CLIMATE CHANGE IN EAST SOUTHERN-AFRICA

A preliminary assessment based on the IPCC Sixth Assessment Report, Working Group 1

Covering Mozambique, Zimbabwe, Eswatini and Lesotho, all but the extreme north of Malawi, and the majority of Zambia and eastern South Africa.

Prepared for
Self Help Africa
September 2021
Dr. Nick Scroxton
School of Earth Sciences
University College Dublin

Funded by Irish Research Council and Marie Skłodowska-Curie Actions CAROLINE fellowship CLNE/2019/290

Cite as: Scroxton (2021) Climate Change in East Southern-Africa: A preliminary assessment based on the IPCC Sixth Assessment Report, Working Group 1. Zenodo. doi.org/10.5281/zenodo.5715148

Headlines for the East-Southern Africa Region[1]

- Observed decreases in mean rainfall
- Observed and projected increases in heavy rainfall and flooding
- Observed and projected increases in aridity and droughts
- Projected increases in mean wind speed and fire weather conditions
- Increase of average tropical cyclone wind speeds and associated heavy precipitation and of the proportion of category 4-5 tropical cyclones.

[1] *From:* https://www.ipcc.ch/report/ar6/wg1/downloads/factsheets/IPCC_AR6_WGI_Regional_Fact_Sheet_Africa.pdf

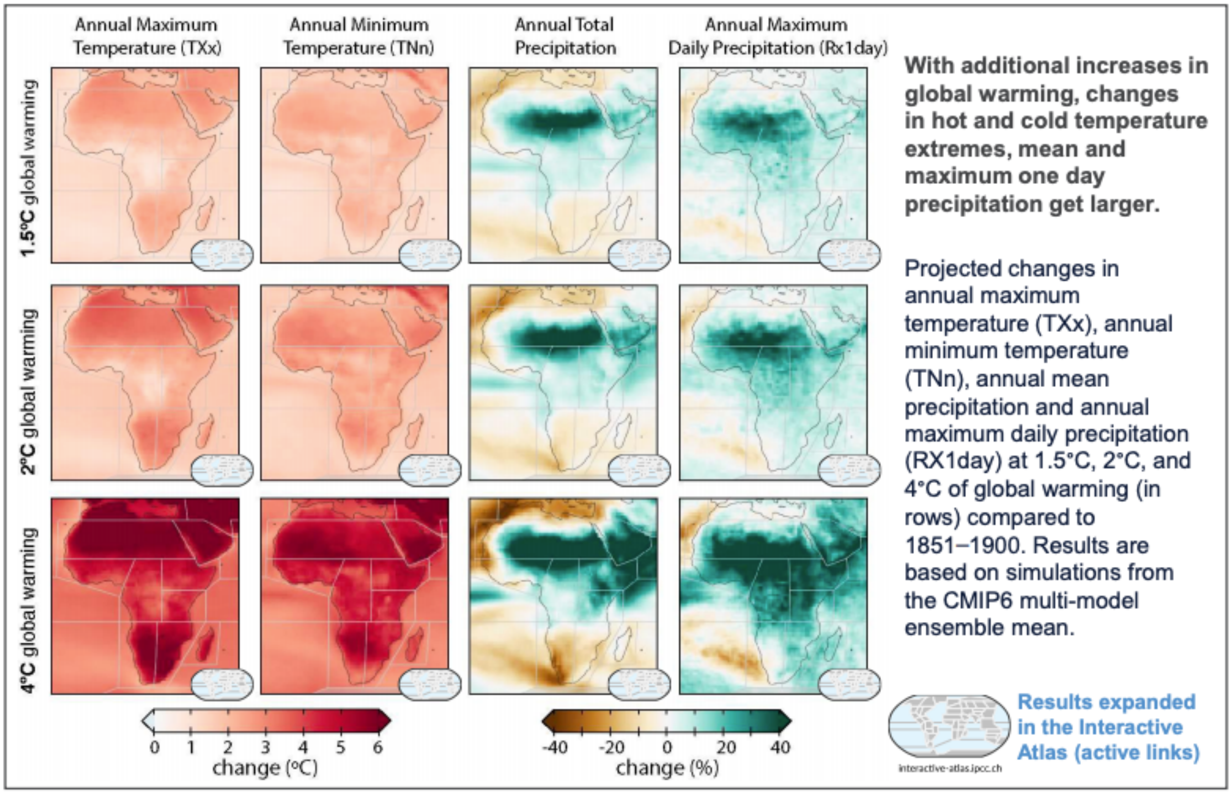

Figure 1: Summary of projected changes in Africa. Figure from the IPCC AR6 Regional Fact Sheet – Africa[2]

[2] From: https://www.ipcc.ch/report/ar6/wg1/downloads/factsheets/IPCC_AR6_WGI_Regional_Fact_Sheet_Africa.pdf

IPCC AR6 Climate Change 2021:

This document synthesizes data on the East Southern-Africa region in the new "Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change". The full report can be found at: https://www.ipcc.ch/report/ar6/wg1/

The Intergovernmental Panel on Climate Change (IPCC) is a United Nations body mandated to provide objective scientific information on climate change. As part of their remit the IPCC has produced a series of assessment reports. The First Assessment Report was published in 1990, with subsequent reports in 1995, 2002, 2007, and 2014 (the Fifth assessment report, also referred to here as AR5). The sixth assessment report (AR6) is being published in 2021 and 2022. Each report collates, assesses, and evaluates the latest research in climate change, and stands as a state-of-the-art synthesis of current best understanding of climate change. The authors of the report are nearly all university research scientists in the field of climate change. They are not paid.

This document focuses on the recent publication of the Working Group 1 report (AR6 WG1). Working Group 1 focuses on the physical science behind climate change, using evidence from observations, paleoclimate, climate physics and climate model simulations. Working Groups 2 and 3 report on climate impacts, vulnerability, adaptation, and mitigation, i.e., interactions with human society and processes to reduce emissions and lessen impacts. Reports from Working Groups 2 and 3 are expected in 2022, with a summary expected by the end of 2022.

If you use this document, we ask that you cite both this document and the AR6 WG1 report:

> *IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.*

The AR6 WG1 report comes with the following disclaimer:

> *The Summary for Policymakers (SPM) is the approved version from the 14th session of Working Group I and 54th Session of the Intergovernmental Panel on Climate Change and remains subject to final copy-editing and layout. The Technical Summary (TS), the full Report Chapters, the Annexes and the Supplementary Materials are the Final Government Distribution versions, and remain subject to revisions following the SPM approval, corrigenda, copy-editing, and layout. Although these documents still carry the note from the Final Government Distribution "Do Not Cite, Quote or Distribute" they may be freely published subject to the disclaimer above, as the report has now been approved and accepted.*

A copyright statement for the AR6 WG1 report can be found as

> *https://www.ipcc.ch/copyright/*

AR6 Regions:

Climate change does not impact the world uniformly. To simplify discussion the AR6 WG1 report divides the world into climatic regions. These regions have a broadly similar climate and similar future projections.

As computing power increases and climate models become more advanced, it becomes possible to assess model predictions of future climate change in smaller and smaller regions. The climate regions used in the AR6 WG1 report are therefore different to those used in previous reports. In Africa, several regions have been split into smaller components, including the East Africa Region (EAF) into the Northern East-Africa (NEAF) and Southern East-Africa (SEAF), and the South Africa region (SAF) into West Southern-Africa (WSAF), East Southern-Africa (ESAF) and Madagascar (MDG). This report focuses on the East Southern Africa region. The region is a rhomboid between vertices at 25°E/10°S (NW corner), 25°E/36°S (SW corner), 31°E/36°S (SE corner) and 46.5°E/10°S (NE corner). This includes all of Mozambique, Zimbabwe, Eswatini and Lesotho, all but the extreme north of Malawi, and the majority of Zambia and South Africa.

However, that is not to say that the ESAF region is entirely climatically homogenous. In general terms the AR6 WG1 report talks about changes in East and West Southern Africa as changes in semi-arid areas with a subtropical climate (highly seasonal rainfall with distinct wet and dry seasons). There may be exceptions: for example, Northern Malawi may conform more to the climate projections of the more tropical Southern East-Africa (SEAF), especially for rainfall projections, which are often the opposite to the ESAF region.

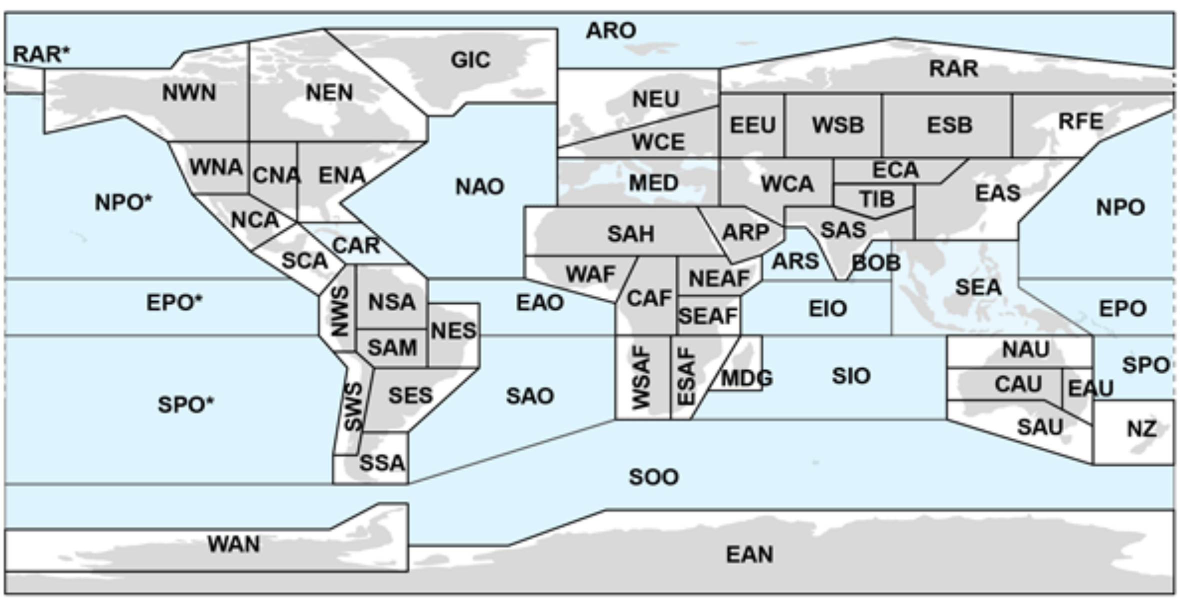

Figure 2: AR6 Regions, from Iturbide et al., (2020)

Key AR6 WG1 terms:

A complete AR6 WG1 report glossary can be found at:
https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Annex_VII.pdf

Confidence and Likelihood:
In the AR6 WG1 report (and in this document), when observed changes or model projections are derived from individual scientific studies, those are referenced. When the IPCC authors have collated or combined multiple lines of evidence to talk more broadly about changes in climate then those are given a confidence or likelihood rating. These rates describe how sure we are that changes have occurred or are likely to occur in the future.

