Form 40 (version 5)
UCPR 35.1

AFFIDAVIT OF PROFESSOR PENNY DIANE SACKETT

5 MARCH 2021

COURT DETAILS	
Court	The Land and Environment Court of NSW
Division	Class 4
Registry	Level 4, 225 Macquarie Street, Sydney
Case number	20/106678
TITLE OF PROCEEDINGS	
Applicant	**Bushfire Survivors for Climate Action Incorporated (INC1901160)**
Respondent	**Environment Protection Authority (ABN 43 692 285 758)**
FILING DETAILS	
Filed for	**Bushfire Survivors for Climate Action Incorporated, Applicant**
Legal representative	Elaine Johnson, Environmental Defenders Office Ltd
Legal representative reference	1926923
Contact name and telephone	Elaine Johnson; Matt Floro; (02) 9262 6989
Contact email	elaine.johnson@edo.org.au; matthew.floro@edo.org.au

AFFIDAVIT

Name	Professor Penny Diane Sackett
Address	Penny D Sackett Strategic Advisory Services 1/6 Hobson Place, Ainslie ACT 2602
Occupation	Strategic Scientific Advisor and Principal, Penny D Sackett Strategic Advisory Services; Distinguished Honorary Professor, Climate Change Institute, Australian National University
Date	5 March 2021

I affirm:

Professional background

1 I am a Strategic Scientific Advisor and the Principal of Penny D Sackett Strategic Advisory Services (**SAS**). I operate SAS as a sole trader assisting governments, businesses and other organisations with matters of science and sustainability.

2 I am also a Distinguished Honorary Professor, Climate Change Institute, Australian National University. In this role, I undertake work relating to community engagement, climate science synthesis and communication.

3 I am Chair of the Australian Capital Territory (ACT) Climate Change Council, and have been a Councillor of that statutory body since 2015.

4 Serving a three-year term, from 2017-2019, I was a member of the Scientific Advisory Board of the Potsdam Institute for Climate Impact Research, one of the world's most renowned institutions for climate research.

5 From 2014-2019, I was Honorary Professor, Climate Change Institute, Australian National University. In that role, I undertook work relating to community engagement, science for policy, and subnational climate change action.

6 From 2008-2014, I was Adjunct Professor, Research School of Astronomy and Astrophysics, Australian National University.

7 From 2008-2011, I was Chief Scientist for Australia. In that role, I provided independent, whole-of-government scientific advice and undertook science advocacy and liaison with community, bureaucracy and state governments.

8 From 2007-2008, I was Professor, Research School of Astronomy and Astrophysics, Australian National University. In that role, I undertook research, research training, and international research co-ordination.

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9 From 2002-2007, I was Director, Research School of Astronomy and Astrophysics, and the Mt Stromlo and Siding Springs Observatories, Australian National University. In that role, I provided strategic leadership and managed budgets, human and facility resources, and undertook liaison and advocacy.

10 From 1983-2002, I held various scientific and academic positions in the United States and the Netherlands.

11 I hold a Ph.D and Master of Science in Physics from the University of Pittsburgh and a Bachelor of Science in Physics from the University of Nebraska-Omaha.

My expert report

12 I have been asked by the Applicant in these Proceedings to prepare an expert report that addresses the amended areas of expert evidence stated in Annex A1 to the orders made by Justice Moore on 26 October 2020.

13 In response, I have prepared the expert report dated 5 March 2021 (**Sackett Report**), which is annexed to this Affidavit and marked '**PDS-1**'.

14 The views expressed in the Sackett Report are my own and correctly state my opinion in relation to the matters set out in the Sackett Report. I believe no further qualifications are required as to the opinions set out in the Sackett Report other than those expressed in the Sackett Report.

15 I have been provided with a copy of Division 2 of Part 31 of the *Uniform Civil Procedure Rules 2005* (**UCPR**) and the *Expert Witness Code of Conduct* (**Code**) in Schedule 7 of the UCPR. I believe that the Sackett Report complies with the Code.

16 I believe that the information set out in this Affidavit is true and correct to my own knowledge.

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AFFIRMED at TURNER, ACT

Signature of deponent [redacted]

Name of witness Frances Bradshaw

Address of witness 21 Barry Drive ACT 2602

Capacity of witness Legal practitioner

And as a witness, I certify the following matters concerning the person who made this affidavit (the **deponent**):

1 #I saw the face of the deponent. [OR, delete whichever option is inapplicable]

~~#I did not see the face of the deponent because the deponent was wearing a face covering, but I am satisfied that the deponent had a special justification for not removing the covering.~~*

2 ~~#I have known the~~ deponent ~~for at least 12 months~~. [OR, delete whichever option is inapplicable]

#I have confirmed the deponent's identity using the following identification document:

ACT Drivers Licence 5177474

Identification document relied on (may be original or certified copy)†

Signature of witness [redacted]

Note: The deponent and witness must sign each page of the affidavit. See UCPR 35.7B.

[* The only "special justification" for not removing a face covering is a legitimate medical reason (at April 2012).]

[† "Identification documents" include current driver licence, proof of age card, Medicare card, credit card, Centrelink pension card, Veterans Affairs entitlement card, student identity card, citizenship certificate, birth certificate, passport or see Oaths Regulation 2011 or refer to the guidelines in the NSW Department of Attorney General and Justice's "Justices of the Peace Handbook" section 2.3 "Witnessing an affidavit" at the following address: http://www.jp.nsw.gov.au/Documents/jp%20handbook%202014.pdf]

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Expert Report to the NSW Land and Environment Court in the matter of Bushfire Survivors for Climate Action Incorporated (INC1901160) v Environment Protection Authority (NSWLEC proceedings 2020/00106678)

Submitted by Professor Penny D Sackett
Strategic Advisory Services

5 March 2021

This is the document referred to as Annexure 'PDS-1' in the affidavit of Professor Penny Diane Sackett, affirmed at Turner on 5 March 2021 before me:

5/3/2021

FRANCES BRADSHAW
Solicitor of the
ACT Supreme Court

Table of Contents

1 Preliminaries

1) This expert report is submitted to the Land and Environment Court of NSW (hereafter, `the Court') as a response to a brief provided to me by Environmental Defenders Office (EDO) on 10 November 2020. That brief is annexed to this report as Appendix A.

2) I understand that this report will serve as expert evidence in a matter before the Court (NSWLEC proceedings 2020/00106678), in which the EDO is acting for Bushfire Survivors for Climate Action Incorporated (INC1901160) in a matter against the NSW Environment Protection Authority (EPA).

3) I have reviewed Division 2 of Part 31 of the *Uniform Civil Procedure Rules 2005* (UCPR) and the Expert Witness Code of Conduct, which govern the use of expert evidence in NSW Courts, and I agree to be bound by their terms.

4) I have read the orders made by Justice Moore on 26 October 2020, including its Annex A1 laying out the Amended Areas of Expert Evidence (see Appendix B). These areas are explicitly addressed in this expert report, as follows:

   a) Area 1: Sections 3, 5, and 6.

   b) Area 2: Sections 3 and 5.

   c) Area 3: Sections 4 and 5.

   d) Area 4: Sections 4 and 5.

   e) Area 5: Sections 4 and 5.

   f) Area 6: Section 7.

5) External sources used in this report are referenced. Any modelling work presented in these external sources is taken at face value, as verifying the results is beyond the scope of this report. Where relevant, underlying assumptions are noted.

6) A brief list of my relevant qualifications and experience is attached as Appendix C to this report.

2 Executive Summary

From Sections 3.1 and 3.2

7) Greenhouse gases (GHGs) trap some of the radiation from the Sun warming the surface of the Earth. Human activities are upsetting a long-standing balance in these gases, adding energy via global warming that fuels changes in the global climate.

8) The primary greenhouse gases driving current anthropogenic (human-caused) climate change are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Most of the carbon dioxide that is not absorbed quickly by ocean and land 'sinks' will remain in the atmosphere for thousands of years. This means that the full effect of past and present emissions is yet to be felt.

9) Current levels of CO_2, CH_4 and N_2O in the atmosphere are 146%, 257% and 122%, respectively, of their pre-industrial levels around 1850. Increased concentration of CO_2 in the atmosphere caused by human activity is the most important contributor to global warming and climate change. Carbon dioxide levels are higher now than any other time our species has inhabited the Earth. At present, 85-90% of the additional CO_2 emitted per year is from the burning of fossil fuels: coal, gas, and oil; all of these major sources of emissions continue to rise.

10) Nearly all of the warming experienced in past 160 years is due to human activities. Since 1970, the average global surface temperature has been changing at a rate 200 times faster than any time in the last 7,000 years.

11) Reducing net anthropogenic GHG emissions to zero and maintaining them at that level is the only way that humans can stabilize the climate. The primary determinant of future climate change, is the trajectory of world emissions, especially the path between now and 2030. Restrictions imposed in response to COVID-19 will have negligible impacts in terms of climate change.

From Section 3.3.1

12) The global mean temperature for 2019 was 1.1°C above pre-industrial levels. The past decade, 2010–2019, is the warmest on record. No one under the age of 43 has ever

experienced a year in which global temperatures were `below normal' by last century's standards.

13) Current effects of climate change worldwide are substantial and costly. Recent examples include, *inter alia*: extreme, long-lived heat waves (the deadliest meteorological hazard in the last five years); extreme unprecedented wildfires in the Amazon rainforest, the Arctic, California and Australia; increases in both heavy, extreme rainfall for some regions and intense droughts in others; and a record-breaking temperature of 38°C in the Arctic.

From Section 3.3.2

14) Large parts of Australia have experienced a long-term increase in extreme fire weather, and fire season length. Cool-season rainfall has declined in southeast and southwest Australia over the past 20 years, leading to reduction of stream flows. Marine heatwaves around Australia are longer and more frequent, depleting sea flora and, together with increased ocean acidity due to climate change, bleaching coral reefs.

15) Australia's hottest year and driest year on record was 2019. Most years in Australia are now warmer than almost any year in the 20th century. National daily average maximum temperatures have skyrocketed: 33 days exceeded 39°C in 2019, more than the number observed from 1960 to 2018 combined, which totalled 24 days.

16) Australians are five times more likely to be displaced by a climate-fuelled disaster than someone living in Europe.

From Section 3.3.3

17) Many climate change impacts are being felt in NSW to an even larger degree than the national average. Penrith Lakes recorded 48.9°C on 4 January 2020, the highest temperature ever recorded in the Sydney basin. NSW had its highest accumulated Forest Fire Danger Index (FFDI) for December in 2019.

18) Nearly all of NSW has had below average rainfall over the past twenty years. Long-term streamflow gauges in the Murray–Darling Basin have been declining since 1970. Unprecedented conditions of inland NSW in mid-2019 correspond to what meteorologists are now calling a 'flash drought.'

From Section 3.3.4

19) Many individual extreme events can be directly linked to climate change. Examples include: the devastating Australian 2019/20 bushfires were at least 30% more likely because of climatic changes caused by humans; widespread coral bleaching of the Great Barrier Reef during 2016 was made 175 times more likely by climate change; and the 2018 record-breaking UK summer temperatures were about 30 times more likely due to climate change.

