OBLIGATIONS OF STATES IN RESPECT OF CLIMATE CHANGE

(REQUEST FOR ADVISORY OPINION)

EXPERT REPORT OF DR. CHRISTOPHER TRISOS

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EVIDENCE OF OBSERVED IMPACTS FROM HUMAN-INDUCED CLIMATE CHANGE, AND PROJECTED FUTURE IMPACTS ON AFRICA

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I – INTRODUCTION

A. BACKGROUND AND EXPERIENCE

1. My name is Dr Christopher Trisos, and I direct the Climate Risk Lab based in the African Climate and Development Initiative at the University of Cape Town. I am also the Director of ASCEND (the African Synthesis Centre for Climate Change, Environment, and Development) that hosts research teams to accelerate actionable research on climate change across Africa and globally.
2. My research integrates data and methods from environmental and social sciences to better understand climate change risks, to assess solutions, and to inform more rapid and just responses to climate change. I focus on understanding where and when climate change risks to people and ecosystems emerge, and providing actionable knowledge to reduce such risks. Examples of this work include: forecasting risks from climate change to human health, food production, and biodiversity; tracking finance for adaptation; and developing new and more policy-relevant climate change risk assessment frameworks.
3. This research integrates diverse knowledge and data from natural and social sciences to understand climate change risks across Africa and globally, working from a global South perspective. By working with knowledge users, an important goal of my research is to produce actionable insights for climate risk management for decision-makers to help society transition to a more just and sustainable future.
4. I hold a doctorate from Oxford (2014) following my studies at the University of Cape Town (B.Sc. Hons. Botany, 2007; and B.Sc. Ecology & Economics, 2006).
5. I have advised on climate change risks and resilience building for the World Bank and UN Environment Programme, as well as for governments and other international organizations, and have participated in UN climate change negotiations on the Global Goal on Adaptation.
6. Since 2023, I have held the position of Chief Research Officer for the African Climate and Development Initiative at the University of Cape Town. I am the Principal Investigator of the Climate Risk Lab. The lab integrates data and methods from environmental and social science to forecast where and when

climate change risks appear and inform more rapid and just responses to climate change. This followed from my position as Senior Researcher from 2019-2023.

7. In 2019, I became a Coordinating Lead Author of the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report on climate change impacts, adaptation and vulnerability (published in 2022), and was also an author of the IPCC's Synthesis Report published in 2023, for which I led the section on near-term risks and responses to climate change.

8. From 2018-2019, I was a Consultant for the Global Climate Research and Advisory Unit of the World Bank, where I conducted a global synthesis of climate change risks and adaptation priorities to guide development of the World Bank Group's $50 billion *Action Plan on Climate Change Adaptation and Resilience*.

9. I have also been a Postdoctoral Fellow at the University of Maryland (2015-2018), Visiting Research Fellow at Yale University (2016-2017) and Postdoctoral Fellow at the South African Environmental Observation Network (2014-2015).

10. I have carried out extensive professional service and policy work that includes roles as, *inter alia*, Advisor for African Negotiations (Global Goal on Adaptation negotiations under UNFCCC, 2023), Zambia Country Delegation Member (Global Goal on Adaptation intergovernmental negotiations, 2023), Co-chair Advisory Board for Connecting Climate Minds for climate change and mental health (2023), Core Writing Team and Section Facilitator (Synthesis Report of the IPCC, 2020–2023), Steering Committee for the South African Modelling Community of Practice for the South African Presidential Climate Commission (2023), Expert Advisory Panel on Solar Geoengineering for the United Nations Environment Programme (2022), Coordinating Lead Author of the Africa chapter, IPCC Working Group II (2019–2022), Lead Author for the Joint IPBES-IPCC workshop report on biodiversity and climate change (2020–2021), Committee member of the African Academy of Sciences Climate Change Advisory Committee (2019) and Consultant for the World Bank Climate Change Adaptation and Resilience Action Plan (2018).

11. I have received numerous awards for my work, including, the Vice-Chancellor's Future Leaders Programme at the University of Cape Town (2021) and a "P" rating granted by the South African National Research Foundation (2020). The National Research Foundation assigns a "P" rating to researchers who have held a doctorate for less than five years. These researchers are considered likely to become future international leaders in their respective fields on the basis of

exceptional potential demonstrated in research performance and output during post-doctoral careers.

12. I have been published extensively, notably in 2023 as a member of the IPCC Core Writing Team and leader of the section of the Report on near-term risks and response options in a changing climate. This Report is the final synthesis of 7 years of IPCC scientific assessment,[1] and in 2022 as an author of the most comprehensive assessment to date of climate change risks, vulnerability, and adaptation options for Africa.[2]

13. A copy of my CV is attached to this report for your reference.[3]

B. Instructions

14. I was contacted by the legal team currently advising the African Union, who requested that I provide an expert report in support of the African Union's submissions in the current advisory proceedings before the International Court of Justice (the "**ICJ**"), regarding obligations of States in respect of climate change.

15. This contact is a result of my expertise in the area, including my recent contribution to Chapter 9 of the second volume of the IPCC's Africa Chapter; I was thus asked if I would be willing to submit an expert report in these proceedings.

16. I was requested to draw upon my work on the Chapter mentioned above, focussing on the impact of anthropogenic emissions of greenhouse gas ("**GHGs**") on the African continent.

17. I was reminded that the purpose of the African Union's submissions is to assist the ICJ in rendering its decision following the request for an advisory opinion that was submitted by the UN General Assembly by way of a resolution. I was further reminded of the specific questions asked to the Court.

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[1] "**Climate Change 2023: Synthesis Report**" Contribution of Working Groups, I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change doi: 10.59327/IPCC/AR6-9789291691647.001).

[2] Trisos, CH, I.O. Adelekan, E. Totin, A. Ayanlade, J. Efitre, A. Gemeda, K. Kalaba, C. Lennard, C. Masao, Y. Mgaya, G. Ngaruiya, D. Olago, N.P. Simpson, and S. Zakieldeen. "Africa climate impacts, adaptation and vulnerability" (2022) In: Climate Change 2022: Impacts, Adaptation, and Vulnerability; contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)], Cambridge University Press.

[3] Also available is a full publication list on my Google Scholar Profile, available at: https://scholar.google.com/citations?hl=en&user=th_p4V8AAAAJ&view_op=list_works.