Confidence is a qualitative expert judgement based on the quality and consistency of available data. How much does data from different sources agree? How trustworthy is the data? etc. Confidence is given when the data might not be good enough to make a statistical analysis, but scientific understanding of the climate processes behind the change is well understood. **Confidence values include Low, Medium, and High** but are generally not given numbers (Previous IPCC reports did attempt to quantify these values as 2, 5 and 8 in ten chances but the AR6 does not do this).

Likelihood is a quantitative measure based on observations and model results. If a likelihood is given, the confidence is usually high. **Likelihood values include Likely: 66-100% chance, Very Likely: 90-100% chance, Extremely Likely: 95-100% chance, and Virtually Certain: 99-100% chance.** However, expert opinion still influences likelihood values. For example, if models are known to not capture all processes correctly, which might alter the spread of future projections, then expert opinion can change likelihood values.

Climate Scenarios:
There are an infinite number of possible pathways that our future emissions might take. To compare results from different studies and different climate models its necessary to model the same emissions pathway. Therefore, most studies stick to five pathways outlined by the IPCC. In the AR6, the updated set of scenarios include both the emissions pathway and societal changes (SSPs). The numbers after the hyphen represent the emissions pathways (RCPs) used in climate models and are largely consistent with the RCPs used in the AR5 report. This allows those working in impact modelling to follow a similar set of controlled criteria.

SSP1-1.9 (previously RCP 1.9): most optimistic scenario with net zero CO_2 emissions at 2050, temperatures peak around 1.5°C, and stabilize at 1.4°C above pre-industrial temperatures.
SSP1-2.6 (previously RCP 2.6): CO_2 emissions are cut severely but not fast, with net zero after 2050. Global temperatures stabilize at 1.8°C.
SSP2-4.5 (previously RCP 4.5): Middle of the road scenario. CO_2 emissions hover around current levels until the middle of the century, with net zero reached by 2100. Socioeconomic factors follow historic trends. Progress is slow and uneven. Temperatures reach 2.7°C by 2100.

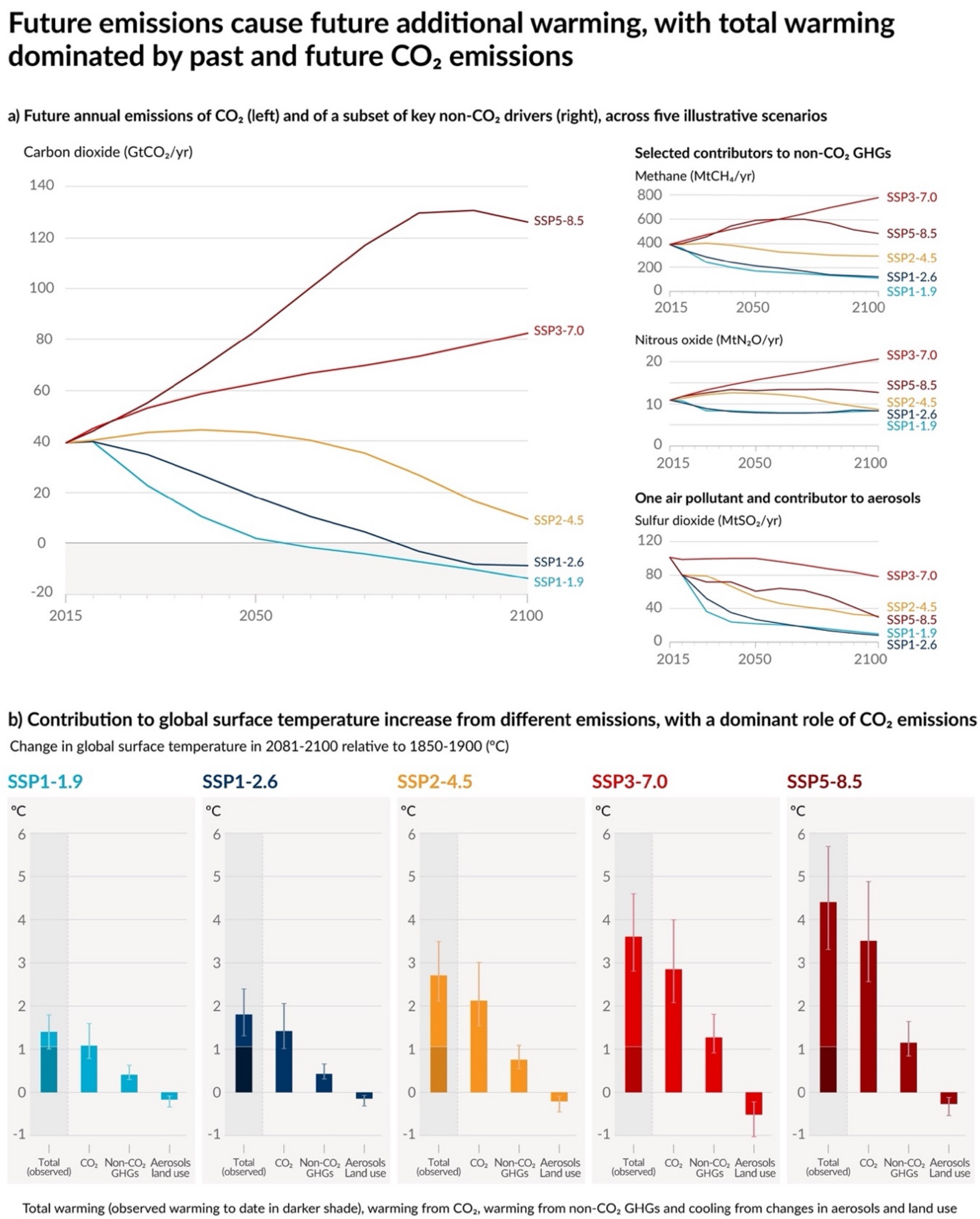

Figure 3: Different climate scenarios used in the AR6 WG1 report. Figure from the IPCC Summary for Policymakers (IPCC, 2021).

SSP3-7.0 (previously RCP7): CO_2 emissions rise steadily to double current levels by 2100. Countries becomes more competitive and isolationist when securing their own food supplies. Temperatures rise by 3.6°C by 2100.
SSP5-8.5 (previously RCP 8.5): Worst case scenario. Current CO_2 emissions continue to accelerate, doubling by 2050. The global economy grows rapidly, fueled by fossil fuels. By 2100, temperatures rise to 4.4°C, or higher.

The SSPs represent an emissions pathway through time rather than a temperature 'destination'. However, for many components of the climate system, the destination is not influenced much by the route. I.e., expected temperature and precipitation patterns from 2°C look very similar regardless of whether the pathway to get there followed RCP4.5 or RCP8.5. Therefore, the IPCC, and many climate modelling studies, also report changes to the earth's climate at a common reference point of globally averaged warming: usually 1.5, 2, 3 and 4°C (although the 3°C warming is less used and reported).

This is not always the case, for example total ice-sheet melt is, somewhat intuitively, dependent on the temperature pathway, not just the instantaneous temperature.

Drought:
The AR6 WG1 report refers to several different kinds of drought which have specific scientific definitions and ways of measuring. These are combined into four separate categories.

Meteorological drought:	relating to changes in rainfall only
Hydrological drought:	relating to changes in the hydrologic system such as river flows, river levels, lake levels, groundwater levels etc.
Agricultural drought:	relating to changes in soil moisture that influence crop growth. Agricultural drought is dependent on rainfall and evaporation.
Ecological drought:	relating to the availability of water to different ecosystems. In the AR6 WG1 this is often incorporated into agricultural drought.