From Section 3.4

20) Changes associated with global warming play direct, multiple and complex roles in increasing the threat of forest fires.

21) The 2019/20 bushfires (`Black Summer') were the worst on record for NSW in terms of fire intensity, area burned, and number of properties lost. NSW had more than 240 days of active fire across the state in the 2019-20 bushfire season. Nearly 80% of all Australians were affected directly or indirectly by the 2019-20 bushfires. Economic costs of Black Summer are still being tallied, but it is likely to be Australia's costliest natural disaster to date.

22) Eighteen pyrocumulonimbus (fire-generated weather) events in a single week of Black Summer had a planetary-scale radiative forcing effect equivalent to a moderate volcanic eruption. In total, the Black Summer fires released an amount of CO_2 into the atmosphere about twice the annual Australian GHG emissions.

23) Across Australia, direct social impacts included the loss of 33 lives (25 in NSW) and the destruction of over 3,000 houses. Indirect health impacts attributed to smoke exposure include an estimated 417 lives lost and 3,151 hospitalisations.

24) In NSW, where the majority of the fires occurred, up to 293 threatened animal species and 680 threatened plant species may have been affected. Overall, it is estimated that three billion individual native vertebrates perished in the fires, comprising: 143 million mammals, 2.46 billion reptiles, 180 million birds and 51 million frogs.

25) In NSW, 37% of the state's rainforests were fire-affected during Black Summer, including over half of the Gondwana Rainforests, an Australia World Heritage Area. In Australia, typically less than 2% of temperate broadleaf forest areas burn annually; during Black Summer that percentage was a globally unprecedented 21%. About half of that forest area lies in NSW. Local tipping points in some NSW forests may have already been crossed, with a danger that large portions may not be able to regenerate fully before the next catastrophic wildfire.

From Section 4.1

26) The UNFCCC Paris Agreement commits signatories to "keeping a global temperature rise this century *well below* 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C." Signatory nations have made separate Nationally Determined Contributions (NDCs) as a step to meet the Paris goals.

27) Estimates suggest that warming between 2.1°C and 3.3°C would result from current NDC commitments. New NDC commitments submitted by 31 December 2020 do not significantly alter this result. Aggravating this state of affairs, most nations are not on-track to meet their current commitments: based on current *policies* as opposed to *pledges*, warming could climb as high as 3.9°C.

28) Furthermore, a three-part test based on recent modelling by the IPCC shows that the world's emissions profile is not compatible with holding warming to 1.5°C. Nor is a conservative precautionary `carbon budget' assessment, or an analysis of the production gap between nations' expectations for their future production of fossil fuels and the Paris warming target range that they support. The latter analysis shows that governments are planning to produce about 120% more than would be consistent with a 1.5°C pathway.

29) The conclusion is that the world is not on track to hold global temperature rise to 1.5°C from pre-industrial levels.

From Section 4.2

30) Australia's NDC is to reduce its emissions by 26%–28% (on 2005 levels) by 2030 is incompatible with holding global warming to below 2°C, let alone 1.5°C. If all governments were to adopt and fulfill targets like those Australia, global warming would exceed 2.0°C

and could climb as high as 3.0°C. Moreover, Australia is not on track to meet its 2030 Paris NDC commitment.

31) The emission trajectories of countries or regions can be assessed by `downscaling' global criteria for holding warming to the 1.5°C goal. Three different such tests, each with its own assumptions, are: the IPCC SR1.5 three-part emissions test; assigning a regional `population share' of the world's remaining precautionary 1.5°C carbon budget; and assessment of regional efforts to close the fossil fuel production gap.

32) On each of these three measures, Australia is not on a path compatible with holding global temperature rise to 1.5°C from pre-industrial levels. The same conclusion was reached by the government's Climate Change Authority in 2015, and by a similar analysis updated in 2021. Nor is Australia's stated GHG policy consistent with a combined sectoral emissions pathway specifically designed for Australia to be consistent with limiting global temperature rise to 1.5°C.

From Section 4.3 and 4.4

33) Although New South Wales has set an aspirational goal of achieving net zero emissions by 2050, and set out plans to **reduce its greenhouse gas emissions by 35% on 2005 levels by 2030**, neither of these actions is sufficient separately or taken together to place NSW on an emissions reduction trajectory in line with limiting global temperate rise to no more than 1.5°C above pre-industrial levels.

34) On the basis of each of the three measures set out in 31), New South Wales is not on a path compatible with holding global temperature rise to 1.5°C from pre-industrial levels.

35) All tests of compatibility for holding global warming to 1.5°C used in this report are summarised in Table 3 for the world as a whole, Australia, and New South Wales.

From Section 5.1

36) Future climate change can be projected on the basis of different scenarios for future human GHG emission trajectories and the speed with which the planet responds to feedbacks in the Earth System (that is, non-human processes that either amplify or diminish climate change). If the trend of rising emissions is continued, global warming could be 3—4°C above pre-industrial times in just 80 years.

37) Climate impacts are hitting harder and sooner than previous scientific assessments have expected. The more we know, the more we realise how dangerous even a small amount of warming can be. Even the Paris Agreement range of 1.5°C to well below 2.0°C is not 'safe'.

38) At 2°C warming, 99% of the world's coral reefs, including the Great Barrier Reef, are very likely to be eliminated, and crisis upon crisis will compound for the world's most vulnerable people.

39) At 3°C–4°C of warming (a consequence of continuing on our current, unchecked path): most of the world's ecosystems would be heavily damaged; extreme weather events would be far more severe and frequent; large areas of the world become uninhabitable; and the entire global economy would be significantly damaged. Furthermore, there would be a moderately high risk that a cascade of tipping points in the climate system would put the Earth system into a state not seen for millions of years, irrespective of humanity's late attempts to reduce emissions.

From Section 5.2

40) In future, Australia will experience climate effects similar to those already in evidence, but considerably more severe. Specifically, for most of the Australian coast, extreme sea levels that had a probability of occurring *once in a hundred years* are projected to become an *annual event* by the end of this century with lower emissions (by mid-century for higher emissions). Australia's hottest year on record (2019) is expected to be an *average* year in a world with 1.5°C of warming. Although the current decade is warmer than any other decade over the last century, it is also likely to be the *coolest decade* for the century ahead.

41) At a global warming of 1.5°C, peak heatwaves that occurred only once per 30 years in pre-industrial times in Australia, will nearly double to once every 2.7 years. In a world with 3°C of average warming, Australians will see such peak heatwaves nearly every year.

42) Annual damages from extreme weather, along with sea-level rise and other impacts of climate change upon Australia, could exceed $100 billion by 2038, and exceed $1.89 trillion by 2050.

43) Fire weather like that in Black Summer is projected to be four times more likely if global warming reaches 2°C, compared to conditions typical in 1900. If GHG emissions are not

curbed sharply, such megafires may be a common Australia feature by late century — even in years with plentiful rainfall.

From Section 5.3

44) The impacts on NSW will be widespread, deleterious and costly if the global 1.5°C target is not met; even half of a degree of global warming makes a difference.

45) For NSW, run-off, water available to feed dams and rivers, will decrease markedly: for every one degree (°C) of global warming, runoff will be reduced by 15%. With current emissions trends leading to a possible *additional* 2°C to 3°C of temperature increase, NSW could be faced with water reductions of 45 – 60%, compared to mid last century.

46) Some NSW forests are near, or may have already crossed, local tipping points that would irretrievably alter those ecosystems, perhaps turning what was forest permanently into dry grassland.

47) NSW/ACT Regional Climate Modelling (NARCliM) finds that under a high, unabated, emissions scenario, the annual number of heatwave days in Sydney will increase from 5.5 days to 23 days, with severe implications for mortality.

48) In a world with 1.5°C of warming, NSW can expect about 2–4 more heatwave days than currently, and 4-8 more with 2°C of global warming. Should global warming reach 3°C or more, as indicated by current policy settings in Australia and elsewhere in the world, NSW will incur one to two more additional weeks in heatwave.

49) Major Australian cities, including Sydney, will incur maximum summer temperatures of 50°C under 2°C of global mean warming. Current models may be underestimating the extreme heat that NSW will feel at 1.5°C, let alone, at 2°C of global warming.

From Section 5.4

50) *Tipping points* in the Earth System are thresholds that, if crossed, would lead to far-reaching, and, in some cases, abrupt and/or irreversible changes in subsystems. The most devastating risk of continued global warming is that some of Earth's subsystems will become unstable and `tip 'irreversibly into new states that accelerate the effects of climate change. Some subsystems are already showing signs of becoming unstable.

51) Continued warming increases the risk of a cascade of transformations that could result in a `Hothouse Earth,' in which average temperatures would rise to match those not seen since the beginning of the Stone Age, with devastating consequences. If such a cascade in a domino effect were to occur, the result would be an unrecognisable landscape for current ecosystems and human civilisation.

From Section 6

52) Unabated climate change poses an enormous threat to the environment and peoples of the world, Australia and NSW, in particular. Unabated anthropogenic climate change is:

a) Fundamental – affecting basic aspects of the physical Earth system, and the ecosystems that depend on it,

b) Global – greenhouse gases emitted anywhere in the world affect the whole globe,

c) Comprehensively Dangerous – with the potential to disrupt/destroy every ecosystem,

d) Rapid – occurring at a speed that precludes many organisms and even whole ecosystems from adapting,

e) Inertial – with a delayed response to emissions that "locks in" some measure of climate change that is greater than that currently experienced,

f) Compounding – the effects of climate change can occur simultaneously, greatly increasing the negative consequences of extreme events,

g) Irreversible – feedbacks in the Earth System have the potential to irreversibly change ecosystems and processes in the Earth system.

53) Taken together, in my opinion it is reasonable to state that unabated climate change is the greatest threat to the environment and people of New South Wales.

From Sections 7.1 and 7.2

54) The NSW Environment Protection Agency (NSW EPA) Tender Bundle was examined and used in this report to address the sixth item of Amended Areas of Expert Evidence as outlined in the Annex A1 of Justice Moore's order of 26 October 2020. For clarity, it is noted that the Tender Bundle documents included all those included in Annex A of EPA's Response dated 5 June 2020.

55) The 399 documents were first searched for keywords that would indicate possible relevance, and then examined to identify those that sought to regulate or reduce greenhouse gases. Of the resulting subset of 55, 14 documents (listed in Table 5) mentioned a specific, quantifiable GHG emissions reduction or global warming goal.

56) Giving detailed reasoning, my conclusion is that the omnibus of the NSW EPA Tender Bundle does not regulate or reduce direct and indirect sources of greenhouse gas emissions in a manner consistent with global temperature rise limited to 1.5°C above pre-industrial levels.

