NOTICE OF FILING

Details of Filing

Document Lodged:	Expert Report
Court of Filing	FEDERAL COURT OF AUSTRALIA (FCA)
Date of Lodgment:	26/05/2023 8:39:10 AM AEST
Date Accepted for Filing:	26/05/2023 8:39:15 AM AEST
File Number:	VID622/2021
File Title:	PABAI PABAI & ANOR v COMMONWEALTH OF AUSTRALIA
Registry:	VICTORIA REGISTRY - FEDERAL COURT OF AUSTRALIA

SEAL OF THE FEDERAL COURT OF AUSTRALIA

Sia Lagos

Registrar

Important Information

This Notice has been inserted as the first page of the document which has been accepted for electronic filing. It is now taken to be part of that document for the purposes of the proceeding in the Court and contains important information for all parties to that proceeding. It must be included in the document served on each of those parties.

The date of the filing of the document is determined pursuant to the Court's Rules.

PRIVILEGED AND CONFIDENTIAL

Pabai & Anor v Commonwealth of Australia (VID622/2021) (Proceedings)

Federal Court of Australia

Expert Report prepared for Phi Finney McDonald

I have read, understood and complied with the Expert Evidence Practice Note (**GPN-EXPT**) of the Federal Court of Australia and agree to be bound by it. This document was provided to me with my Retainer Letter dated 28 April 2022.

Professor David Karoly FAA (climate scientist), 25 May 2023

Expert Report by Professor David Karoly

University of Melbourne

Instructions and Purpose of Report

1. On 28 April 2022, I received my Retainer Letter from Phi Finney McDonald (**PFM**), who act for Pabai Pabai and Guy Paul Kabai (**Applicants**) in the Proceedings against the Commonwealth of Australia (**Respondent**).

2. Phi Finney McDonald has retained my services to act as an expert witness, on a pro bono basis, to impartially assist the Court on matters relevant to climate science by preparing this expert report and appearing as an expert witness in the Proceedings.

3. On 13 December 2022, I received my Letter of Instruction from PFM (attached at Annexure A). The Letter of Instruction included a brief of materials and a set of questions that I have been asked to answer.

<u>Documents provided</u>

4. The Retainer Letter and the Letter of Instruction refer to the following documents:

   a) Federal Court of Australian Expert Evidence Practice Note (**GPN-EXPT**);

   b) Federal Court Rules 2011, Rule 23.13;

   c) Amended Originating Application;

   d) Second Further Amended Statement of Claim; and

   e) Defence to the Second Further Amended Statement of Claim.

<u>Responses to the questions</u>

5. The responses provided below address the questions included in the Letter of Instruction at that letter's Annexure B. I have used the headings provided for each of the groups of questions. In parts, I have answered the questions in a different order to increase the readability and flow of the report.

Basis of expertise

Question 1

Please describe your academic qualifications, professional background, and experience in the field of climate science, and any other training, study, or experience that is relevant to this brief (you may wish to do so by reference to a current curriculum vitae).

6. I am a Professor Emeritus (honorary) in the School of Geography, Earth and Atmospheric Sciences at the University of Melbourne, having retired from full-time employment in February 2022. I completed a Bachelor of Science (Honours) degree in applied mathematics from Monash University in 1976 and a Ph.D. in meteorology from the University of Reading, England in 1980. I am a Fellow of the Australian Academy of Science and a Fellow of the Australian Meteorological and Oceanographic Society. I have more than forty years' experience studying climate variability and climate change, with expertise in identifying the causes of recent observed climate change and its impacts. My experience includes being Co-Coordinating Lead Author of the chapter on "Detection of climate change and attribution of its causes" in the Intergovernmental Panel on Climate Change (**IPCC**) Third Assessment Report in 2001. I was also a Lead Author on the chapter "Assessment of observed changes and responses in natural and managed systems" in the IPCC's Fourth Assessment Report in 2007. More recently, I was a Review Editor of the chapter 'Climate change information for regional impact and for risk assessment' in the IPCC's Sixth Assessment Report of 2021. During 2012-2017, I was a member of the Climate Change Authority (**CCA**), which provides advice to the Australian government on climate change policies. My summary curriculum vitae is attached as Annexure B.

7. I have been an Expert Witness in legal proceedings in several jurisdictions. These include for an independent inquiry under the *Victorian Environmental Effects Act 1978* to the Minister for Planning and Local Government in 1996, in the United States District Court in the Eastern District of California in 2005, and in the Queensland Land Court in 2013. I was also a member of an expert panel for a symposium on "Climate change science and the law" at the Federal Court in Sydney, hosted by the Australian Academy of Science and the Australian Academy of Law in August 2019. Additionally, I gave a presentation to the Judicial Commission of the NSW Land and Environment Court in 2021 entitled "Attribution science and the law: legal reasoning and climate change evidence".

Best available science

Question 6

Please explain what is meant by the term 'best available science' with respect to:

1. *the observations, causes, and impacts of climate change (as defined at [10] of the Applicants' Amended Statement of Claim); and*
2. *the necessary actions to avoid the most dangerous impacts of climate change,*

(Best Available Science)

8. There is no formal dictionary definition of 'best available science' that I am aware of. It refers to the best information currently available that is derived from scientific sources, such as reputable high-impact peer-reviewed scientific journals, that has been accepted by a majority of the scientific community. The very best of the 'best available science' in the context of climate change is provided by the comprehensive and lengthy Assessment Reports of the IPCC from its First Assessment Report released in 1990 to its Sixth Assessment Report released in four volumes between 2021 and 2023. The four volumes of the IPCC Assessment Reports comprise its synthesis report and the reports of its three Working Groups, each of which have different emphases: (1) the Physical Science Basis of Climate Change, (2) Climate Change Impacts, Adaptation and Vulnerability and (3) Mitigation of Climate Change.

9. In addition to the global and regional assessments provided by the IPCC, specific Australian assessments of climate change, its impacts and actions needed to avoid the most dangerous impacts of climate change have been undertaken by the Australian Academy of Science and by government agencies, including the Bureau of Meteorology and the Commonwealth Scientific and Industrial Research Organisation (**CSIRO**), as well as the five-yearly Australian State of the Environment reports. Each of these assessment reports is prepared by multiple scientists as authors, is based on recent relevant peer-reviewed scientific publications, and is subject to independent peer-review, so they all form part of the 'best available science'.

Question 7

In the period 2014 to the present date, what sources describe the Best Available Science?

10. For the period between 2014 and 2023, the Best Available Science includes, but is not limited to, the following sources:

    a) IPCC Fifth Assessment Report (**AR5**):

        i. *Climate Change 2013: The Physical Science Basis;*

        ii. *Climate Change 2014: Impacts, Adaptation and Vulnerability;*

        iii. *Climate change 2014: Mitigation of Climate Change;*

iv. *Climate change 2014: Synthesis Report.*

b) IPCC Special Report 2018: Global Warming of 1.5°C.

c) IPCC Sixth Assessment Report (**AR6**):

i. *Climate Change 2021: The Physical Science Basis;*

ii. *Climate Change 2022: Impacts, Adaptation and Vulnerability;*

iii. *Climate change 2022: Mitigation of Climate Change;*

iv. *AR6 Synthesis Report: Climate Change 2023.*

d) World Meteorological Organisation (**WMO**), annual State of the Global Climate report.

e) United Nations Environment Programme (**UNEP**), annual Emissions Gap report.

f) Australian Academy of Science:

i. *The science of climate change: questions and answers, 2015;*

ii. *The risks to Australia of a 3°C warmer world, 2021.*

g) CSIRO and Bureau of Meteorology, biennial *State of the Climate* reports:

i. *State of the Climate 2022;*

ii. *State of the Climate 2020.*

h) *Australia State of the Environment 2021*, the most recent review report in a five-yearly cycle coordinated by the relevant group in the Australian Government Department of Environment, now the Department of Climate Change, Energy, the Environment and Water (**DCCEEW**).

i) In addition, several recent scientific review papers published in high-impact scientific journals are also referred to in this report, as they form part of the Best Available Science.

Question 8

Please explain what is meant by the terms 'confidence' and 'likelihood' as used in the sources which describe the Best Available Science.

11. The terms 'confidence' and 'likelihood' have been used in the IPCC assessment reports through several assessment cycles. Below, the definitions from the Glossary[1] of the IPCC AR6 report *Climate Change 2021: The Physical Science Basis* are repeated. These definitions are based on the IPCC AR5 *Guidance Note for Lead Authors on Consistent Treatment of Uncertainties*.[2]

a) **Confidence**: "The robustness of a finding based on the type, amount, quality and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgement) and on the degree of agreement across multiple lines of evidence. In this report [AR6], confidence is expressed qualitatively." A level of confidence usually is expressed using four qualifiers: "low", "medium", "high", and "very high".[2] Findings with "very low" confidence are rarely presented in IPCC assessments.

b) **Likelihood**: "The chance of a specific outcome occurring, where this might be estimated probabilistically. Likelihood is expressed in this report [AR6] using a standard terminology". Likelihood is defined in Table 1 below which provides calibrated language for describing quantified uncertainty.

Table 1: IPCC Likelihood scale

Term	Likelihood of the outcome
Virtually certain	99 – 100% probability
Very likely	90 – 100% probability
Likely	66 – 100% probability
About as likely as not	33 – 66% probability
Unlikely	0 – 33% probability
Very unlikely	0 – 10% probability
Extremely unlikely	0 – 5% probability

Adapted from Mastrandrea et al. (2010).[2]

The relationship between emissions and global temperature increase

Question 2

Please explain each of the following concepts and describe their inter-relationship:

a. *the emission of long-lived greenhouse gases (**GHGs**), including the emission of long-lived GHGs from human activities (**anthropogenic GHG emissions**);*

b. *the concentration of GHGs in the Earth's atmosphere (**atmospheric GHG concentration**); and*

c. *the mean temperature of the Earth's surface (**global temperatures**),*

including whether the relationship is linear or non-linear.

12. The following provides a brief introduction to the concepts used in this question and later in this report, based on the Glossary[1] of the IPCC AR6 report *Climate Change 2021: The Physical Science Basis*. The plain-language summary of this report *Climate Change 2021: Summary for All*[3] from the IPCC is also used to provide some less technical descriptions of these concepts.

13. The **greenhouse effect** describes the radiative effect of gases in the atmosphere that absorb radiation at infrared wavelengths. These greenhouse gases (**GHGs**) and clouds absorb infrared radiation emitted upwards from the Earth's surface and lower atmospheric levels. They emit infrared radiation in all directions, but the net effect of these gases is to reduce the outgoing infrared radiation (energy) emitted to space. This leads to a hotter temperature at the Earth's surface and in the lower atmosphere than would occur if these greenhouse gases did not exist in the atmosphere. If the concentration of greenhouse gases in the atmosphere increases, then the magnitude of the greenhouse effect increases, called the 'enhanced greenhouse effect', as shown on the right-hand side of Fig.1 below.

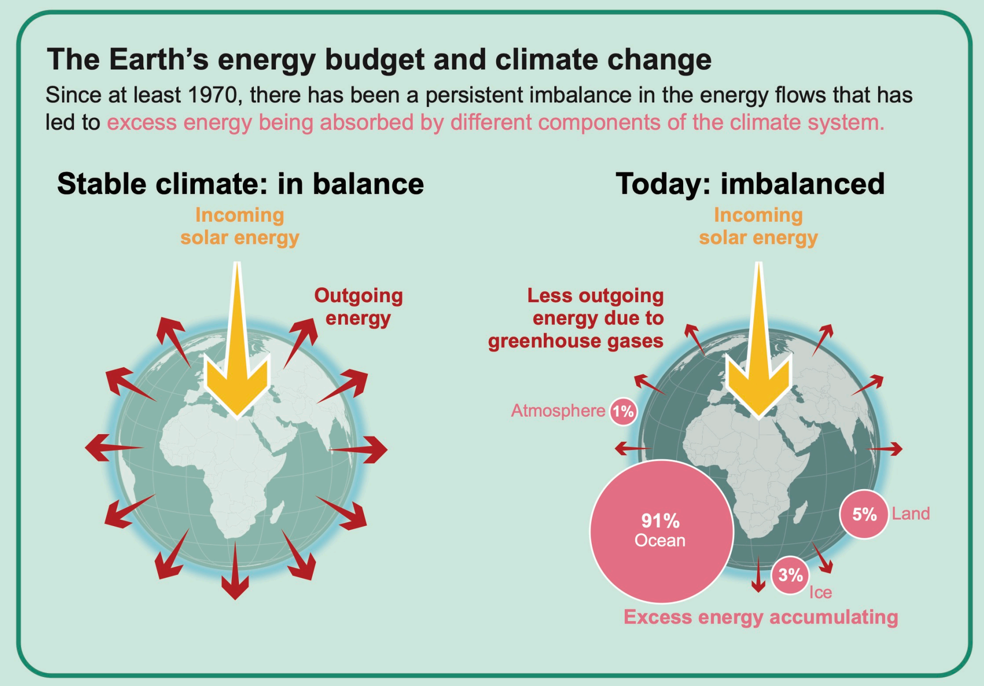


Fig.1: The Earth's energy budget compares the flows of incoming and outgoing energy that are relevant for the climate system. *Reproduced from Graphic B, IPCC Climate Change 2021: Summary for All.*[3]

14. The increase in a greenhouse gas concentration due to anthropogenic (human-caused) emissions of such a gas contributes to an instantaneous 'radiative forcing'. The radiative forcing is the imbalance in the Earth's energy budget at the top of the atmosphere between the incoming solar radiation energy from the sun and the reduced outgoing energy due the additional greenhouse gas concentration. This is illustrated on the right-hand side of Fig.1 above. The imbalance in the Earth's energy budget leads to an accumulation of excess energy, heating up the Earth's oceans, land surface and the lower atmosphere slowly in response to the radiative forcing. The warming of the surface temperatures increases the outgoing energy emitted to space, offsetting the reduced outgoing energy due to the extra greenhouse gases. Hence, the global warming in response to the enhanced greenhouse effect gradually restores the energy balance at the top of the atmosphere between the incoming solar energy and the outgoing energy from outgoing infrared radiation.

15. The major GHGs in the atmosphere are water vapour, carbon dioxide (**CO_2**), methane and nitrous oxide. Global warming potential (**GWP**) is the most common index used to measure the radiative forcing due to the emission of unit mass of any GHG, accumulated over a specified time period, usually 100 years, relative to that of CO_2. The GWP-100 is an index that represents the combined effect of the time gases remain in the atmosphere and their effectiveness in causing radiative forcing. The GWP-100 of water vapour is zero because water vapour added to the atmosphere is removed by precipitation within about one week. Hence, anthropogenic emissions of water vapour do not contribute to global warming. CO_2 has a GWP-100 of 1, as it is the reference gas in the definition of GWP. Methane has an atmospheric lifetime of about 12 years and a GWP-100 of about

30. Nitrous oxide has an atmospheric lifetime of about 109 years and a GWP-100 of about 273.

16. CO_2 has multiple atmospheric lifetimes associated with the many processes in the carbon cycle in the Earth system affecting CO_2 in the atmosphere. There are rapid exchanges of CO_2 between the atmosphere and the ocean, and between the atmosphere and vegetation and soils on land, associated with the natural sources and sinks of CO_2 in the atmosphere (described below in Paragraphs 19 and 20). There is a seasonal variation of global atmospheric CO_2 with a peak in December-February and a minimum in June-August, associated with the seasonal uptake and loss of CO_2 from vegetation in the Northern Hemisphere in spring and autumn respectively. There are also marked year-to-year variations in the uptake and loss of CO_2 from the atmosphere associated with natural climate variations such as El Niño-Southern Oscillation. Much of the CO_2 taken up in the upper layers of the oceans or in vegetation is returned to the atmosphere within years to decades, so the typical atmospheric turnover time of CO_2 is about five years. However, the adjustment time or response time of CO_2 from the atmosphere is determined by the rates of long-term removal of CO_2 from the atmosphere. This involves a range of processes with time scales from centuries to many thousands of years, including the movement of dissolved CO_2 in ocean waters from upper layers into the deep ocean, storage of carbon in lake and ocean sediments, the movement of carbon from vegetation into deep soils and the formation of carbonate rocks. As a result, 15 to 40% of an emitted CO_2 pulse from human activities will cause an increase of the CO_2 concentration in the atmosphere for longer than one thousand years. This means that CO_2 is a very long-lived GHG.

17. The three most important GHGs in terms of their contributions to global warming over the last 100 years are CO_2 and nitrous oxide, both long-lived GHGs (lifetimes over 100 years) and methane, a relatively short-lived GHG (lifetime of about 12 years).[3,5] They all have substantial emissions from human activities and all have GWP-100 of at least 1. Methane, with its atmospheric lifetime of about 12 years, is considered a long-lived GHG throughout the remainder of this report in order to distinguish it from water vapour.

18. The mean temperature of the Earth's surface (**global temperature**) is the average of the near-surface air temperature over land and the sea surface temperature from the oceans. On seasonal, year-to-year and decadal timescales, variations in the global mean land surface temperature are larger than for the global temperature, which in turn are larger than variations of global mean sea surface temperature.

Question 2(a)

19. Each of the three major GHGs, CO_2, methane and nitrous oxide, has important natural sources of emissions. Decomposition of vegetation on land and loss of dissolved CO_2 from oceans are the largest natural causes of emissions of CO_2 into the atmosphere. Microbial decomposition of organic matter in wetlands is the largest natural source of methane emissions. Nitrous oxide is emitted naturally from the land and oceans.

20. These three GHGs also have natural sinks or loss processes that remove these GHGs from the atmosphere. CO_2 from the atmosphere is taken up in plant growth through photosynthesis and is dissolved in water at the ocean's surface. Methane is removed from the atmosphere by chemical reactions with the hydroxyl radical (OH) and converted into CO_2 and water vapour. Nitrous oxide is destroyed mainly by ultraviolet radiation in the stratosphere.

21. In addition, these three GHGs have had substantial emissions from human activities since the industrial revolution (around 1800). Anthropogenic emissions of CO_2 arise from land-clearing and deforestation and from combustion of fossil fuels (coal, oil and natural gas) in a wide range of uses, including generation of electricity, industrial and domestic heating, and in shipping, aviation and surface transport. There can also be anthropogenic sinks of CO_2 from the atmosphere, such as through reforestation and managed tree plantations. This is discussed further in the response to Question 16 below. Net anthropogenic emissions of CO_2 into the atmosphere are the total emissions minus the removal of CO_2 from the atmosphere due to managed human activities. Methane emissions arise from multiple human activities including extraction and use of fossil fuels (including natural gas), farming of livestock, rice cultivation and waste from landfills and agriculture. The use of nitrogenous fertilisers in agriculture is the largest cause of anthropogenic emissions of nitrous oxide.[4]

Question 2(b)

22. Global atmospheric GHG concentrations are determined by the balance between the combined natural and anthropogenic emissions and their sinks. Prior to the industrial revolution, for much of the last two thousand years, the variations of the global GHG concentrations in the atmosphere were quite small (shown in Fig. 2 below), due to the long-term balance between natural emissions and natural sinks for each of these GHGs (Paragraphs 19 and 20). Since the industrial revolution (around 1800), there have been large increases in the global atmospheric concentrations of these GHGs due to the additional anthropogenic GHG emissions (Paragraph 21).[4,5]

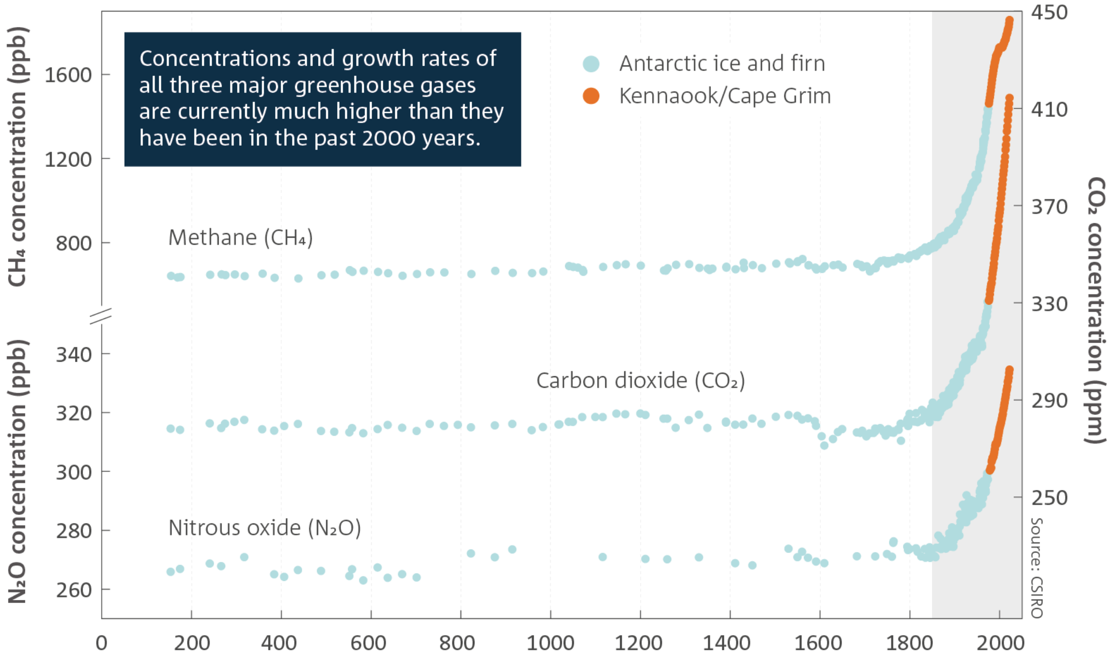


Fig. 2: Concentrations of the major greenhouse gases (CO_2, methane and nitrous oxide) in the atmosphere over the past 2000 years*. Reproduced from State of the Climate 2022.*[4]

Question 2(c)

23. The variations of global temperatures over the last two thousand years are shown in Fig. 3 below. They show small amplitude decadal variations, no trend over the first millennium, then a slight cooling over the second millennium until about 1900, then a marked warming trend. This agrees reasonably well with the variations of the combined global concentrations of the three major GHGs, as shown in Fig.2 above, with relatively stable concentrations till about 1800 and then rapidly growing concentrations.

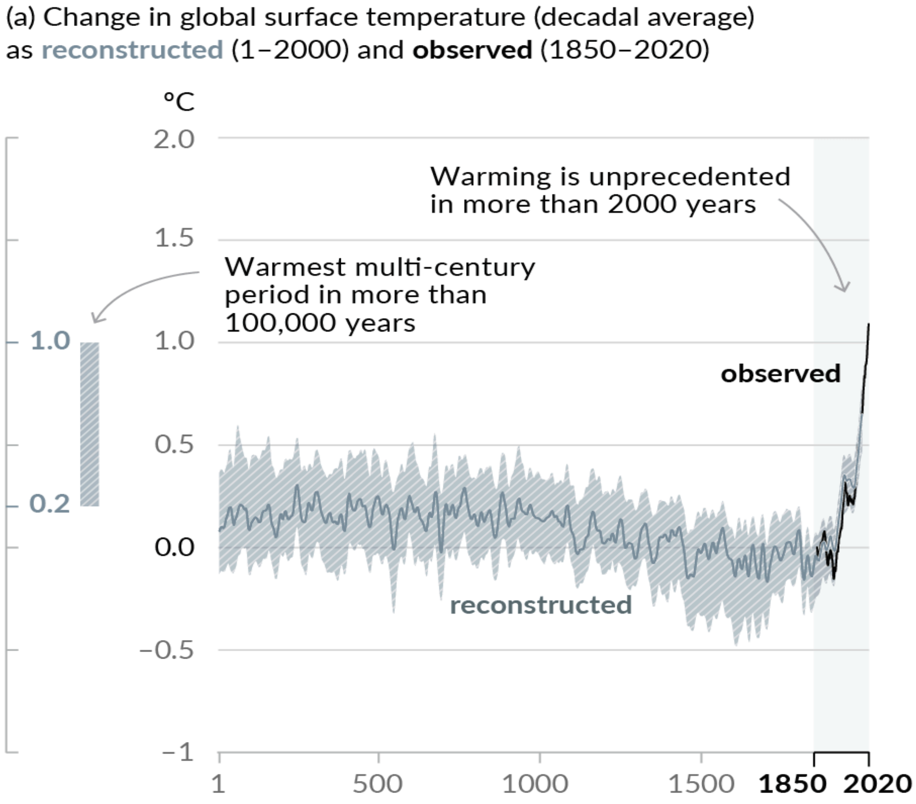


Fig. 3:* “*Changes in global surface temperature *reconstructed from paleoclimate archives (solid grey line, years 1–2000) and from direct observations (solid black line, 1850–2020), both relative to 1850–1900 and decadally averaged.” … “The grey shading with white diagonal lines shows the very likely ranges for the temperature reconstructions.” Reproduced from Figure SPM.1, Summary for Policymakers, IPCC Sixth Assessment Report ‘Climate Change 2021: The Physical Science Basis’.* [5]

24. The best measure of the global warming influence of the increases of the combined global GHG concentrations since the industrial revolution is the ‘carbon dioxide-equivalent concentration’ **(CO_2-e)**. CO_2-e is the concentration of CO_2 that would give the same radiative forcing as the combined mixture of GHGs.[1] CO_2-e is obtained by weighting the concentrations of the individual GHGs by their GWP-100 to calculate the combined radiative forcing.

25. The increase in the global average concentration of CO_2 in the atmosphere since the industrial revolution is directly linearly related to the cumulative emissions of CO_2 from human activities, the sum of anthropogenic emissions since about 1850. This is due to the very long response time for removal of CO_2 added to the atmosphere (see Paragraph 16). Similarly, the increase in the global CO_2-e since the industrial revolution is linearly related to the cumulative anthropogenic emissions of all long-lived GHGs.[5]

26. The multi-decadal increase of global temperature at any time since about 1850 is near-linearly related to the cumulative anthropogenic emissions of CO_2 since 1850 to that time (shown in Fig. 4 below). This applies to changes from 1850 to the present based on

observations, or, in the future, up to 2050 based on climate model simulations. As described in Paragraph 14 above, the increase in a GHG concentration due to anthropogenic emissions contributes to an instantaneous radiative forcing that causes an increase in global temperature. As discussed at Paragraph 25 above, the increase in global CO_2 concentration since the industrial revolution is linearly related to the cumulative anthropogenic emissions of CO_2. Combining these two means that there is a near-linear relationship between cumulative emissions of CO_2 from human activities and increase in global temperature. This is summarised in the heading of Fig.4, "Every tonne of CO_2 emissions adds to global warming".

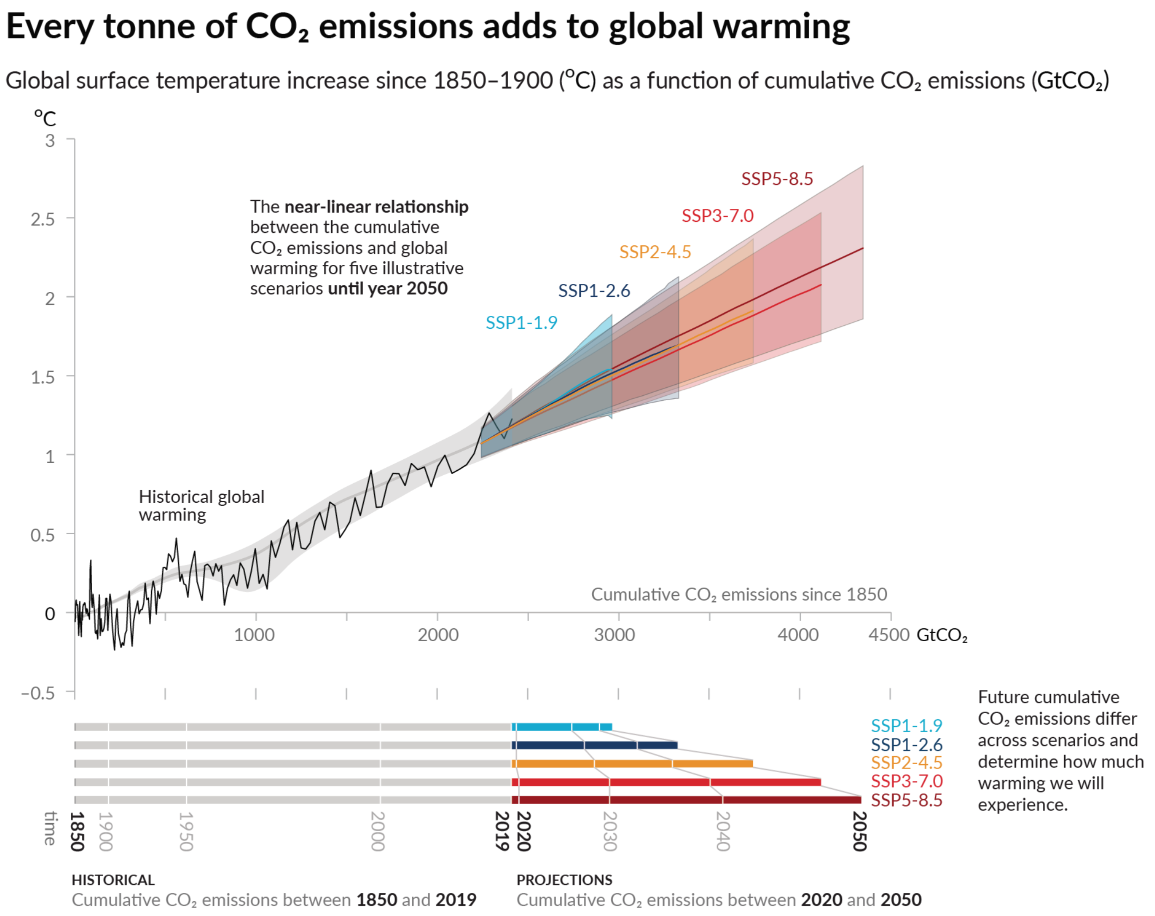


Fig. 4:** "**Near-linear relationship between cumulative CO_2 emissions and the increase in global surface temperature.

