Accepted Manuscript

South Africa's winter rainfall region drought: a region in transition ?

Emma Archer, Willem Landman, Johan Malherbe, Mark Tadross, Simone Pretorius
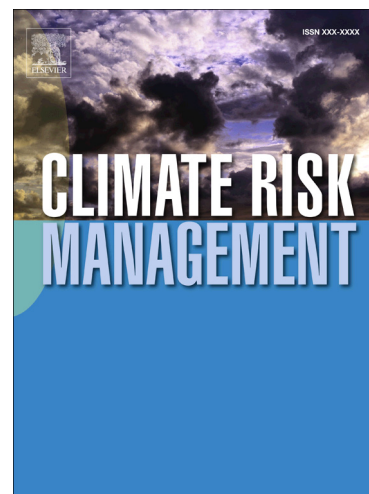
Please cite this article as: E. Archer, W. Landman, J. Malherbe, M. Tadross, S. Pretorius, South Africa's winter rainfall region drought: a region in transition ?, *Climate Risk Management* (2019), doi: https://doi.org/10.1016/j.crm. 2019.100188

South Africa's winter rainfall region drought: a region in transition ?

Emma Archer *[1] , University of Pretoria, Private Bag X20, Hatfield 0028, South Africa

Willem Landman, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa

Johan Malherbe, CSIR Natural Resources and the Environment, Building 33, Meiring Naude campus, Pretoria 0001, South Africa

Mark Tadross, Climate Systems Analysis Group, University of Cape Town/UNDP, Private Bag X3, Rondebosch 7701, South Africa

Simone Pretorius, Agricultural Research Council, Helshoogte Rd, Stellenbosch Central, Stellenbosch, 7599, South Africa

Abstract

The Western Cape region of South Africa is a key producing area for South African agriculture, with a strong dependence on austral winter rainfall. The past three years have, however, seen extensive drought impacting this region, with significant impacts on agriculture. In this article, we unpack how the drought unfolded, as well as possibilities in predicting winter rainfall. We consider how drought impacted agriculture, looking in depth at two commodities key to the winter rainfall region agricultural sector – namely, wheat and apples; concluding with a brief discussion of implications for the future.

Keywords: drought, agriculture, seasonal forecasting, southern Africa

---

[1] Corresponding author: Emma.Archer@up.ac.za

Introduction

Austral winter (June through August) rainfall is critical to the Western Cape region of South Africa, a key producing area in the agricultural sector, which in recent decades has seen increases in, amongst others, the production of potatoes, rooibos, honeybush tea, grapes and deciduous fruit orchards (Hoffman 2018). The last few years, however, have seen the region experiencing severe drought (Wolski 2018), with substantive implications for agriculture, water, as well as settlement areas. In this article, we consider how the drought unfolded, and how well it was predicted by operational centres and what our current forecasting capabilities are; as well as the most critical impacts on the agricultural sector (including two examples of specific agricultural commodities). We conclude by reflecting briefly on potential ways to adapt were there to be a higher frequency of such events in the future.

How did the drought unfold?

Figure 1 shows the 3-month Standardized Precipitation Index (SPI; Mckee et al. 1993) for the winter rainy seasons of 2015, 2016 and 2017 for the early (MAM), middle (JJA) and late (SON) parts of the rainy seasons respectively.
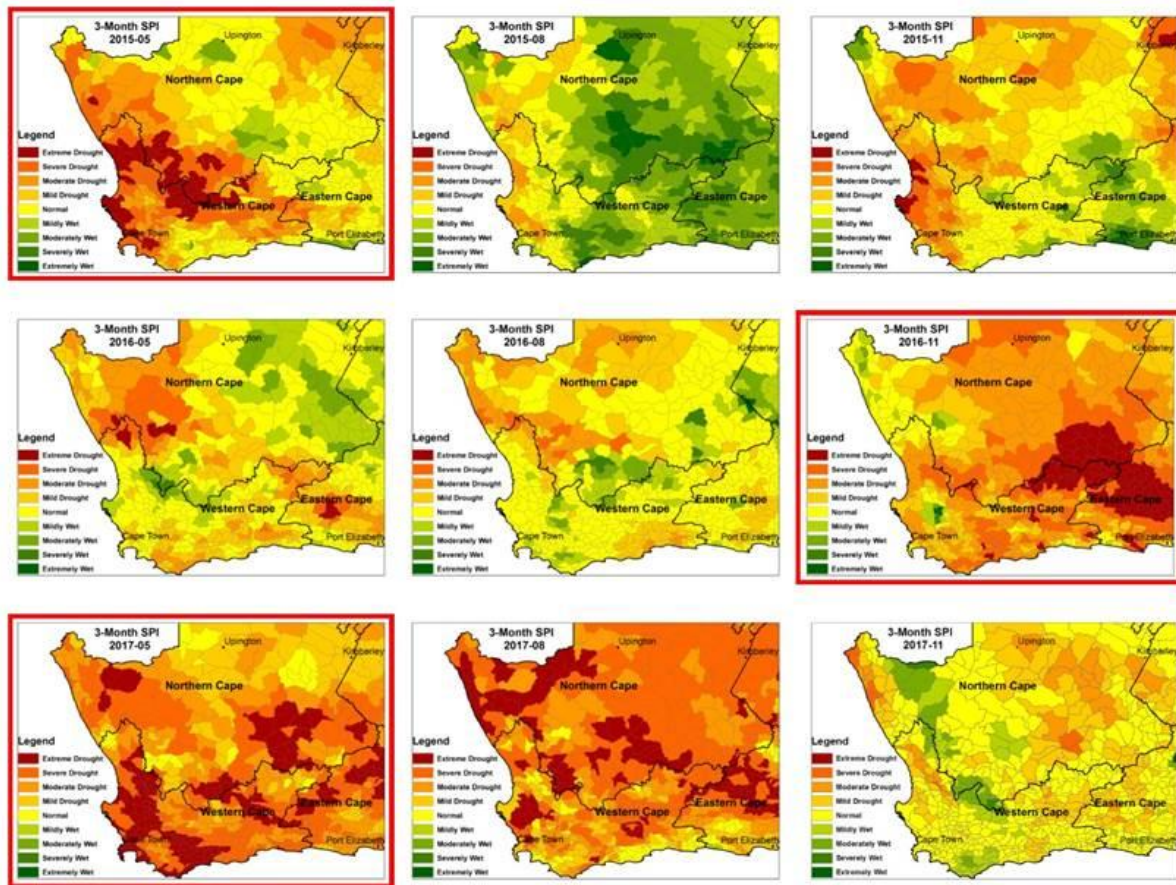
Figure 1   3-Month SPI for MAM (left), JJA (middle) and SON (right) for 2015 (top), 2016 (middle) and 2017 (bottom). The 3-month period with most extensive drought over the winter rainfall region per year is indicated (red frame).

