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Australian Government
Bureau of Meteorology

CMIP6

Julie Arblaster

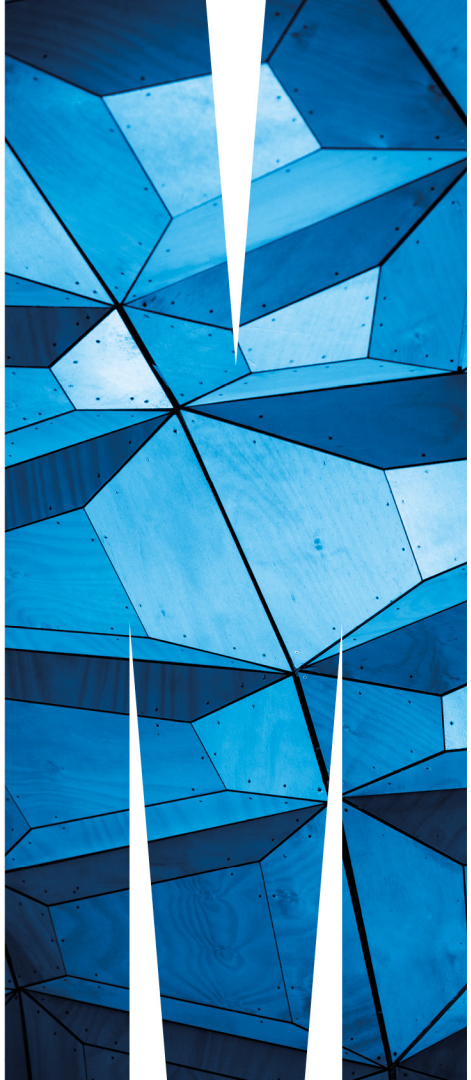
Monash University, Centre of Excellence for Climate Extremes

National Center for Atmospheric Research, USA

with thanks to input from Jingbo Wang (NCI), ACCESS & NCAR scientists and CMIP panel/participants

NCAR

U.S. DEPARTMENT OF ENERGY
Office of Science



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Coupled Model Intercomparison Project

- What is CMIP and how is it designed?
- Why do we need more than one model?
- Why intercompare models?
- CMIP6
  - design
  - infrastructure => including availability @ NCI
  - science!

Prediction versus projection

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Weather to seasonal prediction

Initial state is CRITICAL

Don't really care about whole PDF, just probable phase space

Non-conservation of mass/energy to match observed state

Climate projection

Get rid of any dependence on initial state

Conservation of mass & energy critical

Want to know the PDF of all possible states

Really want to know tails (extreme events)

Predictions to projections

Climate change

IPO/PDO

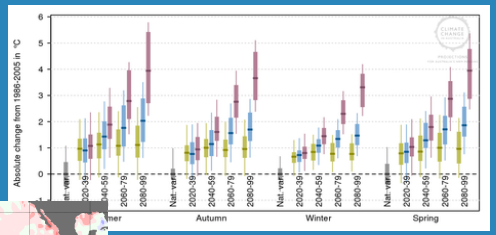
El Niño / La Nina

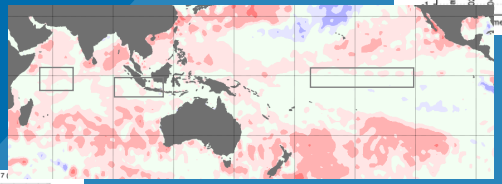
Southern Annular Mode

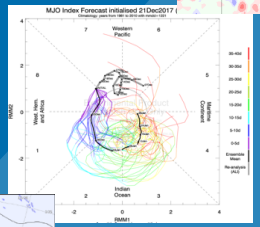
Madden-Julian-Oscilation

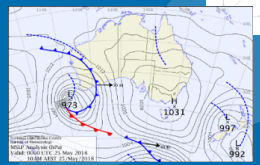
Blocking

Synoptic









Days Week Fortnight Month Season Multi-season Annual

Courtesy BoM

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What is CMIP?

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Coupled Model Intercomparison Project

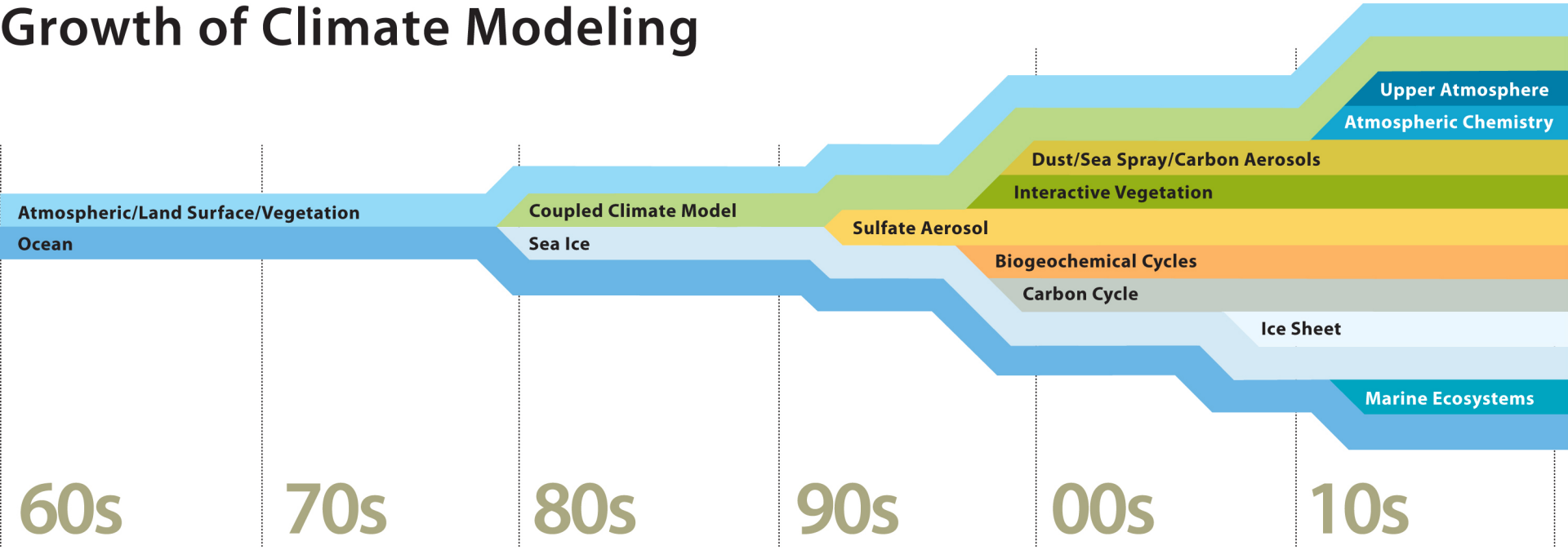
https://www.wcrp-climate.org/wgcm-cmip

"The objective of the Coupled Model Intercomparison Project (CMIP) is to better understand **past, present and future** climate changes arising from **natural**, **unforced variability** or in response to changes in **radiative forcing** in a **multi-model** context."

Began in 1995 and is organised by scientists under the World Climate Research Programme's Working Group on Coupled Modelling

CMIP has coordinated multi-model experiments ~every 7 years and is currently in Phase 6

Growth of Climate Modeling



Increases in components, complexity and range of processes and resolution over time

IPCC AR5 FAQ 12.1 and https://news.ucar.edu/sites/default/files/news/2011/predictFlow2.jpg

CMIP phases

CMIP1 ~1996: document systematic errors in coupled models, quantify effects of flux corrections and document features of climate system variability

CMIP2 ~2000: document and understand the response of coupled climate models to atmospheric CO2 increasing at a rate of 1% per year compounded

CMIP3 ~2000: PIcontrol, 1% CO2, AMIP, historical, SRES scenarios, commitment

CMIP5 ~2011: PIcontrol, 1% CO2, AMIP, historical, RCP scenarios

CMIP6 ~2018: DECK + SSP scenarios, 30+ MIPs

The overall mission of the WCRP Working Group on Coupled Modeling (WGCM) is to foster the development and review of coupled climate models.

Relies on voluntary contributions of many scientists and institutions!

WGCM Members

C. Senior (Co-Chair)	Hadley Centre, UK Met Office, UK
G. Flato (Co-Chair)	Canadian Centre for Climate Modelling and Analysis, Canada
V. Balaji	Princeton University, USA
P. Friedlingstein	University of Exeter, UK
J. Jungclaus	Max Planck Institute (MPI), Germany
M. Kageyama	Laboratoire des Sciences du Climat et de l'Environnement LSCE), France
J.-F. Lamarque	National Center for Atmospheric Research
S. Marsland	CSIRO, Australia
B. O'Neill	National Center for Atmospheric Research (NCAR), USA
S. Panickal	Indian Institute of Tropical Meteorology (IITM), India
M. Watanabe	University of Tokyo, Japan
T. Zhou	LASG, IAP, China

Ex-officio

G. Danabasoglu	Co-Chair of OMDP	NCAR, USA
F. Giorgi	Co-Chair of CORDEX	ICTP, Italy
W. Gutowski	Co-Chair of CORDEX	Iowa State University, USA
J. Renwick	Co-Chair of CliC	Victoria University of Wellington, NZ
F. Straneo	Co-Chair of CliC	NCAR, USA
Carolyn Reynolds	Co-Chair of WGNE	Navy Research Laboratory, USA
K. Williams	Co-Chair of WGNE	UK MetOffice, UK

How is CMIP organised?

CMIP Panel

CMIP activities are overseen by the CMIP Panel which is a standing subcommittee of the WGCM. It is the responsibility of the CMIP Panel to follow the guidance of the WGCM committee. The CMIP Panel oversees the design of the various CMIP experiments, oversees the various CMIP datasets and to helps resolve problems that arise either during the model integrations/data generation phase or in the use of the datasets. The WGCM committee has the ultimate responsibility to oversee the whole CMIP process.

CMIP panel members

Veronika Eyring (Chair)	DLR, Germany
Gregory Flato	CCCma, Canada
Gerald Meehl	NCAR, USA
Cath Senior	Met Office, UK
Jean-Francois Lamarque	NCAR, USA
Ronald Stouffer	NOAA/GFDL, USA
Karl Taylor	PCMDI, USA

Dr Veronika Eying,
CMIP Panel Chair

How is CMIP organised?