<u>Top panel</u>: Historical data (thin black line) shows observed global surface temperature increase in °C since 1850–1900 as a function of historical cumulative carbon dioxide (CO_2) emissions in $GtCO_2$ from 1850 to 2019. Coloured areas show the assessed very likely range of global surface temperature projections, and thick coloured central lines show the median estimate as a function of cumulative CO_2 emissions from 2020 until year 2050 for the set of illustrative scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5.)

<u>Bottom panel</u>: Historical and projected cumulative CO_2 emissions in G CO_2 for the respective scenarios."

Reproduced from Figure SPM.10, Summary for Policymakers, IPCC Sixth Assessment Report 'Climate change 2021: The Physical Science Basis'.[5]

27. A similar near-linear relationship, but with a different scaling factor, or slope, exists between the increase of global temperature since the industrial revolution and the cumulative carbon CO_2-e emissions.[3]

28. The direct result of the near-linear relationship between cumulative CO_2 emissions since 1850 and increases in global temperature is that to stabilise global temperature at any level, global net zero emissions of CO_2 from human activities must be achieved.

Question 3

*Please state the date(s) you will use as a reference point for the period prior to the onset of anthropogenic GHG emissions in answering Questions 4 and 5 (the **Baseline**) and explain the basis for using this Baseline.*

29. The Baseline period used in this Report is the period 1850-1900 used by the IPCC in the AR6. Note that this period is not prior to *all* anthropogenic GHG emissions but is prior to *all substantial* anthropogenic GHG emissions. Prior to this period, there were minor anthropogenic CO_2 emissions from limited burning of coal and some land clearing in Europe, Asia and North America. The period is selected because of the better availability of observational data for estimating global temperatures and anthropogenic GHG emissions.

Question 4

Please describe the amount of change in:

a. *anthropogenic GHG emissions;*

b. *atmospheric GHG concentration; and*

c. *global temperatures,*

from:

i. *the Baseline to the present date; and*

ii. *1990 to the present date.*

Question 4(a)

30. Total global net anthropogenic GHG emissions increased from the 1850-1900 Baseline of near zero emissions to 59 ± 6.6 Gt CO_2-e in 2019.[6] Global net anthropogenic GHG emissions rose by 21 Gt CO_2-e per year from 1990 to 2019. 2019 is the final year of annual anthropogenic GHG emissions assessed in the IPCC AR6 report. Global net anthropogenic emissions of CO_2 increased from the near-zero Baseline to 44.6 ± 7.6 Gt in 2019. Global net anthropogenic CO_2 emissions rose by 16.9 Gt per year from 1990 to 2019.[6]

31. Global anthropogenic emissions of CO_2 fell by about 6% in 2020 compared with emissions in 2019, due to the impacts of COVID-19 on reducing global industrial activity

and restrictions on transport. There was substantial recovery of anthropogenic emissions of CO_2 in 2021 by 5% due to removal of restrictions associated with COVID-19 in many countries, with total anthropogenic CO_2 emissions of 40.0 ± 2.9 Gt,[7] slightly lower than in 2019. Preliminary data for 2022 suggest a further recovery of fossil fuel-related emissions by a further 1%, making them slightly higher in 2022 than in 2019.[7] These preliminary data do not include anthropogenic CO_2 emissions from land clearing in 2022.

Question 4(b)

32. Global atmospheric GHG concentrations rose from the Baseline value of about 280 ppm CO_2-e to 516 ppm CO_2-e in 2021,[4] an increase of about 236 ppm CO_2-e. It rose from the 1990 value of 417 ppm CO_2-e to 516 ppm CO_2-e in 2021,[4] an increase of 99 ppm CO_2-e. The global atmospheric CO_2 concentration rose from the Baseline value of about 280 ppm to 414 ppm in 2021,[4] an increase of about 134 ppm. It rose from the 1990 value of 354 ppm to 414 ppm in 2021,[4] an increase of 60 ppm.

Question 4(c)

33. There is large natural variability in the global mean temperature from year to year, so it is better to consider changes of temperatures averaged over periods of at least a decade in length to identify longer-term trends.

34. Global mean near-surface air temperature increased from the 1850-1900 Baseline to the most recent decade 2011-20 by 1.09 [0.95, 1.20] ºC.[5] The values inside the square brackets represent the very likely or 5% to 95% likelihood range, with almost all of the uncertainty arising from uncertainties in observations of global mean surface temperature during the Baseline period, associated with limited observational data coverage then. Further information on the meaning of the likelihood range is provided in Paragraph 11. The global mean temperature increased from the 1986-95 average to the most recent decade 2011-20 by about 0.52ºC.

35. There were larger increases of global mean temperature over land (1.59 [1.34 to 1.83] °C) from the Baseline to the most recent decade 2011-20 than over the ocean (0.88 [0.68 to 1.01] °C),[5] consistent with expected higher magnitude of changes in global land temperatures than global mean temperatures and global sea surface temperatures described in Paragraph 18. The global mean temperature over land increased from the 1986-95 average to the most recent decade 2011-20 by about 0.74ºC.

Question 5

Please describe the rate of change in:

a. *anthropogenic GHG emissions;*

b. *atmospheric GHG concentration; and*

c. *global temperatures,*

from:

i. *the Baseline to the present date; and*

ii. *1990 to the present date.*

Question 5(a)

36. The average rate of change of global total anthropogenic GHG emissions from the Baseline to 2019 was about 0.5 Gt CO_2-e per year and rose to about 0.7 Gt CO_2-e per year over 1990 to 2019. The average rate of change of global net anthropogenic CO_2 emissions from the Baseline to 2019 was about 0.4 Gt per year and rose to about 0.6 Gt per year over 1990 to 2019.

Question 5(b)

37. The average annual rate of change of global total GHG concentrations from the Baseline to 2019 was about 2.0 ppm CO_2-e per year and rose to about 3.4 ppm CO_2-e per year over 1990 to 2019. The average annual rate of change of global CO_2 concentration from the Baseline to 2019 was about 1.1 ppm per year and rose to about 2.1 ppm per year over 1990 to 2019.

38. The recent variations in anthropogenic CO_2 emissions from 2019 to 2022 are described in Paragraph 31. They were too small to cause a detectable reduction in the rate of increase of the global CO_2 concentration from 2019 to 2022, due to the large year-to-year variations of natural sources and sinks of CO_2.[7]

Question 5(c)

39. The average rate of change of global mean temperature from the Baseline to the most recent decade 2011-2020 was about 0.09ºC per decade and rose to about 0.21ºC per decade from 1986-95 to the most recent decade 2011-2020. Decadal averages of temperature are usually considered to remove the influence of natural variability of global and regional temperatures at year-to-year timescales.

40. The average rate of change of global mean surface air temperature over land from the Baseline to the most recent decade 2011-2020 was about 0.13ºC per decade and rose to about 0.30ºC per decade from 1986-95 to the most recent decade 2011-2020. The average

decadal rate of change of global land temperature is about 40% higher than for global mean temperature.

Current impacts of climate change

<u>Question 9</u>

At a global level, please explain the inter-relationship between each of:

- *a. anthropogenic GHG emissions;*
- *b. atmospheric GHG concentration; and*
- *c. global temperature,*

and each of:

- *d. ocean surface temperature;*
- *e. ocean acidification;*
- *f. sea ice;*
- *g. permafrost;*
- *h. precipitation;*
- *i. humidity;*
- *j. the frequency, size, and intensity of extreme weather events, including heatwaves, droughts, bushfires, tropical cyclones, severe storms, heavy rainfall and associated flooding; and*
- *k. terrestrial ecosystems and non-human species,*

*(**Impacts of Climate Change**),*

including whether:

- *i. the relationship with each impact is linear or non-linear; and*
- *ii. the relationship varies geographically.*

41. In responding to question 9, I use the relationships between cumulative global anthropogenic GHG emissions, global atmospheric GHG concentration and global temperature described in the responses to Question 2 above in Paragraphs 12 to 28.

<u>Question 9(d) Ocean surface temperature</u>

42. The increase in global ocean surface temperatures since the Baseline has been driven by the increase in global atmospheric GHG concentration from human activity, due to the enhanced greenhouse effect (see Paragraphs 13 and 14). This increase has closely followed the increase in global temperature, but with a smaller magnitude increase (see Paragraphs 34 and 35). The relationship between global temperature increases on decadal timescales and increases in global ocean surface temperatures is nearly linear but varies geographically associated with the ocean current systems and variations in the mixing of surface waters into the deeper ocean waters.[4,5]

Question 9(e) Ocean acidification

43. The acidity of ocean waters is determined by CO_2 being dissolved from the atmosphere into the upper layers of the ocean. Higher CO_2 concentrations in the atmosphere cause ocean acidification. Hence, ocean acidification has increased due to the higher atmospheric CO_2 concentration associated with anthropogenic emissions of CO_2. It is only weakly affected by changes in global temperature, as the solubility of CO_2 in water decreases slightly for warmer ocean waters. The relationship between global ocean acidification and increases in global atmospheric CO_2 concentration is nearly linear but varies geographically associated with the ocean current systems and variations in the mixing of surface waters into the deeper ocean waters.[5]

Question 9(f) Sea ice

44. Sea ice forms in higher latitude ocean waters of both the Northern Hemisphere and the Southern Hemisphere when the regional sea surface temperature and atmospheric temperature are cold enough. There are large seasonal differences in the extent of sea ice from a late summer-early autumn minimum to a late winter-early spring maximum. The magnitude of the seasonal cycle of sea ice extent in the Arctic is larger than around Antarctica, due to the larger magnitude of the seasonal cycle in sea surface temperature and atmospheric temperature in the middle and high latitudes of the Northern Hemisphere than in the Southern Hemisphere. This is due to the larger continental land masses in sub-polar latitudes in the Northern Hemisphere than in the Southern Hemisphere.

45. Increases in global temperature and global sea surface temperature (described in Paragraph 42) have caused statistically significant declines in Arctic sea ice extent in all seasons since satellite monitoring began in the late 1970s (as shown in Fig. 5 below), with substantial regional variations.[4] The largest declines in Arctic sea ice have occurred in the September minimum.

46. There has not been a similar declining trend in the extent of sea ice around Antarctica, with no statistically significant trend over the last 40 years, large regional variations in sea ice extent around the Antarctic coast and large natural variability of sea-ice extent on year-to-year and decadal timescales (Fig. 5). There has been a recent rapid decrease in Antarctic sea ice extent since 2015, after a small increase over the period from 1979–2014, but neither is statistically significant.[4] The absence of a clear link between the increases in global temperature and the extent of sea ice around Antarctica is likely due to the large, very cold Antarctic continental ice sheet and land mass at the South Pole and the weak warming of sea surface temperatures of the Southern Ocean at high latitudes around Antarctica.

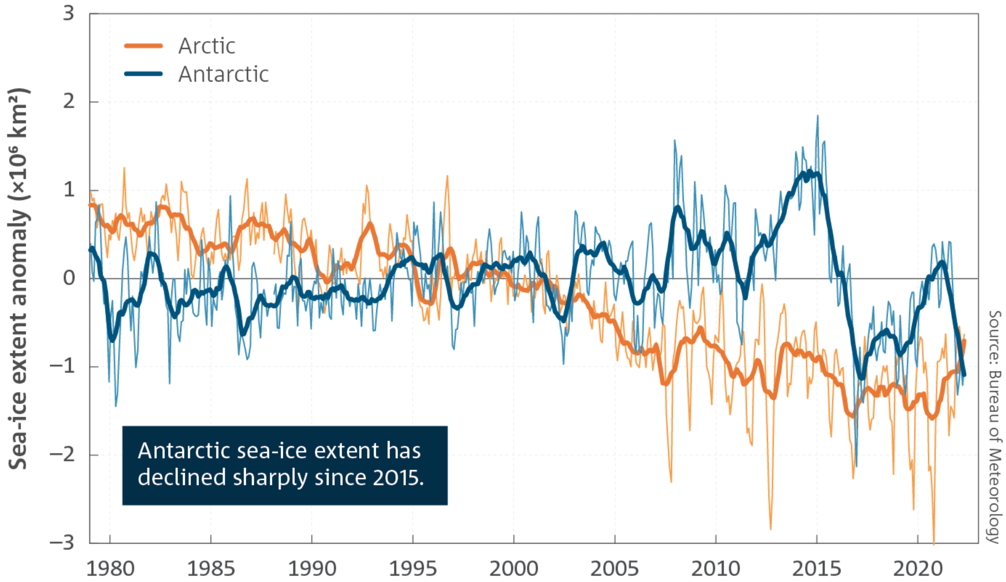


Fig. 5: Antarctic and Arctic sea-ice extent *(shown as the anomalies relative to the 1981–2010 average) for 1979 to 2021. Thin lines are monthly averages and indicate the variability at short timescales, while thick lines are 11-month moving averages. Reproduced from State of the Climate 2022*[4].

47. The relationship between global temperature and Arctic sea ice extent is complex and non-linear. In addition to the role of increasing global temperatures causing declines in Arctic sea ice (see Paragraph 45 above), there is also a feedback relationship between sea ice and global temperature. Reductions in sea ice lead to reduced reflection of sunlight to space and increases in absorbed solar radiation at the sea surface, which increases the sea surface temperature. These regional sea surface temperature increases contribute to increases in global temperature. This is a regional positive feedback, in which increases in global temperature cause decreases in Arctic sea ice extent, which cause regional warming in the Arctic and contributes to further increases in global temperature.[9] This positive feedback between global temperature and Arctic sea ice is represented in global climate models.

Question 9(g) Permafrost

48. Permafrost is frozen ground (soil and included ice and organic material) that remains below 0ºC for more than two years.[1] Permafrost is found in high latitude landmasses primarily in the Northern Hemisphere and very high elevation regions. Near surface permafrost, within 3-4 metres of the surface, responds more rapidly to warming than deeper permafrost and is most relevant to people and ecosystems. Thawing of permafrost leads to aerobic decomposition of included organic material, releasing CO_2, and anaerobic decomposition of organic material, releasing methane.

49. Increases in global temperature on decadal and longer timescales lead to reductions in permafrost in the Arctic and in very high elevation regions. There has been an observed decline in permafrost, as expected from the observed increase in global temperature.[19]

50. The relationship between global temperature, GHG emissions and permafrost is complex and non-linear. In addition to the role of increasing global temperatures causing declines in permafrost (discussed in Paragraph 49), there is also a feedback relationship between permafrost, GHG emissions and global temperature. Thawing of permafrost leads to increases of emissions of CO_2 and methane that increases the concentrations of CO_2 and methane in the atmosphere. These increases in GHG concentrations contributes to increases in global temperature. This is a regional positive feedback that increases global temperature. This regional positive feedback between global temperature, permafrost and GHG emissions is not represented well in global Earth System models but some models have a simplified representation.

Question 9(i) Humidity

51. Humidity is a measure of the amount of water vapour in air. There are two common measures of humidity, relative humidity and specific humidity. Relative humidity is the amount of water vapour in a parcel of air relative to the maximum amount of water vapour that the same parcel of air could hold at the same pressure and temperature, called saturation. Relative humidity of 100% means saturated air, while relative humidity of 0% means air containing no water vapour. Specific humidity is the mass of water vapour in unit mass (1 kg) of air, usually referred to in units of grams per kilogram.[1] Specific humidity is higher in warmer air, as warmer air can hold more water vapour. Air in the tropics has much higher specific humidity than in the colder high latitudes. Air close to the surface has much higher specific humidity on average than at higher elevations, as atmospheric temperature decreases with height by about 6ºC per kilometre in the lowest layer of the atmosphere, called the troposphere.

52. Increases in global temperature lead to increases in global average specific humidity in the lower atmosphere, both near the surface and in the troposphere. The relationship between the increase in specific humidity and global temperature is nearly linear, with a magnitude of about 7% increase of specific humidity per degree Celsius warming in the lower atmosphere. The observed increase of global temperature since the Baseline has led to observed increases in global average specific humidity from weather observations of near-surface air and throughout the troposphere.[19]

53. Water vapour is a very effective GHG with a short atmospheric lifetime (see Paragraph 15). The amount of water vapour in near-surface air and in the lower atmosphere increases when the global temperature increases on yearly timescales, such as due to El Niño events, and on longer timescales due to the observed increase in global temperature. This is a positive feedback, enhancing the greenhouse effect due to the increased water vapour in the atmosphere and further increasing global temperature. This positive feedback is limited by a number of factors that control water vapour increases in the atmosphere, particularly condensation of water vapour into cloud droplets and precipitation of rain and snow. Hence this positive feedback between global temperature and global water vapour is not a runaway feedback effect. This positive feedback

between global temperature and global specific humidity is represented well in global climate models.

Question 9(h) Precipitation

54. Precipitation of rain and snow from the atmosphere is primarily driven by weather systems at daily and longer timescales. It is highly variable between different regions and in different time periods. It is affected by increases in global temperature that increase the specific humidity and the total water content of the global atmosphere (see Paragraphs 52-53). However, the distribution of average precipitation across the globe is driven by the mean large-scale atmospheric circulation, with higher precipitation in the tropics and high latitudes and lower precipitation in sub-tropical latitudes. Increases in global temperature do not lead to globally uniform increases in precipitation but generally lead to increases in the tropics and high latitudes, and decreases in the sub-tropics. An over-simplification is that, on average, wet regions get wetter and dry regions get drier[5].

55. The relationship between increases in global temperature and changes in mean regional precipitation is approximately linear, with similar magnitude increases for every half-degree increase of global temperature.

56. Increases in global temperature and associated increases in specific humidity lead to increases in extreme hourly and daily rainfall amounts in many regions around the world. These increases in extreme rainfall can be modified by large-scale changes in atmospheric circulation, but are more pervasive than changes in mean precipitation.

Question 9(j) Extreme weather events

57. Changes in the frequency, spatial scale and intensity of some types of extreme weather events globally are directly or indirectly related to changes in global temperature. These include extreme temperatures and heatwaves, weather conditions conducive to bushfires, extreme daily rainfall and associated flooding, drought in some areas, and coastal storm surges and associated flooding. These relationships are illustrated in Fig. 6 below and are approximately linear.

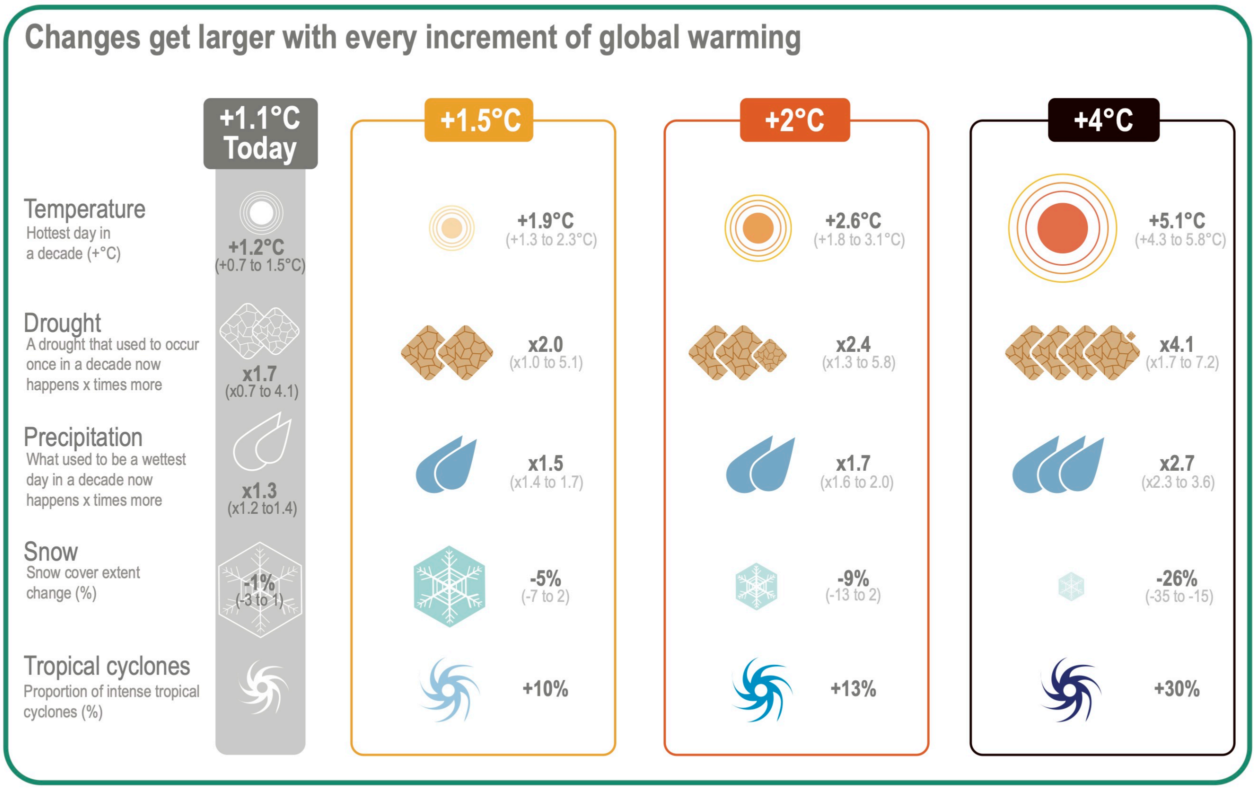


Fig. 6: Changes in some extreme weather events for increases in global temperature. *Changes are relative to the 1850-1900 Baseline for selected weather extremes. Reproduced from Graphic E, IPCC Climate Change 2021: Summary for All.*[3]

58. This relationship between some extreme weather events and global temperature varies between different regions and between different types of extreme weather events. As extreme events are rare, the relationships are clearest when considering long-term changes over large spatial regions. The relationship is simplest and most direct for temperature-related extremes, with increases in hot extremes and reductions in cold extremes in most regions for long-term changes in global temperature. Increases in drought frequency and intensity are associated with increases in global temperature and reduced soil moisture in regions of reduced mean rainfall. Increases in fire weather conditions generally occur with increases in global temperature but are much greater in regions with increases in drought frequency. However, these may not result in increases in bushfire frequency in regions where the fuel load is very low, such as deserts. Increases in storm surges depend on the regional increases in mean sea level due to changes in wind patterns, as well as global sea level rise driven by increases in global temperature.

59. The relationship between increases in global temperature and changes in these extreme weather events is approximately linear, with similar magnitude changes for every half-degree increase of global temperature, but different magnitude changes for different types of extreme. This is illustrated in Fig. 6 above.

60. For several other types of extreme weather events, the relationship with global temperature is more complex and unclear, particularly for severe storms, tropical cyclones (hurricanes and typhoons), hail storms and tornadoes. These severe weather systems are affected primarily by local and regional weather and environmental conditions and less by global climatic factors such as global temperature. The one global climatic factor that may lead to intensification of these extreme weather events is increases of specific humidity (see Paragraphs 51-53), as all these weather systems depend to some extent on the moisture content of the atmosphere. While the frequency of tropical cyclones in a number of regions has declined with increases in global temperature over the last 50 years, the frequency of more intense tropical cyclones is expected to increase on average (as shown in Fig. 6). Similarly, the intensity of severe convective storms is expected to increase with increasing global temperature, but there are large regional and temporal variations and limitations in high-quality long-term observational datasets.

Question 9(k) Terrestrial ecosystems and non-human species

61. The most comprehensive recent assessment of climate change impacts on terrestrial ecosystems and non-human species is provided by the IPCC AR6 Working Group II *Climate Change 2022: Impacts, Adaptation and Vulnerability*.[8] This report assessed the observed relationships with global temperature change and changes in atmospheric GHG concentrations, as well as changes in other climatic impacts, such as precipitation and extreme weather events, and changes in other human-caused impacts, such as deforestation, land use change, invasive species, and air and water pollution. These impacts vary greatly between different regions and between different ecosystems.

62. Human-induced climate change associated with increases in global temperature since the Baseline has caused widespread adverse impacts and damage to terrestrial ecosystems, beyond natural climate variability.[8] Widespread impacts on ecosystems have resulted from observed increases in the frequency and intensity of climate and weather extremes, including hot extremes on land, heavy precipitation events, drought and fire weather.[7] Increases in the frequency of marine heatwaves has led to warm-water coral bleaching and coral mortality. Globally, many species have shifted polewards or to higher elevations on land.[8] Projected adverse impacts and related losses increase with every statistically significant increase of global temperature.[7] Hence, there is an approximately linear relationship between global temperature change and impacts on terrestrial ecosystems, but the strength of this relationship varies substantially between different regions, depending on the complex relationships with other regional impacts of climate change.

Question 10

From the Baseline to the present date, please describe the Impacts of Climate Change:

a. globally;

b. in Australia; and

c. in the Torres Strait Islands.

Question 10(a) Global impacts of climate change to date

63. The global impacts of climate change from the Baseline to the present date are broadly covered in the responses to Question 9 in Paragraphs 41 to 62 above. Further details are provided in the IPCC AR6 Working Group I and Working Group II Summaries for Policymakers.[5,8] Following on from my responses to Question 9, here I focus on impacts of climate change across Australia and in the Torres Strait Islands.

Question 10(b) Impacts of climate change to date in Australia

64. The best available science on the impacts of climate change from the Baseline to the present date in Australia is provided by:

    a) IPCC AR6 Working Group I, *Regional Factsheet for Australasia*;[9]

    b) IPCC AR6 Working Group II, *Fact Sheet – Australasia: Climate Change Impacts and Risks;*[10]

    c) CSIRO and Bureau of Meteorology, *State of the Climate 2022*;[4]

    d) Academy of Science 2021 report, *Risks to Australia of a 3 ℃ warmer world*;[11] and

    e) Australian Government, *State of the Environment 2021* report,[12] released in 2022.

65. The most recent comprehensive assessment of physical climate change impacts across Australia is provided by the CSIRO and Bureau of Meteorology *State of the Climate 2022* report.[4] Key conclusions from this report are:

    a) Average land temperatures across Australia have increased by 1.47 ± 0.24°C since high quality national records began in 1910. Sea surface temperatures around Australia have increased by an average of 1.05°C since 1900. This has led to an increase of extreme heat events over land and sea.

    b) There has been a decline of April-October rainfall by about 15% since 1970 in the southwest of Australia. In the southeast of Australia, April-October rainfall has declined by about 10% since the late 1990s.

c) There has been a decline in streamflow at most monitoring gauges across Australia since 1975.

d) Rainfall and streamflow have increased over parts of northern Australia since the 1970s.

e) Observations show an increase in the intensity of heavy rainfall events in Australia on hourly timescales.

f) There has been an increase in extreme fire weather, and a longer fire season, across large parts of Australia since the 1950s.

g) There has been a decrease in the number of tropical cyclones observed around northern Australia. Any trend in cyclone intensity in the Australian region is harder to quantify, due to uncertainties in estimating the intensity of individual cyclones and the relatively small number of intense cyclones.

h) Oceans around Australia have continued to become more acidic, with changes happening faster in recent decades.

i) Sea levels have been rising around Australia from since 1910, including more frequent extremes that are increasing the risk of inundation and damage to coastal infrastructure and communities.

66. It is important to note that the frequency, intensity and regional occurrence of weather and climate extremes in Australia are strongly affected by natural modes of year-to-year climate variations. Hence, it is important to consider climate change-related changes in the frequency and intensity of climate extremes in different parts of Australia over twenty-year periods or longer, not in single years alone.

67. The most recent comprehensive assessment of the impacts of climate change on terrestrial ecosystems and non-human species across Australia is provided by the Australian Government's *State of the Environment 2021* report.[11] A briefer summary is provided in parts of the IPCC AR6 Working Group II, *Fact Sheet – Australasia.*[10]

68. Selected summary statements on the impacts of climate change on terrestrial ecosystems and on species from the *State of the Environment 2021*[11] report include:

a) Climate change is continuing and is increasing the impacts of other pressures on our environment.

b) In the past decade, climate change in the form of more severe drought, extreme weather events, fire and habitat modification is becoming a new driver for habitat change and species loss in terrestrial ecosystems.

c) Coupled with more gradual climate change shifts, extreme events have resulted in lifecycle shifts, changing species abundances, and range expansions and contractions.

d) Approximately two-thirds of threatened species in Australia are threatened by changing fire regimes (usually in concert with other pressures).

e) Range shifts and extensions on land can be very complicated because different species have markedly different abilities to shift their location and range in order to cope; many terrestrial species are unable to shift their distribution because of the loss of connecting habitats.

f) Alpine ecosystems and biodiversity in Australia are particularly vulnerable to climate change that affects snow depth, and the spatial and temporal extent of snow, which have all declined since the late 1950s.

g) Extensive coral bleaching events and loss of temperate kelp forests have occurred, due to ocean warming and marine heatwaves.[10]

Question 10(c) Impacts of climate change to date in the Torres Strait Islands

69. The impacts of climate change to date in northern Australia described above in response to Question 10(b) are generally relevant to the Torres Strait Islands.

70. Average maximum temperature on the Torres Strait Islands has increased by 0.80°C from 1951-60 to the most recent decade 2011-2020. This is based on analysis of high-quality temperature observations for Horn Island from the Australian Climate Observations Reference Network – Surface Air Temperature (**ACORN-SAT**) dataset of the Bureau of Meteorology.[13] This is consistent with the long-term warming trend in sea surface temperatures around northern Australia (see Paragraph 65).

71. The number of hot days (maximum temperatures greater than 30°C) at Horn Island has increased statistically significantly from 154 days per year in 1951-60 to 231 days per year in 2011-2020.[13] The number of very hot days (maximum temperatures greater than 34°C) at Horn Island has also increased significantly from 0.7 days per year in 1951-60 to 2.5 days per year in 2011-2020.[13]

72. Extensive coral bleaching events have occurred in the Torres Strait Islands over the last two decades, due to ocean warming and marine heatwaves.[10]

73. The Torres Strait Islands has a pronounced wet season from November to April and a dry season from June to September, with large year-to-year and decadal variations in rainfall amounts. Annual total rainfall was somewhat higher in 1995-2022 compared with 1952-80, but this change is not statistically significant. The number of heavy rain days (days of rain > 25mm) has increased from 17 days per year during 1952-80 to 24 days per year during 1995-2022.[14]

74. The comprehensive assessment *Observed and Future Climates of the Torres Strait Region*[15] was prepared by CSIRO in 2010. While this is now somewhat out-of-date compared with more recent assessments from the IPCC AR6 report and the CSIRO and Bureau of Meteorology *State of the Climate* report, it provides a very useful assessment of projected impacts of climate change in the Torres Strait.