All three winters had at least one season characterised by severe to extreme drought over large parts of the winter rainfall region. The 3-month periods with the most extensive drought over the region were MAM 2015, SON 2016 and MAM 2017, suggesting the largest impacts during the shoulder seasons. Considering the large-scale circulation over the Southern Hemisphere, the three winter rainy seasons during 2015 – 2017 together exhibited extraordinary deviations

compared to other years. The 3-month Southern Annular Mode (SAM/AAO; Gong and Wang 1999) for MAM, JJA and SON are shown for the years 1979 to 2017 in Figure 2.
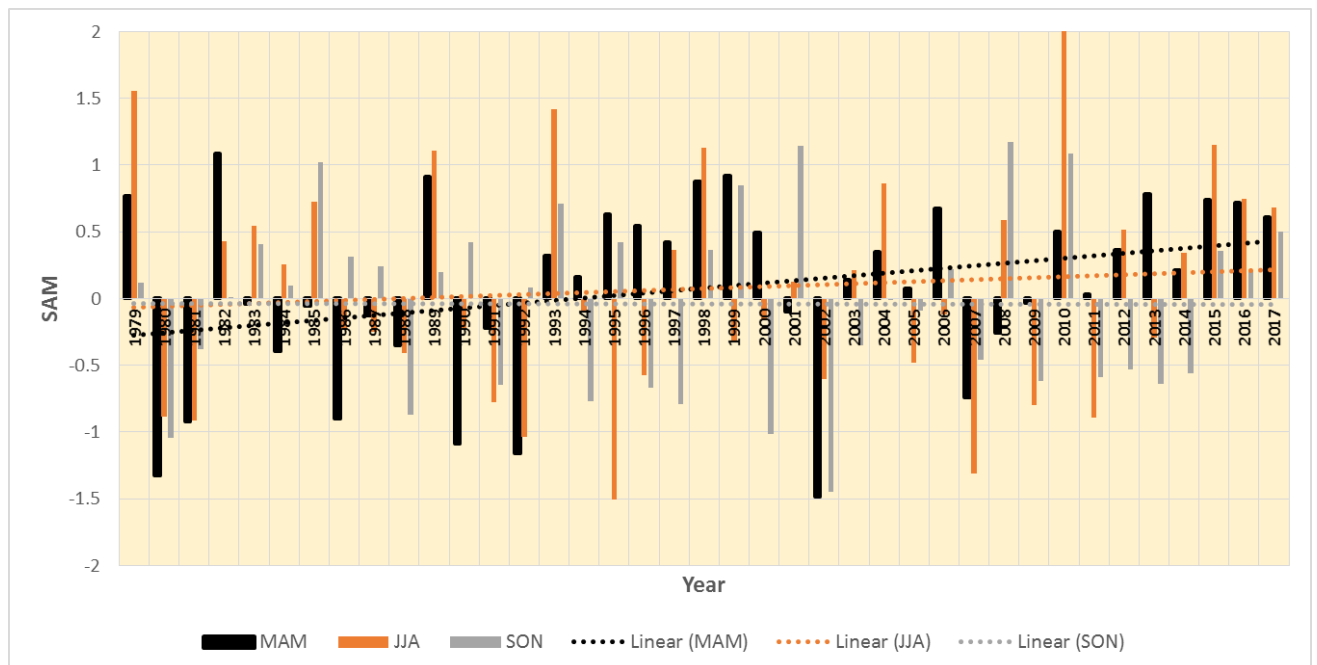
Figure 2: Southern Annular Mode (SAM) and associated linear trends from 1979 to 2017 for MAM (black), JJA (orange) and SON (grey). Data source: NOAA CPC Teleconnections WEB

Considering MAM, JJA and SON atmospheric circulation, the three winters of 2015 – 2017 were characterized by a positive SAM (Table 1) throughout. It is significant, and, the first time where the SAM was positive in all three parts of the winter rainy season for multiple successive years since at least 1979. Dry winters have been associated with a positive SAM (Reason and Rouault, 2005), and cumulative effects through the three-year period (2015-2017) may therefore be related

to this consistent positive anomaly. Moreover, Figure 2 demonstrates that the SAM has, on average, been increasing since 1979 during both MAM and JJA. This upward trend in the SAM is a well-established phenomenon (Marshall 2003), and has been linked to climate change (Miller et al. 2006). The upward trend during MAM is significant at the 95% confidence level, as determined by comparison of the time series to a thousand randomized time series generated through Monte Carlo simulations (Wilks 2011). Winters with a positive SAM are associated with a southward shift in storm tracks in the westerlies, resulting in drier conditions over the winter rainfall region due to the associated changes in low-level moisture flux, low-level convergence and local changes in uplift (Reason and Rouault 2005). Focussing on the driest 3-month period of each of the three winters in 2015-2017 (red frame in each row in Figure 2), Figure 3 shows the anomalies in 850 hPa heights, as well as the wind vector anomalies for each of the periods as indicated.

