climate extremes
ARC centre of excellence
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The latest global climate models present challenges for generating climate projections

A joint ARC Centre of Excellence for Climate Extremes and NESP Earth Systems and Climate Change Hub briefing note

- Climate sensitivity refers to how much global temperature is likely to respond to carbon dioxide in the atmosphere. Climate sensitivity is crucial in understanding future climate change.
- The range of values of climate sensitivity from the latest generation of global climate models from the international Coupled Model Intercomparison Project phase 6 (CMIP6) don't reflect recent estimates of the range of climate sensitivity based on multiple lines of evidence. A large number of models have values in the upper range of what is considered reasonable (i.e. a very strong warming in response to carbon dioxide increase) and some have values in the lower range (i.e. a very weak warming in response to carbon dioxide increase).
- Those seeking to manage climate change risk should be aware that techniques used to generate climate projections from previous generations of global climate models may give misleading results if they are applied to the CMIP6 models. The climate research community is developing techniques to ensure that climate risk information derived from these models is clear and not misleading.
- The latest research on climate sensitivity and the CMIP6 models will be summarised for policymakers by the Intergovernmental Panel on Climate Change in their Sixth Assessment Report in August 2021.
- Further research is needed to fully understand the values of climate sensitivity in the models. Australia has the potential to contribute to this research, including through work with our national climate model (ACCESS).

What is climate sensitivity?

Climate sensitivity describes how sensitive the Earth's temperature is to a doubling of the amount of carbon dioxide in the atmosphere. One measure of climate sensitivity that is particularly relevant for projections of future climate conditions is the Equilibrium Climate Sensitivity (ECS). ECS is the increase in the global average temperature between the pre-industrial era and a future doubled carbon dioxide climate once equilibrium of the climate has been reached. Accurately estimating ECS is an ongoing research challenge.

The latest state-of-the-art assessment of climate sensitivity from Sherwood et al. (2020)[1] is based on multiple lines of evidence, including observations, theory and climate changes in the distant past[2]. The assessment concludes that ECS is *likely* (67% chance) to be within the range 2.6 to 3.9 °C, and *very likely* (90% chance) to be within the range 2.3 to 4.7 °C. The authors acknowledge that alternative judgments about the different lines of evidence would give different ranges, but found that no reasonable set of judgments would assign more than a 5% chance to ECS below 2.0 °C or above 5.7 °C. Values near the upper ends of these ranges imply that future climate change will be characterised by more severe global warming towards the end of the century and beyond, whereas values near the lower ends are consistent with less severe warming.

Global climate models

Global climate models (GCMs) are computer models that attempt to simulate the global climate system. GCM simulations are run at climate modelling centres around the world and are brought together by an international coordinated program called the Coupled Model Intercomparison Project (CMIP). These CMIP model simulations are used by scientists to help them understand how the climate system works and to develop climate projections to inform planning decisions. They are key inputs to the Intergovernmental Panel on Climate Change (IPCC) assessment reports and Australia's national and regional climate projections.

The CMIP GCMs aren't given a prescribed value of climate sensitivity. Instead, a modelled estimate of climate sensitivity arises through the interactions and feedbacks between the various simulated components of the climate system. The simulation of climate processes that contribute to how sensitive a model is to increases in carbon dioxide in the atmosphere differs between models and this results in different values of climate sensitivity for different models. There is no central coordination of how the different models simulate climate processes and the spread of climate sensitivity values across the range of models is not pre-planned.

What do the latest global climate models say about climate sensitivity?

The latest round of internationally coordinated global climate modelling, CMIP6[3], will reach maturity by the end of 2021. So far, around 50 different models from around the world have been used to simulate climate conditions at the end of the 21st century. Simulations that allow the calculation of ECS values are available for 37 of these models. The spread of values emerging from the CMIP6 models is broader than the previous CMIP5 generation. Published ECS values from CMIP5 models

are between 2.1 and 4.7 °C, while CMIP6 models so far give a range between 1.8 and 5.6 °C. The values in CMIP6 are also unevenly distributed compared to independent assessment, and more uneven compared to the older CMIP5 values.

Looking at the 37 CMIP6 models currently available with published ECS values and simulations of 21st century climate conditions (Figure 1), 15 models are within the *likely* range from the review by Sherwood et al. (2020) (2.6 to 3.9 °C). However, 17 models are above the *likely* range, with 12 above the *very likely* range (2.3 to 4.7 °C). All of these 17 models are within the range that is robust to alternative judgments about the different lines of evidence on ECS (2.0 to 5.7 °C). At the low end, five models are below the *likely* range, three below the *very likely* range, and two of these remain below the robust range. This contrasts strongly with the CMIP5 range, especially at the high end. High values lead to stronger global warming around the end of the century.

