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Science advances made possible with CMIP

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and

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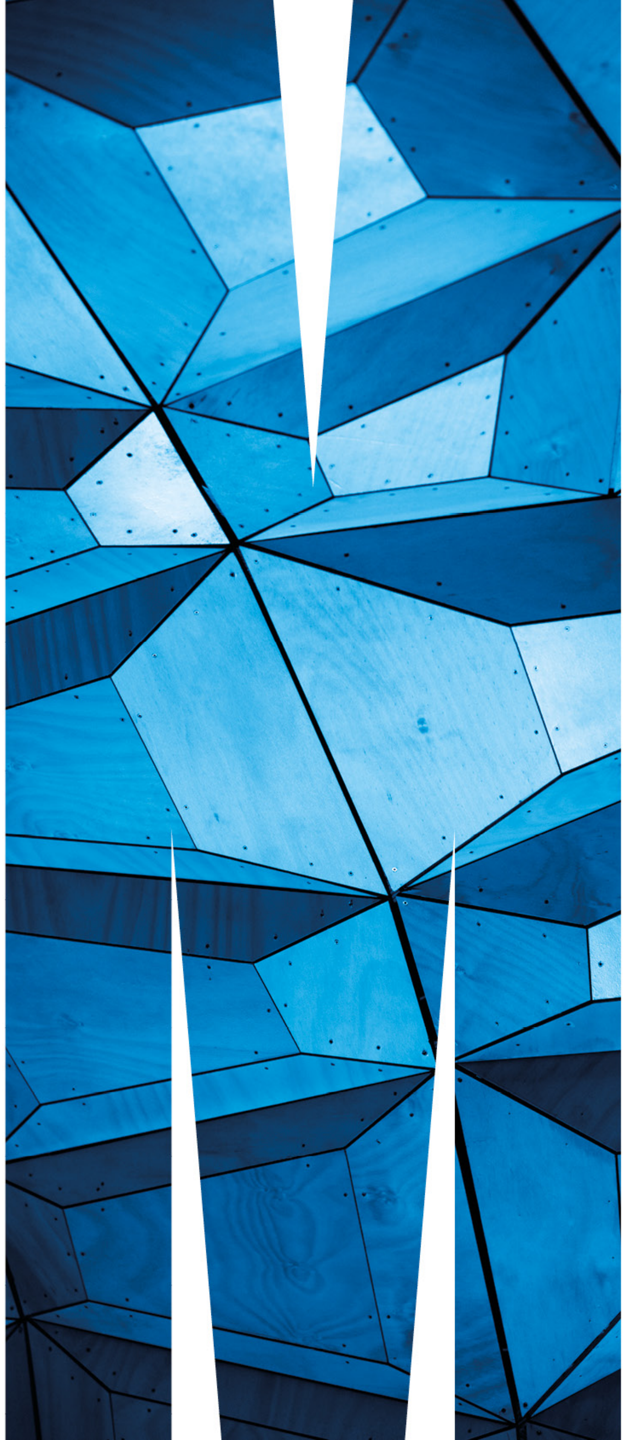
NCAR

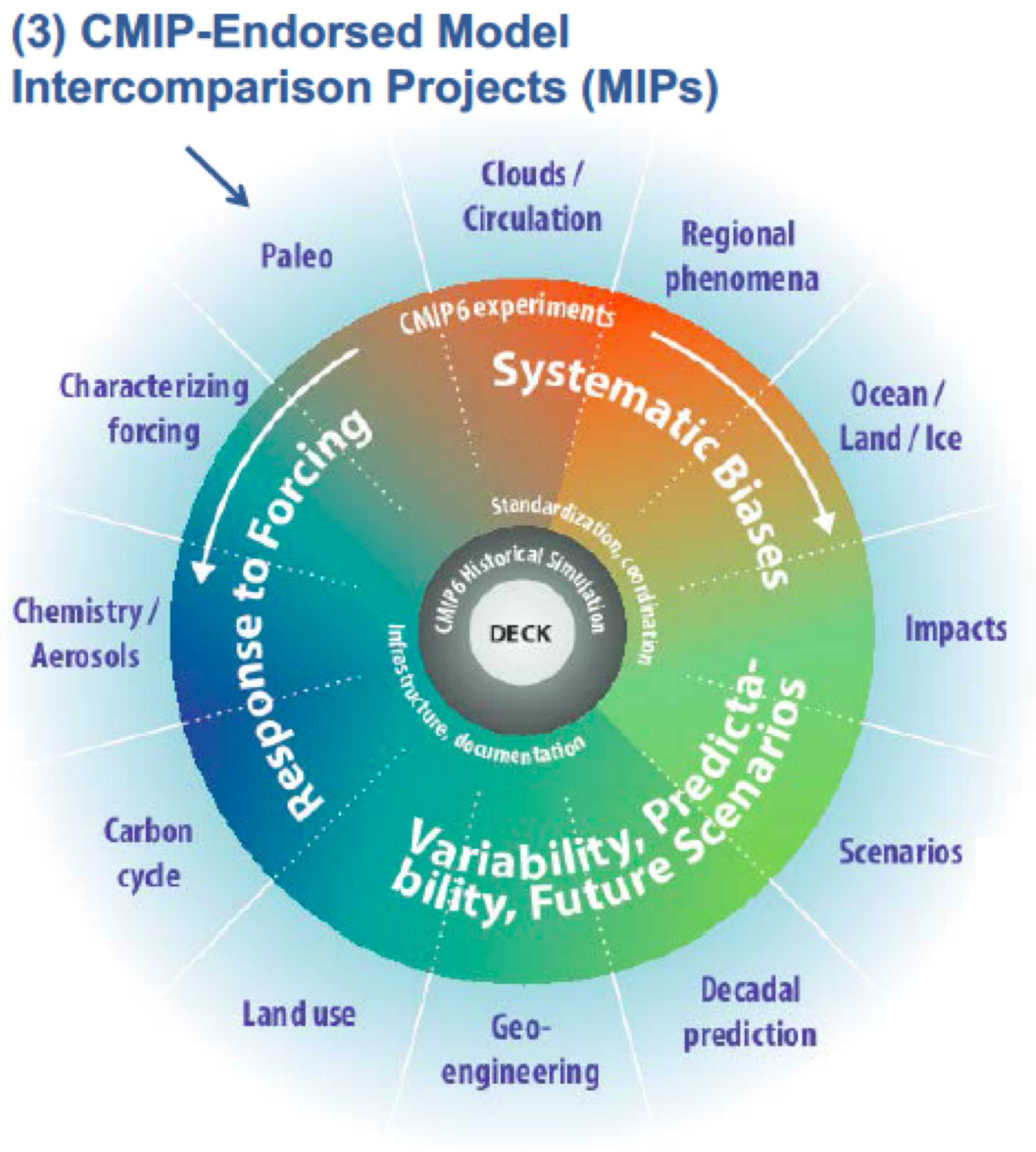
U.S. DEPARTMENT OF ENERGY

Office of Science

ARC CENTRE OF EXCELLENCE FOR CLIMATE EXTREMES



CMIP: a More Continuous and Distributed Organization



Eyring et al., GMD, 2016

1. How does the Earth system respond to forcing?

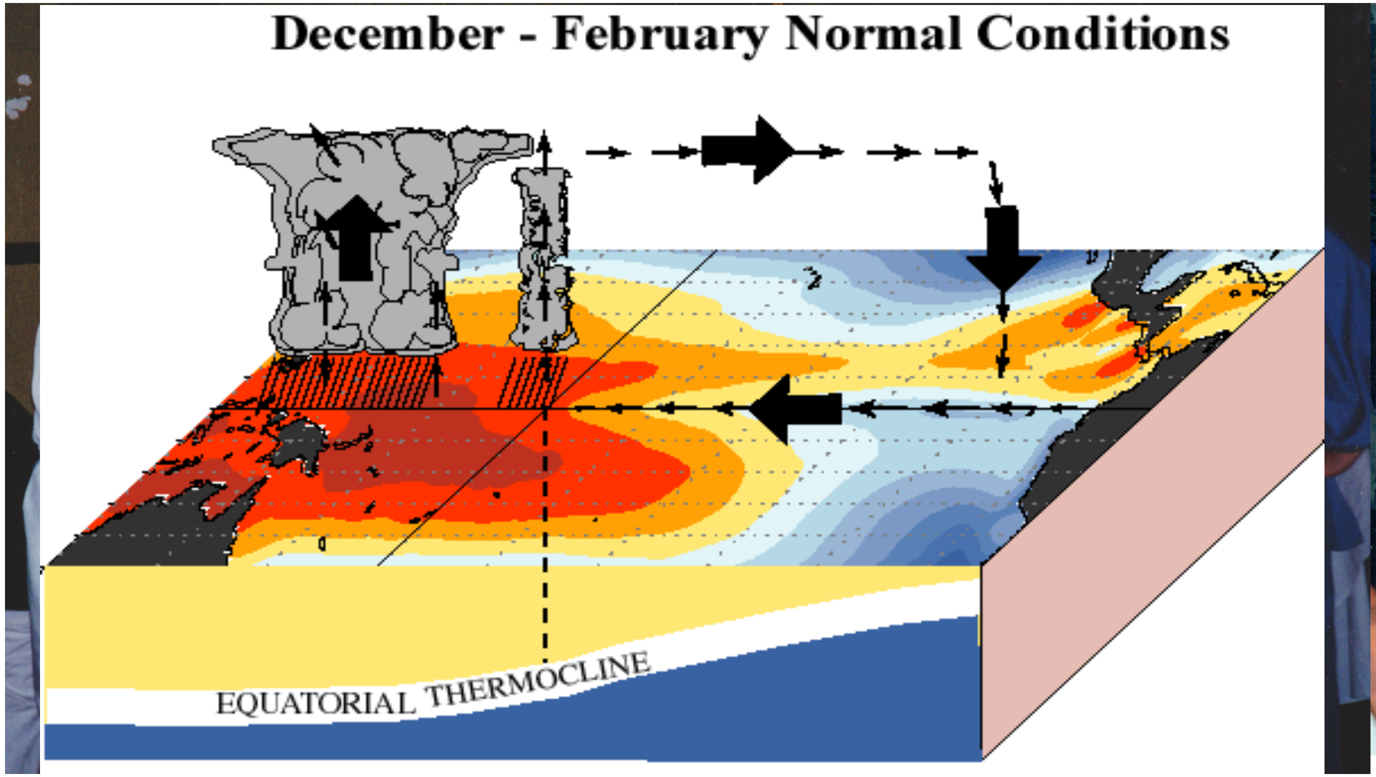
2. What are the origins and consequences of systematic model biases?