From Section 7.3

57) This report defines `fit for purpose' in protecting or mitigating against the threat posed by climate change to the quality of the environment and the people of NSW to mean that:

a) taken as a collection, the documents presented in the NSW EPA Tender Bundle define, and activate through policy, restrictions on activities in the State that directly or indirectly release greenhouse gases that act as pollutants responsible for climate change, and further, that

b) these restrictions are consistent with keeping a global temperature rise *well below* 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C.

58) The following findings are made:

a) The current and planned (with current policy measures) emissions trajectory of NSW is not consistent with well-below 2°C nor with efforts to hold to 1.5°C.

b) The EPA's Strategic Plan 2017-21 does not mention climate, climate change or greenhouse gases.

c) The only policies contained in the NSW EPA Tender Bundle with specific, quantifiable targets for GHG reductions apply to only a small fraction of NSW's total emissions.

d) The major source of GHG emissions in NSW is not addressed: namely that from fossil fuel industries.

e) It is not acknowledged that decisions that allow growth in GHG emissions in some sectors must be matched with even stronger reduction targets in other sectors in order to meet overall emissions targets.

f) Policies related to GHG do not take into account principles that are said to be applied to pollutants in the assessment of some projects, particularly cumulative and threshold effects, and the possibility of irreversibility.

g) There is no consideration of activities in NSW that worsen climate change through their Scope 3 emissions.

h) There is no acknowledgement that from a Precautionary Principle point-of-view, current levels of GHG emissions are *already* dangerous.

i) There is no acknowledgement that current and future GHG emissions `lock in' extra warming, precluding true `remediation' to future generations.

59) Based on the above, it is the conclusion of this report that the objectives, guidelines and policies identified by the NSW EPA are not fit for purpose in protecting or mitigating against the threat posed by climate change to the quality of the environment and the people of New South Wales.

3 Greenhouse Gas Emissions and Anthropogenic Climate Change

3.1 Greenhouse gases

60) **Greenhouse gases (GHGs) trap some of the radiation from the Sun** that would otherwise escape from Earth's upper atmosphere; this radiation warms the lower atmosphere and the surface of the Earth.

61) The primary greenhouse gases driving current anthropogenic (human-caused) climate change are **carbon dioxide (CO_2)**, **methane (CH_4)**, and **nitrous oxide (N_2O)**.

62) These gases differ in concentration in the atmosphere, residence time in the atmosphere and potential to cause a given amount of warming per weight. Of these, **atmospheric concentration is the only property that can be influenced by humans**.

63) Excess amounts of CH_4 and N_2O persist in the atmosphere for about 12 and 121 years, respectively.[1] The life cycle of atmospheric CO_2 is more complex. **Most of the carbon dioxide that is not absorbed quickly by ocean and land 'sinks' will remain in the atmosphere for thousands of years.**[2]

64) Due to their different chemical properties and residency times in the atmosphere, GHGs have different global warming potentials (GWP), that is, they differ in the amount of heat they trap over a given period of time after they are emitted. Over a 20-year period, methane is 84 times more effective than CO_2 in trapping heat, and 28 times more effective over 100 years.[3] Nitrous oxide has a global warming potential about 265 times that of CO_2 on timescales of 20 to 100 years.[4]

65) While GHGs remain in the atmosphere, they continue to contribute to global warming, year after year, regardless of when they were emitted. This means that **the full effect of past and present emissions is yet to be felt**.

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[1] IPCC (2015) Climate Change 2014: Synthesis Report, Box 3.2, Table 1, p87
[2] IPCC 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., et al, eds]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA http://www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf
[3] IPCC (2015) Climate Change 2014: Synthesis Report, Box 3.2, Table 1, p87
[4] IPCC (2015) Climate Change 2014: Synthesis Report, Box 3.2, Table 1, p87

3.2 Increase of greenhouse gases in the atmosphere due to human activity

66) **Human activities are** upsetting a long-standing balance, **adding energy via global warming that fuels changes in the global climate.**[5]

67) ***Anthropogenic* climate change is change in the Earth's climate caused by human activities** that release additional greenhouse gases into the atmosphere or alter the natural land and ocean sinks for these gases.

68) Atmospheric concentrations of CO_2, CH_4 and N_2O have risen since the industrial revolution, with dramatic upward increases of CO_2 beginning around 1960 (Fig. 1).[6]

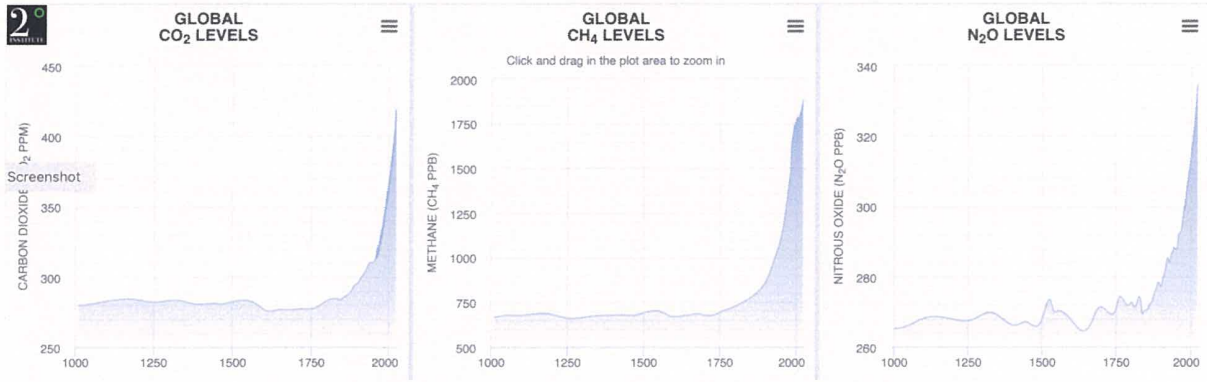

Fig. 1: The rise of GHGs in the atmosphere from 1000AD to present. Graph prepared by the Two Degree Institute, based on ice core records (CSIRO) and in situ measurements (Scripps).

69) Current levels of CO_2, CH_4 and N_2O in the atmosphere are 146%, 257% and 122%, respectively, of their pre-industrial levels around 1850.[7]

70) **Increased concentration of CO_2 in the atmosphere caused by human activity is the most important contributor to global warming and climate change.**[8]

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[5] IPCC (2013): Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., et al, eds]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA http://www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf

[6] 2 Degrees Institute (2020) Accessed at: https://www.climatelevels.org/

[7] WMO (2019) United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

[8] IPCC, SPM (2013), Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Stocker TF, et al. Cambridge and New York, Cambridge University Press, pp 3-29. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf

71) The current level of atmospheric CO_2 is about 415 parts per million (ppm), 25% higher than any other time since the mid-Pliocene, about 3 million years ago.[9]

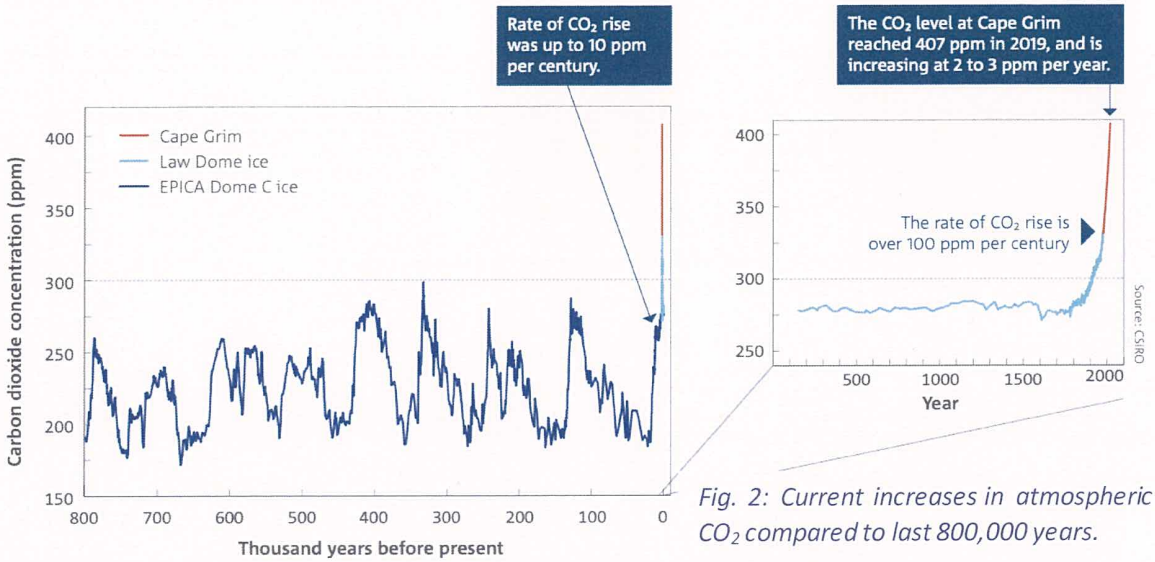

Fig. 2: Current increases in atmospheric CO_2 compared to last 800,000 years.

72) For perspective, the species *Homo sapiens* (modern human) is believed to have arisen only 300,000 to 600,000 years ago. In other words, **carbon dioxide levels are higher now than any other time our species has inhabited the Earth**. (See Fig. 2.)[10]

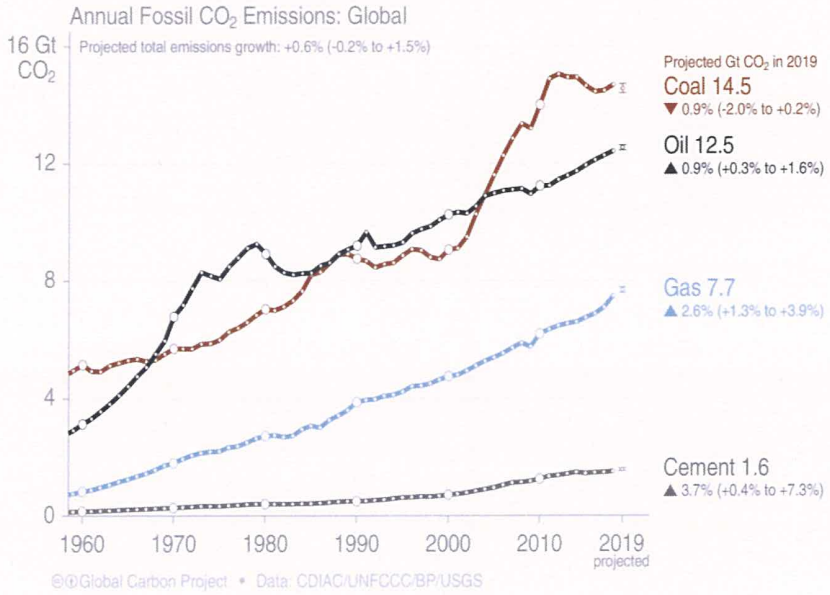

Fig. 3: Global annual CO_2 emissions from fossil fuels and cement production.

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[9] Fedorov, A.V. et al (2013) Patterns and mechanisms of early Pliocene warmth, in Nature, 496, doi:10.1038/nature12003.