850hPa height and wind anomalies: MAM 2015

850hPa height and wind anomalies: SON 2016

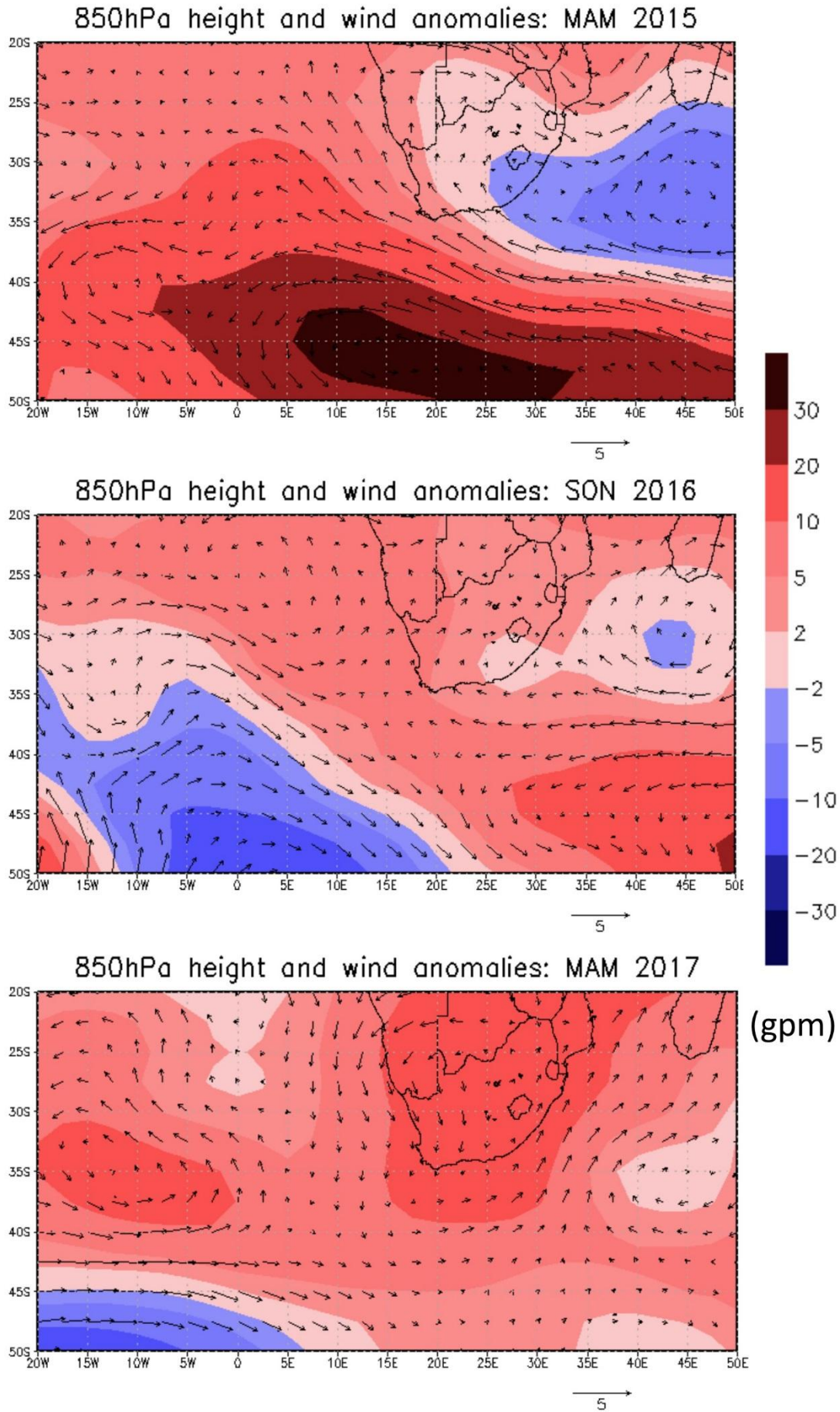850hPa height and wind anomalies: MAM 2017

(gpm)

6

Figure 3: 850 hPa anomalies in geo-potential meters (shading - gpm) and wind anomaly

vectors (arrows – m/s) for MAM 2015 (top), SON 2016 (middle) and MAM 2017 (bottom).

Positive pressure anomalies in the mid-latitudes are dominant on a hemispheric scale during

periods with a positive SAM, a reflection of a southward shift in storm tracks, also associated

with a southward shift in the moisture corridor during the period (Sousa et al. 2018). Whilst a

positive SAM is no guarantee of negative anomalies in the South African winter rainfall region

specifically, it is clear that the local pressure patterns associated with the positive SAM were

conducive to the anomalously low rainfall during each of these dry seasons specifically. In all

three cases (Figure 3), an anticyclonic anomaly in the vicinity of the winter rainfall region,

enhanced an off-shore component of the wind. Two of the seasons were associated with a long-

wave trough visible near 20°W, with the anticyclonic anomaly located towards the east in the

southern African sector. However, during SON 2016, the long-wave trough is situated at 35°E,

with the anticyclonic anomaly to the west.

Possibilities in predicting winter rainfall

Previous efforts to investigate southwestern Cape rainfall predictability have shown low skill for

the region (Landman et al 2005a), providing justification as to why this area has been largely

ignored in predictability studies (e.g. Landman et al 2005b). Hindcasts (or re-forecasts) from a

coupled ocean-atmosphere model of the North American Multi-Model Ensemble (NMME,

Kirtman et al., 2014) are here used to estimate seasonal rainfall predictability over the south-

western Cape. The model is the GFDL-CM2.5-FLOR-B01 and is referred to as GFDL. The

hindcasts from this climate model are for monthly data from the early 1980s to present, and for

12 ensemble members. Here, we analyse only SON, JJA and MAM rainfall forecasts produced at

a 1-month lead-time. For prediction system development and forecast verification, the Climatic

Research Unit (CRU) TS3.22 (Harris et al., 2014) data are used from which the observed seasonal total rainfall is derived. For the purpose of comparing hindcasts for the period from 2013 to 2017 with observations, Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) are used as observed rainfall for that period (Funk et al., 2014). The land area used in the analysis falls within the domain 35.75°S to 30.25°S and 16.25°E to 23.75°E.

