GREENBOOK
adapting settlements for the future

IMPACT OF CLIMATE CHANGE ON DROUGHT

WORKSTREAM 4: RESEARCH REPORT

2019

CSIR
our future through science

www.greenbook.co.za

Project partner

NATIONAL DISASTER MANAGEMENT CENTRE · SOUTH AFRICA

Funded by

IDRC | CRDI
International Development Research Centre
Centre de recherches pour le développement international

Canada

Authors	Asmeron Beraki
Date	2019
ToDB reference	CSIR/NRE/GC/ER/2019/0006/C
Suggested citation	Beraki, A. 2019. *Green Book – The Impact of Climate Change on Drought.* Technical report, Pretoria: CSIR

Disclaimer and acknowledgement: *This work was carried out with the aid of a grant from the CSIR Long-term Thematic Programme, Pretoria, South Africa and the International Development Research Centre, Ottawa, Canada. The views expressed herein do not necessarily represent those of the IDRC or its Board of Governors.*

TABLE OF CONTENTS

1 INTRODUCTION 5

2 METHODOLOGY 6

2.1 Regional climate model and experimental design 6

2.2 Climate extreme indices 7

3 RESULTS 8

4 REFERENCES 13

TABLE OF FIGURES

Figure 1: Observed state of drought (flood) based on SPI (upper panel) and SPEI (lower panel) for the north-eastern (part of the summer rainfall region; (a), (c)) and south-western (part of winter rainfall region; (b, d)) parts of South Africa. 9

Figure 2: Projected change in the drought (flood) tendencies (i.e., number of cases exceeding near-normal per decade) over South Africa for the period 1995-2024 relative to the 1986-2005 baseline period, under a low mitigation scenario (RCP8.5). Projections are shown for each of the six CCAM downscalings (a-f) and ensemble mean (g). The stipples in figure (g) show significance 95% (see text for details). 10

Figure 3: Projected change in the drought (flood) tendencies (i.e., number of cases exceeding near-normal per decade) over South Africa for the period 2015 - 2044 relative to the 1986-2005 baseline period, under a low mitigation scenario (RCP8.5). Projections are shown for each of the six CCAM downscalings (a-f) and ensemble mean (g). The stipples in figure (g) show significance 95% (see text for details). 11

Figure 4: Projected change in the drought (flood) tendencies (i.e., number of cases exceeding near-normal per decade) over South Africa for the period 2035 - 2064 relative to the 1986-2005 baseline period, under a low mitigation scenario (RCP8.5). Projections are shown for each of the six CCAM downscalings (a-f) and ensemble mean (g). The stipples in figure (g) show significance 95% (see text for details). 12

1 INTRODUCTION

The last three years, specifically, have witnessed the occurrence of a number of remarkably intense and high-impact weather events in Africa and the world. The summer of 2015/16 was associated with the most intense El Niño event ever recorded. The year 2015 also turned out to be the warmest calendar year in recorded history, only to be superseded in this regard by 2016. Moreover, in 2015, a critical symbolic (and physical) threshold was exceeded – it was the first year for which the global average surface temperature was 1 °C warmer than the pre-industrial average. This period of unprecedented high global temperatures is thought to have been the result of systematic global warming under the enhanced greenhouse effect in combination with natural variability in the form of an intense El Niño event.

In southern Africa, the impacts of the 2015/16 El Niño event were also significant. The region experienced its warmest summer period in recorded history, in the order of 2 °C warmer than the present-day average climatological temperature. In fact, during this period numerous weather stations in the southern African interior recorded average monthly temperatures in the order of 5 °C above their monthly average climatological temperatures (Engelbrecht et al., 2016). Moreover, large parts of the summer rainfall region of southern Africa recorded their driest summer season since 1900. In the mega-dam region of eastern South Africa, dam levels reached critically low levels. Water restrictions followed over much of South Africa and the maize crop yield was reduced significantly. Over much of the summer rainfall region of southern Africa, the La Niña event of 2016/17 brought significant relief from the oppressive temperatures and drought. However, in 2017, South Africa became acutely aware of a new water crisis, this time in the winter rainfall region. After three successive years of below normal rainfall, dam levels in the Western Cape reached critically low levels by September 2017. During this period of drought, devastating fires occurred in Knysna and along the Garden Route in June 2017. The dry state of vegetation and an exceptionally warm autumn contributed to the outbreak and extent of the fires.