[10] CSIRO/BOM (2020), State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate

73) **At present, 85-90% of the additional CO_2 emitted per year is from the burning of fossil fuels: coal, gas, and oil**,[11,12] with most of the remainder due to land use changes (e.g., deforestation).

74) **CO_2 emissions from fossil fuel sources all continue to rise,** despite what was thought to have been a peak for coal around 2013.[13] (See Fig. 3.)[14]

75) The production, delivery and combustion of **fossil fuels are also associated with the release of CH_4.**[15] A recent surge in atmospheric methane over the past decade is attributed in equal parts to agriculture and fossil fuels.[16]

76) The growing trend in emissions continues: **year-on-year CO_2 emissions from fossil fuels are now more than 300% of 1960s levels.**[17]

77) Restrictions imposed in response to **COVID-19** are responsible for annual human GHG emissions decreasing by about 7% in 2020[18], a result that **will have negligible impacts in terms of climate change.**[19] It is estimated that Australian GHG emissions will be 4.5% lower in 2020 than in 2018, but will rebound to 2018 levels in 2021.[20] After the Global

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[11] Le Quéré, C et al. (2018) Global Carbon Budget 2018, Earth Syst. Sci. Data, 10, 2141–2194, See their Table 6, https://doi.org/10.5194/essd-10-2141-2018

[12] Friedlingstein, P et al. (2019) Global Carbon Budget 2019, Earth Syst. Sci. Data, 11, 1783–1838, See their Table 6, https://doi.org/10.5194/essd-11-1783-2019

[13] WMO 2019, United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

[14] Global Carbon Project (GCP) figure (2019), Accessed at : https://www.globalcarbonproject.org/carbonbudget/archive/2019/GCP_CarbonBudget_2019.pptx

[15] WMO 2019, United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

[16] Jackson, RB et al. (2020) Increasing anthropogenic methane emissions arise equally from agricultural and fossil fuel sources, Environ. Res. Lett., 15, 071002, https://doi.org/10.1088/1748-9326/ab9ed2

[17] Friedlingstein, P et al. (2019) Global Carbon Budget 2019, Earth Syst. Sci. Data, 11, 1783–1838, See their Table 6, https://doi.org/10.5194/essd-11-1783-2019

[18] Friedlingstein, P et al. (2020) Global Carbon Budget 2019, Earth Syst. Sci. Data, 12, 3269-3340, https://doi.org/10.5194/essd-12-3269-2020

[19] CSIRO/BOM (2020), State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate

[20] Sadler, H. (2021) National Energy Emissions Audit, The Australia Institute, Accessed at: https://australiainstitute.org.au/report/national-energy-emissions-audit-january-2021/

Financial Crisis of 2008-2009, global CO_2 emissions from fossil-fuel combustion and cement production grew 5.9% in 2010, more than offsetting the 1.4% decrease in 2009.[21]

78) **Nearly all of the warming experienced in past 160 years is due to human activities**, with natural forces (volcanos, changes in solar radiation, etc) playing a negligible role.[22]

79) Since 1970, the global average surface temperature has been rising at a rate of 2.0°C per century,[23,24] about 200 times faster than the average rate of change of about 0.01°C per century for the last 7,000 years.[25]

80) Reducing net anthropogenic GHG emissions to zero and maintaining them at that level is the only way that humans can stabilise the climate. **The primary determinant of future climate change, beyond that which is already locked in by emissions to date, is the future trajectory of world emissions, especially the path between now and 2030**.[26] The more quickly emissions are brought and held to zero, the lower the peak global warming temperature will be.

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[21] Peters et al. (2012) Rapid growth in CO_2 emissions after the 2008–2009 global financial crisis, Nature Climate Change, 2, 2-4.

[22] Gillett, N.P. et al. (2021) Constraining human contributions to observed warming since the pre-industrial period, in Nature Climate Change, https://doi.org/10.1038/s41558-020-00965-9

[23] NOAA (2016) State of the Climate: Global Analysis for Annual 2015. National Centers for Environmental Information, available at http://www.ncdc.noaa.gov/sotc/global/201513

[24] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

[25] Marcott SA, Shakun JD, Clark PU, Mix A (2013) A reconstruction of regional and global temperature for the past 11,300 years. *Science* 339:1198-1201

[26] WMO (2019) United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

3.3 Current impacts of climate change

3.3.1 The Global Context

81) According to a World Meteorology Organisation (WMO) analysis[27] based on five global datasets, **the global mean temperature for 2019 was 1.1°C above pre-industrial levels**. The past decade, 2010–2019, is also the warmest on record. In fact, since the 1980s, each successive decade has been warmer than any preceding decade since 1850. Since 1978, no year has had a global mean temperature below the 1961–1990 average;[28] thus, **no one under the age of 43 has ever experienced a year in which global temperatures were `below normal' by last century's standards.**

82) At this point in time, the hottest year on record is 2020, at nearly the same temperature as 2016. **The past seven years have been the hottest seven years on record**.[29]

83) The calendar year 2019 brought unprecedented fires in the Arctic and in the Amazon rainforest. In June 2019 alone, Arctic fires emitted 50 megatonnes (Mt) of CO_2 into the atmosphere, more than all of the Junes of 2010 to 2018 combined.[30]

84) **Current effects of climate change worldwide are substantial and costly**. These include[31]: increased severity of storms and heat waves, species extinction, wild fires, coastal inundation from rising sea levels and increased storm surge, and the **risk of crossing so-called 'tipping points' that would accelerate climate change** and greatly intensify its impacts[32], **perhaps irreversibly.**

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[27] WMO (2020), WMO Statement on the State of Global Climate in 2019, WMO-No. 1248, accessed at: https://library.wmo.int/index.php?lvl=notice_display&id=21700

[28] BOM (2020), Annual Climate Statement 2019, accessed at: http://www.bom.gov.au/climate/current/annual/aus/2019/

[29] NASA (2021) 2020 Tied for Warmest Year on Record, NASA Analysis Shows, Press release 21–005, https://www.nasa.gov/press-release/2020-tied-for-warmest-year-on-record-nasa-analysis-shows

[30] WMO (2019), United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

[31] IPCC (2014): Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Field et al. (eds.) Cambridge University Press, pp. 1-32.

[32] Schellnhuber HJ, Rahmstorf S, Winkelmann R (2016) Why the right climate target was agreed in Paris. *Nature Climate Change*, 6:649-653

85) Global effects of climate change are already substantial:[33,34]

a) **Accelerating sea-level rise**, with the observed global rate increasing 25% over the last decade, from 3.04 millimeters per year (mm/yr) during the period 1997– 2006 to approximately 4 mm/yr in 2007–2016, driven in part by accelerating land ice melt from Greenland and West Antarctica.

b) **Heat waves,** which were **the deadliest meteorological hazard in the last five years**, affecting all continents. Between 2000 and 2016, the number of people exposed to heat waves is estimated to have increased by 125 million.

c) **More extreme wildfires,** including the unprecedented wildfires in 2019 in the Arctic and in the Amazon rainforest, 2020 fires in California, and the 2019/20 fires in Australia.

d) **Hotter days and warmer nights** over most land areas. Globally, July 2019 was the hottest month on record, with July 2020 taking second place.[35]

e) **Intensification of the hydrological cycle**: increases in the frequency, intensity and amount of heavy precipitation in many areas, and increases in the intensity and duration of drought in other regions (especially since 1970).

f) **Ocean acidification**, threatening sea life and destroying entire ecosystems.

g) **Increases in coastal flooding**, caused by more, and more extreme, high sea level events.

86) **In 2019 and 2020 alone**, the following extraordinary climate events were recorded,[36] among many others:

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[33] WMO (2019) United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

[34] IPCC, SPM (2013) Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Stocker TF, et al. Cambridge and New York, Cambridge University Press, pp 3-29. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf

[35] NOAO (2020), July 2020 was record hot for N. Hemisphere, 2nd hottest for planet, https://www.noaa.gov/news/july-2020-was-record-hot-for-n-hemisphere-2nd-hottest-for-planet

[36] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction

a) Death Valley in the US reported a temperature of 54.4°C, possibly the **highest temperature ever reliably recorded on Earth**.

b) In South America, record fires burnt over a quarter of the Pantanal, the world's largest tropical wetlands.

c) The highest temperature, 18.4°C, was recorded in Antarctica.

d) **Cyclone Gati**, the strongest landfalling cyclone recorded in Somalia, **brought over a year's worth of rain in two days**.

e) In Siberia, an intense, persistent and widespread heat wave broke temperature records, fuelled large fires, and thawed permafrost. The Russian town of Verkhoyansk recorded **a temperature of 38°C in June, likely the highest temperature ever recorded in the Arctic**.

3.3.2 Australia

87) **Australia is witnessing serious climate-related impacts now**. The Australian Bureau of Meteorology (BOM) and the CSIRO[37,38] report that:

a) **Australia's hottest year and driest year on record was 2019**. Australia has warmed by 1.44 ± 0.24°C since national recording keeping began in 1910. The seven years 2013 – 2019 all rank in the top nine warmest years on record. **Most years in Australia are now warmer than almost any year in the 20th century.**

b) Increased warming is observed across Australia in all months, both at night and during the day. This sharply increases the number of extremely warm days. There were 43 extremely warm days in 2019, more than triple than any prior to 2000.

c) National daily average maximum temperatures have skyrocketed: **33 days exceeded 39°C in 2019, more than the number observed from 1960 to 2018 combined**, which totalled 24 days.

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[37] BOM (2020), Annual Climate Statement 2020, accessed at: http://www.bom.gov.au/climate/current/annual/aus/

[38] CSIRO/BOM (2020), State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate

d) **Very warm day- and night-time temperatures** that occurred only 2% of the time in the past (1960-1989) **now occur five to six times more frequently** (2005-2019). As a result, the frequency of extreme heat events is increasing. (See Fig. 4.)[39]

