

Climate impacts in southern Africa during the 21st Century

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1. Executive Summary

1. There is no scientific doubt that the climate of southern Africa is becoming warmer, the atmospheric concentration of greenhouse gases is increasing and the sea level surrounding the continent is rising. Human activities are by far the largest cause of these changes. The principle causes are the global burning of fossil fuels and the transformation of the global land surface from natural vegetation to croplands, pastures and human settlements.
2. The climate will continue to change throughout the 21st century, to a degree mostly determined by human actions and the policies that guide them. Global 'low mitigation futures' that lead to global mean warming well in excess of 3 °C pose much higher risks to the future development of South Africa than 'high mitigation futures' which limit warming below 2 °C; which in turn have higher risks than futures which stay below 1.5 °C, or only briefly exceed it. The latter two futures require urgent and strenuous efforts to reduce greenhouse gas emissions, including by developing countries like South Africa.
3. Southern Africa is particularly vulnerable to climate change because of its geographical location and socioeconomic development state. It is an already warm and dry region, projected to become warmer and drier, and has many demands on its institutions and finances in addition to climate change. Warming in the interior of southern Africa is occurring at about twice the global average rate.
4. There is a high likelihood that agricultural production in southern Africa, including staple crops and livestock, will be reduced relative to the no climate change case. This is because the region is already beyond the temperature optimum for most crop and livestock production, and crop and forage production in an already dry country decreases if soil moisture decreases further. These impacts increase as the level of global warming increases, and at 3 °C of global warming the collapse of key crops and the livestock sector are likely.
5. Freshwater availability, already critically limited in southern Africa, will be reduced in future as a result of decreasing rainfall and increasing evaporation. These impacts will amplify as the level of global warming increases. Water quality also decreases in a warmer, drier southern Africa, increasing the risk of water-borne diseases.
6. The likelihood of long-duration droughts increases in the future because of two fundamental mechanisms resulting from global warming: the strengthening of subsidence over southern Africa, and the poleward movement of frontal systems. When droughts exceed the historically-experienced frequency and intensity, the coping mechanisms are overwhelmed. These risks increase from 1.5 to 2 °C of global warming, with further increases under higher levels of global warming.
7. The number, intensity and duration of heat waves in South Africa will increase steeply in future as a result of global warming. The capacity to perform manual labour out of doors decreases dramatically as the occurrence of heat waves increases. Human mortality increases, particularly in urban areas with inadequate housing, but may in some locations be offset by decreases in mortality as a result of fewer cold spells.

* Prof. Bob Scholes unexpectedly passed away on 28 April 2021.

8. The risk of severe storms, including intense tropical cyclones and very intense thunderstorms, increases with climate change in southern Africa. As a result, loss of life, injury and damage to infrastructure also increases.
9. Thousands of species, many occurring only in southern Africa, are at increased risk of premature extinction as a result of human-caused climate change. This loss has negative consequences for human wellbeing and the economy, as well as weakening the capacity to adapt to climate change.

2. The purpose of this report

This report summarises what is currently known about human-caused climate change and its consequences with respect to Africa south of about 15 °S. Its intended readership is people who do not have a scientific training in this field, but who need to make decisions that could be influenced by a changing climate, the global efforts to mitigate that change, and adaptation to that part of climate change which can no longer be mitigated.

3. The global climate is changing due to human actions, mostly the burning of fossil fuels

That the Earth's climate system has changed since the pre-industrial revolution¹, relative to the pre-industrial climate, is beyond scientific doubt. Climate change impacts include but are not limited to increases in the temperature over land and oceans and the rise in the sea level.

The rate of change is unsteady at the annual-to-decadal timescale² but climate change has consistently accelerated over the period over three decades or more.

The largest part of the warming, by far, is scientifically attributed to the measured increases in the concentration of several trace gases, known as greenhouse gases, in the atmosphere. The principal ones are carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). There is scientific consensus, based on several lines of evidence, that the main cause of the observed increase is human activities since 1750. These include the cumulative human-driven ('anthropogenic') emissions of greenhouse gases resulting from the combustion of fossil fuels (coal, oil and natural gas) and from changes to the Earth's land surface, largely associated with the expansion of agriculture into formerly natural ecosystems. In the present time³ nearly three-quarters of the global warming effect derives from fossil fuel combustion.