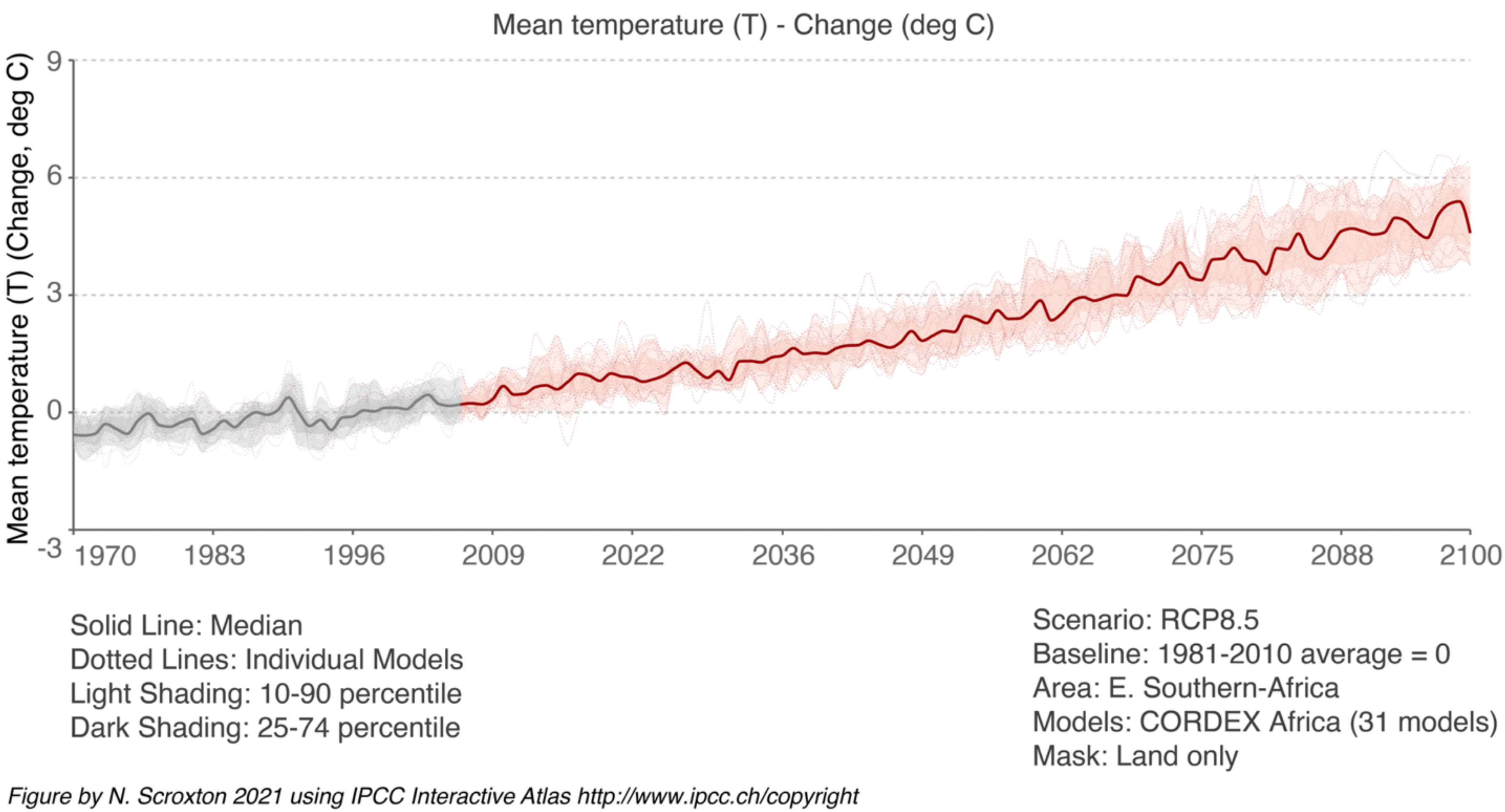

Figure 4: Projected future climate change in East Southern Africa – Mean temperature.

TEMPERATURE

Positive trends are already observed in annual mean, maximum and minimum temperatures in all seasons from 1960–2003 (Collins, 2011; Kruger and Shongwe, 2004; Kruger and Sekele, 2013; MacKellar et al., 2014; Zhou et al., 2010). Minimum temperatures are increasing faster than maximum temperatures (New et al., 2006). In AR5 an anthropogenic cause of observed warming over Africa was given medium confidence, all other inhabited continents were at high confidence. In the new AR6 report, an **anthropogenic cause is now given high confidence**.

The strongest warming in the southern hemisphere is expected to occur in subtropical regions (**high confidence**). All Southern Africa will warm faster than the global average. 1.5°C of globally averaged warming will see 1.5-2°C of warming in Southern Africa, 2°C of global warming will see 2-3°C of regional warming, 4°C of global warming will see 4-5°C of regional warming, etc. Above average temperature increases are likely to impact all seasons by the end of the century.

There is spatial variability to warming in Southern Africa. Interior Southern Africa has seen minimum temperatures decrease (MacKellar et al., 2014), perhaps due to high pressure systems. For future projections, the interior of West Southern-Africa (Namibia, Botswana) will warm even faster, which may influence south-eastern Zambia. The spatial patterns of change do not change under different warming scenarios (high confidence).

<u>TEMPERATURE EXTREMES:</u> It is likely that there has already been an increase in both the intensity and frequency of hot extremes, and a corresponding decrease in the intensity and frequency of cold extremes. (Dunn et al., 2020; Kruger and Nxumalo, 2017; Mbokodo et al., 2020; Perkins-Kirkpatrick and Lewis, 2020; Russo et al., 2016). There is high confidence in role of human contribution to this change (Seong et al., 2021).

Climate model projections predict further increases in the intensity and frequency of hot extremes. For 1.5°C global warming this is considered Likely (relative to today) or Very Likely (relative to pre-industrial climate). For 2°C of global warming it is considered Very Likely (relative to today) or Extremely Likely (relative to pre-industrial climate). For 4°C of global warming the increase in hot extremes is considered Virtually Certain (Coppola et al., 2021a; Engelbrecht et al., 2015; Giorgi et al., 2014; Li et al., 2021; Weber et al., 2018). For example: the **number of days with max temperatures above 35°C is expected to increase by 40-50 days per year by 2050 under the low emissions scenario SSP1-2.6** and 50-100 days per year under SSP5-8.5 (Coppola et al., 2021b) (high confidence). As a result, **mortality-related heat stress and deadly temperatures are very likely to become more frequent** (Ahmadalipour and Moradkhani, 2018; Coffel et al., 2017; Zhao et al., 2015).

Cold events have likely decreased in frequency in the last few decades. Cold spells are likely to decrease under lower warming scenarios and are virtually certain to decrease under high warming scenarios. This may have positive benefits on the risk of frost damage to agriculture but may have other health and ecosystem consequences.

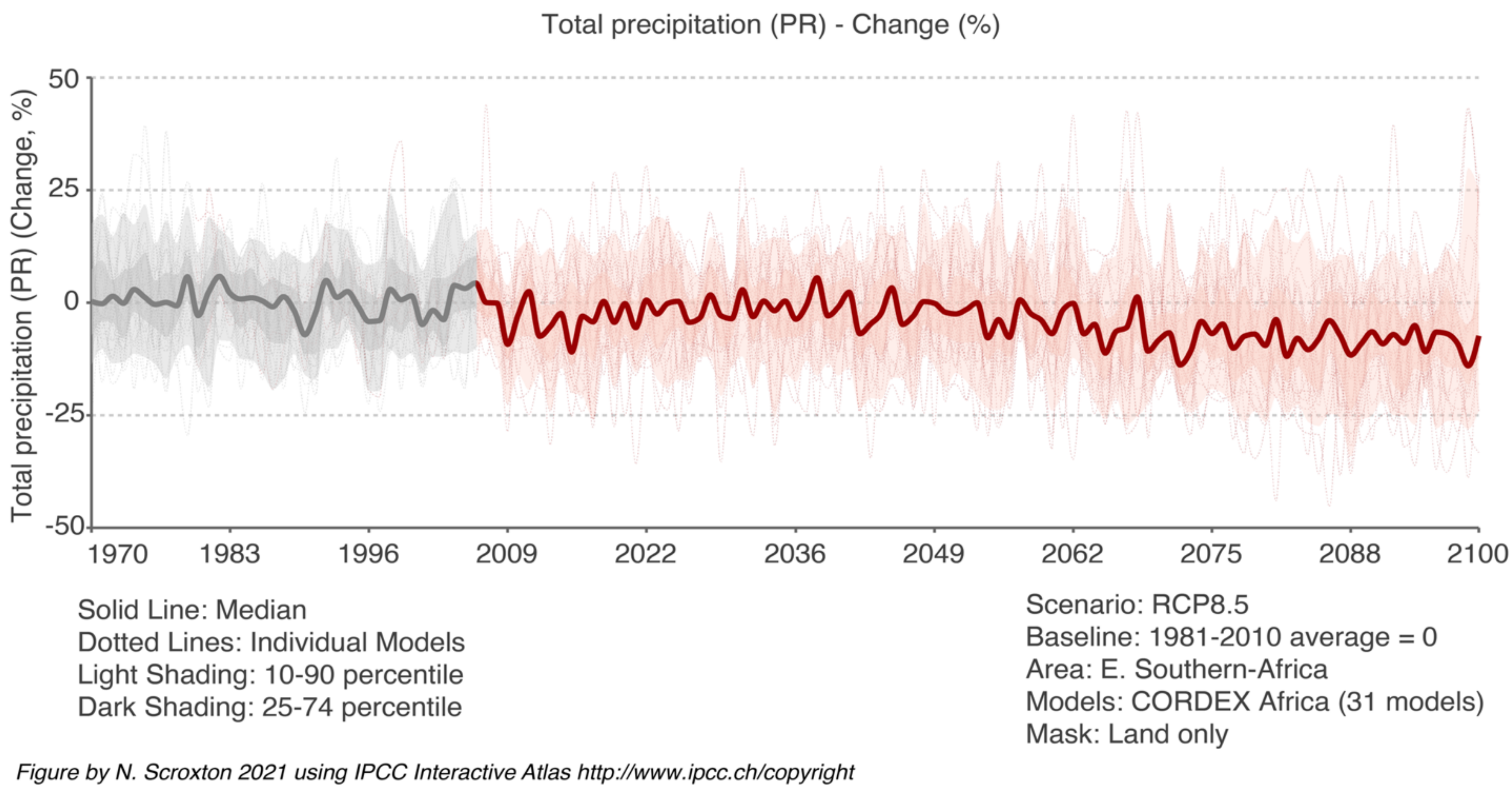

Figure 5: Projected future climate change in East Southern Africa – Total precipitation.

RAINFALL

Rainfall changes are harder to observe than temperature changes because of a high degree of natural variability. For example: an increase in Southern African rainfall between 1983 and 2010 is linked to decadal scale climate variability in the Pacific (Maidment et al., 2015). Further, in many regions of Africa, a lack of robust observational data further limits our ability to draw conclusions on rainfall variability, and there are significant discrepancies between different observation datasets (Panitz et al., 2014; Sylla et al., 2013). General trends are therefore slower to emerge in observations, at least to a degree of statistical significance. Nevertheless, there is **medium or high confidence in projections for a future decrease in rainfall in Southern Africa** due to global warming.

TOTAL RAINFALL: Climate models project a decrease in rainfall in subtropical areas such as Southern Africa at all four levels of global warming (likely). The decrease will amplify at higher levels of global warming (high confidence). Annual average streamflows in Southern Africa are already declining (Gudmundsson et al., 2019) and are expected to continue to decrease. (Döll et al., 2018).

RAINFALL SEASONALITY: **Wet seasons are projected to get wetter and dry seasons to get drier in southern Africa** (high confidence), although changes under low warming scenarios (SSP1-2.6) are small compared to internal variability. The contrast between the wettest and driest month of the year is likely to increase by 3 to 5% per °C of warming (medium confidence), for rainfall, water availability (Precipitation – Evaporation) and runoff. Increased rainfall seasonality will lead to increased seasonality in streamflows (high confidence).

WET SEASON ONSET AND DURATION: Observations suggest that the Southern African wet season is beginning earlier (1985-2007). In contrast, **models predict a delayed onset** to the wet season (Dunning et al., 2018; Maidment et al., 2015). In southern Africa the **wet season may be shorter by 5-10 days** by the end to the 21st century (Dunning et al., 2018).