Variance and bias corrections are performed on the GFDL's ensemble mean seasonal rainfall hindcasts and projected onto the CRU resolution (0.5°x0.5°). Seventeen years of GFDL hindcasts from 1980 to 1996 are used to calculate the statistics to be applied to the following 16 years in order to produce probabilistic hindcasts (Landman et al. 2012) on the CRU grid. The 16-year period serves as the test period over which the hindcasts are verified in their ability to produce probabilistic forecast for three equi-probable categories of below-, near- and above-normal seasonal rainfall totals. The skill scores include ranked probability skill scores (RPSS; Epstein, 1969) and relative operating characteristics (ROC; Mason 1982). RPSS values for the three 3-month seasons (not shown) suggest that SON rainfall is challenging to predict owing to all RPSS values being less than zero (using climatology as a reference forecast). MAM rainfall forecasts show marginally better skill, but are still likely to be too low to justify using forecasts for this season. The best results are obtained from JJA rainfall forecasts. However, most of the positive RPSS values are limited to an area over the domain north of 33.5°S and west of 21.5°E. Consequently, the verification results to follow are presented for this smaller and climatologically drier region and for JJA only. Even though the area for further analysis has been reduced, it still contains areas of high economic and societal significance, such as the larger part of the agriculturally active Boland area.

Figure 4 presents the attributes or reliability diagram (Hamill 1997) for above- (Fig. 4a) and for below-normal (Fig. 4b) JJA rainfall hindcasts over the 16-year test period (1997 to 2012). An important aspect of these diagrams to consider is the location of the weighted regression line

(Murphy and Wilks 1998) relative to the perfect reliability line. This straight line (thin blue or red line) represents the resolution slope of the reliability plot (thick blue or red line). For above-normal JJA rainfall, the thin regression line is slightly below the diagonal representing perfect reliability, suggesting that the hindcast probabilities are higher than the observed frequencies. Such an outcome means that the hindcasts for above-normal rainfall are over-confident. BSS and ROC values for the above-normal category as well as the RPSS over all three categories are also presented in Fig. 4a. Both the BSS and RPSS outscore forecasts of climatology (equal chance of a season being below-, near- or above-normal). The ROC value of 0.7 shows that the forecast model also has the ability to discriminate above-normal JJA rainfall seasons from the rest of the JJA seasons. Over-confidence for the below-normal rainfall category ("drought") is small, as can be seen from the close proximity of the thin red line to the diagonal perfect reliability line. Hindcasts for below-normal JJA rainfall seasons have consequently been found to be highly reliable. For below-normal JJA rainfall, the ROC value is about 0.7 and thus shows that the model also has the attribute of discrimination for below-normal JJA rainfall totals. These verification results, albeit for a reduced area of the south-western Cape, provide strong evidence of mid-winter rainfall predictability by a state-of-the-art seasonal climate forecast model. Moreover, these results show a general improvement in the forecast skill levels over the region that was established more than a decade ago (Landman et al., 2005a).

Next we compare the model's probability forecasts with observed rainfall during a recent 5-year period (2013 to 2017), immediately following the verification period (1997 to 2012). In terms of forecasts, Fig. 5. shows JJA probabilistic rainfall forecasts produced in a manner that is reminiscent of an operational forecast setting. The blue and yellow bars respectively represent probabilistic above-normal and below-normal JJA rainfall forecasts for the reduced area. The red line is a rainfall index that represents observed rainfall for the same area. Above-normal JJA rainfall is predicted to be the most likely category for 2013 and 2015 - these forecasts turned out

9

to be quite useful, since the observed rainfall for these two seasons are extremely high (above the 75th percentile). Similarly useful, for the more likely below-normal category predicted for 2014, the observed rainfall is lower than the 33rd percentile. The JJA rainfall forecast for 2016 may be considered less useful than the forecasts for the preceding years, since the 2016 forecast is very confident for drought, yet the observed rainfall is slightly above the median albeit below the average. The 2017 forecast turns out to be the most disappointing, since the most likely category is above-normal while the observed rainfall was below the median. So for the 5-year "operational" forecast period (2013 to 2017), the JJA rainfall forecasts provided the correct direction (e.g. highest forecast probability for below-normal rainfall in a season when below-normal rainfall occurred) for 3 of the 5 years. This result is a further demonstration of rainfall predictability over the region.

Forecasts issued by some of the operational centres, one locally (the South African Weather Service (SAWS); unfortunately, archived forecasts are currently unavailable on their site) and one internationally (the International Research Institute for Climate and Society (IRI); https://iri.columbia.edu/our-expertise/climate/forecasts/seasonal-climate-forecasts/) for the main rainfall season of JJA over three years (2015 to 2017) are not in strong agreement with each other. The SAWS JJA rainfall forecasts (not shown) produced in May all show enhanced probabilities of above-normal rainfall totals, while the IRI's forecasts are more in agreement with the forecasts shown in Figure 5. Therefore, the forecasts for the three main rainfall seasons discussed in the paper have not been particularly useful, since the forecast direction was predicted correctly only in 2015.