Several persistent directional changes (as opposed to short-term fluctuations) have been detected in the global climate system over the period of record, and particularly over the past half century:

¹ The Industrial Revolution nominally began in 1750. Since accurate direct measurements of the Earth's climate only became widespread from 1850 onwards, including in South Africa, the period 1850-1900 is used by the Intergovernmental Panel on Climate Change (IPCC) to approximate pre-industrial climate. Many proxy climate records, for instance tree rings and ice cores, provide confidence in extending the record back to 1750, and show that only about 0.1 °C of global warming occurred in the period 1750 to 1849.

² More so for quickly-responding variables, such as air temperature, than for slowly-responding variables such as the water temperature in the deep oceans.

³ 2010-2019 for CO₂, 2008-2017 CH₄, 2007-2016 for N₂O. These data are from the Global Carbon Project 2020 summaries (<https://www.globalcarbonproject.org/carbonbudget/20>), which is the latest and most comprehensive scientific source. They assume a 100-year global warming potential of CH₄ of 28, and N₂O of 298.

⁴ IPCC Assessment Report Six Working Group I report, Summary for Policy Makers

⁵ IPCC Special Report on the Ocean and Cryosphere, Summary for Policy Makers.

⁶ IPCC Special Report on Global Warming of 1.5 °C, Chapter 3.

- **Increase in near surface air temperature:** The global mean surface temperature is estimated to have increased by 1.1 °C for the period 2011-2020 relative to the period 1850-1900⁴.
- **Melting of ice caps:** The loss in global ice mass on land has increased substantially over recent decades, including from the Greenland ice sheet, West Antarctic ice sheet and glaciers⁵.
- **Sea Level Rise:** Due to the combined effects of global ice loss and oceanic temperature increase (which result in the expansion of sea-water), the global mean sea-level has risen with about 0.16 m (likely range 0.12 to 0.21 m) between 1902 and 2015. The rate of global mean sea-level rise has accelerated in recent decades, and was 3.6 cm per year for 2006–2015 (likely range 3.1–4.1 cm) – the highest high rate in the past century⁵.
- **Extreme weather events:** Changes in weather and circulation patterns have also been detected over the last several decades, including the more frequent occurrence of heat-waves in the oceans and over land^{4,6}.

All of the above changes can be attributed with high confidence to anthropogenic climate forcing, and predominantly to the increase in CO₂ concentrations in the atmosphere^{4,5,6}.

4. The climate will continue to change, to a degree mostly determined by human actions and the policies that guide them.

The world is committed to further global warming for as long as greenhouse gas concentrations, in aggregate, continue to rise. The degree of future global warming therefore depends directly on international policy and national actions in terms of greenhouse gas emission reductions ('climate change mitigation'). In order to explore the range of possibilities that exists, the Intergovernmental Panel on Climate Change (IPCC) in its Assessment Report Six (AR6) developed a set of plausible future greenhouse gas concentration trajectories⁴. Over 30 global climate models were used to project global warming under different future scenarios, an approach collectively called an 'ensemble', that is more reliable than arbitrarily picking any one model. The ensemble global mean temperature ranges for the period 2081-2100 relative to 1850-1900, are given in Table 1⁴. These estimates are largely consistent with the findings of Assessment Report Five (AR5) of the IPCC, published in 2013, but for an updated set of mitigation scenarios.

Table 1: Projected range in global warming as estimated in AR6 of the IPCC for the period 2081-2100 relative to 1850-1900. SSP stands for 'Shared Socio-economic Pathway'. The five scenarios listed here span the range of plausible human-caused climate forcing in the 21st century, reaching an annual additional warming effect by the end of the century of 1.9 W m⁻² (SSP1-1.9) to 8.5 W m⁻² (SSP5-8.5).