RAINFALL EXTREMES: There is medium confidence that there has already been an increase in the intensity of heavy rainfall in East Southern Africa (Donat et al., 2013; Sun et al., 2021), although direct attribution to human activity is so far limited. Under 1.5°C warming, increases in both the intensity and frequency of heavy rainfall has medium confidence compared to today and high confidence compared to the pre-industrial. This increases to high confidence and Likely for 2°C global warming, and Very Likely and Extremely Likely for 4°C of global warming. Relative to today increases of more than 2% in the 1 day and 5 day extremes are predicted for the lower degrees of global warming, but 15% in 4°C scenarios (Li et al., 2021). Pinto et al., 2018

SURFACE HUMIDITY: Models project a decrease in near-surface relative humidity. Under low-emissions scenarios (SP1-2.6) decreases will be insignificant compared to natural variability. Under high emissions scenarios (SSP3-7.0) decreases are expected to be significant.

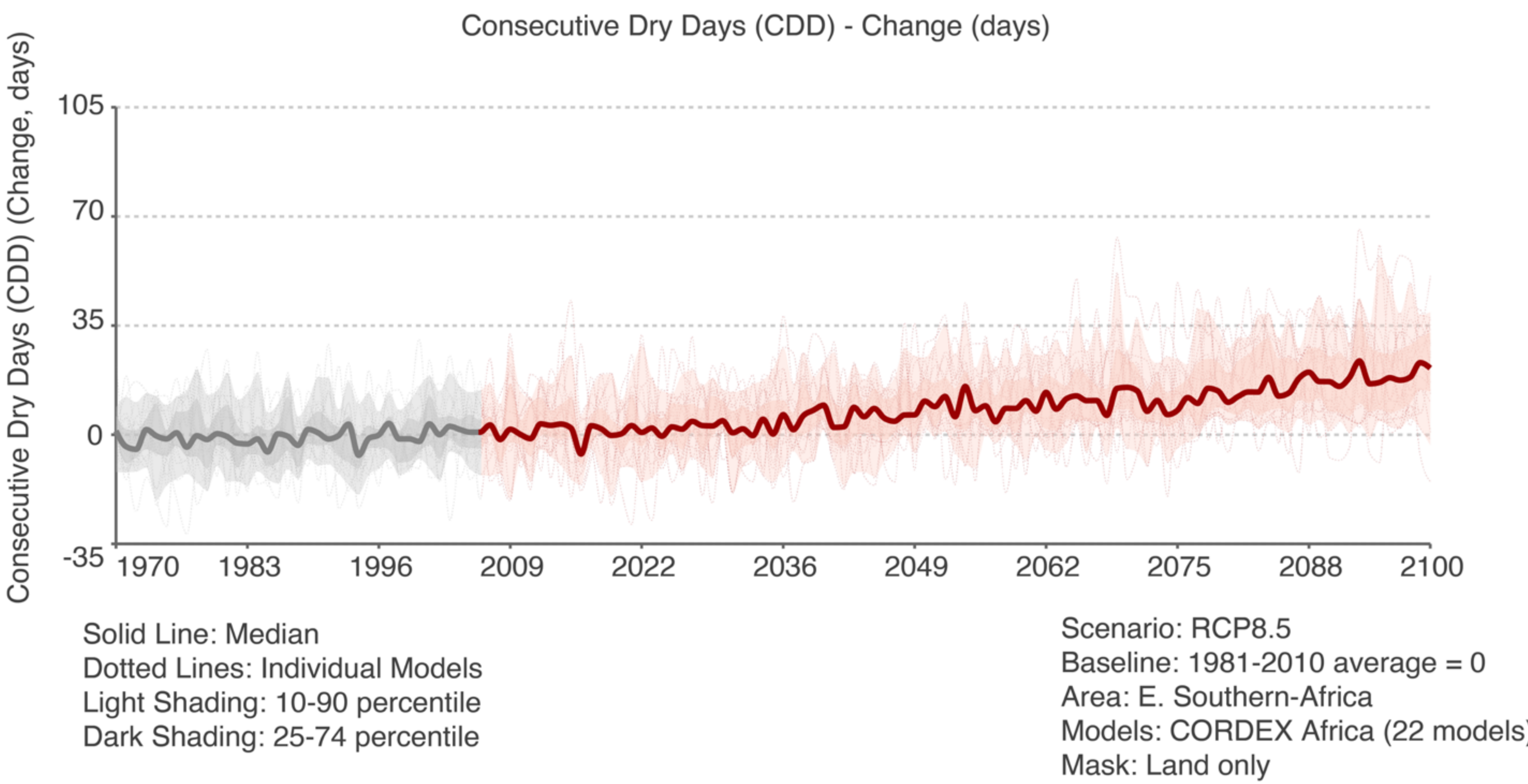

Figure by N. Scroxton 2021 using IPCC Interactive Atlas http://www.ipcc.ch/copyright

Figure 6: Projected future climate change in East Southern Africa – Consecutive Dry Days.

DROUGHT

There is medium confidence that anthropogenic warming has contributed to recent drought events in Southern Africa.

In the future, the **likelihood of extreme droughts** (less than 10% of the 1851-1880 average rainfall) **will double under low emissions scenarios**, and treble or even quadruple under high emissions scenarios (Cook et al., 2020). **Significant increases in drought duration** are expected in southern Africa. Droughts will be longer by 0.5–1 month for a moderate emissions scenario (SSP2-4.5) and 2 months for a high emissions scenario (SSP5-8.5) (Ukkola et al., 2020).

METEOROLOGICAL DROUGHT
There is medium confidence that there has already been in an increase in meteorological drought in ESAF both through a decrease in the amount of rainfall and through an increase in the number of consecutive dry days (Dunn et al., 2020; Spinoni et al., 2019). While there is limited evidence (low confidence) attributing this trend to human activity, there is medium confidence that humans have influenced recent meteorological droughts (Bellprat et al., 2015; Funk et al., 2018; Yuan et al., 2018).

Climate model projections suggest a medium confidence in there being an increase in consecutive dry days and the number of dry days under 1.5°C warming. This increases to high confidence under 2°C warming and Likely at 4°C warming (Coppola et al., 2021b; Maúre et al., 2018). Changes in rainfall amount leading to drought are slightly less certain under weaker warming scenarios (Abiodun et al., 2017) but are predicted to occur under stronger warmer scenarios (Abiodun et al., 2019).

AGRICULTURAL DROUGHT
There is medium confidence that there has already been an increase in agricultural drought (Dai and Zhao, 2017; Greve et al., 2014; Padrón et al., 2020; Spinoni et al., 2019). Flash droughts (rapid onset and durations from days to months) have increased by 220% between 1961 and 2016 because of human acitivity, but evidence for human activity driving other droughts is currently limited (Yuan et al., 2018). **Soil moisture is expected to show significant decreases even under low emissions scenarios** (SP1-2.6)(high confidence). Future projections have a medium confidence in an increase in agricultural drought, but the magnitude of change is inconsistent (Cook et al., 2020; Naumann et al., 2018; Xu et al., 2019). At 4°C global warming, there is a high confidence in agricultural drought increasing (Cook et al., 2020; Vicente-Serrano et al., 2019).

HYDROLOGICAL DROUGHT
There is limited evidence of increased hydrological drought in ESAF in the recent past, and hydrological drought may not increase under 1.5°C of global warming (Touma et al., 2015). This is a decrease in certainty relative to the AR5 observation (all be it of the entire Southern Africa region). Under the 2°C and 4°C warming projections there is medium confidence in increased hydrological drought (Cook et al., 2020; Touma et al., 2015; Zhai et al., 2020).

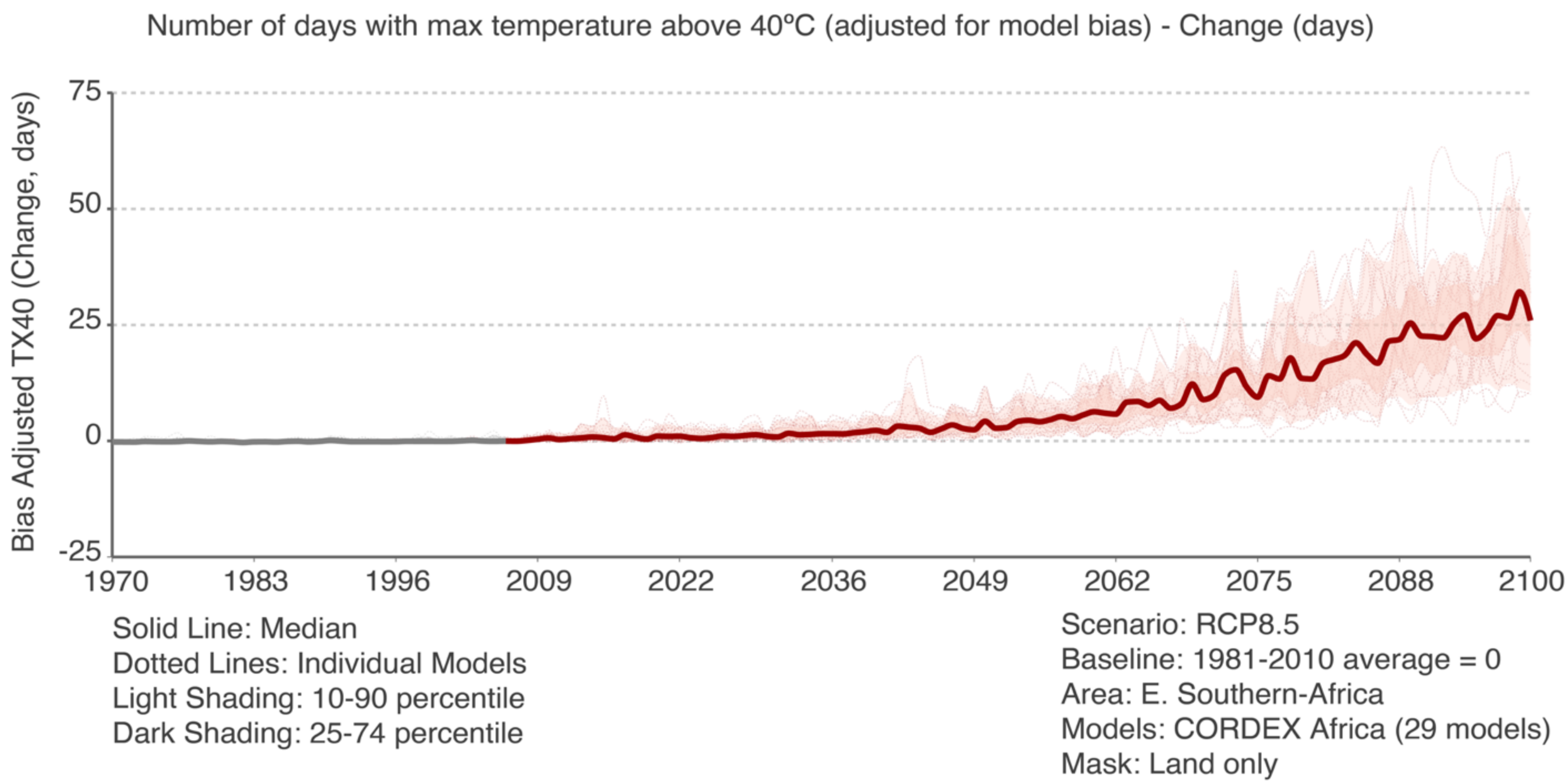

Figure by N. Scroxton 2021 using IPCC Interactive Atlas http://www.ipcc.ch/copyright

Figure 7: Projected future climate change in East Southern Africa – Number of days with maximum temperatures above 40°C.