The southern African region (particularly South Africa) is projected to become generally drier under enhanced anthropogenic forcing, with an associated increase in dry spells and droughts (e.g. Christensen et al., 2007; Engelbrecht et al., 2009). East Africa and much of tropical Africa are projected to become generally wetter (Christensen et al., 2007; Engelbrecht et al., 2009; James and Washington, 2013; Niang et al., 2014). Tropical cyclone tracks are projected to shift northward, bringing more flood events to northern Mozambique and fewer to the

Limpopo province in South Africa (Malherbe et al., 2013). Such changes in temperature and rainfall patterns will plausibly have a range of impacts on our region, including impacts on energy demand (in terms of ensuring human comfort within buildings and factories), agriculture (e.g. reductions of yield in the maize crop under higher temperatures and reduced soil moisture), livestock production (e.g. higher cattle mortality as a result of oppressive temperatures), water security (through reduced rainfall and enhanced evapotranspiration) and other similar climate sensitive segments of the economy (Thornton et al., 2011; Engelbrecht et al., 2015; Garland et al., 2015).

2 METHODOLOGY

2.1 Regional climate model and experimental design

High-resolution regional projections of future climate change over Africa were analysed to describe how the regional climate change signal over South Africa may unfold under different degrees of global warming. The regional climate model used is the conformal-cubic atmospheric model (CCAM), a variable-resolution global climate model (GCM) developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia (McGregor, 2005; McGregor and Dix, 2001, 2008). CCAM runs coupled to a dynamic land-surface model CABLE (CSIRO Atmosphere Biosphere Land Exchange model). Six GCM simulations of the Coupled Model Intercomparison Project Phase Five (CMIP5) and Assessment Report Five (AR5) of the Intergovernmental Panel on Climate Change (IPCC), obtained for the emission scenarios described by Representative Concentration Pathways 4.5 and 8.5 (RCP4.5 and 8.5) were downscaled to a 50 km resolution globally. The simulations span the period 1971-2099. RCP4.5 is a high mitigation scenario, whilst RCP8.5 is a low mitigation scenario. The scope of the analysis is confined to assessing the impact of climate change under the low mitigation scenario (RCP8.5) on the current and future moisture budget of the country. The GCMs downscaled are the Australian Community Climate and Earth System Simulator (ACCESS1-0), the Geophysical Fluid Dynamics Laboratory Coupled Model (GFDL-CM3), the National Centre for Meteorological Research Coupled Global Climate Model, version 5 (CNRM-CM5), the Max Planck Institute Coupled Earth System Model (MPI-ESM-LR), the Norwegian Earth System Model (NorESM1-M) and the Community Climate System Model (CCSM4). The simulations were performed on supercomputers of the Centre for High Performance Computing (CHPC) of the Meraka Institute of the CSIR in South Africa.

In these simulations CCAM was forced with the bias-corrected daily sea surface temperatures (SSTs) and sea ice concentrations of each host model, and with CO_2, sulphate and ozone forcing consistent with the RCP4.5 and RCP8.5 scenarios. The bias is computed by subtracting for each month the Reynolds et al. (2002) SST climatology (for 1961-2000) from the corresponding CGCM climatology. The bias-correction is applied consistently throughout the simulation. Through this procedure the climatology of the SSTs applied as lower boundary forcing is the same as that of the Reynolds SSTs. However, the intra-annual variability and climate change signal of the CGCM SSTs are preserved (Katzfey et al., 2009). The model's ability to realistically simulate present-day southern African climate has been extensively demonstrated (e.g. Engelbrecht et al., 2009; Engelbrecht et al., 2011; Engelbrecht et al., 2013; Malherbe et al., 2013; Winsemius et al., 2014; Engelbrecht et al., 2015) and is thus not featured in this section.