Shared Socio-economic Pathway These are scenarios of future greenhouse gas concentrations in the atmosphere, with a brief interpretation of the conditions that give rise to them	Change in global average surface temperature (°C) for 2081-2100 relative to 1850-1900
SSP1-1.9: A very strong mitigation future, beginning immediately and reaching net-zero emissions by 2050.	1.0 to 1.8
SSP1-2.7: Very strong mitigation, but not reaching net-zero emissions by 2050.	1.3 to 2.4
SSP4.5: A modest to strong mitigation effort, ramping up more gradually	2.1 to 3.5
SSP60: A future with low mitigation effectiveness	2.8 to 4.6
SSP8.5: A future with weak and delayed mitigation efforts	3.3 to 5.7

The long term global goal of the 2015 Paris Agreement on Climate Change is to restrict global warming to well below 2°C, and preferably below 1.5°C, relative to the pre-industrial climate. These thresholds were agreed by the signatories, after consideration of the dangerous climate change impacts that are increasingly likely to occur as the global mean temperature rises. Of particular concern is the potential for some aspects of climate change to become irreversible if particular thresholds are exceeded. An example is the irreversible melting of the Greenland ice sheet. The existence of such thresholds within the range of plausible 21st century warming is not in doubt, but the exact global warming level to which they correspond remains uncertain⁴. In the scenarios considered in AR6, it is only SSP1-1.9 and SSP1-2.6 (very strong mitigation) that provides a reasonable chance for global warming to be restricted to below 2°C⁴.

Many at-risk countries, including South Africa, argued that a restricting global warming to 2°C will not be sufficient to prevent dangerous climate change from occurring. The IPCC was requested to perform a special assessment of the mitigation targets that must be achieved for the world to stand a reasonable chance of restricting global warming to 1.5°C above pre-industrial, as well as an assessment of climate change impacts at 1.5 vs 2 °C of global warming. The resulting report was named the Special Report on Global Warming of 1.5 °C (SR1.5). The report assessed that there are substantial benefits in restricting global warming to 1.5 °C as opposed to 2 °C, because the risk for irreversible climate change is reduced, and increases in the frequency of occurrence of extreme events are smaller.

Restricting global warming to 1.5 °C was still regarded as achievable by SR1.5, but only in the presence of stringent mitigation measures. The SR1.5 assessment is that it would require CO₂ emissions to be reduced with 45% by 2030 (with respect to their 2010 levels), reaching 'net zero' emissions by 2050⁷. The AR6 has updated this assessment through analysing future global warming under SSP1-1.9, and found that even under this 'best-effort' mitigation effort it is more likely than not that the 1.5 °C threshold will be exceeded, as early as the early 2030s⁴. However, the overshoot is likely to be small (about 0.1 °C), and if carbon dioxide removal technologies can be applied at scale in the second half of the century, the global surface temperature can potentially return to a value below 1.5 °C. By contrast, avoidance of global warming of 2°C requires a 25% reduction in CO₂ emissions by 2030, and net zero emissions by 2070⁷. SR1.5 elaborates on the large reduction in a wide range of risks that is achieved by staying below 1.5°C warming rather than 2°C or higher levels⁶. Briefly stated, risks of all sorts rise at an ever-steepening rate the higher the final warming level^{4,6}.

5. Southern Africa is particularly vulnerable to climate change

The SR1.5 identified southern Africa as a climate change 'hotspot', meaning a location where climate change impacts are abnormally high in a global context⁶. This finding stems from the region's subtropical climate, already warm and dry, which under climate change is projected to become drastically warmer and likely also drier^{6,8}. This combination of changes implies that options for adaptation are limited. Over the last several decades, warming in the southern African interior has occurred at about twice the average rate of global warming⁹. Systematic increases in extreme temperature events such as heat-waves and high fire-danger have also

⁷ IPCC SR1.5, Chapter 2

⁸ IPCC Assessment Report Six, Chapter 4

⁹ Engelbrecht F.A., 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 under low mitigation. *Env. Res. Letters*. 10 085004.