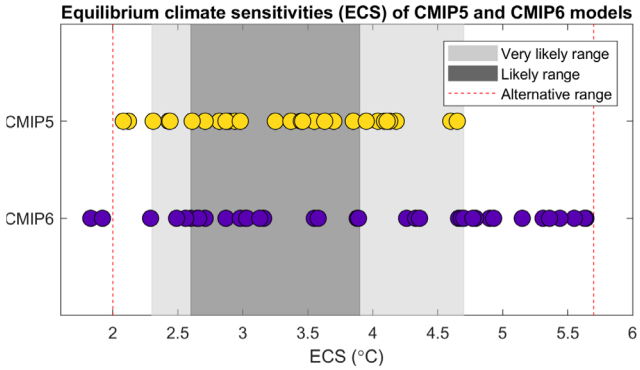

Figure 1. Equilibrium climate sensitivity (ECS) values for the CMIP5 and CMIP6 models with published ECS values and simulations of 21st century climate conditions available. Grey shading shows ranges of ECS values estimated for the real world by Sherwood et al. (2020). Red dashed lines show the range that is robust to alternative judgments about the different lines of evidence on ECS.

Why do so many models have very high or very low values of climate sensitivity?

The 17 CMIP6 GCMs with high climate sensitivity include models from well-respected modelling centres. Their results can't be rejected out of hand, even though they are giving ECS values that are considered unlikely. Various lines of evidence can be used to assess these models, including how well they simulate the global warming observed since the 19th century, and how realistically they simulate clouds and other important phenomena. It should be noted that the CMIP6 climate model simulations generally agree better with the magnitude and pattern of observed warming between 1900 and 2015 than the CMIP5 model simulations. Valuable insights can also be derived from how models simulate the very different climates of the more distant past (e.g. the last Ice Age). Research is now being conducted around the world to investigate why some models have a high climate sensitivity and others don't. Similarly, the cause of the very low values in two models, both from the Marchuk Institute of Numerical Mathematics (INM) in Russia, is not entirely clear yet.

Australia's contribution to global climate modelling efforts

Australia has the potential to contribute significantly to this global research. The Australian Community Climate and Earth System Simulator (ACCESS) program (a collaboration between the ARC Centre of Excellence for Climate Extremes, the Bureau of Meteorology, CSIRO and international collaborators) has contributed two world-class models to CMIP6: ACCESS-CM2[4] and ACCESS-ESM1.5[5]. ACCESS-CM2 is in the group of models with high climate sensitivity, with an ECS of 4.7 °C, while ACCESS-ESM1.5 has an ECS value of 3.9°C.

Australia has a climate research and modelling partnership with the UK, and the atmosphere component of the ACCESS models is similar to the UK's CMIP6 models. However, the UK models have even higher ECS values (5.6 and 5.4 °C respectively), so there are research opportunities to compare the models to understand the roles of the components that differ (e.g. the ocean component) in determining climate sensitivity.

Using the latest Global Climate Models to produce climate projections

Some traditional approaches to producing climate projections may result in misleading results if they are applied to CMIP6. In the past, IPCC and many other projections, including Australia's national projections[6], have given equal weight to the different CMIP GCMs, a 'one model, one vote' approach. Applying this approach to CMIP6 produces a higher upper bound and a cooler lower bound for Australian temperature projections than CMIP5[7]. However, given our understanding of climate sensitivity, this equal weighting over-emphasises the possibility of low or high temperature changes – including changes that should be considered unlikely. While there is no firm and agreed method to address this issue in Australia or overseas, there are various options:

Model rejection or weighting - Models could be excluded from, or given lower weighting in, climate projections if they have unrealistic climate sensitivity or poor simulation of past climate changes. Studies are already emerging that propose weightings that remove or reduce the low end and high end of warming for CMIP6[8,9]. If models are rejected or down weighted to make projections of global temperature, it is then an open question whether they should also be rejected or down weighted for regional projections, including projections of climate variables other than temperature. Other models (CMIP5, simpler models, statistical models) can also be used and weighted along with CMIP6. The research community will need a clear and convincing rationale for any choice to accept and weight models when producing climate projections for Australia.