Skill in predicting winter rainfall has been demonstrated by analysing the verification results of 16 years (1997 to 2012) of probabilistic rainfall hindcasts over parts of the south-western Cape. In

addition to the test period, the model was configured to produce forecasts for a further 5 years. It was again confirmed that the model was able to capture most of the observed JJA rainfall anomalies. Notwithstanding the demonstrated seasonal rainfall predictability over the region, there is still higher predictability found over the summer rainfall regions (e.g. Landman et al. 2012), predictability is restricted to only a specific area of the region, and there is still low predictability for the seasonal onset (MAM) and cessation (SON) seasons. More modelling work is therefore certainly needed in order to improve on winter rainfall predictability for southern Africa.
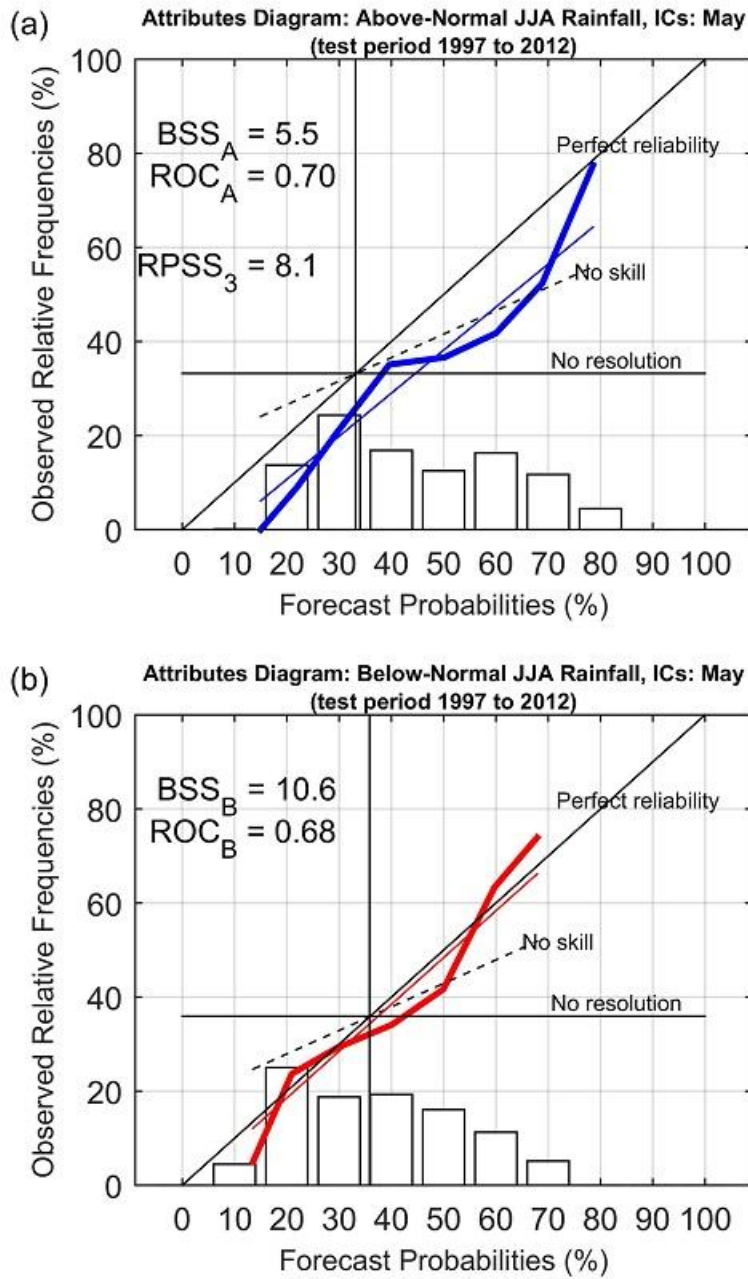
Figure.4. Reliability diagram and associated frequency histogram for above-normal (a) and below-normal (b) JJA rainfall totals over the reduced area. The Brier skill score (BSS) and relative operating characteristic (ROC) score for two categories are presented, as well as the ranked probability skill score (RPSS) over the three categories.
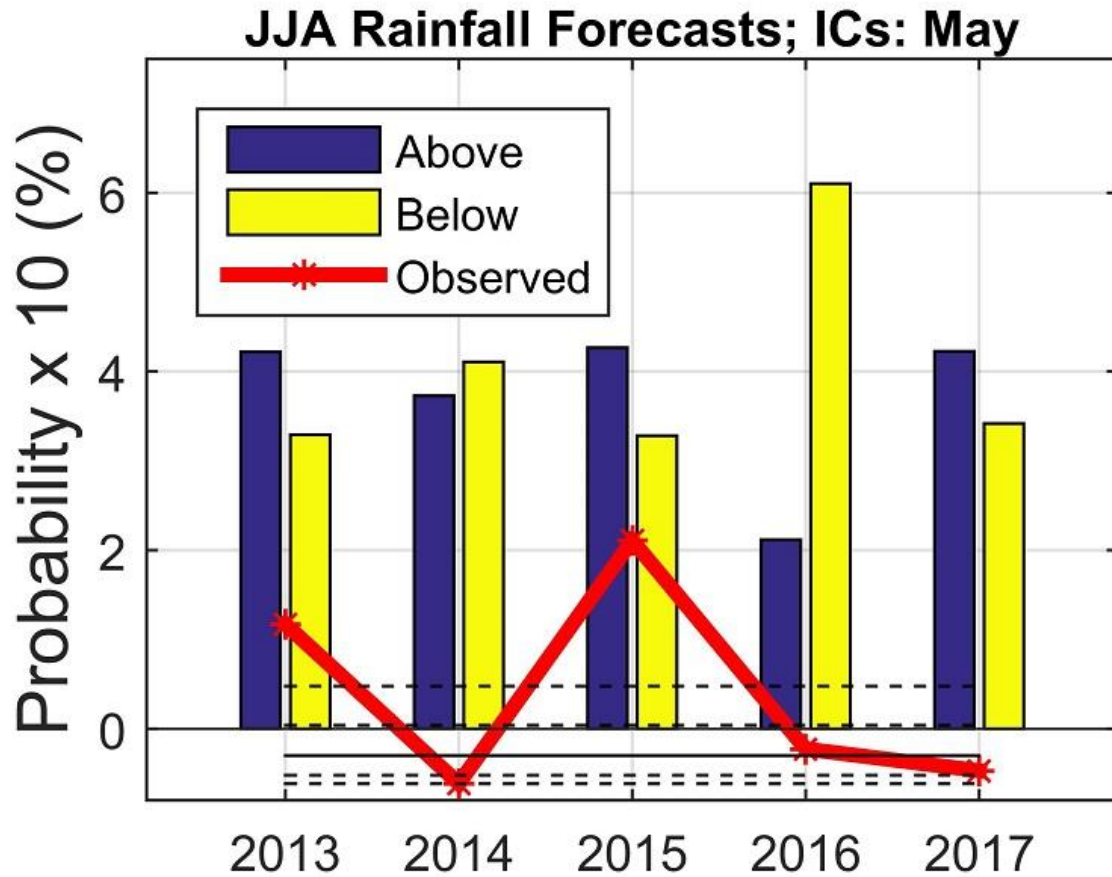
Figure 5. Area-averaged probabilistic JJA rainfall forecasts for above- (blue bars) and below-normal (yellow bars) rainfall totals. The red line represents area-averaged observed rainfall as standardised values. The horizontal lines represent (from top to bottom) the 75th, 66th, 50th (median), 33rd and 25th percentile values of climatology.