2.2 Climate extreme indices

The study primarily uses the Standardized Precipitation Index (SPI) (McKee et al., 1993, 1995), which is recommended by the World Meteorological Organization (2006) and also acknowledged as a universal meteorological drought index by the Lincoln Declaration on Drought (Hayes et al., 2011), to characterize the extent of the severity, tendency and time evolution of drought (flooding) over South Africa. The SPI, with a two-parameter gamma distribution fit with maximum likelihood estimates of the shape and scale parameters, was applied on monthly mean daily rainfall accumulations for a 3, 6, 12, 24 and 36 months base period (scale). The SPI severity index is interpreted in the context of negative values indicating droughts and positive values indicating floods. These values range from exceptionally drier (<-2.0) or wetter (>2.0) to near-normal (region bounded within -0.5 and 0.5). The extent of moisture stress or loss due to global warming was also assessed using the Precipitation-Evapotranspiration Index (SPEI) (Vicente-Serrano et al., 2010; Beguería et al., 2013). The SPEI utilizes a similar concept but instead normalizes accumulated climatic water balance by deducting the possible moisture loss under a given environmental circumstance due to potential evapotranspiration (PET) from accumulated precipitation. The use of SPEI is not extensively tested in the context of the African climate regimes regarding the choice and fitting of a univariate probability distribution as the drought severity is found to be sensitive to these choices (Sienz et al., 2012). Here we used the generalized extreme value distribution to compute the SPEI as suggested by Stagge et al. (2015) though their recommendation was based on the European state of climate. The SPEI may provide a plausible characterization of climate water balance and the evolution of moisture loss as a function of climate change, while the SPI may provide an important insight into how the rainfall regime may shift in a changing African climate.

We explored the observed state of African extreme climate using an improved version of the Climate Research Unit (CRU TS v. 4.01) (Harris et al., 2013) which covered the period 1901-2016 at the time of writing this report. This dataset has a range of climate variables including rainfall and PET where the latter motivates our enthusiasm to consider the impact of the evolving temperature on the country's moisture budget, which is found to be of great societal interest in the view of the region's projected temperature changes toward the end of the 21st century. The CRU is presumably the most reliable available high-resolution observed dataset for Africa as the continent is lacking dedicated or readily available alternative observed datasets.

A significance test was conducted using a variant of the Mann-Whitney nonparametric procedure that explicitly accounts for variance adjustment caused by incidents of ties (Mason and Graham, 2002; Wilks, 2006; Beraki et al., 2015). The paradigm provides appealing flexibility (under various contexts such as tracing the signal of climate change) to test whether two populations are significantly different.

3 RESULTS

The signature of climate change on the South African climate extremes with regard to moisture budget is explored both in the model and through observation. Figure 1 presents how the summer and winter regions of South Africa evolve in terms of droughts and floods. According to the analysis based on the SPI, during the last 100 years the occurrence of extremes in the South African climate barely showed any signature of the climate change signal. This can be interpreted as evidence for the moisture budget generally being explained by natural variability. In addition, the PET has a marginal impact on the long-term drought tendency. However, over the last couple of decades (both over the summer Figure 1 (c) and winter rainfall regions Figure 1(d) of South Africa), the loss of moisture due to PET has intensified, presumably attributed to global warming. This suggests that it is important for South Africa to explore options on how to better manage the loss of moisture due to evapotranspiration.