Based on an extensive period (two years) of community consultation

- Based on the summer 2013 CMIP5 survey and Aspen & WGCM/AIMES 2013 meetings
- Initial proposal for the design of CMIP6 (Meehl et al., EOS, 2014).
- Feedback on this initial CMIP6 proposal was solicited over the year from modeling groups and model analysts until September 2014.
- The WGCM and the CMIP Panel then finalized the CMIP6 design at the WGCM 18th session (October 2014, Grainau) in consultation with the model groups and MIP co-chairs.

How is CMIP organised?

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CMIP6 Organization and Support

- **CMIP Panel** (V. Eyring (chair), J. Meehl, B. Stevens, R. Stouffer, K. Taylor) which is responsible for direct coordination of CMIP and overseeing the whole CMIP process.
- **WGCM Infrastructure Panel** (WIP, co-chairs V. Balaji & K. Taylor): Establishes standards and policies for sharing climate model output; puts the data request together technically (M. Juckes)
- **input4MIPs:** infrastructure for forcing data (Chair: P. Durack)
- **ESGF** supports a federated data archive hosting the CMIP6 data
- **Other infrastructure support components are the responsibility of multiple, independently-funded projects (e.g., ES-DOC, data citation service, errata services)**
- **Routine evaluation** of the models with newly available tools is now available for the first time

V. Eyring, CMIP6 modelling status and goals, Barcelona, March 2019

CMIP
The World Climate Research Programme's Coupled Model Intercomparison Project

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Coupled Model Intercomparison Project

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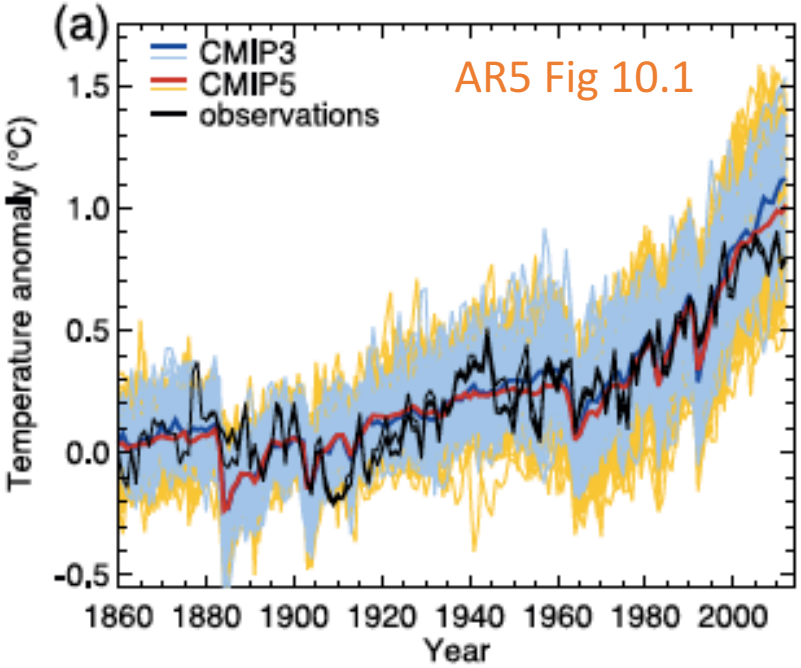
Why do we need more than one model?

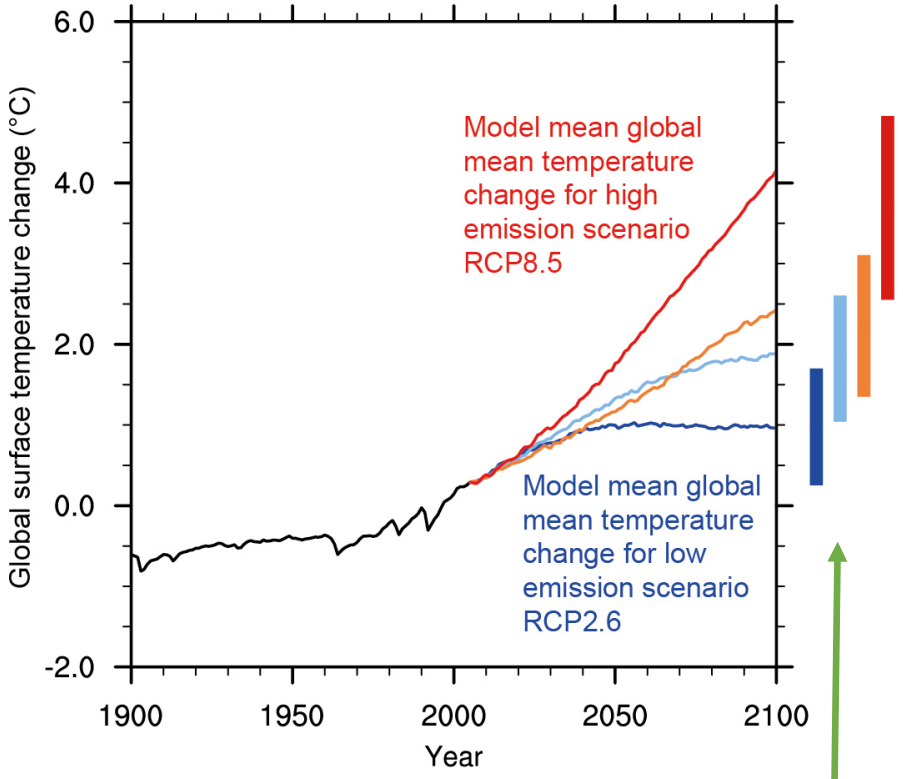
Diversity of equally plausible approaches to modelling the climate system
=> no best model !

Numerous modelling centres worldwide

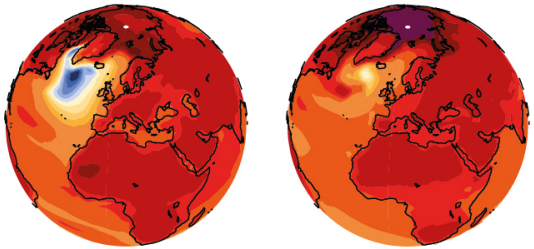


Attempts to link model performance to projections, for the most part, have proven difficult so multimodel distribution required (though see Gab's talk on Monday)

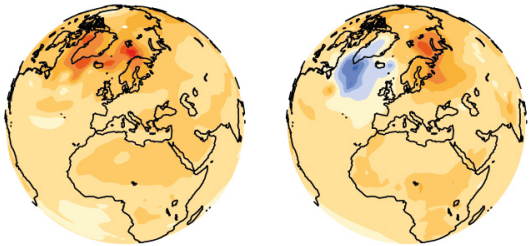
Why do we need more than one model?

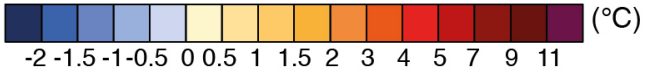


Possible temperature responses in 2081-2100 to high emission scenario RCP8.5



Possible temperature responses in 2081-2100 to low emission scenario RCP2.6





climate sensitivity

IPCC AR5 FAQ 12.1

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Why intercompare models?

Might seem obvious but it consumes large resources, both in terms of computing and human energy, so needs to be justified

CMIP stats

- “Arguably the world’s largest most complex distributed database”
- CMIP3=40TB, CMIP5=1.5 PB+, at least 40X bigger
- CMIP5 = 40 models, CMIP6 = 100+ models

CMIP
The World Climate Research Programme's Coupled Model Intercomparison Project

Why intercompare models?

Might seem obvious but it consumes large resources, both in terms of computing and human energy, so needs to be justified

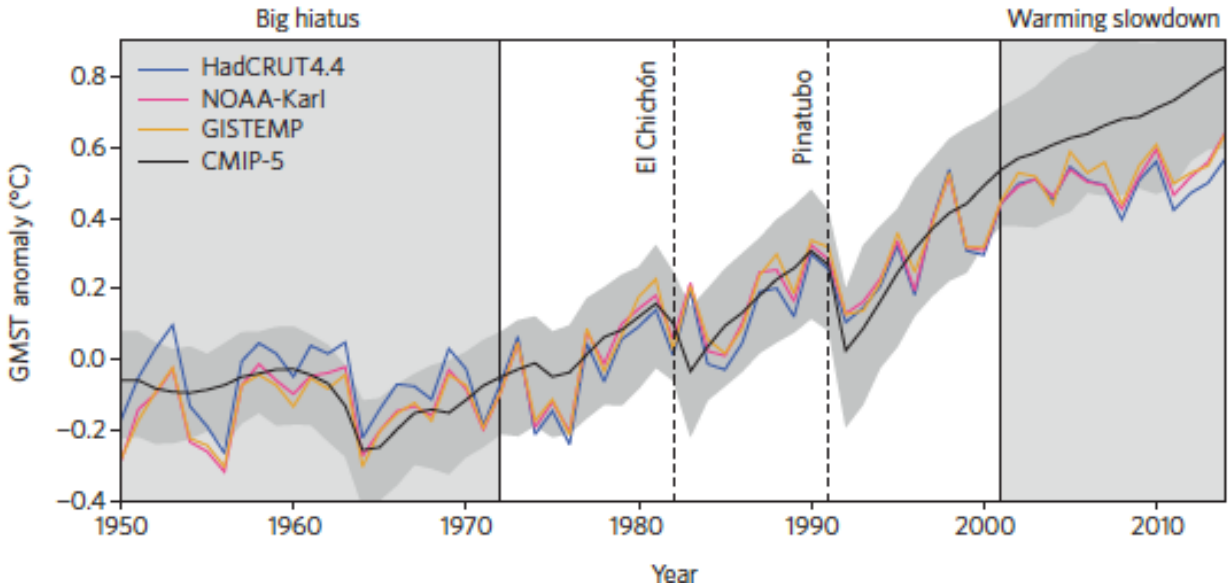
- enables fundamental research (1000s of papers using CMIP5)
- highlights systematic biases and helps set model development priorities
- allows models to be scrutinised by whole climate research community
- provides input to IPCC and UNFCCC (global stocktake)

V. Eyring, CMIP6 modelling status and goals, Barcelona, March 2019

CMIP
The World Climate Research Programme's Coupled Model Intercomparison Project

Why intercompare models?