75. A comprehensive recent assessment of the impacts of climate change in the Torres Strait Islands is available in *Torres Strait 2021 State of the Environment Report Card.*[16] It concludes that “Global, human-induced climate change is the greatest threat to the health of the region’s (Torres Strait Islands) natural values.” It identifies that the key factors arising from human-caused climate change in the Torres Strait Islands are hotter air temperatures, warming oceans, sea level rise and more acidic oceans.[16]

76. The Bramble Cay Melomys, an endemic mammal species, became extinct due to loss of habitat associated with sea-level rise and storm surges in the Torres Strait.[10,16]

77. Sea levels have been rising statistically significantly in the Torres Strait with more frequent extreme sea levels and storm surges causing to damage to communities.[16]

Emissions Pathways

Question 19

*Please explain the terms 'Representative Concentration Pathways' (**RCPs**) and 'Shared Socioeconomic Pathways' (**SSPs**) as used by the Intergovernmental Panel on Climate Change (**IPCC**). In your answer, please explain the relationship of RCPs and SSPs to:*

a. anthropogenic GHG emissions;

b. atmospheric GHG concentrations; and

c. global temperatures.

78. The Representative Concentration Pathways (**RCPs**) are scenarios of atmospheric GHG concentrations and associated consistent anthropogenic GHG emission scenarios that were used for many climate model simulations for the period 2010 to 2100. These climate model simulations were undertaken by international climate research and modelling groups as part of a coordinated series of experiments called the Coupled Model Intercomparison Project Phase 5 (**CMIP5**) during 2008 to 2014.[17] They include a low emission scenario (**RCP2.6**), a medium emission scenario (**RCP4.5**) and a high emission scenario (**RCP8.5**), with the number representing the approximate increase in radiative forcing in 2100, relative to the Baseline period, associated with each scenario. These climate model simulations were assessed in the IPCC AR5 released in 2013.

79. The Shared Socioeconomic Pathways (**SSPs**) are emission scenarios for 2015 to 2300 that were updated for use in global climate model simulations in the 6th phase of the Coupled Model Intercomparison Project (**CMIP6**) and combined with a range of consistent socioeconomic development scenarios to form the new Shared Socioeconomic Pathways.[18] They include a low emission scenario (**SSP1-2.6**), a medium emission scenario (**SSP2-4.5**) and a high emission scenario (**SSP5-8.5**), with similar greenhouse gas emissions and concentration pathways as the RCPs. A very low emission scenario (**SSP1-1.9**) is also included in the SSPs to represent more rapid emission reductions than the low emission scenario. The future CO_2 emissions for 2015 to 2100 from the SSPs are shown in Fig. 7.

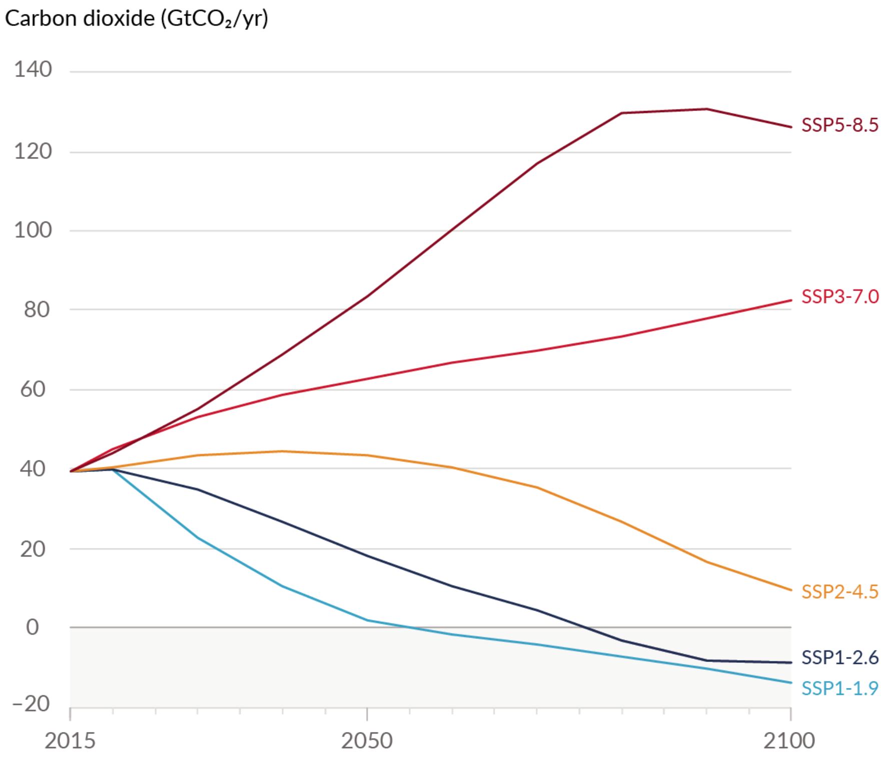


Fig. 7: Future carbon dioxide emissions *(in $GtCO_2$/year) from the SSPs. Reproduced from Figure SPM.4(a), Summary for Policymakers, IPCC Sixth Assessment Report 'Climate change 2021: The Physical Science Basis'.*[5]

80. Recent global climate model simulations for the period 2015 to 2100 have used the SSP emission scenarios and these simulations were assessed in the IPCC AR6 in 2021.[5] Global temperature projections from these climate model simulations for the SSP emission scenarios are shown in Fig. 8.

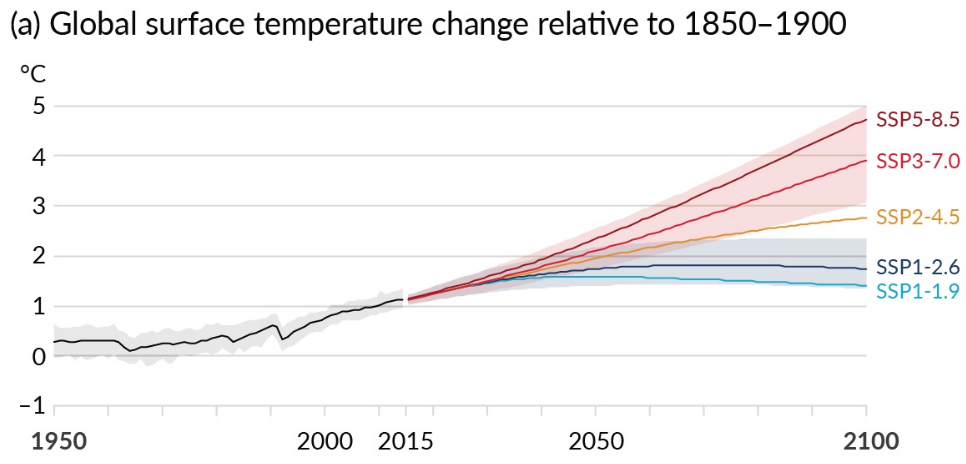


Fig. 8: Global surface temperature changes in °C relative to 1850–1900*. Future projections for each of the five SSP scenarios are shown in colour, with the black curve representing the historical simulations. Changes relative to 1850–1900 are based on 20-year averaging periods averaged across all models. Very likely (5% - 95%) ranges are shown with grey shading for*

SSP1-2.6 and SSP3-7.0 simulations. Reproduced from Figure SPM.8(a), Summary for Policymakers, IPCC Sixth Assessment Report 'Climate change 2021: The Physical Science Basis'.[5]

81. The IPCC AR6 provided a comparison of anthropogenic GHG emissions and concentrations for the RCP scenarios and the SSP scenarios at (that report's) Figure 2 of Cross-Chapter Box 1.4, which is reproduced as Fig. 9 below. Note that the CO_2 emissions and concentrations are typically higher for the SSP scenarios than for the corresponding RCP scenarios, associated with the use of consistent socioeconomic development scenarios for the GHG emissions scenarios.

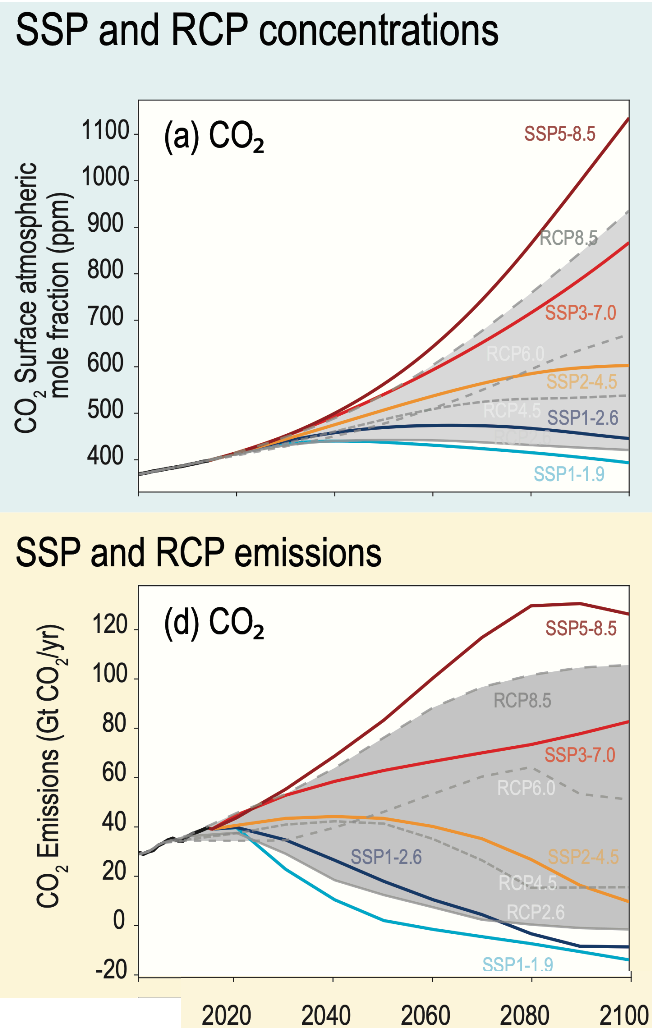


Fig. 9: Comparison between the SSP scenarios and the RCP scenarios *in terms of (a) their global CO_2 concentrations and (d) global anthropogenic CO2 emissions (d). Reproduced from Figure 2 of Cross-Chapter Box 1.4, IPCC Sixth Assessment Report 'Climate change 2021: The Physical Science Basis'.*[19]

82. The IPCC AR6 also provided a comparison of global temperature changes simulated by a simple global Earth System model for the SSP and RCP scenarios, which is shown in Fig. 10 below. The simulated global temperature increases in 2081-2100 are about 0.2ºC to 0.3ºC higher from the SSP emission scenarios than from the comparable RCP scenarios.

The IPCC AR6 Chapter 4 concluded that about half of the warming increase in the climate model simulations assessed in the IPCC AR6 is due to higher climate sensitivity (global temperature increase for a given radiative forcing) in the more recent climate models, while the other half is from the higher radiative forcing (due to the higher greenhouse gas concentrations) from the SSP scenarios than from the comparable RCP scenarios.[19]

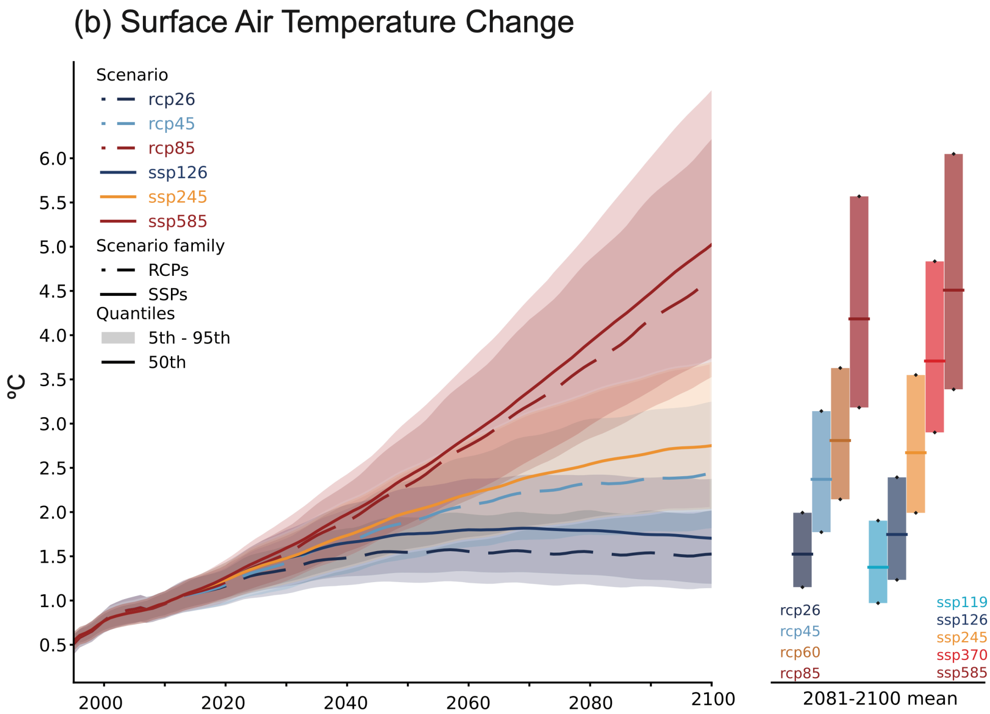


Fig.10: Comparison of global temperature changes simulated by a simple global model for the SSP and RCP scenarios. *Time series with 5–95% ranges and medians of global temperature projections relative to 1850–1900 for the RCP and SSP scenarios from MAGICC 7.5 simple global Earth System Model. MAGICC7.5 was run in the recommended setup used in IPCC AR6 Working Group 3. Reproduced from Figure 4.35(b), IPCC Sixth Assessment Report 'Climate change 2021: The Physical Science Basis'.*[19]

<u>Question 20</u>

Please explain the relationship between the RCPs and SSPs and each of the following:

a. a world where global temperatures are 1.5°C warmer than the Baseline;

b. a world where global temperatures are 2°C warmer than the Baseline; and

c. a world where global temperatures are 3°C warmer than the Baseline.

83. Table SPM.1 of the IPCC AR6 Working Group 1 report[5] summarises the changes in global temperature from the Baseline for selected 20-year periods for each of the SSPs. The changes in global temperature for the corresponding RCPs are similar to but slightly lower than those reported in the IPCC AR6 for the SSPs, as shown in Fig.8 above and explained in Paragraph 82. In the following, I refer primarily to the global temperature

changes for the different SSP scenarios. Table SPM.1 from the IPCC report is reproduced as Table 2 below.

	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

Table 2: Changes in global temperature for selected 20-year periods and five SSP scenarios. *Temperature differences relative to the 1850–1900 Baseline are reported as the best estimate and 5-95% range. Reproduced from Table SPM.1, Summary for Policymakers, IPCC Sixth Assessment Report 'Climate change 2021: The Physical Science Basis'.*[5]

Question 20(a)

84. The only emission scenario that simulates a world in which global temperatures are about 1.5°C warmer than the Baseline in the long term (2081-2100) is the very low emissions (SSP1-1.9) scenario.[4] Under this scenario, as with all the emission scenarios, it is more likely than not that global warming of 1.5°C will be exceeded in the near term (2021-2040). Under the SSP1-1.9 scenario, global temperatures are expected to peak around the middle of the century, with a temporary overshoot of no more than 0.1°C above 1.5°C global warming. Global temperature would then decline slowly, as net global emissions of CO_2 in this scenario fall below zero between 2050 and 2060, reaching substantial net negative emissions of CO_2 larger than 10 Gt per year, as shown in Fig. 7 above.[5]

85. The lowest emission scenario in the RCP scenario group is RCP2.6, with slightly higher emissions and CO_2 concentrations, and median global average temperatures above 1.5°C from about 2050 till 2100, as shown in Fig. 9 and Fig. 10 above. The decline in global temperature from above 1.5°C for the RCP2.6 scenario is slower and smaller than for SSP1-1.9, as the net negative emissions of CO_2 for the RCP2.6 scenario are much smaller and start later that for the SSP1-1.9 scenario.

86. The extent to which current technologies are able to support the assumptions of net negative emissions of CO_2 in scenarios SSP1-1.9, SSP1-2.6 and RCP2.6 is discussed in the response to Question 16 below.

Question 20(b)

87. Global warming of 2°C above the Baseline is extremely likely to be exceeded in the long term (2081-2100) under the intermediate, high and very high GHG emissions scenarios (SSP2-4.5, SSP3-7.0 and SSP5-8.5, respectively).[5] Under the low GHG emission

scenario (SSP1-2.6), global warming is expected to peak below 2°C in 2080-2100 and then fall slowly, as net global emissions of CO_2 in this scenario fall below zero around 2080. SSP1-2.6 is the best scenario for considering a world where global temperatures are 2°C warmer than the Baseline, as the very likely range for global temperatures in the long term is from 1.3°C to 2.4°C.[5]

88. The RCP4.5 scenario provides an alternative and slightly warmer scenario for considering a world where global temperatures are 2°C warmer than the Baseline. Net global emissions of CO_2 for the RCP4.5 scenario remain above zero by 2100 and global temperature continues to increase slowly after 2100.

Question 20(c)

89. In the last two decades of the 21st century, global warming of 3°C is very likely to be exceeded under the very high GHG emissions scenario (SSP5-8.5) and is likely to be exceeded under the high GHG emissions scenarios (SSP3-7.0). The intermediate emission scenario (SSP2-4.5) is the best scenario for considering a world where global temperatures are 3°C warmer than the Baseline, as the very likely range for global temperatures in 2081-2100 is from 2.1°C to 3.5°C, with a best estimate of 2.7°C.[4] Under this scenario, net global emissions of CO_2 remain above zero by 2100 and global temperature continues to increase slowly after 2100.

90. The RCP6.0 scenario provides an alternative scenario for considering a world where global temperatures are 3°C warmer than the Baseline, with a very likely range for global temperatures in 2081-2100 from 2.4°C to 3.7°C, with a best estimate of 2.8°C, as shown in Fig.10 above. Under this scenario, global temperature continues to increase after 2100.

Question 11

Please describe what would happen to atmospheric GHG concentration and global temperatures if the rate of anthropogenic GHG emissions from now until the conclusion of the 21st century remained consistent with the continuation of current global commitments.

91. The Paris Agreement under the UN Framework Convention on Climate Change (**UNFCCC**) is an international treaty on climate change, adopted by 196 Parties that came into force in 2016. Its goal is to pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels" at the end of this century. Under the Paris Agreement, countries have submitted their Nationally Determined Contributions **(NDCs)** since 2020. In their NDCs, each country communicates actions they will take to reduce their greenhouse gas emissions in order to reach the goals of the Paris Agreement. Countries also communicate in their NDCs the actions they will take to build resilience to adapt to the impacts of climate change.

92. Future trajectories of global temperatures and atmospheric GHG concentrations have been assessed by the United Nations Environment Programme (**UNEP**) through their *Emissions Gap Report 2022*,[20] which was released prior to the 27th Conference of Parties

(**COP**) of the UNFCCC in October 2022. That report assesses the gap between emissions reduction commitments made by all countries through their NDCs to the UNFCCC following the COP26 in 2021. That report should be considered as part of the Best Available Science because it has been prepared by a large group of expert scientists as lead authors and contributing authors and then reviewed by more than 50 independent scientists.

93. Policies for emissions reduction in place across all countries in 2021 and referred to in their NDCs, with no additional emissions reductions, are projected to result in global warming of 2.8°C above the Baseline over the twenty-first century.[20] Implementation of unconditional and conditional emission reduction scenarios in some NDCs, with some increased national emissions reduction commitments, would reduce this to 2.6°C and 2.4°C respectively. Hence, under current commitments from 2021, the world would appear to follow the SSP2-4.5 scenario in terms of future anthropogenic GHG emissions (Fig. 7), atmospheric GHG concentrations (Fig. 9) and global temperatures (Fig. 10 and Table 2).[11]

94. To limit global warming to 1.5°C, global annual GHG emissions would need to be reduced by an additional 45 per cent by 2030 compared with emissions projections under national policies reported in their NDCs to COP26 in 2021, and they would need to continue to decline rapidly after 2030.[11]

Projected impacts of climate change

Question 12

Please describe the likely nature and scale of the Impacts of Climate Change from now until the conclusion of the 21st century:

- *a. globally;*
- *b. in Australia; and*
- *c. in the Torres Strait Islands,*

in a world where:

- *i. global temperatures are 1.5°C warmer than the Baseline;*
- *ii. global temperatures are 2°C warmer than the Baseline; and*
- *iii. global temperatures are 3°C warmer than the Baseline.*

95. The IPCC AR6 provides the most comprehensive recent assessment of the global Impacts of Climate Change, both physical impacts,[5] and impacts on terrestrial ecosystems.[8] The answers to question 20 above (Paragraphs 83-90) describe the appropriate emission scenarios to consider for a world where global temperatures are 1.5°C warmer than the Baseline, 2°C warmer than the Baseline, and 3°C warmer than the Baseline towards the end of the 21st century. A key conclusion from IPCC AR6 is that "[m]any changes in the climate system become larger in direct relation to increasing global warming." [5] Hence, many impacts of climate change will increase over time as global warming increases. In a world with global warming of 1.5°C, these impacts will be greater than at present, larger again in a world with global warming of 2°C, and even larger in a world with global warming of 3°C. This is shown in Fig. 6 above.

Question 12 (a) Impacts of climate change globally until the end of the 21st century

96. In the following Paragraphs, I describe the global Impacts of Climate Change individually, as listed in Question 9, for the three different levels of global warming.

97. **Global temperature**:

    a) In a world where global temperatures are 1.5°C warmer than the Baseline at the end of the 21st century, global temperatures are expected to increase from current levels, peak around the middle of the century, with a temporary overshoot of no more than 0.1°C above 1.5°C global warming, and then decline slowly to the end of the century (Paragraph 84-86 and Table 2, SSP1-1.9).

    b) In a world where global temperatures are 2°C warmer than the Baseline at the end of the 21st century, global temperatures are expected to increase from current levels, peak just below 2°C in 2080-2100 and then fall slowly or to reach 2°C in 2080-2100 and continue to rise slowly beyond 2100 (Paragraph 87-88 and Table 2, RCP2.6).

    c) In a world where global temperatures are 3°C warmer than the Baseline at the end of the 21st century, global temperatures are expected to increase from current levels, reach just below 3°C in 2080-2100 and then continue to increase after 2100 (Paragraph 89-90 and Table 2, SSP2-4.5, RCP6.0).

98. **Ocean surface temperature**: Increases in global average ocean surface temperature will follow those in global mean temperature described in the previous Paragraph but the changes will be about 20% smaller. The global land surface temperature will continue to increase more than the ocean surface temperature (likely 1.4 to 1.7 times more)[5] and more than the global mean temperature.

99. **Ocean acidification**: Ocean acidification will increase in direct response to the increases in atmospheric CO_2 concentrations (Paragraph 43). For global warming of 1.5°C, ocean acidity will be about 20% higher than current levels, about 30% higher for global warming of 2°C at the end of the century, and about 50% higher for global warming of 3°C at the end of the century.[5]

100. **Sea ice**: Arctic sea ice area at its September minimum has already fallen from 1970 levels by about 30% for current global warming of 1.1°C. It is expected to decline about an additional 15% from current levels for global warming of 1.5°C, a further 30% from current levels for global warming of 2°C, and for the Arctic to be practically ice-free at its September minimum for global warming of 3°C or more. Projections of sea ice extent in the Antarctic have large uncertainties, but show large declines for global for global warming of 3°C or more.

101. **Permafrost**: Quantitative estimates of global reductions in permafrost are not available because it is not represented well in current global Earth System models. Melting of permafrost increases in direct relation to increases in global land surface temperatures. Hence, reductions in permafrost will be greater than at present for global warming of 1.5°C, greater again for global warming of 2°C and it may disappear completely for global warming of 3°C.

102. **Humidity**: Global average specific humidity near the surface and in the lower atmosphere is projected to increase by about 7% for every degree of global warming relative to the Baseline (Paragraph 52). Hence, specific humidity will be about 3% higher than current levels for global warming of 1.5°C, about 7% higher for global warming of 2°C and about 14% higher for global warming of 3°C. Global average relative humidity is projected to change little with global warming but average relative humidity over land is projected to decrease slightly as global warming increases.[19]

103. **Precipitation**: "Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation and the severity of wet and dry events."[5] "Precipitation is projected to increase over high latitudes, the equatorial Pacific and parts of the monsoon regions, but decrease over parts of the subtropics and in limited areas of the tropic."[5] Extreme daily precipitation is projected to increase linearly with increases in global mean temperature (as shown in Fig.6 in Paragraph 57).

104. **Extreme weather events**: The changes in the climate system that become larger in direct relation to increasing global warming "include increases in the frequency and intensity of hot extremes, marine heatwaves, and heavy precipitation, agricultural and ecological droughts in some regions, and proportion of intense tropical cyclones, as well as reductions in Arctic sea ice, snow cover and permafrost."[5] The global increases of extreme temperatures, drought, extreme daily rainfall, and the proportion of intense tropical cyclones with global warming are illustrated in Fig.6 above (Paragraph 57-60) for global warming at current levels and for global warming of 1.5°C, 2°C and 4°C.

105. **Sea level rise**: Relative to 1995-2014, the likely global mean sea level rise by 2100 is 0.28-0.55m in a world with global warming of 1.5°C (SSP1-1.9), 0.32-0.62m in a world with global warming of 2°C (SSP1-2.6), and 0.44-0.76m in a world with global warming of 3°C (SSP2-4.5). [5] It is important to note that the magnitude of sea level rise is delayed relative to changes in global temperature and will continue for a very long period after global temperature has stabilised. "In the longer term, sea level is committed to rise for centuries to millennia due to continuing deep ocean warming and ice sheet melt."[5]

106. **Terrestrial ecosystems**: "Biodiversity loss and degradation, damages to and transformation of ecosystems are already key risks for every region due to past global warming and will continue to escalate with every increment of global warming (very high confidence). In terrestrial ecosystems, 3 to 14% of species assessed will likely face very high risk of extinction at global warming levels of 1.5°C, increasing up to 3 to 18% at 2°C, 3 to 29% at 3°C …".[8]

Question 12 (b) Impacts of climate change in Australia until the end of the 21st century

107. The response to this question is based on the following recent assessments:

    a) IPCC AR6 Working Group I, *Regional Factsheet for Australasia*;[9]

    b) IPCC AR6 Working Group II, *Fact Sheet – Australasia: Climate Change Impacts and Risks*;[10] and

    c) CSIRO and Bureau of Meteorology, *State of the Climate 2022*.[4]

108. The increase in Australian average annual temperature above the Baseline for different global warming levels is illustrated in Fig. 11 below. In a world with global warming of 1.5°C, Australian average temperature would be about 2.1°C above 1850-1900 levels. This is likely to be experienced in the 2021-2040 period. In a world with global warming of 2°C, Australian average temperature would be about 2.8°C above 1850-1900 levels.

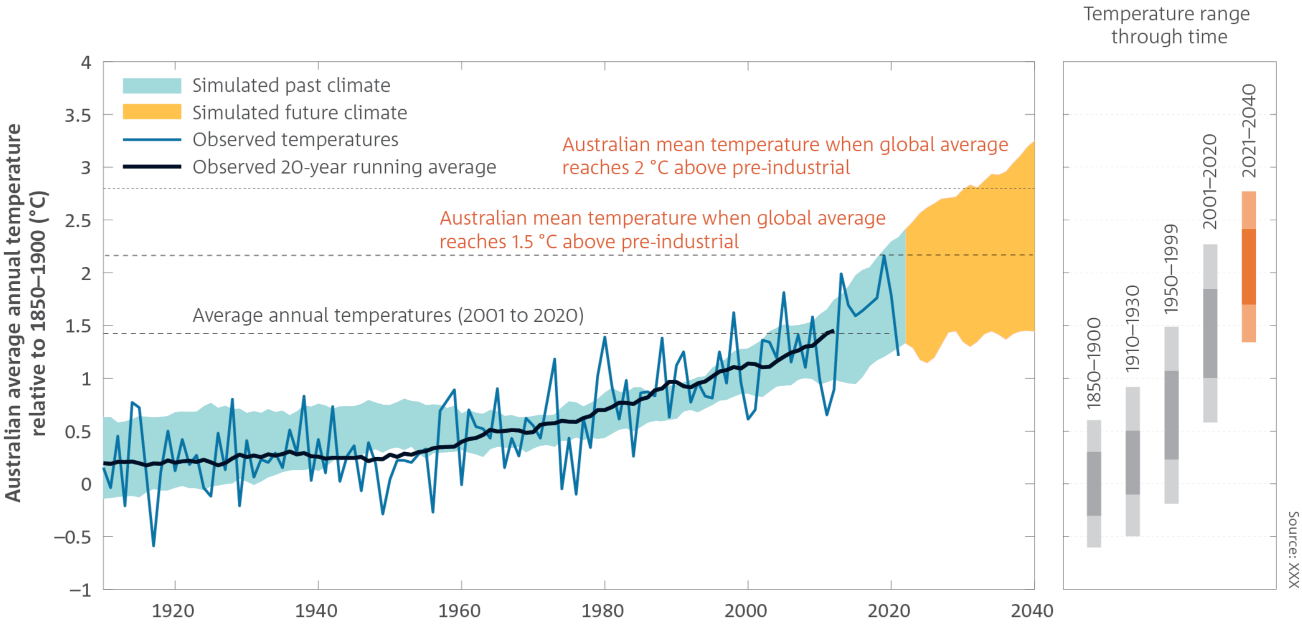


Fig. 11: Australian average annual temperature in observations and global climate models relative to the 1850–1900 Baseline*. Past and future coloured bands show the 20-year running average from models for historical conditions and all plausible future scenarios to 2040. Black dashed lines show the average warming expected for Australia when the global average temperature reaches 1.5 and 2.0 °C above the pre-industrial era. The panel to the right shows the range of temperatures (one and two standard deviations) in various epochs from observations and the 2021–40 period as simulated by one climate model (the results from which are close to the mean of all models). Reproduced from State of the Climate 2022*[3]

109. The physical impacts of climate change across Australia in coming decades, for global warming of 1.5°C to 2°C, are illustrated in Fig.12 below, from the *State of the Climate 2022* report.

