The IPCC Assessment Report Six Working Group 1 report and southern Africa: Reasons to take action

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HOW TO CITE:
Engelbrecht FA, Monteiro PMS. The IPCC Assessment Report Six Working Group 1 report and southern Africa: Reasons to take action. S Afr J Sci. 2021;117(11/12), Art. #12679. https://doi.org/10.17159/sajs.2021/12679

ARTICLE INCLUDES:
☐ Peer review
☐ Supplementary material

KEYWORDS:
climate change, coupled carbon-climate systems, net zero CO_2 emissions, southern Africa

PUBLISHED:
9 November 2021

The release of the Intergovernmental Panel on Climate Change (IPCC) Assessment Report Six (AR6) Working Group I (WG1) report in August 2021 brought to completion what is arguably the most thorough and scrutinised assessment of climate knowledge needed to steer the planet away from dangerous and irreversible climate change.[1] The AR6 WG1 report builds on the Assessment Report Five WG1 report published in 2013, as well as on three special reports commissioned during the AR6 cycle: the *Special Report on Global Warming of 1.5 °C* (SR1.5), the *Special Report on the Ocean and Cryosphere in a Changing Climate*, and the *Special Report on Climate Change and Land*. The AR6 WG1 report as such does not come up with fundamentally new insights into the planet's coupled carbon-climate systems, but through its assessment of ~14 000 publications and response to 78 000 review comments, it provides an unprecedented level of confidence to earlier findings. What it reveals is that there have been critical methodological advances in both observation and modelling that have enabled improved levels of confidence[2] and opened doors for new science on global and regional climate-carbon challenges. These improved confidence levels are necessary to support the deeply transformative global, and South African, decision-making towards net zero CO_2 emissions by 2050 in support of restricting global warming to below 1.5 °C relative to the pre-industrial temperatures.[3,4] Our Commentary focuses on the assessment of the global climate-carbon system with implications for adaptation and mitigation action in southern Africa, and we provide a view of new research opportunities for regional climate and sustainability science.

Dangerous and irreversible climate change may already be unavoidable

Five illustrative scenarios of future greenhouse gas emissions underpin the AR6 WG1 report. These are referred to as Shared Socio-economic Pathways (SSPs) and range from high (SSP1-1.9 and SSP2-2.7) to low (SSP3-7.0 and SSP5-8.5) mitigation futures.[1] SSP1-1.9 may be described as a 'best effort' mitigation scenario. In this scenario, CO_2 emissions are cut by about half by the year 2030, compared to present-day levels. Thereafter CO_2 emission reductions continue to be implemented, with net-zero emissions (that is, further increases in atmospheric CO_2 concentrations cease) reached by 2050 within a required remaining carbon budget.[1,5]

The report assesses that the best estimate of global warming (the increase in the average surface temperature of the planet) for the period 2011–2020 with respect to pre-industrial temperature is 1.1 °C[1], approaching the thresholds of 1.5 °C and 2 °C that define 'dangerous climate change' in the Paris Agreement on Climate Change. At these levels of global warming, aspects of climate change such as drastic sea-level rise may become irreversible, whilst extreme weather events may occur at unprecedented frequencies and intensities. A startling assessment of the report is that it is more likely than not (the probability is greater than 50%) that the 1.5 °C threshold of global warming will be exceeded by a small margin even with the best-effort mitigation, and that this exceedance may occur as soon as the early 2030s.[1,6] Exceedance is defined in terms of the mid-point of a 20-year long period of average global surface temperature[6], implying that the world may already be in the first 20-year period for which the average surface temperature will be 1.5 °C higher than the pre-industrial baseline. This is perhaps one reason why the AR6 WG1 report has been described as a 'code red' for humanity by the United Nations Secretary General – the notion that exceeding at least the lower threshold defining dangerous climate change may no longer be avoidable. Humanity seems to have delayed strong climate action for too long, and the window to avoid dangerous or even catastrophic impacts may already be closed.