Impacts on key sectors

The 2015-2018 multi-year drought described in previous sections resulted in lower levels of water in Western Cape dams, dropping to 17% by April 2018 (DWS 2018). Following three years

of decreasing water levels, the hydrological impacts influenced the agricultural sector through decreased availability of irrigation water. In some areas, lower priority vegetables such as onions, potatoes and tomatoes were not planted due to the drought and limited availability of irrigation water. Other crops such as citrus also suffered losses related to unavailability of irrigation quotas (Trautman 2018). The drought further resulted in damage to perennial crops (where impacts will still be felt during the next few years) (Pienaar and Boonzaaier 2018).

Production losses such as sunburn damage, directly related to hot and dry conditions, also occurred in the citrus, pome- and stone fruit markets. Further, depleted grazing and fodder necessitated cattle and sheep herd size reductions (Trautmann 2018). The production of wheat, of which the province is the main producer in the country, suffered a sharp decline during this period. Wheat production in the province declined by 45%, year-on-year, in 2017 (CEC 2018). The low wheat yields in the Western Cape in 2015 and 2017 during the drought period resulted in a reduction of 25% in the production of wheat nationally compared to the production of a decade earlier (CEC 2018, see further detail below)

Agricultural production losses over the 3-year drought period had a serious economic impact, including on job numbers. Employment losses, focussing on farmworkers specifically, amounted to between 28 00 and 35 000 over the three year period, with a further knock-on effect in the processing and food sectors (Pienaar and Boonzaaier 2018). Specific more in-depth examples of sector impacts for wheat and apples (critical agricultural sectors in the Western Cape) are provided below in more detail.

Wheat Production

Wheat production across the province varies, yet the majority is rainfed, reliant on adequate rainfall for good yield (ARC-SGI, 2018). The Swartland and Rûens are the two primary wheat growing areas in the winter rainfall region (Kloppers, 2014). For winter wheat, which is planted in May, rainfall timing is crucial. In order for new plants emergence and establishment, it is preferable that rain falls before the end of May, but imperative that rain falls before mid-June. Rain must also fall in the vegetative part of the growth season from June to August. Rainfall in September, when the plants are in their reproduction phase, is also critical - without it, drought-induced stress is significant (AgriOrbit, 2018).

Impacts of the 2015-2018 drought on wheat yield have been varied, but concerning. Yield in the 2016 season was on par with yields in 2013, and the total national harvest increased by 30% year-on-year (compared to 2015) and by 13% above the three-year average (Western Cape Department of Agriculture, 2017). However, 2015/2016 and 2017/2018 showed a marked decrease in yield. The Western Cape Department of Agriculture reported "record losses in wheat production" after a 47% decline from 1.1 million tonnes in 2016/2017 to 586 000 tonnes in 2017/2018 was noted (Western Cape Department of Agriculture, 2018). The significant decrease in yield in 2017/2018 can be attributed to aforementioned below average rainfall and very low soil moisture in parts of the Western Cape. Furthermore, significant variation in wheat crop condition was observed, affecting overall yield. In Figure 6, yield variation between the Swartland and Rûens areas can be clearly noted - on average, the drought affected yield in the Swartland more severely than in the Rûens and during drought years, wheat yield was higher in the latter.

Drought conditions not only affect wheat yields, but also impacts the quality of wheat harvested. Water stress causes higher whole wheat protein concentrations in the yield, which, in fact,

improves overall quality. The 2017/2018 harvest in the winter rainfall region had a whole wheat protein average of 13.2%, the highest in 20 years, and approximately 0.8% more than the 4-year average preceding the drought (ARC- SGI, 2015; South African Grain Laboratory, 2017 & 2018).

	2013	2014	2015	2016	2017
Swartland	4.77	4.03	2.21	3.94	2.54
Ruens	3.66	3.1	3.89	4.35	3.03

Figure 6. Trends in wheat production from 2013-2016 for the two primary wheat regions in the winter rainfall region of the Western Cape. Data obtained from ARC-SGI, (2018).

Apple Production

There are two primary apple producing regions in the Western Cape namely: Elgin-Grabouw-Vyeboom-Villiersdorp (EGVV) and Koue Bokkeveld (KBV). Quantifying the impact of the drought on the apple sector in the province is challenging, partly because sector drought impacts vary markedly between regions, and even between neighbouring farms (Hortgro, 2018). The

16

apple producing regions also have well developed irrigation infrastructure, providing something of a buffer (assuming water stores hold). Furthermore, the effects of the prolonged drought have only started to impact the apple sector in 2017 and 2018, when the water allocations for agriculture were cut between 60% and 86% (Pienaar and Boonzaaier 2018). It is expected that the apple industry will experience reduced growth at least until water availability has returned to normal (Western Cape Department of Agriculture, 2017). Further, drought often has a significantly delayed effect on fruit trees, impacting future production seasons, as it may take years for trees to recover from a drought cycle. Severe drought stress causes weaker flowering of apple trees, and the flowers produced are of poor quality, resulting in fewer cells and a shorter lifespan which may impact the fruit in the following seasons (FruitSA, 2018).