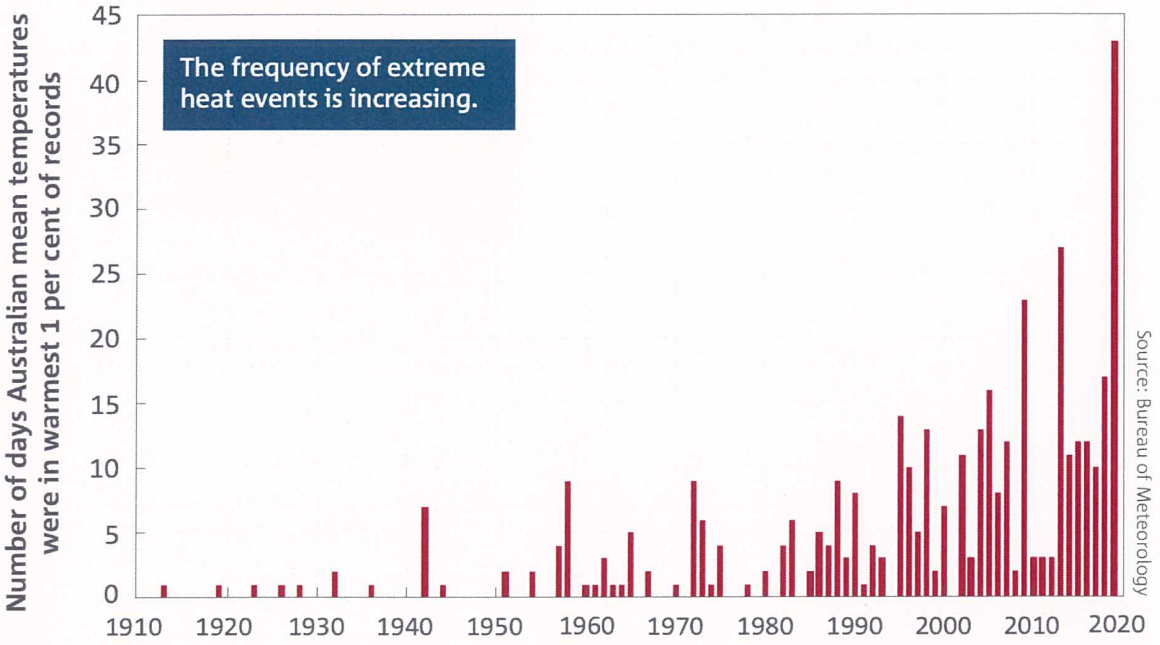

Fig. 4: Number of extreme (top 1%) heat days from 1910 to 2019.

e) In December 2019, there were 11 days for which the *national area-averaged* maximum was 40 °C or above[40]. Only 11 other such days have been recorded since 1910, seven of which occurred in the summer of 2018–19. (See Fig. 5.)[41]

[39] CSIRO/BOM (2020), State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate

[40] BOM (2019) Special Climate Statement 70b update. Accessed at: http://www.bom.gov.au/climate/current/statements/

[41] BOM (2019) Special Climate Statement 73. Accessed at: http://www.bom.gov.au/climate/current/statements/

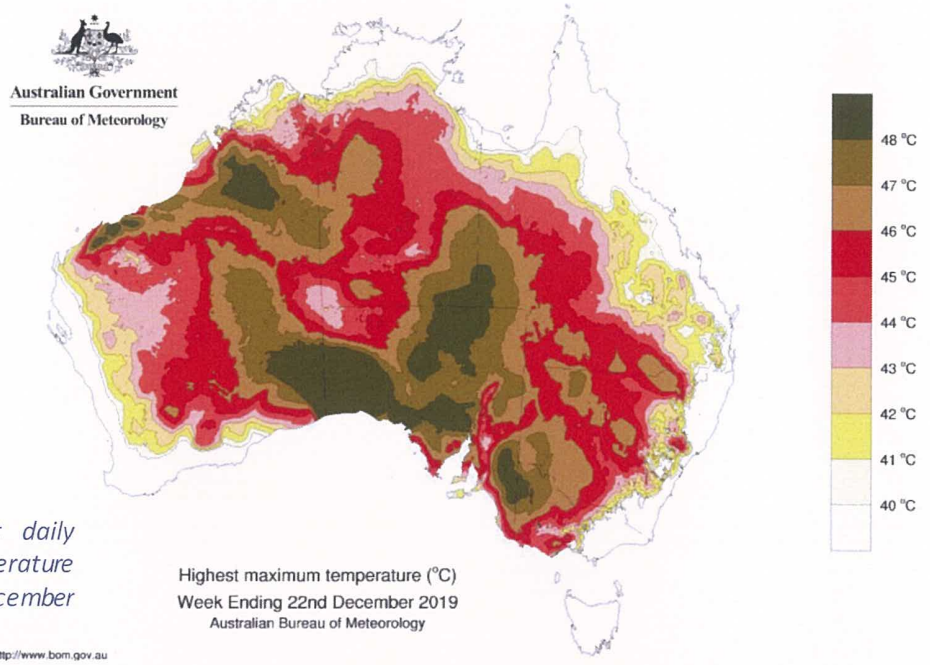

Fig. 5: Highest daily maximum temperature from 16-22 December 2019.

f) A **long-term increase in extreme fire weather, and fire season length, has occurred across large parts of Australia**, with devastating consequences. This consequence of climate change is discussed in more detail in Section 3.4.

g) **Cool-season rainfall has declined in southeast and southwest Australia** over the past 20 years, while rainfall has increased in northern Australia. (See Fig. 6.)[42]

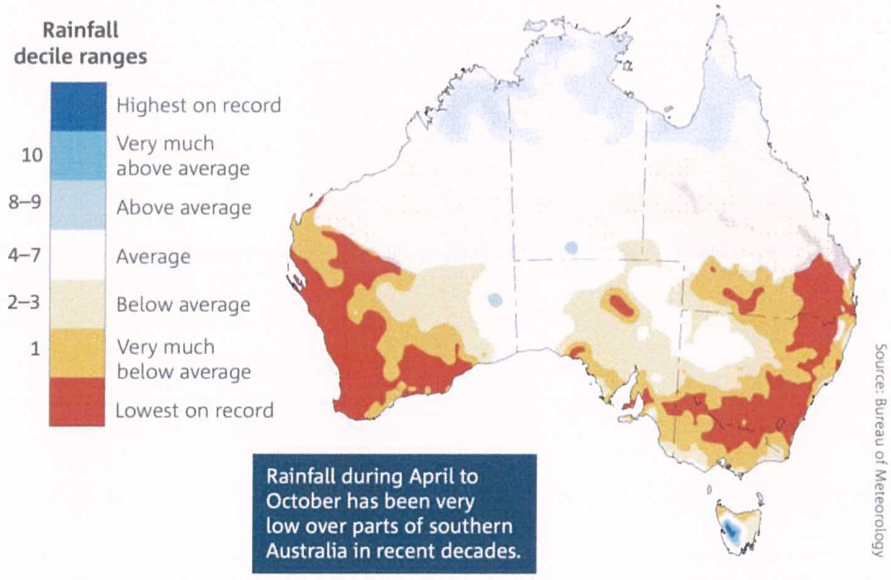

Fig. 6 April to October rainfall deciles for the last 20 years (2000 – 2019) compared to the total entire rainfall record since 1900.

[42] CSIRO/BOM (2020), State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate

h) The observed long-term reduction in rainfall across southern Australia has led to even **greater reductions in stream flows**.

i) More of the total annual rainfall in recent decades has come from heavy rain days. **Heavy rainfall events are becoming more intense**.

j) Warming of the ocean, particularly around southeast Australia and in the Tasman Sea (where surface temperatures are rising at more than 0.16°C per decade) has contributed to **longer and more frequent marine heatwaves**, which often last multiple months or years, depleting kelp forests and sea grasses, increasing disease and bleaching coral reefs.

k) The rate of decrease in pH **(increased acidity) of oceans has accelerated to** over 0.02 per decade, more than five times faster than from 1900 to 1960, and **10 times faster than at any time in the past 300 million years. The entire marine ecosystem is affected.** In particular, this has led to a significant reduction in coral calcification and growth rates on coral reefs such as the Great Barrier Reef.

l) Sea level varies from year to year and place to place. Rates of sea level rise to the north and southeast of Australia have been significantly higher than the global average.

88) A new trend, called `**flash drought' is emerging in Australia**. Flash droughts occur when there is a very fast reduction in soil moisture, typically resulting from a lack of rainfall alongside factors that increase evaporation including high temperatures, low humidity, and strong winds. **Flash droughts occur so quickly, that adaptation by farmers is difficult**, and can occur even when there have been no pre-conditions for drought[43].

89) The cost of extreme weather disasters in Australia has more than doubled since the 1970s, reaching $35 billion for the decade 2010-2019. **Australians are five times more likely to be displaced by a climate-fuelled disaster than someone living in Europe**.[44]

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[43] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction

[44] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction

3.3.3 New South Wales

90) Most all of these **climate change impacts are being felt in New South Wales, many to an even larger degree than the national average.**[45,46,47] These are just some of the consequences for NSW at the current level of 1.1°C of global warming:

a) The five warmest years on record for NSW are (in order of decreasing temperature) 2019, 2018, 2014, 2017 and 2009.

b) **NSW had its hottest and driest year in 2019, with a mean temperature 1.95°C above average and 0.27°C warmer than the previous warmest year, 2018**. Days were especially warm in 2019, with the NSW mean maximum temperature at a record high of 2.44°C above average.

c) **Penrith Lakes recorded 48.9°C on 4 January 2020, the highest temperature ever recorded in the Sydney basin**. Many sites in metropolitan Sydney exceeded 47°C. Such temperatures are dangerously hot, and place extreme thermal stress on humans and the environment.

d) NSW not only experienced extreme heat in December 2019 and January 2020, but also increased bushfire activity and poor air quality in Sydney. **NSW had its highest accumulated Forest Fire Danger Index (FFDI) for December in 2019**. FFDI records date back to 1950.

e) **Nearly all of NSW has had below average rainfall over the past twenty years**, with about half of the State experiencing record lows. Total rainfall for NSW was the lowest on record in 2019 at 55% below average; well below the previous driest year of 1944.

f) **Rainfall for the northern Murray-Darling Basin** (in NSW) for the 34 months **in the period January 2017 to October 2019 was the lowest on record** by a substantial margin, **breaking records originally set during the Federation Drought in 1900–1902**.

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[45] BOM (2019), Annual Climate Statement 2019, NSW, accessed at: http://www.bom.gov.au/climate/current/annual/nsw/archive/2019.summary.shtml
[46] BOM (2020), Annual Climate Statement 2020, NSW, accessed at: http://www.bom.gov.au/climate/current/annual/nsw/archive/2020.summary.shtml
[47] BOM (2020) Special Climate Statement 73 update, Accessed at: http://www.bom.gov.au/climate/current/statements/

g) The extent and timing of the dry conditions meant that **agriculture was particularly affected with the top 100cm of soil at record moisture lows at** many locations (see Fig. 7).[48] Root zone soil moisture for October 2019 was below average to very much below average across most of the Murray–Darling Basin, with some areas in the centre and north of the Basin having the lowest soil moisture levels for October on record since 1910. The **unprecedented conditions of inland NSW in mid-2019 correspond to what meteorologists are now calling a 'flash drought,'** conditions that were similar to those along the east coast in the months bridging 2017 and 2018[49].