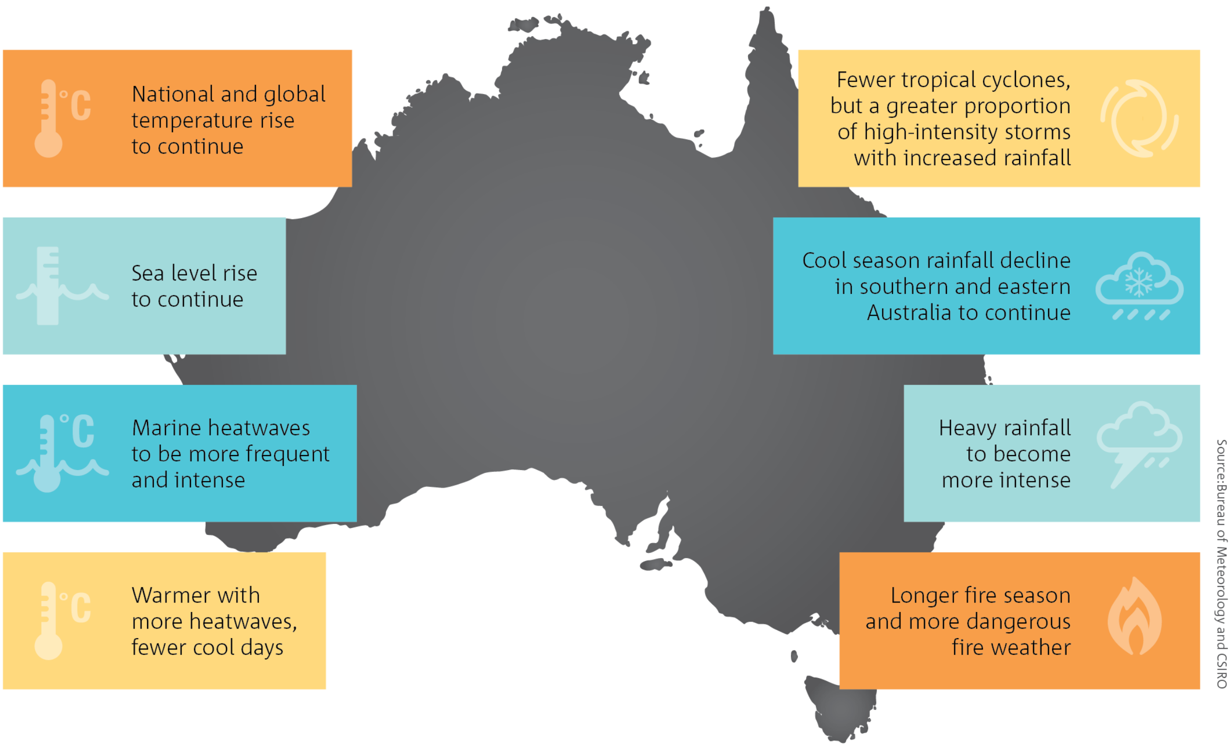


Fig. 12: Projected physical impacts of climate change across Australia in coming decades. *Reproduced from State of the Climate 2022.*[4]

110. The IPCC AR6 Working Group I *Regional Factsheet for Australasia*[9] states that changes in "… heatwaves, droughts, floods; … would be more widespread at 2°C compared to 1.5°C global warming and even more widespread and/or pronounced for higher warming levels." For Northern Australia, it concludes:

a) "Projected mean rainfall changes are uncertain. An increase in heavy rainfall and river flooding (is) projected by mid century (medium confidence)."

b) "Projected decrease in cyclone frequency but increase in the proportion of severe cyclones (medium confidence)."

111. IPCC AR6 Working Group II *Fact Sheet – Australasia: Climate Change Impacts and Risks*[10] identifies nine key risks from climate change that are projected to increase for a wide range of systems, sectors and communities. Those most relevant to Northern Australia and the Torres Strait Islands include:

a) "Loss and degradation of coral reefs and associated biodiversity and ecosystem service values in Australia due to ocean warming and marine heatwaves (very high confidence)."

b) "Loss of natural and human systems in low-lying coastal areas due to sea-level rise (high confidence)."

<u>Question 12 (c) Impacts of climate change in the Torres Strait Islands until the end of the 21st century</u>

112. The recent report *Climate Change in Cape York region*[21] has been prepared by the Queensland Government. It presents details of the expected changes to temperature, rainfall and the sea across the Cape York region. It highlights the likely impacts of climate change on people and the environment and presents ways to respond. A summary of the likely physical impacts of climate change in this region are presented in Fig. 13 below.

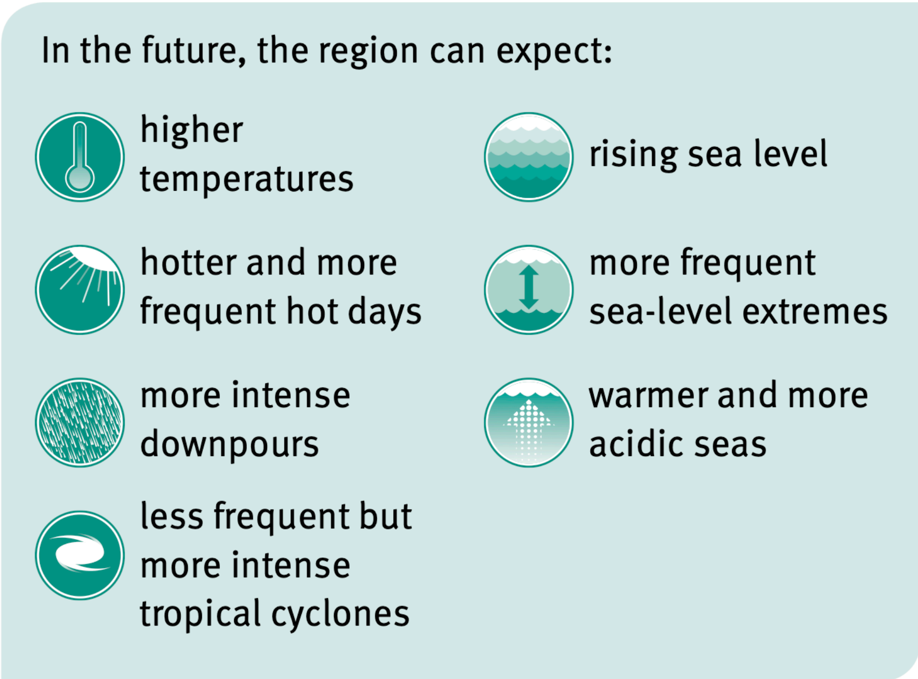


Fig. 13: How will climate change affect the Cape York region?
Reproduced from 'Climate change in the Cape York region'.[18]

113. Specific projections of the future climate of the Torres Strait Islands have been prepared using down-scaled high resolution regional climate model simulations undertaken by the Queensland Government and extracted from the *Queensland Future Climate Dashboard*.[22] These projections are available for a 20-year period centred on 2030, representative of a world with global warming of 1.5°C (for both RCP4.5 or RCP8.5 as global warming in 2030 is not sensitive to the emission scenario), a 20-year period centred on 2070, with mid-range emissions (RCP4.5), representative of a world with global warming of 2°C, and a 20-year period centred on 2070, with high emissions (RCP8.5), representative of a world with global warming of 3°C (See Fig. 10 for the relevant global temperature). The projections are presented as changes relative to the average for the period 1986-2005, not changes relative to the 1850-1900 Baseline. The changes are presented as the median change across the group of eleven models used, together with the uncertainty range across the models from the 10th and 90th percentile changes in brackets. Details of the physical impacts of climate change in the Torres

Strait from these projections are presented for the most important variables in the paragraphs below.

114. Mean annual temperature change in the Torres Strait region relative to 1986-2005 is projected to be 0.7°C (0.5°C - 0.9°C) for global warming of 1.5°C; 1.3°C (0.9°C – 1.5°C) for global warming of 2°C; and 2.0°C (1.7°C – 2.5°C) for global warming of 3°C.[22]

Changes over time for regions

Long-term changes relative to reference period (1986-2005)

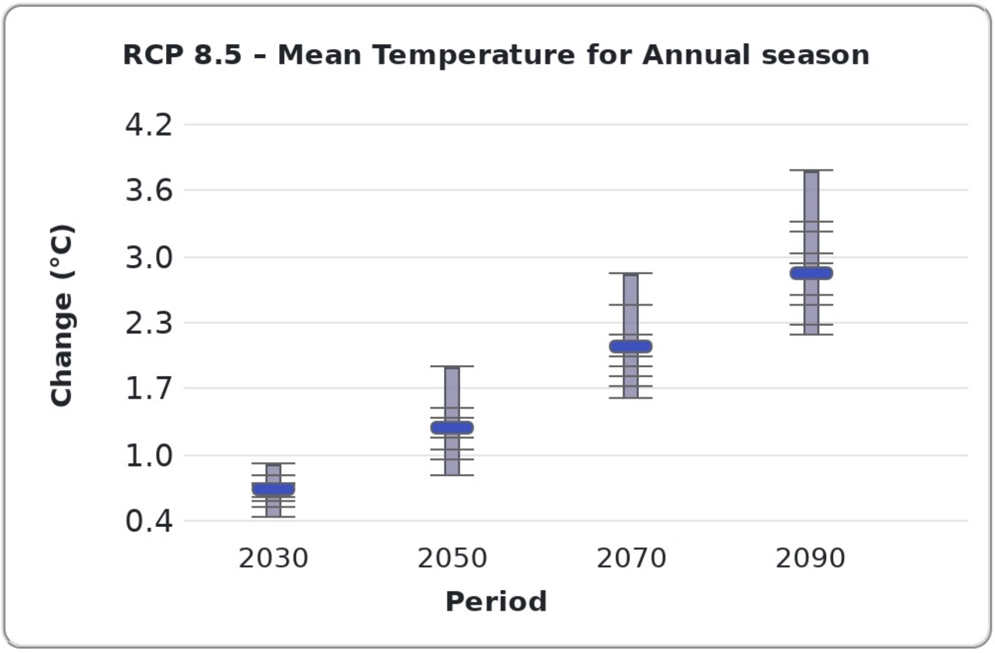


Fig. 14: Mean temperature change in the Torres Strait region.
Extracted from the Queensland Future Climate Dashboard.[22]

115. The mean annual change in heatwave duration in the Torres Strait region relative to 1986-2005 is projected to be an increase of 2.5 days per year (-0.4 days to +3.0 days per year) for global warming of 1.5°C; 9 days per year (5 days to 17 days per year) for global warming of 2°C; and 55 days per year (37 days to 120 days per year) for global warming of 3°C.

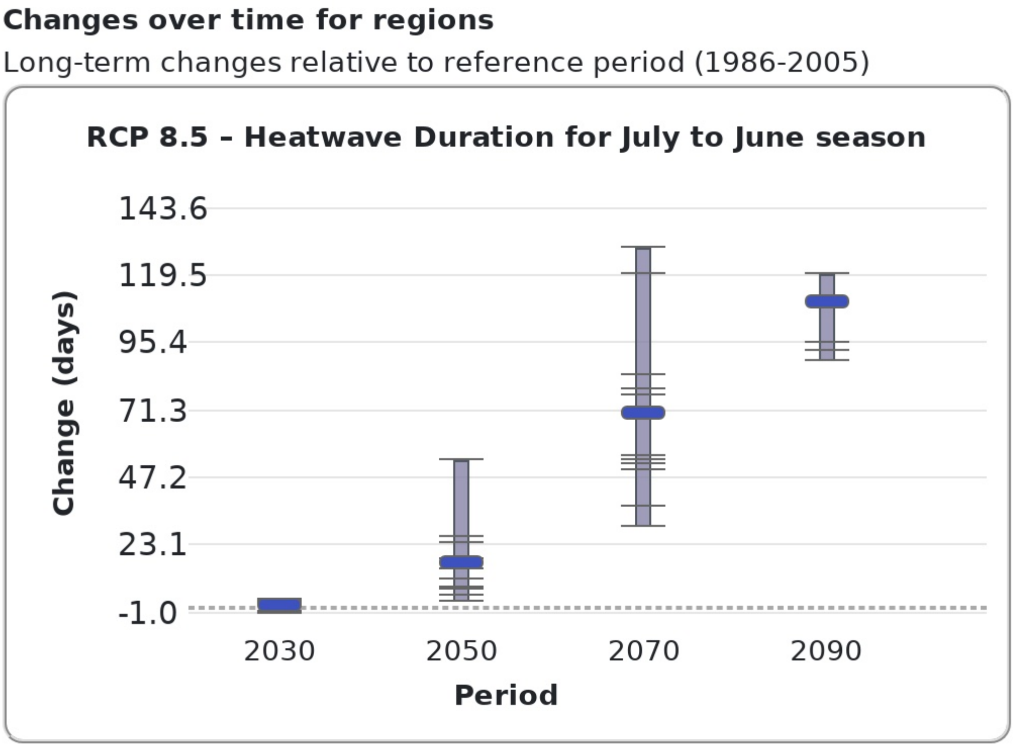


Fig. 15: Change in mean heatwave duration in the Torres Strait region.
Extracted from the Queensland Future Climate Dashboard.[22]

116. The projected increase in the heatwave peak temperature due to climate change is similar to but slightly larger than the increases in mean annual temperature described in Paragraph 114 above and Fig. 14.

117. The mean changes in total annual rainfall in the Torres Strait region are small and quite uncertain across the range of different global climate models. The rainfall change is projected to be -2% (-13% to +6%) for global warming of 1.5°C; and -4% (-17% to +8%) for global warming of 2°C; and -8% (-20% to +2%) for global warming of 3°C.

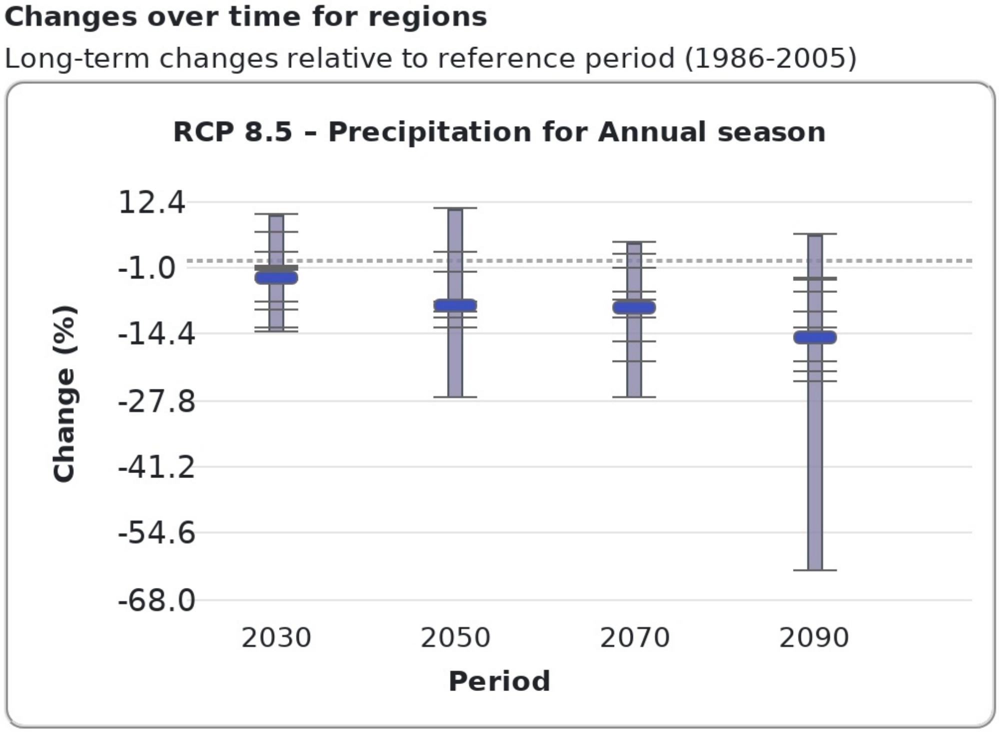


Fig. 16: Mean rainfall change (%) in the Torres Strait region.
Extracted from the Queensland Future Climate Dashboard.[22]

118. For several key impacts of climate change in the Torres Strait region, the *Queensland Future Climate Dashboard*[22] does not show any statistically significant projected changes.

   a) For extreme rainfall, it does not show a change in the projected rainfall for the wettest day of the year. However, this is expected to increase for sub-daily and hourly extreme rainfall from thermodynamic arguments, as indicated in Fig.13 above.

   b) Relative humidity is an important component of the health impacts of climate change during heat waves. For the Torres Strait Islands, relative humidity is high throughout the year, particularly during the wet season with values around 80%. Projected impacts of climate change on relative humidity are small, with small projected increases of less than 1% even for global warming of 3°C.

Tipping points

Question 13

Please explain the concept of 'tipping points' and the relevance (if any) that they have on the relationship between GHG emissions, atmospheric GHG concentration, and global temperatures.

119. Tipping points in the climate system or the Earth system refer to critical thresholds in components of the system, beyond which the component, or tipping element, reorganises abruptly and sometimes irreversibly.[1] There is discussion in Box TS.9 *Irreversibility, Tipping Points and Abrupt Changes* in the Technical Summary of the IPCC AR6 Working Group 1 Report[19] on a number of past and potential future examples of tipping elements. Over the relatively stable climate of the last two thousand years, exceedance of any of the tipping points can be considered as extremely low probability events that would have major impacts on global or regional climate if they were to occur. There has been substantial research and consideration of possible tipping points associated with human-caused climate change in the IPCC assessment reports, including the AR6.

120. The risk of exceedance of the critical thresholds for any of the tipping elements increases greatly with higher levels of global warming and climate change. Some of the tipping elements are part of positive feedback loops in which global temperature increase can trigger the tipping element, which leads to increased GHG emissions, increased atmospheric GHG concentrations, and further global warming. An example is melting of Artic permafrost, which would release trapped methane and CO_2 (see Paragraphs 48-50). Another example is the warming and drying of regional climate in South America causing Amazon deforestation, which would increase CO_2 emissions and remove an important sink of atmospheric CO_2.

Question 14

Please explain the relevance (if any) that tipping points have on the Impacts of Climate Change.

121. The current Impacts of Climate Change are addressed in Paragraphs 41-62 in answer to Question 9 above. Tipping elements are very likely to substantially increase some of the Impacts of Climate Change in the future if the critical threshold for the tipping element is exceeded. Some tipping elements are likely to have more regional impacts, such as the die-off of low latitude coral reefs, whereas others would have global impacts, such as sea level rise from the collapse of the Greenland ice sheet or the West Antarctic ice sheet. Both these tipping elements, tropical coral bleaching and sea level rise, are impacts of climate change in the Torres Strait Islands and have global warming thresholds of less than 2°C, as shown in Fig. 17 below.

122. A number of the tipping elements in the Earth system are only crudely represented in the current generation of Earth system models assessed in IPCC AR6 or are not represented at all. As discussed in Paragraph 120, some of these tipping elements are part of positive feedback loops that could lead to amplification of climate change and its impacts. However, these tipping elements are not represented well in the current generation of global Earth system models. Hence, projections of climate change based on current global Earth system models may underestimate the risks of possible higher magnitudes of future global warming.

123. A key conclusion from the IPCC AR6,[5] based on its assessment of tipping points and abrupt changes, is that "[l]ow-likelihood outcomes, such as ice sheet collapse, abrupt ocean circulation changes, some compound extreme events and warming substantially larger than the assessed *very likely* range of future warming cannot be ruled out and are part of risk assessment."

Question 15

Please explain the risk of reaching 'tipping points' in a world where:

a. global temperatures are 1.5°C warmer than the Baseline;

b. global temperatures are 2°C warmer than the Baseline; and

c. global temperatures are 3°C warmer than the Baseline.

124. An assessment of the global warming levels at which a number of tipping elements would likely exceed their critical thresholds has been reported in a recent multi-author review paper in the high-impact scientific journal *Science*.[23] Fig. 17 below shows the selected wide range of tipping elements in different geographical regions, together with estimated global warming ranges that would exceed their critical thresholds. Some of these tipping elements are described above in Paragraphs 120 and 121.

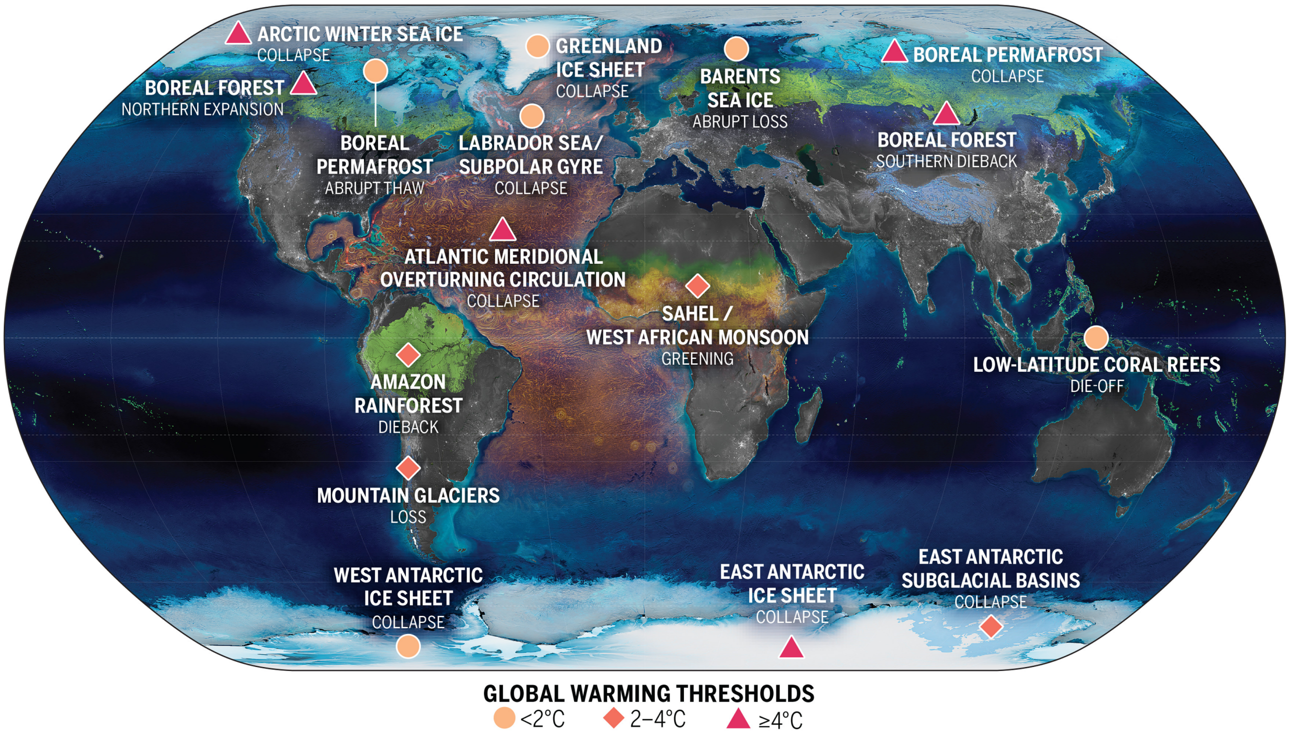


*Fig. 17: **Global warming thresholds for a range of climate tipping elements.** The locations of climate tipping elements in the cryosphere (blue), biosphere (green), and ocean/atmosphere (orange), and global warming levels at which their tipping points will likely be triggered. Reproduced from Armstrong McKay, D.L., et al. (2022).*[16]

125. The risk of exceeding any of the critical thresholds (tipping points) shown in Fig.17 is much lower in a world where global temperatures are less than 1.5°C warmer than the Baseline, such as in the current climate. The risk of reaching any of these tipping points is greater for every increase of global temperature from 1.5°C warmer than the Baseline, and much greater for global warming of 3°C.

126. All of the tipping elements in Figure 17 with global warming thresholds of less than 2°C (indicated with circles) are likely to be triggered in a world where global temperatures are 2°C warmer than the Baseline. These would lead to much greater risks of higher magnitude climate change impacts than have been projected at present. As described in Paragraph 120, this could lead to unexpected rapid changes in components of the Earth system, included major increases in greenhouse gas emissions from permafrost melting or dieback of the Amazon rainforest; rapid enhancement of sea level rise from the collapse of the Greenland or West Antarctic ice sheets; and major ecosystem collapses associated with die-off of tropical coral reefs. Any and all of these tipping elements, if triggered, would greatly increase the impacts of climate change in the Torres Strait Islands.

Removing GHGs from the atmosphere

Question 16

Please describe the current state of science and technology with respect to the ability to remove GHGs from the atmosphere.

128. As discussed above in Paragraph 20, there are natural sinks or loss processes that remove the three main long-lived GHGs, CO_2, menthane and nitrous oxide, from the atmosphere. I answer this question in terms of human activities to increase the removal of CO_2 from the atmosphere, often called 'negative emission technologies'. In November 2022, CSIRO released a report (commissioned by the CCA) entitled *Australia's carbon sequestration potential*[24] on the potential in Australia for net CO_2 emissions reductions through avoided and negative emissions. This report is a stocktake and analysis of carbon sequestration technologies in Australia, including their costs and risks, and novel technologies that may have the potential to deliver enhanced net emission reductions over the next 5-10 years.

129. This CSIRO report uses the IPCC definition of carbon sequestration as "the storage of carbon in a carbon pool"[24]. It assesses different technologies in terms of their sequestration potential in three different classifications: technical, economic, and realisable sequestration potential:

    a) ***Technical sequestration potential*** is the maximum technically or biophysically possible sequestration for the technology being reviewed.

    b) ***Economic sequestration potential*** is the amount of sequestration considering economic feasibility and concerted efforts to implement technical and management changes.

    c) ***Realisable sequestration potential*** considers the limitations of resource constraints and implementation feedbacks that limit scaling, as well as institutional settings and removal of barriers.

130. The CSIRO report considers technical sequestration potential and the economic sequestration potential, which is smaller than the technical potential. The report does not consider realisable sequestration potential at all, which in my opinion, is likely to be much smaller, by a factor of five to ten, than the estimates of the economic sequestration potential. In addition, climate change impacts on possible nature-based sequestration, such as increases in bushfires, increases in heatwaves and reductions in rainfall, are not considered in the report.

131. The wide range of carbon sequestration technologies assessed in this CSIRO report is illustrated in Fig.18 below, reproduced from the report. This shows that the economic sequestration potential with the lowest costs and the highest commercial readiness are the nature-based technologies. Other technologies, such as geological carbon capture and storage (**CCS**) and direct air capture, have higher costs, lower commercial readiness

and, in some cases, unknown magnitudes of economic sequestration potential because these technologies have not been developed, tested nor used at industrial scale in Australia.

132. The CSIRO report provides a comparison of the differences between the estimated technical potential for sequestration from nature-based technologies in 2050 with the economic potential (shown in Fig. 18). These technologies include permanent plantings, plantation and farm forestry, and soil carbon, with total technical sequestration potential of 1,220 Mt per year by 2050. The total economic sequestration potential for these technologies is only 93 Mt per year by 2050 (Fig.18), smaller by more than a factor of ten than the technical sequestration potential.

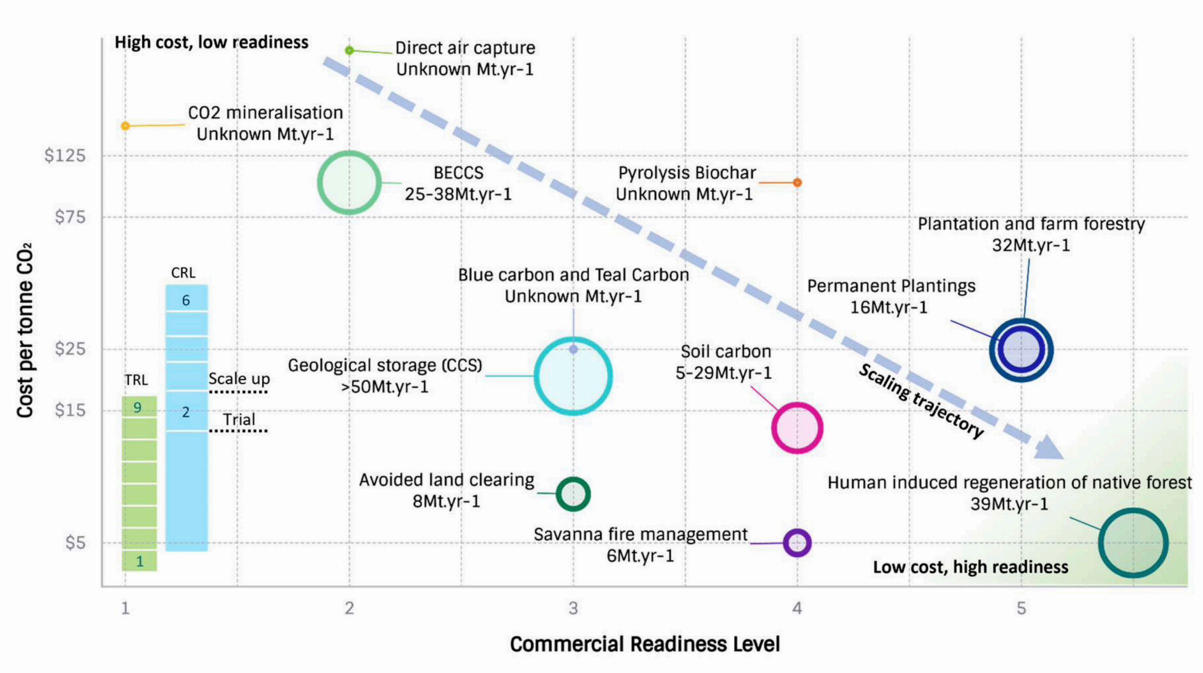


Fig. 18: Overview of economic carbon sequestration potential in 2050 for reviewed technologies, *indicating their commercial readiness level and cost per tonne. Note the anticipated scaling trajectory to the lower right corner, corresponding to low cost and high commercial readiness. Reproduced from Figure 3 of Fitch, P., M. Battaglia, et al. (2022).*[24]

133. Nature-based technologies for carbon sequestration are already being used in Australia and are reported by the Department of Climate Change, Energy, the Environment and Water (**DCCEEW**) under the Land Use, Land Use Change and Forestry (**LULUCF**) sector. Annual GHG emissions in the LULUCF sector[25] were 85 Mt CO_2-e in 2005 but changed to GHG removal of 39 Mt CO_2-e by 2020 through reductions in land clearing and major increases in afforestation and reforestation. *Australia's emission projections 2022*[25] from DCCEEW reports baseline projections for negative GHG emissions in the LULUCF sector of 33 Mt CO_2-e in 2030 and 44 Mt CO_2-e in 2035. These would amount to about a 10% reduction of Australia's total GHG emissions in other sectors in 2035.