Highlights systematic biases
e.g. understanding the slowdown in global temperatures
=> CMIP5 enabled forcing comparisons, assessment of internal variability, decadal predictions



Fyfe et al 2016
and AR5 Ch11

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https://cmip6workshop19.sciencesconf.org/

WCRP World Climate Research Programme

BSC Barcelona Supercomputing Center Centro Nacional de Supercomputación

- Single and multi-model CMIP6 analyses and evaluation that take advantage of the large suite of CMIP6 experiments
- Efforts to connect model development and analysis to identify Earth system model improvements that help reduce systematic biases and/or increase the realism of models
- Methods for multi-model analysis
- Climate change impacts

CMIP6 & WCRP Grand Challenges

Science backdrop of WCRP GCs for CMIP6

The current Grand Challenges are:

- Melting Ice and Global Consequences
- Clouds, Circulation and Climate Sensitivity
- Carbon Feedbacks in the Climate System
- Weather and Climate Extremes
- Water for the Food Baskets of the World
- Regional Sea-Level Change and Coastal Impacts
- Near-term Climate Prediction

https://www.wcrp-climate.org/grand-challenges/grand-challenges-overview

CMIP6 Science Questions

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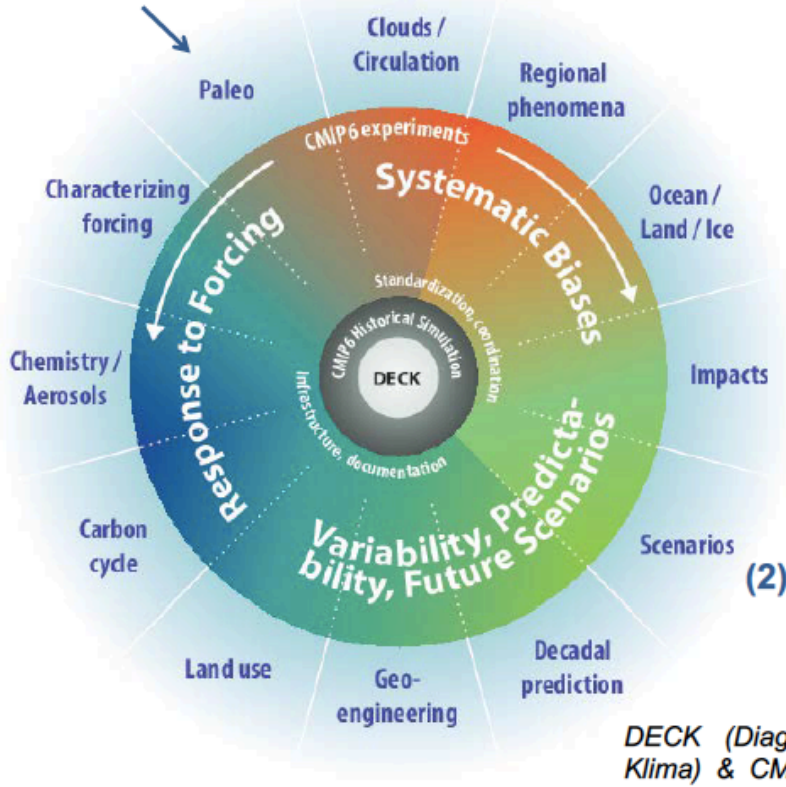
1. How does the Earth system respond to forcing?

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?

CMIP: a More Continuous and Distributed Organization

(3) CMIP-Endorsed Model Intercomparison Projects (MIPs)



Eyring et al., GMD, 2016

(1) A handful of common experiments

DECK (entry card for CMIP)

i. AMIP simulation (~1979-2014)
ii. Pre-industrial control simulation
iii. 1%/yr CO_2 increase
iv. Abrupt 4xCO_2 run

CMIP6 Historical Simulation (entry card for CMIP6)

v. Historical simulation using CMIP6 forcings (1850-2014)

(2) Standardization, coordination, infrastructure, documentation

DECK (Diagnosis, Evaluation, and Characterization of Klima) & CMIP6 Historical Simulation to be run for each model configuration used in CMIP6-Endorsed MIPs

CMIP6 structure

A handful of common experiments

DECK (entry card for CMIP)

1. AMIP simulation (~1979-2014)
2. Pre-industrial control simulation
3. 1%/yr CO2 increase
4. Abrupt 4xCO2 run

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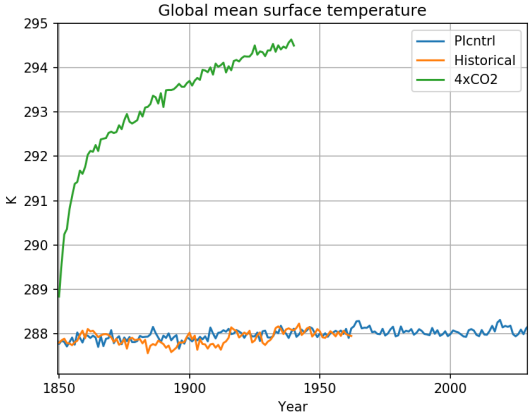
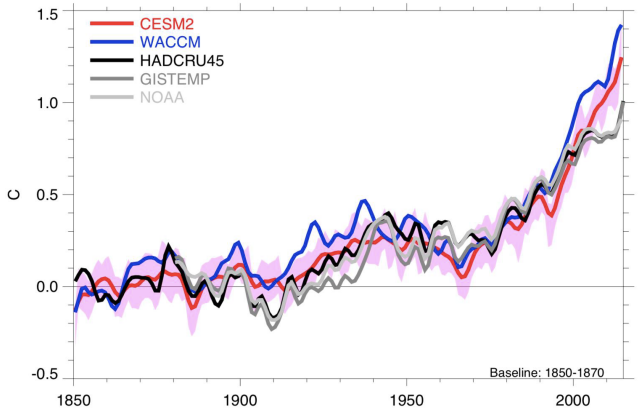


Courtesy Martin Dix



Courtesy G Danabasoglu, CMIP6 workshop slides

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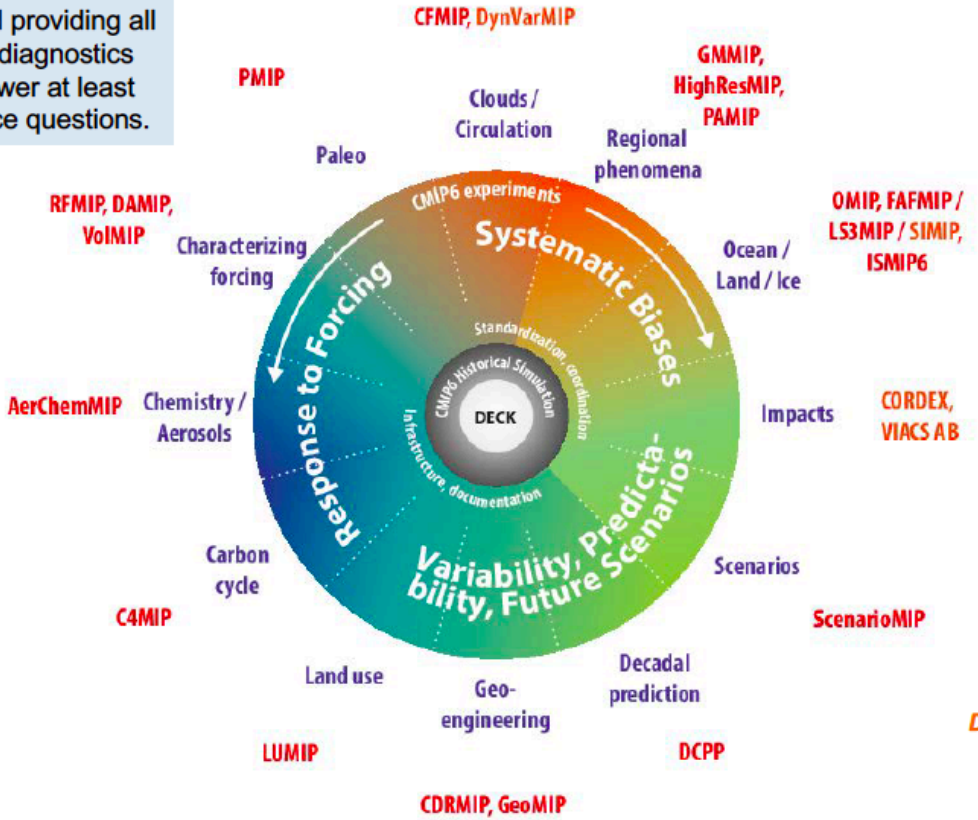
GMD special issue for MIPs and Input4MIPs
https://www.geosci-model-dev.net/special_issue590.html

V. Eyring, CMIP6 modelling status and goals, Barcelona, March 2019

CMIP
The World Climate Research Programme's Coupled Model Intercomparison Project

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.

23 CMIP6-Endorsed MIPs



Diagnostic MIPs

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

CMIP6 endorsed MIPs

https://www.wcrp-climate.org/modelling-wgcm-mip-catalogue/modelling-wgcm-cmip6-endorsed-mips

I. Overview CMIP6-Endorsed MIPs

1. AerChemMIP- Aerosols and Chemistry Model Intercomparison Project
2. C^{4}MIP - Coupled Climate Carbon Cycle Model Intercomparison Project
3. CDRMIP - The Carbon Dioxide Removal Model Intercomparison Project
4. CFMIP - Cloud Feedback Model Intercomparison Project
5. DAMIP - Detection and Attribution Model Intercomparison Project
6. DCPP - Decadal Climate Prediction Project
7. FAFMIP - Flux-Anomaly-Forced Model Intercomparison Project
8. GeoMIP - Geoengineering Model Intercomparison Project
9. GMMIP - Global Monsoons Model Intercomparison Project
10. HighResMIP - High-Resolution Model Intercomparison Project
11. ISMIP6 - Ice Sheet Model Intercomparison Project for CMIP6
12. LS3MIP - Land Surface, Snow and Soil Moisture
13. LUMIP - Land-Use Model Intercomparison Project
14. OMIP - Ocean Model Intercomparison Project
15. PAMIP – Polar Amplification Model Intercomparison Project
16. PMIP - Palaeoclimate Modelling Intercomparison Project
17. RFMIP - Radiative Forcing Model Intercomparison Project
18. ScenarioMIP - Scenario Model Intercomparison Project
19. VolMIP - Volcanic Forcings Model Intercomparison Project
20. CORDEX - Coordinated Regional Climate Downscaling Experiment
21. DynVarMIP - Dynamics and Variability Model Intercomparison Project
22. SIMIP - Sea Ice Model Intercomparison Project
23. VIACS AB - Vulnerability, Impacts, Adaptation and Climate Services Advisory Board

CMIP6 & WCRP Grand Challenges

The current Grand Challenges are:

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- Clouds, Circulation and Climate Sensitivity
- Carbon Feedbacks in the Climate System
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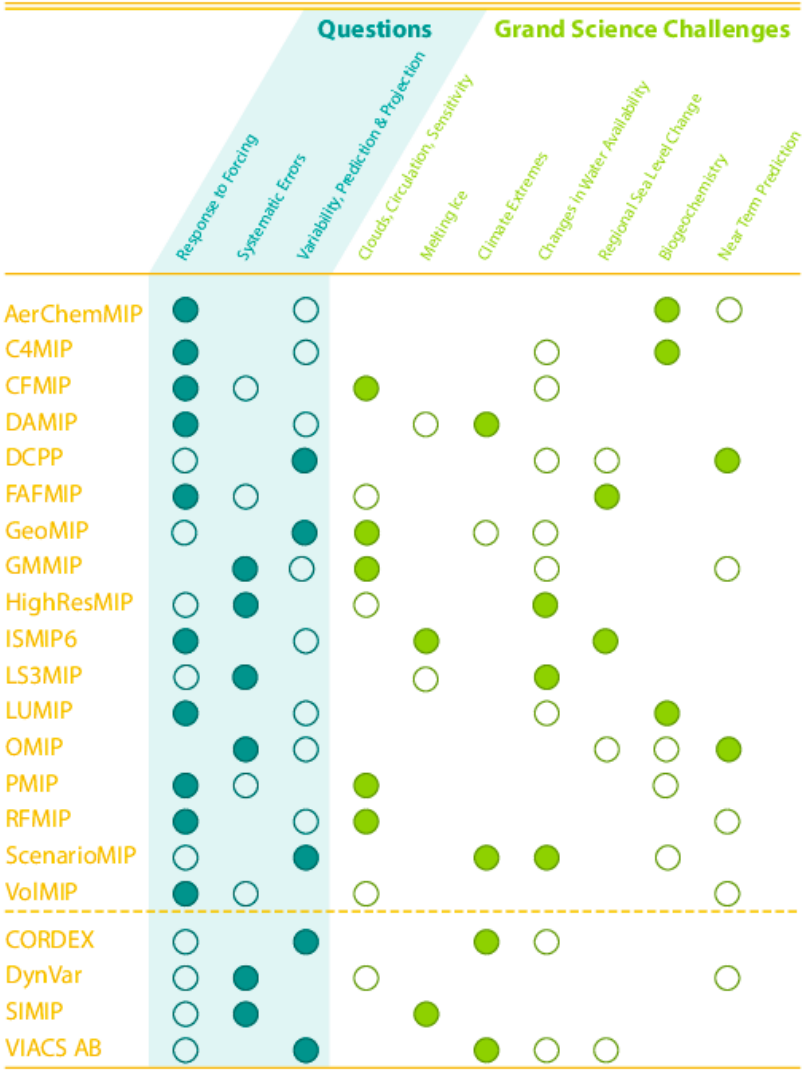

Eyring et al 2016

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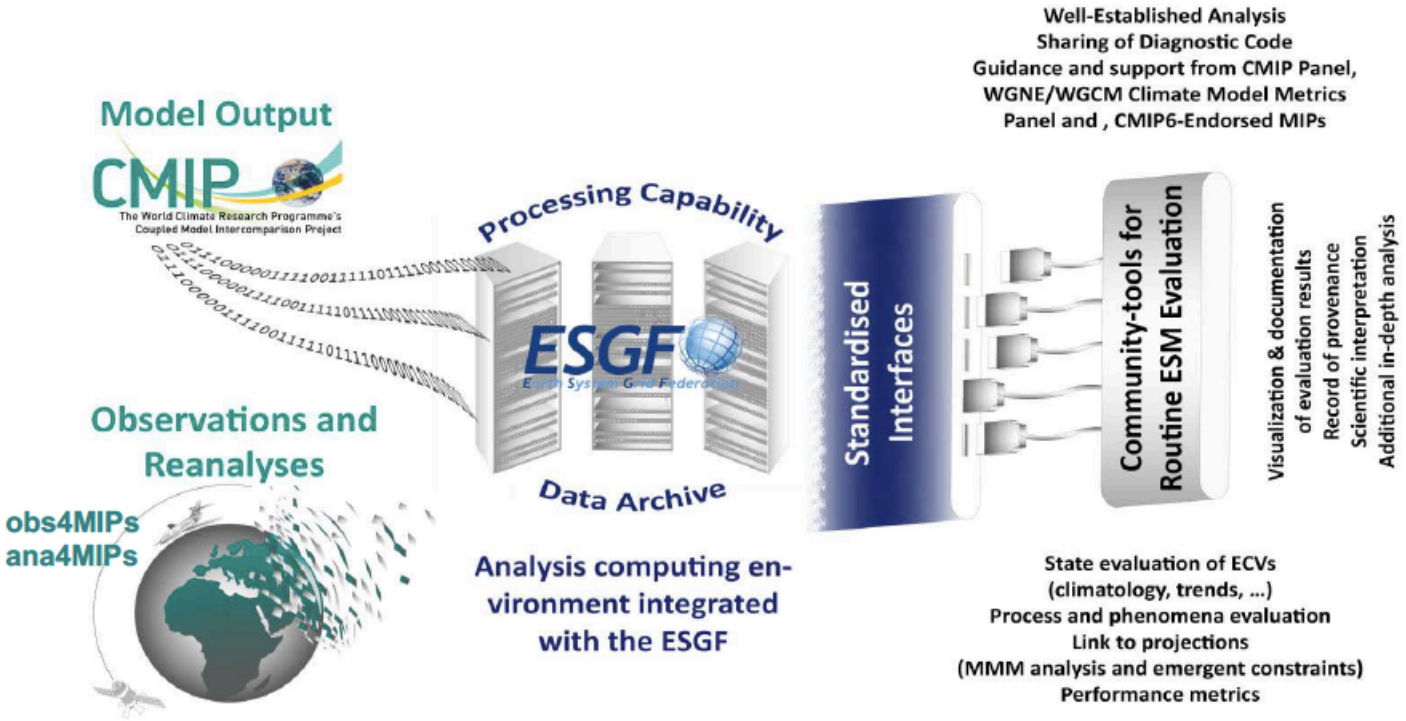
Workflow for Routine Evaluation in CMIP

- Ensuring traceability and provenance of the results -



Eyring et al., ESD (2016)

ESMValTool
Earth System Model eValuation Tool

CMEC

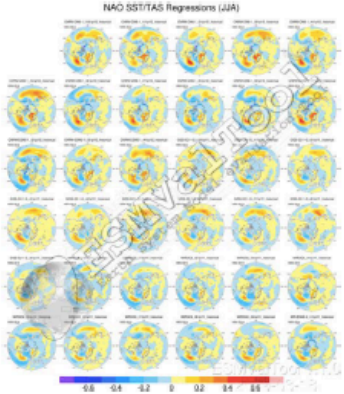
DLR

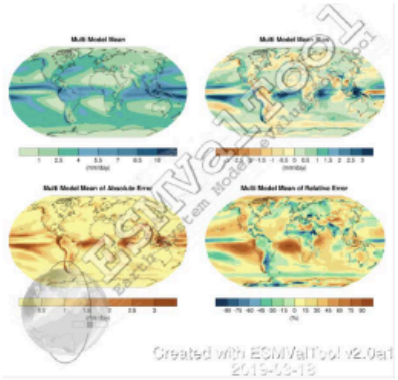
NCAR UCAR | CGD's Climate Analysis Section
Climate Variability Diagnostics Package

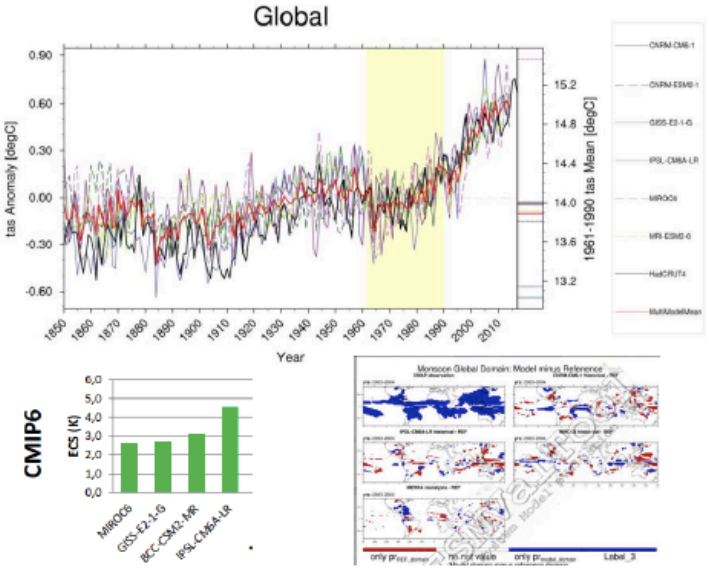
First CMIP6 Results from ESMValTool incl. NCAR CVDP

(Password restricted website and watermarked for quality control)

http://cmip-esmvaltool.dkrz.de/







Namelists include for example

- AR5 Chapter 9 Model Evaluation
- Modes of Variability (NCAR CVDP)
- Monsoon, evapotransporation, carbon cycle
- ECS, ozone, aerosols

DLR

ESMValTool
Earth System Model eValuation Tool

NCAR UCAR | CGD's Climate Analysis Section
Climate Variability Diagnostics Package

- Two Australian ACCESS models are registered for CMIP6 contributions:
  - ACCESS-CM2

  Potential additional MIPs: OMIP, FAFMIP, RFMIP and ScenarioMIP
  - ACCESS-ESM1-5

  Potential additional MIPs: C4MIP, CDRMIP, OMIP, RFMIP and ScenarioMIP.

  Contributions from these models expected to start being published Q3/Q4 2019.

Searching CMIP data

- The CMIP data hosted at NCI can be accessed directly on the filesystem via Raijin or the VDI.

- Due to the complexity and volume of the CMIP datasets, manual searching and accessing the data you are after is highly inefficient and difficult. We thus recommend using the CleF tool developed by CLEX for all CMIP5 and CMIP6 data search needs.

- Examples to follow in jupyter notebook.

CMIP Projects and Access

NCI host CMIP3, CMIP5 and CMIP6 data collections. To access the data at NCI you need to register for the correct projects and agree to the terms and conditions for the data collections.