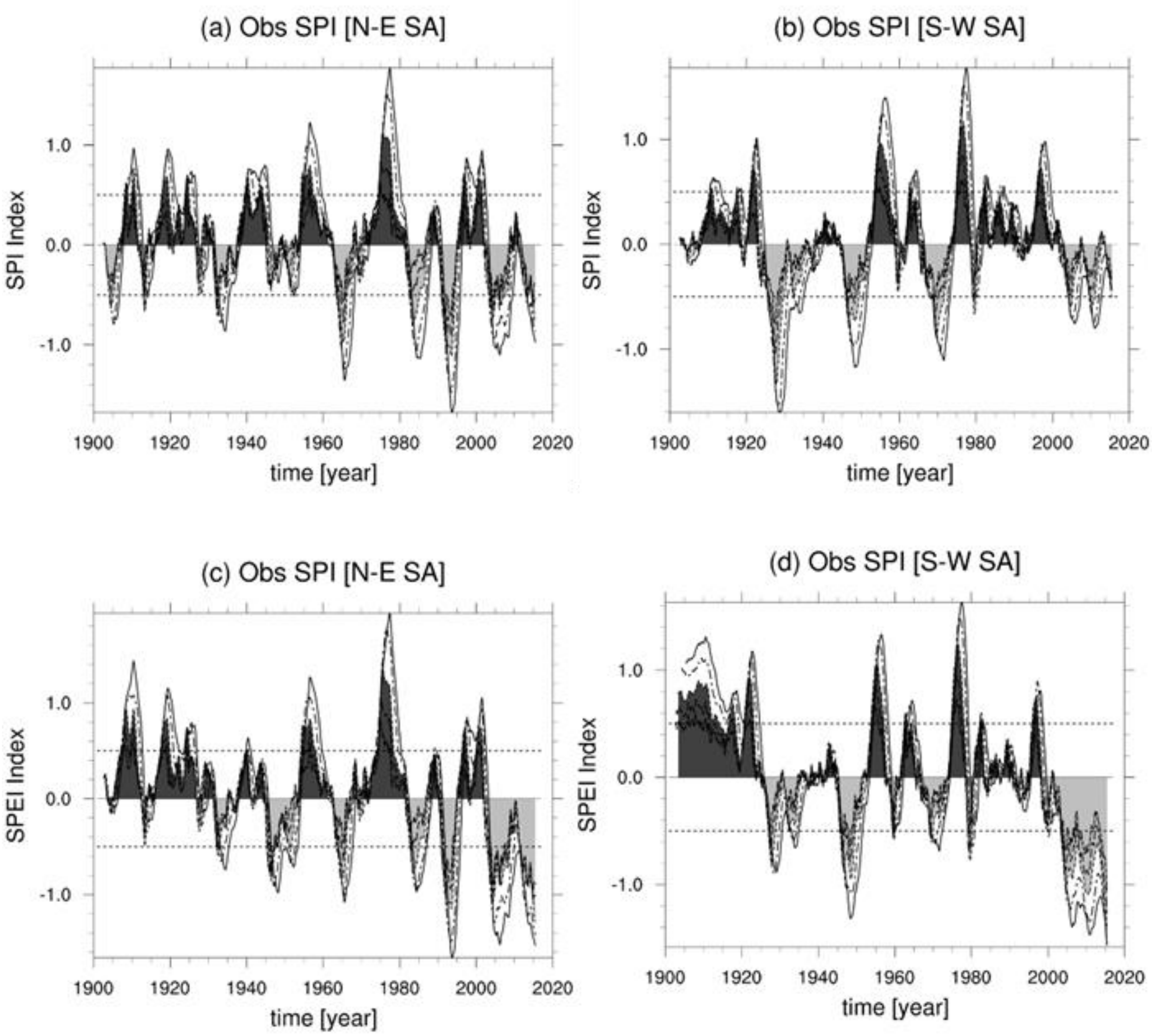

Figure 1: Observed state of drought (flood) based on SPI (upper panel) and SPEI (lower panel) for the north-eastern (part of the summer rainfall region; (a), (c)) and south-western (part of winter rainfall region; (b, d)) parts of South Africa.

Note: The standardized climate indices were computed using CRU rainfall and PET (1901-2016). The 3, 6 12, 24 and 36 months scale was further subject to a 36 months running mean (smoothing) to detect the slowly evolving signal. The severity and scale tend to increase proportionally where the ≤12 months' scale is shaded with dark and light grey for the tendency of wetness and dryness respectively. The near-normal region is bounded within the dash lines.