Grouping models - An alternative approach to model rejection or weighting models is to present results separated into model groups according to their climate sensitivity. This may be warranted where the values of climate sensitivity make a dramatic difference to the messages around risk, such as for global warming under high greenhouse gas emissions pathways later in the century. A simple example below shows a wide range of change in global surface temperature in the 37 CMIP6 models under very high greenhouse gas concentrations under the Shared Socio-economic Pathway SSP5-85 for the end of the 21st century (Figure 2). If models with ECS values outside the *likely* range are simply rejected, then the projected temperature range from the remaining group of models is much narrower than when all models are included. Results from models with ECS above and below the *likely* range can be used to give a 'low likelihood, high impact' projection and a 'low likelihood, low impact' projection. These may be unlikely but are useful when managing the full range of risks if the world follows this pathway.

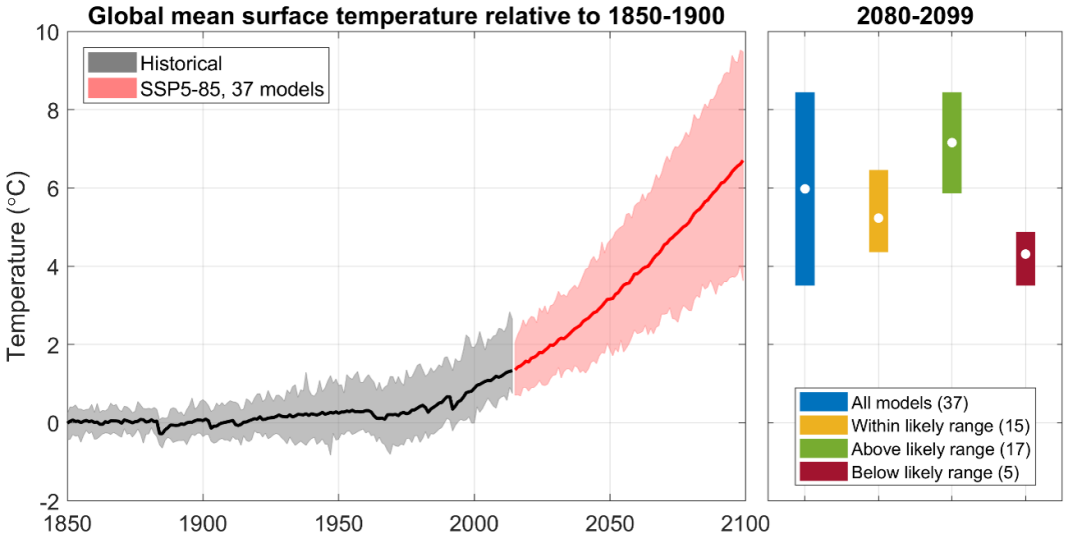

Figure 2. The global mean surface temperature relative to 1850-1900 in a group of 37 CMIP6 models for the very high emissions Shared Socio-economic Pathway SSP5-85 (full range of models and multi-model mean shown). Bars to the right show the 2080-2099 average in all 37 models, the 15 models with ECS values within the likely range from Sherwood et al. (2020) and those above and below the likely range.

Reporting on 'warming levels' rather than emissions pathways - There is now interest in what the regional climate looks like at global warming levels since the pre-industrial era. This includes the +1.5 and +2 °C global warming targets from the 2015 Paris Agreement, but also +3 and +4 °C. By generating climate projections for warming levels, GCM information on climate sensitivity and how fast the models reach each level is not used directly. Instead, GCM simulations are interrogated for regional climate changes consistent with chosen global warming levels. The independently assessed likely timing of reaching these warming levels can be reported alongside the global warming level projections. However, the climate sensitivities of the GCMs are still relevant to this approach. Imperfections in a GCM that lead to a particularly low or high climate sensitivity may also be responsible for a poor simulation of regional climate changes for a given global warming level.

Summary

The CMIP6 GCMs have a wider and more uneven range of climate sensitivity than the previous generation of GCMs, including a large group of models with values in the upper range of what is considered possible, and at least two with very low values. The Australian research community has the potential to contribute to research aimed at understanding this spread. Given the growing need to appropriately communicate climate risk, more care is needed than ever before in how the results from GCMs are used and communicated. The IPCC will address the latest thinking on the climate sensitivity of the real world and how to generate climate projections using the CMIP6 models in August 2021 in its Sixth Assessment Report.

Michael Grose and Ian Macadam, 16th June 2021

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Contacts

ARC Centre of Excellence for Climate Extremes science contact:
Prof Steven Sherwood, UNSW Sydney
s.sherwood@unsw.edu.au

NESP ESCC Hub science contact:
Dr Michael Grose, CSIRO
michael.grose@csiro.au

ARC Centre of Excellence for Climate Extremes knowledge broker:
Dr Ian Macadam, UNSW Sydney
i.macadam@unsw.edu.au

NESP ESCC Hub knowledge broker:
Sonia Bluhm, CSIRO
sonia.bluhm@csiro.au

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