OTHER COMPONENTS OF THE CLIMATE SYSTEM

WIND: There is medium confidence for an increase in average wind speed (Jung and Schindler, 2019; Karnauskas et al., 2018). There is low confidence of a general increasing trend in extreme wind speeds.

FIRE: Days prone to fire conditions will increase due to the increasing aridity (high confidence) and reduction in soil moisture (high confidence) (Abatzoglou et al., 2019; Engelbrecht et al., 2015).

TROPICAL CYCLONES: There has been an observed increase in Category 5 cyclones in the Southern Indian Ocean (Fitchett, 2018). There is a projected decrease in the frequency of cyclones making landfall in the EASF region in a warmer world (medium confidence) (Knutson et al., 2020; Malherbe et al., 2013; Muthige et al., 2018; Roberts et al., 2015; Roberts et al., 2020). However, there is also medium confidence for an increase in the intensity of cyclones in African regions.

SAND AND DUST STORMS: There is little confidence over any global warming related trends in either observations or projections of changes in sand and dust storms. This is mainly due to the complex feedbacks and responses sand and dust storms have to multiple aspects of the climate system (wind, precipitation, vegetation) and to human and pest related land use change.

SOLAR RADIATION (ie. SUNSHINE): There is medium confidence that solar radiation will increase in ESAF (Sawadogo et al., 2021; Sawadogo et al., 2020; Soares et al., 2019; Tang et al., 2019; Wild et al., 2015; Wild et al., 2017).

FLOODS: Flood trends in Southern Africa were decreasing prior to 1980 and increasing afterwards (medium confidence) (Tramblay et al., 2020). River discharge is expected to increase across Africa by up to 10% (Dankers et al., 2014), increasing river floods.

SEA LEVEL: The 1900-2018 sea-level rise on the Indian Ocean coastline was at about 1.33mm per year (Frederikse et al., 2020), slightly lower than the global average of 1.77 mm per year. More recently, the 1993-2018 rise was 3.65 mm per year, higher than the global average of 3.25mm per year. Sea level rise is virtually certain to continue and ranges from 0.4-0.5m by 2100 under SSP1-2.6 to 0.8 to 0.9m under SSP5-8.5, within the range of the global average.

COASTAL FLOODS AND EROSION: Absolute sea-level is only one component of coastal flooding, tides, storm surges and coastal geometry all contribute. Coastal flooding is predicted to occur both more frequently and with higher magnitudes in the future (high confidence). In Southern Africa the present day 1 in 100 year ‘extreme total water level’ is projected to have a return time of 1:10 to 1:20 years by 2050 and 1:1 to 1:5 years by 2100 (Vousdoukas et al., 2018). Under RCP4.5 coastlines in ESAF will retreat by ~30m by 2050 (Vousdoukas et al., 2020), although this masks areas with higher retreat, and some areas may prograde due to increased sediment supply.

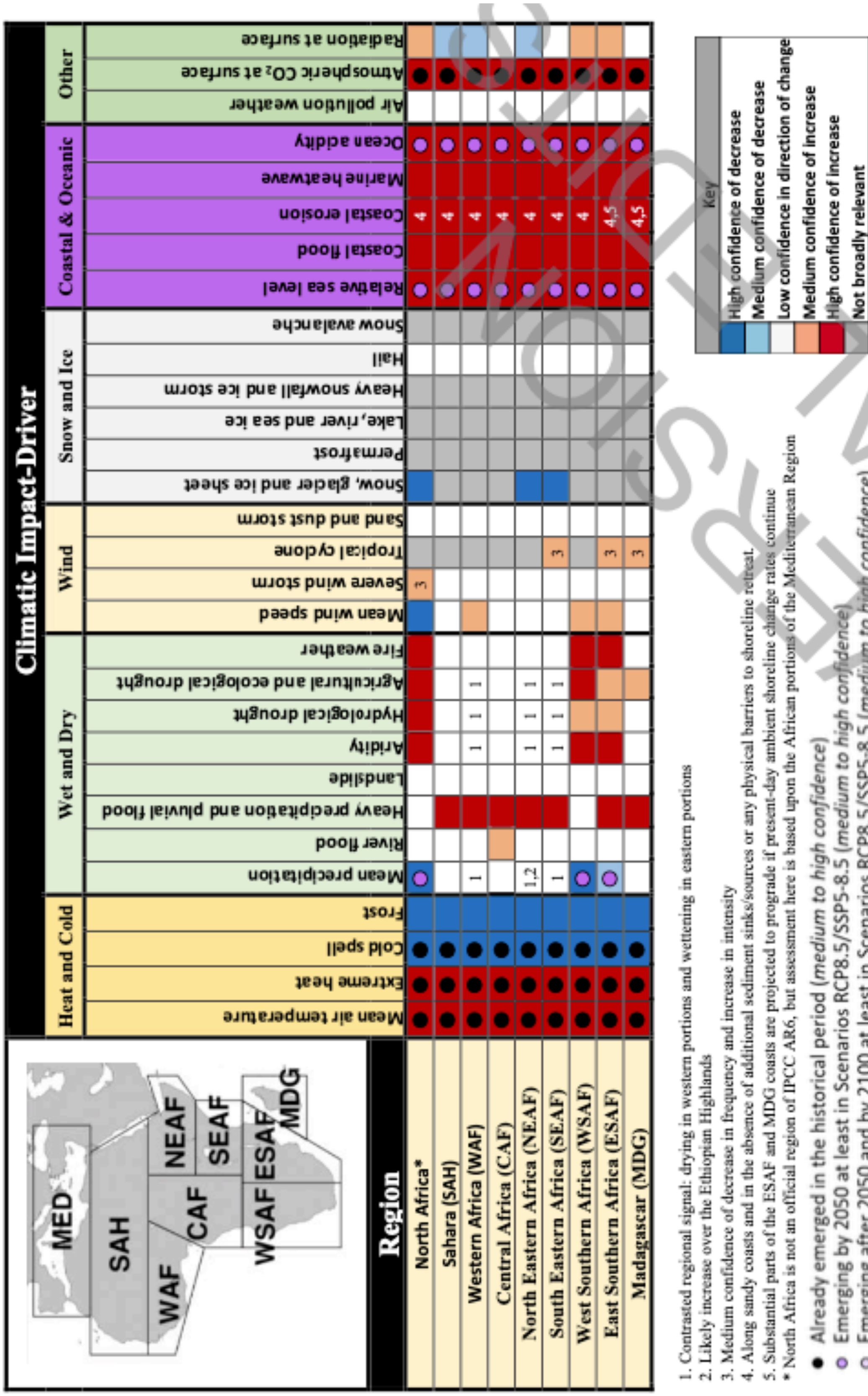

Figure 8: IPCC AR6 Table 12.3 (with watermark unfortunately)

<u>What changes in the climate system are behind these projections?</u>

Projected changes in the future climate of East Southern Africa relative to today might seem complex at first. However, many are driven by a few fundamental changes in atmospheric circulation over Africa. This page details the changes that influence mean conditions while the following page on global climate modes considers the changes to year-to-year (interannual) climate variability.

<u>ITCZ POSITION:</u> Greenhouse gas warming is expected to intensify the heat low over the Sahara. (Dong and Sutton, 2015) This will cause the tropical rainbelt (also known as the ITCZ) to migrate further north during the northern hemisphere summer and stay further north for longer (Cook and Vizy, 2012; Dunning et al., 2018; Wainwright et al., 2019) (Medium Confidence). Consequently, there is an expected delay to the southward movement of the tropical rainbelt in the northern hemisphere autumn/southern hemisphere spring, and its arrival over East South Africa in the southern hemisphere summer. Therefore, wet season onset in East Southern Africa is expected to occur later and the wet season will be shorter in duration (Dunning et al., 2018), leading to an overall drying.

Enhanced high pressure systems also lead to an increased drying out of soils (Engelbrecht et al., 2015; Vogel et al., 2017). In East Southern-Africa there is a strong relationship between soil moisture and temperature. This is the likely cause of the above-average increases in temperature (relative to the global average) in the region.

<u>ITCZ WIDTH:</u> The ITCZ is also likely to contract. Under warmer conditions convection gets stronger and more focused within the core of the ITCZ (Byrne and O'Gorman, 2018; Lau and Kim, 2015). Cloud feedbacks reinforce this change (Popp and Silvers, 2017; Su et al., 2017; Su et al., 2019; Su et al., 2020; Talib et al., 2018). This leads to stronger rainfall in the core of the ITCZ and weaker rainfall at the edges (Byrne and Schneider, 2016). How this might impact individual locations is uncertain as ITCZ position is also important, but it is likely that this process will serve to increase drying in East Southern-Africa.

<u>ATMOSPHERIC RIVERS:</u>

A warmer atmosphere holds more moisture (about 7% per °C). The amount and intensity of rainfall in extra-tropical storms is expected to increase, particularly in atmospheric rivers. This will drive increased rainfall intensity and flooding (Algarra et al., 2020; Espinoza et al., 2018; Xu et al., 2020; Yettella and Kay, 2017; Zavadoff and Kirtman, 2020; Zhao, 2020). Atmospheric rivers are important for non-ITCZ related rainfall in the subtropics including over the Shire Basin in Malawi and the Zambezi River system, and to a lesser extent over the Limpopo (Munday et al., 2021).