The report, however, also assesses that, with best-effort mitigation specifically under SSP1-1.9, the chance of restricting global warming to below 2 °C is excellent.[1,6] Moreover, the chances are good that, even if an overshoot of the 1.5 °C level occurs, global warming can be reduced again in the second half of the century to below this threshold, in the presence of CO_2 removal technologies (still to be developed at scale). Certainly, at least to some extent, the level of future global warming and the range of future climate change impacts remain in the hands of humanity.

The AR6 goes to some lengths to reaffirm why the 1.5 °C and 2 °C levels of global warming are thought to be critical to avoid. These levels of global warming are thresholds at which global tipping points may be reached and aspects of climate change may become irreversible.[7] First and foremost is the potential instability of both the Greenland and West Antarctic ice sheets – the assessment being that irreversible collapse of both sheets may be triggered by sustained global warming of 1.5–2 °C.[7] Complete loss of the ice sheets will likely take place at timescales of millennia. Sustained global warming of 2 °C is assessed to be associated with 6 m of sea-level rise over a period of 2000 years – implying that a lack of climate action today will commit future generations to a completely different coastline and reduced living space. Moreover, the report assesses, that under low mitigation futures, sea-level rise may reach levels of about 1–1.9 m by 2150[1,7] – sufficient to displace hundreds of millions of people from coastal areas[8]. It should be realised that sea-level rise is fundamentally irreversible across the lifetimes of many generations.

Every bit of global warming matters

Increasingly, climate change attribution science is capable of quantifying the role of human influence in the occurrence of individual weather events (as opposed to these events occurring entirely because of natural variability). For example, the June 2021 heatwave in the Pacific Northwest has been assessed to have been impossible without the effects of anthropogenic warming[9], whilst climate change made the flooding that occurred in Germany in July 2021 up to nine times more likely to occur[10]. The AR6 WG1 report points out that increases in extreme weather events can already be detected across all regions of the world, and that these increases can be attributed to human-induced global warming.[1] Global warming of 1.5–2 °C brings a commitment to increases in the frequency and intensity of a multitude of extreme weather events, such as heatwaves, heavy precipitation, intense tropical cyclones and droughts in some regions.[11] Such changes are referred to as 'dangerous climate change'. The report is clear that increases in extreme weather events, both in terms of frequency and intensity, are higher at 2 °C than at 1.5 °C global warming, with further increases as the level of global warming increases.[11] That is, even if a best-effort mitigation fails to restrict global warming to below 1.5 °C, there will still be substantial benefits in limiting the overshoot to under 2 °C, and then bringing the temperature down through negative emissions.[5,6,12]

Southern Africa as a climate change hotspot and the potential for regional tipping points

The AR6 WG1 report confirms previous IPCC assessments: the southern African region is likely to become drier, even under 1.5 °C of global warming (Figure 1).[6] Moreover, the observed rate of warming in recent decades is about twice the global average[13], and further drastic warming is projected for the region as the level of global warming increases (Figure 2)[6]. This renders the region a climate change hotspot[14]: when a region that is naturally dry and warm becomes drastically warmer and drier, the options for adaptation are limited.

The report assesses that it is not only general reductions in precipitation that are likely over southern Africa in a warmer world, droughts are also projected to occur more frequently, even under 1.5 °C of global warming. Moreover, as the level of global warming increases, so does the frequency and intensity of drought.[11] Over the eastern part of southern Africa, increases in heavy precipitation are projected in a warmer world, despite the region projected to become generally drier.[11] Against this general assessment from the report, it is important to consider the possibility of the existence of regional tipping points in the southern African climate system, where a new climate regime is reached and high-impact climate events unprecedented in this historical record start to occur.

The single biggest climate change risk that South Africa may have to face in the near term (2021–2040), is one or more 'day zero' droughts occurring in the Gauteng Province. Such an event, where the portion of Gauteng's water supply from the eastern mega dams is severely compromised by a multi-year drought, may be devastating to the South African economy. Gauteng is the economic heartland of the country where most of the industries are located, and where 16 million people live. It may be noted that in September 2016, the level of the Vaal Dam in South Africa fell to about 26%[15] at the end of a 4-year drought. The drought culminated with the 2015/2016 El Niño, one of the strongest ever recorded[16], and brought the realisation that the risk of a 'day zero' drought in Gauteng already exists. That is, the level of the dam came close to falling to below 20% – the threshold at which the Gauteng water supply would have been severely compromised. Multi-year droughts have also impacted severely on South Africa's southern coastal cities Gqeberha and Cape Town in recent years[17], and, in the latter case, it has been assessed that climate change has already increased the likelihood of 'day zero' type droughts to occur by a factor of three[18].