134. Net zero global emissions of CO_2 and other GHGs are required by 2050 to limit global temperature rise to 1.5°C above the Baseline (Paragraph 84 and Fig.9). In my opinion, there is a negligible chance that the realisable carbon sequestration potential in Australia will be sufficient to reduce Australia's net emissions to zero by 2050. This is because nature-based technologies are expected to make only a very small contribution of negative emissions to Australia's projected total GHG emissions in 2035 and the magnitude of realisable carbon sequestration potential from other technologies in 2050 is highly uncertain.

Australia's role in climate change

Question 17

Please explain the terms 'scope 1', 'scope 2', and 'scope 3' emissions.

135. Scope 1, scope 2 and scope 3 emissions are defined under the National Greenhouse and Energy Reporting (**NGER**) scheme,[26] which applies to large businesses and companies in Australia.

a) ***Scope 1*** GHG emissions are the emissions released to the atmosphere as a direct result of an activity, or series of activities, at a business. Scope 1 emissions are sometimes referred to as direct emissions (for example, emissions associated with fossil fuel combustion in boilers, furnaces and vehicles).

b) ***Scope 2*** greenhouse gas emissions are the emissions released to the atmosphere from the indirect consumption of an energy commodity. For example, 'indirect emissions' come from the use of electricity produced by the burning of coal in another business. Scope 2 emissions from one business are part of the scope 1 emissions from another business. Both scope 1 and scope 2 emissions are specified under the NGER legislation and must be reported.

c) ***Scope 3*** emissions are indirect greenhouse gas emissions other than scope 2 emissions that are generated in the wider economy. They occur as a consequence of the activities of a business, such as product purchases or sales along its supply chain, but from sources not owned or controlled by that business. Scope 3 emissions are not reported under the NGER scheme.

136. Australia's national greenhouse gas emissions reports under the UNFCCC include all domestic scope 1, scope 2 and scope 3 emissions from all human-related activities undertaken within Australia, whether by businesses, governments or organisations. However, these reports do not include the associated GHG emissions from exports of fossil fuels, such as coal and gas that are extracted in Australia but exported and used in other countries. In effect, these GHG emissions in other countries associated with Australia's fossil fuel exports are scope 3 emissions for Australia. Australia's GHG emission reports do include the GHG emissions from imported fossil fuels, such as oil, petrol and diesel, that are used within Australia, as these are scope 1 emissions.

Question 18

*Please provide an overview of Australia's contribution to global anthropogenic GHG emissions (**Australia's contribution**) since 1990 both overall and in relation to each of 'scope 1', 'scope 2' and 'scope 3' emissions.*

In your answer, please include:

a. *the total quantum of Australia's contribution;*

b. *Australia's contribution as a percentage of total global anthropogenic GHG emissions; and*

c. *Australia's contribution expressed on a per capita basis in comparison with the per capita contribution of other nations.*

137. Australia's emissions of greenhouse gases from 1990 to 2020 have been reported to the UNFCCC and are available on the UNFCCC GHG Data Interface. Over the period 1990-2020, Australia's cumulative GHG emissions from all sectors, including LULUCF, was 17.3 Gt CO_2-e. This is the total quantum of Australia's domestic contribution to global anthropogenic greenhouse gas emissions during 1990-2020. As noted in Paragraph 136 above, these annual data for Australian emissions include all scope 1, scope 2 and scope 3 emissions from activities undertaken within Australia.

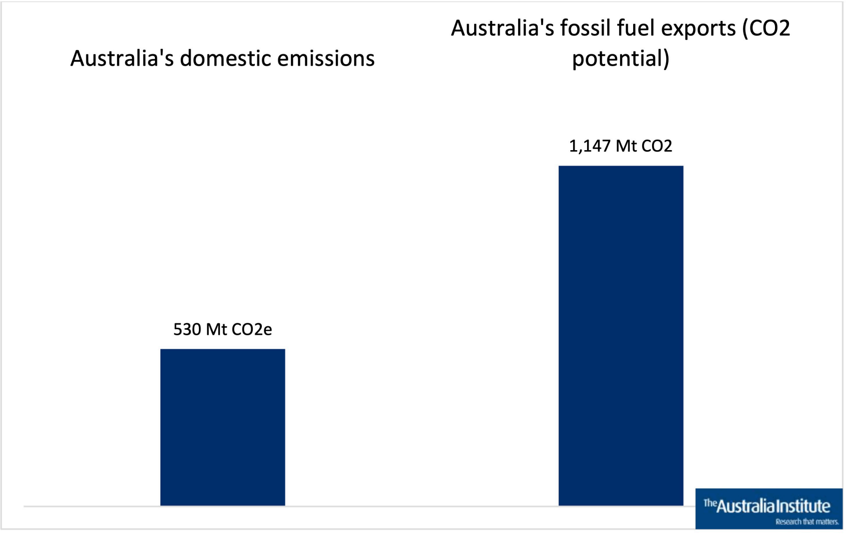
138. Global anthropogenic GHG emissions from all countries are not available from the UNFCCC from 1990 as some countries were not required to report their emissions from that year. Annual total global anthropogenic GHG emissions are available from Jones at al. (2023),[27] published in a high-quality scientific journal. These data have been used to calculate Australia's contribution as a percentage of cumulative total global anthropogenic GHG emissions over 1990-2020, which is 1.21 percent. Australia's contribution as a share of global GHG emissions has fallen over time, from 1.38 percent in 1990-99 to 1.03 percent in 2010-19, as Australia's emissions have fallen and global emissions have grown substantially over this period. The decade 2010-2019, was used to show how Australia's contribution as a share of global GHG emissions has changed over time. This is because global GHG emissions and Australian GHG emissions were lower in 2020 due the effects of COVID restrictions on economic activity and therefore GHG emissions in 2020 (See Paragraph 31).

139. Australia's contribution to global anthropogenic GHG emissions expressed on a per-capita basis shows that Australia's per capita emissions have fallen substantially from 1990, when they were 31.6 tonnes per person, to 2020 when they were 23.5 tonnes per person, due to a 22% reduction in annual emissions and growth in Australia's population. However, it is important to compare Australia's per capita emissions to those for other developed countries. In 1990, Australia had the highest per capita emissions of all developed countries in the world. In 2020, Australia continues to have higher per capita emissions than other developed countries, such as Canada (20.0t), United States (16.8t), New Zealand (13.7t), Germany (8.5t) and the United Kingdom (6.1t).[28] While GHG emissions from China are now the highest for any country in the

world and its per capita emissions have grown rapidly from 3.8t in 1990 to 9.2t in 2020, its per capita emissions are still less than half of Australia's per capita emissions in 2020.

140. Australia's contribution to global anthropogenic GHG emissions is much larger than just its national emissions from activities undertaken within Australia. In addition, Australia is responsible for substantial scope 3 emissions associated with its fossil fuel exports of coal and natural gas. These fossil fuel exports are used and reported in other countries but they benefit the Australian economy [redacted].

141. The estimated magnitude of the GHG emissions associated with the use of Australia's fossil fuel exports in 2018 by other countries is more than double Australia's domestic GHG emissions in 2018, as shown below in Fig. 19 from Swann (2019).[29]



Source: IEA (2018) *World Energy Balances*; IPCC (2006) *IPCC Guidelines*, as described in text; Commonwealth of Australia (2019) *Quarterly Update of Australia's National Greenhouse Gas Inventory for September 2018*

Fig. 19: Australia's domestic GHG emissions vs fossil fuel exports.
Reproduced from Figure 10 of Swann (2019).[29]

Declaration

I declare that:

(a) my opinions in this report are based wholly or substantially on specialised knowledge arising from my training, study and experience;

(b) the opinions stated in this report are genuinely held by me;

(c) the factual matters stated in this report are, as far as I know, true;

(d) I have made all the inquiries which I believe are desirable and appropriate; and

(e) No matters of significance which I regard as relevant have, to my knowledge, been withheld.

David Karoly

Professor David Karoly FAA 25 May 2023

References

[1] IPCC, 2021a: Annex VII: Glossary [Matthews, J.B.R., et al. (eds.)]. In *Climate Change 2021: The Physical Science Basis.* Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, et al. (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 2215–2256.

[2] Mastrandrea, M.D., et al., 2010: *Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties*, Intergovernmental Panel on Climate Change, p. 6.

[3] IPCC, 2021b: *Climate Change 2021: Summary for All,* 16 p. This summary was written and reviewed by the two Co-Chairs of the IPCC AR6 Working Group I, members of the IPCC AR6 Working Group 1 Technical Support Unit, and twelve chapter Lead Authors of the IPCC AR6 Working Group I report. Available from https://www.ipcc.ch/report/ar6/wg1/downloads/outreach/IPCC_AR6_WGI_SummaryForAll.pdf

[4] CSIRO and the Bureau of Meteorology, 2022: *State of the Climate 2022*. Commonwealth of Australia. 28 pp. ISBN 978-1-4863-1770-7. Available from https://www.csiro.au/-/media/OnA/Files/SOTC22/22-00220_OA_REPORT_StateoftheClimate2022_WEB_221115.pdf

[5] IPCC, 2021c: Summary for Policymakers. In *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, et al. (eds.)]. Cambridge University Press, p. 41.

[6] IPCC, 2022a: Summary for Policymakers. In *Climate Change 2022: Mitigation of Climate Change.* Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, et al. (eds.)], Cambridge University Press, p. 53.

[7] Friedlingstein, P., et al., 2022: Global Carbon Budget 2022. *Earth Syst. Sci. Data*, **14**, 4811–4900.

[8] IPCC, 2022b: Summary for Policymakers. 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* [Drafting Authors, H-O. Portner L.A. Roberts, et al.] IPCC, Geneva, Switzerland, p. 35.

[9] IPCC 2021c: *Regional Factsheet – Australasia*, released as part of *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, p. 2. Available from https://www.ipcc.ch/report/ar6/wg1/downloads/factsheets/IPCC_AR6_WGI_Regional_Fact_Sheet_Australasia.pdf

[10] IPCC 2022c: *Factsheet – Australasia*, Sixth Assessment Report, Working Group II – Impacts, Adaptation and Vulnerability. Available from https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FactSheet_Australasia.pdf

[11] Australian Academy of Science, 2021: *The risks to Australia of a 3°C warmer world*, p. 97. Available from https://www.science.org.au/files/userfiles/support/reports-and-plans/2021/risks-australia-three-deg-warmer-world-report.pdf

12 Cresswell I.D., T. Janke and E.L. Johnston, 2021: *Australia state of the environment 2021: overview*, independent report to the Australian Government Minister for the Environment, Commonwealth of Australia, Canberra, p. 272.

13 Data used for Horn Island (site 027058) from ACORN-SAT v2.2 high quality temperature dataset from the Bureau of Meteorology. Available from http://www.bom.gov.au/climate/data/acorn-sat/

14 Based on Bureau of Meteorology monthly climate statistics for Horn Island (site 027058) and Thursday Island MO (site 027022). Available from http://www.bom.gov.au/climate/data/index.shtml?bookmark=200

15 Suppiah, R., et al, 2010: *Observed and Future Climates of the Torres Strait Region,* Report prepared for the Torres Strait Regional Authority, CSIRO Marine and Atmospheric Research, p. 60.

16 Torres Strait Regional Authority, *Torres Strait 2021 State of Environment Report Card*. Available from https://torresstraitsoe.org.au/media/15ecppyz/tsra-state-of-environment-report.pdf

17 Taylor, K.E., R.J. Stouffer and G.A. Meehl, 2012: An Overview of CMIP5 and the Experiment Design, *Bull. Amer. Met. Soc*., **93**, 485-498.

18 Grose, M. R., et al., 2020: Insights from CMIP6 for Australia's future climate. *Earth's Future*, **8**, e2019EF001469.

19 IPCC, 2021d: *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, et al. (eds.)], Cambridge University Press, p. 2391.

20 United Nations Environment Programme, 2022: *Emissions Gap Report 2022: The Closing Window – Climate crisis calls for rapid transformation of societies*, Nairobi, p. 128.

21 State of Queensland, 2019: *Climate change in the Cape York region,* Dept. of Environment and Science, p. 8. Available from https://www.qld.gov.au/__data/assets/pdf_file/0019/68140/cape-york-climate-change-impact-summary.pdf

22 Syktus, J., et al., 2020: *Queensland Future Climate Dashboard: Downscaled CMIP5 climate projections for Queensland*. Available from https://www.longpaddock.qld.gov.au/qld-future-climate/

23 Armstrong McKay, D.L. et al., 2022: Exceeding 1.5C global warming could trigger multiple climate tipping points. *Science,* **377**, 1171.

24 Fitch, P., M. Battaglia, et al., 2022: *Australia's carbon sequestration potential*, A report to the Climate Change Authority, CSIRO, p. 243.

25 Department of Climate Change, Energy, the Environment and Water, 2022: *Australia's emission projections 2022,* Australian Government Department of Climate Change, Energy, the Environment and Water, Canberra, p. 82.

26 Greenhouse gases and energy website, Clean Energy Regulator, Australia. Available from https://www.cleanenergyregulator.gov.au/NGER/About-the-National-Greenhouse-and-Energy-Reporting-scheme/Greenhouse-gases-and-energy

[27] Jones, M.W., et al., 2023: National contributions to climate change due to historical emissions of carbon dioxide, methane, and nitrous oxide since 1850. *Sci Data* **10**, 155. Available from https://doi.org/10.1038/s41597-023-02041-1

[28] Data sourced from *Our World in Data* website and emissions data from Jones et al. (2023), available from https://ourworldindata.org/greenhouse-gas-emissions#per-capita-greenhouse-gas-emissions-how-much-does-the-average-person-emit

[29] Swann, T., 2019: *High Carbon from a Land Down Under: Quantifying CO_2 from Australia's fossil fuel mining and exports*, The Australia Institute. Available from https://australiainstitute.org.au/wp-content/uploads/2020/12/P667-High-Carbon-from-a-Land-Down-Under-WEB_0_0.pdf

Annexure A

PHI x FINNEY x MCDONALD

13 December 2022

PRIVILEGED AND CONFIDENTIAL

Professor David Karoly
School of Geography, Earth and Atmospheric Sciences,
University of Melbourne

By email: [redacted]

Dear Professor Karoly,

Pabai & Anor v Commonwealth of Australia (VID622/2021)

---

1. Letter of Instruction

1.1. We refer to our letter of retainer dated 28 April 2022 (**Retainer Letter**) and confirm that you are retained by Uncle Pabai Pabai and Uncle Paul Kabai (**Applicants**) to act as an independent expert in the matter of *Pabai & Anor v Commonwealth of Australia*, VID622/2021 (**Proceeding**).

1.2. We confirm that the confidentiality obligations in respect of documents and information provided to you for the purpose of this engagement are governed by the terms of the Retainer Letter and the Deed of Confidentiality dated 16 May 2022.

1.3. We also remind you of the roles and duties of expert witnesses as set out in the Retainer Letter and ask that you refer to them as you prepare your expert report(s) in this proceeding. In particular, please take some time to reacquaint yourself with the following documents, which we provided to you with our original letter:

(a) the Federal Court of Australia Expert Evidence Practice Note (**GPN-EXPT**), including the Harmonised Expert Witness Code of Conduct (the **Code**) at Annexure A of that Practice Note and the Concurrent Expert Evidence Guidelines (the **Guidelines**) at Annexure B (collectively, the **Practice Note**); and

(b) Rule 23.13 of the *Federal Court Rules 2011* (Cth).

1.4. The purpose of this letter is to request that you prepare a written report, providing your independent expert opinion, in response to the questions outlined at Annexure B to this letter.

2. Brief of Materials

2.1. Set out at Annexure A is an index of the documents provided to you, which form your brief. If you would prefer to receive a copy of some or all of the Annexure A documents in hard copy, please do not hesitate to contact us with such a request.

2.2. If you consider that you require any additional documents or materials in order to complete your work, please request such materials from us.

3. Your Opinion

3.1. Once you have reviewed the material in your brief, we request that you provide a written report addressing the questions set out in Annexure B to this letter.

3.2. In answering the Annexure B questions, please provide detailed reasons for your opinions, including the facts or assumptions that affect your reasoning and conclusions.

4. Preparation of Your Report

4.1. We would be grateful if you would set out the answers to the questions at Annexure B in a written report, having regard to the requirements set out in the Practice Note.

4.2. After you have had the opportunity to consider the questions at Annexure B, as well as the materials listed in Annexure A, we would be grateful if you could advise of any material not currently in your brief which you require to respond to any of the Annexure B questions.

If you have any questions, please do not hesitate contact me [redacted]

Yours faithfully,

Brett Spiegel
Principal Lawyer
Phi Finney McDonald

Encl.

ANNEXURE A

Index to Brief

Tab No.	Date	Description of document(s) / category
A	**LETTERS OF INSTRUCTION**	
A1.	13 December 2022	Letter of instruction
B	**PLEADINGS**	
B1.	7 October 2022	Amended Originating Application
B2.	12 August 2022	Amended Statement of Claim
B3.	21 September 2022	Defence to Amended Statement of Claim

ANNEXURE B

Basis of expertise

1. Please describe your academic qualifications, professional background, and experience in the field of climate science, and any other training, study, or experience that is relevant to this brief (you may wish to do so by reference to a current curriculum vitae).

The relationship between emissions and global temperature increase

2. Please explain each of the following concepts and describe their inter-relationship:

   a. the emission of long-lived greenhouse gases (**GHGs**), including the emission of long-lived GHGs from human activities (**anthropogenic GHG emissions**);

   b. the concentration of GHGs in the Earth's atmosphere (**atmospheric GHG concentration**); and

   c. the mean temperature of the Earth's surface (**global temperatures**),

   including whether the relationship is linear or non-linear.

3. Please state the date(s) you will use as a reference point for the period prior to the onset of anthropogenic GHG emissions in answering Questions 4 and 5 (the **Baseline**) and explain the basis for using this Baseline.

4. Please describe the amount of change in:

   a. anthropogenic GHG emissions;

   b. atmospheric GHG concentration; and

   c. global temperatures,

   from:

   i. the Baseline to the present date; and

   ii. 1990 to the present date.

5. Please describe the rate of change in:

   a. anthropogenic GHG emissions;

   b. atmospheric GHG concentration; and

   c. global temperatures,

   from:

   i. the Baseline to the present date; and

   ii. 1990 to the present date.

Best available science

6. Please explain what is meant by the term 'best available science' with respect to:

   a. the observations, causes, and impacts of climate change (as defined at [10] of the Applicants' Amended Statement of Claim); and
   b. the necessary actions to avoid the most dangerous impacts of climate change,

   (**Best Available Science**).

7. In the period 2014 to the present date, what sources describe the Best Available Science?

8. Please explain what is meant by the terms ‘confidence’ and ‘likelihood’ as used in the sources which describe the Best Available Science.

Current impacts of climate change

9. At a global level, please explain the inter-relationship between each of:

   a. anthropogenic GHG emissions;

   b. atmospheric GHG concentration; and

   c. global temperatures,

   and each of:

   d. ocean surface temperature;

   e. ocean acidification;

   f. sea ice;

   g. permafrost;

   h. precipitation;

   i. humidity;

   j. the frequency, size, and intensity of extreme weather events, including heatwaves, droughts, bushfires, tropical cyclones, severe storms, heavy rainfall and associated flooding; and

   k. terrestrial ecosystems and non-human species,

   (**Impacts of Climate Change**),

   including whether:

   i. the relationship with each impact is linear or non-linear; and

   ii. the relationship varies geographically.

10. From the Baseline to the present date, please describe the Impacts of Climate Change:

   a. globally;

   b. in Australia; and

   c. in the Torres Strait Islands.

Projected impacts of climate change

11. Please describe what would happen to atmospheric GHG concentration and global temperatures if the rate of anthropogenic GHG emissions from now until the conclusion of the 21st century remained consistent with the continuation of current global commitments.

12. Please describe the likely nature and scale of the Impacts of Climate Change from now until the conclusion of the 21st century:

   a. globally;

   b. in Australia; and

   c. in the Torres Strait Islands,

   in a world where:

i. global temperatures are 1.5°C warmer than the Baseline;
ii. global temperatures are 2°C warmer than the Baseline; and
iii. global temperatures are 3°C warmer than the Baseline.

Tipping points

13. Please explain the concept of ‘tipping points’ and the relevance (if any) that they have on the relationship between GHG emissions, atmospheric GHG concentration, and global temperatures.

14. Please explain the relevance (if any) that tipping points have on the Impacts of Climate Change.

15. Please explain the risk of reaching ‘tipping points’ in a world where:
    a. global temperatures are 1.5°C warmer than the Baseline;
    b. global temperatures are 2°C warmer than the Baseline; and
    c. global temperatures are 3°C warmer than the Baseline.

Removing GHGs from the atmosphere

16. Please describe the current state of science and technology with respect to the ability to remove GHGs from the atmosphere.

Australia’s role in climate change

17. Please explain the terms ‘scope 1’, ‘scope 2’, and ‘scope 3’ emissions.

18. Please provide an overview of Australia’s contribution to global anthropogenic GHG emissions (**Australia’s contribution**) since 1990 both overall and in relation to each of ‘scope 1’, ‘scope 2’ and ‘scope 3’ emissions. In your answer, please include:
    a. the total quantum of Australia’s contribution;
    b. Australia’s contribution as a percentage of total global anthropogenic GHG emissions; and
    c. Australia’s contribution expressed on a per capita basis in comparison with the per capita contribution of other nations.

Emissions Pathways

19. Please explain the terms ‘Representative Concentration Pathways’ (**RCPs**) and ‘Shared Socioeconomic Pathways’ (**SSPs**) as used by the Intergovernmental Panel on Climate Change (**IPCC**). In your answer, please explain the relationship of RCPs and SSPs to:
    a. anthropogenic GHG emissions;
    b. atmospheric GHG concentrations; and
    c. global temperatures.

20. Please explain the relationship between the RCPs and SSPs and each of the following:
    a. a world where global temperatures are 1.5°C warmer than the Baseline;
    b. a world where global temperatures are 2°C warmer than the Baseline; and
    c. a world where global temperatures are 3°C warmer than the Baseline.

ANNEXURE B

FULL CURRICULUM VITAE
(March 2023)

PERSONAL:

Name: David John KAROLY

[redacted]

[redacted]

Nationality: Australian

[redacted]

ORCID: https://orcid.org/0000-0002-8671-2994
ResearcherID: C-8262-2011

EDUCATION:

Dec 1976
Qualified for the Bachelor of Science (Honours) degree at Monash University, Australia with First Class Honours in Applied Mathematics.

Oct 1977
Commenced study for a higher degree in the Department of Meteorology, University of Reading, England with Dr B.J. Hoskins as my supervisor.

June 1978
Participated in the summer colloquium on the general circulation of the atmosphere for 8 weeks at the National Center for Atmospheric Research, Boulder, Colorado, U.S.A.

Dec 1980
Qualified for the degree of Doctor of Philosophy from the University of Reading with thesis entitled ``Stationary planetary waves in the atmosphere".

EMPLOYMENT:

Current position (September 2022 – present)
Councillor (part-time), Climate Council, Australia

Current position (February 2023 – present)
Professor Emeritus (honorary), School of Geography, Earth and Atmospheric Sciences, University of Melbourne
Senior Research Fellow (honorary), Melbourne Climate Futures, University of Melbourne

July 2021 – January 2022
Chief Research Scientist, Climate Science Centre, CSIRO Oceans & Atmosphere

Feb 2018 – January 2023
Honorary Professor, School of Earth Sciences, then School of Geography, Earth and Atmospheric Sciences, University of Melbourne

Feb 2018 – June 2021
Leader, Earth Systems and Climate Change Hub, National Environmental Science Program, CSIRO Oceans & Atmosphere

May 2012 – February 2018

Professor of Atmospheric Science, School of Earth Sciences and ARC Centre of Excellence for Climate System Science, University of Melbourne, Australia

January – July 2017

Visiting Fellow, Oxford Martin School and Environmental Change Inst., University of Oxford, UK

May 2007 – May 2012

ARC Federation Fellow and Professor, School of Earth Sciences, University of Melbourne, Australia

January, 2003 - May, 2007

Williams Chair Professor of Meteorology, School of Meteorology, University of Oklahoma, USA

June, 2005 - July, 2005

Visiting Scientist at the Hadley Centre for Climate Prediction and Research, Meteorological Office, at the University of Reading, Reading, UK

May, 2001 - Dec, 2002

Professor of Meteorology, School of Mathematical Sciences, Monash University, Australia

January, 2001 - Dec, 2002

Head, School of Mathematical Sciences, Monash University, Australia

Sept, 1995 - Sept, 2000

Director, Cooperative Research Centre for Southern Hemisphere Meteorology and Professorial Fellow, Monash University, Australia

Nov, 1994 - July, 1995

Visiting Scientist at the Hadley Centre for Climate Prediction and Research, Meteorological Office, Bracknell, UK

Jan, 1994

Accelerated promotion to substantive position of Reader in the Dept of Mathematics, Monash Univ.

July, 1993 - Sept, 1994

Acting Professor and Director (Acting), CRC for Southern Hemisphere Meteorology.

Aug, 1988 - June, 1989

Visiting Research Scientist at the Geophysical Fluid Dynamics Laboratory, Princeton University, Princeton, NJ, USA.

Jan, 1988

Accelerated promotion to Senior Lecturer, Department of Mathematics, Monash University, Australia.

1986-2002

Honorary Visiting Scientist, Bureau of Meteorology Research Centre under Monash/Bureau of Meteorology Affiliation Agreement.

Dec, 1984-June, 1985

Secondment as Scientific Visitor, National Center for Atmospheric Research, Boulder, CO, USA.

March, 1983-Dec, 1987

Lecturer, Department of Mathematics, Monash University, Australia

Jan, 1981-Feb, 1983

Postdoctoral Research Fellow, CSIRO Australian Numerical Meteorology Research Centre, Melbourne, Australia.

AWARDS:

Dec 1976

Awarded a Shell Company of Australia Science and Engineering Postgraduate Scholarship. This scholarship supports the holder for at least two years of postgraduate study at a university in England.

July 1981

Awarded the Meteorology Prize from the University of Reading for the best undergraduate or postgraduate thesis submitted in the Department of Meteorology in the Session 1980-81.

Jan 1993

Received the Clarence Leroy Meisinger Award from the American Meteorological Society, with citation ``for contributions to the understanding of the role of Rossby wave propagation in atmospheric teleconnections and to greenhouse climate change research".

Jan 1998

Received the NOAA Environmental Research Lab. Outstanding Science Paper Award for "A search for human influences on the thermal structure of the atmosphere", *Nature*, **382**, 39-46 (1996) with B. D. Santer, K. E. Taylor, T. M. L. Wigley, T. C. Johns, P. D. Jones, J. F. B. Mitchell, A. H. Oort, J. E. Penner, V. Ramaswamy, M. D. Schwatrzkopf, R. J. Stouffer, and S. Tett .

June 1998

Received the Norbert Gerbier - MUMM International Award for 1998 from the World Meteorological Organization for the paper "A search for human influences on the thermal structure of the atmosphere", *Nature*, **382**, 39-46 (1996) with B. D. Santer, K. E. Taylor, T. M. L. Wigley, T. C. Johns, P. D. Jones, J. F. B. Mitchell, A. H. Oort, J. E. Penner, V. Ramaswamy, M. D. Schwatrzkopf, R. J. Stouffer, and S. Tett .

Oct 1998

Elected a Fellow of the American Meteorological Society in recognition of outstanding contributions to the atmospheric and related sciences during a substantial period of years.

Feb 2000

Presented the R. H. Clarke Lecture of the Australian Meteorological and Oceanographic Society at its 7th National Conference.

July 2004

Selected as a Gary Comer Science and Education Foundation Mentor with funding of $550,000 over five years to support postdoctoral fellows in climate change research.

April 2006

Awarded an Australian Research Council Federation Fellowship, valued at nearly $A5M over 5 years, based in the School of Earth Sciences at the University of Melbourne, to start in May 2007.

October 2007

As a Lead Author for the Intergovernmental Panel on Climate Change, shared in the award of the 2007 Nobel Peace Prize jointly to the IPCC and to Al Gore, with citation "for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change".

19 June 2008

Presented the Annual A. W. Howitt Lecture to the Geological Society of Australia Victoria Division and the Royal Society of Victoria, *Lies, damn lies and climate change sceptics: What has caused recent global warming?*

24 November 2009

Presented the Hamer Oration in Good Government in Melbourne, *Fiddling while Australia burns: Will this be history's judgment on our governments' response to climate change?*

January 2013

Elected a Fellow of the Australian Meteorological and Oceanographic Society.

September 2014

Shared in the Eureka Prize for Interdisciplinary Scientific Research to the SEARCH (South-East Australian Recent Climate History) project team

December 2014

Awarded the Morton Medal of the Australian Meteorological and Oceanographic Society for "leadership in meteorology, oceanography, climate and related fields, particularly through education and the development of young scientists"

September 2015

Presented the G. S. Watson Annual Lecture at La Trobe University, Bendigo, *Signal and noise, evidence and misinformation about climate change*

December 2015

Awarded the 2015 Royal Society of Victoria Medal for Scientific Excellence in the Earth Sciences

August 2018

Presented the Bert Halpern Annual Lecture, School of Chemistry, University of Wollongong, *Chemistry and climate change: Looking back from 2038 – the good, the bad and the ugly.*

May 2019

Elected a Fellow of the Australian Academy of Science

August 2019

Presented the annual Archimedes Lecture, Dept. of Mathematics, Swinburne University, Melbourne, *Modelling the climate system to understand the human role in recent climate change*.