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

TOGA 95 conference: Melbourne 1995

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

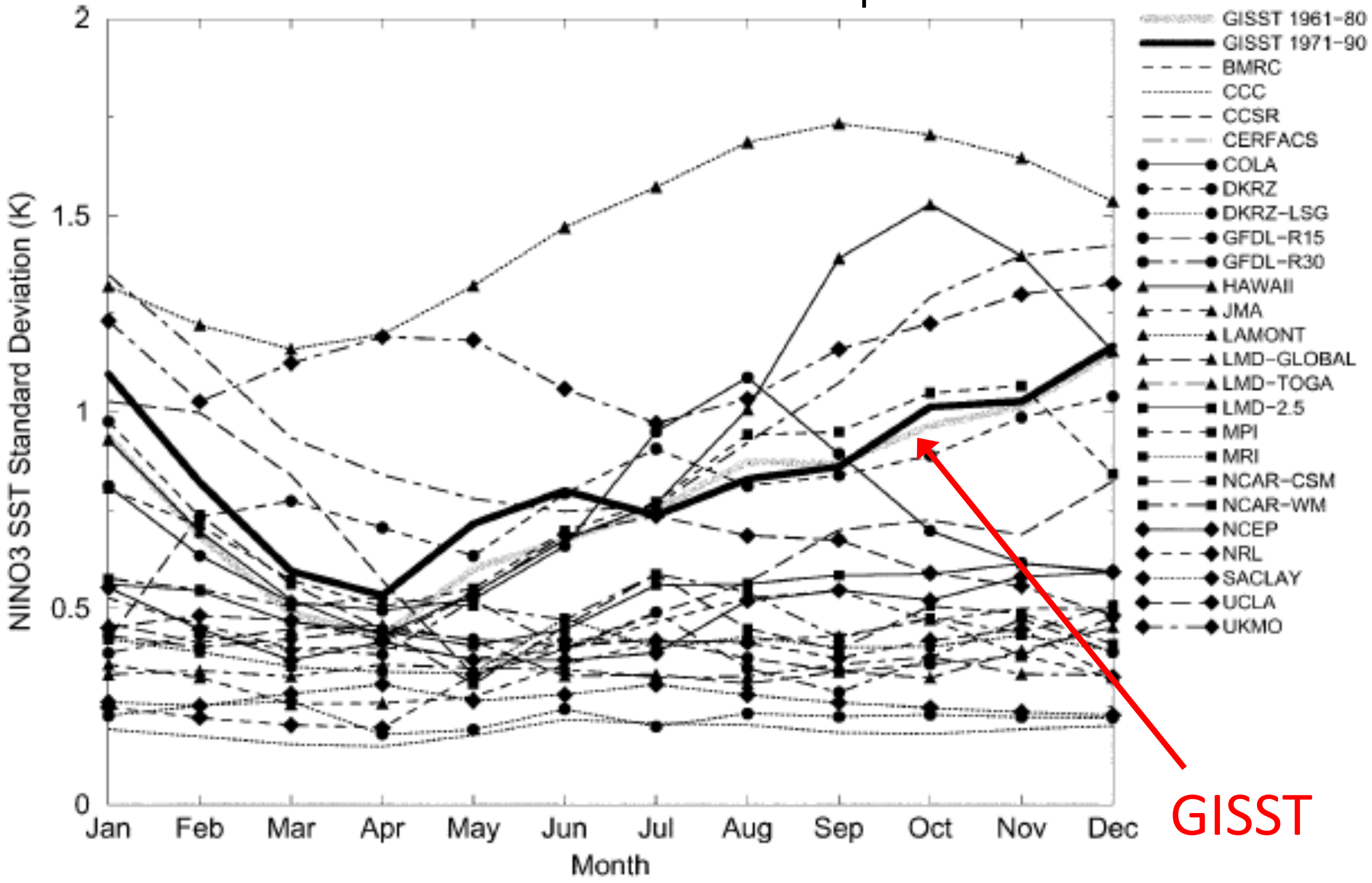


Photos courtesy Neville Smith

Systematic biases: El Niño Southern Oscillation

ENSIP: The El Niño Southern Oscillation simulation intercomparison project

Std deviation of Ninõ3 SST in 24 coupled models



Latif et al 2001

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

Systematic biases: El Niño Southern Oscillation

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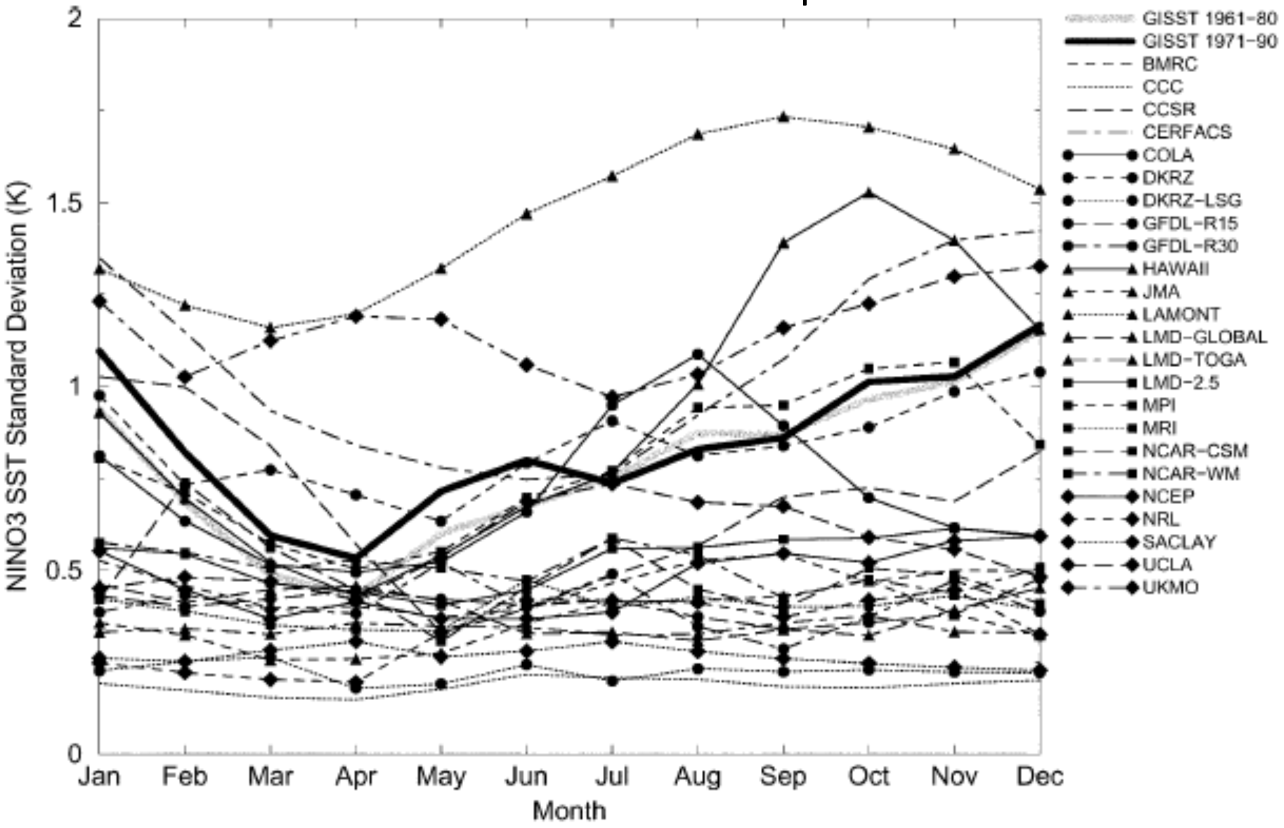
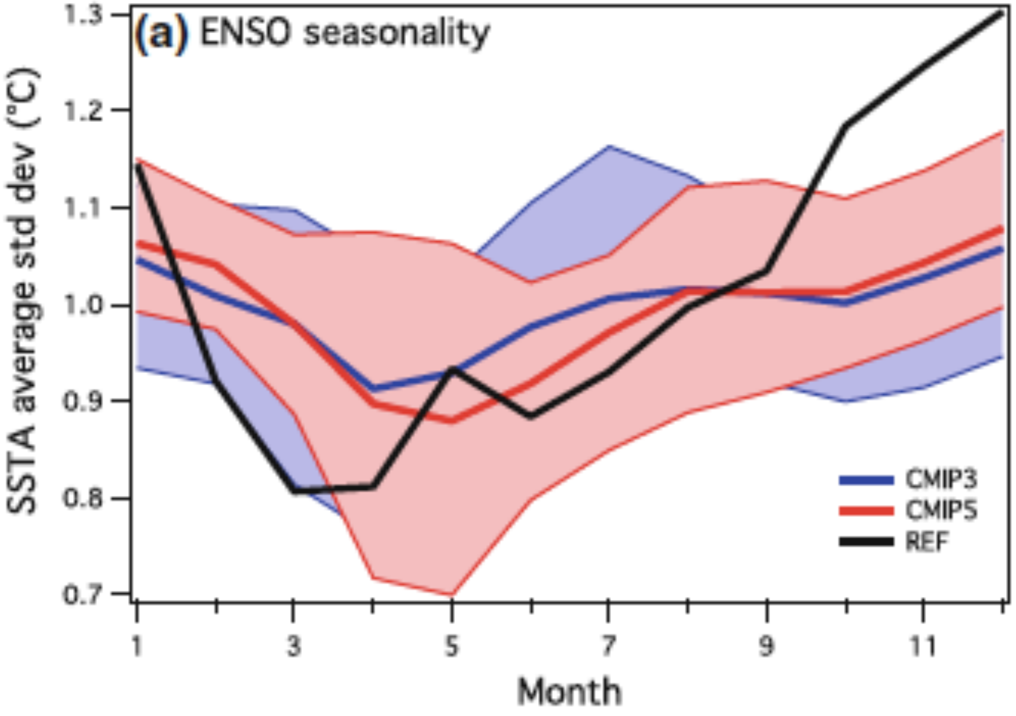
Some improvements in simulating the El Niño Southern Oscillation over the course of CMIP, though many biases still remain