C. STRUCTURE OF THE REPORT

18. The present report will be structured as follows:

    a. Section II will be an Executive Summary of my findings;

    b. Section III will address Physical climate change and historical responsibility;

    c. Section IV will address Vulnerability and exposure to climate change;

    d. Section V will address Observed impacts and loss and damage from climate change in Africa;

    e. Section VI will address Future impacts and loss and damage; and

    f. Section VII will address Support for climate change adaptation and mitigation.

II – EXECUTIVE SUMMARY

- Human-caused Climate Change has led to increased heatwaves, heavy precipitation and drought in Africa.
- Africa contributed only 3% to the cumulative production-based CO2 emissions from fossil fuels and industry from 1850–2019, and Africa is the continent with the lowest per capita greenhouse gas emissions.
- Many African states that have historically contributed among the least to current climate change are disproportionately more vulnerable to climate change impacts. The majority of people living in countries with very high vulnerability to climate change are in Africa.
- Africa has already experienced negative impacts and loss and damage from Human-caused Climate Change to important sectors for human health and the environment, including loss of biodiversity, reduced food production, water shortages, loss of lives, and reduced economic growth.
- Climate change has negatively impacted African economies, and impacts in Africa have been more severe than in developed countries in high latitude climates.
- Negative impacts from climate change and related loss and damage in Africa are projected to become widespread and severe between 1.5°C and 2°C of global warming above pre-industrial levels, including reduced food production, loss of biodiversity, and increased human morbidity and mortality. The Intergovernmental Panel on Climate Change ("**IPCC**") projects a global warming level of 1.5°C is more likely than not to be reached before 2040.
- Current adaptation finance provided by developed countries to African countries is insufficient to meet adaptation needs. Adaptation costs are projected to increase rapidly with further global warming and the feasibility and effectiveness of existing adaptation options will be reduced, with further global warming causing hard limits to some adaptation options in ecosystems, water, and agriculture.
- A substantial increase in grants and other non-debt public finance from developed countries to developing countries in Africa is necessary to support adaptation of the most vulnerable to increasing negative impacts and loss and damage from climate change.

III – PHYSICAL CLIMATE CHANGE AND HISTORICAL RESPONSIBILITY

19. According to the scientific assessment of the IPCC published in 2023, global surface temperature in 2013–2022 was 1.15°C above 1850–1900 levels, and it is unequivocal that human activities, principally through emissions of greenhouse gases from fossil fuel combustion and industrial processes, are the primary cause of this warming of the atmosphere, ocean, and land ("**Human-caused Climate Change**").[4]
20. While it has been one of those most vulnerable to Human-caused Climate Change, it is estimated by the IPCC in their assessment on the mitigation of climate change published in 2022 that Africa has contributed only 3% to the cumulative production-based CO2 emissions from fossil fuels and industry from 1850–2019.
21. Least Developed Countries are estimated to have contributed only 0.4% to the cumulative production-based CO2 emissions from fossil fuels and industry from 1850–2019 (with 33 of the 45 countries classed as Least Developed Countries in 2023 being in Africa).[5]
22. The population of Africa was estimated at 1.312 billion for 2020 and Africa is the continent with the lowest per capita greenhouse gas emissions.[6] Per capita greenhouse gas emissions across Africa in 2021 were 2.4 tonnes CO2 equivalent (tCO2-eq), compared to 8.1 tCO2-eq per capita across the European Union 27 countries, 8.3 tCO2-eq per capita across G20 countries, and 12.8 tCO2-eq per capita across G7 countries. This illustrates the low contribution made by most Africans – compared to populations in developed countries and to many in other developing country – to the historical GHG emissions causing climate change.[7]
23. Based on the scientific assessment of the physical science basis of climate change by IPCC Working Group I, published in 2021, and the scientific assessment of climate change impacts, adaptation, and vulnerability by IPCC Working

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4 IPCC Synthesis Report 2023: Section 2.1

5 IPCC WGIII 2022: Chapter 2, Figure 2.10. The estimate of Africa's contribution to cumulative production-based CO2 emissions during the 1850–2019 period increases to 7% when emissions from land use, land use change, and forestry are included.

6 IPCC WGII 2022: Chapter 9 Figure 9.2

7 United Nations Environment Programme (2023). Emissions Gap Report 2023: Broken Record – Temperatures hit new highs, yet world fails to cut emissions (again). https://doi.org/10.1101/2023.07.16.23292713. Net greenhouse gas emissions from land use, land use change, and forestry are excluded from these per capita estimates due to a lack of country resolution.

Group II, published in 2022, Human-caused Climate Change has led to the following changes in physical climate hazards across Africa:

a. Increasing mean and extreme hot temperatures, including increasing frequency and intensity of heatwaves. Many regions such as north Africa, west Africa, and south-western Africa have warmed at 0.2–0.5°C per decade since the mid-20th century, which is faster than the global average warming. There has also been a decrease in the intensity and frequency of cold extremes.[8]

b. Increasing heavy precipitation in eastern and western southern Africa that can lead to pluvial floods.[9]

c. Increasing agricultural and ecological drought (that is, a lack of sufficient soil moisture) in Mediterranean, west, central and southern Africa.[10]

d. The doubling of the probability of marine heatwaves (that is, extreme warm sea surface temperature that persists for days to months) around most of Africa's coast.[11]

e. Increasing ocean acidity and increasing sea levels.[12]

24. Sustained weather station observation networks are essential for analysis and attribution of climate trends and weather and climate extreme events. However, it is estimated only 10% of the world's ground-based weather observation networks are in Africa, which is disproportionately low compared to Africa's large 20% share of the global land surface, with many African national meteorological and hydrology services facing structural, financial, and technical barriers to installing and maintaining weather observation networks.[13] These data limitations negatively affect the scientific assessment of changes in physical climate hazards in Africa, especially precipitation trends and drought. Nevertheless, there are individual extreme drought and heavy rainfall events where attribution analyses have been conducted, such as quantification that:

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8 IPCC WGI 2021: Chapter 12 Section 12.4.1.1; IPCC WGII Chapter 9 Section 9.5.1 and Figure 9.13. Limited data prevents assessment for central Africa but the same result would be expected were sufficient data available.