October 2020

Presented the annual Investigator Lecture, Flinders University, Adelaide, *Climate Change: Managing the unavoidable, avoiding the unmanageable*, by video, lecture and panel conversation.

TEACHING: UNIVERSITY OF MELBOURNE

Courses developed and taught:

625-101	The global environment (6 lectures) 2008-2010
ERTH10001	The global environment (9 lectures) 2011-2015
EVSC10001	The global environment (10 lectures) 2016
625-656	Current topics in atmospheric science 2010
600-654	Global environmental change (3 lectures) 2009-2010
EVSC90017	Global environmental change (3 lectures) 2011-2016
200-001	Climate variability and climate change (One week intensive short course) 2009-2010
ENST90011	Climate variability and climate change (One week intensive short course) 2011, 2013, 2015
UNIB30003	Climate change III (Supervise group project) 2012
UNIB10007	Introduction to climate change (9 lectures) 2014-2017
ATOC90002	Climate Affairs (co-teach half the subject) 2013, 2015, 2016
Coursera MOOC	Climate Change 2014

TEACHING: UNIVERSITY OF OKLAHOMA

Courses developed and taught:

METR 4233 Physical Meteorology III: Radiation and Climate 2003-2006
METR 4803 Climate change 2005
METR 4900 Seminar on climate change and societal impacts 2005
METR 4922 Senior Capstone course 2006-2007

Courses taught:

METR 2413 Introduction to Synoptic Meteorology (with Dr M. Laufersweiler) 2004

TEACHING: MONASH UNIVERSITY

Courses developed and taught:

Atmospheric Science Fourth Year:
Tropical Meteorology and Convection (with Dr J. McBride) 2000-2001
Large-scale Dynamics 2002

Atmospheric Science Third Year:
part of Climate Change and Variability 1997-2001
Weather and Climate Phenomena (with Dr S. Siems) 2001-2

Atmospheric Science Second Year:
Large-Scale Weather and Climate (with Dr M. Reeder) 2000-2002

Atmospheric Science First Year:
part of The Dynamic Atmosphere 1999

Applied Mathematics Fourth Year:
Time Series and Data Analysis 1983-90, 1992-94
Waves in Fluids 1991

Applied Mathematics Third Year:
Dynamical Meteorology 1986-89
Fluid Dynamics 1983-84, 1990
Atmospheric Science 1991-94

Courses taught:
Applied Mathematics Second Year:
Methods of Applied Mathematics II 1983-87
Introduction to Numerical Methods 1989
Introduction to Fluid Dynamics 1990-91

Mathematics First Year:
Modelling and Methods of Applied Mathematics 1985-87

RESEARCH GRANTS: AUSTRALIA 2007 – 2018

Australian Antarctic Division
"The Influence of Ozone Recovery on Climate Change in the Southern Hemisphere", with A. Klekociuk (AAD)
2012-2014, $150K

DIISRTE Collaborative Research Network
"Self-sustaining Regions Research and Innovation Initiative", P. Gell (U Ballarat), D. Karoly, with Deakin and Monash Uni partners,
2011-14, $330K for School of Earth Sciences

National Environmental Science Program (NESP)
Earth Systems and Climate Change Hub, Director: Dr H. Cleugh (CSIRO), 19 CIs including D. Karoly (Uni. Melb.), 2015-2021, $23.9M. CI until Feb 2018, then moved to CSIRO as ESCC Hub Leader.

Australian Research Council
Centre of Excellence for Climate Extremes, Centre Director: Prof A Pitman (UNSW), 18 CIs including D. Karoly and T. Lane (Uni. Melbourne), 2017-2023, $30M. CI until Feb 2018.

Linkage Project "Megadrought likelihood and water resource impacts in Southeast Australia", D. Karoly (CI), with M. Peel, R Nathan (Melb Uni), A. Gallant (Monash) and 4 others, 2015-2018, $387K. CI until Feb 2018

Linkage Infrastructure, "Connecting big data with high performance computing for climate science", Prof A Pitman (UNSW), 2 others, T. Lane, 6 others, D. Karoly, and 16 others, 2014, $490K

Centre of Excellence for Climate System Science, Centre Director: Prof A Pitman (UNSW), 13 CIs including D. Karoly and T. Lane (Uni. Melbourne), 2011-2018, $21.4M

Discovery Project “Assimilation of trace atmospheric constituents for climate (ATACC): Linking chemical weather and climate”, with Peter Rayner (Uni Melbourne) as CI
2010-2015, $940K

Linkage Project “Transforming our research capacity in the analysis of climate extremes”, with Lisa Alexander (UNSW) as CI and 2 others
2010 - 2013, $290K

Linkage Project “Narrowing the scatter and assessing the uncertainty of climate change projections of Australian river flows”, with Tom McMahon (Uni Melbourne) as CI
2010 - 2012, $240K

Linkage Project “Reconstructing pre-20th century rainfall, temperature and pressure for south-eastern Australia using palaeoclimate, documentary and early weather station data”, with Joelle Gergis (Uni Melbourne) as CI and 12 others
2009 - 2012, $340K

Discovery Project “Storm activity in the Arctic and implications for rapid climate change in polar regions”, with Ian Simmonds (Uni Melbourne) as CI
2009-2011, $360K

Federation Fellowship “Improving understanding of climate change and its impacts in Australia through detection and attribution of climate change”
2007 - 2012, $1,780K

Linkage Project “Hot Science Global Citizens: The Agency of the Museum Sector in Climate Change Debates and Decision-Making”, with Fiona Cameron (UWS) as CI and 10 others
2007 - 2010, $570K

RESEARCH GRANTS: USA 2003 - 2008

National Science Foundation
``Improving Projections of Regional Climate Change for the United States using Detection and Attribution Studies'', with Q. Wu (OU)
2006-09, $340,906

Small Grant for Exploratory Research ``Assessment of the severe weather environment simulated by global climate models'', with H. Brooks, (NOAA NSSL)
2006-07, $52,550

Climate Model Evaluation Project ``Simple indices of climate variability and change''
2004-05, $24,888

Gary Comer Science and Education Foundation
``Climate change research''
2004-08, $550,000

NOAA Climate Change Data and Detection
``Detection and attribution of climate change using climate indices for the United States'', with D. Easterling and J. Lawrimore (NOAA NCDC)
2004-07, $191,972

RESEARCH GRANTS: AUSTRALIA 1984-2002

Antarctic Science Advisory Committee
``Variations of stratospheric ozone at Macquarie Island", with R. Atkinson, P. Lehmann (Bureau of Meteorology) and D. Waugh
1996-1999, $84,200

Australian Research Council
``Understanding inter-annual variability and long-term trends in the Southern Hemisphere stratosphere"
2001-2002, $113,700
``Stratospheric transport and the Antarctic ozone hole"
1991-1993, $112,400
``Greenhouse climate change and natural climate variability "
1991, $11,000
``Southern Hemisphere circulation features associated with equatorial sea surface temperature anomalies"
1987-1990, $44,100

Australian Research Council Collaborative Research Grant
``TOGA-COARE and variations of the atmospheric circulation over the tropical western Pacific Ocean", with the Bureau of Meteorology
1993-1994, $79,800

DASETT NGAC Greenhouse Research Grant
``Physical processes underlying climate change", with B.R. Morton and 3 others
1991-1993, $558,000

DITAC US/Australia Bilateral Science and Technology Collaborative Program
``Observations and modelling of greenhouse climate change"
1990 $6,500
``TOGA-COARE and variations of the atmospheric circulation over the tropical western Pacific Ocean"
1993 $9,000

CSIRO/Monash University Collaborative Research Fund
``Analysis of Southern Hemisphere stratospheric circulation using satellite data", (with Dr R.A. Plumb, CSIRO Div. of Atmospheric Research)
1984-1986, $18,684

STUDENT SUPERVISION: UNIVERSITY OF MELBOURNE

Ph.D.
Roger Bodman 2008 – 2011
Claire Fenby 2009 – 2012 (with J. Gergis)
John Allen 2009 – 2013
Julie Arblaster 2007 – 2013 (with J. Meehl, NCAR)
Doerte Jakob 2008 – 2014
Linden Ashcroft 2010 – 2013 (with J. Gergis)
Kane Stone 2012 – 2016 (with R. Schofield)
Andrea Dittus 2012 – 2016 (with L. Alexander, UNSW)
Mitchell Black 2013 – 2016
Daniel Pazmino 2013 –2017 (with A. Pezza)
Anita Talberg 2013 – 2018 (with P. Christoff and S. Thomas)
Mandy Freund 2014 – 2019 (with B Henley)
Kate Saunders (School of Mathematics) 2014 – 2018 (with P. Taylor)
Annabelle Workman 2015 – 2019 (with J. Wiseman, K Bowen and G. Blashki)

M.Sc.
Dian Nur Ratri 2010 – 2012
Adrian D'Allesandro 2016 – 2018 (with A. King)

Honours:
Julia Carpenter 2008
Tom Fejes 2009

STUDENT SUPERVISION: UNIVERSITY OF OKLAHOMA

Ph.D.
Melissa Bukovsky 2005-2009
Derek Rosendahl 2008 - 2013

M.Sc.
Aaron Ruppert 2004-2005
Bryan Burkholder 2006-2007
Patrick Marsh 2006-2007

STUDENT SUPERVISION: MONASH UNIVERSITY

Ph.D.
Michael Coughlan 1983-84 (with Prof B. Morton)
Imre Szeredi 1984-87
Noel Davidson 1990-95 (with Dr K. Puri, BMRC)
Louis Whitehead 1991-95
Leon Rotstayn 1993-97 (with Dr B. Ryan, CSIRO)
Allyson Williams 1992-97 (with Prof N. Tapper)
Simon Grainger 1994-98 (with Dr R. Atkinson, BMRC)
Mark Harvey 1993-2001
Shuhua Li 1997-2000 (with Dr E. Cordero)
Tahl Kestin 1997-2000 (with Dr N. Nicholls, BMRC)
Noel Keenlyside 1997-2001 (with Dr R. Kleeman, BMRC)
Karl Braganza 1998-2002
Terrence O'Kane 1999-2002 (with Dr J. Frederiksen, CSIRO)

M.Sc.
Paul Nydam 1986-89
Henry Mulenga 1987-89
Darren Wells 1988-90
Trevor Casey 1988-92
Russell Stringer 1990-92
Dean Collins 1992-94
Greg Tyrrell 1993-95
Jim Fraser 1993-95
Thuy Do 1996-98
Bodo Zeschke 1998-2001
Eddy Suaydhi 1999-2001
Phetolo Phage 1999-2002

Honours:
Roger Deslandes 1984
Wing Fu Chang 1986
Moya Tyndall 1986
Darren Wells 1987
Jenny Cohen 1989
Craig Blundell 1989
Miriam Karelsky 1990
Chris Brown 1991
Linda Hopkins 1991
Megan Hopley 1992
Greg Tyrrell 1992
Pandora Hope 1993
Michelle Cox 1997
Andrew Marshall 1998
Jonty Hall 1999
Briony Macpherson 2001
Robyn Gardiner 2002

ACADEMIC ADMINISTRATION: UNIVERSITY OF MELBOURNE

Climate and Energy Research Director, EU Centre for Shared Complex Challenges, 2014 - 2017
Deputy Head, School of Earth Sciences, 2013 - 2016
Member, Faculty of Science Research and Industry Committee, 2013 - 2017
University of Melbourne representative, ARC Centre of Excellence for Climate System Science 2011 – 2013
Climate Change theme leader, Melbourne Sustainable Society Institute 2010 – 2012
University of Melbourne representative, Universities Climate Consortium 2008 – 2010
Member, Faculty of Science Professorial promotion panel 2009, 2013, 2014

Member, Course Advisory Committee, Climate Change Breadth Subject 2008 – 2015
Member, Advisory Board, Climate Adaptation Science-Policy Initiative 2007 – 2008

ACADEMIC ADMINISTRATION: UNIVERSITY OF OKLAHOMA

Associate Director, School of Meteorology, 2006
Chair, Graduate Studies Committee, School of Meteorology, 2004-2006
Member, Graduate Studies Committee, School of Meteorology, 2003-2004
Member, Undergraduate Studies Committee, School of Meteorology, 2003

ACADEMIC ADMINISTRATION: MONASH UNIVERSITY

Head, School of Mathematical Sciences, Monash University 2001-2002
Director, Centre for Dynamical Meteorology and Oceanography, Monash University 2000
Director, Cooperative Research Centre for Southern Hemisphere Meteorology, Sept. 1995-Sept. 2000
Interim Director, Cooperative Research Centre for Southern Hemisphere Meteorology, 1993-94
Monash University representative on Committee of Management, Victorian Institute of Earth and Planetary Sciences, 1993-94.
Director, Centre for Dynamical Meteorology, Monash University, 1992-93
Deputy Director, Victorian Institute of Earth and Planetary Sciences, 1992
Coordinator, Meteorology program, Department of Mathematics, 1991-93
Coordinator, Second Year Applied Mathematics, Department of Mathematics, 1984, 1986, 1987, 1989, 1991
Coordinator, Second Year Mathematical Methods, Department of Mathematics, 1990-91
Member, Faculty of Science, Undergraduate Matters Committee, 1987 Elected representative of sub-professorial staff of Science Faculty on Academic Board and Professorial Board, 1989-91.

LEADERSHIP AND MANAGEMENT TRAINING:

March - Oct, 2013

Future Academic Leaders Program, University of Melbourne

23 June, 2009

Supervisory Skills workshop, Transdisciplinary graduate student supervision, School of Graduate Research, University of Melbourne

6 - 15 June, 2004

American Meteorological Society Summer Policy Colloquium, Washington DC

8, 15, 22 May, 2000

Monash University Occupational Health and Safety Branch *First Aid Level 2* course

3 May, 1999

Monash University Professional Development and Training Branch *Performance Management Scheme for academic staff* workshop

February - May, 1999

CSIRO and B/HERT *Achievement Through Teams: Leadership in Innovation* three-week residential program

21 October, 1998

Monash University Occupational Health and Safety Briefing session *Identification and management of risk*

25 August, 1997

Monash University Occupational Health and Safety Briefing session for Heads of budgetary units and Centres

26 October, 1995

Monash University Professional Development Centre *Managing conflict in your Department* workshop

9 October, 1995

Monash University Professional Development Centre *Performance Appraisal for Supervisors* workshop

1-6 May, 1994

Monash University Staff Development Branch Middle Managers Residential Program *Leadership Skills for the 90's*

PROFESSIONAL ACTIVITIES:

2022 – present

Ambassador, ClimARTe, Melbourne

2019-2020

Member, Coordinating Working Group, Australian Sustainable Finance Initiative

2018-2021

Review Editor, Chapter 12 'Climate change information for regional impact and for risk assessment' in *Climate Change 2021: The Physical Science Basis*, IPCC 6th Assessment Report

2018-2019

Member, National Climate Science Advisory Committee

2017- present

Member, Advisory Board, Climate Reality Project Australia, based at the University of Melbourne

2017 – 2018

Member, Scientific Steering Comm., WMO/UNEP Scientific Assessment on Ozone Depletion 2018

2015-2016

Chief Editor, *Journal of Southern Hemisphere Earth System Science*

2013 – 2014

Member, Scientific Steering Comm., WMO/UNEP Scientific Assessment on Ozone Depletion 2014

2012 – 2013

Review Editor, Chapter 25 'Australasia' in *Climate Change 2013: Impacts, Adaptation and Vulnerability*, IPCC Fifth Assessment Report

2012 – 2017

Member, Climate Change Authority, Australia

2011 – 2012

Member, Joint Scientific Committee, WMO/ICSU World Climate Research Programme

2011 – 2013

Member, Science Advisory Panel, Australian Government's Climate Commission

2010 – present

Member, Expert Advisory Committee, Climate and Health Alliance, Australia

2009 - 2015

Chief Editor, *Australian Meteorological and Oceanographic Journal*

2009-2011

Member, Australian Government's High Level Coordination Group on Climate Change Science

2009-2014

Member, Climate Scientists Australia

2008-present

Member, Wentworth Group of Concerned Scientists, Australia

2008-2014

Member, Australian Academy of Sciences National Committee on Earth System Science

2008-2009

Lead author, Chapter 4 “Stratospheric changes and climate”, in WMO/UNEP *Scientific Assessment of Ozone Depletion: 2010*

2008-2009

Chair, Premier of Victoria’s Climate Change Reference Group

April, 2008

Invited participant, Australia 2020 Summit, Parliament House, Canberra

2007-2009

Treasurer, Local Organising Committee, 9th Intl. Conference on SH Meteorology and Oceanography, Melbourne, February, 2009

2007-2008

Lead author, US Climate Change Science Program Synthesis and Assessment Product 1.3 *Re-Analysis of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of Observed Change*

2006-2010

Member, WMO CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices

2006-2007

Member, Core Writing Team, IPCC Fourth Assessment Synthesis Report

2006-2007

Member, National Research Council Committee to Review the U.S. Climate Change Science Program’s Synthesis and Assessment Product 3.3 “Weather and Climate Extremes in a Changing Climate”

2005-2011

Member, World Climate Research Program Working Group on Coupled Modelling

2005-2006

Review Editor, Chapter 9 "Understanding and attributing climate change", Working Group I, IPCC Fourth Assessment Report *Climate Change 2007: The Physical Science Basis*

2004-2007

Lead Author, Chapter 1 "Assessment of observed changes and responses in natural and managed systems", Working Group II, IPCC Fourth Assessment Report *Climate Change 2007: Impacts, Adaptation and Vulnerability*

2004-2005

Invited Co-Editor, Special Issue on Regional Climate Variability and Change, *Meteorology and Atmospheric Physics*, **89**, No. 1-4.

2004

Chair, National Research Council Committee to Review of the US CLIVAR Program Office

2003-2006

Member, NCAR University Relations Committee

2003-2006

Member, US National Research Council Climate Research Committee

March, 2003

Member, NOAA Climate Change Data and Detection proposal review panel

2002-2004

Member, Council, American Meteorological Society

2002-2005

Member, WMO/CLIVAR Expert Team on Climate Change Detection, Monitoring and Indices

2000-2002

Member, Antarctic Sciences Advisory Committee, Australian Government

1999-2002

Chair, Course Advisory Committee, Grad. Dip. Met., Bureau of Meteorology Training Centre

1998-2001

Co-Coordinating Lead Author, Detection of Climate Change and Attribution of Causes, IPCC Third Assessment Report.

1998-2001

Member, WMO/CLIVAR Working Group on Climate Change Detection

1998-2002

Member, Medical and Scientific Committee, Anti-Cancer Council of Victoria

1998-1999

Member, Local Organising Committee, Fifth Intl. Conf. on School and Popular Education in Meteorology and Oceanography, Ballarat and Melbourne, July 1999.

1997-2002

Member, Scientific Steering Group, WCRP Project on "Stratospheric Processes and their Role in Climate" (SPARC)

1996-2000

Member, Aust. Academy of Sciences National Committee on Climate and Global Change

1996-1998

Member, Course advisory committee, Grad. Dip. Met., Bureau of Meteorology Training Centre

1995-1998

Co-Editor, Am. Met. Soc. Monograph *Meteorology of the Southern Hemisphere*

1995-1996

Chair, Local Organising Committee, WCRP First General Assembly on `Stratospheric Processes and their Role in Climate', Melbourne, December 1996.

1993-1998

Member, Aust. Global Climate Observing System Expert Sub-group

1994-1995

Contributing Author to IPCC Second Scientific Assessment of Climate Change 1995.

1993-1995

Member, US NOAA Science Advisory Panel for the Comprehensive Aerological Reference Data Set

1993-1994

Member, CSIRO INRE Climate Change Research Program Advisory Panel

1991-1995

Member, Aust. Academy of Sciences National Committee on Climate and Atmospheric Science

1990-1993

Chair, American Meteorological Society Committee on Southern Hemisphere Meteorology and Oceanography

1990-1993

Convenor, 4th Intl. Conference on SH Meteorology and Oceanography, Hobart, April, 1993

1989-1991

Contributing Author to Intergovernmental Panel on Climate Change (IPCC) First Scientific Assessment of Climate Change in 1990 and update in 1992.

1989

Committee member, American Meteorological Society Committee on Southern Hemisphere Meteorology and Oceanography

1988-1993

Associate Editor, Australian Meteorological Magazine

July, 1987-July, 1988

Secretary, Australian Meteorological and Oceanographic Society.

Jan., 1987-July, 1988

Treasurer, Organising committee, Meeting on Priorities in Research, Operations and Education in Meteorology and Physical Oceanography, Melbourne, July, 1987.

July, 1986-July, 1988

Co-convenor, International Conference on Tropical Meteorology, Brisbane, July, 1988.

Jan.,1986-July,1988

Honorary Secretary, Royal Meteorological Society (Australian Branch).

1983-1984

Committee Member, Royal Meteorological Society (Australian Branch) and Convenor of Meetings Sub-committee.

REFEREES

Professor Kate Auty
Professorial Fellow, University of Melbourne
Chair, EPA Victoria Governing Board
[redacted]

Dr Greg Ayers
Chair, Hub Steering Committee
NESP Earth Systems and Climate Change Hub
[redacted]

Professor Andrew Pitman
Director, ARC Centre of Excellence for Climate System Science,
The University of New South Wales, Sydney, NSW, 2052.
[redacted]

Professor David J Karoly

REFEREED PUBLICATIONS (March 2023)

(208) Lestari, S., A.D. King, C. Vincent, A. Protat, D. Karoly and S. Mori (2022) Variability of Jakarta rain-rate characteristics associated with the Madden-Julian Oscillation and topography, *Mon. Wea. Rev.*, **150**, 1953-75. https://doi.org/10.1175/MWR-D-21-0112.1

(207) Hoegh-Guldberg, O., K. Bowen, 4 others, D. Karoly, and 7 others (2021) *The risks to Australia of a 3°C warmer world*, 97 pp. Aust. Academy Science.

(206) Saunders, K.R., A.G. Stephenson and D.J. Karoly (2021) A regionalisation approach for rainfall based on extremal dependence, *Extremes*, **24**, 215-240. https://doi.org/10.1007/s10687-020-00395-y.

(205) Bodman, R.W., D.J. Karoly, M.R. Dix, I.N. Harman, J. Srbinovsky, P.B. Dobrohotoff, and C. Mackallah (2020) Evaluation of CMIP6 AMIP climate simulations with the ACCESS-AM2 model, *JSHESS*, **70**, 166-179. https://doi.org/10.1071/ES19033.

(204) Freund, M.B., J.R. Brown, B.J. Henley , D.J. Karoly, J.N. Brown, E.-P. Lim (2020) Warming patterns affect El Niño diversity in CMIP5 and CMIP6 models. *J. Clim*., **33**, 8237-8260.

(203) Workman, A., G. Blashki, K.J. Bowen, D.J. Karoly and J. Wiseman (2020) Political leadership on climate change: The role of health in Obama-era U.S. climate policies, *Env. Res. Lett.*, **15**, 105003. https://doi.org/10.1088/1748-9326/aba8c3

(202) Ashcroft, L., D. J. Karoly and A. J. Dowdy (2019) Historical extreme rainfall events in southeastern Australia. *Wea. Clim. Ext*., **25**, 100210.

(201) Freund, M.B., B.J. Henley, D.J. Karoly, H.V. McGregor, N.J. Abram, and D. Dommenget (2019) Higher frequency of Central Pacific El Niño events in recent decades relative to past centuries, *Nat. Geosci*, **12**, 450-455.

(200) Grose, M.R., M.T. Black, G. Wang, A.D. King, P. Hope and D.J. Karoly (2019) The warm and extremely dry spring in 2015 in Tasmania contained the fingerprint of human influence on the climate. *JSHESS*, **69**, 183 - 195.

(199) Henley, B.J., M.C. Peel, R. Nathan, A.D. King, A.M. Ukkola, D.J. Karoly and K.S. Tan (2019) Amplification of risks to water supply at 1.5°C and 2°C in drying climates: a case study for Melbourne, Australia. *Env. Res. Lett*., **14**, 084028.

(198) King, A., B. Henley, D.J. Karoly, J Kala (2019) What does the Paris agreement mean for Australia's ecosystems?, *Austral Ecology*, **44**, 571-572

(197) Lestari, S., A. King, C. Vincent, D. Karoly, A. Protat (2019) Seasonal dependence of rainfall extremes in and around Jakarta, Indonesia, *Wea. Clim. Ext*., **24**, 100202.

(196) Ratnayake, H.U., M.R. Kearney, P. Govekar, D. Karoly and J.A. Welbergen (2019) Forecasting wildlife die-offs from extreme heat events, *Animal Conserv*., **22**, 386-395.

(195) Vogel, E., M. Donat, L. Alexander, M. Meinshausen, D. Ray, D. Karoly, N. Meinshausen, K. Frieler, (2019) The effects of climate extremes on global agricultural yields, *Env. Res. Lett*., **14**, 054010.

(194) Workman, A., G. Blashki, K. J. Bowen, D. J. Karoly and J. Wiseman (2018) Health co-benefits and the development of climate change mitigation policies in the European Union, *Climate Policy*, **19**, 585-597.

(193) Baker, H.S., R.J. Millar, D.J. Karoly, U. Beyerle, B.P. Guillod, D. Mitchell, H. Shiogama, S. Sparrow, T. Woollings, and M. R. Allen (2018) Higher CO_2 concentrations increase extreme event risk in a 1.5°C world, *Nat. Clim. Change*, **8**, 604-608.

(192) Dätwyler, C., R. Neukom, N.J. Abram, A.J.E. Gallant, M. Grosjean, M. Jacques-Coper, D.J. Karoly and R. Villalba (2018) Teleconnection stationarity, variability and trends of the Southern Annular Mode (SAM) during the last millennium. *Clim. Dyn*., **51**, 2321-2339.

(191) Dittus, A.J., D.J. Karoly, M.G. Donat, S.C. Lewis and L.V. Alexander (2018) Understanding the role of sea surface temperature-forcing for variability in global temperature and precipitation extremes, *Wea. Clim. Ext*., **21**, 1-9.

(190) King, A.D., M.G. Donat, S.C. Lewis, B.J. Henley, D.M. Mitchell, P. Stott, E.M. Fischer, and D.J. Karoly (2018) Reduced heat exposure by limiting global warming to 1.5°C. *Nat. Clim. Change*, **8**, 549-551.

(189) Oreskes, N., E. Conway, D. J. Karoly, J. Gergis, U. Neu and C. Pfister (2018) The denial of global warming. In *Handbook of Climate History*, White S., Pfister C., Mauelshagen F. (Eds.), Palgrave Macmillan, London, 149-171.

(188) Talberg, A., S. Thomas, P. Christoff, and D. Karoly (2018) How geoengineering scenarios frame assumptions and create expectations, *Sust. Sci*., **13**, 1093-1104.

(187) Talberg, A., P. Christoff, S. Thomas, and D. Karoly (2018) Geoengineering governance-by-default: an earth system governance perspective, *Int. Environ. Agreements*, **18**, 229-253.

(186) Workman, A., G. Blashki, K. J. Bowen, D. J. Karoly and J. Wiseman (2018) The political economy of health co-benefits: Embedding health in the climate change agenda, *Int. J. Environ. Res. Public Health*, **15**, 674.

(185) Freund, M., B. J. Henley, D. J. Karoly, K. J. Allen, P. J. Baker (2017) Multi-century cool and warm season rainfall reconstructions for Australia's major climatic regions. *Clim. Past*, **13**, 1751-1770.

(184) Henley, B.J., G. Meehl, S.B. Power, C.K. Folland, A.D. King, J.N. Brown, D.J. Karoly, F. Delage, A.J.E. Gallant, M. Freund, and R. Neukom (2017) Spatial and temporal agreement in climate model simulations of the Interdecadal Pacific Oscillation. *Env. Res. Lett*., **12**, 044011.

(183) King, A.D., and D.J. Karoly (2017) Climate extremes in Europe at 1.5 and 2 degrees of global warming. *Env. Res. Lett*., **12**, 114031.

(182) King, A.D., D.J. Karoly and B.J. Henley (2017) Australian climate extremes at 1.5 and 2 degrees of global warming. *Nature Clim. Ch*., **7**, 412-416.

(181) King, A.D., M.G. Donat, E. Hawkins, D.J. Karoly (2017) Timing of anthropogenic emergence in climate extremes. Chapt 6 in *Climate Extremes: Patterns and Mechanisms*, S.-Y. Wang, J-H Yoon, C. Funk and R. Gillies (Eds.), Wiley UK, 93-103.

(180) Kornhuber, K., V. Petoukhov, D. Karoly, S. Petri, S. Rahmstorf, D. Coumou (2017) Summertime planetary wave resonance in the Northern and Southern Hemispheres. *J. Clim*., **30**, 6133-6150.

(179) Lewis, S., D.J. Karoly, A.D. King, S.E. Perkins and M.G. Donat (2017) Mechanisms explaining recent changes in Australian climate extremes. Chapt 15 in *Climate Extremes: Patterns and Mechanisms*, S.-Y. Wang, J-H Yoon, C. Funk and R. Gillies (Eds.), Wiley UK, 249-263.

(178) Saunders, K., A. G. Stephenson, P. G. Taylor and D. J. Karoly (2017) The spatial distribution of

rainfall extremes and the influence of El Niño-Southern Oscillation. *Wea. Clim. Ext*., **18**, 17-28.

(177) Stott, P.A., D.J. Karoly and F.W. Zwiers (2017) Is the choice of statistical paradigm critical in extreme event attribution studies?, *Clim. Change*, **144**, 143-150.

(176) Ashcroft, L., J. Gergis and D. J. Karoly (2016) Long-term stationarity of El Niño-Southern Oscillation teleconnections in southeastern Australia. *Clim. Dyn.*, **46**, 2991-3006.

(175) Black, M. T., D. J. Karoly, S. M. Rosier, S. M. Dean, A. D. King, N. R. Massey, S. N. Sparrow, A. Bowery, D. Wallom, R. G. Jones, F. E. L. Otto, and M. R. Allen, (2016) The weather@home regional climate modelling project for Australia and New Zealand, *Geosci. Model Dev.*, **9**, 3161–3176.

(174) Black, M.T., and D. J. Karoly (2016) Southern Australia's warmest October on record: The role of ENSO and climate change, [in "Explaining Extremes of 2015 from a Climate Perspective"]. *Bull. Am. Met. Soc*., **97**, S118-S121.