¹⁰ Kruger A.C. and Sekele S.S. (2013). Trends in extreme temperature indices in South Africa: 1962–2009. *Int. J. Climatol*. 33 661–676.

¹¹ MacKellar N., New M. and Jack C. (2014). Observed and modelled trends in rainfall and temperature for South Africa: 1960-2010. *S. Afr. J. Sci.* doi:10.1590/sajs.2014/20130353

been recorded¹⁰. Rainfall trends in the region have in general not been statistically significant, but there is some evidence of decreasing rainfall over the eastern summer rainfall regions¹¹. This currently weak signal of drying is projected to strengthen over both the winter and summer rainfall regions in association with continued strong regional warming should the level of global warming exceed 1.5 °C⁴.

The availability of freshwater resources in South Africa is exceptionally sensitive to climate change, for reasons which are discussed in detail in later sections.

The IPCC SR1.5 pointed out two major agricultural risks for southern Africa under drastically warmer and drier futures (there may be more): The maize crop, the region's staple food, is likely to be substantially reduced - even to the point of collapse - under 3°C of global warming. This is a consequence of the vulnerability of maize crop yield to the combined effects of high temperatures and drought. The livestock industry is similarly at risk becoming unviable under 3°C of global warming, due to the negative effects of heat stress on wool, milk and meat production.

A further reason for southern Africa's vulnerability to current and future climate change impacts is the developmental status of economies, infrastructure and institutions in the region, which implies limited technical and financial capacity to adapt to current and future risks.

6. Freshwater availability, already critically limited, will be reduced in future

South Africa is already a water-scarce country, due to the combination of an inherently low and variable rainfall, high evaporative demand, and the rapidly rising demand for water for agriculture, industries and urban areas. In the summer rainfall region, surface and groundwater resources are already declining due to less, and more variable, rainfall¹¹. In the winter rainfall region, although presence of statistically significant downward trends in rainfall is debated, there is nevertheless strong evidence that the risk of multi-year droughts has increased substantially¹². Lower rainfall and increased evaporative demand (driven by increasing temperatures) are projected to increasingly lead to reduced soil-moisture⁹, which translates to reduced run-off in rivers and reduced groundwater recharge.

In semi-arid areas such as South Africa the hydrological system amplifies the climate signal (either increases or decreases in rainfall) about three-fold. In other words, if the rainfall decreases, for example by 1 litre (1 mm/m²/y), the amount of water available as a usable resource decreases by about 3 litres. The response of runoff in rivers and recharge of groundwater to changes in the water balance (the ratio of rainfall (P) to evaporative demand (E)) is not linear (ie, proportional) but follows a steepening curve with a lower threshold. This means for semi-arid landscapes (where P:E <0.6, which includes most of South Africa), perennial rivers can easily become intermittent if the P:E drops below the lower threshold, as it is projected to do over increasing areas of Southern Africa during the 21st century, in most models and under most scenarios (ie even under high mitigation). The combination of these two well-established hydrological effects is the underlying reason why freshwater resources in South Africa are so sensitive to climate change, particularly 'at the margin', ie in places that only just have enough water at present to support current activities and keep the river flow perennial. The impacts of climate change on freshwater resources availability in southern Africa are projected to become increasingly negative as the level of global warming increases (or in other words, are worst under low mitigation compared to high mitigation).

¹² Otto F.E.L. et al. (2018). Anthropogenic influence on the drivers of the Western Cape droughtv2015–2017. *Env. Res. Letters* 13 124010.

¹³ Nannan N, Dorrington RE, Laubscher R, Zinyakatira N, Prinsloo M, Darikwa TB, Matzopoulos R, Bradshaw D. (2012). Under-5 mortality statistics in South Africa: Shedding some light on the trends and causes 1997-2007. Cape Town: South African Medical Research Council, 2012

In addition to the negative impacts on quantity of water available in southern Africa, there is also a high likelihood of strongly negative impacts on its quality. As the air temperature increases and flow in rivers decreases, the average temperature of surface water bodies rises. This leads to a deterioration in water quality, through processes such as increased biological oxygen demand, algal blooms, and the proliferation of pathogenic microbes. The effects of water pollution on humans and aquatic ecosystems is made worse by reduced river flows, which otherwise dilute the pollutants and flush them out of the system. The result of decreasing and more intermittent water supplies with deteriorating water quality, both partly due to anthropogenic climate change, is an increase in the risk of water-borne diseases such as diarrhoea, particularly among the large fraction of people in South Africa who remain dependent on untreated or inadequately treated water resources for their domestic needs. Diarrheal disease accounts for over a fifth of all deaths under the age of 5 years in South Africa, the single largest post-natal cause¹³.