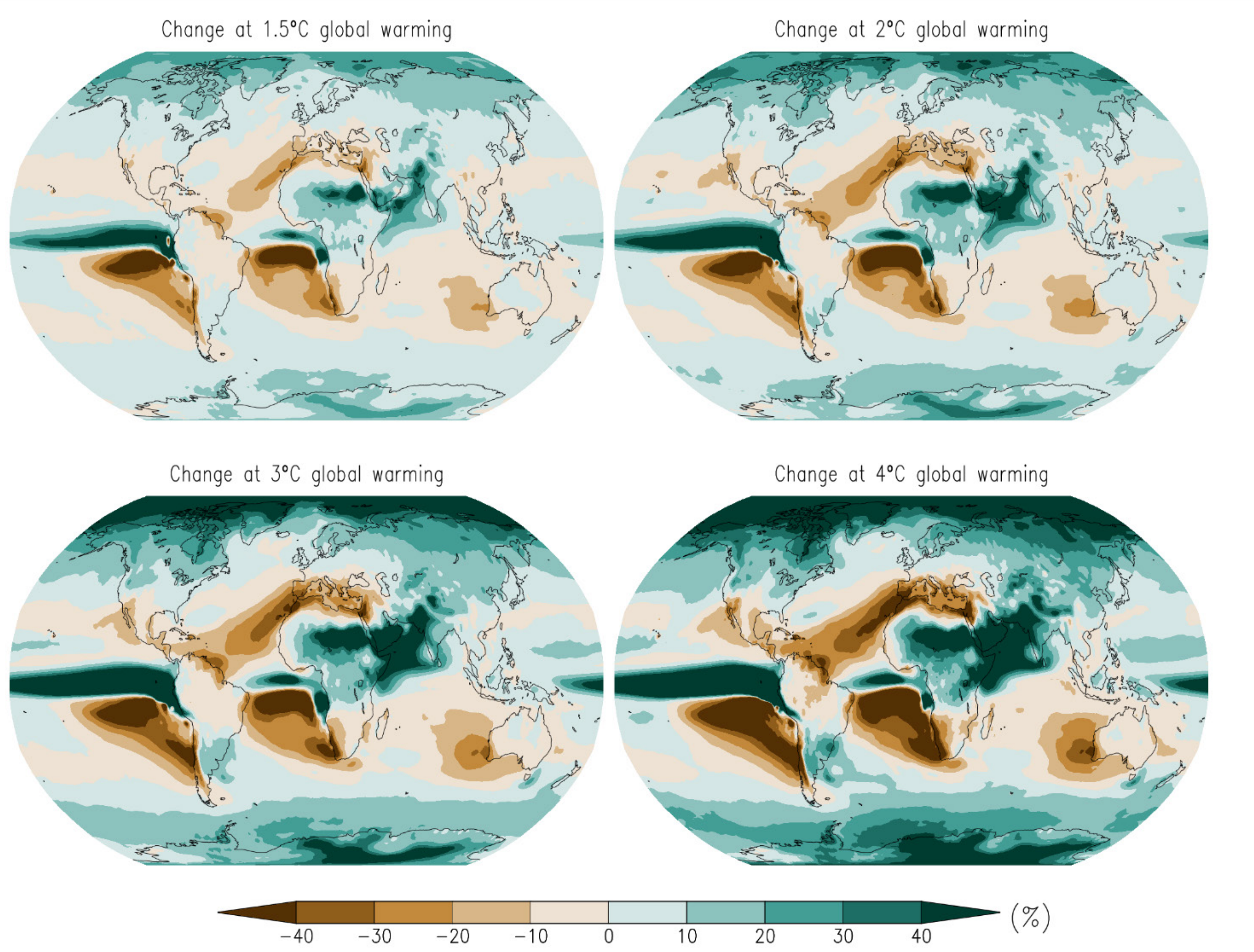


Figure 1: Projected spatial patterns of change in annual average precipitation (expressed as a percentage change) at different levels of global warming (1.5 °C, 2 °C, 3 °C, and 4 °C) relative to the period 1850–1900. Values were assessed from a 20-year period at a given warming level, based on model simulations under SSP5-8.5 by 30 global circulation models that contributed to the Coupled Model Intercomparison Project Phase Six (CMIP6).