Changes to Global Climate Modes

Interannual rainfall variability in the ESAF region is influenced by several global climate 'modes' including El Nino-Southern Oscillation, the Indian Ocean Basin Mode and Pacific Decadal Variability. These tend to influence the year-to-year climate variability.

El Niño-Southern Oscillation (ENSO) is a cross basin dipole of sea surface temperatures and associated changes in atmospheric circulation in the Pacific Ocean, i.e., the east and west shift in the opposite direction to each other. It has far reaching climate consequences around the globe through what are known as teleconnections. ENSO has a strong control on summer temperatures and medium control on rainfall in the ESAF region. Specifically, El Niño events decrease precipitation. Longer term decadal variability in the Pacific (PDV) also has a small control on rainfall variability. Models do not agree on whether there will be a change in the amplitude of ENSO (Cai et al., 2015; Power et al., 2013). It is uncertain how the teleconnections from ENSO that influence other regions will change in the future (AR5: (IPCC, 2013)).

The Indian Ocean Basin Mode (IOBM) is a basin wide oscillation of sea surface temperatures, i.e., the entire tropical Indian Ocean warms or cools. The IOBM has a medium control on southern hemisphere autumn temperatures and small control on rainfall. The Indian Ocean Basin is the fastest warming ocean basin in the world. However, there is no robust evidence for significant changes in the IOBM in the near term.

The Indian Ocean Dipole (IOD) is a cross basin dipole of sea surface temperatures and associated changes in atmospheric circulation in the Indian Ocean, i.e., the east and west shift in the opposite direction to each other. The IOD does not significantly control variability in the ESAF region. This is because the IOD mainly influences spring rainfall rather than summer rainfall or temperature. The IOD is very important further north in Eastern Africa. Faster warming of the west Indian Ocean basin than the east suggests that the mean state of the Indian Ocean may resemble a positive IOD event in the future. This change may lead to a reduction in the amplitude of IOD events, but there is no evidence for this leading to a cessation of IOD variability, or any change in the frequency of events (Cai et al., 2014).

Summary:

The East Southern-African region is likely to warm at a faster rate than the global average, and across all seasons. Cold extremes will decrease, and warm extremes will increase. Annual rainfall is expected to decrease. However, rainfall seasonality is expected to increase, with more extreme precipitation events and more extreme dry spells. This will likely lead to greater seasonal variation in streamflow, increased flooding, and more droughts.

References

Abatzoglou, J.T., Williams, A.P., and Barbero, R., (2019). Global emergence of anthropogenic climate change in fire weather indices. *Geophysical Research Letters*, 46326–336, 10.1029/2018GL080959

Abiodun, B.J., Adegoke, J., Abatan, A.A., Ibe, C.A., Egbebiyi, T.S., Engelbrecht, F.A., and Pinto, I., (2017). Potential impacts of climate change on extreme precipitation over four African coastal cities. *Climatic Change*, 143399–413, 10.1007/s10584-017-2001-5

Abiodun, B.J., Makhanya, N., Petja, B., Abatan, A.A., and Oguntunde, P.G., (2019). Future projection of droughts over major river basins in Southern Africa at specific global warming levels. *Theoretical and Applied Climatology*, 1371785–1799, 10.1007/s00704-018-2693-0

Ahmadalipour, A., and Moradkhani, H., (2018). Escalating heat-stress mortality risk due to global warming in the Middle East and North Africa (MENA). *Environment International*, 117215–225, 10.1016/j.envint.2018.05.014

Algarra, I., Nieto, R., Ramos, A.M., Eiras-Barca, J., Trigo, R.M., and Gimeno, L., (2020). Significant increase of global anomalous moisture uptake feeding landfalling Atmospheric Rivers. *Nature Communications*, 1110.1038/s41467-020-18876-w

Bellprat, O., Lott, F.C., Gulizia, C., Parker, H.R., Pampuch, L.A., Pinto, I., Ciavarella, A., and Stott, P.A., (2015). Unusual past dry and wet rainy seasons over Southern Africa and South America from a climate perspective. *Weather and Climate Extremes*, 936–46, 10.1016/j.wace.2015.07.001

Byrne, M.P., and Schneider, T., (2016). Narrowing of the ITCZ in a warming climate: Physical mechanisms. *Geophysical Research Letters*, 4311350–11357, 10.1002/2016GL070396

Byrne, M.P., and O'Gorman, P.A., (2018). Trends in continental temperature and humidity directly linked to ocean warming. *Proceedings of the National Academy of Sciences*, 115(19), 4863–4868, 10.1073/pnas.1722312115

Cai, W., Santoso, A., Wang, G., Weller, E., Wu, L., Ashok, K., Masumoto, Y., and Yamagata, T., (2014). Increased frequency of extreme Indian Ocean Dipole events due to greenhouse warming. *Nature*, 510254–258, 10.1038/nature13327

Cai, W., Santoso, A., Wang, G., Yeh, S.W., An, S.I., Cobb, K.M., Collins, M., Guilyardi, E., Jin, F.-F., Kug, J.-S., Lengaigne, M., McPhaden, M.J., Takahashi, K., Timmermann, A., Vecchi, G., Watanbe, M., and Wu, L., (2015). ENSO and greenhouse warming. *Nature Climate Change*, 5849–859, 10.1038/NCLIMATE2743

Coffel, E.D., Horton, R.M., and De Sherbinin, A., (2017). Temperature and humidity based projections of a rapid rise in global heat stress exposure during the 21st century. *Environmental Research Letters*, 13(1), 014001, 10.1088/1748-9326/aaa00e

Collins, J.M., (2011). Temperature variability over Africa. *Journal of Climate*, 243649–3666, 10.1175/2011JCLI3753.1

Cook, B.I., Mankin, J.S., Marvel, K., Williams, A.P., Smerdon, J.E., and Anchukaitis, K.J., (2020). Twenty-first century drought projections in the CMIP6 forcing scenarios. *Earth's Future*, 810.1029/2019EF001461

Cook, K.H., and Vizy, E.K., (2012). Impact of climate change on mid-twenty-first century growing seasons in Africa. *Climate Dynamics*, 392937–2955, 10.1007/s00382-012-1324-1

Coppola, E., Nogherotto, R., Ciarlo', J.M., Giorgi, F., van Meijgaard, E., Kadygrov, N., Iles, C., Corre, L., Sandstad, M., and Somot, S., (2021a). Assessment of the European climate projections as simulated by the large EURO-CORDEX regional and global climate model ensemble. *Journal of Geophysical Research: Atmospheres*, 126(4), e2019JD032356, 10.1029/2019JD032356

Coppola, E., Raffaele, F., Giorgi, F., Giuliani, G., Xuejie, G., Ciarlo, J.M., Sines, T.R., Torres-Alavez, J.A., Das, S., and di Sante, F., (2021b). Climate hazard indices projections based on CORDEX-CORE, CMIP5 and CMIP6 ensemble. *Climate Dynamics*, 571293–1383, 10.1007/s00382-021-05640-z

Dai, A., and Zhao, T., (2017). Uncertainties in historical changes and future projections of drought. Part I: Estimates of historical drought changes. *Climatic Change*, 144519–533, 10.1007/s10584-016-1705-2

Dankers, R., Arnell, N.W., Clark, D.B., Falloon, P.D., Fekete, B.M., Gosling, S.N., Heinke, J., Kim, H., Masaki, Y., Satoh, Y., Stacke, T., Wada, Y., and Wisser, D., (2014). First look at changes in flood hazard in the Inter-Sectoral Impact Model Intercomparison Project ensemble. *Proceedings of the National Academy of Sciences*, 111(9), 3257–3261, 10.1073/pnas.1302078110

Döll, P., Trautmann, T., Gerten, D., Schmied, H.M., Ostberg, S., Saaed, F., and Schleussner, C.-F., (2018). Risks for the global freshwater system at 1.5 C and 2 C global warming. *Environmental Research Letters*, 1310.1088/1748-9326/aab792

Donat, M.G., Alexander, L.V., Yang, H., Durre, I., Vose, R., Dunn, R.J.H., Willet, K.M., Aguilar, E., Bador, M., Caesar, J., Hewitson, B., Jack, C., Klein Tank, A.M.G., Kruger, A.C., Marengo, J., Peterson, T.C., Renom, M., Oria Rojas, C., Rusticucci, M., Salinger, J., Elrayah, A.S., Sekele, S.S., Srivastava, A.K., Trewin, B., Villarroel, C., Vincent, L.A., Zhai, P., Zhang, X., and Kitching, S., (2013). Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: The HadEX2 dataset. *Journal of Geophysical Research*, 1182098–2118, 10.1002/jgrd.50150

Dong, B., and Sutton, R., (2015). Dominant role of greenhouse-gas forcing in the recovery of Sahel rainfall. *Nature Climate Change*, 5757–760, 10.1038/nclimate2664

Dunn, R.J.H., Alexander, L.V., Donat, M.G., Zhang, X., Bador, M., Herold, N., Lippmann, T., Allan, R., Aguilar, E., and Barry, A.A., (2020). Development of an updated global land in situ-based data set of temperature and precipitation extremes: HadEX3. *Journal of Geophysical Research: Atmospheres*, 125(16), e2019JD032263, 10.1029/2019JD032263

Dunning, C.M., Black, E., and Allan, R.P., (2018). Later wet seasons with more intense rainfall over Africa under future climate change. *Journal of Climate*, 319719–9738, 10.1175/JCLI-D-18-0102.1

Engelbrecht, F., Adegoke, J., Bopape, M.-J., Naidoo, M., Garland, R., Thatcher, M., McGregor, J., Katzfey, J., Werner, M., and Ichoku, C., (2015). Projections of rapidly rising surface temperatures over Africa under low mitigation. *Environmental Research Letters*, 10(8), 085004, 10.1088/1748-9326/10/8/085004

Espinoza, V., Waliser, D.E., Guan, B., Lavers, D.A., and Ralph, F.M., (2018). Global analysis of climate change projection effects on atmospheric rivers. *Geophysical Resarch Letters*, 454299–4308, 10.1029/2017GL076968

Fitchett, J.M., (2018). Recent emergence of CAT5 tropical cyclones in the South Indian Ocean. *South African Journal of Science*, 114(11/2), 10.17159/sajs.2018/4426