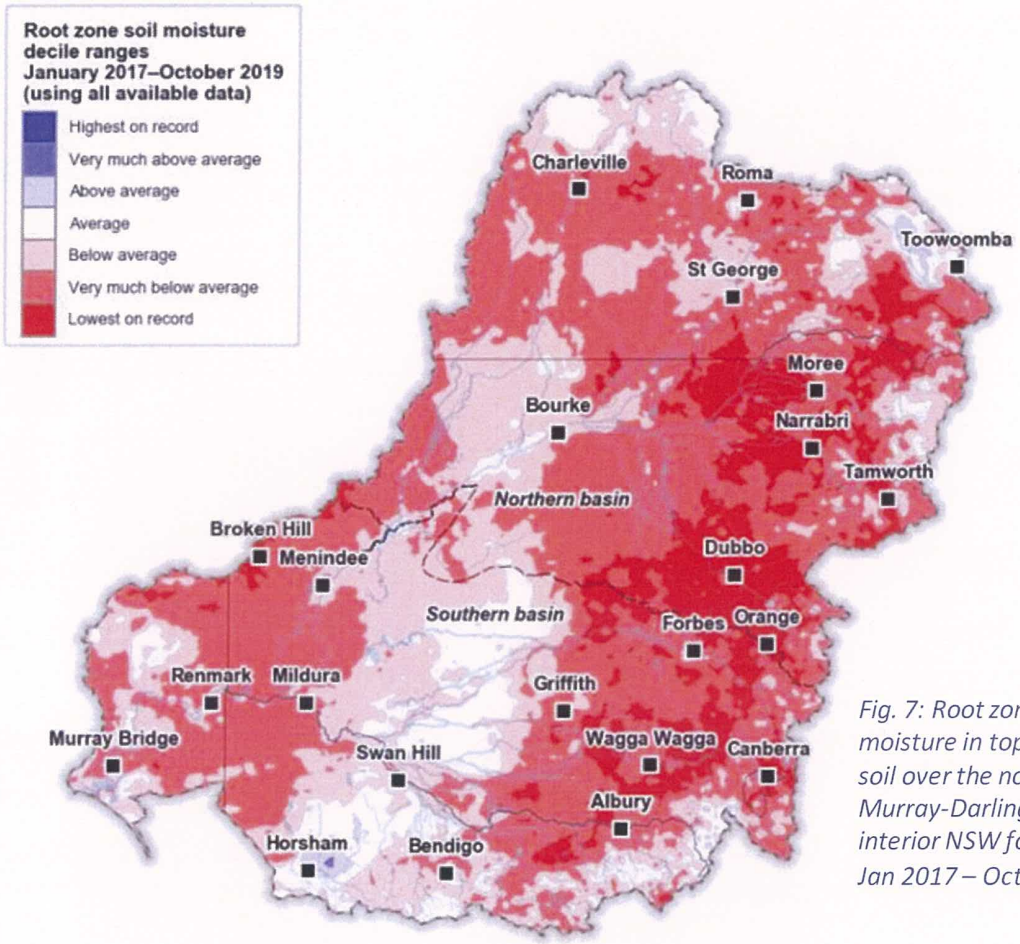

Fig. 7: Root zone soil moisture in top 100cm of soil over the northern Murray-Darling Basin in interior NSW for period Jan 2017 – Oct 2019.

[48] BOM (2019) Special Climate Statement 70 update, Accessed at: http://www.bom.gov.au/climate/current/statements/

[49] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction

h) **Storage volumes in the northern Murray–Darling Basin reached a combined volume in mid-November 2019 of 6.7% of capacity,** which is **1.6% lower than at the lowest point during the Millennium Drought**.

i) More than three quarters of the **long-term streamflow gauges in the Murray–Darling Basin show a declining trend since records began in 1970**. This is more severe in the northern Basin where 94 per cent of the gauges show a declining trend in streamflow.

j) Switching abruptly from record low rainfall in 2019 to **heavy rain records in 2020**, many **NSW sites experienced their highest annual rainfall on record or their highest for at least 20 years**. In early 2020, coastal regions had especially heavy rain, when many sites had their highest daily rainfall on record.

3.3.4 Attribution: Was this particular extreme event made more likely by climate change?

91) All extreme weather events, in fact, **all weather events are affected by climate change**, because the environment in which they occur is warmer, moister and contains more energy than used to be the case.[50] The new field of **attribution science is now allowing scientists to quantity the effect of climate change on many extreme events**. A few examples, several taken from a recent review,[51] are listed below.

92) Of the 131 studies investigating whether climate change is influencing extreme weather published in the Bulletin of the American Meteorological Society between 2011 and 2016, **65 percent found that the probability of the event occurring was increased due to anthropogenic climate change**. In the case of some extreme high temperatures, the probability increased by a factor of ten or more.[52]

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[50] Trenberth, K. E. (2012), Framing the way to relate climate extremes to climate change, Climate Change, 115(2), 283–290, doi:10.1007/s10584-012-0441-5

[51] Steffen, W. Dean, A. and Rice, M. (2019) Weather Gone Wild: Climate change-fuelled extreme weather in 2018. Published by the Climate Council. Accessed at: https://www.climatecouncil.org.au/resources/climate-change-extreme-weather

[52] WMO (2018) July sees extreme weather with high impacts. Accessed at: https://public.wmo.int/en/media/news/july-sees-extreme-weather-high-impacts

93) Recent research[53] has found that **the devastating Australian 2019/20 bushfires were at least 30% more likely because of climatic changes caused by humans.** Further detail about this extraordinary bushfire season is provided in Section 3.4.1.

94) The Australian hot summer of 2013 was 2.5 to 5 times more likely due anthropogenic climate change.[54] When focusing on the regions of Australia that were most anomalous, the contribution of climate change was assessed at almost 100%.[55]

95) Analysis suggests the cumulative forest area burned between 1984 and 2015 in the western United States was twice what it would have been without climate change.[56]

96) The **widespread coral bleaching of the Great Barrier Reef during 2016 was made 175 times more likely due to climate change**.[57]

97) According to the UK Met Office,[58] **human-induced climate change has made the 2018 record-breaking UK summer temperatures about 30 times more likely** than they would naturally occur.

98) The **2020 Siberian heatwave would have been "almost impossible" without human-induced climate change**, as it was made at least 600 times more likely as a result of human-induced climate change.[59]

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[53] Oldenborgh, G.J. et al. (2020) Attribution of the Australian bushfire risk to anthropogenic climate change, in Natural Hazards and Earth System Sciences, 1-46. Accessed at: https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2020-69/

[54] Lewis, S.C., and D.J. Karoly, 2013: Anthropogenic contributions to Australia's record summer temperatures of 2013. *Geophys. Res. Lett.*, **40**, 3708–3709, doi:10.1002/grl.50673.

[55] Knutson TR, Zeng F and Wittenberg AT (2014) Multimodel assessment of extreme annual-mean warm anomalies during 2013 over regions of Australia and the western tropical Pacific, *Bulletin of the American Meteorological Society,* 95(9): S26-S30.

[56] Gonzalez P et al (2018) Southwest (chapter 25). In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II, Reidmiller DR, CW Avery, DR Easterling, KE Kunkel, KLM Lewis, TK Maycock and BC Stewart (eds.) U.S. Global Change Research Program, Washington, DC, USA; 1101–1184.

[57] King A, Karoly D, Black M, Hoegh-Guldberg O, and Perkins-Kirkpatrick S (2016) Great Barrier Reef bleaching would be almost impossible without climate change. The Conversation, April 29, 2016.

[58] UK Met Office (2018) 2018 UK summer heatwave made thirty times more likely due to climate change. Accessed at https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2018/2018-uk-summer-heatwave

[59] Ciavarella, A. et al. (2020) Prolonged Siberian Heat of 2020. *World Weather Attribution.* https://www.worldweatherattribution.org/siberian-heatwave-of-2020-almost-impossible-without-climate-change

3.4 *Impact of Climate Change on Wildfire Risk in Australia and NSW*

99) **Climate is connected to bushfires in two major ways: by influencing the amount, type and moisture content of fuel, and by determining the frequency, extremity and duration of fire weather.** Drought combined with extreme heat results in abundant, dry fuel that is at high risk of burning. Fire weather is the key indicator of fire behaviour, fire severity, and the amount of area burned in a fire.[60]

100) As Fig. 8 indicates, the **changes associated with global warming play direct, multiple and complex roles in increasing the threat of forest fires**.[61]

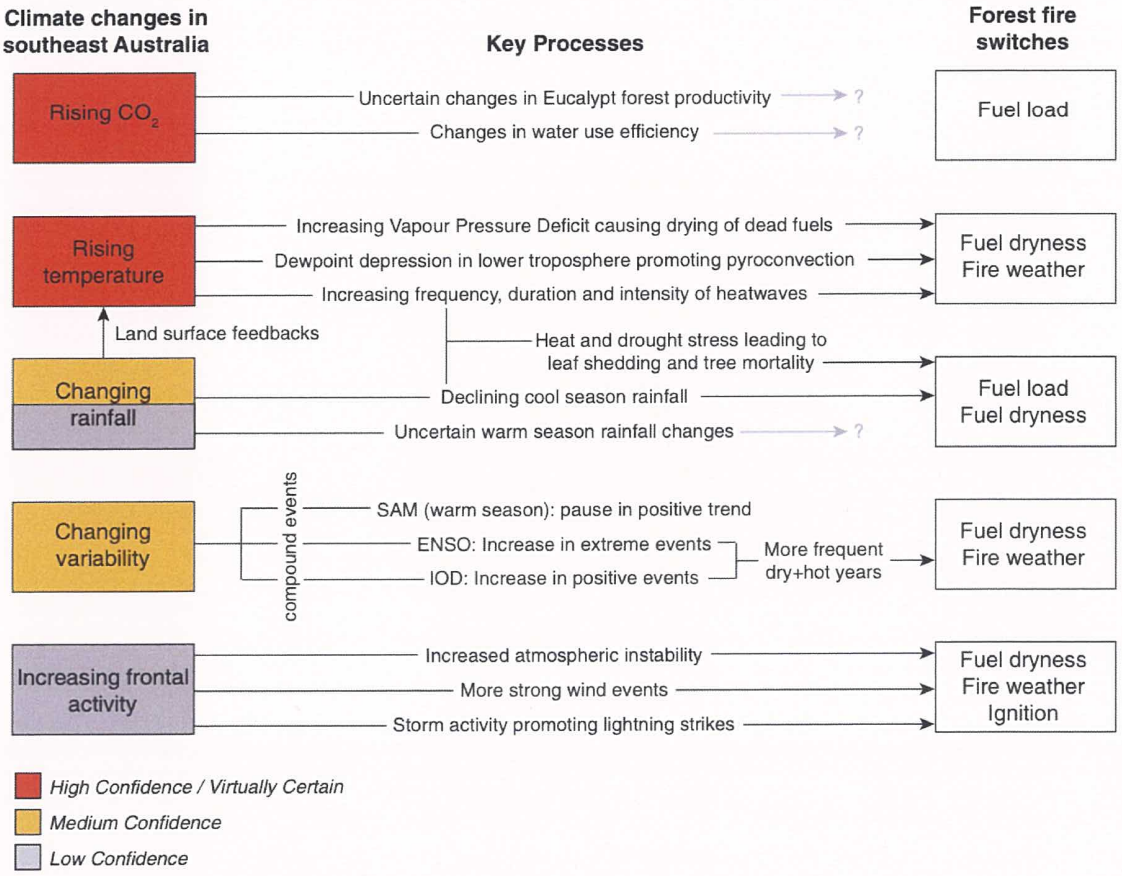

Fig. 8: Changes associated with global warming (left hand column) influence environmental processes (centre column) that directly increase key forest fire switches (right hand column. (Fig. 7 in Abram et al 2021).