Std deviation of Ninõ3 SST in 24 coupled models



Latif et al 2001



Bellenger et al 2014

Systematic biases: El Niño Southern Oscillation

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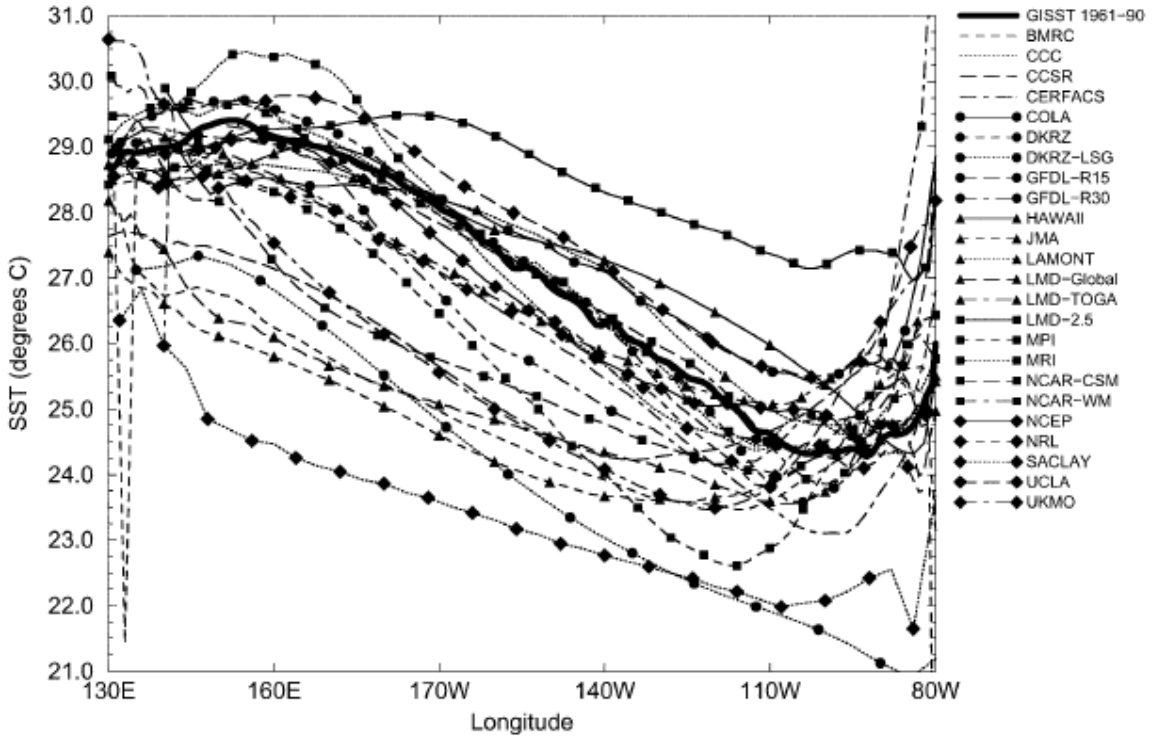
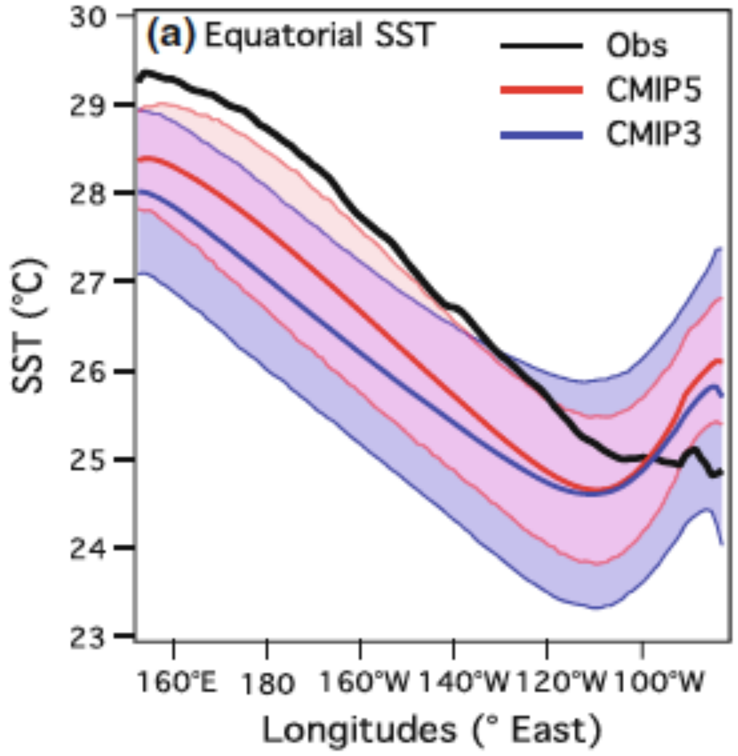
Some improvements in simulating the El Niño Southern Oscillation over the course of CMIP, though many biases still remain