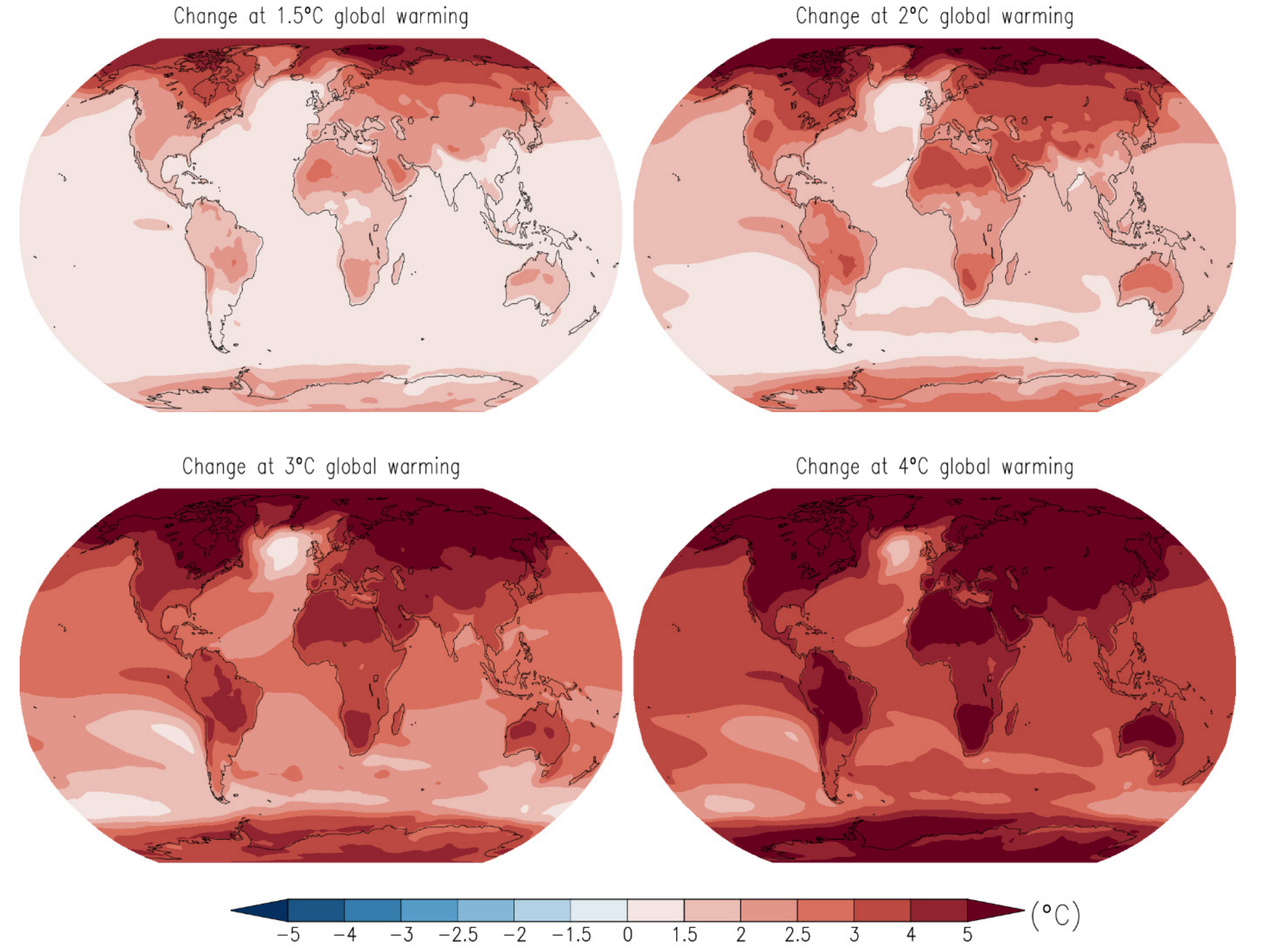


Figure 2: Projected spatial patterns of change in surface temperature (°C) at different levels of global warming (1.5 °C, 2 °C, 3 °C, and 4 °C) relative to the period 1850–1900. Values were assessed from a 20-year period at a given warming level, based on model simulations under SSP5-8.5 by 30 global circulation models that contributed to the Coupled Model Intercomparison Project Phase Six (CMIP6).

The possibility therefore exists that South Africa's climate may drift into an entirely new regime, where 'day zero' droughts become regular events, substantially impacting on the sustainable growth of the biggest cities. Generating probabilistic projections to better quantify the magnitude of this risk needs to be a priority area of research for South African climatologists and hydrologists.

Periods of drought are also associated with increasing heatwave frequencies in southern Africa. Heatwaves are certain to occur at unprecedented intensities in a warmer world, with direct implications for unprecedented impacts on human mortality in many parts of the world, including southern Africa.[14,19] The combination of more frequent heatwaves and multi-year droughts may be devastating to agriculture, local livelihoods and food production in the region. The IPCC SR1.5 assessed that, under 3 °C of global warming, both the maize crop and the cattle industry in southern Africa are likely to collapse, largely because of the biophysical impacts of increased heat stress in a drier climate.[14] What is less well understood, is whether this tipping point may be reached at even lower levels of global warming, due to the economic impacts of drought on farmers, at least in those areas in the region where farming is already marginal. Finally, in Mozambique and northeastern South Africa, the potential for a completely different type of tipping points exists. In a warmer world, intense tropical cyclones are likely to occur more frequently[11], and the possibility exists that these systems can follow more poleward trajectories[20]. It is possible that an intense tropical cyclone (equivalent to a category three to five hurricane) can make landfall at Maputo, or even further to the south, at Richards Bay. More research is needed to better quantify how the risk of such an event occurring depends on the level of global warming.