Possible future changes in the state of drought and flood over South Africa under the low mitigation scenario (RCP8.5) were estimated using the six climate projections in terms of SPI. Daily accumulated monthly mean precipitation values were used, as noted above, to estimate the SPI for multiple scales (3, 6, 12, 24 and 36 months) at a spatial resolution of 50 km over the country. Since the analysis yields similar results, however, results from the 36 months (three annual) scale are presented. The annual mean was used as it represents the contribution of all the different climate regimes of South Africa (such as winter, summer and year-round rainfall regions). As noted in Figure 1, the severity becomes noticeable as the scale increases which further exposes the extent of moisture stress due to amplified atmospheric moisture demand. This global warming-induced moisture deficit may have far-reaching agricultural and hydrological implications.

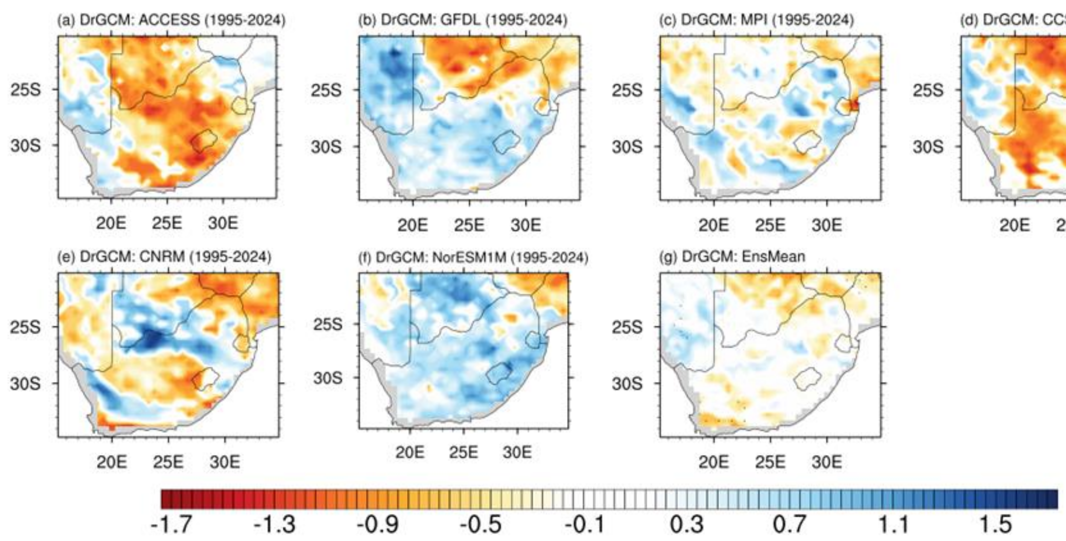

Figure 2: Projected change in the drought (flood) tendencies (i.e., number of cases exceeding near-normal per decade) over South Africa for the period 1995-2024 relative to the 1986-2005 baseline period, under a low mitigation scenario (RCP8.5). Projections are shown for each of the six CCAM downscalings (a-f) and ensemble mean (g). The stipples in figure (g) show significance 95% (see text for details).

Figure 2 reveals that southern Africa is already experiencing increased conditions of dryness and is likely heading towards a regional climate system that may well be associated with more frequently occurring droughts. During the period of 2035-2064 a high likelihood of increased conditions of drought are projected to occur within the presence of a drastic increase in maximum temperature and very hot days. Such a change, of a hot and dry climate system becoming even hotter and drier would offer very few options for climate change mitigation. It is likely that under an enhanced global warming scenario, this general pattern of increased dryness will already be manifested over South Africa, but it is not projected that it will be significantly drier over the periods of 1995-2024 (Figure 2) and 2015-2044 (Figure 3). Despite the enormous uncertainty that exists among the model simulations forced with six CMIP5 models, the analysis generally suggests that South Africa's state of drought and its frequency becomes noticeable with a statistical significance at 95% during the period 2044-2064 under the low mitigation scenario (RCP8.5) (Figure 4). Nonetheless, the containment of the global average temperature within a 1.5 °C increase (as stipulated in the 2015 Paris Agreement) compared to its present-day climate, potentially offers a greater opportunity to reverse the looming threat of our region's poor climate state.