	Australian Published CMIP Data	Replicated CMIP Data	Replicated Observational and Reanalysis Data
NCI Project Code	**TBC** = CMIP6-era **rr3** = CMIP5-era	**oi10** = CMIP6-era **al33** = CMIP5-era **cb20** = CMIP3	**qv56** = input4MIPs

Request to join a data collection through my.nci.org.au/mancini.

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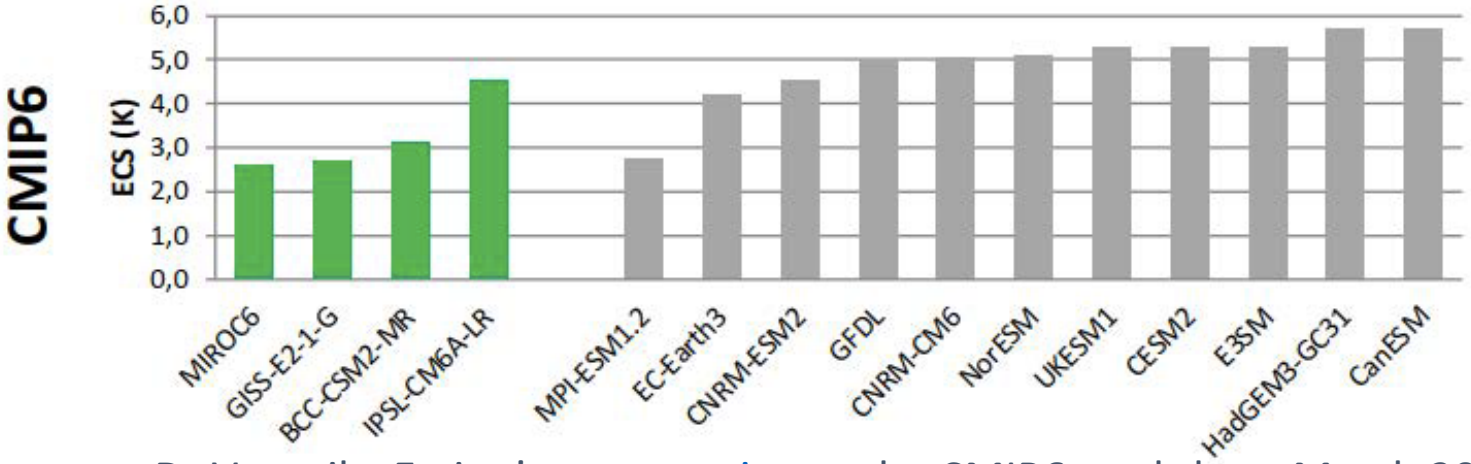
Many CMIP6 models are warmer

Equilibrium climate sensitivity (ECS) = equilibrium temperature response to a doubling of CO_2



Dr Veronika Eyring's presentation at the CMIP6 workshop, March 2019

IN DEPTH | GLOBAL WARMING

New climate models forecast a warming surge

Paul Voosen

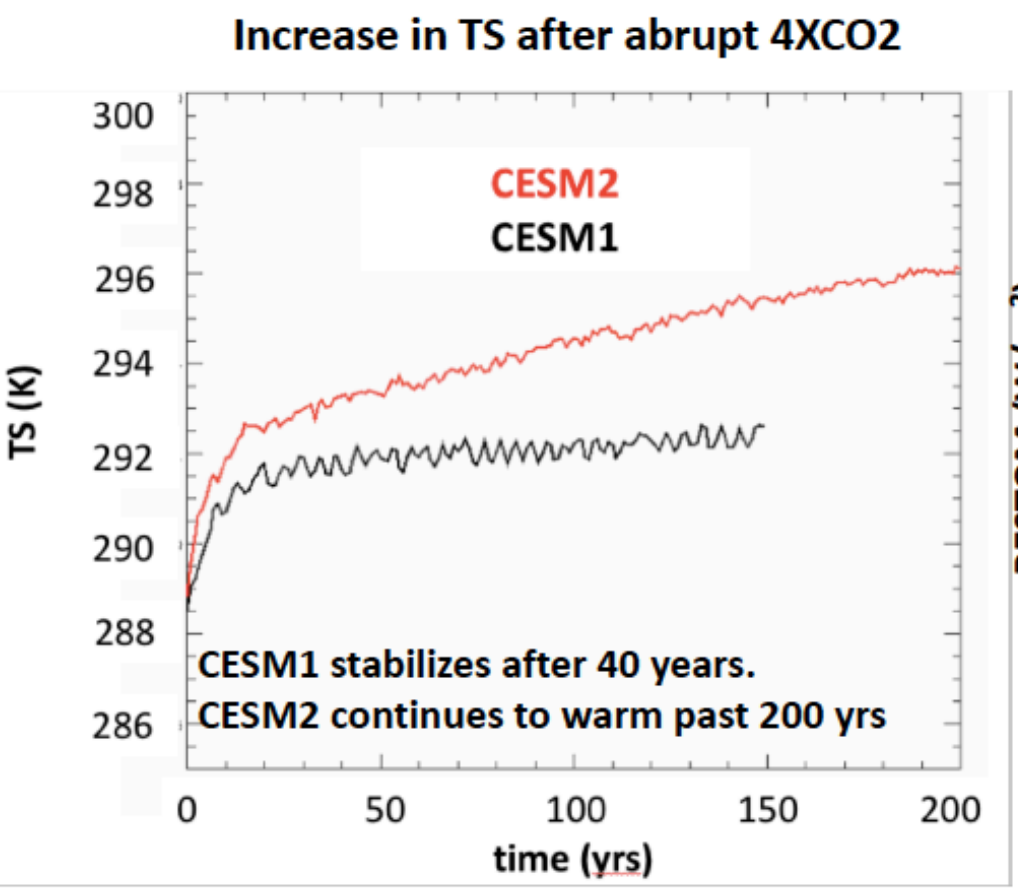
+ See all authors and affiliations

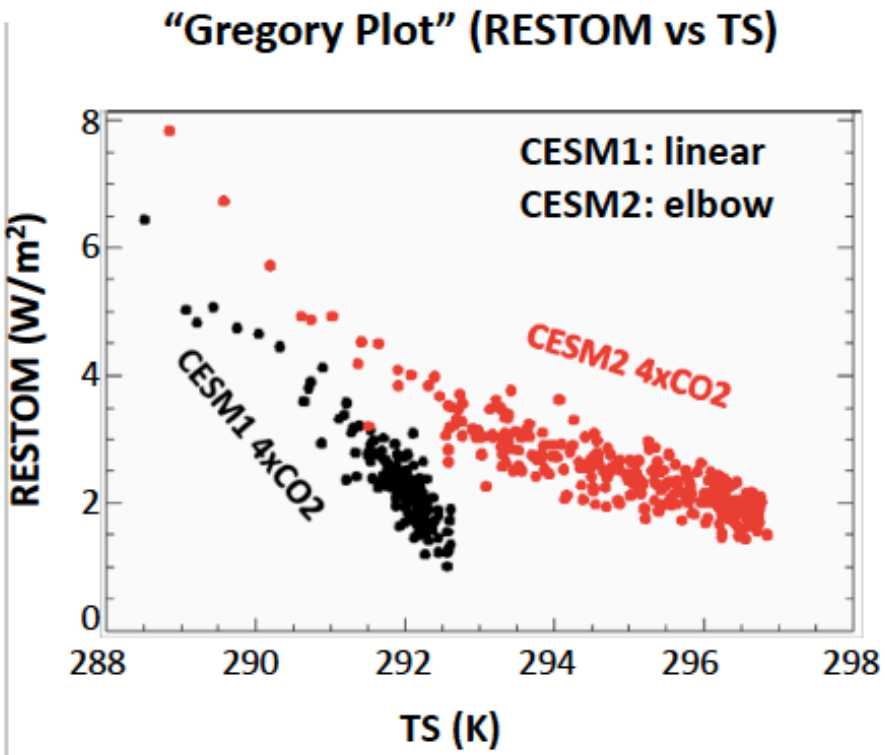
Science 19 Apr 2019:
Vol. 364, Issue 6437, pp. 222-223
DOI: 10.1126/science.364.6437.222

CarbonBrief
CLEAR ON CLIMATE

https://climateextremes.org.au/cmip6-models-produce-higher-equilibrium-climate-sensitivity/