(173) Dittus, A.J., D.J. Karoly, S.C. Lewis, L.V. Alexander, and M.G. Donat (2016) A multiregion model evaluation and attribution study of historical changes in the area affected by temperature and precipitation extremes. *J. Clim*., **29**, 8285-8299. doi:10.1175/JCLI-D-16-0164.1.

(172) Donat, M.G., A.D. King, J.T. Overpeck, L.V. Alexander, I. Durre, and D.J. Karoly (2016) Extraordinary heat during the 1930s US Dust Bowl and associated large-scale conditions. *Clim. Dyn*., **46**, 413-426.

(171) Gergis, J., R. Neukom, A. J. E. Gallant and D. J. Karoly (2016) Australasian temperature reconstructions spanning the last millennium. *J Clim.,* **29**, 5365-5392.

(170) Karoly, D. J., M.T. Black, M.R. Grose and A. D. King (2016) The roles of climate change and El Niño in the record low rainfall in October 2015 in Tasmania, Australia [in "Explaining Extremes of 2015 from a Climate Perspective"]. *Bull. Am. Met. Soc*., **97**, S127-S130.

(169) King, A. D., G. J. van Oldenborgh and D. J. Karoly (2016) Climate change and El Niño increase likelihood of Indonesian heat and drought [in "Explaining Extremes of 2015 from a Climate Perspective"]. *Bull. Am. Met. Soc*., **97,** S113-S117.

(168) Otto, F.E.L., G.J. van Oldenborgh, J. Eden, P.A. Stott, D.J. Karoly and M.R. Allen (2016) The attribution question. *Nature Clim. Ch*., **6**, 813-816.

(167) Stone, K.A., O. Morgenstern, D. J. Karoly, A. R. Klekociuk, W.J.R. French, N. L. Abraham and R. Schofield (2016) Evaluation of the Australian Community Climate and Earth-System Simulator Chemistry-Climate Model. *Atmos. Chem. Phys*., **16**, 2401-2415.

(166) Workman, A., G. Blashki, D. Karoly and J. Wiseman (2016) The role of health co-benefits in the development of Australian climate change mitigation policies. *Int. J. Environ. Res. Public Health*, **13**, 927; doi:10.3390/ijerph13090927.

(165) Barria, P., K.J.E. Walsh, M.C. Peel and D. Karoly (2015) Uncertainties in runoff projections in southwestern Australian catchments using a global climate model with perturbed physics. *J. Hydrol*., **529**, 184-199.

(164) Black, M.T., A. D. King, and D. J. Karoly (2015) The contribution of anthropogenic forcing to the Adelaide and Melbourne, Australia heat waves of January 2014. *Bull. Am. Met. Soc*., **96** (12), S145-148.

(163) Dittus, A.J., D. J. Karoly, S. C. Lewis and L. V Alexander (2015) A multi-region assessment of observed changes in the areal extent of temperature and precipitation extremes. *J Clim.*, **28**, 9206-9220.

(162) Grose, M.R., M.T. Black, J.S. Risbey, and D. J. Karoly (2015) Attribution of exceptional mean sea level pressure anomalies south of Australia in August 2014. *Bull. Am. Met. Soc.*, **96** (12), S158-162.

(161) Henley, B. J., J. Gergis, D. J. Karoly, S. Power, J. Kennedy and C. K. Folland (2015) A Tripole Index for the Interdecadal Pacific Oscillation, *Clim. Dyn.*, **45**, 3077-3090.

(160) King, A. D., G.J. van Oldenborgh, D.J. Karoly, S.C. Lewis and H. Cullen (2015) Attribution of the record high Central England Temperature of 2014 to anthropogenic influences. *Env. Res. Lett.*, **10**, 054002, doi:10.1088/1748-9326/10/5/054002.

(159) King, A. D., M. G. Donat, L. V. Alexander, D. J. Karoly (2015) The ENSO-Australian rainfall teleconnection in reanalysis and CMIP5. *Clim. Dyn.*, **44**, 2623-2635.

(158) King, A. D., M.T. Black, D. J. Karoly and M. G. Donat, (2015) Increased likelihood of Brisbane, Australia, G20 heat event due to anthropogenic climate change. *Bull. Am. Met. Soc.*, **96** (12), S141-144.

(157) King, A.D., M. Donat, E. Fischer, E. Hawkins, L. Alexander, D.J. Karoly, A. Dittus, S. Lewis, S. Perkins (2015) The timing of anthropogenic emergence in simulated climate extremes. *Env. Res. Lett.*, **10**, 094015, doi:10.1088/1748-9326/10/9/094015.

(156) Lewis, S. C. and D. J. Karoly (2014) Are estimates of anthropogenic and natural influences on Australia's extreme 2010-2012 rainfall model-dependent? *Climate Dynamics,* **45**, 679-695.

(155) McMahon, T.A., M.C. Peel and D.J. Karoly (2015) Assessment of precipitation and temperature data from CMIP3 global climate models for hydrologic simulation. *Hydrol. Earth Syst. Sci.,* **19**, 361-377.

(154) Peel, M. C., R. Srikanthan, T. A. McMahon and D. J. Karoly (2015) Approximating uncertainty of annual runoff and reservoir yield using stochastic replicates of global climate model data. *Hydrol. Earth Syst. Sci.,* **19**, 1615-1639.

(153) Tyler, J., K. Mills, C. Barr, K. Sniderman, P. Gell and D. Karoly (2015) Identifying coherent patterns of environmental change between multiple, multivariate records: an application to four 1000-year diatom records from Victoria, Australia. *Quatern. Sci. Rev.*, **119**, 94-105.

(152) Allen, J. T, and D. J. Karoly (2014) A climatology of Australian severe thunderstorm environments 1979-2011: Inter-annual variability and ENSO influence. *Int. J. Climatol.,* **34**, 81-97.

(151) Allen, J.T., D. J. Karoly and K.J. Walsh (2014) Future Australian severe thunderstorm environments Part A: A novel evaluation and climatology of convective parameters from two climate models for the late 20th century. *J. Clim.*, **27,** 3827-3847.

(150) Allen, J.T., D. J. Karoly and K.J. Walsh (2014) Future Australian severe thunderstorm environments Part B: The influence of a strongly warming climate on convective environments. *J. Clim.*, **27,** 3848-3868.

(149) Ashcroft, L., D. J. Karoly and J. Gergis (2014) Southeastern Australian climate variability 1860–2009: a multivariate analysis. *Int. J. Climatol.,* **34**, 1928–1944.

(148) Ashcroft, L., J. Gergis and D. J. Karoly (2014) A historical climate dataset for southeastern Australia, 1788–1859. *Geosci. Data J.*, **1**, 158-178.

(147) Dittus, A. J., D. J. Karoly, S. C. Lewis, and L. V. Alexander (2014) An investigation of some unexpected frost day increases in southern Australia. *Aust. Met. Ocean. J.*, **64**, 261-271.

(146) Gallant, A. J. E., D. J. Karoly and K. L. Gleason (2014) Consistent Trends in a Modified Climate Extremes Index in the U.S.A., Europe and Australia. *J. Clim*., 27, 1379-1394.

(145) Karoly, D. J. (2014) Climate change: Human-induced rainfall changes, *Nature Geosci*., **7**, 551-552.

(144) Kearney, M. R., A. Shamakhy, R. Tingley, D. J. Karoly, A. A. Hoffmann, P. R. Briggs and W. P. Porter (2014) Microclimate modelling at macro scales: a test of a general microclimate model integrated with gridded continental-scale soil and weather data. *Methods Ecol. Evol.,* **5**, 273-286.

(143) King, A. D., D. J. Karoly, M. G. Donat, and L. V. Alexander (2014) Climate change turns Australia's 2013 Big Dry into a year of record-breaking heat. *Bull. Am. Met Soc.*, *Bull. Am. Met Soc.*, **95** (9), S41-S45.

(142) Lewis, S. C., and D. J. Karoly (2014) Assessment of forced responses of the Australian Community Climate and Earth System Simulator (ACCESS) version 1.3 in CMIP5 historical detection and attribution experiments. *Aust. Met. Ocean. J.*, **64**, 87-101.

(141) Lewis, S. C., and D. J. Karoly (2014) The role of anthropogenic forcing in the record 2013 Australia-wide annual and spring temperatures. *Bull. Am. Met Soc.*, **95** (9), S31-S34.

(140) Lewis, S. C., D. J. Karoly and M. Yu (2014) Quantitative estimates of anthropogenic contributions to extreme Australia- and state -wide monthly, seasonal and annual average temperatures, *Aust. Met. Ocean. J.*, **64**, 215-230.

(139) Neukom, R., J. Gergis, D. J. Karoly, H. Wanner, M. Curran, J. Elbert, F. González-Rouco, B. K. Linsley, A. D. Moy, I. Mundo, C. C. Raible, E. J. Steig, T. van Ommen, T. Vance, R. Villalba, J. Zinke and D. Frank (2014) Inter-hemispheric temperature variability over the past millennium. *Nature Clim. Change*, **4**, 362-367.

(138) Wiseman, J., D. Karoly and A. Sheko (2014) Cool Melbourne: Towards a Sustainable and Resilient Zero Carbon City in a Hotter World. In Whitzman, C., Gleeson, B. & Sheko, A. (2014). *Melbourne: What Next?*, Research Monograph No. 1, Melbourne Sustainable Society Institute, The University of Melbourne, pp. 63-73.

(137) WMO (World Meteorological Organization), *Assessment for Decision-Makers: Scientific Assessment of Ozone Depletion: 2014*, 88 pp., Global Ozone Research and Monitoring Project—Report No. 56, Geneva, Switzerland, 2014 (Authors A-L Ajavon, 10 others, D. J. Karoly, and 16 others)

(136) Bodman, R., P. Rayner and D. Karoly (2013) Uncertainty in temperature projections reduced using carbon cycle and climate observations. *Nature Clim. Change*, **3**, 725-729. doi:10.1038/nclimate1903 .

(135) Boulter, S., J. Palutikof, D. J. Karoly, and D. Guitart, Eds. (2013) *Natural Disasters and Adaptation to Climate Change.* CUP, New York, USA, 273 pp.

(134) Boulter, S., J. Palutikof and D. Karoly (2013) Lessons learned for adaption for climate change. Chapt 24 in *Natural Disasters and Adaptation to Climate Change.* Eds. Boulter, S., J. Palutikof, D. J. Karoly, and D. Guitart, CUP, New York, USA, 236-251.

(133) Christidis, N., P. A. Stott, D. J. Karoly and A Ciavarella (2013) An attribution study of the heavy rainfall over eastern Australia in March 2012. [In "Explaining Extreme Events of 2012 from a Climate Perspective"], *Bull. Amer. Meteor. Soc*., **94** (9), S58-S61.

(132) Gallant, A. J. E., S. J. Phipps, D. J. Karoly, A. B. Mullan and A. M. Lorrey (2013) Non-stationary Australasian teleconnections and implications for paleoclimate reconstructions. *J. Clim*., **26**, 8827-8849 doi: 10.1175/JCLI-D-12-00338.1 .

(131) Karoly, D. J., and S. Boulter (2013) Afterword: floods, storms, fire and pestilence – disaster risk in Australia during 2010-11. Chapt 25 in *Natural Disasters and Adaptation to Climate Change.* Eds. Boulter, S., J. Palutikof, D. J. Karoly, and D. Guitart, CUP, New York, USA, 252-263.

(130) King, A. D., S. C. Lewis, S. E. Perkins, L. V. Alexander, M. G. Donat, D. J. Karoly and M. T. Black (2013) Limited Evidence of Anthropogenic Influence on the 2011–12 Extreme Rainfall Over Southeast Australia. [In "Explaining Extreme Events of 2012 from a Climate Perspective"], *Bull. Amer. Meteor. Soc*., **94** (9), S55-S58.

(129) Lewis, S. C., and D. J. Karoly (2013) Evaluation of historical diurnal temperature range trends in CMIP5 models. *J. Clim*., **26**, 9077-9089, doi: 10.1175/JCLI-D-13-00032.1.

(128) Lewis, S.C., and D. J. Karoly (2013) Anthropogenic contributions to Australia's record summer temperature of 2013. *Geophys. Res. Lett*., **40,** 3705-3709. DOI: 10.1002/grl.50673

(127) Palutikof, J., S. Boulter, D. Guitart and D. J. Karoly (2013) Introduction. Chapt. 1 in *Natural Disasters and Adaptation to Climate Change.* Eds. Boulter, S., J. Palutikof, D. J. Karoly, and D. Guitart,, CUP, New York, USA, 1-5.

(126) Siddaway, J. M., S. V. Petelina, D. J. Karoly, A. R. Klekociuk, and R. J. Dargaville (2013) Evolution of Antarctic ozone in September–December predicted by CCMVal-2 model simulations for the 21st century. *Atmos. Chem. Phys*., **13**, 4413-4427.

(125) Whetton, P., D. Karoly, I. Watterson, L. Webb, F. Drost, D. Kirono and K. McInnes (2013) Australia's climate in a four degree world. Chapt. 2 in *Four Degrees of Global Warming. Australia in a Hot World.* Ed. P. Christoff, Routledge, UK, 17-32.

(124) Whittaker J., J. Handmer, and D. Karoly (2013) After 'Black Saturday': adapting to bushfires in a changing climate. In *Natural Disasters and Adaptation to Climate Change.* Eds. Boulter, S., J. Palutikof, D. J. Karoly, and D. Guitart, CUP, New York, USA, 75-86.

(123) Ashcroft, L., D. J. Karoly and J. Gergis (2012) Temperature variations of southeastern Australia, 1860–2011. *Aust. Met. Ocean. J.,* **62**, 227-245.

(122) Bodman, R. W., D. J. Karoly, S. E. Wijffels, and I. G. Enting (2012), Observational constraints on parameter estimates for a simple climate model, *Aust. Met. Ocean. J.,* **62**, 277-285.

(121) Boone, K. M., R. A. McPherson , M. B. Richman, and D. J. Karoly (2012) Spatial coherence of rainfall variations using the Oklahoma Mesonet. *Int. J. Climatol.,* **32**, 843-853. doi:10.1002/joc.2322.

(120) Drost, F., and D. J. Karoly (2012) Evaluating global climate responses to different forcings using simple indices, *Geophys. Res. Lett.*, **39**, L16701, 5pp, doi:10.1029/2012GL052667.

(119) Drost, F., D. J. Karoly and K. Braganza (2012) Communicating global climate change using simple indices: an update. *Clim. Dyn.*, **39**, 989-999. DOI: 10.1007/s00382-011-1227-6

(118) Gallant, A. J. E., A. S. Kiem, D. C. Verdon-Kidd, R. C. Stone, D. J. Karoly (2012) Understanding hydroclimate processes in the Murray-Darling Basin for natural resources management. *Hydrol. Earth Syst. Sci.*, **16**, 2049-2068. doi:10.5194/hess-16-2049-2012 .

(117) Gergis, J., A. J. E. Gallant, K. Braganza, D. J. Karoly, K. Allen, L. Cullen, R. D'Arrigo, I. Goodwin, P.

Grierson and S. McGregor (2012) On the long-term context of the 1997–2009 'Big Dry' in south-eastern Australia: insights from a 206-year multi-proxy rainfall reconstruction. *Climatic Change*, **111**, 923-944. DOI: 10.1007/s10584-011-0263-x.

(116) Karoly, D. (2012) Greenhouse gas emissions and climate change. In *2020: Vision for a Sustainable Society*. Pearson, C.J. (ed.), Melbourne Sustainable Society Inst., University of Melbourne, 27-36.

(115) Watson, P. A. G., D. J. Karoly, M. R. Allen, N. Faull, and D. S. Lee (2012) Quantifying uncertainty in future Southern Hemisphere circulation trends. *Geophys. Res. Lett*., **39,** L23708, 6pp, DOI: 10.1029/2012GL054158 .

(114) Allen, J. T., D. J. Karoly and G. A. Mills (2011) A severe thunderstorm climatology for Australia and associated thunderstorm environments. *Aust. Met. Ocean. J.,* **61**, 143-158.

(113) Allison, I., N. L. Bindoff, R. A. Bindschadler, P. M. Cox, N. de Noblet, M. H. England, J. E. Francis, N. Gruber, A. M. Haywood, **D. J. Karoly**, G. Kaser, C. Le Quéré, T. M. Lenton, M. E. Mann, B. I. McNeil, A. J. Pitman, S. Rahmstorf, E. Rignot, H. J. Schellnhuber, S. H. Schneider, S. C. Sherwood, R. C. J. Somerville, K. Steffen, E. J. Steig, M. Visbeck, A. J. Weaver (2011) *The Copenhagen Diagnosis: Updating the world on the latest climate science*, Elsevier, Netherlands, 114 pp.

(112) Arblaster, J. M., G. A. Meehl and D. J. Karoly (2011) Future climate change in the Southern Hemisphere: Competing effects of ozone and greenhouse gases. *Geophys Res. Lett*., **38**, L02701, 6 pp., doi:10.1029/2010GL045384.

(111) Bukovsky, M. S., and D. J. Karoly (2011) A regional modeling study of climate change impacts on warm-season precipitation in the central U.S. *J. Clim*., 24, 1985-2002, doi: 10.1175/2010JCLI3447.1, .

(110) Jakob, D., D. Karoly and A. Seed (2011) Non-stationarity in daily and sub-daily intense rainfall Part I: Sydney, Australia. *Nat. Hazards Earth Syst. Sci*., 11, 2263–2271.

(109) Jakob, D., D. Karoly and A. Seed (2011) Non-stationarity in daily and sub-daily intense rainfall Part II: Regional assessment for sites in south-east Australia. *Nat. Hazards Earth Syst. Sci*., 11, 2273–2284.

(108) Ren, D., R. Fu, L. M. Leslie, D. J. Karoly, J. Chen and C. Wilson (2011) A multi-rheology ice model: Formulation and application to the Greenland ice sheet. *J. Geophys. Res*., **116**, D05112, doi:10.1029/2010JD014855.

(107) Ren, D., R. Fu, L. M. Leslie, J. Chen, C. Wilson and D. J. Karoly (2011) The Greenland ice sheet response to transient climate change. *J. Clim*., **24**, doi: 10.1175/2011JCLI3708.1.

(106) Thompson, D.W.J., S. Solomon, P. Kushner, M. H. England, K.M. Grise and D.J. Karoly (2011) Signatures of the Antarctic ozone hole in Southern Hemisphere surface climate change. *Nat. Geosci.,* **4**, 741-749.

(105) Allison, I., M. Bird, J. Church, M. England, I. Enting, D. Karoly, M. Raupach, J. Palutikof, and S. Sherwood (2010) *The Science of Climate Change: Questions and Answers*, Aust. Acad. Science, 16pp.

(103) Bodman, R. W., D. J. Karoly, and I. G. Enting (2010) Utilising temperature differences as constraints for estimating parameters in a simple climate model. *IOP Conf. Series: Earth and Env. Sci.*, **11,** 6pp, 012024 doi:10.1088/1755-1315/11/1/012024

(103) Forster, P. M., D. W. J. Thompson, M. P. Baldwin, M. P. Chipperfield, M. Dameris, J. D. Haigh, D. J. Karoly, P. J. Kushner, W. J. Randel, K. H. Rosenlof, D. J. Seidel, and S. Solomon (2010) Stratospheric changes and climate. In WMO/UNEP *Scientific Assessment of Ozone Depletion: 2010,* WMO Global Ozone Research and Monitoring Project, Report No. 52, Geneva, pp 3.1 – 3.60.

(102) Gallant, A. J. E., and D. J. Karoly (2010) A combined Climate Extremes Index for the Australian region. *J. Clim.*, **23**, 6153-6165.

(101) Kearney, M. R., N. J. Briscoe, D. J. Karoly, W. P. Porter, M. Norgate and P. Sunnucks (2010) Early emergence in a butterfly causally linked to anthropogenic warming. *Biology Letters*, **6,** 674-677. doi:10.1098/rsbl.2010.0053.

(100) Stott, P. A., N. P. Gillett, G. C. Hegerl, D. Karoly, D. Stone, X. Zhang and F. Zwiers (2010) Detection and attribution of climate change: a regional perspective. *WIREs: Climate Change*, **1**, 192-211, DOI:10.1002/wcc.34.

(99) Allison, I., 8 others, D. Karoly, and 16 others (2009) *The Copenhagen Diagnosis: Updating the world on the latest climate science*, UNSW, Sydney, Australia, 60 pp

(98) Bukovsky, M. S., and D. J. Karoly (2009) A note on precipitation simulations using WRF as a nested regional climate model. *J. App. Met. Clim.,* **48**, 2152-2159.

(97) Gallant, A. J. E., and D. J. Karoly (2009) The atypical influence of the 2007 La Niña on rainfall and temperature in southeastern Australia. *Geophys. Res. Lett*., **36**, L14707, doi:10.1029/2009GL039026.

(96) Gergis, J., D. J. Karoly and R. J. Allan (2009) A climate reconstruction of Sydney Cove, New South Wales, using weather journal and documentary data, 1788–1791. *Aust. Met. Ocean. J.,* **58**, 83-98.

(95) Karoly, D.J. (2009) The blame game: Assigning responsibility for the impacts of anthropogenic climate change. In *Climate Change and Social Justice*, J. Moss (Ed.), Melb. Uni. Press, 25-37.

(94) Marsh, P.T., H.E. Brooks and D.J. Karoly (2009) Preliminary investigation into the severe thunderstorm environment of Europe simulated by the Community Climate Systems Model 3. *Atmos. Res.*, **93**, 607-618, doi:10.1016/j.atmosres.2008.09.014.

(93) Meehl, G. A., 10 others, D. Karoly, and 8 others (2009) Decadal Prediction: Can it be skillful? *Bull Am Met. Soc*., **90**, 1467—1485.

(92) Ren, D., J. Wang, R. Fu, D. J. Karoly, Y. Hong, L. M. Leslie, C. Fu, and G. Huang (2009), Mudslide-caused ecosystem degradation following Wenchuan earthquake 2008, *Geophys. Res. Lett*., **36**, L05401, doi:10.1029/2008GL036702.

(91) Walsh, K., D. Karoly and N. Nicholls (2009) Detection and attribution of climate change effects on tropical cyclones. In *Hurricanes and Climate Change*, J.B. Elsner and T.H. Jagger (Eds.), Springer, 1-20.

(90) Gleason, K.L., J.H. Lawrimore, D.H. Levinson, T.R. Karl and D.J. Karoly (2008) A revised U.S. Climate Extremes Index. *J. Climate*, **21**, 2124-2137.

(89) Hoerling, M., G. Hegerl, D. Karoly, A. Kumar, and D. Rind (2008) Attribution of the causes of climate variations and trends over North America during the modern reanalysis period. In: *Reanalysis of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of Observed Change.* A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [Randall Dole, Martin Hoerling, and Siegfried Schubert (eds.)]. National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, 47-92.

(88) Ren, D., and D.J. Karoly (2008) Predicting the response of seven Asian glaciers to future climate scenarios using a simple linear glacier model, *J. Geophys. Res*., **113**, D05103, doi:10.1029/2007JD008997.

(87) Ren, D., L.M. Leslie, and D.J. Karoly (2008) Landslide risk analysis using a new constitutive relationship for granular flow. *Earth Interactions*, **12** (4), 1-16, DOI: 10.1175/2007EI237.1

(86) Ren, D., L.M. Leslie, and D.J. Karoly (2008) Sensitivity of an ecological model to soil moisture simulations from two different hydrological models. *Met. Atmos. Phys.*, **100**, 87-99.

(85) Rosenzweig, C., D. Karoly, M. Vicarelli, P.r Neofotis, Q. Wu, G. Casassa, A. Menzel, T.L. Root, N. Estrella, B. Seguin, P. Tryjanowski, C. Liu, S. Rawlins and A. Imeson (2008) Attributing physical and biological impacts to anthropogenic climate change. *Nature*, **453**, 353-357.

(84) Wu, Q. D.J. Karoly, and G.R. North (2008) Role of water vapor feedback on the amplitude of season cycle in the global mean surface air temperature. *Geophys. Res. Lett*., L08711, doi:10.1029/2008GL033454.

(83) Blashki G., T. McMichael, and D.J. Karoly (2007) Climate change and primary health care. *Aust. Fam. Phys*., **36**, 986-989.

(82) Bukovsky, M.S., and D.J. Karoly (2007) A brief evaluation of precipitation from the North American Regional Reanalysis. *J. Hydrometeor*., **8**, 837-846.

(81) Christidis, N., P.A. Stott, S. Brown, D.J. Karoly, and J. Caesar (2007) Human contribution to the lengthening of the growing season during 1950–99. *J. Climate*, **20**, 5441–5454

(80) Dixon, H.G., D.J. Hill, D.J. Karoly, D. J. Jolley, and S.M. Aden (2007) Solar UV forecasts: A randomized trial assessing their impact on adults' sun-protection behavior. *Health Education & Behavior*, **34**, 486-502.

(79) IPCC (2007) *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team (including D. Karoly), Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 102 pp.

(78) IPCC (2007) Summary for Policymakers, Drafting authors: N. Adger, 24 coauthors, D. Karoly, and 37 coauthors. 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,* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7-22.

(77) Leslie, L.M., D.J. Karoly, M. Leplastrier and B.W. Buckley (2007) Variability of tropical cyclones over the southwest Pacific Ocean using a high-resolution climate model. *Meteor. Atmos. Phys*., **97**, 171-180.

(76) Marsh, P.T, H.E. Brooks, and D.J. Karoly (2007) Assessment of the severe weather environment in North America simulated by a global climate model. *Atmos. Sci. Lett.*, **8**, 100-106.

(75) Ren, D., D.J. Karoly and L.M. Leslie (2007) Temperate mountain glacier-melting rates for the period 2001–30: Estimates from three coupled GCM simulations for the Greater Himalayas. *J. App. Met. Clim.*, **46**, 890-99.

(74) Rosenzweig, C., G. Casassa, D.J. Karoly, A. Imeson, C. Liu, A. Menzel, S. Rawlins, T.L. Root, B. Seguin, P. Tryjanowski, (2007) Assessment of observed changes and responses in natural and managed systems. 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*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 79-131.

(73) Verbout, S.M., D.M. Schultz, L.M. Leslie, H.E. Brooks, D.J. Karoly, and K.L. Elmore (2007) Tornado outbreaks associated with landfalling hurricanes in the North Atlantic Basin: 1954–2004. *Meteor. Atmos. Phys*., **97**, DOI 10.1007/s00703-006-0256-x

(72) Wu, Q., and D. J. Karoly (2007) Implications of changes in the atmospheric circulation on the detection of regional surface air temperature trends, *Geophys. Res. Lett*., **34**, L08703, doi:10.1029/2006GL028502.

(71) Haylock, M. R., 12 coauthors, D. Karoly, and 10 coauthors (2006) Trends in total and extreme South American rainfall in 1960ñ2000 and links with sea surface temperature. *J. Climate*, **19**, 1490-1512.

(70) Hegerl, G.C., T.R. Karl, M. Allen, N.L. Bindoff, N. Gillett, D. Karoly, X. Zhang and F. Zwiers (2006) Climate change detection and attribution: Beyond mean temperature signals. *J. Climate*, **19**, 5058-5077.

(69) Karoly, D.J., and P.A. Stott (2006) Anthropogenic warming of central England temperature. *Atmos. Sci. Lett.*, **7**, DOI: 10.1002/asl.136.

(68) Ren, D., and D. Karoly (2006) Comparison of glacier-inferred temperatures with observations and climate model simulations. *Geophys. Res. Lett.* , **33**, L23710, doi: 10.1029/2006GL027856.

(67) Karoly, D.J., and Q. Wu (2005) Detection of regional surface temperature trends. *J. Climate*, **18**, 4337-4343.

(66) Karoly, D.J., and K. Braganza (2005) A new approach to detection of anthropogenic temperature changes in the Australian region. *Meteorol. Atmos. Phys.*, **89**, 57-67.

(65) Karoly, D.J., and K. Braganza (2005) Attribution of recent temperature changes in the Australian region. *J. Climate*, **18**, 457-464.

(64) Vincent, L.A., 23 coauthors, and D. Karoly, (2005) Observed trends in indices of daily temperature extremes in South America 1960-2000. *J. Climate*, **18**, 5011-5023.

(63) Braganza, K., D.J. Karoly, and J. Arblaster (2004) Diurnal temperature range as an index of global climate change during the twentieth century. *Geophys. Res. Lett.*, **31**, L13217, doi:10.1029/2004GL019998.

(62) Braganza, K., D.J. Karoly, A.C. Hirst, P. Stott, R.J. Stouffer, and S.F.B. Tett (2004) Simple indices of global climate variability and change: Part II ñ Attribution of climate change during the 20th century. *Climate Dynamics*, **22**, 823-838.

(61) Randel, W., E. Fleming, M. Gelman, M. Geller, K. Hamilton, D. Karoly, and 11 coauthors (2004) The SPARC intercomparison of middle atmosphere climatologies. *J. Climate*, **17**, 986-1003.

(60) Karoly, D.J., K. Braganza, P.A. Stott, J.M. Arblaster, G.A. Meehl, A.J. Broccoli and K.W. Dixon (2003) Detection of a human influence on North American climate. *Science*, **302**, 1200-1203.

(59) Karoly, D.J. (2003) Ozone and climate change. *Science*, **302**, 236-237.

(58) Cai, W., P.H. Whetton, and D.J. Karoly (2003) The response of the Antarctic Oscillation to increasing and stabilised CO. *J. Climate*, **16**, 1525-1538.

(57) Grainger, S., and D.J. Karoly (2003) A transport model study of the breakup of the Antarctic ozone hole in November 2000. *Geophys. Res. Lett.*, **30**, 1368, doi: 10.1029/2002GL016494.

(56) Li, S., E. C. Cordero and D. J. Karoly (2003) Three-dimensional simulations of the springtime breakup of the Antarctic ozone hole. *Aust. Met. Mag.*, **52**, 1-9.

(50) Chane-Ming, F., F.M. Guest and D.J. Karoly (2003) Gravity waves observed in temperature, wind and ozone data over Macquarie Island, *Aust. Met. Mag.*, **52**, 11-21.