A special research focus is needed to develop a probabilistic perspective on the occurrence of regional tipping points in the southern African climate-ecosystem-human-system nexus. This should include both a biophysical perspective as well as take into account how socio-economics may accelerate the potential collapse of existing industries and systems. Even if these events are found to be of low probability, they are potentially of such high – or even devastating impact – that they need to be considered in risk assessments for adaptation planning and, in particular, disaster risk reduction strategies.

Improving the confidence in climate change projections depends strongly on a good understanding of the global coupled carbon-climate system and its feedbacks under increasing, decreasing and negative emissions.[1] Carbon-climate linkages are discussed in more detail in the following sections, again through a southern African lens.

The past, present and future of carbon sinks and emerging feedbacks

Carbon is the main lever by which to strengthen or weaken global warming and climate change – it sets the rate of global and regional warming through a logarithmic relationship between concentration of CO_2 in the atmosphere and resulting radiative forcing.[12] The AR6 WG1 report assessed that it is unequivocal that increasing greenhouse gases in the atmosphere are linked to human activities.[1,5] However, the rate at which CO_2 builds up in the atmosphere depends both on emissions as well as on the magnitudes of the ocean and land carbon sinks.[5] Understanding and predicting the trends and variability of the land and ocean sinks and their sensitivity to both carbon and climate feedbacks is therefore essential to improving the confidence of future climate change projections under low and high mitigation scenarios.[5,6,21]