9 IPCC WGI 2021: SPM Figure SPM.3. Limited data availability in other regions due to a lack of weather station data on rainfall limits scientific assessment of trends in heavy precipitation across other regions of Africa.

10 IPCC WGI 2021: Chapter 11 Table 11.6; IPCC WGII Chapter 9 Section 9.5.3. Limited rainfall data availability in many regions due to a lack of weather station data limits scientific assessment of trends in rainfall deficits leading to meteorological and hydrological drought.

11 IPCC WGII 2022: Chapter 9 Section 9.5.10

12 IPCC Special Report on the Ocean and Cryosphere in a Changing Climate 2019: SPM Figure SPM.2

13 IPCC WGII 2022: Chapter 9 Section 9.5.1 and Figure 9.15

a. the reduced rainfall that led to the extreme 2015–2017 drought in Cape Town, South Africa was three times more likely to have occurred because of human-caused Climate Change;[14]

b. the 2021–2022 drought severity in the Horn of Africa was about 100 times more likely because of human-caused Climate Change;[15] and

c. in 2022 heavy rainfall over the lower Niger Basin was about twice as likely and approximately 5% more intense and increased seasonal rainfall in the Lake Chad region was about 80 times more likely and approximately 20% more intense, because of climate change, with this rainfall contributing to large-scale flooding of vulnerable communities.[16]

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14 Otto, F. E. et al., 2018: Anthropogenic influence on the drivers of the Western Cape drought 2015–2017. Environmental Research Letters, 13(12), 124010, doi:https://doi.org/10.1088/1748-9326/aae9 f9

15 World Weather Attribution https://www.worldweatherattribution.org/human-induced-climate-change-increased-drought-severity-in-southern-horn-of-africa/

16 World Weather Attribution https://www.worldweatherattribution.org/climate-change-exacerbated-heavy-rainfall-leading-to-large-scale-flooding-in-highly-vulnerable-communities-in-west-africa/

IV – VULNERABILITY AND EXPOSURE TO CLIMATE CHANGE

25. Increasing adverse impacts from climate change and related loss and damage depend on changes in physical climate hazards, as well as on the vulnerability and exposure of people and ecosystems to those hazards. According to the scientific assessment of the IPCC on climate change impacts, adaptation and vulnerability published in 2022, vulnerability to climate change is multi-dimensional and people in regions with considerable development constraints have high vulnerability to climate hazards with present development challenges causing high vulnerability influenced by historical and ongoing patterns of inequity, such as colonialism and subsequent development contexts.
26. Vulnerability is higher in regions with limited access to basic services, poverty, governance challenges, violent conflict, and high levels of climate-sensitive livelihoods. Unsustainable use of natural resources adversely affects the capacities of ecosystems and people to adapt to climate change.[17]
27. Many African states that have historically contributed among the least to the greenhouse gas emissions driving Human-caused Climate Change are also disproportionately more vulnerable to the adverse impacts and loss and damage from climate change.[18]
28. Global hotspots of high human vulnerability to climate change are found in Africa and the majority of people that live in countries with very high vulnerability are in Africa.
29. Observed average mortality from floods, droughts, and storms is 15 times higher for countries ranked as very high vulnerability, such as Nigeria, Somalia, and Mozambique, compared to those ranked as very low vulnerability, such as the United Kingdom, Sweden, Canada, and Australia.[19]
30. This is partly because human vulnerability to climate change hazards is high in informal settlements with approximately 59% of Sub-Saharan Africa's urban population living in informal settlements.

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17 IPCC WGII 2022: SPM Section B.2

18 IPCC WGII 2022: Chapter 8 Section 8.3.2

19 IPCC WGII 2022: Chapter 8 Section 8.3.2 and Figure 8.6. African countries ranked as very highly vulnerable are South Sudan, Somalia, Central African Republic, Chad, Democratic Republic of the Congo, Niger, Liberia, Guinea-Bissau, Sudan, Burundi, Sierra Leone, Mali, Uganda, Mauritania, Eritrea, Togo, Madagascar, Congo, Ethiopia, Nigeria, Malawi, Burkina Faso, Lesotho, Guinea, Angola, Tanzania, Cote d'Ivoire, Kenya, Benin, Zambia, Cameroon, Djibouti.

31. The population in Africa living in informal settlements is expected to increase because Africa is the most rapidly urbanizing region in the world and is projected to transition to a majority urban population in the 2030s. Although urbanization is due to multiple factors, climate-related displacement is widespread in Africa and increased migration to urban areas has been linked to decreased rainfall in rural areas.

32. Furthermore, many informal settlements in African cities, such as those in coastal cities of north, east, and west Africa, are in low-lying coastal zones that are exposed to sea level rise from Human-caused Climate Change.

33. Accounting for a continuing young population and migration to regional growth centres, projections indicate 108–116 million people will be exposed to mean sea level rise in African low-lying coastal zones by 2030 (compared to 54 million in 2000).

34. African countries are also highly vulnerable to flood-induced displacement even at low-levels of exposure to flood hazards, because of high levels of poverty that often drive people to live in vulnerable informal settlements. People in buildings that are poorly ventilated or insulated are more prone to heat stress, with these building features common in structures in informal and low-income settlements and temperature extremes expected to result in relatively more deaths in informal settlements than other settlement types, with vulnerability in urban informal settlements compounded by the urban heat island effect.