Frederikse, T., Landerer, F., Caron, L., Adhikari, S., Parkes, D., Humphrey, V.W., Dangendorf, S., Hogarth, P., Zanna, L., Cheng, L., and Wu, Y.-H., (2020). The causes of sea-level rise since 1900. *Nature*, 584393–397, 10.1038/s41586-020-2591-3

Funk, C., Davenport, F., Harrison, L., Magadzire, T., Galu, G., Artan, G.A., Shukla, S., Korecha, D., Indeje, M., Pomposi, C., Macharia, D., Husak, G., and Nsadisa, F.D., (2018). Anthropogenic enhancement of moderate-to-strong El Niño events likely contributed to drought and poor harvests in southern Africa during 2016. *Bulletin of the American Meterological Society*, 99(1), 91–96, 10.1175/BAMS-D-17-0112.1

Giorgi, F., Coppola, E., Raffaele, F., Diro, G.T., Fuentes-Franco, R., Giuliani, G., Mamgain, A., Llopart, M.P., Mariotti, L., and Torma, C., (2014). Changes in extremes and hydroclimatic regimes in the CREMA ensemble projections. *Climatic Change*, 125(1), 39–51, 10.1007/s10584-014-1117-0

Greve, P., Orlowsky, B., Mueller, B., Sheffield, J., Reichstein, M., and Seneviratne, S.I., (2014). Global assessment of trends in wetting and drying over land. *Nature Geoscience*, 7716–721, 10.1038/NGEO2247

Gudmundsson, L., Leonard, M., Do, H.X., Westra, S., and Seneviratne, S.I., (2019). Observed trends in global indicators of mean and extreme streamflow. *Geophysical Research Letters*, 46(2), 756–766, 10.1029/2018GL079725

IPCC, 2013. Climate phenomena and their relevance for future regional climate change. Climate Change 2013 – The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press,

IPCC, 2021. Summary for Policymakers. in: MassonDelmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J.B.R., Maycock, T.K., Waterfield, T., O, Y., Yu, R., and Zhou, B., (eds.), Climate Change 2021: The Physical Science Basis. Contribution of

Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press,

Iturbide, M., Gutiérrez, J.M., Alves, L.M., Bedia, J., Cerezo-Mota, R., Cimadevilla, E., Cofiño, A.S., Si Luca, A., Faria, S.H., Gorodetskaya, I.V., Hauser, M., Herrera, S., Hennessy, K., Hewitt, H.T., Jones, R.G., Krakovska, S., Manzanas, R., Martínez-Castro, D., Narisma, G.T., Nurhati, I.S., Pinto, I., Seneviratne, S.I., van den Hurk, B., and Vera, C.S., (2020). An update of IPCC climate reference regions for subcontinental analysis of climate model data: definition and aggregated datasets. *Earth System Science Data*, 122959–2970, 10.5194/essd-12-2959-2020

Jung, C., and Schindler, D., (2019). Changing wind speed distributions under future global climate. *Energy Conversion and Management*, 198111841, 10.1016/j.enconman.2019.111841

Karnauskas, K.B., Lundquist, J.K., and Zhang, L., (2018). Southward shift of the global wind energy resource under high carbon dioxide emissions. *Nature Geoscience*, 1138–43, 10.1038/s41561-017-0029-9

Knutson, T., Camargo, S.J., Chan, J.C.L., Emanuel, K., Ho, C.-H., Kossin, J., Mohapatra, M., Satoh, M., Sugi, M., Walsh, K., and Wu, L., (2020). Tropical cyclones and climate change assessment: Part II: Projected response to anthropogenic warming. *Bulletin of the American Meterological Society*, 101(3), E303–E322, 10.1175/BAMS-D-18-0194.1

Kruger, A.C., and Shongwe, S., (2004). Temperature trends in South Africa: 1960–2003. *International Journal of Climatology*, 24(15), 1929–1945, 10.1002/joc.1096

Kruger, A.C., and Sekele, S.S., (2013). Trends in extreme temperature indices in South Africa: 1962–2009. *International Journal of Climatology*, 33(3), 661–676, 10.1002/joc.3455

Kruger, A.C., and Nxumalo, M., (2017). Surface temperature trends from homogenized time series in South Africa: 1931–2015. *International Journal of Climatology*, 37(5), 2364–2377, 10.1002/joc.4851

Lau, W.K.M., and Kim, K.M., (2015). Robust Hadley circulation changes and increasing global dryness due to CO2 warming from CMIP5 model projections. *Proceedings of the National Academy of Sciences*, 112(12), 3630–3635, 10.1073/pnas.1418682112

Li, C., Zwiers, F., Zhang, X., Li, G., Sun, Y., and Wehner, M., (2021). Changes in annual extremes of daily temperature and precipitation in CMIP6 models. *Journal of Climate*, 34(9), 3441–3460, 10.1175/JCLI-D-19-1013.1

MacKellar, N., New, M., and Jack, C., (2014). Observed and modelled trends in rainfall and temperature for South Africa: 1960-2010. *South African Journal of Science*, 110(7/8), 10.1590/sajs.2014/20130353

Maidment, R.I., Allan, R.P., and Black, E., (2015). Recent observed and simulated changes in precipitation over Africa. *Geophysical Research Letters*, 428155–8164, 10.1002/2015GL065765

Malherbe, J., Engelbrecht, F.A., and Landman, W.A., (2013). Projected changes in tropical cyclone climatology and landfall in the Southwest Indian Ocean region under enhanced anthropogenic forcing. *Climate Dynamics*, 402867–2886, 10.1007/s00382-012-1635-2

Maúre, G., Pinto, I., Ndebele-Murisa, M., Muthige, M., Lennard, C., Nikulin, G., Dosio, A., and Meque, A., (2018). The southern African climate under 1.5C and 2C of global warming as simulated by CORDEX regional climate models. *Environmental Research Letters*, 1310.1088/1748-9326/aab190

Mbokodo, I., Bopape, M.-J., Chikoore, H., Engelbrecht, F., and Nethengwe, N., (2020). Heatwaves in the future warmer climate of South Africa. *Atmosphere*, 11(7), 712, 10.3390/atmos11070712

Munday, C., Washington, R., and Hart, N., (2021). African Low-Level Jets and Their Importance for Water Vapor Transport and Rainfall. *Geophysical Research Letters*, 48(1), 10.1029/2020GL090999

Muthige, M.S., Malherbe, J., Englebrecht, F.A., Grab, S., Beraki, A., Maisha, T.R., and Van der Merwe, J., (2018). Projected changes in tropical cyclones over the South West Indian Ocean under different extents of global warming. *Environmental Research Letters*, 1310.1088/1748-9326/aabc60

Naumann, G., Alfieri, L., Wyser, K., L, M., Betts, R.A., Carrao, H., Spinoni, J., Vogt, J., and Feyen, L., (2018). Global changes in drought conditions under different levels of warming. *Geophysical Research Letters*, 453285–3296, 10.1002/2017GL076521

New, M., Hewitson, B., Stephenson, D.B., Tsiga, A., Kruger, A., Manhique, A., Gomez, B., Coelho, C.A.S., Masisi, D.N., Kululanga, E., E, M., Adesina, F., Saleh, H., Kanyanga, J., Adosi, J., Bulane, L., Fortunata, L., Mdoka, M.L., and Lajoie, R., (2006). Evidence of trends in daily climate extremes over southern and west Africa. *Journal of Geophysical Research*, 11D14102, 10.1029/2005JD006289

Padrón, R.S., Gudmundsson, L., Decharme, B., Ducharne, A., Lawrence, D., Mao, J., Peano, D., Krinner, G., Kim, H., and Seneviratne, S.I., (2020). Observed changes in dry-season water availability attributed to human-induced climate change. *Nature Geoscience*, 13(7), 477–481, 10.1038/s41561-020-0594-1

Panitz, H.J., Dosio, A., Büchner, M., Lüthi, D., and Keuler, K., (2014). COSMO-CLM (CCLM) climate simulations over CORDEX-Africa domain: analysis of the ERA-Interim driven simulations at 0.44 and 0.22 resolution. *Climate Dynamics*, 423015–3038, 10.1007/s00382-013-1834-5

Perkins-Kirkpatrick, S.E., and Lewis, S.C., (2020). Increasing trends in regional heatwaves. *Nature Communications*, 11(1), 1–8, 10.1038/s41467-020-16970-7

Popp, M., and Silvers, L.G., (2017). Double and single ITCZs with and without clouds. *Journal of Climate*, 30(22), 9147–9166, 10.1175/JCLI-D-17-0062.1

Power, S., Delage, F., Chung, C., Kociuba, G., and Keay, K., (2013). Robust twenty-first-century projections of El Niño and related precipitation variability. *Nature*, 502541–545, 10.1038/nature12580

Roberts, M.J., Vidale, P.L., Mizielinski, M.S., Demory, M.-E., Schiemann, R., Strachan, J., Hodges, K., Bell, R., and Camp, J., (2015). Tropical cyclones in the UPSCALE ensemble of high-resolution global climate models. *Journal of Climate*, 28(2), 574–596, 10.1175/JCLI-D-14-00131.1

Roberts, M.J., Camp, J., Seddon, J., Vidale, P.L., Hodges, K., Vannière, B., Mecking, J., Haarsma, R., Bellucci, A., Soccimarro, E., Caron, L.-P., Chauvin, F., Terray, L., Valcke, S., Moine, M.-P., Putrasahan, D., Roberts, C.D., Senan, R., Zarzycki, C., Ulrich, P., Yamada, Y., Mizuta, R., Kodama, C., Fu, D., Zhang, Q., Danabasoglu, G., Rosenbloom, N., Wang, H., and Wu, L., (2020). Projected future changes in tropical cyclones using the CMIP6 HighResMIP multimodel ensemble. *Geophysical Research Letters*, 47e2020GL088662, 10.1029/2020GL088662

Russo, S., Marchese, A.F., Sillmann, J., and Immé, G., (2016). When will unusual heat waves become normal in a warming Africa. *Environmental Research Letters*, 11(5), 054016, 10.1088/1748-9326/11/5/054016

