Science advances made possible with CMIP

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1. How does the Earth system respond to forcing?

2. What are the origins and consequences of systematic model biases?

3. How can we assess future climate change given climate variability, climate predictability, and uncertainties in scenarios?

Eyring et al., GMD, 2016
My first exposure to WCRP was as an undergraduate student during the Tropical Oceans and Global Atmosphere (TOGA) conference held in Melbourne in 1995.

TOGA was instrumental in establishing a observational network in the tropical oceans that remains critical to our ability to understand and predict the El Niño Southern Oscillation.
Systematic biases: El Niño Southern Oscillation

ENSIP: The El Niño Southern Oscillation simulation intercomparison project

Observed standard deviations of Niño3 SSTs show a large annual cycle, with a minimum in April and maximum in December.

Most models at this time did not capture the phase locking of ENSO variability to the annual cycle.

Latif et al 2001
Some improvements in simulating the El Niño Southern Oscillation over the course of CMIP, though many biases still remain.
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Climatology of annual equatorial Pacific SSTs

Latif et al 2001

Bellenger et al 2014
Southern Annular Mode (SAM) index measures pressure difference between 40°S and 65°S and strength & position of Southern Ocean winds in lower atmosphere.

Systematic biases: SH mid-latitude jet, storm tracks and annular mode

Observed (reanalysis) trends in near-surface summer winds

WMO/UNEP Ozone Assessment 2010

Systematic biases: SH mid-latitude jet, storm tracks and annular mode

SH rainfall change @ 2100 is associated with the SAM change in mid-high latitudes

Kidston & Gerber 2010

Eq biased jets have > shifts with warming

CMIP3

> +ve SAM trend with > warming

Lim et al 2016

Arblaster et al 2011
Still not a complete theoretical understanding of why the jet shifts poleward in response to increasing CO$_2$ or ozone depletion or why the jet position is biased equatorward

Moist processes are likely a large part of the story (Ceppi & Hartmann, 2014; Ceppi et al 2012, 2016; Shaw et al 2016)

Ceppi et al 2014 argue jet latitude biases are primarily induced by the midlatitude SWCF anomalies
How does the Earth system respond to forcings?

Both ozone depletion and increasing GHGs increase the meridional temperature gradient,

- Increasing GHGs => poleward shift in the jet
- Ozone recovery => eqwd shift in the jet

Perlwitz, 2011
How does the Earth system respond to forcings?

CCMVal and CMIP showed the importance of incorporating time-varying ozone forcing for SH climate change. In CMIP3, only half of the models included time-varying ozone. In CMIP5, all models included time-varying ozone, either prescribed, semi-offline or with interactive chemistry. Son et al. (2009); Eyring et al. (2013); Son et al. (2018); 2018 ozone assessment.
CMIP has been critical for providing the experimental framework and historical forcings for detection and attribution studies and statements in IPCC

- Most of the observed warming over the last 50 years is *likely* to have been due to the increase in greenhouse gas concentrations (IPCC 2001)
- Most of the observed warming over the last 50 years is *very likely* to have been due to the increase in greenhouse gas concentrations (IPCC, 2007)
- It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th Century (IPCC, 2013)
A recent focus has been to understand and predict decadal variability. Many studies on understanding the contribution of internal variability to the slowdown in the global temperature trend between ~2000-2013.
Assessing future change given climate variability

CMIP5 enabled forcing comparisons, assessment of internal variability and decadal predictions to gain a better understanding of the global temperature slowdown

Fyfe et al 2016 and AR5 Ch11
An early phase of CMIP established the 1% per year increasing CO$_2$ experiment, defining a standard way to diagnose and understand the transient climate response (TCR).

Equilibrium climate sensitivity estimates today* are similar to ranges estimated by the Charney report in 1979.

* stay tuned for CMIP6!
Cess et al 1990 found that most of the variation in climate sensitivity was due to differences in cloud feedback

Cloud feedbacks remain the largest uncertainty in total feedbacks today

“cloud feedback is the consequence of all interacting physical and dynamical processes in a general circulation model”

“climate research benefits from a diversity of climate models. If only one model were available, we could not so confidently conclude that cloud feedback is a key issue for climate dynamics.”

Gettelman and Sherwood, 2016
Assessing future change given uncertainty in scenarios

IPCC 2001

IPCC 2007

IPCC 2021

Global CO₂ emissions (gigatonnes, GtCO₂) for all IAM runs in the SSP database. SSP no-climate-policy baseline scenarios are shown grey, while various mitigation targets are shown in colour. Bold lines indicate the subset of scenarios chosen as a focus for running CMIP6 climate model simulations. Chart produced for Carbon Brief by Glen Peters and Robbie Andrews from the Global Carbon Project.
Assessing future change given uncertainty in scenarios

IPCC, 2013
The availability of sub-monthly output was limited in early CMIP phases, making it difficult to study extreme events.

In CMIP3, ‘extremes indices’ enabled one of the first multimodel assessments of future changes in extremes.

Focused on the robustness of the change in terms of sign and significance.

Tebaldi et al 2006 and AR4 Ch10
Assessing future climate change - extremes

CMIP6 will provide many more models with high frequency output and large ensembles and new MIPs to better enable a process-based understanding of extremes in the multimodel context.

IPCC, 2012; Zscheischler et al., 2018
Assessing future change – constraining projections

Process-based emergent constraints – statistical relationships between current climate and future change across the CMIP models – aim to reduce uncertainty in future projections and in combination with observations could help to focus model evaluation.

Eyring et al 2019; Hall et al 2019
A sufficient number of modelling centers (~8) are committed to performing all of the MIP's Tier 1 experiments and providing all the requested diagnostics needed to answer at least one of its science questions.

See Special Issue on the CMIP6 experimental design and organization at https://www.geosci-model-dev.net/special_issue590.html for description of the CMIP6-Endorsed MIPs.
Summary

CMIP has helped to advance our understanding of the Earth system and its response to forcing since the 1990s. Thousands of scientific articles have been written through analysis of its many petabytes of archived multimodel output.

CMIP6 holds promise for more advances, with additional experiments and larger amounts and types of output and MIPs designed by the scientific community to focus on understanding processes, biases and feedbacks, centered around the following questions:

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2. What are the origins and consequences of systematic model biases?
3. How can we assess future climate change given climate variability, climate predictability, and uncertainties in scenarios?
My first exposure to WCRP was as an undergraduate student during the Tropical Oceans and Global Atmosphere (TOGA) conference held in Melbourne in 1995.

My supervisor snuck me in to meet with Kevin Trenberth during a coffee break to discuss my thesis results which were evaluating SH storm tracks in the BMRC AMIP experiment.

Let’s show our support to the students and ECRs who will shape the next 40 years of WCRP!

Trenberth, 1991, Storm tracks in the Southern Hemisphere, J Climate