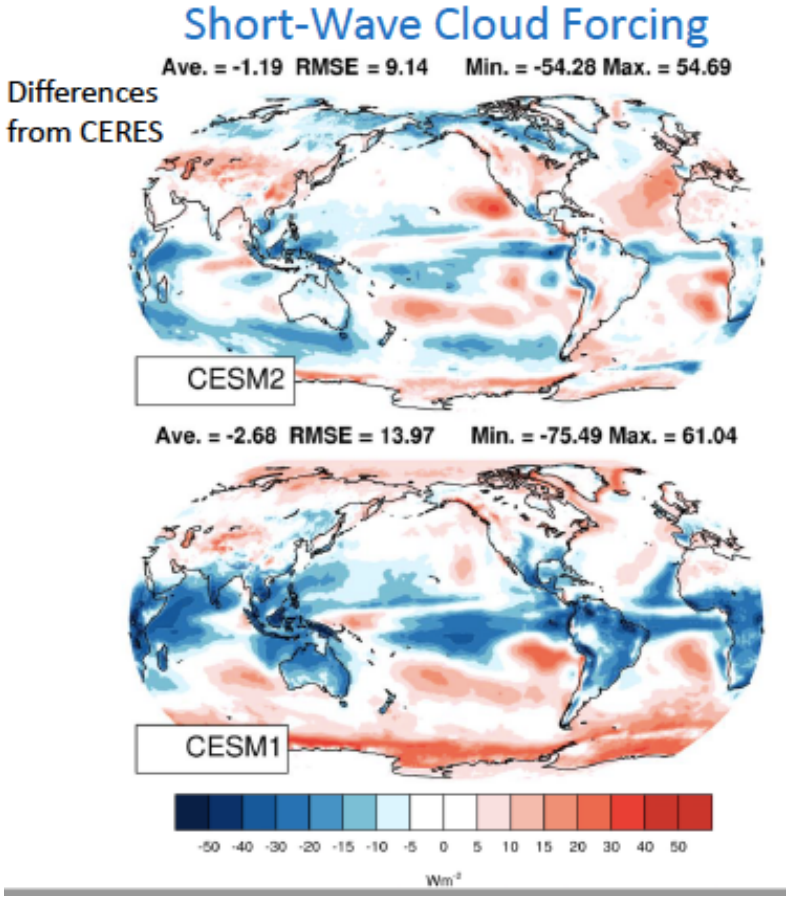
e.g. CESM1 => CESM2

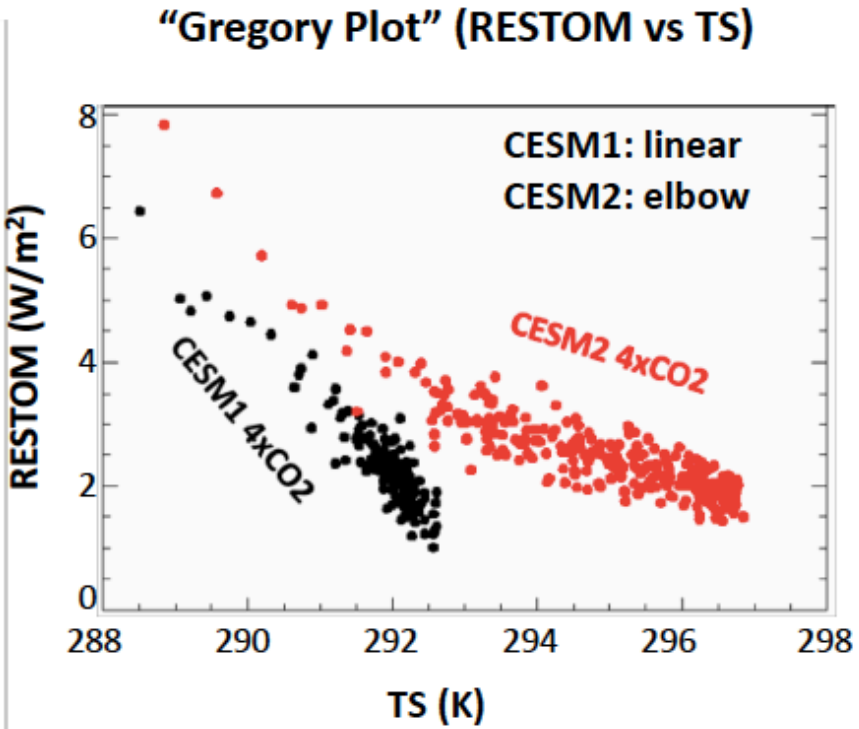




Cecile Hannay's presentation: CESM workshop

e.g. CESM1 => CESM2



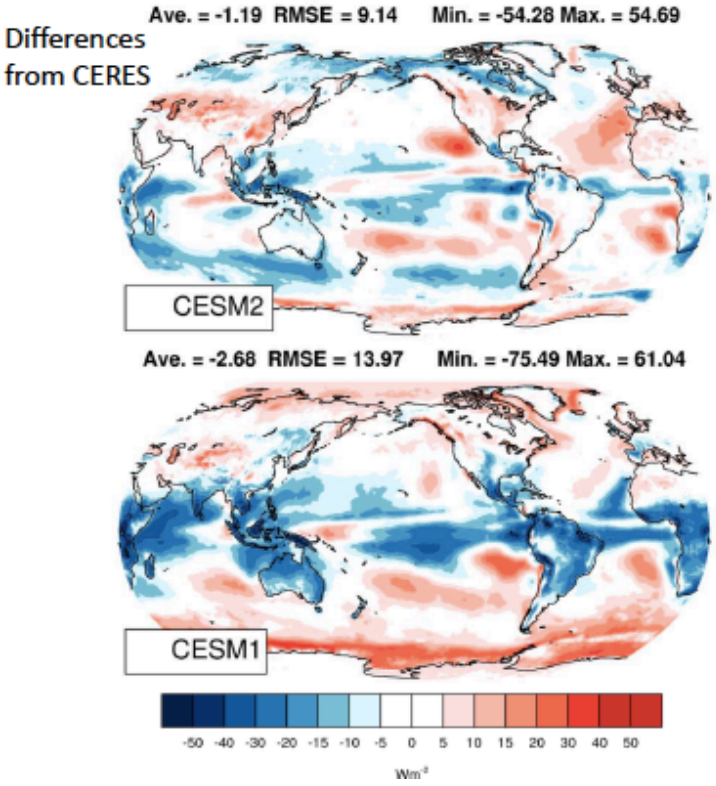


Cecile Hannay's presentation: CESM workshop

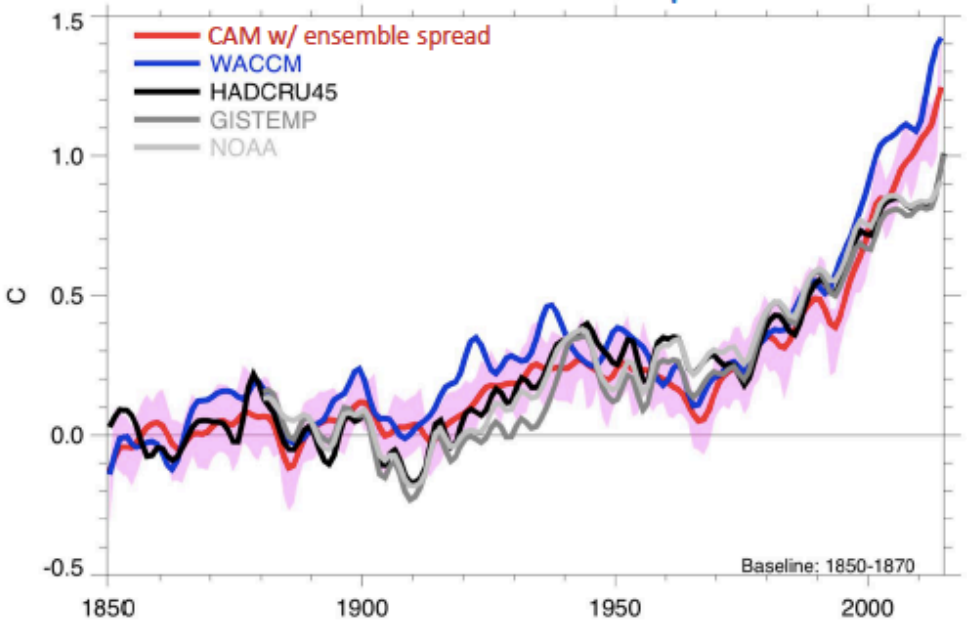
The Community Earth System Model version 2 (CESM)

Gokhan Danabasoglu, Jean-Francois Lamarque, and CESM Collaborators
National Center for Atmospheric Research, Boulder, CO USA

Short-Wave Cloud Forcing

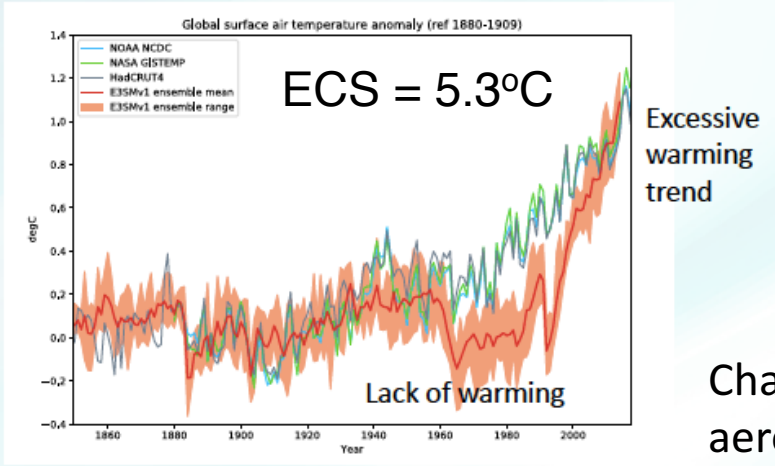


Global-Mean Surface Temperature

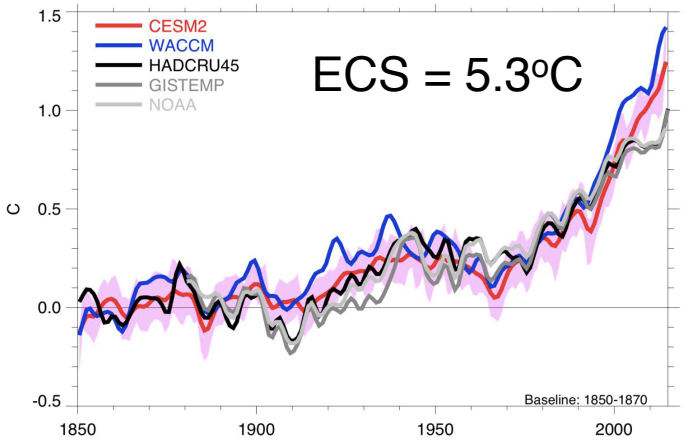


Equilibrium Climate Sensitivity (ECS) = 5.3°C

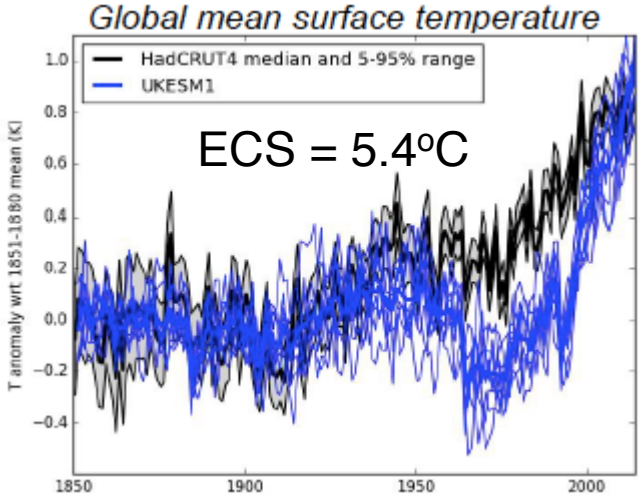
Courtesy G Danabasoglu, CMIP6 workshop slides