Climatology of annual equatorial Pacific SSTs



Latif et al 2001

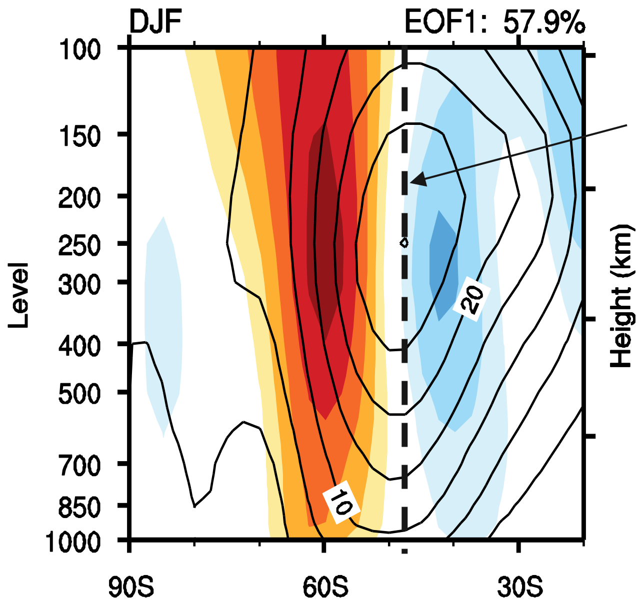


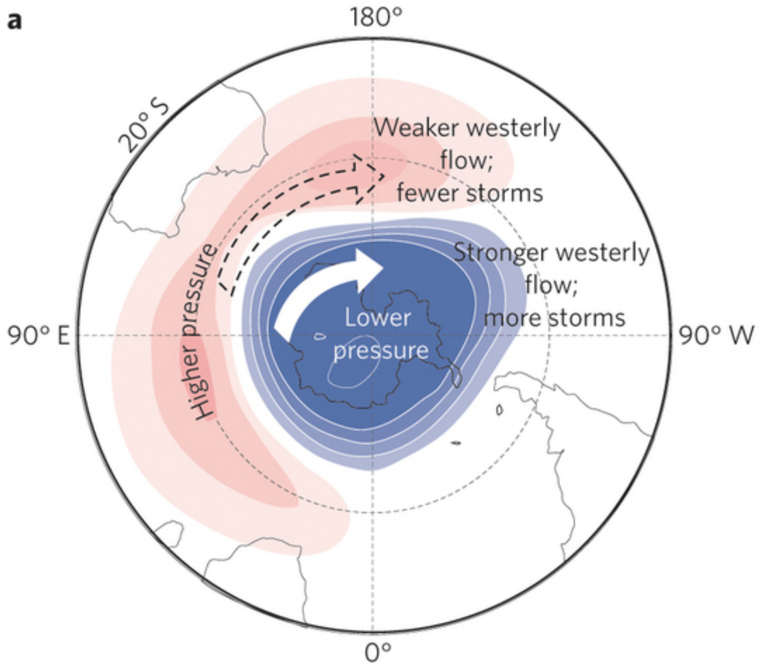
Bellenger et al 2014

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

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

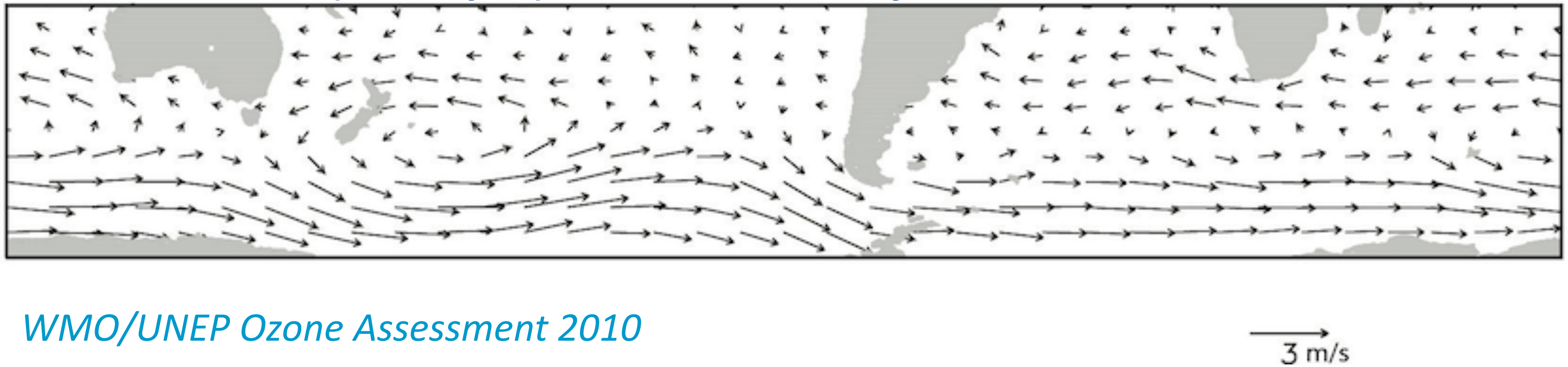
+ve SAM





Jones et al, Nature, 2012

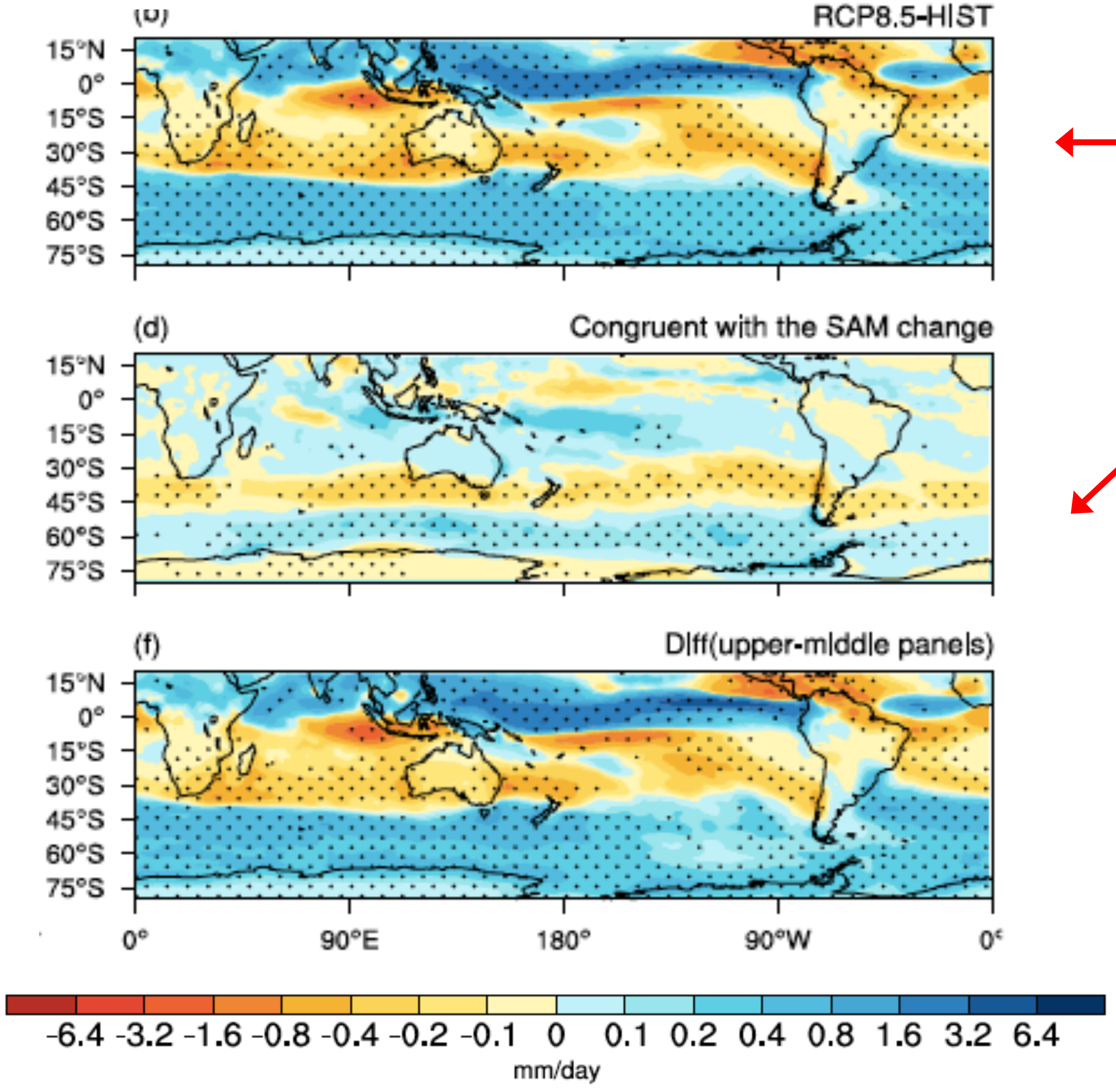
Observed (reanalysis) trends in near-surface summer winds



WMO/UNEP Ozone Assessment 2010

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

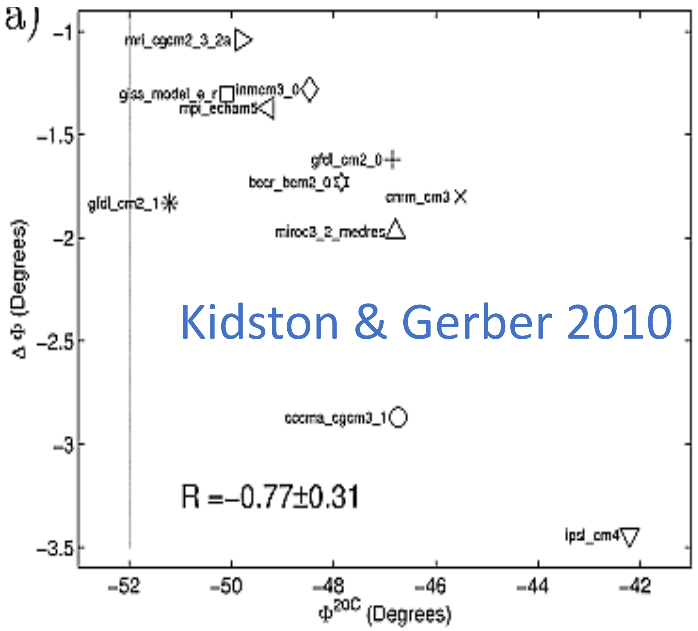
JJA rainfall change at end of 21st C



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

Lim et al 2016

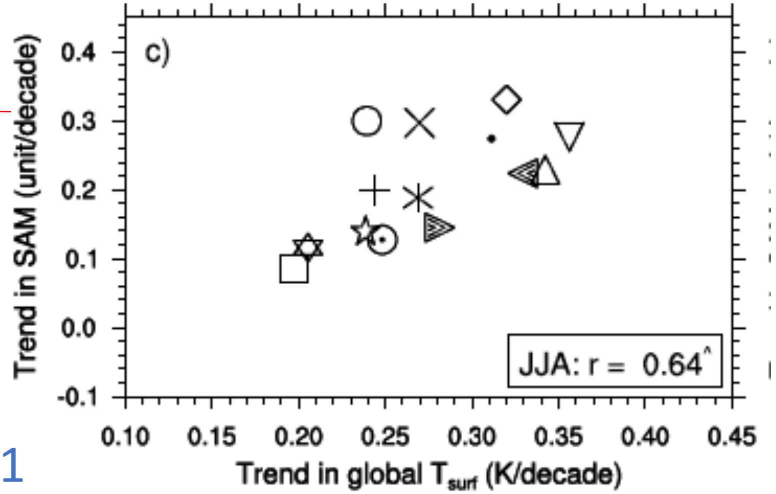
Eq biased jets have > shifts with warming