In the EGVV region, the effects of the drought have varied spatially. The Vyeboom-Villersdorp area, dependent on the Theewaterskloof water scheme for irrigation, has been severely impacted by water curtailments (Western Cape Department of Agriculture, 2017). However, the Grabouw-Elgin area, less than 40km away, experienced less severe drought, as the region received adequate rainfall and relies on private on-farm dams for irrigation (Hortgro, 2018). In the KBV, drought has been more pronounced, as the region received less than half its normal annual rainfall - coupled with heatwave conditions, this led to the depletion of on-farm dams, resulting in increased stress on the fruit trees. KBV is strongly dependent on rainfall and groundwater for irrigation. Overall, the drought has caused a 16% decrease in volume of fruit harvested in 2017 , and apple export volumes are estimated to decrease by 8% compared to 2017 (Jansen, 2018). The decrease is caused by a combination of factors, with drought negatively impacting production volumes, fruit size, and pack outs. However, hail, wind, and sunburn have also contributed to lower export volumes (African Farming, 2018). Interestingly, in terms of fruit quality, some fruit farmers reported improved fruit quality, as fruit under water scarce conditions usually contains higher sugar levels (improving taste) (Hortgro, 2018).

Conclusions and Moving Forward

The Western Cape will most likely face a warmer future, with evidence to suggest that rainfall may on average decrease (e.g. Engelbrecht et al. 2009, Otto et al. 2018), all of which will continue to stress agriculture in the province (particularly when multiple stressors are taken into account – see, for example, recent studies undertaken through the Green Book initiative, further highlighting national significance of Western Cape agriculture). Changes to the spatial distribution, seasonal cycles and extremes in rainfall are also likely (SmartAgri, 2016). Such climatic changes are likely to cause agricultural regions to shift spatially, with significant agricultural impacts, including (but not limited to) those described above, with irrigated agriculture and urban water demand competing for allocations from the Western Cape Water Supply System (WCWSS; Lötter 2019). During the recent drought affecting the winter rainfall region, as mentioned above, agricultural allocations were reduced and urban demand curbed by placing restrictions on households and fining excessive use (Davids 2019). Under future climate, water supply pressure will likely increase, and the agricultural sector needs to continue the process of adapting their water management strategies and broader adaptation strategies – for example using adapted types and cultivars, using heat protection measures, and introducing more water efficient technologies (SmartAgri 2016). Such approaches are critical for the export fruit industry in particular, as there is very little scope for expansion of irrigation, given the limited supply of water (Western Cape Department of Agriculture, 2011); and particularly given the aforementioned key role that the Western Cape plays in contributing to national agriculture (Lötter 2019).

Forecasts themselves can help support and inform adaptive measures, if conditions to improve forecast application are met. We have shown here promise in seasonal prediction for the winter

18

rainfall region (albeit mostly for the mid-winter season of JJA), although continued strategic effort is required to improve their development and application. A strong (although not singular) focus here should be on forecast system development (including further investment in basic forecast research) – we would argue that this could take place in tandem with a focus on improved application, as a two-way iterative process. With improved forecasts, including improved development of applied forecasting, the province would need to carefully consider current and future conditions for improved forecast application, such that such information might inform adaptive measures in realistic and practical ways.

References

African Farming. 2018. *Drought to Slash SA Apple and Pear Exports*. Retrieved 5 25, 2018, from https://www.africanfarming.com/drought-slash-sa-apple-pear-exports-2018/

Agriculture, Western Cape Department of. 2018. *Drought Policy Brief*. Cape Town: Western Cape Department of Agriculture.

AgriOrbit. 2018. *Uncertainty over Western Cape wheat cultivation conditions*. Retrieved 06 15, 2018, from https://agriorbit.com/uncertainty-western-cape-wheat-cultivation-conditions/

ARC-SGI. 2018. *Wheat*. Retrieved 6 18, 2018, from http://www.arc.agric.za/arc-sgi/Pages/General%20Information%20on%20SGI%20Homepage/Wheat.aspx

ARC-SGI. 2018. *Guideline: Production of Small Grains in the Winter Rainfall Area*. Stellenbosch: Agricultural Research Council-Small Grains Institute

CEC. 2018. Crop Estimates Committee, Department of Agriculture, Forestry and Fisheries, Pretoria. Winter Cereal (2017): *Final Production Forecast*.

Davids, N. 2019. Cape Town's drought under the microscope. *UCT News*, 29th January 2019. Cape Town: University of Cape Town.

DWS. 2018. Department of Water and Sanitation.

http://www.dwa.gov.za/Hydrology/Weekly/Province.aspx

Engelbrecht, F.A., McGregor, J.L. and Engelbrecht, C.J., 2009. Dynamics of the Conformal-Cubic Atmospheric Model projected climate-change signal over southern Africa. *International Journal of Climatology*: A Journal of the Royal Meteorological Society, 29(7), pp.1013-1033.

Epstein, E.S., 1969. A scoring system for probability forecasts of ranked categories. *Journal of Applied Meteorology*, 8, 985–987.

FruitSA. 2018. Drought challenges fruit industry. Retrieved 6 14, 2018, from FruitSA:

https://www.fruitsa.co.za/drought-challenges-fruit-industry/

Funk, C. C, Peterson, P. J., Landsfeld, M. F., Pedreros, D. H., Verdin, J. P., Rowland, J. D., Romero, B. E., Husak, G. J. Michaelsen, J. C., and Verdin, A. P., 2014. A quasi-global precipitation time series for drought monitoring: *U. S. Geological Survey Data Series 832*, 4 p., http://dx.doi.org/110.3133/ds832.

Gong, D. & Wang, S., 1999. Definition of Antarctic Oscillation Index. *Geophysical Research Letters* 26: 459-462.