7. The likelihood of long-duration droughts increases in the future

In a warmer world, the frontal systems which are an important feature of the climatology of southern Africa are systematically displaced poleward, to the extent that they will bring rainfall to the continent less frequently. The risk of multi-year droughts in the winter rainfall region (such as the 2015-2017 Cape Town drought) has already increased by a factor of three due to climate change¹², and will increase further as global warming intensifies. The phenomenon of multi-year droughts will also affect rainfall in the summer rainfall region more frequently, should global warming reach values of 1.5° C or higher⁴. This is due to the more frequent formation of high-pressure systems that suppress rainfall over southern Africa in summer.

The duration, severity and frequency of regional-scale droughts all interact to create a steeply-rising risk of agricultural and water supply system failure with increasing levels of global warming. This is because these systems are designed or adapted to cope with the level of drought which they have historically experienced. There is high certainty that the historically-expected levels of drought will be exceeded in the future. Several of the intrinsic drought-buffering mechanisms – such as the amount of water that can be stored in the soil profile, or the capacity of wild plants or animals to tolerate dry periods - are effectively impossible to change in the short and medium term.

Other adaptive actions, such as the building of increased water storage capacity, are technically feasible, but at escalating cost because the most promising sites are already occupied; and with decreasing efficiency, because of increased evaporative losses. For instance, the water supply system which serves Gauteng, the Northwest province and some of Limpopo province has a water storage capacity sufficient for about five years of operation if it starts out with the dams full. Longer-duration droughts (or shorter droughts commencing with an initially low storage volume) require stringent water use restrictions, with high economic costs, if catastrophic water supply failure is to be avoided. Similarly, farming enterprises typically only have financial buffers sufficient to allow them to cope with one or at best a few years of drought. Multi-year droughts lead to farm bankruptcies unless emergency drought aid is supplied. In the wildlife sector, high mortalities in wild herbivore populations are associated with two consecutive years of drought¹⁴. The most recent drought costed South Africa R2.5 billion in drought relief expenditure alone.

8. The number, intensity and duration of heat waves will increase steeply

Substantial changes in the number of extreme temperature events in southern Africa can already be detected¹⁰, and further drastic increases in events such as heat waves, high fire-danger days and oppressive temperatures impacting on human comfort and health can be

expected under futures in which climate change mitigation efforts are low or unsuccessful^{4,6,9,15}.

The susceptibility of warm-bodied animals, including humans, mammals and birds, to ambient temperatures that approach or exceed their body temperature is well-established. It is apparently not amenable to genetic adaptation, and very little to physiological adaptation. Organisms cool themselves largely by sweating or panting, which requires a water supply, and a relatively dry atmosphere. Therefore heat stress is also more likely if the atmosphere is humid. For example, when certain combinations of temperature and humidity are exceeded, dairy cows produce substantially less milk, beef cattle and poultry put on less mass, and sheep produce less wool. The capacity of humans to perform outdoor work approximately halves for every 2 °C rise in wet bulb globe temperature (a particular measure of the temperature-humidity combination) above 25 °C for heavy work, and above 30 °C for light work^{16,17}. Morbidity in humans and other warm-bodied animals increases at a steepening rate when the daily maximum temperature exceeds 35 °C for three consecutive days or more^{18, 19}. In Cape Town, Durban and Johannesburg, the mortality from all causes, for all age groups combined, increases by 0.9% for every 1 °C increase in the 'daily apparent temperature' above 19 °C (except for Durban, where the threshold is 25 °C). For people older than 65 years, the mortality increase was 2.1% per degree of warming. A second study based on South African mortality data found that exceedance of the 85th percentile of the temperature distribution is associated with steepening all-cause mortality in adults. In infants and adolescents the mortality increase occurred above the 20th percentile. On the other hand, the reduced number of cold-days that would be expected under climate change caused an almost equal decrease in all-cause mortality²⁰.