Kidston & Gerber 2010

CMIP3

> +ve SAM trend with > warming



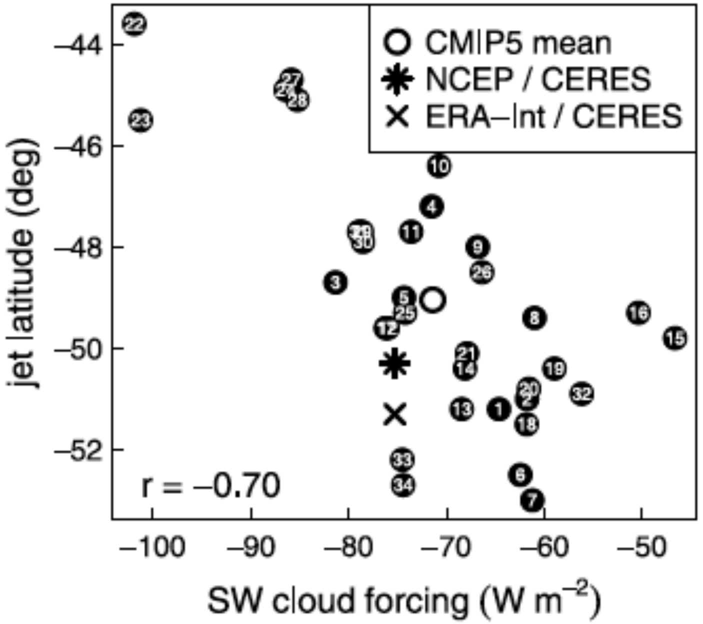
Arblaster et al 2011

Systematic biases: SH mid-latitude jet and annular mode

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

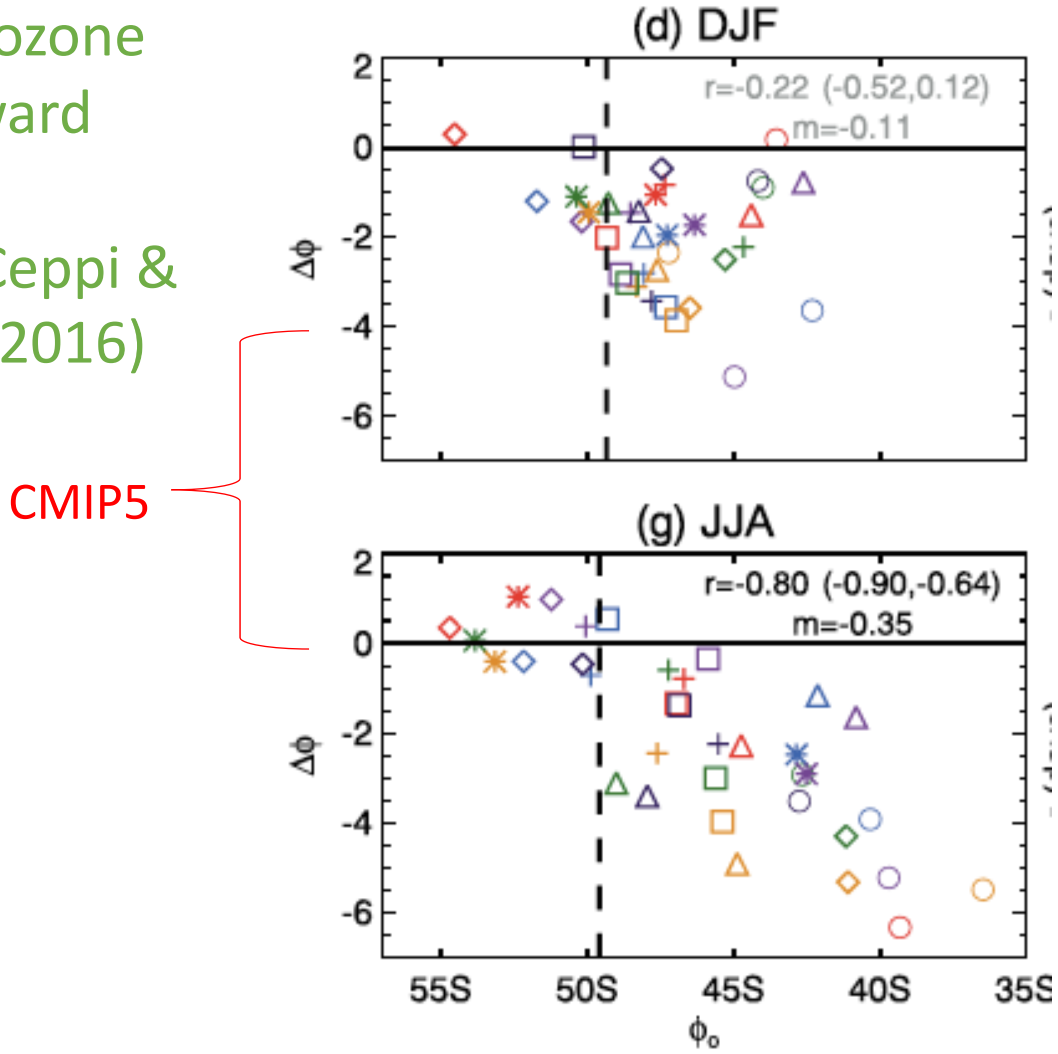
Moist processes are likely a large part of the story (Ceppi & Hartmann, 2014; Ceppi et al 2012, 2016; Shaw et al 2016)

Ceppi et al 2014 argue jet latitude biases are primarily induced by the midlatitude SWCF anomalies



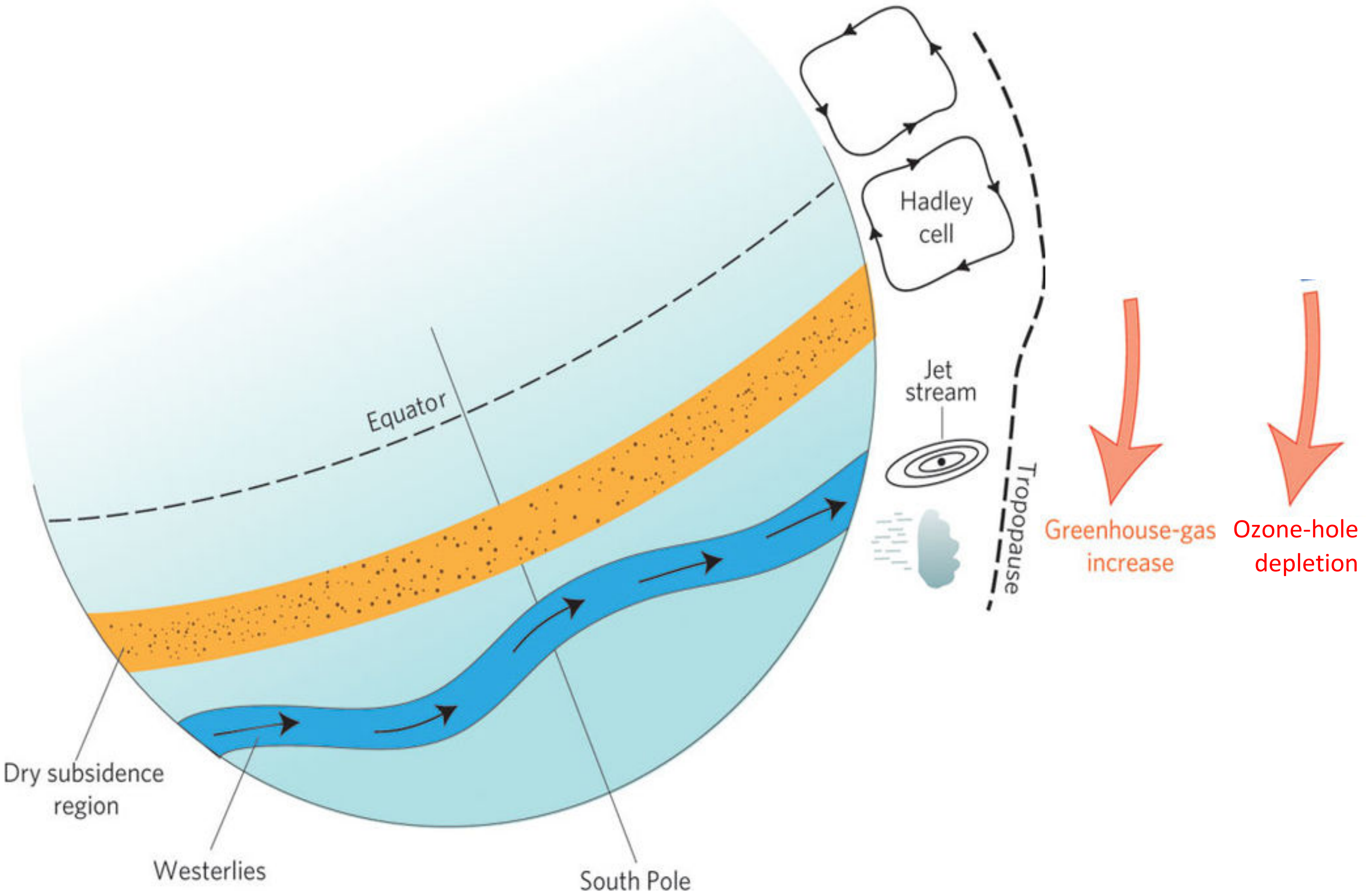
Ceppi et al 2014

Jet Latitude vs Jet shift



Simpson & Polvani 2016

How does the Earth system respond to forcings?



Perlwitz, 2011

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

How does the Earth system respond to forcings?

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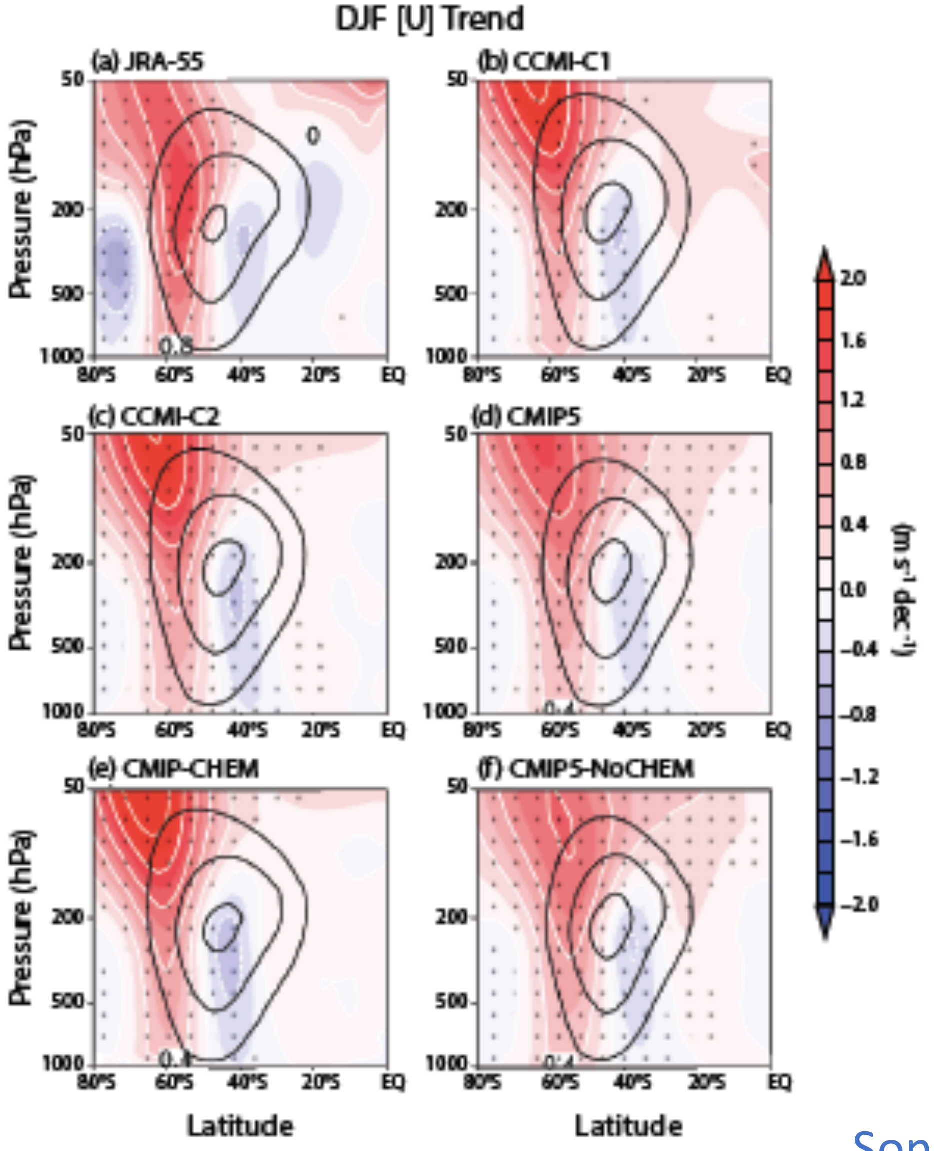
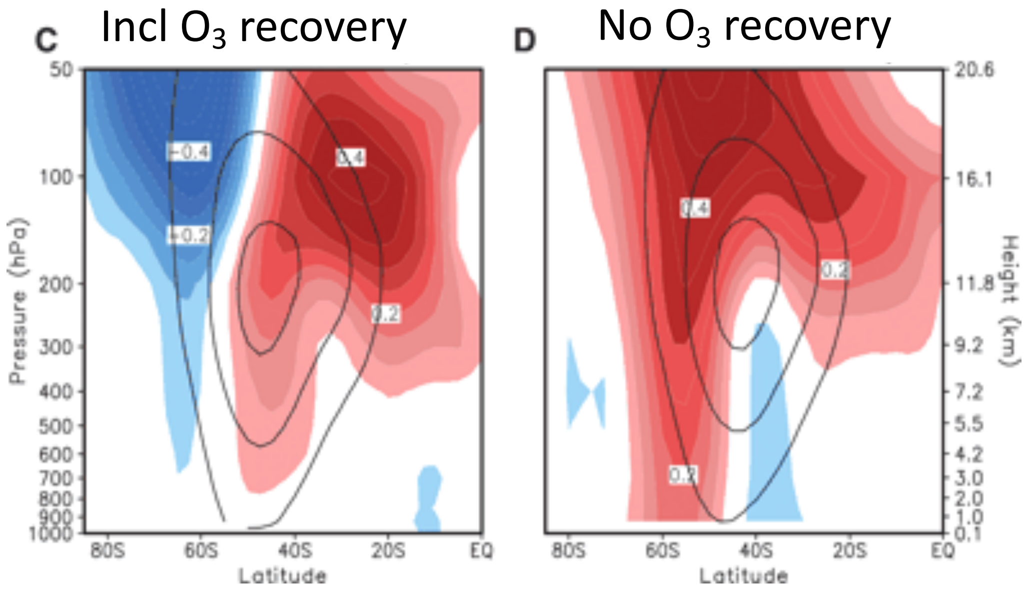
CCMVal and CMIP showed the importance of incorporating time-varying ozone forcing for SH climate