Hamill, T. M., 1997. Reliability diagrams for multicategory probabilistic forecasts. *Weather and Forecasting*, 12, 736–741.

Harris, I., Jones, P. D., Osborn, T. J., and Lister, D. H., 2014: Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 Dataset. *Int. J. Climatol.*, 34: 623-642. doi: 10.1002/joc.3711

Hoffman, M.T. 2018. Land use, land cover and vegetation change in southern Africa. Chapter 6 in Holmes, P.J. & Boardman, J. (eds). *Southern African Landscapes and Environmental Change.* London: Routledge. 328 pp.

Hortgro. 2018, 1 22. Drought Challenges for Deciduous Industry. Retrieved 6 14, 2018, from Hortgro: https://www.hortgro.co.za/industry-news/drought-challenges-for-deciduous-industry/

Hortgro. 2018, 20 2. Fruit Producers Open Hearts and Sluices. Retrieved 6 15, 2018, from Hortgro: https://www.hortgro.co.za/news/fruit-producers-open-hearts-and-sluices/

Jansen, C. 2018. Challenging season for fruit production around Ceres. Retrieved 5 25, 2018, from http://www.freshplaza.com/article/192722/Challenging-season-for-fruit-production-around-Ceres

Kirtman, B. P., and Coauthors, 2014. The North American Multimodel Ensemble: Phase-1 seasonal-to-interannual prediction; Phase-2 toward developing intraseasonal prediction. *Bull. Amer. Meteor. Soc.*, 95, 585–601. doi: http://dx.doi.org/10.1175/BAMS-D-12-00050.1.

Kloppers, P. 2014. *Investigating the relationships between wheat-specific rainfall characteristics, large-scale modes of climate variability and wheat yields in the Swartland region, South Africa*. Cape Town: University of Cape Town.

Landman, W.A., Botes, S., Goddard, L., and Shongwe, M. (2005). Assessing the predictability of extreme rainfall seasons over southern Africa. *Geophysical Research Letters*, 32, L23818, DOI: 10.1029/2005GL023965.

Landman, W.A. and Goddard, L. (2005). Predicting southern African summer rainfall using a combination of MOS and perfect prognosis. *Geophysical Research Letters*, 32, L15809, DOI: 10.1029/2005GL022910.

Landman, W.A., Beraki, A., DeWitt, D. and Lötter, D. 2014. SST prediction methodologies and verification considerations for dynamical mid-summer rainfall forecasts for South Africa, *Water SA*, 40(4), 615-622, http://dx.doi.org/10.4314/wsa.v40i4.6.

Landman, W.A., DeWitt, D. Lee, D.-E., Beraki, A. and Lötter, D. 2012. Seasonal rainfall prediction skill over South Africa: 1- vs. 2-tiered forecasting systems. *Weather and Forecasting*, 27, 489-501. DOI: 10.1175/WAF-D-11-00078.1.

Lötter, D. 2019. *Green Book – Climate change impacts on agriculture, forestry and fisheries*. Technical report, Pretoria: CSIR

Mason, I.B., 1982. A model for assessment of weather forecasts. *Australian Meteorological Magazine*, 30, 291–303.

McKee, T.B., Doesken, N.J. and Kleist, J., 1993. The relationship of drought frequency and duration to time scales. In *Proceedings of the 8th Conference on Applied Climatology* (Vol. 17, No. 22, pp. 179-183). Boston, MA: American Meteorological Society.

Miller, R.L., Schmidt, G.A. and Shindell, D.T., 2006. Forced annular variations in the 20th century intergovernmental panel on climate change fourth assessment report models. *Journal of Geophysical Research: Atmospheres*, *111*(D18).

Murphy, A.H., and D.S. Wilks, 1998. A case study in the use of statistical models in forecast verification: precipitation probability forecasts. *Weather and Forecasting*, 13, 795–810.

NOAA CPC Teleconnections WEB.
http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/aao/aao.shtml

Pienaar L and Boonzaaier J. 2018. *Drought Policy Brief, Western Cape Agriculture*. A report compiled by the Department of Agriculture, in collaboration with the Bureau for Food and Agricultural Policy (BFAP). https://www.westerncape.gov.za/sites/www.westerncape.gov.za/files/droughtpolicybrief_2018.pdf Accessed: 2018-06

Reason, C.J.C. and Rouault, M., 2005. Links between the Antarctic Oscillation and winter rainfall over western South Africa. *Geophysical Research Letters*, 32(7).

SmartAgri. 2016. *Status Quo Review of Climate Change and Agriculture in the Western Cape Province.* Western Cape Department of Agriculture from http://www.greenagri.org.za/smartagri-2/smartagri-plan/

Sousa, P.M., Blamey, R.C., Reason, C.J., Ramos, A.M. and Trigo, R.M., 2018. The 'Day Zero' Cape Town drought and the poleward migration of moisture corridors. *Environmental Research Letters*, 13(12), p.124025.

South African Grain Laboratory. 2016. *Wheat Report 2015/2016*. Pretoria: South African Grain Laboratory.

Trautmann, I., 2018. Drought fact sheet-informing the Western Cape agricultural sector on the 2015-2017 drought. *Agriprobe*, *15*(1), pp.13-13.

Western Cape Department of Agriculture. 2017. *Informing the Western Cape agricultural sector on the 2015-2017 drought.* Cape Town : Western Cape Department of Agriculture.

Wilks, D.S., 2011. *Statistical methods in the atmospheric sciences*, 3rd edn. Academic Press, Amsterdam

Wolski, P., 2018. How severe is Cape Town's "Day Zero" drought?. *Significance*, 15(2), pp.24-27.

Otto, F.E., Wolski, P., Lehner, F., Tebaldi, C., Van Oldenborgh, G.J., Hogesteeger, S., Singh, R., Holden, P., Fučkar, N.S., Odoulami, R.C. and New, M., 2018. Anthropogenic influence on the drivers of the Western Cape drought 2015–2017. *Environmental Research Letters*, 13(12), p.124010.