The critical thresholds of combined heat and humidity leading to heat stress are surpassed by a greater amount, on more occasions per year, for longer stretches of consecutive days, and in larger parts of South Africa, as the global mean temperature rises. As a consequence, for

¹⁴ Walker, B., Emslie, R., Owen-Smith, R., & Scholes, R. (1987). To Cull or Not to Cull: Lessons from a Southern African Drought. *Journal of Applied Ecology*, 24(2), 381-401. doi:10.2307/2403882.

¹⁵ 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.

¹⁶ Xingcai Liu 2020 Reductions in Labor Capacity from Intensified Heat Stress in China under Future Climate Change *International Journal of Environmental Research and Public Health* 17, 1278; doi:10.3390/ijerph17041278

¹⁷ Kjellstrom, T et al 2016 Heat, Human Performance and Occupational Health:A Key Issue for the Assessment of Global Climate Change Impacts. *Annu. Rev. Public Health* 37:97–112

¹⁸ This threshold is for Australia, in Peng Bi et al 2011 The Effects of Extreme Heat on Human Mortality and Morbidity in Australia: Implications for Public Health, *Asia-Pacific Journal of Public Health* 23:27-36 DOI: 10.1177/1010539510391644

¹⁹ Wichmann, J., 2017: Heat effects of ambient apparent temperature on all-cause mortality in Cape Town, Durban and 6 Johannesburg, South Africa: 2006-2010. *Sci Total Environ*, **587-588**, 266-272, 7 doi:10.1016/j.scitotenv.2017.02.135

²⁰ Scovronick, N. et al., 2018: The association between ambient temperature and mortality in South Africa: A time-series 47 analysis. *Environ Res*, **161**, 229-235, doi:10.1016/j.envres.2017.11.001.

²¹ Jagadish, SVK 2020 Heat stress during flowering in cereals – effects and adaptation strategies *New Phytologist* 226: 1567–1572

²² Bignaut, J., Ueckermann, L. and Aronson, J., 2009. Agriculture production's sensitivity to changes in climate in South Africa. *South African Journal of Science*

²³ Thornton, P. K. and M. Herrero, 2015: Adapting to climate change in the mixed crop and livestock farming systems in sub-Saharan Africa. *Nature Climate Change*, 5(9), 830-836, doi:10.1038/nclimate2754, 105(1-2), pp.61-68.

global warming above 2° C (equivalent to more than 3°C in much of South Africa), free-range livestock enterprises become economically unviable over much of the country, and outdoor work capacity is reduced by about half.

9. The yield and viability of most major agricultural products will decline

All crops show a hump-shaped yield response to ambient temperature, with a minimum temperature below which they will not thrive, a range in which warming leads to improved yield up to an optimum, followed by a range where further warming results in progressively lower yields. Many crops have very specific requirements at particular stages of their development, such as the need by deciduous fruits for a cool dormant period, or in maize for temperature not to be excessive during silking. The temperature thresholds vary from crop to crop and variety to variety, but broadly speaking the optima for most crops lie in the 27 to 30 °C range of daytime mean temperature. In cereals there is an upper limit for successful pollination, with near complete failure at day temperatures above 40 °C and night temperature above 30 °C, with a 50% reduction in pollination success for day temperatures above 36 °C and night temperatures of 26 °C.^{21,22}

All crops also have a requirement for a minimum period of adequate soil moisture to complete their life cycles. Extremely drought-tolerant crops such as millet and sorghum need about 60 days, while maize needs 90 to 120 days, and some tropical fruits need moisture throughout the year. Generally, within their lower to upper tolerance ranges, crop yields in South Africa increase more-or-less linearly with increasing soil moisture duration in the growing season.