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[60] Mackey, B, Gould, S., Lindenmayer, D., Norman P. and Taylor C. (2020) Bushfire Science Report No. 1: How Does Climate Affect Bushfire Risks in the Native Forests of South-eastern Australia? Bushfire Recover Project, and references therein. Accessed from www.bushfirefacts.org

[61] Abram, N.J., et al. (2021) Connections of climate change and variability to large and extreme forest fires in southeast Australia, Communications Earth & Environment 2:8, https://doi.org/10.1038/s43247-020-00065-8

101) Bushfires are also more likely to occur in southeast Australia during certain phases of large interdecadal ocean movements, particularly the El Niño phase of the El Niño/Southern Oscillation and negative phases of the Interdecadal Pacific Oscillation.[62]

102) **Weather anomalies superimposed on these conditions** such as wind anomalies, low overnight values of relative humidity, lightning storms, fire-generated lightning, and frontal systems **can then create extremely dangerous fires**. The development of these fires is **further exacerbated by the violent pyrocumulonimbus clouds that can form above the fire, and their associated whirlwinds, tornadoes, long-range spotting, and cloud-to-ground lightning strikes.**[63] **Pyrocumulonimbus phenomena have been confirmed for at least 85 fires in Australia**[64].

103) These fire-generated thunderstorms can lead to extremely dangerous fire conditions, as observed during the 2019–20 `Black Summer' fires, and the Canberra (2003) and Victorian Black Saturday (2009) fires. In some cases, the lightning strikes produced from the smoke plumes generate new, additional fires.[65]

104) **The Forest Fire Danger Index (FFDI) indicates the fire danger on a given day** based on daily values for temperature, humidity and wind speed, and a drought factor that represents the influence of recent temperatures and rainfall events on fuel moisture. Extremely dangerous fire weather results in high FFDI values. **An FFDI larger than 50 representing `severe' fire risk and resulting in a total fire ban. Fire weather drives the chances of a fire starting, its subsequent behaviour, and the difficulty of suppressing it.**

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[62] Verdon, D. C., Kiem, A. S. & Franks, S. W. (2004) Multi-decadal variability of forest fire risk - eastern Australia. *International Journal of Wildland Fire* **13**, 165-171

[63] Mackey, B, Gould, S., Lindenmayer, D., Norman P. and Taylor C. (2020) Bushfire Science Report No. 1: How Does Climate Affect Bushfire Risks in the Native Forests of South-eastern Australia? Bushfire Recover Project, are references therein. Accessed from www.bushfirefacts.org

[64] Ndalila, M. N. et al. (2020) Evolution of an extreme Pyrocumulonimbus event associated with an extreme wildfire in Tasmania, Australia. *Nat. Hazards Earth Syst. Sci.*, 20, 1497–1511, 2020 https://doi.org/10.5194/nhess-20-1497-2020

[65] CSIRO/BOM (2020) State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate/

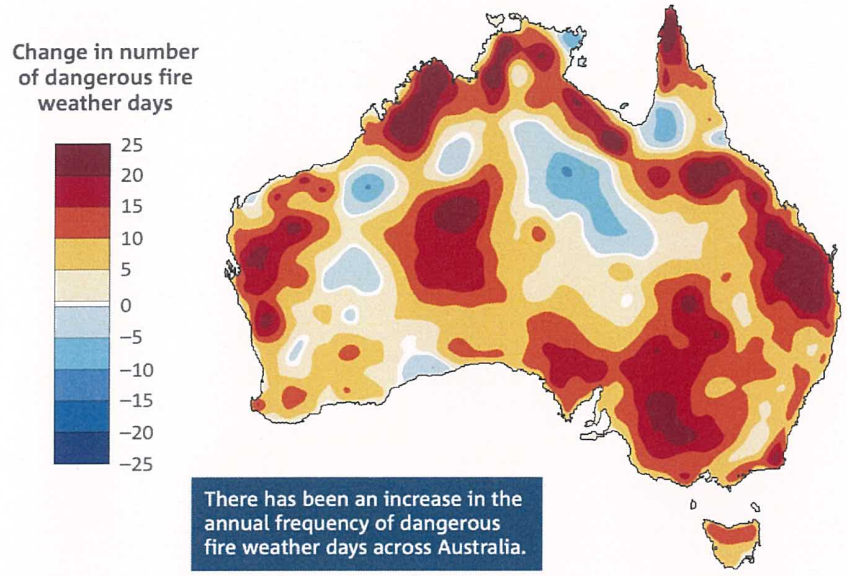

Fig. 9: Change in number of days of dangerous fire weather in 1985-2020 compared to 35 years earlier, 1950-1985.

These are days recording a Forest Fire Danger Index (FFDI) that exceeds its 90th percentile.

(From CSIRO/BOM 2020).

105) **All regions of NSW are now witnessing many (up to 25) more days with weather conditions conducive to extreme bushfires that can generate thunderstorms within their smoke plumes compared to 1950-1985.** (See Fig. 9.)[66]

3.4.1 Black Summer: Climate Change fuelled fires in the Here and Now

106) In 2019, the national annual accumulated FFDI was its highest since 1950, when national records began.[67] It is not surprising, therefore, that **the Australian 2019/20 bushfires were the worst on record on many measures**.[68,69]

107) The 2019-20 bushfire season started in winter and was the **worst on record for New South Wales in terms of its intensity, the area burned, and the number of properties lost.**[70]

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[66] CSIRO/BOM (2020) State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate/

[67] BOM (2020) Special Climate Statement 73 update, Accessed at: http://www.bom.gov.au/climate/current/statements/

[68] Hughes, L, Steffen, W, Mullins, G, Dean, A, Weisbrot, E, and Rice, M (2020) *The Summer of Crisis.* Published by the Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/summer-of-crisis/ and references cited therein.

[69] Abram, N.J., et al. (2021) Connections of climate change and variability to large and extreme forest fires in southeast Australia, Communications Earth & Environment 2:8, https://doi.org/10.1038/s43247-020-00065-8

[70] Hughes, L, Steffen, W, Mullins, G, Dean, A, Weisbrot, E, and Rice, M (2020) *The Summer of Crisis.* Published by the Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/summer-of-crisis/ and references cited therein.

108) **NSW had more than 240 days of active fire across the state in the 2019-20 bushfire season.**[71] **Over 15,000 individual fires were responsible for impacting a total area of 19 million hectares.**[72]

109) **Nearly 80% of all Australians were affected directly or indirectly by the 2019-20 bushfires,**[73] **which has now come to be known as `Black Summer.'**

110) Economic costs of Black Summer are still being tallied and will go beyond the direct impact on gross domestic product (GDP). Nationally, the fire season is expected to break new records for economic costs from bushfires,[74] and is **likely to be Australia's costliest natural disaster to date**.[75] The tourism sector alone is likely to lose at least $4.5 billion due to effects of the fires,[76] and the **costs of economic disruptions from smoke have been estimated at $12-50 million per day in Sydney alone.**[77]

111) It is estimated that an unprecedented **29 additional pyrocumulonimbus fire events occurred during Black Summer, including 18 in a single week** that had impacts on winds

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[71] SBS News (2020) For the first time in 240 days, there are no active bush or grass fires in NSW, report updated on 03/03/2020, Accessed at: https://www.sbs.com.au/news/for-the-first-time-in-240-days-there-are-no-active-bush-or-grass-fires-in-nsw

[72] Filkov, A. I., Ngo, T., Matthews, S., Telfer, S. & Penman, T. D. (2020) Impact of Australia's catastrophic 2019/20 bushfire season on communities and environment. Retrospective analysis and current trends. J. Safe. Sci. Resil. 1, 44–56

[73] Biddle et al. (2020) Exposure and the impact on attitudes of the 2019-20 Australian Bush Fires. ANU Centre for Social Research Methods. Accessed at: https://csrm.cass.anu.edu.au/sites/default/files/docs/2020/2/Exposure_and_impact_on_attitudes_of_the_2019-20_Australian_Bushfires_publication.pdf

[74] ANZ Research (2020) Australian bushfires: Impacting GDP. Accessed at: https://bluenotes.anz.com/posts/2020/01/anz-research-australian-bushfires-economic-impact-gdp

[75] Read, P. & Denniss, R. (2020) With costs approaching $100 billion, the fires are Australia's costliest natural disaster. Conversation. Accessed at: https:// theconversation.com/with-costs-approaching-100-billion-the-fires-are- australias-costliest-natural-disaster-129433

[76] AFR (Australian Financial Review) (2020) Tourism loses $4.5b to bush res as overseas visitors cancel. Accessed at: https://www.afr.com/companies/tourism/tourism-loses-4-5b-to-bushfires-as-overseas-visitors-cancel-20200116-p53s0s/

[77] SMH (2019) The economic cost of bushfires on Sydney revealed: up to $50 million a day and rising. Accessed at: https://www.smh.com.au/national/nsw/the-economic-cost-of-bushfires-on-sydney-revealed-up-to-50-million-a-day-and-rising-20191212-p53jbq.html

and chemical composition into the stratosphere unlike any other documented, and a **planetary-scale radiative forcing effect equivalent to a moderate volcanic eruption**.[78]

112) During the 2019/20 season, the Gospers Mountain mega-fire threatened the Clarence Colliery near Lithgow[79] and the Green Wattle Creek Fire forced the closure of the Tahmoor coalmine for several days.[80] These events highlight the increased risk that climate-stoked bushfires may enter collieries and coal seams, resulting in enormous CO_2 emissions from fires that are notoriously difficult to extinguish.

113) **According to early estimates, the Black Summer** fires released between 650 million and 1.2 billion tonnes of CO_2 into the atmosphere.[81] The median value of **900 million tonnes** is **nearly twice the 2018 Australian emissions of all greenhouse gases**, which is about 537 million tonnes of CO_2-equivalent (CO_2-e)[82]. This is an example of how climate change can be self-reinforcing, through what is known scientifically as `carbon feedback.'

114) A recent scientific review of Black Summer and similar fires,[83] and their connection to climate change, makes many of the following points:

a) **Australia is the most fire-prone continent on Earth**,[84,85] and the accumulation of charcoal (residue from fires) in Australia is now higher than at any other time during the last 70,000 years.[86]

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[78] Abram, N.J., et al. (2021) Connections of climate change and variability to large and extreme forest fires in southeast Australia, Communications Earth & Environment 2:8, and references therein. https://doi.org/10.1038/s43247-020-00065-8

[79] ABC News (2020) 'We need to find a way forward': The NSW community that put aside differences to battle the Gospers Mountain fires. Accessed at: https://www.abc.net.au/news/2020-02-09/gospers-mountain-miners-puts-differences-aside-to-fight-fires/11946672

[80] The Guardian (2020) Tahmoor coalmine evacuated as Green Wattle Creek blaze rages – as it happened. Accessed at: https://www.theguardian.com/australia-news/live/2019/dec/19/nsw-and-qld-fires-australia-braces-for-extreme-bushfires-danger-amid-sweltering-heatwave-live

[81] Climate Council of Australia Ltd (2020) Summer of Crisis, Accessed from: https://www.climatecouncil.org.au/resources/summer-of-crisis/

[82] National Greenhouse Gas Inventory, maintained by the Australian Government's Department of the Environment and Energy. Accessed at http://ageis.climatechange.gov.au/

[83] Abram, N.J., et al. (2021) Connections of climate change and variability to large and extreme forest fires in southeast Australia, Communications Earth & Environment 2:8, https://doi.org/10.1038/s43247-020-00065-8

[84] Sharples, J. J. et al. (2016) Natural hazards in Australia: extreme bushfire. Clim. Chang. 139, 85–99

[85] Bradstock, R. A. (2010) A biogeographic model of fire regimes in Australia: current and future implications. Glob. Ecol. Biogeogr. 19, 145–158.