35. In the near-term, high human vulnerability to climate change is expected to continue to concentrate in informal settlements and is rapidly growing in smaller settlements in Africa.[20]

36. Africans are also disproportionately employed in sectors exposed to climate change and have high levels of reliance on climate-sensitive livelihoods. Informal employment accounts for around 86% of total employment in Africa, which is a similar level to southern Asia and compares to around 50% in East Asia, and less than 20% in North America and Europe.[21] The informal sector can be highly exposed to extreme climate events because informal sector activities are often located in more exposed locations, such as more flood-prone, low elevation areas or sloped or other hazardous zones. Furthermore, street vendors, construction

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20 IPCC WGII 2022: Chapter 9 Sections 9.9.1, 9.9.2, Figure 9.28, 9.10.2.3.2; Kakinuma et al. 2020 Environmental Research Letters https://doi.org/10.1088/1748-9326/abc586

21 International Labour Organisation, 2018: Women and men in the informal economy: a statistical picture. Available at: https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/documents/publication/wcms_626831.pdf

workers, domestic workers and others in the informal sector often cannot operate when climate hazards strike due to interruptions in commodity flows and transportation, and without the ability to insure against risk and with limited access to credit and savings, they struggle to recover lost assets and cannot invest to reduce vulnerability to future climate change hazards.[22]

37. Agriculture comprised 51.7% of total employment in Sub-Saharan Africa in 2022[23]—more than any other region—and 90% or more of agricultural land is rainfed, making African agriculture and the livelihoods depending on it highly vulnerable to rainfall deficits, reduced soil moisture and heatwaves.[24] Outdoor manual labourers are also more exposed to extreme temperatures that reduce worker productivity and increase risk of heat-related morbidity and mortality.[25] Lost agricultural income is an important factor that drives disproportionate adverse impacts from climate change on poor households, with erosion of livelihood security for vulnerable households creating the risk of poverty traps.[26]

38. High poverty rates make most African households highly vulnerable to climate change.

39. At the community and household level, adverse climate change impacts that erode livelihood security create the risk of poverty traps as poor households are less equipped to prepare for extreme climate events, may be forced to sell productive assets such as distress sales of livestock during drought periods, and struggle to recover lost assets.[27] Because of having more assets and higher incomes, more affluent individuals poor may lose more in absolute terms from an extreme climate event, yet poor people often lose more in relative terms – and it is these relative losses that matter most for livelihoods and welfare.

40. Exposure to climate hazards can trap poorer households in a cycle of poverty, while they are also more often exposed to climate hazards than non-poor people.

41. In multiple African countries, poor households are more exposed to flooding.[28] The increase in so-called weather whiplash events in a warmer world, where there is an abrupt shift from drought conditions to heavy rainfall in a location, have increased by between 24%–48% from 1980 to 2010. This significant increase

22 IPCC WGII 2022: Chapter 9 Section 9.11.3
23 https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?end=2022&start=1991&view=chart
24 IPCC WGII 2022: Chapter 5 Figure 5.5 ; IPCC WGII Chapter 9 Section 9.8
25 IPCC WGII 2022: Chapter 5 Table 5.14; Chapter 9 Table 9.2, Figure 9.34, Section 9.11.2
26 IPCC WGII 2022: Chapter 8 Section 8.2.1.2
27 Hallegatte et al. 2016 Shockwaves. World Bank
28 IPCC WGII 2022: Chapter 9 Section 9.11.4

is occurring in the poorest 20% of regions globally, especially in African countries, and not in wealthier regions.[29]

42. Higher vulnerability of countries to climate change has been shown to negatively impact sovereign credit ratings and increase the cost of debt, especially for developing countries, including African states, thereby increasing financial constraints on the ability of African countries to reduce their vulnerability and adapt to climate change.[30]

43. Increasing understanding and disclosure of climate risks for those countries highly vulnerable to climate change, such as those in Africa, could also lead to capital flight.[31] Furthermore, climate change impacts that incur loss and damage and impede economic growth can also reduce financial resources for adaptation, particularly for developing and least developed countries.

[29] Zhang et al. 2023 Geophysical Research Letters https://doi.org/10.1029/2023GL105640
[30] IPCC WGII 2022: Chapter 16
[31] IPCC WGII 2022: Chapter 17 Cross-chapter Box Finance; IPCC WGII Chapter 16

V – OBSERVED IMPACTS AND LOSS AND DAMAGE FROM CLIMATE CHANGE IN AFRICA

44. Although Africa has historically contributed among the least to the greenhouse gas emissions driving Human-caused Climate Change, Africa has already experienced significant negative impacts and loss and damage from Human-caused Climate Change to key development sectors.[32]

45. Climate change has negatively impacted food security in Africa. Human-caused Climate Change slowed down growth in agricultural total factor productivity in Africa by 34% in the period 1961–2015, a greater slowdown than for any other region globally, which is especially concerning given 51.7% of total employment in Africa is in agriculture.[33]

46. Maize provides the largest percentage of food calories in Sub-Saharan Africa and it is estimated that Human-caused Climate Change reduced maize yields by greater than 4% in many regions of tropical and sub-tropical Africa, but increased maize yields in higher latitudes in North America and Europe during the period 1981–2010, relative to what would have occurred without Human-caused Climate Change.[34]

47. Heat and rainfall extremes intensified by Human-caused Climate Change in the period 2000–2009 led to average yield reductions of 10–20% for millet and 5–15% for sorghum across West Africa, amounting to average annual production losses of 2.33–4.02 billion USD for millet and 0.73–2.17 billion USD for sorghum relative to what would have occurred without Human-caused Climate Change.[35]

48. Increased extreme events such as droughts due to climate change is an important driver of rises in food insecurity and malnutrition in Africa. Increased intensity of the 2015/2016 El Niño increased drought-induced crop losses in Southern Africa, and Human-caused Climate Change also exacerbated the 2007 drought in southern Africa, causing food shortages, price spikes and acute food insecurity in Lesotho.[36]

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32 IPCC WGII 2022: Chapter 9 Executive Summary

33 IPCC WGII 2022: Chapter 9 Section 9.8.1; Ortiz-Bobea et al. 2021 Nature Climate Change https://doi.org/10.1038/s41558-021-01000-1

34 IPCC WGII 2022: Chapter 5 Section 5.2.1; Iizumi et al. 2018 International Journal of Climatology DOI: 10.1002/joc.5818.

35 Sultan et al. 2019 Scientific Reports https://doi.org/10.1038/s41598-019-49167-0

36 IPCC WGII 2022: Chapter 5 Section 5.2.1

49. Warming temperatures have increased vertical water stratification patterns in African lakes causing reductions or redistributions of primary productivity leading to reduced fish biomass, with these changes partially explaining reduced fish catches in Lake Tanganyika.[37]

50. Most of the health burden of climate change is expected to be concentrated in low- and middle-income countries that are least responsible for the historical greenhouse gas emissions causing climate change.[38]

51. Few studies have been conducted attributing negative health impacts to Human-caused Climate Change in Africa, but there is high agreement that increases in extreme heat from Human-caused Climate Change are leading to loss of lives on the continent.