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

How does the Earth system respond to forcings?

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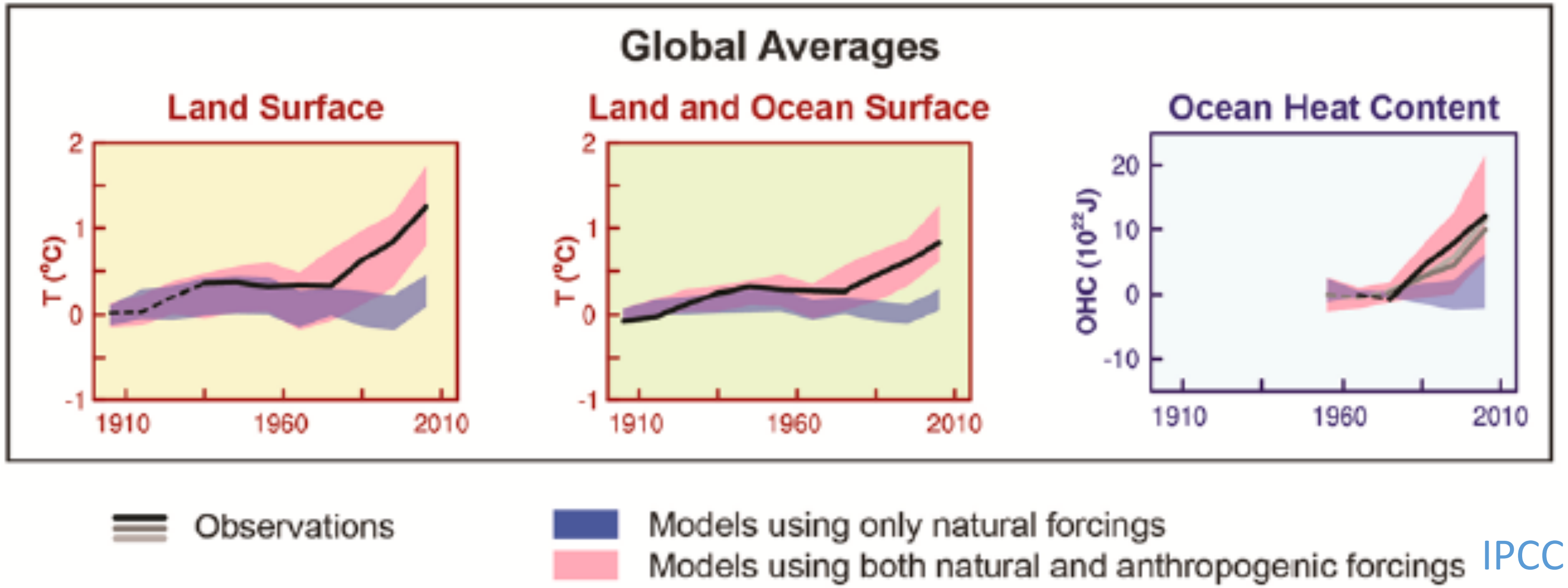
CMIP has been critical for providing the experimental framework and historical forcings for detection and attribution studies and statements in IPCC

- 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)