In the past six decades, the large negative feedbacks of the ocean and terrestrial carbon sinks have slowed global warming by partitioning anthropogenic CO_2 emissions by ~23% and ~27%, respectively, leaving a quasi-steady residual of 44% in the atmosphere. It is this airborne fraction that drives the increasing CO_2 concentrations and global warming.[5] Palaeo and historical observations, together with significantly improved models, have provided significantly greater confidence in the assessment of the constraints of the global carbon budget and the sensitivity of the sinks to both carbon and climate feedbacks. Assessed paleo observations highlighted that although the magnitudes of CO_2 in the atmosphere are unprecedented in the past 1 Myr, they scale to the magnitudes preceding the late Miocene period, 3–5 Myr ago.[5,21] What is unprecedented about the historical CO_2 emissions are the rates at which contemporary CO_2 is increasing in the atmosphere, which have been assessed to be at least an order of magnitude higher than at any time in the past 60 Myr.[5] The contemporary global carbon-climate system is thus in a far more perturbed transient state than was the case in the pre-industrial and most of the palaeo periods. Notwithstanding the exponential rate of increase in historical global CO_2 emissions, the land and ocean carbon sinks slowed global warming by taking up about a combined 50% of CO_2 emissions over the past 60 years.[5] These negative feedbacks are mainly driven by the physics and CO_2 chemistry in the ocean and the biosphere on land.[5] Observations show that carbon and climate positive feedbacks that could increase the CO_2 fraction in the atmosphere are still too small. However, observations also show that processes that may influence future positive feedbacks are undergoing observable changes in both the ocean and on land. Decreasing ocean buffering capacity, ocean acidification, and ocean warming as well as warming and rainfall extremes on land serve as examples.[5]

Model projections show that ocean and land carbon sinks will weaken across all scenarios in the second half of the century, but the processes that drive this weakening are quite different between high and low mitigation pathways.[21] Whereas under high mitigation the weakening ocean and land sinks are linked to a decreasing atmospheric CO_2 arising from negative emissions, under low mitigation scenarios the weakening is driven by the growing positive carbon-concentration and carbon-climate positive feedbacks on both land and the ocean.[21] One of the outcomes of these different sink responses is that the stronger the emission scenario, the smaller the fraction of emitted CO_2 that is taken up by the sinks. This increases the rate at which emitted CO_2 builds up in the atmosphere as the airborne fraction. The full understanding of the mechanistic basis of the feedback responses in the ocean and on land under both high and low emissions remains an important research challenge to improve the confidence in model projections.

On the global spatial scale, projections provide an indication of the geographical heterogeneity of the sensitivity of ocean and land carbon sinks to climate and carbon forcing (Figure 3). These show that the negative feedback of land and ocean carbon sinks to rising atmospheric CO_2 are offset by positive feedback responses to climate forcing (warming and rainfall) and decreasing buffering capacity in the ocean. Importantly it points to the global role of southern hemisphere tropical and sub-tropical terrestrial ecosystems as well as the Southern Ocean, both of which highlight southern Africa's underutilised comparative geographic advantage for regional and global climate and earth system science research and climate risk projection.[5,21]

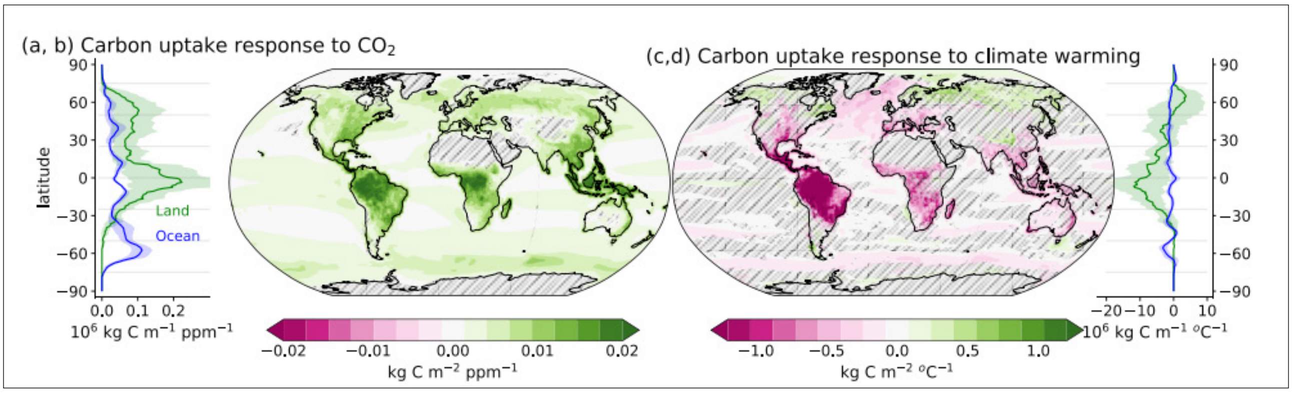
Slowing down and stopping warming – every ton of CO_2 adds to global warming