52. Heat-related child mortality across Africa during 2011–2020 was estimated to be 12 000–19 000 deaths per year; double what it would have been without climate change. The increase due to climate change outweighed the reduction in heat mortality from improvements associated with development.39 Estimates of the burden of mortality associated with heat exposure indicate approximately 44% of heat-related mortality in South Africa during 1991–2018 was attributable to Human-caused Climate Change.[40]

53. Data limitations have so far prevented similar analyses being conducted for other African countries, but based on population vulnerability and increases in heatwaves across the continent, it is expected that a substantial proportion of heat-related deaths would be attributable to Human-caused Climate Change.

54. Climate change has also increased risk from infectious disease in Africa with expansion of malaria into higher elevation regions of the continent.[41] Africa has the highest disease burden for malaria globally. Recent analysis estimates that Human-caused Climate Change has increased the prevalence of childhood malaria across Africa since 1901 and that by 2014, Human-caused Climate Change was responsible for an average of 84 excess cases per 100 000 children ages 2–10 in Africa.[42]

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37 IPCC WGII 2022: Chapter 9 Section 9.6.1 and Section 9.8.5

38 McMichael et al. 2004 "Climate Change" In Chapter 20. Comparative Quantification of Health Risks. World Health Organisation.

39 Chapman et al. 2022 Environment Research Letters https://doi.org/10.1088/1748-9326/ac7ac5

40 Vicedo-Cabrera et al. 2021 Nature Climate Change https://doi.org/10.1038/s41558-021-01058-x

41 IPCC WGII 2022: Chapter 9.10.2.1

42 Carlson et al. 2023 https://doi.org/10.1101/2023.07.16.23292713

55. Climate change has negatively impacted African economies. Increased average temperatures and lower rainfall have reduced economic output and growth in Africa, with larger negative impacts than other regions of the world.

56. In one global study, the estimated effect of Human-caused Climate Change on GDP per capita was on average 13.6% lower across 48 African countries over the period 1981–2010, compared to what it would have been without climate change. As such, Human-caused Climate Change has led to greater economic inequality between temperate, northern Hemisphere countries and those in Africa compared to a counterfactual scenario without climate change.

57. Aggregate macroeconomic impacts manifest through many channels with a larger role for agricultural losses than losses in manufacturing, and sector-specific analyses confirm declines in productivity of food crops, commodity crops, and overall land productivity contribute to lower macroeconomic performance with rising temperatures.

58. Drought and extreme events have also led to reduced income and job losses in specific sectors. In South Africa, the extreme 2015–2017 drought in Cape Town, made more likely by Human-caused Climate Change, led to a reduction in tourism revenues and in a case study of a rural town in South Africa over 80% of businesses (both formal and informal) lost over 50% of employees and revenue due to agricultural drought.[43]

59. Climate change has also had widespread impacts on African ecosystems and biodiversity. Increasing atmospheric CO2 levels and climate change are destroying marine biodiversity, reducing lake productivity, and changing animal and vegetation distributions. Severe coral bleaching linked to increased marine heatwaves has negatively impacted approximately 80% of major reef areas in the western Indian Ocean and Red Sea along Africa's eastern coast.

60. Shifts in the demography, geographic ranges, and abundance of plants and animals consistent with expected impacts of climate change are evident across Africa including shifts of terrestrial species to higher elevations and poleward shifts in geographic distributions of marine species. For vegetation, the overall observed trend is woody plant expansion, particularly into grasslands and savannas, reducing grazing land and water supplies.[44]

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43 IPCC WGII 2022: Chapter 9 Section 9.11.1.1

44 IPCC WGII 2022: Chapter 9 Section 9.6

VI – FUTURE IMPACTS AND LOSS AND DAMAGE

61. According to the scientific assessment of the IPCC, global warming is more likely than not to reach 1.5°C before 2040.[45] With increasing global warming, loss and damage will increase and become increasingly difficult to avoid and is expected to be strongly concentrated among the poorest vulnerable populations.[46]
62. For risks of mortality and morbidity from heat and infectious disease, risk of biodiversity and ecosystem disruption, and risk of reduced food production from crops, fisheries, and livestock best estimate for the transition to a high risk state of widespread and severe negative impacts is at 1.5°C of global warming.
63. Projected impacts considered high risk around 1.5°C include:
    a. Across more than 90% of Africa, more than 10% of species at risk of local extinction;
    b. The further expansion of woody plants into grass-dominated biomes, thereby reducing water yields and grazing land;
    c. Declines of around 9% in maize yield for west Africa, and 20–60% decline in wheat yield for southern and northern Africa, as well as declines in coffee and tea in east Africa and sorghum in west Africa, and a greater than 12% decline in marine fisheries catch potential for multiple west African countries, potentially leaving millions at risk of nutritional deficiencies;
    d. Tens of millions more people exposed to vector-borne diseases in east and southern Africa for malaria, and north, east and southern Africa for dengue and zika;
    e. An increased risk of malnutrition in central, east, and west Africa; and
    f. More than 15 additional deaths per 100,000 annually due to heat in parts of west, east and north Africa.
64. The transition from high to very high risk—that is severe, widespread and irreversible—begins either at or just below 2°C global warming for all three risks. The assessed temperature range for the transition to very high risk is wider for food production than for biodiversity and health.

[45] IPCC Synthesis Report: SPM Section B.1
[46] IPCC WGII 2022: SPM Section C.3; Chapter 9 Section 9.1.6

65. Projected impacts for food include:

    a. 10–30% decline in marine fisheries catch potential for the Horn of Africa region and southern Africa and more than 30% decline for west Africa at 2°C global warming, with greater declines at higher levels of warming;
    b. Beyond 2°C global warming, over 50% of commercially important freshwater fish species across Africa are projected to be vulnerable to extinction;
    c. Between 2°C and 4°C, wheat, maize and rice yields are projected, on average, to be lower than 2005 yields across all regions of Africa;
    d. From 2°C global warming, over 40% losses in rangeland productivity are projected for western Africa; and
    e. By 3.75°C, severe heat stress may be near year-round for cattle across tropical Africa. Multiple countries in west, central and east Africa are projected to be at risk from simultaneous negative impacts on crops, fisheries and livestock.