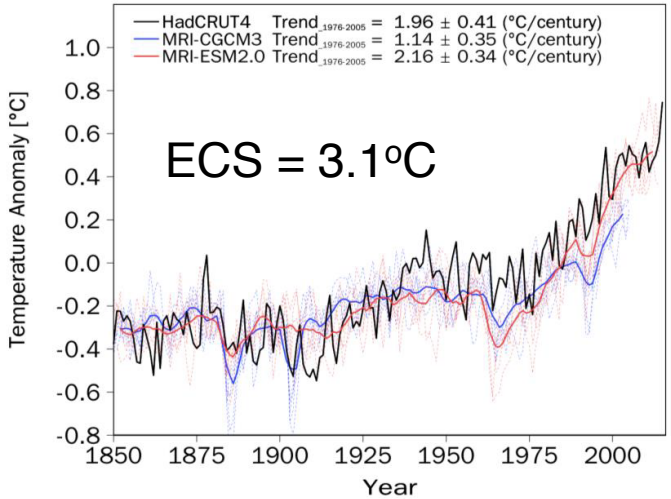


Excessive warming trend



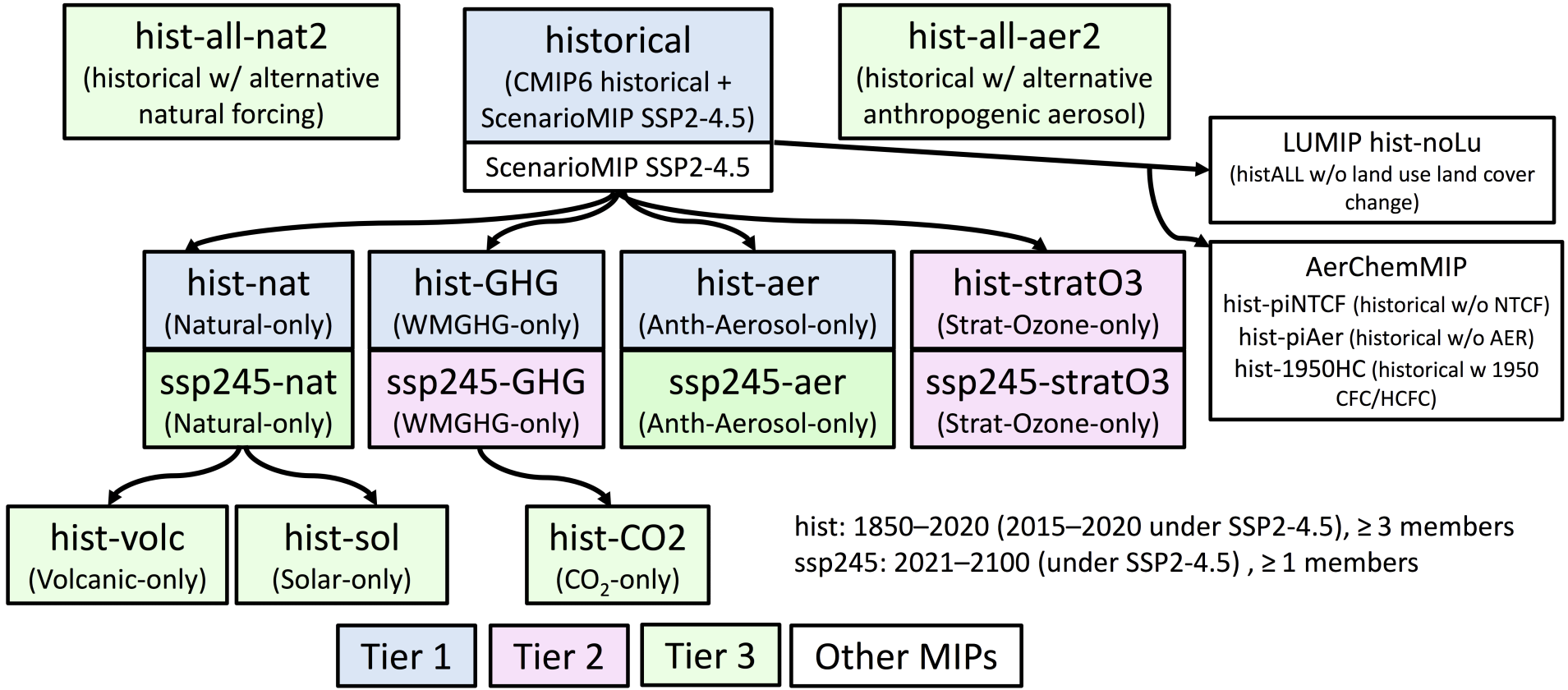
Changes to clouds and aerosols contribute to some of the increase in Equilibrium Climate Sensitivity (ECS)



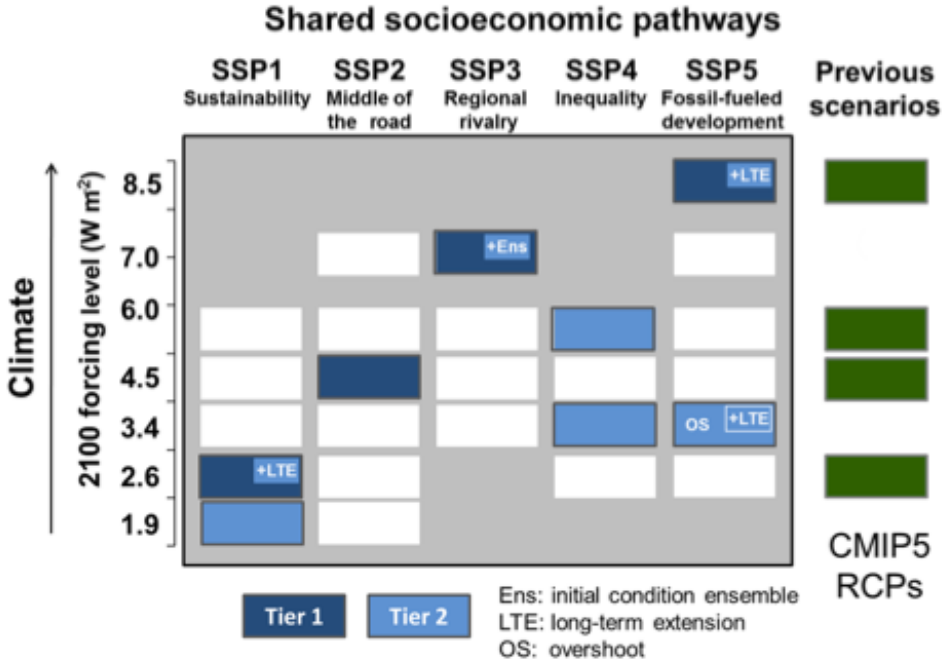


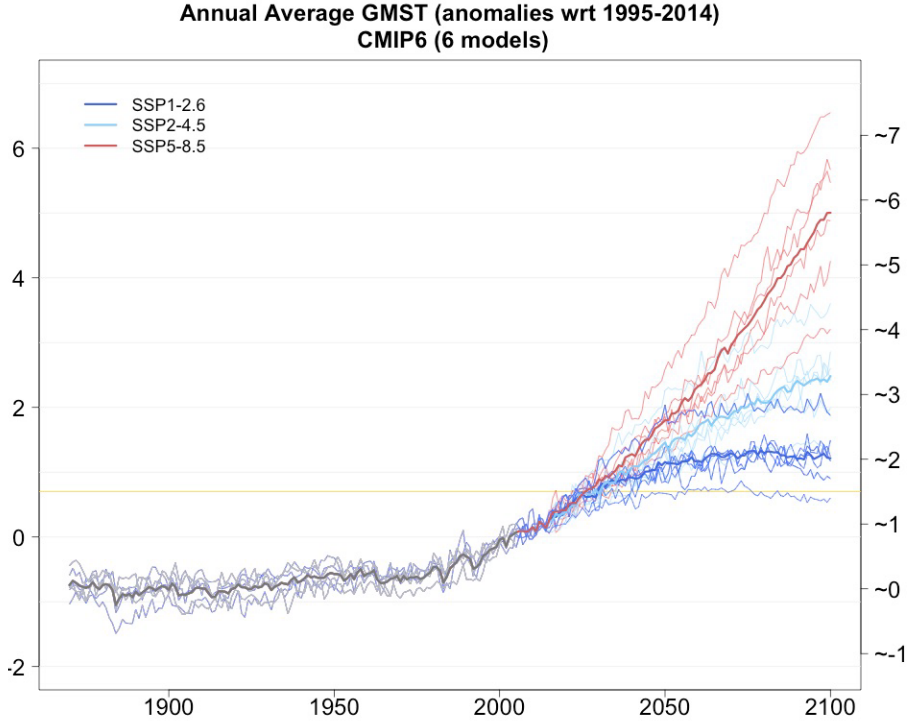
[CMIP6 workshop slides]

DAMIP (Detection/Attribution)



ScenarioMIP





Riahi et al (2016); O'Neill et al GMD (2017)

Courtesy C Tebaldi, [CMIP6 workshop slides]

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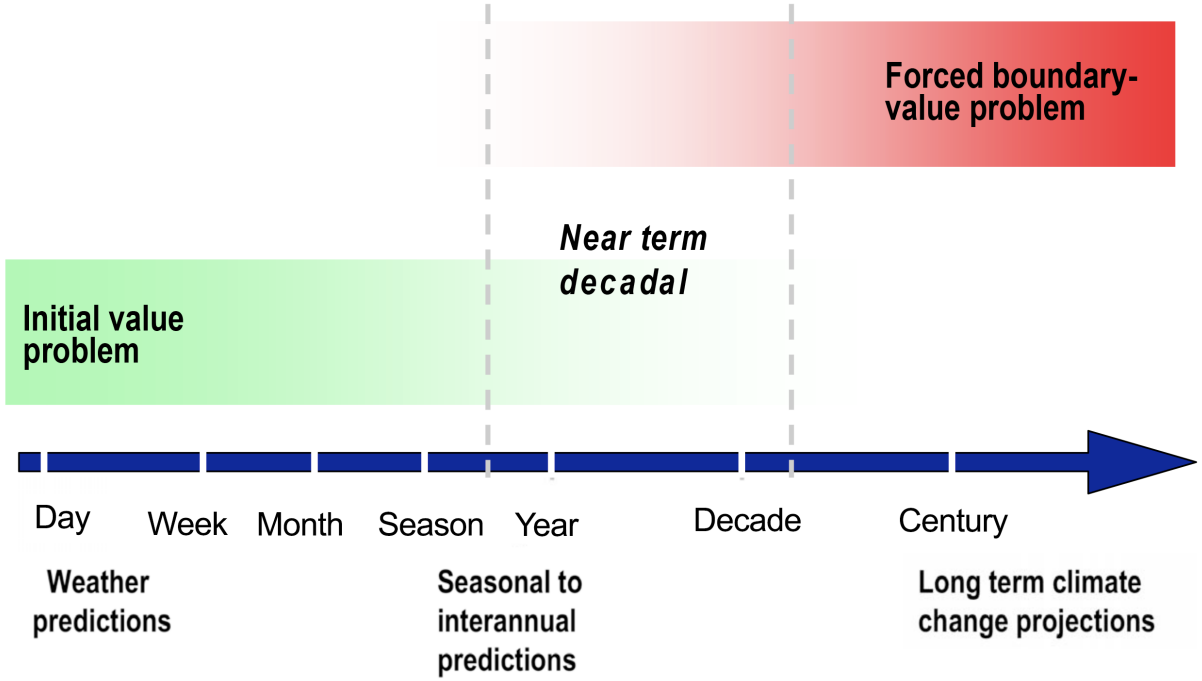
The Decadal Climate Prediction Project (DCPP) contribution to CMIP6