(55) Braganza, K., D.J. Karoly, A.C. Hirst, M.E. Mann, P. Stott, R.J. Stouffer, and S.F.B. Tett (2003) Simple indices of global climate variability and change: Part I - Variability and correlation structure. *Climate Dynamics*, **20**, 491-502. DOI 10.1007/s00382-002-0286-0 .

(54) Karoly, D.J., J.F.B. Mitchell, M.R. Allen, G. Hegerl, F. Zwiers, and J. Marengo (2003) Comment on Soon et al. (2001) Modeling climatic effects of anthropogenic carbon dioxide emissions: unknowns and uncertainties. *Clim. Res.*, **24**, 91-92.

(53) Li, S., E. C. Cordero and D. J. Karoly (2002) Transport out of the Antarctic polar vortex from a three-dimensional transport model. *J. Geophys. Res.*, **107**, 4132, DOI 10.1029/2001JD000508/4132.

(52) Mitchell, J. F. B., D. J. Karoly, G. C. Hegerl, F. W. Zwiers, J. Marengo and M. Allen (2001) Detection of climate change and attribution of causes. In *Climate Change 2001: The Scientific Basis*, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., et al., (eds.)]. Cambridge University Press, 695-738.

(51) Hall, J. D., A. J. Matthews, and D. J. Karoly (2001) The modulation of tropical cyclone activity in the Australian region by the Madden-Julian oscillation. *Mon. Wea. Rev.*, **129**, 2970-2982.

(50) Karoly, D. J., and K. Braganza (2001) Identifying global climate change using simple indices. *Geophys. Res. Lett.* **28**, 2205-2208.

(49) Sexton, D. M. H., D. P. Rowell, C. K. Folland, and D. J. Karoly (2001) Detecting anthropogenic climate change using an atmospheric GCM. *Climate Dynamics*, **17**, 669-685.

(48) Williams, A. A. J., D. J. Karoly and N. Tapper (2001) The sensitivity of Australian fire danger to climate change. *Climatic Change*, **49**, 171-191.

(47) Karoly, D. (2000) Ready for IPCC-2001: A practical approach to a daunting task. (Editorial Comment) *Climatic Change*, **45**, 469-470.

(46) Risbey, J. S., M. Kandlikar and D. J. Karoly (2000) A framework to articulate and quantify uncertainties in climate change detection and attribution. *Climate Research*, **16**, 61-78.

(45) Guest, F. M., M. J. Reeder, C. J. Marks and D. J. Karoly (2000) Inertia-gravity waves observed in the lower stratosphere over Macquarie Island. *J. Atmos. Sci.*, **57**, 737-752.

(44) Williams, A. A. J., and D. J. Karoly (1999) Extreme fire weather in Australia and the impact of the El Nino-Southern Oscillation. *Aust. Met. Mag.*, **48**, 15-22.

(43) Waugh, D. W., J. M. Sisson and D. J. Karoly (1998) Predictive skill of a NWP model in the southern lower stratosphere. *Quart. J. Roy. Met. Soc.*, **124**, 2181-2200.

(42) Kestin, T. A., D. J. Karoly, J.-I. Yano and N. Rayner (1998) Time-frequency analysis of ENSO and stochastic simulations. *J. Climate*, **11**, 2258-2272.

(41) Karoly, D. J., and D. G. Vincent, Editors (1998) *Meteorology of the Southern Hemisphere*, *Met. Monog.*, **49**, Am. Met. Soc., 410 pp.

(40) Karoly, D. J., D. G. Vincent, and J. M. Schrage (1998) General circulation. In *Meteorology of the Southern Hemisphere*, D. J. Karoly and D. G. Vincent, Eds., *Met. Monog.*, **49**, 47-85, Am. Met. Soc.

(39) Folland, C. K., D. M. H. Sexton, D. J. Karoly, C. E. Johnson, D. P. Rowell, and D. E. Parker (1998) Influences of anthropogenic forcing, sea surface temperature and sea ice extent on recent climate change. *Gephys. Res. Lett.*, **25**, 353-356.

(38) Trenberth, K. E., G. W. Branstator, D. Karoly, A. Kumar, N.-C. Lau, and C. Ropelewski (1998) Progress during TOGA in understanding and modeling global teleconnections associated with tropical sea surface temperatures. *J. Geophys. Res.*, **103**, 14291-14324.

(37) Karoly, D. J. (1997) Synergistic effects of greenhouse climate change and ozone depletion on human health. In *Climate Change and human health in the Asia-Pacific region*, P. Curson, C. Guest and E. Jackson Eds., Aust. Medical Assoc., 63-69.

(36) Karoly, D. J. (1997) Physics of stratospheric ozone and UV-B radiation. *Aust. Met. Mag.*, **46**, 179-184.

(35) Karoly, D. J., P.C. McIntosh, P. Berrisford, T.J. McDougall, and A.C. Hirst (1997) Similarities of the Deacon cell in the Southern Ocean and the Ferrel cells in the atmosphere. *Quart. J. Roy. Met. Soc.*, **122**, 519-526.

(34) Karoly, D. J. (1996) Physics of stratospheric ozone and UV-B radiation. *Cancer Forum*, **20**, 157-162.

(33) Tyrrell, G. C., D. J. Karoly and J. McBride (1996) Links between tropical convection and variations of the extratropical circulation during TOGA COARE. *J. Atmos. Sci.*, **53**, 2735-2748.

(32) Santer, B. D., K. E. Taylor, T. M. L. Wigley, T. C. Johns, P. D. Jones, D. J. Karoly, J. F. B. Mitchell, A. H. Oort, J. E. Penner, V. Ramaswamy, M. D. Schwatrzkopf, R. J. Stouffer, and S. Tett (1996) A search for human influences on the thermal structure of the atmosphere. *Nature*, **382**, 39-46.

(31) Karoly, D. J., G. L. Roff and M. J. Reeder (1996) Gravity wave activity associated with tropical convection detected in TOGA COARE sounding data. *Geophys. Res. Lett.*, **23**, 261-264.

(30) Collins, D. A., and D. J. Karoly (1996) Eddy tansports in a greenhouse climate simulation. *Aust. Met. Mag.*, **47**, 113-122.

(29) Karoly, D.J., P. Hope, and P.D. Jones (1996): Decadal variability of the Southern Hemisphere circulation. *Int. J. Climatol.*, **16**, 723-738.

(28) Karoly, D.J. (1995): Observed variability of the Southern Hemisphere atmospheric circulation. In *Natural Climate Variability on Decade-to-Century Time Scales*, D.G. Martinson et al. eds., Nat. Acad. Press, Washington, D.C., 111-118.

(27) Karoly, D.J., and R.D. Rosen (1994): The Fourth International Conference on Southern Hemisphere Meteorology and Oceanography. *Bull. Am. Met. Soc.*, **75**, 340-343.

(26) Karoly, D.J., J.A. Cohen, G.A. Meehl, J.F.B. Mitchell, A.H. Oort, R.J. Stouffer, and R.T. Wetherald (1994): An example of fingerprint detection of greenhouse climate change. *Climate Dynamics*, **10**, 97-105.

(25) Lehmann, P., D.J. Karoly, P.A. Newman, T.S. Clarkson and W.A. Matthews (1992): An investigation into the causes of stratospheric ozone loss in the southern Australasian region. *Geophys. Res. Lett.*, **19**, 1463-1466.

(24) Lehmann, P., D.J. Karoly, P.A. Newman, T.S. Clarkson and W.A. Matthews (1992): Long-term winter total ozone changes at Macquarie Island. *Geophys. Res. Lett.*, **19**, 1459-1462.

(23) Lavery, B., and D J. Karoly (1992): The 1986-89 ENSO cycle over the western Pacific Ocean. *Aust. Met. Mag.*, **40**, 71-79.

(22) Karoly, D.J., and D.S. Graves (1990): On data sources and quality for the Southern Hemisphere stratosphere. In *Dynamics, transport and photochemistry in the middle atmosphere of the Southern Hemisphere*, A. O'Neill Ed., NATO ASI Series C321, Kluwer Acad. Pub., 19-32.

(21) Karoly, D.J. (1990): The role of transient eddies in low-frequency zonal variations of the Southern Hemisphere circulation. *Tellus*, **42A**, 41-50.

(20) Karoly, D.J. (1989): Southern Hemisphere circulation features associated with El Nino-Southern Oscillation events. *J. Climate*, **2**, 1239-1252.

(19) Karoly, D.J., R.A. Plumb and M. Ting (1989): Examples of the horizontal propagation of quasi-stationary waves. *J. Atmos. Sci.*, **46**, 2802-2811.

(18) Karoly, D.J. (1989): Northern Hemisphere temperature trends: a possible greenhouse gas effect? *Geophys. Res. Lett.*, **16**, 465-468.

(17) Karoly, D.J. (1989): The impact of base-level analyses on stratospheric circulation statistics for the Southern Hemisphere. *PAGEOPH*, **130**, 181-194.

(16) Karoly, D.J. (1988): Evidence of recent temperature trends in the Southern Hemisphere. In *GREENHOUSE, Planning for climate change*, 52-59. G. I. Pearman, Ed., CSIRO, Australia.

(15) Szeredi, I., and D.J. Karoly (1987): The horizontal structure of monthly fluctuations of the Southern Hemisphere troposphere. *Aust. Met. Mag.*, **35**, 119-129.

(14) Szeredi, I., and D.J.Karoly (1987): The vertical structure of monthly fluctuations of the Southern Hemisphere troposphere. *Aust. Met. Mag.*, **35**, 19-30.

(13) Karoly, D.J. (1987): Southern Hemisphere temperature trends: a possible greenhouse gas effect? *Geophys. Res. Lett.*, **14**, 1139-1141.

(12) Karoly, D.J., and A.H.Oort (1987): A comparison of Southern Hemisphere circulation statistics based on GFDL and Australian analyses. *Mon. Wea. Rev.*, **115**, 2033-2059.

(11) Karoly, D.J., G.A.M.Kelly, J.F.Le Marshall and D.J.Pike (1986): An atmospheric climatology of the Southern Hemisphere based on ten years of daily numerical analyses (1972-1982). *WMO Long-Range Forecasting Research Report No.7*, WMO/TD-No.92, 73pp.

(10) Karoly, D.J. (1985): An atmospheric climatology of the Southern Hemisphere based on ten years of daily numerical analyses (1972-1982): II Standing wave climatology. *Aust. Met. Mag.*, **33**, 105-116.

(9) Le Marshall, J.F., G.A.M.Kelly and D.J.Karoly (1985): An atmospheric climatology of the Southern Hemisphere based on ten years of daily numerical analyses (1972-1982): I Overview. *Aust. Met. Mag.*, **33**, 65-85.

(8) Karoly, D.J. (1983): Atmospheric teleconnections, forced planetary waves and blocking. *Aust. Met. Mag.*, **31**, 51-56.

(7) Karoly, D.J. (1983): Rossby wave propagation in a barotropic atmosphere. *Dyn. Atmos. Oceans*, **7**, 111-125.

(6) Karoly, D.J. and B.J.Hoskins (1983): The steady linear response of the stratosphere to tropospheric forcing. *Quart. J.R. Met. Soc.*, **109**, 455-478.

(5) Karoly, D.J. (1982): Atmospheric vacillations in a general circulation model III: Analysis using transformed Eulerian-mean diagnostics. *J. Atmos. Sci.*, **39**, 2916-2922.

(4) Karoly, D.J. (1982): Eliassen-Palm cross sections for the Northern and Southern Hemispheres. *J. Atmos. Sci.*, **39**, 178-182.

(3) Karoly, D.J. and B.J.Hoskins (1982): Three dimensional propagation of planetary waves. *J. Met. Soc. Japan*, **60**, 109-123.

(2) Hoskins, B.J., and D.J.Karoly (1981): The steady linear response of a spherical atmosphere to thermal and orographic forcing. *J. Atmos. Sci.*, **38**, 1178-1196.

(1) Tsong, I.S.T., C.A.Cornelius and D.J.Karoly (1977): A quantitative demonstration of the Coriolis effect. *Physics Education*, **12** (2), 117-121.

REPORTS AND OTHER PUBLICATIONS:

(O76) Mullins, G., M. Rice, J. Gergis and D. Karoly (2023) *Powder keg: Australia primed to burn*, Climate Council of Australia, 36 pp.

(O75) Karoly, D. (2022) Disconnect: Climate change and the Australian election. *Pursuit*, University of Melbourne, 11 May 2022. https://pursuit.unimelb.edu.au/articles/disconnect-climate-change-and-the-australian-election

(O74) Karoly, D. (2022) Foreword, In *The Lost Years: Counting the costs of climate inaction in Australia*, Climate Council of Australia, 78 pp. https://www.climatecouncil.org.au/wp-content/uploads/2022/03/FINAL_CC_The-Lost-Decade_Low-Res.pdf

(O73) Karoly, D. (2021) Monday's IPCC report is a really big deal for climate change. So what is it? And why should we trust it? *The Conversation*, 7 Aug., 2021, https://theconversation.com/mondays-ipcc-report-is-a-really-big-deal-for-climate-change-so-what-is-it-and-why-should-we-trust-it-165614

(O72) Karoly, D., M. Grose, J. Clarke, R. Colman, J. Evans, J. Brown, A. Moise, S. Narsey, A. King and G. Boschat (2021) *Australia's Next Generation of Regional Climate Projections*, Final report to NCSAC, 38 pp., ESCC Hub Report No.23. Available from www.nespclimate.com.au

(O71) Australian Sustainable Finance Initiative (2020) *Australian Sustainable Finance Roadmap*. Principal authors: G. Noble and M. Pepper, with 8 contributing authors, including D. Karoly. 94 pp. Available from https://www.sustainablefinance.org.au/roadmap

(O70) Karoly, D. (2020) Record 2020 Spring temperature across Australia virtually impossible without human-caused climate change. NESP Earth Systems and Climate Change Hub News blog, 8 Dec. 2020. http://nespclimate.com.au/record-2020-spring-event-attribution/

(O69) Freund, M., B. Henley, D. Karoly, H. McGregor and N. Abram (2019) El Niño has rapidly become stronger and stranger, according to coral records. *The Conversation*, 7 May 2019. https://theconversation.com/el-nino-has-rapidly-become-stronger-and-stranger-according-to-coral-records-115560

(O68) Karoly, D. (2018) Foreword. In *Sunburnt Country: The history and future of climate change in Australia*, J. Gergis, Melb. Univ. Press, 310 pp

(O67) King, A., and D. Karoly (2017) 2017 is set to be among the three hottest years on record, *The Conversation,* 6 Nov. 2017. https://theconversation.com/2017-is-set-to-be-among-the-three-hottest-years-on-record-86934

(O66) Saddler, H., A. Pears and D. Karoly (2017) Energy solutions but weak on climate – Experts react to the Finkel review. *The Conversation,* 9 June 2017. https://theconversation.com/energy-solutions-but-weak-on-climate-experts-react-to-the-finkel-review-79178

(O65) King, A.D., D.J. Karoly and B.J. Henley (2017) Why 2°C of global warming is much worse for Australia than 1.5°C. *The Conversation*, 16 May 2017, https://theconversation.com/why-2-of-global-warming-is-much-worse-for-australia-than-1-5-77548

(O64) King, A., D. Karoly, G.J. van Oldenborgh, M. Hale and S. Perkins-Kirkpatrick (2017) Climte change signature was writ large on Australia's crazy summer of 2017. *The Conversation,* 2 March 2017. https://theconversation.com/climate-changes-signature-was-writ-large-on-australias-crazy-summer-of-2017-73854

(O63) Ashcroft, L., D. Karoly and J. Gergis (2017) Delving through settler's diaries can reveal Australia's colonial era climate. *The Conversation,* 10 Feb. 2017. https://theconversation.com/delving-through-settlers-diaries-can-reveal-australias-colonial-era-climate-72652

(O62) Henley, B., A. King, C. Folland, D. Karoly, J. Brown, and M. Freund, (2017) Meet El Niño's cranky uncle that could send global warming into hyperdrive. *The Conversation*, 6 Feb. 2017, https://theconversation.com/meet-el-ninos-cranky-uncle-that-could-send-global-warming-into-hyperdrive-72360

(O61) Hamilton, C., and D. Karoly (2016) The Climate Change Authority Report: a dissenting view. *The Conversation*, 5 Sept. 2016. https://theconversation.com/the-climate-change-authority-report-a-dissenting-view-64819

(O60) Karoly, D., and C. Hamilton (2016) David Karoly and Clive Hamilton: why we can't sign the latest Climate Change Authority report. *Sydney Morning Herald*, 4 Sept. 2016. http://www.smh.com.au/comment/david-karoly-and-clive-hamilton-why-we-cant-sign-the-latest-climate-change-authority-report-20160904-gr8e54.html

(O59) King, A.D., and D.J. Karoly (2016) How we can link some extreme weather to climate change. *Pursuit*, 18 March 2016. https://pursuit.unimelb.edu.au/articles/how-we-can-link-some-extreme-weather-to-climate-change

(O58) King, A., D. Karoly, M. Black, O. Hoegh-Guldberg and S. Perkins (2016) Great Barrier Reef bleaching would be almost impossible without climate change. *The Conversation*, 29 April 2016. https://theconversation.com/great-barrier-reef-bleaching-would-be-almost-impossible-without-climate-change-58408

(O58) Arblaster, J., I. Jubb, K. Braganza, L. Alexander, D. Karoly and R. Colman (2015) *Weather extremes and climate change - The science behind the attribution of climatic events*, ACCSP, Bureau of Met., 8pp. https://www.cawcr.gov.au/projects/Climatechange/wp-content/uploads/2015/11/Weather_Extremes_Report-FINAL.pdf

(O57) Black, M.T., A. D. King and D. J. Karoly (2015) A year of records: the human role in 2014's wild weather. *The Conversation*, 5 Nov 2015. https://theconversation.com/a-year-of-records-the-human-role-in-2014s-wild-weather-50208

(O56) Karoly, D., and G. Abrahams (2015) Climate science is looking to art to create change. *The Conversation*, 7 May 2015. https://theconversation.com/climate-science-is-looking-to-art-to-create-change-41185

(O55) Karoly, D. and M. Black (2015) It's been Australia's hottest ever October and that's no coincidence. *The Conversation*, 29 Oct. 2015. https://theconversation.com/its-been-australias-hottest-ever-october-and-thats-no-coincidence-49941

(O54) Saunders, K. R., D. Karoly and P. Taylor (2015) Explainer: Was the Sydney storm 'once-in-a-century'? *The Conversation*, 28 April 2015. https://theconversation.com/explainer-was-the-sydney-storm-once-in-a-century-40824

(O53) Karoly, D. (2014) Maurice Newman's flat-earth thinking ignores climate change facts, *The Age* Opinion, 1 Jan., http://www.theage.com.au/federal-politics/political-opinion/maurice-newmans-flatearth-thinking-ignores-climate-change-facts-20140101-305h6.html

(O52) Karoly, D. (2014) Explainer: How are IPCC reports written? *The Conversation*, 28 March, 2014. https://theconversation.com/explainer-how-are-ipcc-reports-written-24641

(O51) King, A., and D. Karoly (2014) Hot 2014 closes in on top spot in world temperature rankings. *The Conversation*, 5 Dec. 2014. http://theconversation.com/hot-2014-closes-in-on-top-spot-in-world-temperature-rankings-35046

(O50) King, A., D. Karoly and S. Lewis (2014) Scorching 2014 sees records tumble in 19 European countries. *The Conversation*, 17 Dec. 2014. http://theconversation.com/scorching-2014-sees-records-tumble-in-19-european-countries-35317

(O49) Lewis, S. and D. Karoly (2014) Australia's hottest year was no freak event: humans caused it. *The Conversation*, 6 Jan. 2014. https://theconversation.com/australias-hottest-year-was-no-freak-event-humans-caused-it-21734

(O48) Lewis, S. C., and D. J. Karoly (2014) Attributing Australia's record warm summer 2012/2013 and record warm calendar year 2013 to human influences. In *WMO statement on the status of the global climate in 2013*. WMO - No. 1130, World Met. Organization, Geneva. pp 20-21.

(O47) Bodman, R, and D. Karoly (2013) Uncertainty no excuse for procrastinating on climate change. *The Conversation*, 27 May 2013. https://theconversation.com/uncertainty-no-excuse-for-procrastinating-on-climate-change-14634

(O46) Karoly, D., M. England and W. Steffen (2013) *Off the charts: Extreme Australian summer heat.* Climate Commission, 5pp.

(O45) Karoly, D., and S. Lewis (2013) Hottest 12-month period confirmed – so what role did humans play? *The Conversation*, 2 September 2013. https://theconversation.com/hottest-12-month-period-confirmed-so-what-role-did-humans-play-17737

(O44) King, A., D. Karoly and L. Alexander (2013) The blame for rain is mainly done in vain. *The Conversation*, 6 September 2013. https://theconversation.com/the-blame-for-rain-is-mainly-done-in-vain-17896

(O43) Lewis, S. and D. Karoly (2013) The human role in our 'angry' hot summer. *The Conversation*, 27 June 2013. http://theconversation.com/the-human-role-in-our-angry-hot-summer-15596.

(O42) Steffen, W., L Hughes, and D. Karoly (2013) *The Critical Decade: Extreme Australian.* Climate Commission, 64pp.

(O41) Karoly, D. (2012) The Antarctic ozone hole and climate change. *The Conversation*, 14 Sept. 2012, http://theconversation.edu.au/the-antarctic-ozone-hole-and-climate-change-an-anniversary-worth-celebrating-9404

(O40) Karoly, D., C. Slattery, K. Townley and K. Haria-Adams (2012) Biased newspaper reporting on the carbon pricing mechanism. *The Conversation*, 18 Dec. 2012, http://theconversation.edu.au/biased-newspaper-reporting-on-the-carbon-pricing-mechanism-11373

(O39) Karoly, D. (2012) Not just another war story. Michael Mann: *The Hockey Stick and the Climate Wars*. In *Aust. Book Rev*., No. 343, 30-31.

(O38) Karoly, D. (2011) Beyond reasonable doubt. Ross Garnaut: *The Garnaut Review 2011.* In *Aust. Book Review,* No. 336.

(O37) Karoly, D. (2011) Climate futures and choices for society. In *Climate Futures Pathways for Society*,

(J. Lawrence, A. Cornforth and P. Barrett Eds.), NZ CCRI, Victoria Univ. Wellington, NZ, 23-29.

(O36) Karoly, D. (2011) Bob Carter's climate counter-consensus is an alternate reality. *The Conversation*, 24 June 2011, http://theconversation.edu.au/bob-carters-climate-counter-consensus-is-an-alternate-reality-1553.

(O35) Karoly, D. (2011) Talking about geo-engineering may prevent us needing it. *The Conversation*, 24 Nov 2011, http://theconversation.edu.au/talking-about-geo-engineering-may-prevent-us-needing-it-4263

(O34) Karoly, D. (2011) Our planet has a fever – Is geoengineering a safe treatment? *Crikey*, 26 Sept 2011. http://blogs.crikey.com.au/rooted/2011/09/26/david-karoly-our-planet-has-a-fever-is-geoengineering-a-safe-treatment/

(O33) Karoly, D. (2010) Remember that successful global climate treaty? *Cosmos Online*, 12 Oct 2010, http://www.cosmosmagazine.com/features/online/3798/remember-successful-global-climate-treaty

(O32) Karoly, D.J. (2009) The recent bushfires and extreme heatwave in southeast Australia. *Bull. Aust. Met. Ocean. Soc.*, **22**, 10-13.

(O31) Karoly, D. (2009) Quarry Vision Correspondence. *Quarterly Essay*, **34**, 120-121.

(O30) Karoly, D.J. (2008) Global warming science: Some responses to common misinformation. *Bull. Aust. Met. Ocean. Soc.*, **21**, 107-110.

(O29) Karoly, D.J. (2008) Anthropogenic climate change: why chemistry is relevant. *Chemistry in Australia*, **75**, No. 11, 13-17.

(O28) The Australian Climate Group (O. Hoegh-Guldberg, D. Karoly, I. Lowe, A. McMichael, G. Pearman, A. Coleman and G Bourne) (2008). *Climate Change: Solutions for Australia 2008*. WWF-Australia, Sydney, Aust. 17pp.

(O27) Gyakum, J., H. Willoughby, C. Cooper, M.J. Hayes, G. Jenkins, D. Karoly, R. Rotunno, C. Tebaldi and C. H. Marshall (2007) *Review of the U.S. Climate Change Science Program's Synthesis and Assessment Product 3.3 "Weather and Climate Extremes in a Changing Climate*", 49pp, Nat. Acad. Press, Washington, DC.

(O26) National Research Council (2004) *Review of the US CLIVAR Project Office*, (D.J. Karoly Chair), Nat. Acad. Press, 36 pp.

(O25) The Australian Climate Group (A. Coleman, O. Hoeve-Guldberg, D. Karoly, I. Lowe, A. McMichael, C. Mitchell, P. Scaife, G. Pearman, and A. Reynolds) (2003) *Climate Change - Solutions for Australia* Insurance Australia Group and WWF Australia, 35 pp.

(O24) Karoly, D., J. Risbey, A. Reynolds, and K. Braganza (2003) Global warming contributes to Australia's worst drought. *Australasian Science*, April 2003 issue, 14-17.

(O23) Karoly, D., J. Risbey, and A. Reynolds (2003) *Global warming contributes to Australia's worst drought*, WWF Australia, Sydney Aust., 8pp.

(O22) Karoly, D. J., and G. Teggart (2002) *Climate change science: An update of current understanding and uncertainties*, J. Ellis and J. Zillman Eds., Aust. Acad. Tech. Sci. and Eng., Parkville, Vic., 7pp.

(O21) Karoly, D. (2001) Interannual and longer-term variations of Australian mean climate parameters from observations and model simulations. *Understanding the climate of Australia and the Indo-Pacific region: 13th Annual BMRC Modelling Workshop*, BMRC Research Report No. 84, 49-52.

(O20) Karoly, D. (2001) SPARC-related activities in Australia. *SPARC Newsletter*, No. 17, 29-32.

(O19) Karoly, D. (2001) Detection and attribution of a stratospheric role in climate change: An IPCC perspective. *SPARC Newsletter*, No. 16, 16-18.

(O18) Karoly, D. (2000) Stratospheric aspects of climate forcing. *SPARC Newsletter*, No. 14, 15-16.

(O17) Karoly, D. J., K. Braganza, and S. Power (1998) Climate change detection and attribution using simple global indices. *Coupled Climate Modelling*, BMRC Research report No. 69, 85-88.

(O16) Karoly, D., (1998) The transition from the RMS(AB) to AMOS: Ten years on. *Bull. Aust. Met. Ocean. Soc.*, **11**, 64-65.

(O15) Roff, G., D. Karoly, M. Reeder, and T. Lane (1997) Gravity wave activity associated with tropical convection detected in TOGA COARE sounding data. *Proc. First SPARC General Assembly*, WMO/TD No. 814, 279-282.

(O14) Guest, F. M., M. Reeder, C. Marks, and D. Karoly (1997) Analyses of stratospheric gravity waves over Macquarie Island. *Proc. First SPARC General Assembly*, WMO/TD No. 814, 319-322.

(O13) Sisson, J. M., D. Waugh, and D. Karoly (1997) Predictive skill of a NWP model in the southern lower stratosphere. *Proc. First SPARC General Assembly*, WMO/TD No. 814, 649-652.

(O12) Karoly, D., D. Sexton, C. Folland and D. Rowell (1996) Simulating the climate of the 20th century. *Proc. Symp. Clim. Prediction and Predictability*, BMRC, Melbourne, 115-118.

(O11) Karoly, D. J., G. L. Roff and M. J. Reeder (1995) Gravity wave activity associated with tropical convection detected in TOGA COARE sounding data. *Proc. Int. Sci. Conf. Tropical Ocean Global Atmosphere (TOGA) Programme*, WMO/TD No. 717, 413-417.

(O10) Tyrrell, G. C., D. J. Karoly and J. L. McBride (1995) Links between tropical convection and variations of the extratropical circulation during TOGA COARE. *Proc. Int. Sci. Conf. Tropical Ocean Global Atmosphere (TOGA) Programme*, WMO/TD No. 717, 439-443.

(O9) Karoly, D.J., and D. Collins (1992): Variations of mean flow and eddy fluxes in a GCM. Proceedings of Third BMRC Modelling Workshop, BMRC Res. Report No. 33, 289-298.

(O8) Lavery, B.M., N.E. Davidson, D.J. Karoly, and B.J. McAvaney (1991): A climatology of the western Pacific region based on the Australian tropical analysis scheme. *BMRC Research Report No.28*, Bureau of Meteorology, Melbourne, 46pp.

(O7) Karoly, D.J. (1990): Greenhouse climate change fingerprint detection, in *IGBP Workshop 13 Mathematical and Statistical Modelling of Global Change Processes*, (G.A. Latham and J.A. Taylor eds.), Proceedings of the Centre for Mathematical Analysis, ANU, **25** (1990), 49-60.

(O6) Karoly, D.J., and B. Lavery (1989): The 1986-88 ENSO event over the western Pacific. *Tropical Ocean-Atmos. Newsletter*, No.49, 1-2.

(O5) Karoly, D.J., G.A.M. Kelly and J.F. Le Marshall (1987): The Australian Southern Hemisphere Climatology data tape, *BMRC Research Report No.7*, Bureau of Meteorology, Melbourne, Australia, 14pp.

(O4) Karoly, D.J. (1985): Southern Hemisphere circulation anomalies associated with ENSO events. *Tropical Ocean-Atmos. Newsletter*, No.33, 19.

(O3) Karoly, D.J. (1985): Australian Southern Hemisphere analyses for the FGGE year. *The G.W.E. Newsletter*, No.9, 10-15, USC-GARP JH810, Washington, D.C.

(O2) Karoly, D.J. (1985): The typicalness of the FGGE year in the Southern Hemisphere: A southern perspective. *GARP Special Report No.42*, pp I29-I43, WMO/TD-No.22.

(O1) Karoly, D.J. (1978): Rossby wave ray paths and horizontal wave propagation, in ``The General Circulation: Theory, Modelling and Observations" NCAR/CQ-6+1978-ASP, pp 474-484.