66. The best estimate for the onset of very high risk for biodiversity and health is at 2.1°C. Projected impacts considered very high risk for biodiversity include potential destabilisation of the African tropical forest carbon sink, risk of local extinction of more than 50% of plants, vertebrate and insect species across one-fifth of Africa, 7–18% of African species at risk of total extinction including, a third of freshwater fish, and more than 90% warm-water coral reefs lost.

67. For health, projected impacts considered very high risk include potentially lethal heat exposure for more than 100 days per year in west, central, and east Africa, with more than 50 additional heat-related deaths per 100,000 annually across large parts of Africa, and hundreds of millions more people exposed to extreme heat in cities, tens to hundreds of thousands of additional cases of diarrhoeal disease in east, central and west Africa, and tens of millions more people exposed to mosquito-borne arboviruses like dengue in north, east and southern Africa.[47]

68. An excess of 250,000 deaths per year by 2050 attributable to climate change is projected due to heat, undernutrition, malaria and diarrhoeal disease, with more than half of this excess mortality projected for Africa compared to a 1961–1991 baseline period and for an intermediate future greenhouse gas emissions scenario.[48]

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[47] IPCC WGII 2022: Chapter 9 Section 9.2

[48] IPCC WGII 2022: Chapter 7 Executive Summary

VII – SUPPORT FOR CLIMATE CHANGE ADAPTATION AND MITIGATION

69. The costs of adapting to climate change are projected to increase rapidly with further increases in global warming.
70. Current tracked finance targeted to climate change adaptation activities largely provided from public funds by developed countries to African countries is insufficient to meet adaptation needs and constrain implementation of adaptation, being many billions of US dollars less than even the lowest adaptation cost estimates for near-term climate change.
71. Many African countries are at high risk of debt distress, including due to the COVID-19 pandemic, and need decreased debt levels to have more fiscal space to invest in reducing vulnerability to climate change.
72. In 2022, the total external debt servicing for public and publicly guaranteed debt for 44 African countries was USD 67 billion, far exceeding levels of annual finance flows for climate change adaptation to Africa.
73. A substantial increase in grants and other non-debt and highly concessional finance is necessary to support adaptation of the most vulnerable in Africa, such as those living in informal settlements.[49]
74. It has been suggested that increased private sector finance is needed to meet the adaptation finance gap but the percentage of tracked private sector finance for climate change action that is targeted to adaptation has remained small, estimated at 1% of adaptation finance in 2018. A key challenge for private sector finance is demonstrating a financial return because although adaptation projects are often cost effective, they do not return a direct revenue stream as many benefits arise as avoided damages or public goods. It is therefore expected that public sector finance will have to remain the major source of adaptation finance, especially for vulnerable countries and communities.
75. Adaptation finance has also not been targeted more towards more vulnerable countries. Reasons for this include fast-growing middle-income countries offering larger gains in emission reductions, so finance has favoured mitigation in these economies, even within sub-Saharan Africa, and as more climate finance uses

[49] IPCC WGII 2022: Chapter 9 Section 9.4.1; World Bank https://data.worldbank.org/indicator/DT.TDS.DPPG.CD

debt instruments, mitigation projects are further preferred because returns are perceived to be more certain.

76. The greatest gains in well-being in urban areas can be achieved by prioritizing finance to reduce climate risk for people living in informal settlements but there is limited evidence of investment in informal settlements that host the most vulnerable urban residents.[50]

77. With further increases in global warming the feasibility (that is, the potential for an adaptation option to be implemented) and the effectiveness of many adaptation options is decreased and hard limits to adaptation are reached, including for biodiversity and ecosystems, and for the water and agriculture sectors—further increasing projected loss and damage in Africa.

78. A 5-fold to 12-fold increase in financial investments for mitigation efforts in Africa is needed until 2030 in scenarios that likely limit global warming to 2°C or lower. Public and private finance flows for fossil fuels are still greater than those for climate change adaptation and mitigation.[51]

79. According to the IPCC scientific assessment published in 2023:

> There is sufficient global capital and liquidity to close global investment gaps [for climate change mitigation and adaptation], given the size of the global financial system, but there are barriers to redirect capital to climate action both within and outside the global financial sector and in the context of economic vulnerabilities and indebtedness facing developing countries. Reducing financing barriers for scaling up financial flows would require clear signalling and support by governments, including a stronger alignment of public finances in order to lower real and perceived regulatory, cost and market barriers and risks and improving the risk-return profile of investments…. Accelerated financial support for developing countries from developed countries and other sources is a critical enabler to enhance adaptation and mitigation actions and address inequities in access to finance, including its costs, terms and conditions, and economic vulnerability to climate change for developing countries. Scaled-up public grants for mitigation and adaptation funding for vulnerable regions, especially in Sub-Saharan Africa, would be cost-effective and have high social returns in terms of access to basic energy.[52]

[50] IPCC WGII 2022: Chapter 9 Section 9.4.1; Chapter 17 Executive Summary and Cross-Chapter Box FINANCE
[51] IPCC Synthesis Report 2023: SPM Section A.4; Section 4 Figure 4.6
[52] IPCC Synthesis Report 2023: SPM Section C.7

18 March 2024

Dr Christopher Trisos
Cape Town, South Africa

Dr Christopher H. Trisos

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website: https://climaterisklab.com   @christrisos

Profile

My research focus is understanding where and when climate change risks to people and ecosystems emerge, and providing actionable knowledge to reduce risks. Examples of this work include: forecasting risks from climate change to human health, food production, and biodiversity; tracking finance for adaptation; and developing new and more policy-relevant climate change risk assessment frameworks. My research integrates diverse knowledge and data across natural and social sciences to understand climate change risks across Africa and globally, working from a global South perspective. By working with knowledge users, an important goal of my research is to produce actionable insights for climate risk management for decision-makers to help society transition to a more just and sustainable future.

Education

D. Phil. Zoology, University of Oxford. 2014

M.Sc. Integrative Bioscience, University of Oxford. *Distinction.* 2009

B.Sc. Hons. Botany, University of Cape Town. *First Class.* 2007

B.Sc. Ecology & Economics, University of Cape Town. *Distinction.* 2006

Employment

Chief Research Officer, African Climate and Development Initiative, University of Cape Town 2023–present
Principal Investigator of the Climate Risk Lab. The lab integrates data and methods from environmental and social science to forecast where and when climate change risks appear and inform more rapid and just responses to climate change.