The consequence of these two general constraints on crop yields is that South Africa, over most of its extent, is already too warm and/or too dry for optimal crop production^{21,22,23}. Further warming and drying will lead to decreased crop yields for most crops in most places. The capacity to compensate by increasing irrigation is limited by the shrinking water supply and competition from other economic sectors for what is available. In some high-value crops such as deciduous fruit and the grapes used for wine-making, the reduction of chilling-units (periods of cold weather needed for trees/grapevines to blossom) is restricting the areas that can be planted. On the other hand, some areas formerly susceptible to frost will become more favourable for tropical fruit production under global warming, but are simultaneously increasingly limited by water availability and increasing risk of damage by hail, pests and diseases. The decreased viability of the livestock sector under rising temperatures has been discussed earlier.

Overall, agriculture as an economic sector (including downstream value addition) in South Africa is already under climate stress. The stress increases with global warming, bearing in mind that temperatures over the interior of South Africa rise at an above-average rate, and the net trend in the region is towards drier soils.

In 2019, 6.5 million South Africans (11% of the population) were classified as food insecure. The risk of food insecurity, and in particular national food sovereignty, increases in Southern Africa for a 1.5 °C global mean temperature rise, and increasingly so for warming above that level⁶.

10. The risk of damage to infrastructure from severe storms and flooding may increase

Worldwide, the number of intense tropical cyclones (category 4 and 5 hurricanes) is projected to increase as the world continues to warm. Moreover, tropical cyclones and storms, when they do occur, are expected to deliver more rainfall than in the past⁴. This follows directly from the thermodynamics of a warmer world, which yields that storms can carry more moisture than

in the past. The cyclones which affect southern Africa originate in the southwest Indian Ocean, where category 5 events have only been detected over the last two decades²⁴.

The high winds, elevated sea levels and extreme precipitation associated with cyclones result in loss of life, injury and major damage to coastal infrastructure, such as buildings, roads and bridges. They also pose risks far inland, after they have weakened to tropical depressions, which nevertheless result in flooding. Cyclone Idai in March 2019 affected 2.2 million people, caused more than 2000 deaths, damage to about 100 000 homes and crop and infrastructure losses in excess of USD 773 million.

A related but smaller-scale phenomenon is the increase in frequency of very large thunderstorms ('super cells'), some of which may be associated with high winds ('tornadoes'). Some evidence exists for a greater frequency of extreme rainfall, hail and damaging wind events associated with thunderstorms over parts of the South African interior. Associated with such storms are the risk of hail damage to crops, people, livestock and assets, localised flash-flooding and mudslides.

11. Thousands of species, many occurring only in South Africa, are at increased risk of premature extinction

South Africa is one of 17 'mega biodiverse' countries worldwide; in other words, countries with exceptionally high numbers of unique species in relation to their area. The emerging 'green economy' is built on this biological richness and diversity. Human wellbeing depends fundamentally on the continued existence of well-functioning ecosystems to provide services such as clean water, breathable air, a regulated climate and control of pests and diseases. Particularly under circumstances of a changing climate, the reliability of ecosystem functioning depends on having a large and diverse pool of organisms to draw on.

In South Africa, principally due to habitat loss and degradation, 14% of plants, 17% of mammals and 15% of birds are currently classified as threatened with extinction. The risk of extinction rises ever more steeply with climate change, exacerbated by air pollution and water shortages. Wild species have adapted to past climate changes, though not without substantial waves of extinction. Anthropogenic climate change is a bigger challenge, because it is very rapid, and the fragmentation of habitats by human activities means that organisms cannot easily migrate to areas of more favourable climate. For many species, suitable future habitats in the wild are projected to no longer exist under unmitigated climate change

²⁴ Fitchett, FM 2018. Recent emergence of CAT5 tropical cyclones in the South Indian Ocean. *S. Afr. j. sci.* vol.114 n.11-12 Pretoria Nov./Dec. 2018 <http://dx.doi.org/10.17159/sajs.2018/4426>