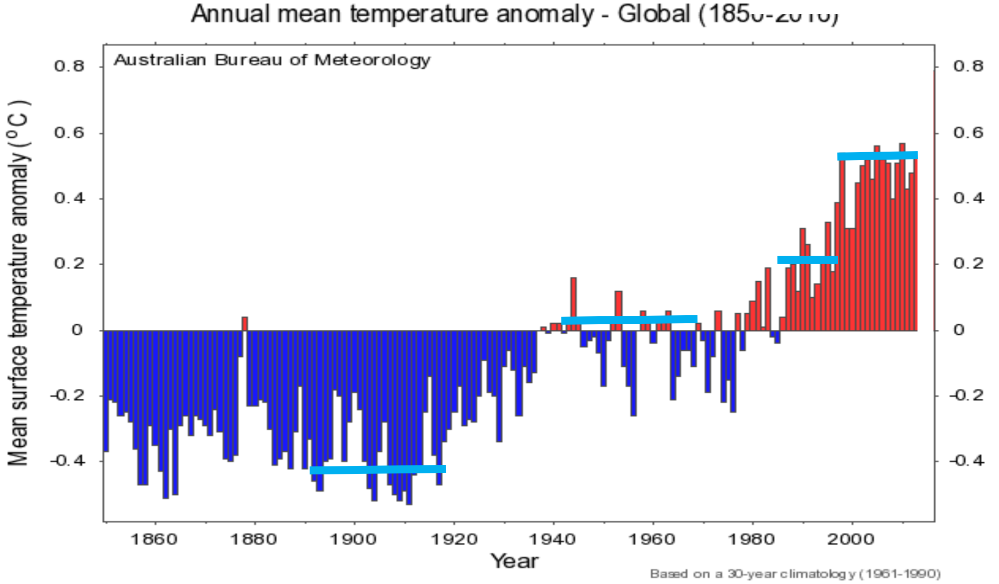


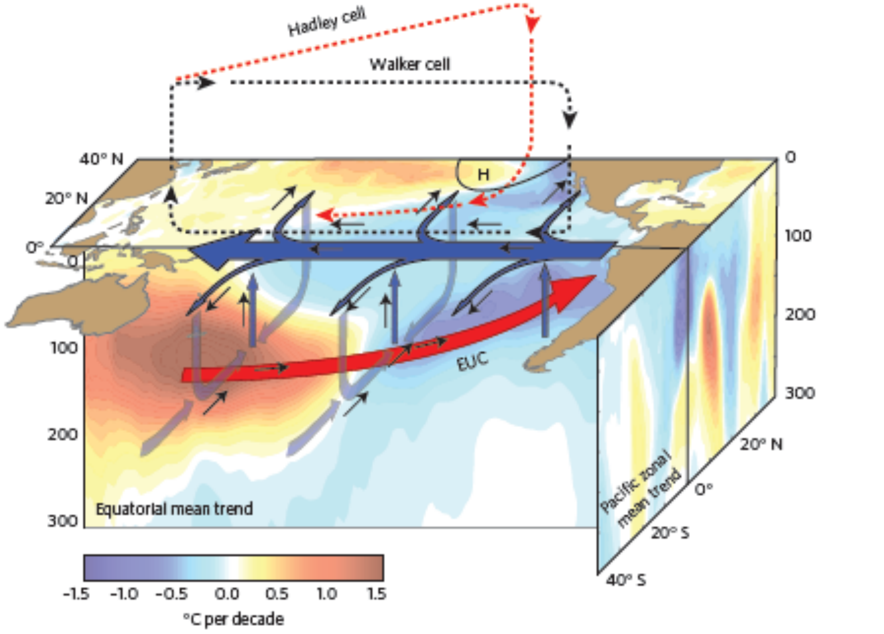
IPCC (2013) Figure SPM.6

Assessing future change given climate variability

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

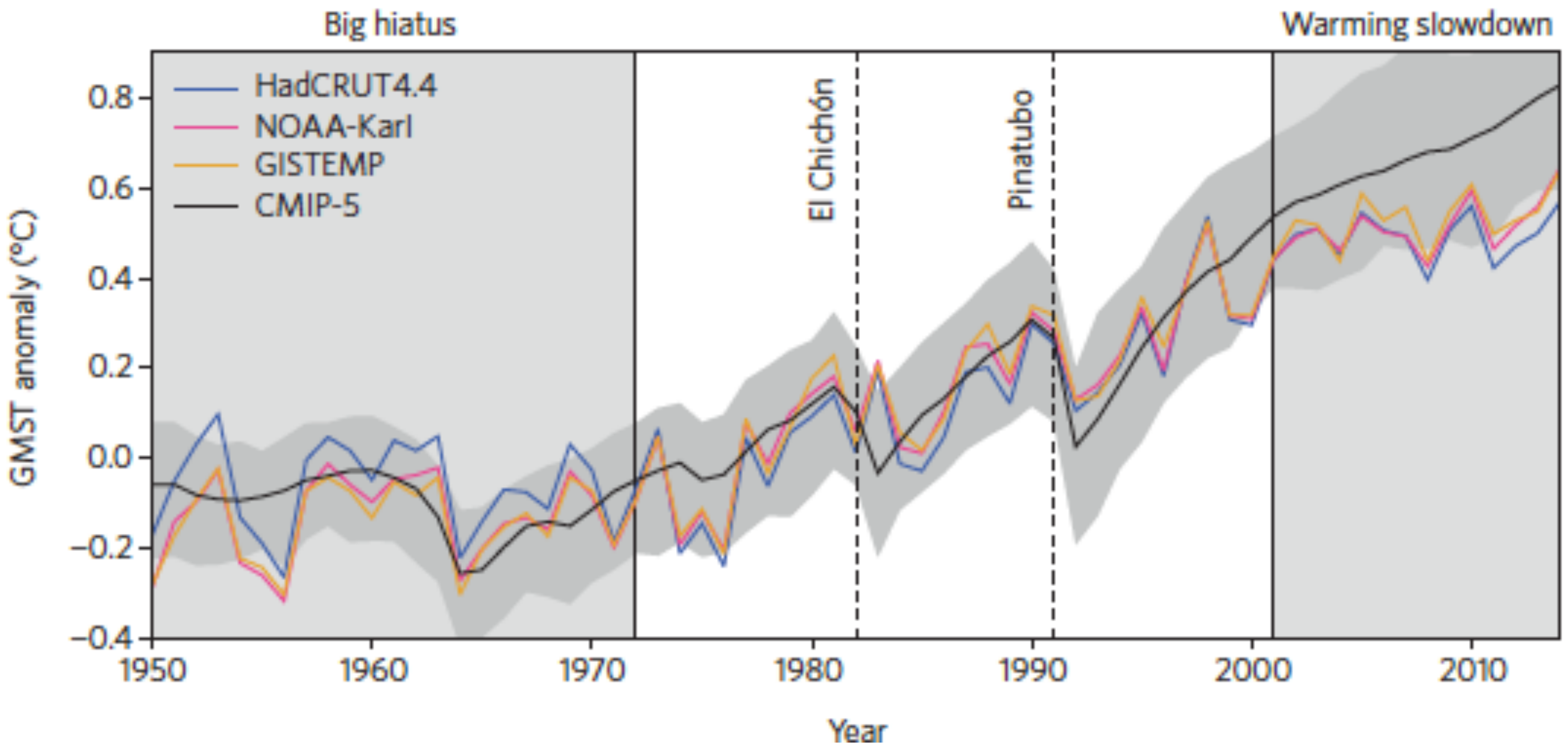




England et al 2014

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

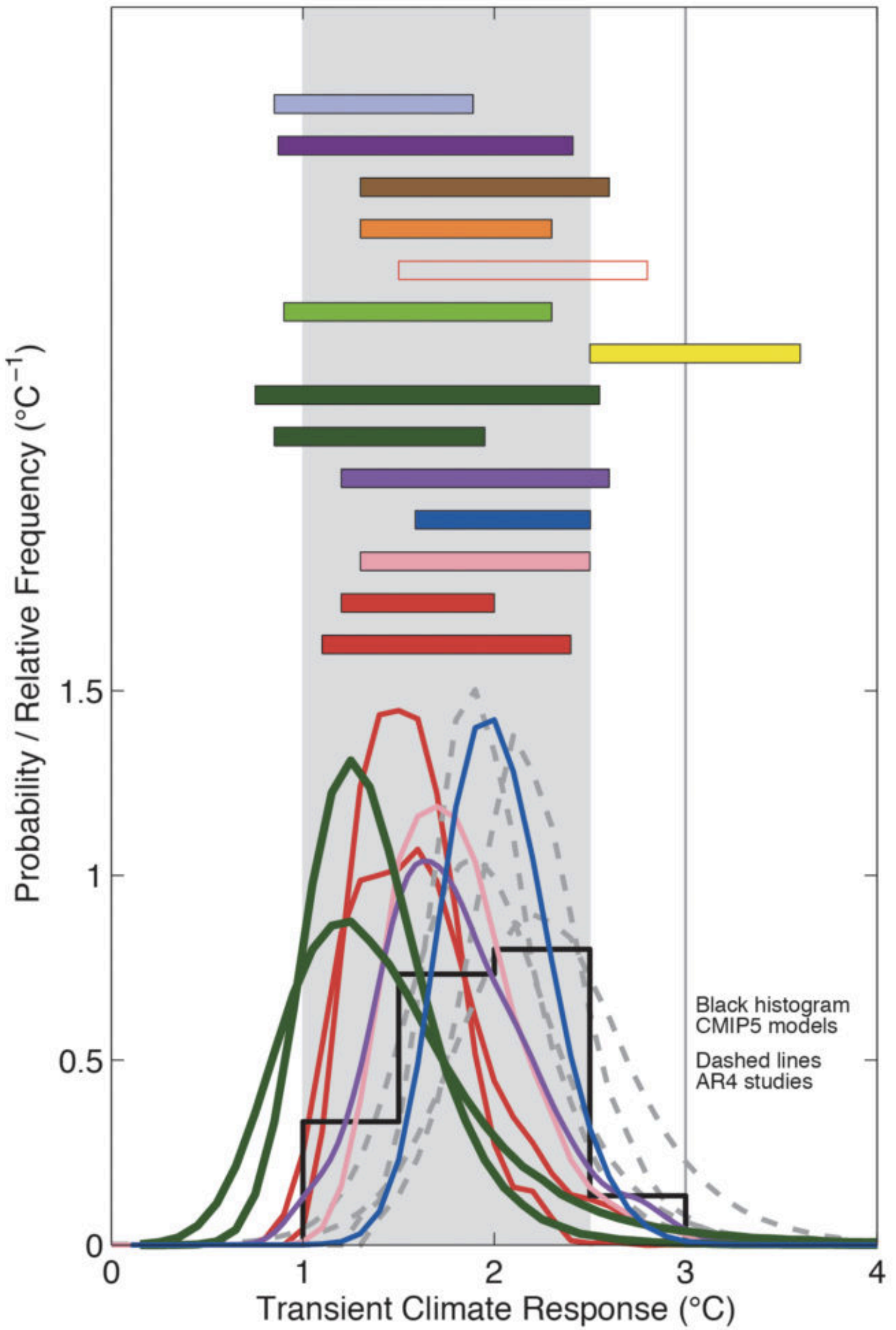
How does the Earth system respond to CO_2?

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!

IPCC (2013) TFE



Response to CO_2 – cloud feedbacks

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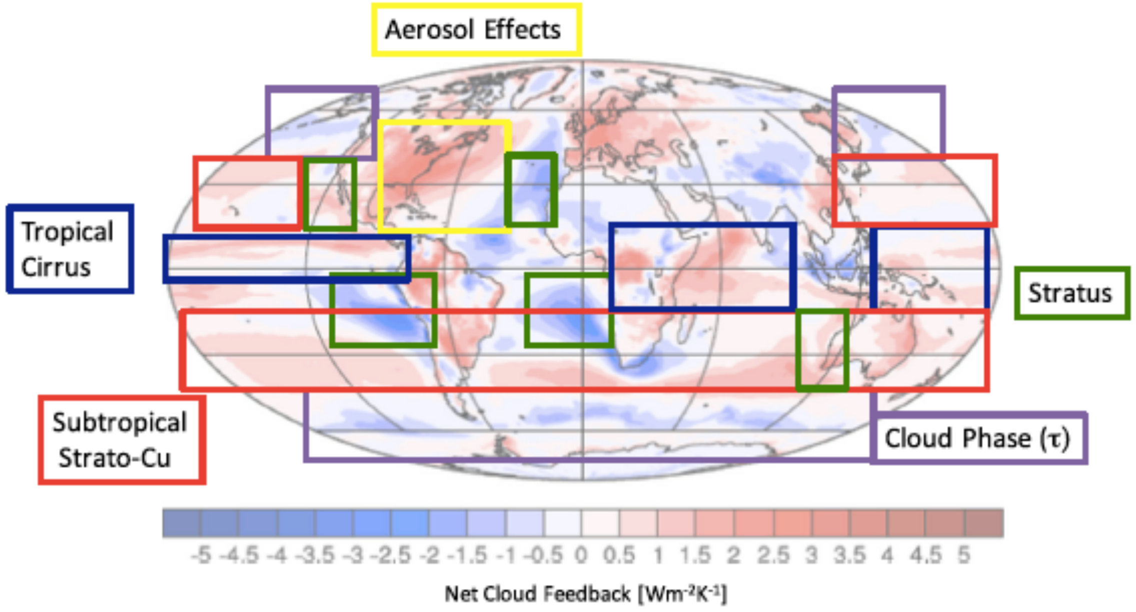
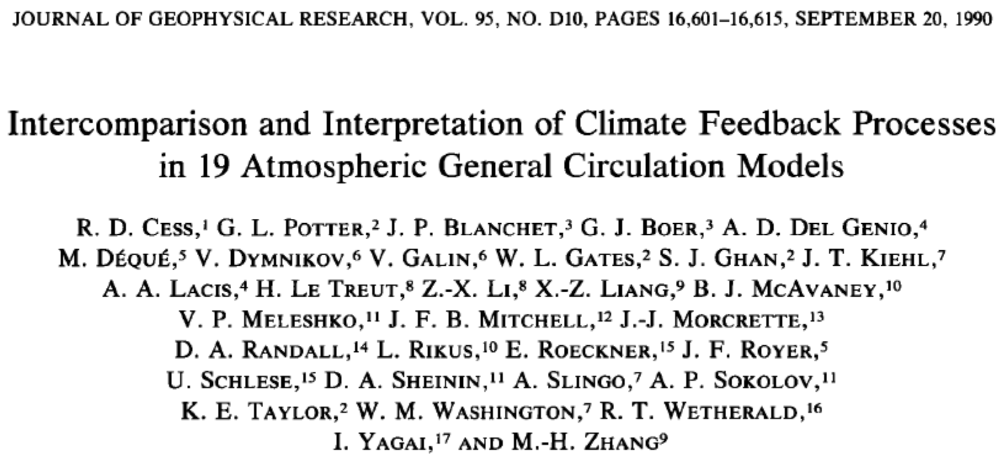
Cess et al 1990 found that most of the variation in climate sensitivity was due to differences in cloud feedback