The plausible physical mechanism underlying the moisture budget reduction in the region is apparently due to a reduction of tropical temperate trough (TTT) related rainfall activities over the region, with a potential northward migration of the tropical cloud bands and a strengthening of the subtropical high-pressure belt over southern Africa (e.g. Engelbrecht et al., 2009). Furthermore, the likelihood of an enhanced drought tendency over the winter rainfall region of South Africa is presumably caused by the poleward displacement of the westerlies (e.g., Weldeab et al., 2013) and associated frontal activities. The latter is the main winter rainfall bearing system over the country and is believed to remain confined within the southern oceans under climate change scenario (e.g. McCabe et al., 2001).

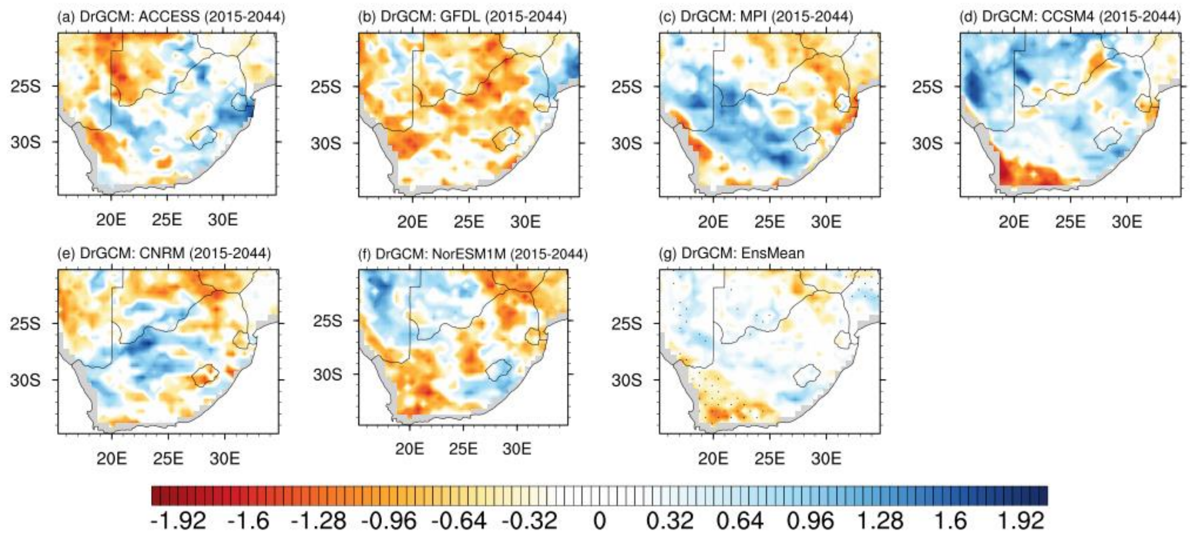

Figure 3: Projected change in the drought (flood) tendencies (i.e., number of cases exceeding near-normal per decade) over South Africa for the period 2015 - 2044 relative to the 1986-2005 baseline period, under a low mitigation scenario (RCP8.5). Projections are shown for each of the six CCAM downscalings (a-f) and ensemble mean (g). The stipples in figure (g) show significance 95% (see text for details).

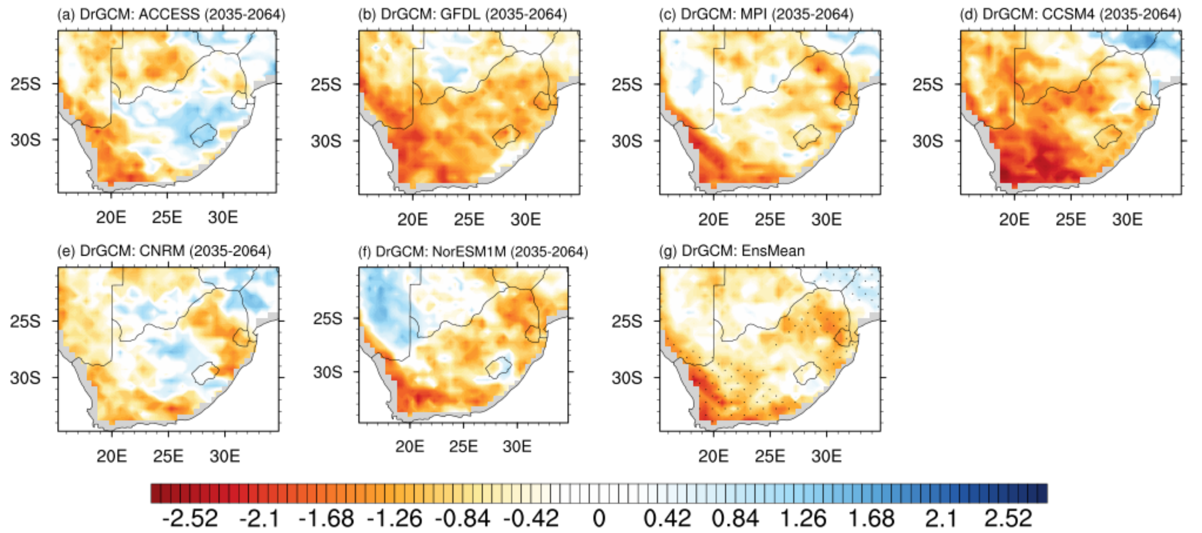

Figure 4: Projected change in the drought (flood) tendencies (i.e., number of cases exceeding near-normal per decade) over South Africa for the period 2035 - 2064 relative to the 1986-2005 baseline period, under a low mitigation scenario (RCP8.5). Projections are shown for each of the six CCAM downscalings (a-f) and ensemble mean (g). The stipples in figure (g) show significance 95% (see text for details).

4 REFERENCES

Begueria S., Vicente-Serrano S.M., Reig F. and Latorre B., 2013. Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. Int. J. Climatol. 34: 3001–3023.

Beraki A.F., Landman W. and DeWitt D., 2015. Comparison on the seasonal predictive skill of global circulation models: coupled versus uncoupled, Journal of Geophysical Research Atmosphere, 120, doi:101002/2015JD023839.

Christensen J.H., Hewitson B., Busuioc A., Chen A., Gao X., Held I., Jones R., Kolli R.K., Kwon W.-T., Laprise R., Magana Rueda V., Mearns L., Menendez C.G., Raisanen J., Rinke A., Sarr A., Whetton P., 2007. Regional climate projections. In: Solomon S., Qin D., Manning M., Chen Z., Marquis M., Averyt A.B., Tignor M., Miller H.L. (eds). Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Inter-governmental Panel on Climate Change. Cambridge University Press, Cambridge.

Engelbrecht C.J., Engelbrecht F.A. and Dyson L.L., 2013. High-resolution model-projected changes in mid-tropospheric closed-lows and extreme rainfall events over southern Africa. International Journal of Climatology 33 173-187. DOI: 10/1002/joc.3420.

Engelbrecht, C, Landman, S. and Malherbe, J., 2016. The 2015/16 Summer vs the Summers of the Last Decade. 32nd Annual Conference of South African Society for Atmospheric Sciences, Cape Town, South Africa, 31 October -1 November 2016.

Engelbrecht F, Adegoke J, Bopape M-J, Naidoo M, Garland R, Thatcher M, McGregor J, Katzfey J, Werner M., Ichoku C and Gatebe C., 2015. Projections of rapidly rising surface temperatures over Africa. Env. Res. Letters. 10 085004.

Engelbrecht F.A., Landman W.A., Engelbrecht C.J., Landman S., Roux B., Bopape M.M., McGregor J.L. and Thatcher M., 2011. Multi-scale climate modelling over southern Africa using a variable-resolution global model. Water SA 37 647-658.

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 29 1013-1033. DOI: 10/1002/joc.1742.

Garland R.M., Matooane M., Engelbrecht F.A., Bopape M-J.M., Landman W.A., Naidoo M., Van der Merwe J. And Wright C.Y., 2015. Regional projections of extreme apparent temperature days in Africa and the related potential risk to human health. International Journal of Environmental Research and Public Health 10/2015 12 12577-12604. DOI:10.3390/ijerph121012577.

Harris, I., Jones, P.D., Osborn, T.J. and Lister, D.H., 2013. Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 Dataset. International Journal of Climatology. 34, 623-642.

Hayes M, Svoboda M, Wall N, Widhalm M., 2011. The Lincoln declaration on drought indices: universal meteorological drought index recommended. Bull. Am. Meteorol. Soc. 92: 485–488.

James R. and Washington R., 2013. Changes in African temperature and precipitation associated with degrees of global warming. Clim. Change 117 859–72.

Katzfey K.K., McGregor J.L., Nguyen K. and Thatcher M., 2009. Dynamical downscaling techniques: Impacts on regional climate change signals. 18th World IMACS/MODSIM Congress, Cairns, Australia, July 2009.

Malherbe J., Engelbrecht F.A., Landman W.A. and Engelbrecht C.J., 2013. Tropical systems from the southwest Indian Ocean making landfall over the Limpopo River Basin, southern Africa: a historical perspective. International Journal of Climatology 32 1018–1032. DOI: 10.1002/joc.2320.

Mason S.J. and Graham N.E., 2002. Areas beneath the relative operating characteristics (ROC) and relative operating levels (ROL) curves: statistical significance and interpretation. Q. J. R. Meteorol. Soc. 128: 2145–2166.

McCabe, G. J., M. P. Clark, and M. Serreze, 2001. Trends in Northern Hemisphere surface cyclone frequency and intensity. J. Climate, 14, 2763–2768.

McKee, T.B., Doesken, N.J. and Kleist J., 1993. The relationship of drought frequency and duration ot time scales. Eighth Conference on Applied Climatology, American eteorological Society Jan 17-23, 1993, Anaheim CA, pp. 179-186.

McKee T.B., Doesken N.J. and Kleist J., 1995. Drought monitoring with multiple time scales. Ninth Conference on Applied Climatology, American Meteorological Society Jan 15-20, 1995, Dallas TX, pp. 233-236.

Reynolds R.W., Rayner N.A., Smith T.M. and Stokes D.C., 2002. An improved in situ and satellite SST analysis for climate. J. Clim. 15: 1609–1625.

Sienz F., Bothe O., Fraedrich K., 2012. Monitoring and quantifying future climate projections of dryness andwetness extremes: SPI bias. Hydrol. Earth Syst. Sci. 16: 2143–2157.

Stagge, J.H., Tallaksen L.M., Gudmundsson L., Van Loonc A.F. and Stahle K., 2015. Candidate Distributions for Climatological Drought Indices (SPI and SPEI), Int. J. Climatol. 35: 4027–4040, DOI: 10.1002/joc.4267

Vicente-Serrano S.M., Beguería S., López-Moreno J.I., 2010. A multi-scalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index – SPEI. J. Clim. 23: 1696–1718.

Weldeab, S., Stuut J.-B. W., Schneider R. R. and Siebel W., 2013. Holocene climate variability in the winter rainfall zone of South Africa. Clim. Past, 9, 2347–2364.

Wilks DS 2011 Statistical Methods in the Atmospheric Sciences, Vol. 100. Academic Press: San Diego, CA.

Winsemius H.C., Dutra E., Engelbrecht F.A., Archer Van Garderen E., Wetterhall F., Pappenberger F. and Werner M.G.F., 2014. The potential value of seasonal forecasts in a changing climate in southern Africa. Hydrol. Earth Syst. Sci. 18 1525–1538.

WMO. 2006. Drought monitoring and early warning: Concepts, progress and future challenges. WMO-No. 1006, World Meteorological Organization, Geneva, Switzerland.