One of the most important metrics, which sets the scientific basis for the need to achieve net-zero CO_2 emissions within a specific remaining carbon emissions budget to remain below a specific warming level by 2050, is the Transient Climate Response to cumulative carbon Emissions (TCRE).[1,3,5] It is a quasi-linear relationship between warming and cumulative CO_2 emissions, which shows that to arrest additional warming, the emissions-driven increase in atmospheric CO_2 must stop completely. It also provides the science basis to constrain the remaining carbon budget that can be emitted for a given probability to remain below a chosen global mean surface temperature target; for example, 1.5 °C or 2 °C.[4,5]

This transient relationship between warming and cumulative emissions is a property of the planet's carbon-climate system. It is largely regulated by the ocean's capacity to take up heat and the unique chemical properties of CO_2 that enables it to be stored in the ocean in much greater quantities as a salt rather than as a dissolved gas.[5] Again, the role of the Southern Ocean in sustaining this relationship under positive and negative emissions continues to present a global science challenge, which also highlights South Africa's comparative geographical advantage in respect of Antarctica and the Southern Ocean carbon-climate science (Figure 4).

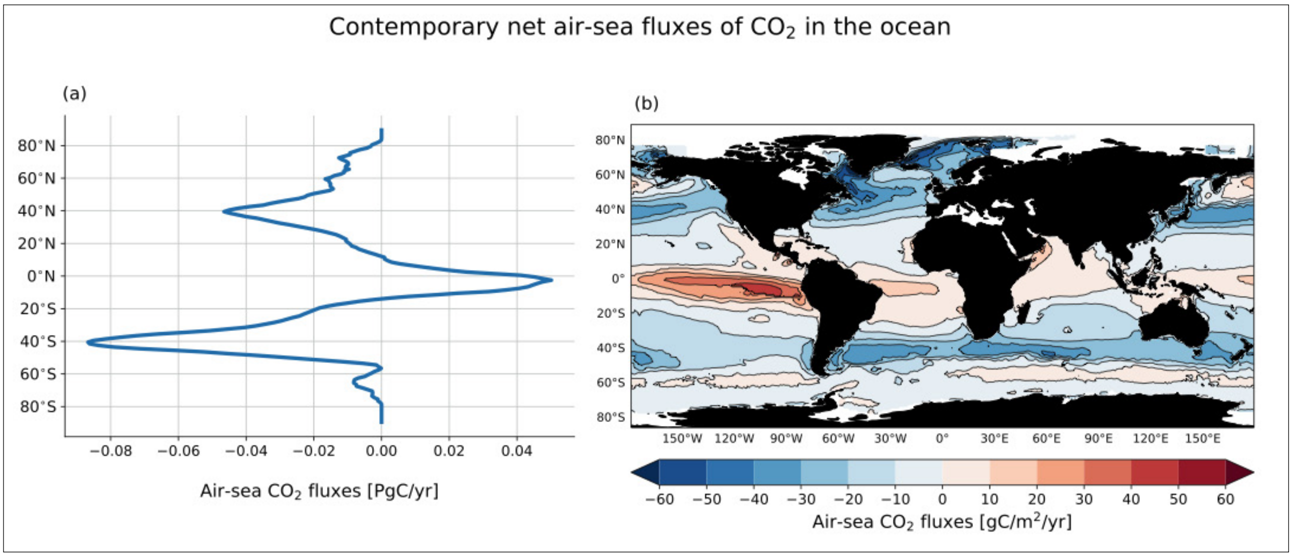
Negative emissions – carbon dioxide removal

To restrict global warming to below the threshold of 1.5 °C by the end of the century, especially in the presence of an overshoot in the surface air temperature above 1.5 °C in the coming decades, lies the larger global and regional science and technology challenge of negative emissions. This removal of CO_2 from the atmosphere is necessary to offset the warming, the Zero Emissions Commitment (ZEC), associated with atmospheric CO_2 from historical emissions and to manage possible 1.5 °C temperature overshoot scenarios.[5,23,24]