Hindcasts, predictions and also looks at case studies e.g. early 2000s slowdown to understand internal vs forced contributions

(Boer et al., GMD, 2016)

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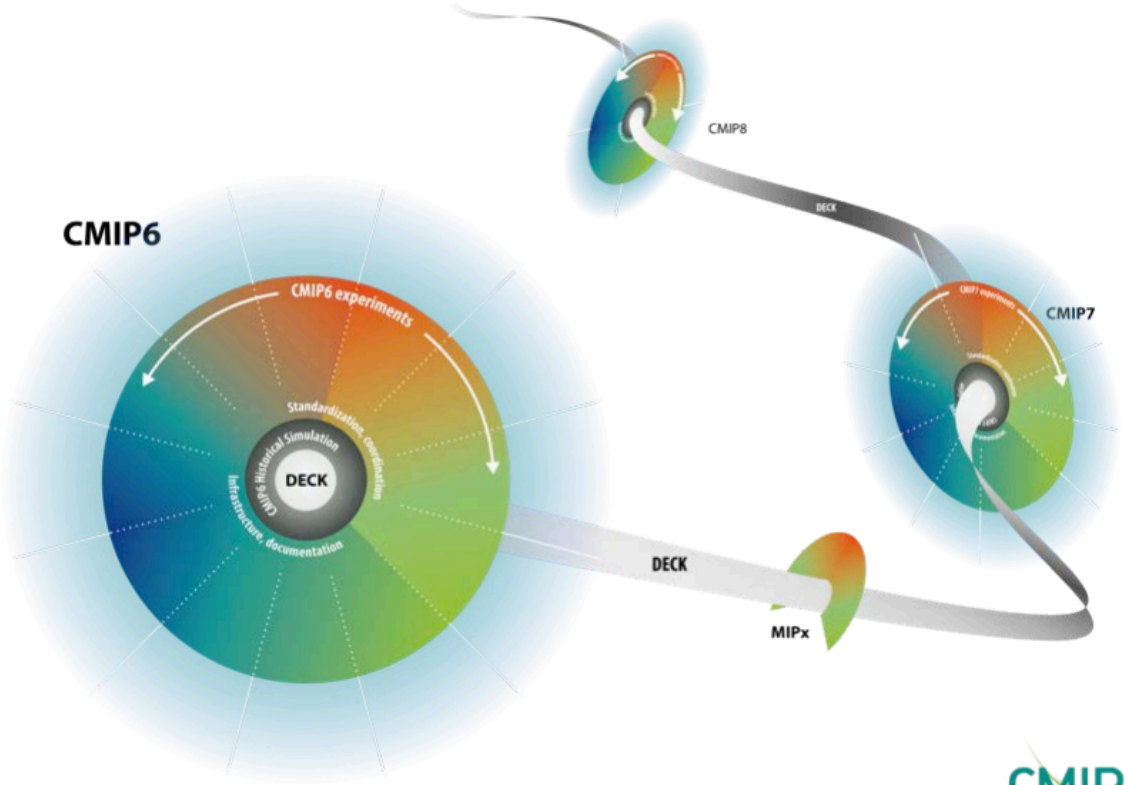
Coupled Model Intercomparison Project

- What is CMIP and how is it organised?
- Why do we need more than one model?
- Why intercompare models?
- CMIP6
  - design
  - infrastructure => including availability @ NCI
  - science!
- Next steps

CMIP Continuity

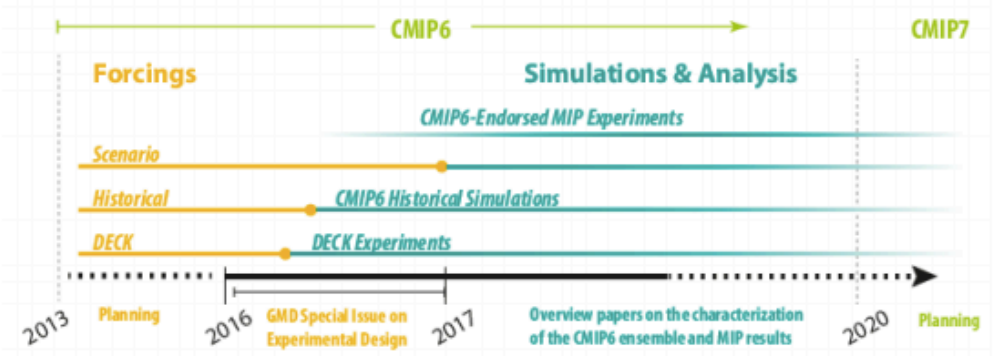
A common suite of experiments for each phase of CMIP provides an opportunity to construct a multi-model ensemble using model output from various phases of CMIP



Eyring et al., CMIP6 Experimental Design and Organization, GMD, 2016

CMIP
The World Climate Research Programme's Coupled Model Intercomparison Project

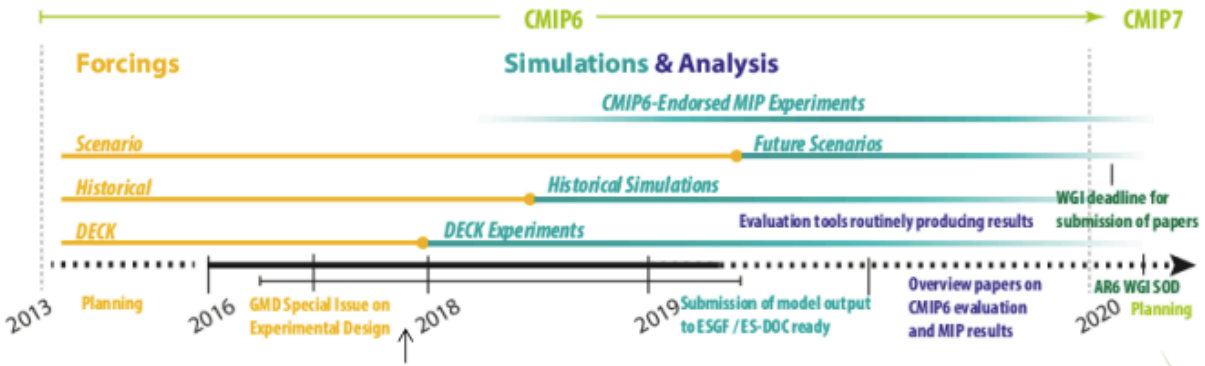
Planning for CMIP6 began in 2013, and the timeline was finalized before IPCC AR6 was initiated; but delays subsequently developed



Eyring et al., GMD, 2016

May 2016

This is where we are now (March 2019)



CMIP
The World Climate Research Programme's Coupled Model Intercomparison Project

Summary

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CMIP6

- ✓ Multiple models are essential for future projections and intercomparison, enable a better understanding of past, present and future climate change
- ✓ CMIP has had significant successes, ever evolving and improving
- ✓ Some remaining challenges & areas of focus
  - improved physical processes
  - improved estimates of forcing
  - improved resolution
  - constraining climate sensitivity

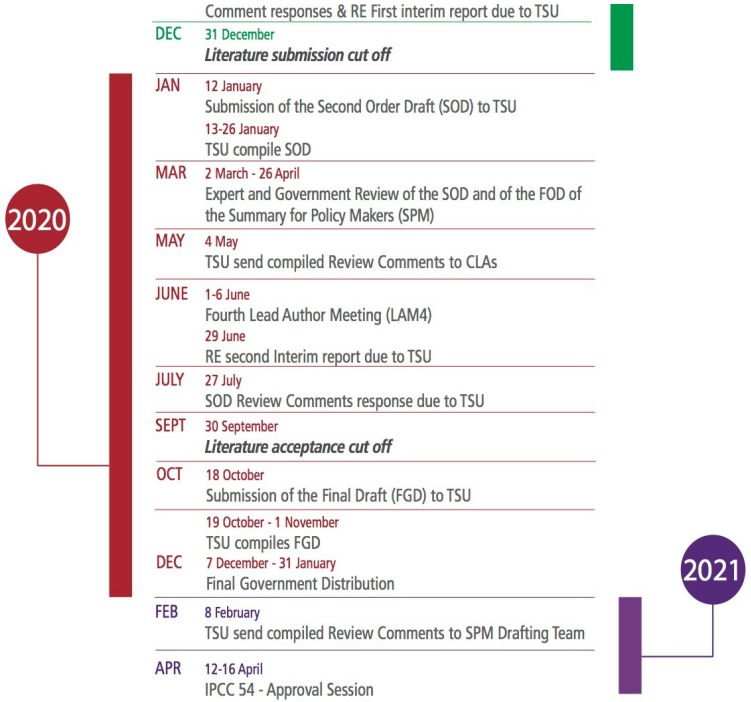
Opportunities

CMIP6 Hackathon @ NCAR Oct 2019: registration by July 31
https://cmip6hack.github.io/#/

CMIP6 data challenges workshop: August 14. Contact Anna Ukkola or Margot Bador for more information

Papers need to be submitted by Dec 31 2019 to be cited by AR6 but analysis will continue for many years to come!

AGU 2019: Climate Science Week



https://wg1.ipcc.ch/AR6/AR6.html

References

https://www.wcrp-climate.org/ - sign up to their news!

CMIP design, Meehl et al 1997, Intercomparison makes for a better model, EoS

CMIP6 design: Meehl et al 2014, Climate Model Preparations, Preparing for the next phase, Eos

CMIP6 special issue: https://www.geosci-model-dev.net/special_issue590.html

Eyring et al 2016, CMIP6 overview paper, Geosci. Model Dev., 9, 1937-1958, doi:10.5194/gmd-9-1937-2016, 2016.

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NextGen Climate Change Projections: Science ideas and issues for national climate projections in Australia, report