Sawadogo, W., Reboita, M.S., Faye, A., da Rocha, R.P., Odoulami, R.C., Olusegun, C.F., Adeniyi, M.O., Abiodun, B.J., Sylla, M.B., Diallo, I., Coppola, E., and Giorgi, F., (2021). Current and future

potential of solar and wind energy over Africa using the RegCM4 CORDEX-CORE ensemble. *Climate Dynamics*, 571647–1672, 10.1007/s00382-020-05377-1
Sawadogo, W., Abiodun, B.J., and Okogbue, E.C., (2020). Impacts of global warming on photovoltaic power generation over West Africa. *Renewable Energy*, 151263–277, 10.1016/j.renene.2019.11.032
Seong, M.-G., Min, S.-K., Kim, Y.-H., Zhang, X., and Sun, Y., (2021). Anthropogenic greenhouse gas and aerosol contributions to extreme temperature changes during 1951–2015. *Journal of Climate*, 34(3), 857–870, 10.1175/JCLI-D-19-1023.1
Soares, P.M.M., Brito, M.C., and Careto, J.A.M., (2019). Persistence of the high solar potential in Africa in a changing climate. *Environmental Research Letters*, 14124036, 10.1088/1748-9326/ab51a1
Spinoni, J., Barbosa, P., Jager, A.D., McCormick, N., Naumann, G., Vogt, J.V., Magni, D., Masante, D., and Mazzeschi, M., (2019). A new global database of meteorological drought events from 1951 to 2016. *Journal of Hydrology: Regional Studies*, 22100593, 10.1016/j.ejrh.2019.100593
Su, H., Jiang, J.H., Neelin, J.D., Shen, T.J., Zhai, C., Yue, Q., Wang, Z., Huang, L., Choi, Y.-S., Stephens, G.L., and Yung, Y.L., (2017). Tightening of tropical ascent and high clouds key to precipitation change in a warmer climate. *Nature Communications*, 815771, 10.1038/ncomms15771
Su, H., Zhai, C., Jiang, J.H., Wu, L., and Neelin…, J.D., (2019). A dichotomy between model responses of tropical ascent and descent to surface warming. *Climate and Atmospheric Science*, 2(8), 10.1038/s41612-019-0066-8
Su, H., Wu, L., Zhai, C., Jiang, J.H., Neelin, D., and Yung, Y.L., (2020). Observed tightening of tropical ascent in recent decades and linkage to regional precipitation changes. *Geophysical Research Letters*, 47(3), e2019GL085809, 10.1029/2019GL085809
Sun, Q., Zhang, X., Zwiers, F., Westra, S., and Alexander, L.V., (2021). A global, continental, and regional analysis of changes in extreme precipitation. *Journal of Climate*, 34(1), 243–258, 10.1175/JCLI-D-19-0892.1
Sylla, M.B., Giorgi, F., Coppola, E., and Mariotti, L., (2013). Uncertainties in daily rainfall over Africa: assessment of gridded observation products and evaluation of a regional climate model simulation. *International Journal of Climatology*, 33(7), 1805–1817, 10.1002/joc.3551
Talib, J., Woolnough, S.J., Klingaman, N.P., and Holloway, C.E., (2018). The role of the cloud radiative effect in the sensitivity of the intertropical convergence zone to convective mixing. *Journal of Climate*, 31(17), 6821–6838, 10.1175/JCLI-D-17-0794.1
Tang, C., Morel, B., Wild, M., Pohl, B., Abiodun, B., Lennard, C., and Bessafi, M., (2019). Numerical simulation of surface solar radiation over Southern Africa. Part 2: projections of regional and global climate models. *Climate Dynamics*, 532197–2227, 10.1007/s00382-019-04817-x
Touma, D., Ashfaq, M., Nayak, M.A., Kao, S.C., and Diffenbaugh, N.S., (2015). A multi-model and multi-index evaluation of drought characteristics in the 21st century. *Journal of Hydrology*, 526196–207, 10.1016/j.jhydrol.2014.12.011
Tramblay, Y., Villarini, G., and Zhang, W., (2020). Observed changes in flood hazard in Africa. *Environmental Research Letters*, 151040b5, 10.1088/1748-9326/abb90b
Ukkola, A.M., Kauwe, M.G.D., Roderick, M.L., Abramowitz, G., and Pitman, A.J., (2020). Robust future changes in meteorological drought in CMIP6 projections despite uncertainty in precipitation. *Geophysical Research Letters*, 47(11), e2020GL087820, 10.1029/2020GL087820
Vicente-Serrano, S.M., Domínguez-Castro, F., McVicar, T.R., Tomas-Burguera, M., Peña-Gallardo, M., Noguera, I., López-Moreno, J.I., Peña, D., and El Kenawy, A., (2019). Global characterization of hydrological and meteorological droughts under future climate change: The importance of timescales, vegetation-CO2 feedbacks and changes to distribution functions. *International Journal of Climatology*, 40(5), 2557–2567, 10.1002/joc.6350

Vogel, M.M., Orth, R., Cheruy, F., Hagemann, S., Lorenz, R., van den Hurk, B.J.J., and Seneviratne, S.I., (2017). Regional amplification of projected changes in extreme temperatures strongly controlled by soil moisture-temperature feedbacks. *Geophysical Research Letters*, 44(3), 1511–1519, 10.1002/2016GL071235

Vousdoukas, M.I., Mentaschi, L., Voukouvalas, E., Verlaan, M., Jevrejeva, S., Jackson, L.P., and Feyen, L., (2018). Global probabilistic projections of extreme sea levels show intensification of coastal flood hazard. *Nature Communications*, 92360, 10.1038/s41467-018-04692-w

Vousdoukas, M.I., Ranasinghe, R., Mentaschi, L., Plomaritis, T.C., Athanasiou, P., Luijendijk, A., and Feyen, L., (2020). Sandy coastlines under threat of erosion. *Nature Climate Change*, 10260–263, 10.1038/s41558-020-0697-0

Wainwright, Keane, R.J., Rowell, D.P., Finney, D.L., Black, E., and Allan, R.P., (2019). 'Eastern African Paradox' rainfall decline due to shorter not less intense Long Rains. *Climate and Atmispheric Science*, 234, 10.1038/s41612-019-0091-7

Weber, T., Haensler, A., Rechid, D., Pfeifer, S., Eggert, B., and Jacob, D., (2018). Analyzing regional climate change in Africa in a 1.5, 2, and 3 C global warming world. *Earth's Future*, 6(4), 643–655, 10.1002/2017EF000714

Wild, M., Folini, D., Henschel, F., Fischer, N., and Müller, B., (2015). Projections of long-term changes in solar radiation based on CMIP5 climate models and their influence on energy yields of photovoltaic systems. *Solar Energy*, 11612–24, 10.1016/j.solener.2015.03.039

Wild, M., Folini, D., and Henschel, F., (2017). Impact of climate change on future concentrated solar power (CSP) production. *AIP Conference Proceedings*, 181010.1063/1.4975562

Xu, L., Chen, N., and Zhang, X., (2019). Global drought trends under 1.5 and 2 C warming. *International Journal of Climatology*, 39(4), 2375–2385, 10.1002/joc.5958

Xu, Y., Zhang, H., Liu, Y., Han, Z., and Zhou, B., (2020). Atmospheric rivers in the Australia–Asian region under current and future climate in CMIP5 models. *Journal of Southern Hemisphere Earth Systems Science*, 70(1), 88–105, 10.1071/ES19044

Yettella, V., and Kay, J.E., (2017). How will precipitation change in extratropical cyclones as the planet warms? Insights from a large initial condition climate model ensemble. *Climate Dynamics*, 491765–1781, 10.1007/s00382-016-3410-2

Yuan, X., Wang, L., and Wood, E.F., (2018). Anthropogenic intensification of southern African flash droughts as exemplified by the 2015/16 season. *Bulletin of the American Meterological Society*, 99(1), S86–S89, 10.1175/BAMS-D-17-0077.1

Zavadoff, B.L., and Kirtman, B.P., (2020). Dynamic and thermodynamic modulators of European atmospheric rivers. *Journal of Climate*, 33(10), 4167–4185, 10.1175/JCLI-D-19-0601.1

Zhai, J., Mondal, S.K., Fischer, T., Wang, Y., Su, B., Huang, J., Tao, H., Wang, G., Ullah, W., and Jalal Uddin, M., (2020). Future drought characteristics through a multi-model ensemble from CMIP6 over South Asia. *Atmospheric Research*, 246105111, 10.1016/j.atmosres.2020.105111

Zhao, M., (2020). Simulations of atmospheric rivers, their variability, and response to global warming using GFDL's new high-resolution general circulation model. *Journal of Climate*, 33(23), 10287–10303, 10.1175/JCLI-D-20-0241.1

Zhao, Y., Ducharne, A., Sultan, B., Braconnot, P., and Vautard, R., (2015). Estimating heat stress from climate-based indicators: present-day biases and future spreads in the CMIP5 global climate model ensemble. *Environmental Research Letters*, 10(8), 084013, 10.1088/1748-9326/10/8/084013

Zhou, L., Dickinson, R.E., Dai, A., and Dirmeyer, P., (2010). Detection and attribution of anthropogenic forcing to diurnal temperature range changes from 1950 to 1999: comparing multi-model simulations with observations *Climate Dynamics*, 351289–1307, 10.1007/s00382-009-0644-2

Beatrice Abukayot at her farm in Teso South, Busia, Kenya

ETHIOPIA
PO Box 1204
Addis Ababa
Tel. +251 116 620 659

KENYA
PO Box 25503-00100
Nairobi
Tel. +254 703 946477

MALAWI
PO Box B-495
Lilongwe,
Tel. +265 175 0568

UGANDA
P.O. Box 34429,
Plot 44 Ministers' Village,
Ntinda, Kampala
Tel: +256 414 286 305

WEST AFRICA
12 PO Box 418,
Ougadougou 12, Burkina Faso
Tel. +226 503 68960

ZAMBIA
87 Provident Street,
Fairview, Lusaka
tel +260 211 236 595

DUBLIN
Kingsbridge House, 17-22 Parkgate
Street, Dublin 8, Co. Dublin
Tel. +353 (0)1 6778880

BELFAST
41 University Street
Belfast, NI, BT7 1FY
Tel: +44 (0)28 90232064

SHREWSBURY
Westgate House, Dickens Court Hills
Lane, Shrewsbury, SY1 1QU
Tel. +44 (0) 174 327 7170

LONDON
14 Dufferin Street,
London, EC1Y 8PD
Tel. +44 (0) 20 7251 6466

USA
41 Union Square West, Suite 1027
New York, NY 10003, USA
Tel. +1 212 206 0847

Self Help Africa

www.selfhelpafrica.org