Source: From Box TS.5 Figure 1 of Arias et al.[21]

Figure 3: Global and regional carbon cycle responses to carbon and climate forcing. Projected spatial and zonally integrated responses of terrestrial and ocean carbon sinks to carbon (a,b) and climate (c,d) forcing under a scenario of 1% increase in atmospheric CO_2 per year. It highlights that the ocean responses are mainly in the southern hemisphere mid- to high latitudes (blue in a,d) and terrestrial are mainly in the tropics and subtropics (green in a,d).



Source: Djeutchouang L, personal communication using the South African CSIR-ML6 machine learning model for global ocean CO_2 used in AR6 WG1[5,22]

Figure 4: Contemporary mean state of the global net ocean CO_2 fluxes (2008–2018) (sinks and sources) and showing the prominent role of the Southern Ocean (south of 30°S) as a global ocean CO_2 sink.

Photo: Kristi Ebi

Figure 5: The IPCC *Special Report on Global Warming of 1.5 °C* was released under the banner of 'Reasons for Hope' in October 2020, indicating that strong climate action could still restrict global warming to below 1.5 °C. In 2021, that hope has faded.

The impacts and effectiveness of CO_2 removal present enormous ethical, governance and technological scaling-up challenges.[5] However, they will be critical to avoiding catastrophic costs of climate extremes. The opportunity for South African science and technology innovation lies in the reality that, at this stage, there are no proven methods which are both technologically feasible and scalable to have the regional or global impact on atmospheric CO_2 needed to arrest warming and ameliorate ocean acidification. This is an enormous challenge and opportunity for large interdisciplinary consortia of South African science and technology innovation systems to address with directed public and private funding.

Reasons for despair, hope, or action?

When the IPCC released the SR1.5 report in 2018, it framed the report under the message of 'Reasons for Hope' (Figure 5), pointing out that strong climate action could still prevent the dangerous threshold of global warming of 1.5 °C being reached. The SR1.5 report proceeded to outline the substantial benefits that exist in restricting global warming to 1.5 °C, as opposed to 2 °C, in terms of reduced impacts. In this respect, the assessment of the AR6 WG1 report is sobering: it is now considered more likely than not that the 1.5 °C threshold will be exceeded (as soon as the early 2030s, and probably by a small margin under best-effort mitigation). The realisation that the world is committed to further warming and further increases in extreme events, and possibly even elements of 'dangerous climate change' should, however, not lead to despair. Rather, the AR6 WG1 report should be seen as a call for strong climate change action, in terms of both mitigation and adaptation.

Best-effort mitigation requires strong, rapid and sustained cuts in greenhouse gas emissions towards net-zero global emissions within the prescribed remaining carbon budget, followed by negative emissions in the second half of the century. The pace and magnitude at which CO_2 emissions will have to be reduced for global warming to be restricted to 1.5 °C is staggering, and will require the formation of the strongest climate pact to date at the 26th Conference of the Parties (COP26) in Glasgow in November 2021. It will also require a concerted national and local mobilisation and sets of institutional architectures and actions to implement change. South Africa will be faced with tremendous challenges towards contributing fairly to global mitigation, whilst taking advantage of new investment opportunities to help ensure that its own transition away from fossil fuels is a just transition. The risks posed by future regional climate change impacts need to be quantified to the best level of confidence to formulate actionable messages for adaptation, and to pursue those actions with the same vigour as climate change mitigation. Of particular importance in this regard, is to develop improved probabilistic understanding of the potential for regional tipping points being reached in the southern African climate-ecosystem-human-system nexus, in the near term and beyond. The benefits of avoiding social and economic damage through immediate and effective mitigation, will minimise the costs of adaptation and support a just transition towards a low-carbon modern economy. South African science and technological innovation systems should be key partners in these challenges.

Acknowledgements

We thank two anonymous readers for their comments, which helped to improve the clarity of the discussion.

Competing interests

We have no competing interests to declare. F.A.E. and P.M.S.M. are Members of Working Group I of Assessment Report Six.

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