Senior Researcher, African Climate and Development Initiative, University of Cape Town 2019–2023
Principal Investigator of the Climate Risk Lab.

Consultant, Global Climate Change Research and Advisory Unit, World Bank 2018–2019
Conducted a global synthesis of climate change risks and adaptation priorities to guide development of the World Bank Group's $50 billion *Action Plan on Climate Change Adaptation and Resilience.*

Postdoctoral Fellow, National Socio-Environmental Synthesis Center (SESYNC), University of Maryland 2015–18

Visiting Research Fellow, Dept Ecology and Evolutionary Biology, Yale University. 2016–17

Postdoctoral Fellow, South African Environmental Observation Network (SAEON) 2014–15

Professional Service and Policy Work

Advisor for African Negotiators, Global Goal on Adaptation negotiations under UNFCCC. 2023

Zambia Country Delegation Member, Global Goal on Adaptation intergovernmental negotiations. 2023

Co-chair Advisory Board, Connecting Climate Minds for climate change and mental health. 2023

Core Writing Team and Section Facilitator, Synthesis Report of the IPCC. 2020–2023

Steering Committee, South African Modelling Community of Practice for the South African Presidential Climate Commission. 2023

Expert Advisory Panel on Solar Geoengineering, United Nations Environment Programme. 2022

Coordinating Lead Author, Africa chapter, IPCC Working Group II. 2019–2022

Lead Author, Joint IPBES-IPCC workshop report on biodiversity and climate change. 2020–2021

Committee member, African Academy of Sciences Climate Change Advisory Committee. 2019

Consultant, World Bank Climate Change Adaptation and Resilience Action Plan. 2018

AWARDS

Vice-Chancellor's Future Leaders Programme, University of Cape Town 2021

"P" rating—South African National Research Foundation 2020
The NRF assigns a "P" rating to researchers who have held a doctorate for less than five years. These researchers are considered likely to become future international leaders in their respective fields on the basis of exceptional potential demonstrated in research performance and output during post-doctoral careers.

Young Researcher Award, University of Cape Town 2020
Award offered annually in recognition of outstanding scholarly work by young academics who have made significant independent contributions to research in their field.

Rhodes Scholarship 2008–12
Awarded for academic excellence, leadership and commitment to public service.

SELECTED GRANTS

Principal Investigator: *Schmidt Science Polymath*, USD 2.5 million 2023–28
Schmidt Futures

Principal Investigator: *Synthesis Project for Climate Change,* CAD 2.1 million 2023–26
International Development Research Canada

Principal Investigator: *Synthesis Programme on Climate and Development*, ZAR 5 million 2023
Gabriel Foundation

Principal Investigator: *Technical Support for Global Goal on Adaptation,* USD 500,000 2023
Bill and Melinda Gates Foundation

Co-Investigator: *RESCUE: Response of the Earth System to Overshoot* 2022–25
EU Horizons, Euro 8.7 million (ZAR 2.6 million to UCT)

Principal Investigator: *Choose your own climate future: a cli-fi story of chance and consequences* 2020–21
Global Strategic Communications Council and Climate Interactive, USD 30,000

Principal Investigator: *Amplifying the uptake of African Adaptation Science in the 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)* 2020–21
International Development Research Centre, CAD 250,000

Principal Investigator: *Future Leader – African Independent Research (FLAIR) Fellowship "Forecasting climate risks to biodiversity and ecosystem services to strengthen climate change adaptation in Africa"* The U.K. Royal Society, GBP 244,107 2019–21

Principal Investigator: *New Scenarios and Models for Climate Engineering* 2018–20
U.S. National Science Foundation, USD 200,000

SELECTED RECENT PUBLICATIONS

Please see my Google Scholar Profile for a full publication list (H-index
https://scholar.google.com/citations?hl=en&user=th_p4V8AAAAJ&view_op=list_works

First or last author position indicates leadership or co-leadership of research

* indicates MSc or PhD student I have supervised.

Pigot, AL, Merow, C, Wilson, A and **Trisos, CH** (2023). "Abrupt expansion of climate change risks for species globally" ***Nature Ecology & Evolution*** 7, 1060-1071.
North, MA, Franke, JA, Ouweneel, B and **Trisos, CH** (2023). "Global risk of heat stress to cattle from climate change" ***Environmental Research Letters*** 18, 094027.

The Core Writing Team (2023). "Climate Change 2023: Synthesis Report" Contribution of Working Groups, I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change doi: 10.59327/IPCC/AR6-9789291691647.001

- I was a member of the IPCC Core Writing Team and leader of the section of the report on near-term risks and response options in a changing climate. This report is the final synthesis of 7 years of IPCC scientific assessment.

Trisos, CH, I.O. Adelekan, E. Totin, A. Ayanlade, J. Efitre, A. Gemeda, K. Kalaba, C. Lennard, C. Masao, Y. Mgaya, G. Ngaruiya, D. Olago, N.P. Simpson, and S. Zakieldeen. "Africa climate impacts, adaptation and vulnerability". (2022) In: *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the **Sixth Assessment Report of the Intergovernmental Panel on Climate Change** [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press.

- The most comprehensive assessment to date of climate change risks, vulnerability, and adaptation options for Africa.

Meyer, ALS, Bentley, J, Odoulami, R, Pigot, AL and **Trisos, CH** (2022). "Risks to biodiversity from temperature overshoot pathways" ***Phil. Trans. Roy. Soc. B*** https://doi.org/10.1098/rstb.2021.0394

- First research to quantify risks to biodiversity globally from a climate change overshoot pathway. Featured in BBC, Sky News, Reuters, among others.

Carlson, C.J., Albery, G.F., Merow, C., **Trisos**, **C.H.**, Zipfel, C.M., Eskew, E.A., Olival, K.J., Ross, N., Bansal, S. (2022). "Climate Change increases cross-species viral transmission risk". ***Nature***

- Featured in over 700 news articles, with an Altmetric score of 8042 giving it the highest online attention score for any research paper ever featured by *Carbon Brief.*

*Zvobgo, L, Johnson, P, Williams, PA, **Trisos CH,** Simpson, NP. (2022). "The role of Indigenous knowledge and local knowledge in water sector adaptation to climate change in Africa: A structured assessment. ***Sustainability Science*** 17, 2077-2092.