[86] Mooney, S. D. et al. (2011) Late Quaternary fire regimes of Australasia. Quat. Sci. Rev. 30, 28–46.

b) **Australia's Black Summer is consistent with previous scientific assessments dating back at least 30 years that human-caused climate warming will increase the duration, frequency and intensity of forest fires in southeast Australia.**[87,88,89]

c) The Black Summer fires resulted in extensive social, environmental and economic impacts. **The direct social impacts included the loss of 33 lives (25 in NSW)**[90] **and the destruction of over 3,000 houses.**[91] **Indirect health impacts attributed to smoke exposure include an estimated 417 lives lost and 3,151 hospitalisations**.[92]

d) Longer-term health impacts are difficult to quantify, but in the years following previous major fire events ongoing **post-traumatic stress disorder and depression** have been reported among fire-affected populations.[93] New research points to an under-recognised, potential health threat: **microbes that thrive in pyrogenic carbon** created by bushfires and can travel hundreds of kilometres once airborne, generating reduced airway conductance and inflammation.[94]

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[87] Beer, T., Gill, A. M. & Moore, P. H. R. (1988) in Greenhouse: Planning for Climatic Change (ed. Pearman, G. I.) 421–427 (CSIRO Publishing)

[88] Reisinger, A. et al. (2014) in Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (eds V. R. Barros et al.) Ch. 25, 1371–1438 (Cambridge University Press, 2014).

[89] Hennessy, K. et al. (2007) Australia and New Zealand in Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (eds Parry, M. L. et al.) 507–540 (Cambridge University Press, 2007).

[90] Hughes, L, Steffen, W, Mullins, G, Dean, A, Weisbrot, E, and Rice, M (2020) *The Summer of Crisis.* Published by the Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/summer-of-crisis/ and references cited therein.

[91] Filkov, A. I., Ngo, T., Matthews, S., Telfer, S. & Penman, T. D. (2020) Impact of Australia's catastrophic 2019/20 bushfire season on communities and environment. Retrospective analysis and current trends. J. Safe. Sci. Resil. 1, 44–56

[92] Borchers Arriagada, N. et al. (2020) Unprecedented smoke-related health burden associated with the 2019–20 bushfires in eastern Australia. Med. J. Aust. 213, 282–283.

[93] Bryant, R. A. et al. (2014)Psychological outcomes following the Victorian Black Saturday bushfires. Aust. N. Z. J. Psychiatry 48, 634–643.

[94] Kobziar, L. & Thompson, G.R. (2020) Wildfire smoke, a potential infectious agent: Bacteria and fungi are transported in wildland fire smoke emissions , Science, 18 December 2020, 370, 6523, p 1408-1410. Accessed at: https://science.sciencemag.org/content/370/6523/1408

e) Environmental impacts will take some time to become fully apparent.[95] Nevertheless, in NSW, where the majority of the fires occurred, **up to 293 threatened animal species and 680 threatened plant species may have been affected, given records of their location in the fire ground**.[96]

f) Overall, it is estimated **that three billion individual native vertebrates perished in the fires**, comprising: 143 million mammals, 2.46 billion reptiles, 180 million birds and 51 million frogs.[97]

g) **In NSW, 37% of the state's rainforests were fire-affected during Black Summer, including over half of the Gondwana Rainforests, an Australia World Heritage Area**.[98] These ecosystems are not considered to be resilient to fire,[99] and even in ecological communities that are resilient to fire, such as resprouting eucalypt forests, severe drought had already stressed ecosystems ahead of the Black Summer fires.[100] **Recurrent fire damage in some areas may impair the ability of ecosystems to recover.**[101]

115) Research substantiates that the **Black Summer fires burned a globally unprecedented percentage of any continental forest biome: at least 21% of the Australian Temperate broadleaf and mixed (TBLM) forest biome was burnt in a single season** (Fig. 10)[102].

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[95] Ward, M. et al. Impact of 2019–2020 mega-fires on Australian fauna habitat. (2020) Nat. Ecol. Evol. 4, 1321–1326.

[96] State of NSW Department of Planning Industry and Environment (2020) NSW Fire and the Environment 2019-20 Summary: Biodiversity and landscape data and analyses to understand the effects of fire events. 20pp. (NSW Government, 2020).

[97] Van Eeden, L. et al. (2020) Australia's 2019-2020 Bushfires: The Wildlife Toll Interim Report, WWF Australia. Accessed from: https://www.wwf.org.au/news/news/2020/3-billion-animals-impacted-by-australia-bushfire-crisis

[98] State of NSW Department of Planning Industry and Environment (2020) NSW Fire and the Environment 2019-20 Summary: Biodiversity and landscape data and analyses to understand the effects of fire events. 20pp. (NSW Government, 2020).

[99] Bowman, D. M. J. S. (2000) Australian Rainforests: Islands of Green in a Land of Fire. (Cambridge University Press, 2000).

[100] De Kauwe, M. G. et al. (2020) Identifying areas at risk of drought-induced tree mortality across South-Eastern Australia. Glob. Chang. Biol. 26, 5716–5733.

[101] Lindenmayer, D. B. & Taylor, C. (2020) New spatial analyses of Australian wildfires highlight the need for new fire, resource, and conservation policies. Proc. Natl Acad. Sci. USA 117, 12481.

[102] M. M. Boer, V. Resco de Dios, R. A. Bradstock, (2020) Unprecedented burn area of Australian mega forest fires. Nat. Clim. Chang. 10, 171–172. doi: 10.1038/s41558- 020-0716-1

116) The average annual area burnt for most continents is well below 5%, except for Africa and Asia, which have average annual areas burnt of 8-9% for some biomes. **In Australia, typically less than 2% of temperate broadleaf forest areas burn annually**, even in extreme fire seasons.[103] TBLM forests in eastern Australia cover about 27 Mha; **about half of that forest area lies in NSW**.

117) Although the **forest areas lost in Black Summer could, in principle, be recovered by regrowth and replanting**, this will only **take place when the new trees reach full maturity in roughly 100 years**,[104,105] which is **longer than the time left to reach net zero emissions, if even a 2°C warming limit is to be maintained**. Furthermore, it is not clear that these forests can fully recover in a climate that continues to warm and dry as a result of climate change.[106]

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[103] Boer MM, Resco de Dios V, & Bradstock RA (2020) Unprecedented burn area of Australian mega forest fires, Nature Climate Change. Accessed at: https://www.nature.com/articles/s41558-020-0716-1

[104] Ngugi MR, Doley D, Cant M & Botkin DB (2015) Growth rates of Eucalyptus and other Australian native tree species derived from seven decades of growth monitoring. Journal of *Forestry Research*, 26 (4) and references therein.

[105] Land for Wildlife. How to Age Trees. Accessed from https://www.lfwseq.org.au/how-to-age-trees/

[106] Science News Magazine (2020) Will Australia's forests bounce back after devastating fires? Posted 11 February 2020. Accessed at: https://www.sciencenews.org/article/australia-forest-ecosystem-bounce-back-after-devastating-fires

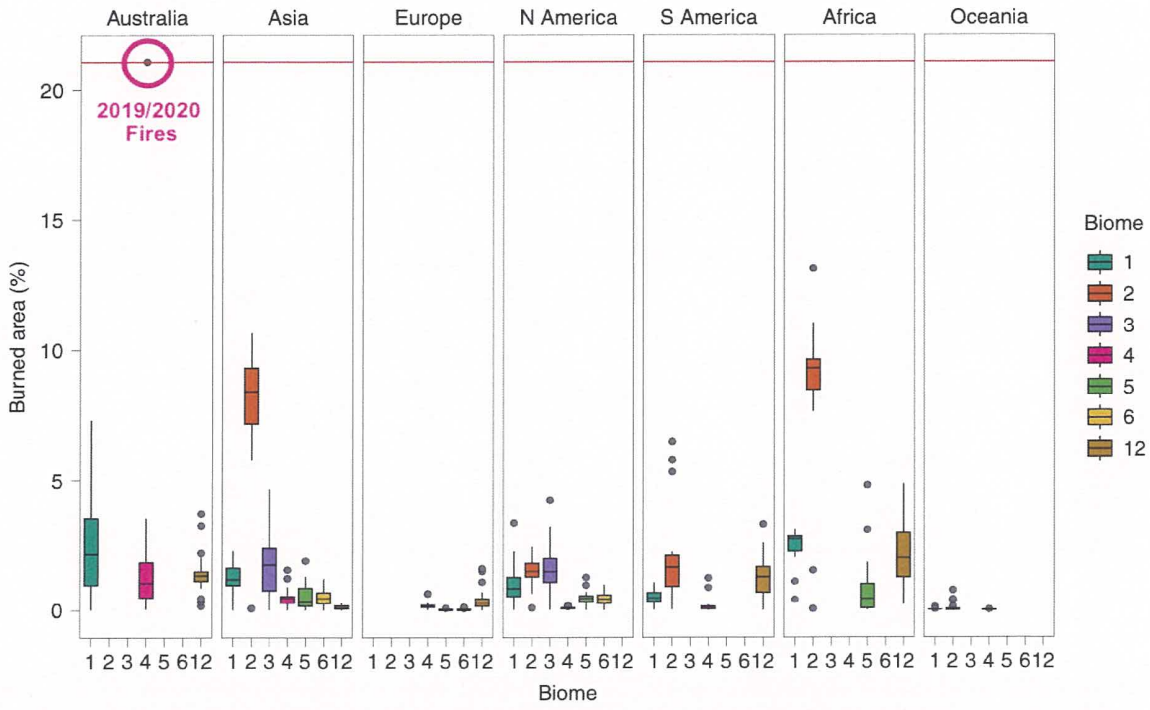

Fig. 10: Annual areas burned for different continental forest types (biomes). Boxplots show the median for each continent. The red horizontal line indicates the burned area of 21% observed for the Australian TBLM forest (biome 4, magenta) resulting from the Black Summer forest fires, far above typical forest areas burnt on any continent. Figure from Boer et al. 2020.

118) Consequently, **local tipping points in some Australian forests may have already been crossed.**[107] The future of these forests will be unlike their historical past, with a **danger that large portions may not be able to regenerate fully before the next catastrophic wildfire**.

[107] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction