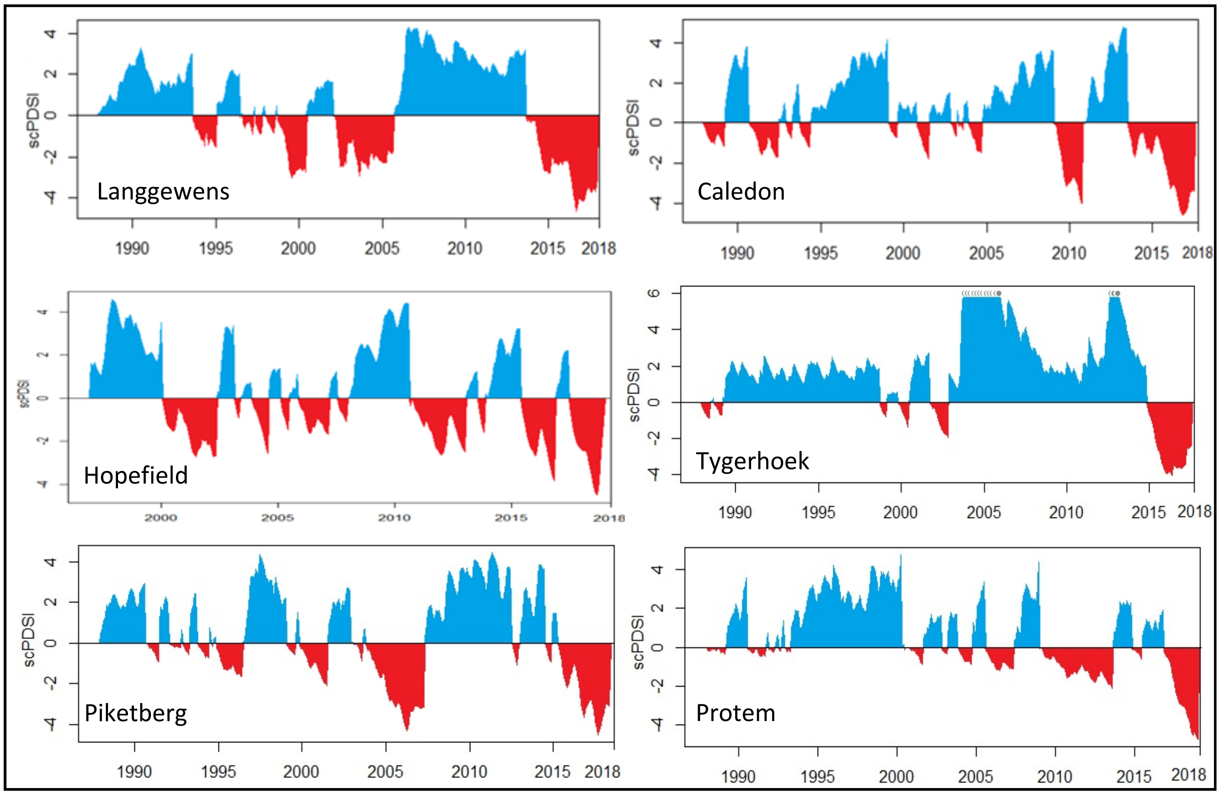

Fig 4. Sc-PDSI for the period 1988-2018 for six stations (Langgewens, Piketberg, Hopefield, Tygerhoek, Caledon, Protem) in the wheat-growing areas, South-Western Cape, South Africa.

3.7. Onset/End of the Rainy Season

During the study period (1988-2018), changes in the length of the rainy season were found at most stations. Findings are summarised in Table 7, Hopefield was not included since the length of data available for that station was too short for adequate significance testing. In general, there appears to be a shortening of the rainfall period mostly caused by a later start date observed at three of the five stations. However, the results of the t-test showed no significant changes ($p < 0.05$) in the start/end or length of the rainy season during the drought relative to the pre-drought period. This may suggest that the impacts of the drought were due to lower rainfall totals and not the timing or length of the growing season.

Table 7

Mean start and end dates for the rainy season (with drought in brackets) for the wheat-growing regions in the Western Cape, South Africa.

Station	Start (Julian Date)	End (Julian Date)	Length (Days)	Changes in long-term trends
		Swartland		
Langgewens	121 (120)	231 (170)	110 (50)	A decrease in length as start is later end is earlier.
Piketberg	140 (150)	240 (250)	140 (110)	Shorter season as the start is later.
		Rûens		
Tygerhoek	110 (120)	260 (270)	150 (150)	No change
Caledon	132 (130)	236 (246)	130 (113)	Extended end date and increased length.
Protem	120 (140)	230 (270)	120 (140)	Decrease in length as start is later.

3.8.Spatial Variability

3.8.1. 12-Month SPEI Spatial Variability

Figure 5 illustrates how drought severity varied both spatially and temporally over the two wheat-growing regions. The maps show that the drought reached its maximum regional extent in 2017 with both wheat regions experiencing moderate to severe drought conditions. The northern Swartland and Western Rûens experienced more severe drought in 2015. These conditions continued in 2016 in the Rûens, with the Swartland experiencing milder drought. In 2018, the Swartland showed some recovery from drought conditions, yet the western Rûens still experienced drought conditions.

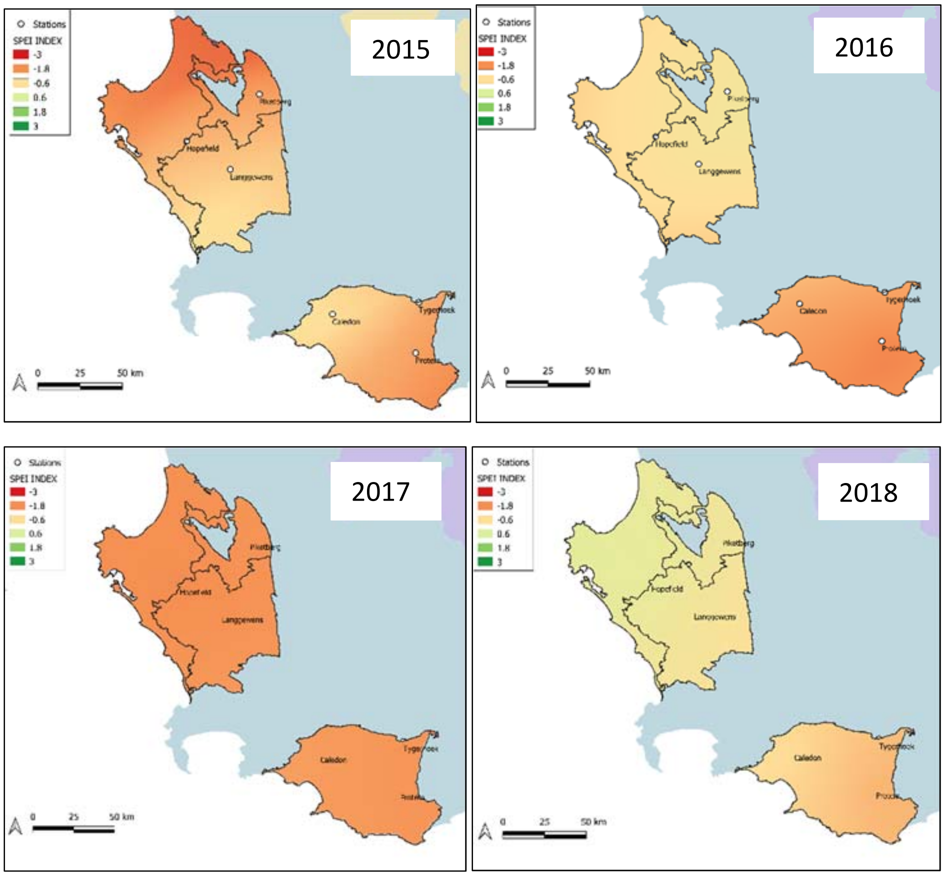

Fig 5. Maps showing 12- month SPEI (varying from red=-3 drought to green =+3 wet) for each of the drought years in the wheat-growing areas of the South-Western Cape, South Africa.

3.8.2. SPEI Spatial Variability over the wheat season

To determine drought intensity during the wheat season SPEI-6 was calculated for a start time of May ending in October as rainfed wheat is generally harvested in October. This period was chosen to capture the wheat season including rainfall before planting. Drought during the wheat season varied spatially, as well as temporally. Piketberg experienced the most severe drought during the wheat season in 2015, with the other regions showing no or mild drought conditions. According to Figure 6, the wheat-growing season in 2016 showed no drought conditions. This suggests that although there was drought recorded at the 12-month scale (Fig.5) rainfall in the 2016 wheat season was normal. Similar to Figure 5, the drought reached its maximum regional extent in 2017, with all stations recording moderate to severe drought conditions. Recovery of the Swartland commenced in 2018, with SPEI values of 0 to 2, while the area around Protem continued to experience mild drought conditions during the 2018 growing season. Figure 6 shows the importance of capturing SPEI for the growing season as it illustrates more subtle spatial variability than SPEI-12 (Fig. 5). Timing and amount of rainfall are the main factors that determine final wheat yields, and thus are the major contributors to the spatial variability drought impacts (Potgieter, et al., 2013).

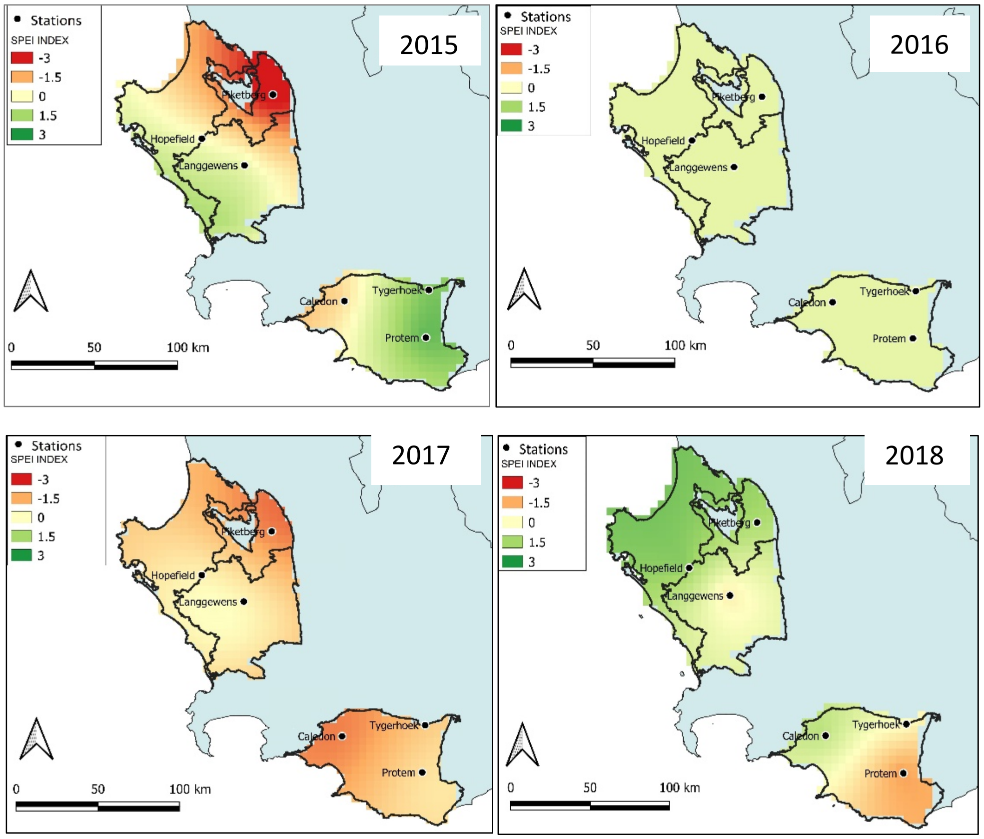

Fig. 6. Spatial maps showing 6-month SPEI ending in October (varying from red=-3 drought to green =+3 wet) for each of the drought years in the wheat-growing areas of the South-Western Cape, South Africa.

3.9. Consequences for Winter Wheat

As stated earlier, rainfed agriculture is one of the most vulnerable sectors to climate variability and drought. The above results show that the Western Cape region experienced a severe drought, beginning in 2015, with most areas showing some recovery by 2018. The following section explores the relationship between climate variability and wheat yield in the region.

Table 8 shows the Kendall correlation between the detrended wheat yields and annual, winter and autumn rainfall for the wheat growing regions. The strongest correlation is with winter and autumn combined rainfall (τ=0.13) although this too is weak. Similar correlations were found with winter (τ=0.12) and autumn (τ=0.11) rainfall. Weak correlations may be attributed to the small sample size (n=30). There was no correlation with Tmax.

Table 8

The correlation between annual, winter (JJA) and autumn (MAM) rainfall as well as autumn Tmax and winter Tmax and wheat yield for the wheat-growing region.

		Autumn Rain	Winter Rain	**Combined Autumn and Winter Rain**	Annual Rain	Autumn Tmax	Winter Tmax
Yield	Kendall Correlation τ value	0.11	0.12	0.13	0.06	0,045	0,01
	p-value	0,4	0.34	0.33	0.66	0,74	0,95

In general, wheat yields have increased over the past 30 years due to changing cultivars and technologies (Fig. 7). The impacts of drought on wheat yield fluctuated sharply, with a steep decrease in 2015 and 2017, and a higher yield again in 2016 and 2018. This observation correlates better with the spatial variability maps of SPEI-12 than SPEI-6 especially for the Swartland. After detrending was conducted, the relationship between rainfall and yield for the period 1988-2018 is shown in Figure 8. For the Swartland winter rainfall was chosen as it showed the greatest correlation (Table 8) and because rainfall is concentrated in the winter months (JJA). The relationship is still weak ($R^2 = 0.045$). For the Rûens (Fig. 8 (2)) autumn and winter rainfall was combined because rainfall is more evenly spread between these two seasons. Once again, the relationship is weak and a similar R^2 value, 0.046, to Figure 8(1) was generated.

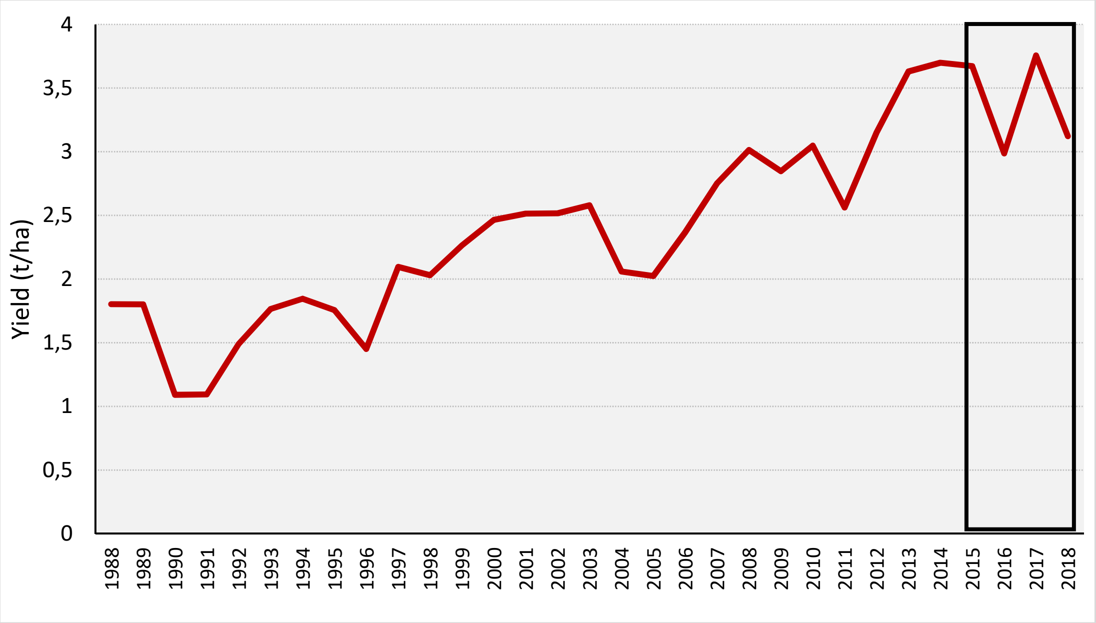

Fig. 7: Wheat yields for the period 1988-2018 for the Western Cape, South Africa. The block indicates drought years.

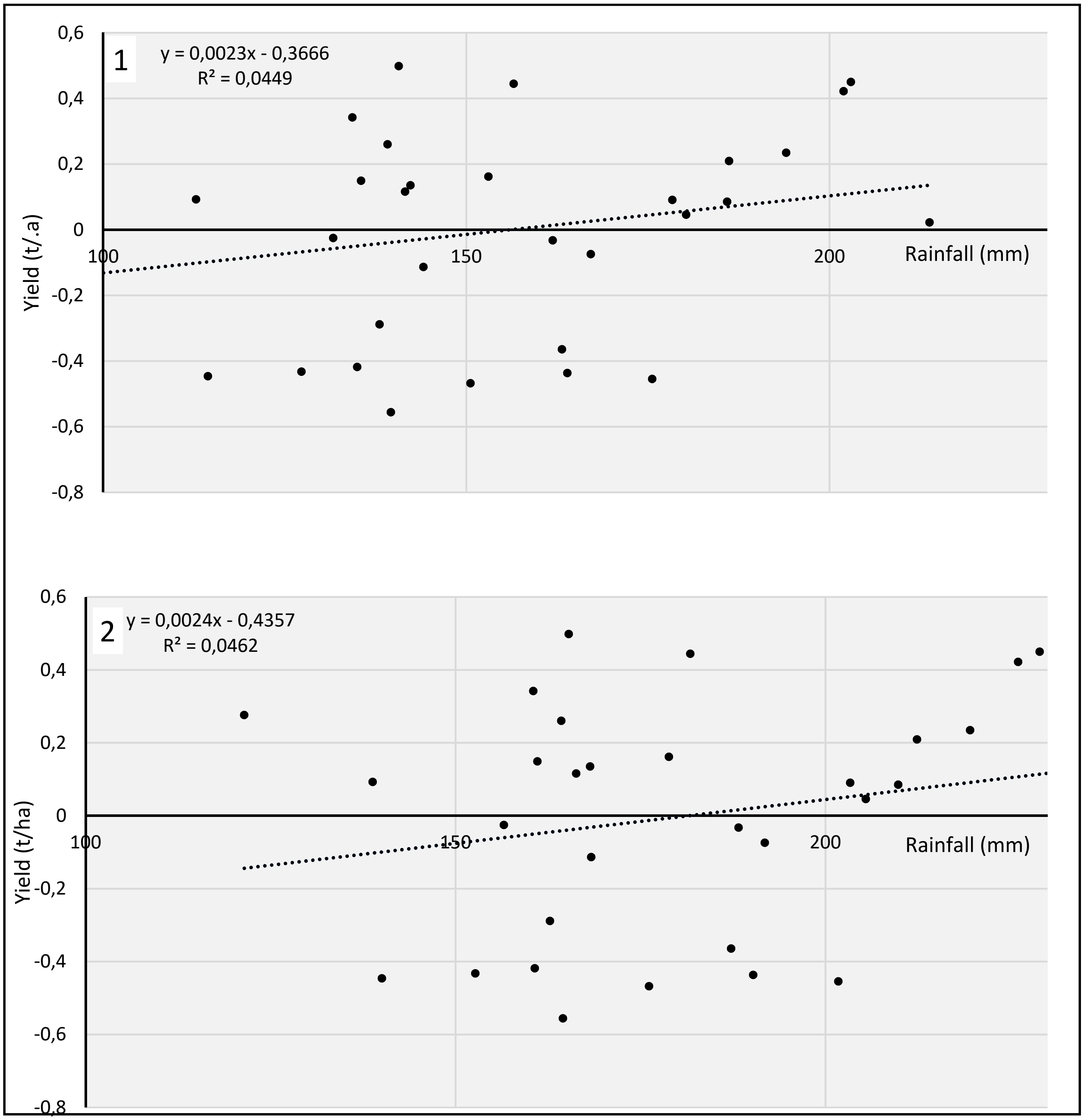

Fig. 8. (1) Wheat yield against winter rainfall (1988-2018) for the Swartland in the Western Cape, South Africa. Dotted line indicates the trend with $R^2 = 0.0449$ and **(2)** Wheat yield against winter and autumn rainfall (1988-2018) for the Rûens in the Western Cape, South Africa. Dotted line indicates the trend with $R^2 = 0.0462$.

The low R^2 values derived from the plots in Figure 8, as well as the poor Kendall correlation limits the use of simplified climate models for yield estimation in this study. Attempting to estimate wheat yield had the drought not occurred (i.e. for a normal year) warrants stronger R^2 values. However, the low values observed in Figure 8 is notable since it was expected that higher winter and/or autumn rainfall would account for higher yields. This is most likely due to the resolution of the two datasets used. While the rainfall data covered the study area well (six stations across the regions), the wheat yield data used was an average of provincial wheat yields. Yield data for each study area is available from the Agricultural Research Council-Small Grains (ARC-SG) but only for the period 2010-2018 (Agricultural Research Council Small Grains Production Guidelines, 2018). Using the ARC-SG data produces higher R^2 values for both the Swartland (0.49) and Rûens (0.29) than the provincial yield dataset. However, the low temporal resolution of this dataset (8 years) is too short for adequate modelling to be conducted. Nevertheless, t these results suggest that other factors have a significant contribution to wheat yields in the province, which in itself is a noteworthy observation.

4. Discussion

While the 2015-2018 drought in the Western Cape, South Africa has been analysed in-depth, much of the focus was on the urban impacts for the City of Cape Town (Climate Systems Analysis Group, 2018; Otto, et al., 2018; Ziervogel, 2019). This paper presents a detailed analysis of the 2015-2018 drought from an agricultural perspective, placing it in both a historical and future context while emphasising the differences between the core wheat-growing regions of the Western Cape. Of notable importance, the study shows that between 1988 and 2018, the region experienced persistent drought with high spatial-temporal variability. Yet, the 2015-2018 drought was the most severe experienced in the 30-year study period at five of the six stations.

In general, both the Swartland and the Rûens experienced lower than normal rainfall and higher than normal Tmax between 2015 and 2018. Trend analysis suggests the increase in temperatures, particularly in the Rûens, is part of a long-term trend. The increasing trends in Tmax and Tmin notably in summer and autumn, is consistent with trends found by Davis-reddy and Vincent (2017, Chapter 1) and the Department of Environmental Affairs (2013). Increases in temperature in autumn will have consequences for rainfed agriculture particularly with regards to increased evapotranspiration which need to be considered.

Lower annual rainfall (Rûens 25%, Swartland 22%) was recorded during the drought period. Mann-Kendall tests suggest that this may be part of a longer-term trend in the Swartland. For the Swartland, this trend is most consistent in the summer months and with a decreasing trend in rainfall intensity and fewer rainfall events of greater than 20mm. The Rûens suggest a decreasing seasonal rainfall trend at two of the three stations for autumn. This may be of concern since the autumn months contribute a significant portion of the annual rainfall in that region. The 30-year study period is acknowledged as a limitation to the study particularly as the final years saw a significant change in Tmax, Tmin and rainfall. Thus, the trend analyses conducted here, serve as an indication of expected trends and further studies using longer time series is recommended. However, these results are consistent with other studies which have shown that significantly drier winters should be expected as the impacts of climate change unfold (Davis-reddy and Vincent, 2017; Department of Environmental Affairs, 2018). This is due to the projected poleward shift of the westerlies and mid-latitude cyclones (Tennant & Reason 2005; Stager et al., 2012; Davis-reddy and Vincent, 2017; Davis-reddy, 2017; Burls et al., 2019).

SPEI and similar drought indices indicate the probability of recurrence of drought at a range of levels of severity (Rouault and Richard, 2003). Our results show that the winter rainfall region of the Western Cape has experienced persistent (up to seven drought events in the 30-year study period) agricultural (> 12-month SPEI) and hydrological (> 36-month SPEI) droughts, consistent with results found by Botai et al. (2017). The literature on drought return periods for the region is, as yet, limited to Botai et al., (2017) and Kam et al., (2021) who briefly recorded drought reoccurrences of between two and five years, but with limited detail. Our results show that length of drought period and persistence in this region is highly variable. Return periods vary from one to four years for agricultural drought, and up to ten years for hydrological drought (although shorter return periods of one year have also been recorded at Piketberg and Tygerhoek). At the 36-month SPEI, however, the Rûens experienced fewer drought events than the Swartland. In the Swartland, drought appears to more frequently manifest as hydrological drought events. This suggests that the 2015-2018 drought is a manifestation of past drought conditions. The only difference between past droughts and the 2015-2018 drought would then be that the 2015-2018 drought was the most severe experienced at the 12- and 36-month SPEI in the past 30 years. The drought came after a generally wet period (up to ten years in four of six regions), which may have initially had implications for lack of preparedness and responses. The region is projected to experience more frequent drought conditions under climate change (Davis-reddy and Vincent, 2017; Sweijd and Tsedu, 2017). Otto et al. (2019) found that the likelihood of an event such as the observed 2015–2018 drought increased by a factor of 3.3 (1.4–6.4) due to anthropogenic climate change. While Kam et al., (2021) found that the probability of such a long lasting drought occurring increased by a factor of 2 due to climate change.

Considering the 12-, 36- month SPEI and PDSI, the 2015-2018 drought was the most extreme drought experienced in the past 30 years for five of the six stations. Thus, our results are consistent with conditions which may be expected with climate change in the future.

Results show that the 2015-2018 drought was highly heterogenous spatially and temporally, both between and within regions. Spatial analysis shows that the drought reached its maximum regional extent in 2017. Our results demonstrate that although both regions experienced drought conditions, there were variations in seasonal drought conditions with the Rûens experiencing more severe drought in autumn and less so in winter. Onset and cessation of drought in the Rûens was later than in the Swartland yet overall, the Swartland experienced a shorter growing season relative to normal. Understanding how drought varies across space and time is key for informing response. The regional extent of the drought is not always consistent when considering impacts and meteorological drivers (Otto, 2019), making drought forecasting, preparedness and response challenging. Our results indicate that the Rûens may be more vulnerable to seasonal changes brought about by climate change than the Swartland. This is reflected in the long-term trends suggesting lower autumn rainfall and higher summer and autumn temperatures for the region. Yet, the Swartland may be more vulnerable to drought indicated by the longer drought (SPEI- 36) and frequency of return periods experienced in the region. The differences highlighted here between long-term challenges (faced in the Rûens) and short-term risk (faced in the Swartland) support the need for flexible and site-specific management of climate risk and drought in the Western Cape. Currently, drought relief in South Africa is steered by the Disaster Management Act (Act 57 of 2002), although a range of provincial legislation also guides responses at the provincial and local levels. A key objective and need is the development of frameworks and plans, which shift disaster risk management away from a reactive to a more proactive role (Midgley & Methner 2016; WCDoA, 2019).

Finally, results showed a weak correlation between climate variability and wheat yield in the two regions. Correlation coefficients and R^2 values were much lower than expected. This was most likely due to the resolution of the datasets. The results do, however, suggest that other factors have a greater contribution to wheat yields in the region. These factors are most likely crop management strategies and cultivar selection including the adoption of conservation agriculture practices which aim to improve soil moisture, soil carbon and soil water holding capacity. These results may be a promising early indication of the resilience and adaptive capacity of farmers in the regions. However, further studies using higher temporal and spatial resolution datasets are needed to better understand the key factors contributing to wheat yields in the province. These results also call for investigation into farmer adaptation strategies and resilience assessments to better understand their vulnerability to climate change.

5. Conclusion

Although the 2015-2018 drought and its impacts on the City of Cape Town have been discussed in-depth (Ziervogel et al., 2019; Wolski 2017), the drought and its consequences for the surrounding agricultural areas in the winter rainfall region of the Western Cape have received less attention. A more complete understanding of the 2015-2018 drought (key for informed response) includes an awareness of how it affected the agricultural areas, as well as how it compares against past droughts in the region. Our study presented an analysis of the drought, as well as climate trends computed from weather data sets (1988–2018) from six weather stations across the two core wheat-growing regions. Analysis of 12- and 36- month SPEI and Sc-PDSI illustrate that between 1988 and 2018, these regions experienced recurrent drought with high spatial-temporal variability. Yet, the 2015-2018 drought was the most severe experienced in the 30-year study period. Drought severity was likely exacerbated by climate change, as indicated by Otto et al. (2019) and Kam et al., (2021). Trend analysis of the time series suggests mostly weak and inconsistent trends across the two core regions for rainfall. Yet, increased temperature trends were observed at most stations.

Our study was unable to tease out the finer details of climate vulnerability and wheat yields. Results suggest that rainfall only accounts for 4% of yield variation. A more detailed analysis using higher spatial and temporal resolution data is needed which also incorporates agronomic and management related factors contributing to wheat yields in the province. This can help in the refinement of robust yield prediction models as well as to understand what factors contribute to agricultural vulnerability. We also suggest future research investigate farmer adaptation strategies and resilience to better understand the sectors' vulnerability to changing drought risks and climate change.

Analysis of historical drought characteristics and quantification is an important first step towards placing the conditions experienced during the 2015-2018 drought in the Western Cape, South Africa in context. Along with hindsight analysis of the response, such studies strengthen the foundation of drought monitoring, and can support the development of early warning systems (Botai et al., 2017; WCDoA, 2019). Our study aimed to go a step further by exploring which aspects of the recent drought form part of longer-term trends. This would enable governments and communities to focus disaster risk reduction efforts on key hazards, rather than the last disaster, which can help shift responses from reactive to proactive.

Declaration of Competing Interest.

None.

Acknowledgements

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Appendix 1

Mean and standard deviation of long-term rainfall, Tmax and Tmin per station and difference from mean for each of the drought years, cells highlighted in yellow and red show σ-1 and σ-2 respectively

DJF = summer; MAM = autumn; JJA = winter; SON = spring. LTA= Long-term average, DAv=Drought Average

Rainfall (mm)						Maximum Temperature (ºC)						Minimum Temperature (ºC)					
Swartland																	
LTA	25.13	77.52	168.81	64.07	335.04	LTA	31.64	26.53	18.59	24.57	25.34	LTA	16.1	13	7.44	10.5	11.74
DAv	13.00	49.22	135.10	42.37	239.69	DAv	32.94	27.51	20.08	24.08	25.78	DAv	15.9	12.7	7.03	10.2	11.46
%	51.8	63.5	80.029	66.122	71.54	%	104	104	107.99	98	101.7	%	98.6	97.8	94.6	97.5	97.64
Langgewens																	
Mean	28.77	100.46	197.18	76.77	401.70	Mean	30.26	25.53	17.67	23.86	24.35	Mean	16.54	13.94	8.63	11.21	12.59
Stdev	14.64	50.77	58.96	32.68	96.62	Stdev	1.36	0.74	0.76	0.81	0.46	Stdev	0.74	0.59	0.67	0.83	0.52
2015	10.37	61.46	61.78	42.57	174.70	2015	0.38	-0.38	0.60	-1.20	-0.19	2015	1.14	0.41	0.51	0.05	0.18
2016	-0.63	23.46	-12.42	20.17	29.10	2016	-1.53	0.37	-0.60	-0.29	-0.12	2016	-0.76	0.56	0.41	0.58	0.54
2017	6.77	66.86	66.18	17.77	156.10	2017	-0.46	-2.09	0.02	-0.15	-0.49	2017	0.57	-0.47	0.91	0.87	0.20
2018	17.37	-1.94	26.98	21.77	62.70	2018	-0.75	0.88	0.00	-0.94	-0.65	2018	0.57	0.54	0.25	0.00	0.48
Piketberg																	
Mean	19.30	66.54	142.82	50.94	279.60	Mean	33.20	27.32	19.23	24.84	26.15	Mean	16.58	13.11	6.88	10.34	11.73
Stdev	14.52	39.08	46.22	32.21	74.21	Stdev	0.99	1.08	1.42	1.76	0.61	Stdev	0.80	0.48	0.70	0.93	0.43
2015	9.39	60.91	18.34	34.90	123.64	2015	0.43	-1.11	-0.74	0.17	-0.31	2015	1.05	0.25	0.06	-0.15	0.31
2016	11.94	18.75	32.82	-0.40	63.21	2016	-1.70	-0.40	-2.44	1.11	-0.86	2016	-1.02	0.25	-0.20	0.57	-0.10
2017	12.69	51.77	53.39	21.69	139.64	2017	-0.97	-2.74	-2.78	1.12	-1.34	2017	0.28	0.11	0.76	0.03	0.29
2018	17.53	8.08	35.87	8.22	69.80	2018	-0.92	0.17	-2.26	1.48	-0.38	2018	-0.33	0.05	0.08	0.35	0.04
Hopefield																	
Mean	27.31	65.55	166.43	64.51	323.80	Mean	31.47	26.74	18.88	25.01	25.53	Mean	15.04	11.71	6.62	9.71	10.77
Stdev	24.96	28.72	54.12	28.84	102.80	Stdev	0.85	0.73	0.82	1.26	0.50	Stdev	0.70	0.63	0.67	0.93	0.44

2015	12.51	44.95	49.03	49.91	156.40	2015	0.93	-0.50	0.60	-1.13	-0.02	2015	0.96	0.61	0.18	0.03	0.45
2016	12.31	-10.65	-22.57	3.51	-17.40	2016	-1.32	0.75	-0.59	-0.14	-0.32	2016	-1.01	0.19	0.00	0.10	-0.18
2017	17.51	37.35	74.43	29.31	158.60	2017	-0.04	-1.96	0.18	-0.09	-0.55	2017	0.71	0.28	1.06	0.44	0.63
2018	17.71	-21.65	20.63	10.91	27.60	2018	-0.25	1.10	-0.14	-0.71	0.00	2018	0.06	0.06	0.09	-0.20	0.00
Ruens																	
LTA	76.87	113.88	142.96	90.39	424.63	LTA	28.35	24.45	18.35	22.65	23.50	LTA	15.60	12.44	6.84	10.27	11.31
DAv	55	53.47	136.8	75.356	320.6	DAv	29.3	25.6	19.7	23.2	24.33	DAv	16.2	13.1	7.67	10.7	11.55
%	71.5	46.96	95.692	83.367	75.5	%	103	105	107.34	102	103.6	%	104	105	112	104	102.1
Tygerhgoek																	
Mean	97.50	114.88	134.93	122.02	469.32	Mean	28.90	24.84	18.80	23.48	24.01	Mean	15.63	11.98	5.70	9.94	10.81
Stdev	71.72	60.75	54.01	60.85	113.74	Stdev	0.74	0.92	1.56	0.84	0.63	Stdev	0.56	0.59	0.68	0.84	0.44
2015	21.65	102.19	1.44	-31.29	93.99	2015	-0.86	-0.16	1.80	-1.52	-0.19	2015	0.32	-0.37	-0.92	-0.22	-0.29
2016	3.50	60.28	128.33	99.92	292.02	2016	-1.83	-0.68	-0.524	-0.86	-0.97	2016	-0.14	0.35	0.11	0.35	0.17
2017	36.40	76.98	-10.67	-6.68	96.02	2017	-0.41	-2.55	-1.18	-1.11	-1.31	2017	0.89	0.63	0.94	1.35	0.95
2018	31.30	41.68	2.33	-3.08	72.22	2018	-0.82	-0.88	-0.56	-1.23	-0.87	2018	0.52	0.56	0.28	0.33	0.42
Protem																	
Mean	84.25	121.26	124.19	116.40	446.10	Mean	27.46	23.73	18.14	21.59	22.73	Mean	15.42	12.93	8.30	10.78	11.86
Stdev	48.50	64.62	38.49	62.85	89.35	Stdev	0.90	1.11	1.31	1.12	0.61	Stdev	0.48	0.40	0.52	0.50	0.29
2015	32.44	57.76	-89.43	-8.31	-7.54	2015	-0.79	-1.34	-0.45	0.22	-0.59	2015	0.06	0.01	0.38	-0.52	-0.02
2016	18.72	18.14	-39.39	43.50	40.97	2016	-1.63	-0.48	-1.54	0.25	-0.85	2016	-0.80	0.19	-0.37	-0.17	-0.29
2017	25.83	94.08	34.529	17.84	172.28	2017	-1.28	-2.45	-2.34	0.56	-1.38	2017	0.15	-0.22	0.20	0.46	0.14
2018	41.33	76.31	29.70	28.26	175.60	2018	-0.70	-1.36	-3.21	0.54	-1.18		0.23	-0.15	-0.59	-0.07	-0.14
Caledon																	

Mean	48.87	105.50	169.75	32.76	358.46	Mean	28.69	24.78	18.12	22.87	23.75	Mean	15.75	12.40	6.51	10.10	11.26
Stdev	29.56	50.43	35.42	16.80	64.18	Stdev	0.81	1.02	0.85	1.16	0.95	Stdev	0.94	1.13	1.04	0.94	0.84
2015	21.44	69.68	-61.90	8.20	39.01	2015	0.40	-0.62	0.48	-1.90	-0.28	2015	-0.50	-1.16	-1.98	-1.65	-1.25
2016	18.38	33.87	-21.77	20.74	52.80	2016	-2.42	-1.00	-1.97	-2.07	-1.73	2016	-1.83	-1.23	-1.99	-1.42	-1.55
2017	-4.21	64.86	94.32	6.09	162.64	2017	-1.86	-3.22	-0.77	0.56	-1.19	2017	-0.87	-1.33	-0.87	-0.08	-0.71
2018	15.86	29.05	6.43	5.24	58.16	2018	0.73	0.84	0.03	-0.21	0.48	2018	-0.05	-0.38	-0.74	-0.48	-0.34