Trisos, CH, Auerbach, J and Katti, M (2021) "Decoloniality and anti-oppressive practices for a more ethical ecology" ***Nature Ecology & Evolution***, 9, 1205-1212 https://doi.org/10.1038/s41559-021-01460-w

- Downloaded over 87 000 times.

Simpson, NP., Andrews, T., Kroenke, M., Ouweneel, BO. Oudaloumi, R. and **Trisos, C.H.** (2021) "Climate change literacy in Africa". ***Nature Climate Change*** 11, 937-944

Adade Williams, P, Simpson, NP, Totin, E, North, MA & **Trisos, C.H.** (2021) "Feasibility of climate change adaptation across Africa: an evidence-based review" ***Environmental Research Letters*** 7, 073004

- This paper won an award from the editors at Environmental Research Letters for the best paper from a developing country author team.

*Wessels, C, Merow, C and **Trisos, CH**. (2021) Climate change risks to southern African wild food plants. ***Regional Environmental Change*** 21, 1-14

Simpson, NP, Mach, K, Constable, A, […], Totin, E and **Trisos, CH** (2021) "A framework for complex climate change risk assessment" ***One Earth*** 4, 489-501

- This climate risk assessment framework has been used by the Belgian Government and the U.S. Department of Energy to develop their climate risk management strategies.

Trisos, CH, Merow, C and Pigot, AL (2020) "The projected timing of abrupt ecological disruption from climate change" ***Nature***, 580,496-501 https://doi.org/10.1038/s41586-020-2189-9

- Downloaded over 43 000 times and featured in over 120 news articles.
- This research was selected to illustrate climate change risks to biodiversity globally in the IPCC Synthesis Report's 'Summary for Policymakers'.

Science Communication

Interviewed and quoted frequently on climate change risks and adaptation by journalists for news articles, radio and podcasts, including for *News24, SABC, Daily Maverick, BBC, New York Times*, *The Guardian*, *Time*, *USA Today*, *The Atlantic*, *Carbon Brief, Sky News, CBS,* and multiple other news outlets in Africa, Europe, and Asia.

Author of 9 articles in *The Conversation* that have had over 250,000 readers https://theconversation.com/profiles/christopher-trisos-394653/articles

Co-creator, *Survive the Century: a cli-fi game of choice and consequences* 2021

You can play it at https://survivethecentury.net/

An online interactive game where players experience the consequences of trying to adapt (or not) to climate change. I led a collaboration between scientists, artists and sci-fi authors to create the game. It has been played by over 30,000 people from classrooms to corporate boardrooms (e.g., Exxaro mining company) as a way to start in-depth discussions on climate change risk management. It is also available as a book.

Selected Supervision and Teaching

Graduated 2 MSc students (one at UCT), supervisor for two UCT MSc students (both submitted) and co-supervisor for one UCT PhD student (submitted); guest lecturer on MSc courses in climate change and conservation biology at UCT.

Course convener and lecturer *'Transdisciplinary Champions',* University of Zurich 2019

Co-organiser postdoctoral professional development in transdisciplinary research, National Socio-Environmental Synthesis Center, University of Maryland 2018

Selected Recent Invited Talks

Climate change risks and response options in Africa 2023
Keynote speaker. The Board of Woolworths Holdings Ltd.

Climate change risks and climate resilient development in Southern Africa 2023
Keynote speaker. Senior management of Singita Safari Lodges.

Synthesis Report of the IPCC 6th Assessment Cycle 2023
Invited talk for South African Presidential Climate Commission

Climate change risks and climate resilient development 2023
Invited talk for United Arab Emirates government negotiators.

Climate change impacts and adaptation: Key message for Africa
Keynote speaker. South Africa Pavilion at CoP28 2022

Climate change and Ecosystems 2022
Expert panel speaker. IPCC Pavilion at CoP28.

Carbon Dioxide Removal 2022
Expert panel speaker. IPCC Pavilion at CoP28.

Climate change risks and response options for Africa 2022
South African Presidential Climate Commission

Climate change risks to Africa 2022
Plenary Speaker. United Nations Framework Convention on Climate Change, African Group of Negotiators, Bonn, June 2022.

Enhancing Climate Action on Land 2022
Plenary Speaker. African Group of Negotiators Expert Support Meeting, Zambia.

Solar geoengineering 2022
Carnegie Climate Governance Initiative, China, virtual event.

Climate change risks to African biodiversity 2021
Plenary Speaker. The Conservation Symposium Africa.

Solar geoengineering risks 2021
Plenary Speaker. Sandia National Laboratories, a U.S. Dept of Energy National lab

Climate change risk assessment in ecology 2021
Seminar speaker. Paleobiology Research Group, University of Bristol

Choose your own climate scenario 2020
Seminar speaker. Community Climate Intervention Strategies, U.S. National Center for Atmospheric Research (NCAR)

The projected timing of ecological disruption from climate change 2019
Plenary Speaker. Global Change and Biodiversity Conference, Monte Verita, Switzerland

The timing of abrupt ecological disruption from climate change 2019
Seminar speaker. Centre for Complex Systems in Transition, Stellenbosch University.

Risks to biodiversity from geoengineering 2019
Seminar speaker. University of Minnesota.

PROFESSIONAL SERVICE

Associate Editor at the journal *Climate Risk Management* 2021-2022

Scientific Steering Committee *Commonwealth Science Conference* 2021
Theme leader for 'Building Resilient Societies'

Reviewer
Peer reviewer for U.S. National Science Foundation and multiple peer-reviewed journals: *Nature*, *Trends in Ecology and Evolution, PNAS, Ecology, Global Ecology and Biogeography, Climactic Change, African Journal of Ecology, Biodiversity and Conservation, Proceedings of the Royal Society B, Journal of Biogeography, Evolutionary Ecology, Organisms Diversity and Evolution*, *Functional Ecology, Ecography, Journal of Animal Ecology.*

COMPUTING

- Extensive experience with *R* programming, statistical analysis and data visualisation.
- Regular user of GitHub to manage collaborations among multiple project contributors.
- Completed *Open Science for Synthesis* computational training at the National Center for Ecological Analysis and Synthesis at U.C. Santa Barbara in 2014.