Cloud feedbacks remain the largest uncertainty in total feedbacks today



Gettelman and Sherwood, 2016



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 95, NO. D10, PAGES 16,601–16,615, SEPTEMBER 20, 1990

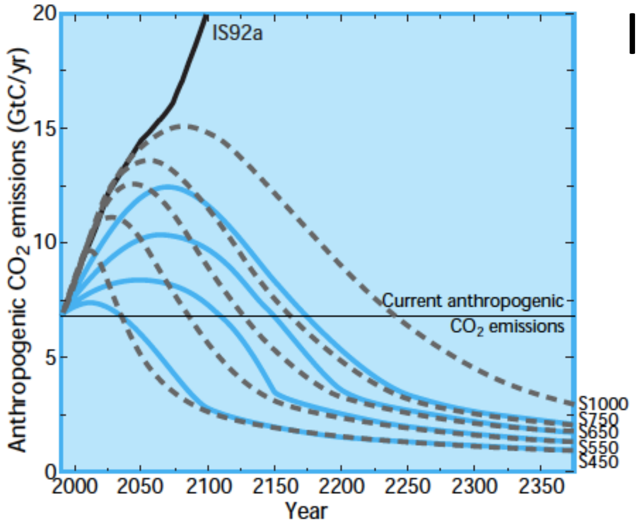
Intercomparison and Interpretation of Climate Feedback Processes in 19 Atmospheric General Circulation Models

R. D. Cess,[1] G. L. Potter,[2] J. P. Blanchet,[3] G. J. Boer,[3] A. D. Del Genio,[4] M. Déqué,[5] V. Dymnikov,[6] V. Galin,[6] W. L. Gates,[2] S. J. Ghan,[2] J. T. Kiehl,[7] A. A. Lacis,[4] H. Le Treut,[8] Z.-X. Li,[8] X.-Z. Liang,[9] B. J. McAvaney,[10] V. P. Meleshko,[11] J. F. B. Mitchell,[12] J.-J. Morcrette,[13] D. A. Randall,[14] L. Rikus,[10] E. Roeckner,[15] J. F. Royer,[5] U. Schlese,[15] D. A. Sheinin,[11] A. Slingo,[7] A. P. Sokolov,[11] K. E. Taylor,[2] W. M. Washington,[7] R. T. Wetherald,[16] I. Yagai,[17] and M.-H. Zhang[9]

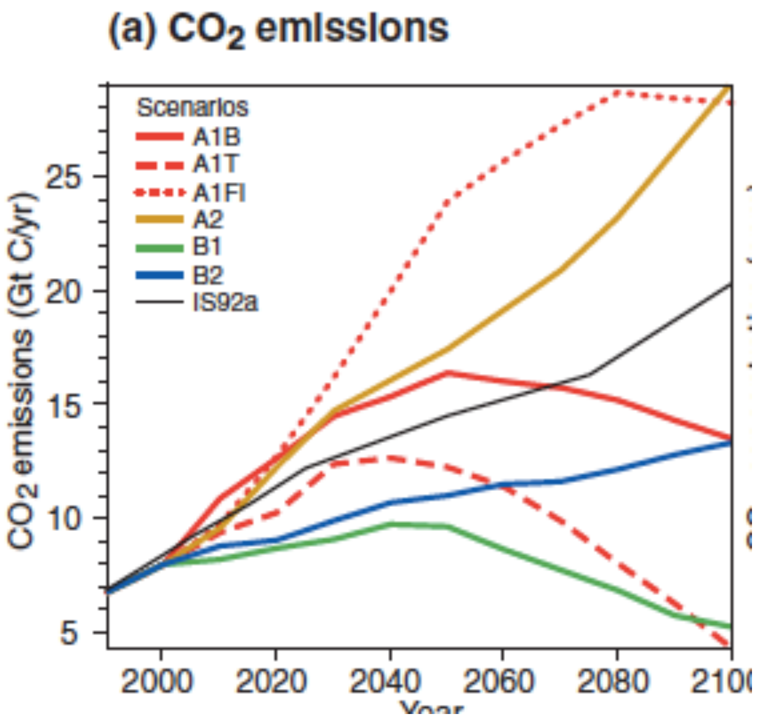
"cloud feedback is the consequence of all interacting physical and dynamical processes in a general circulation model"

"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."

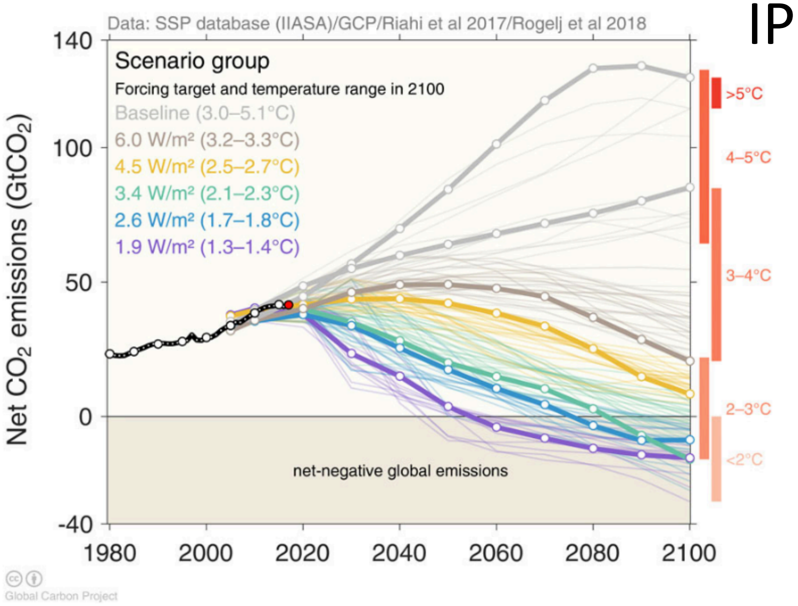
Assessing future change given uncertainty in scenarios



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

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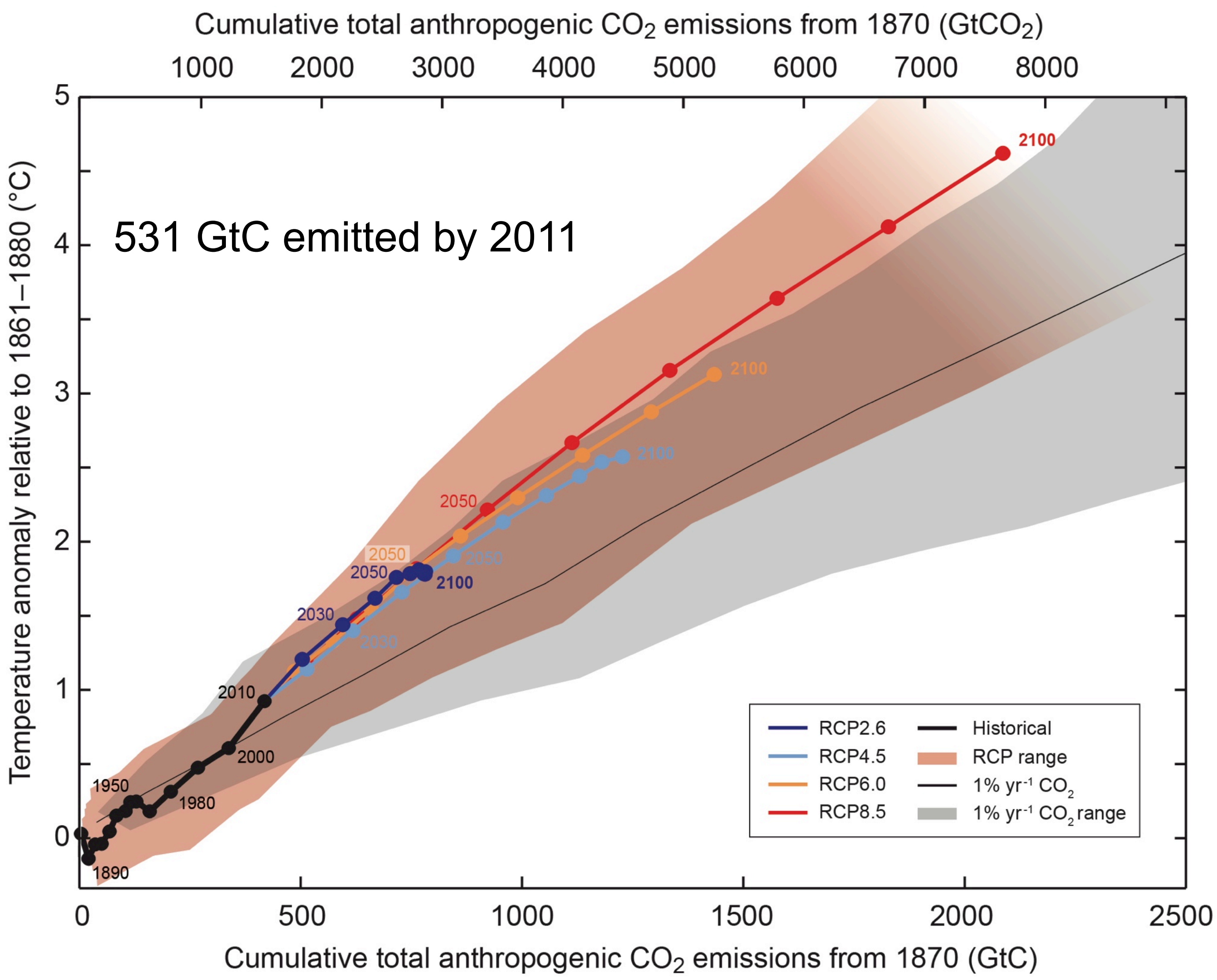


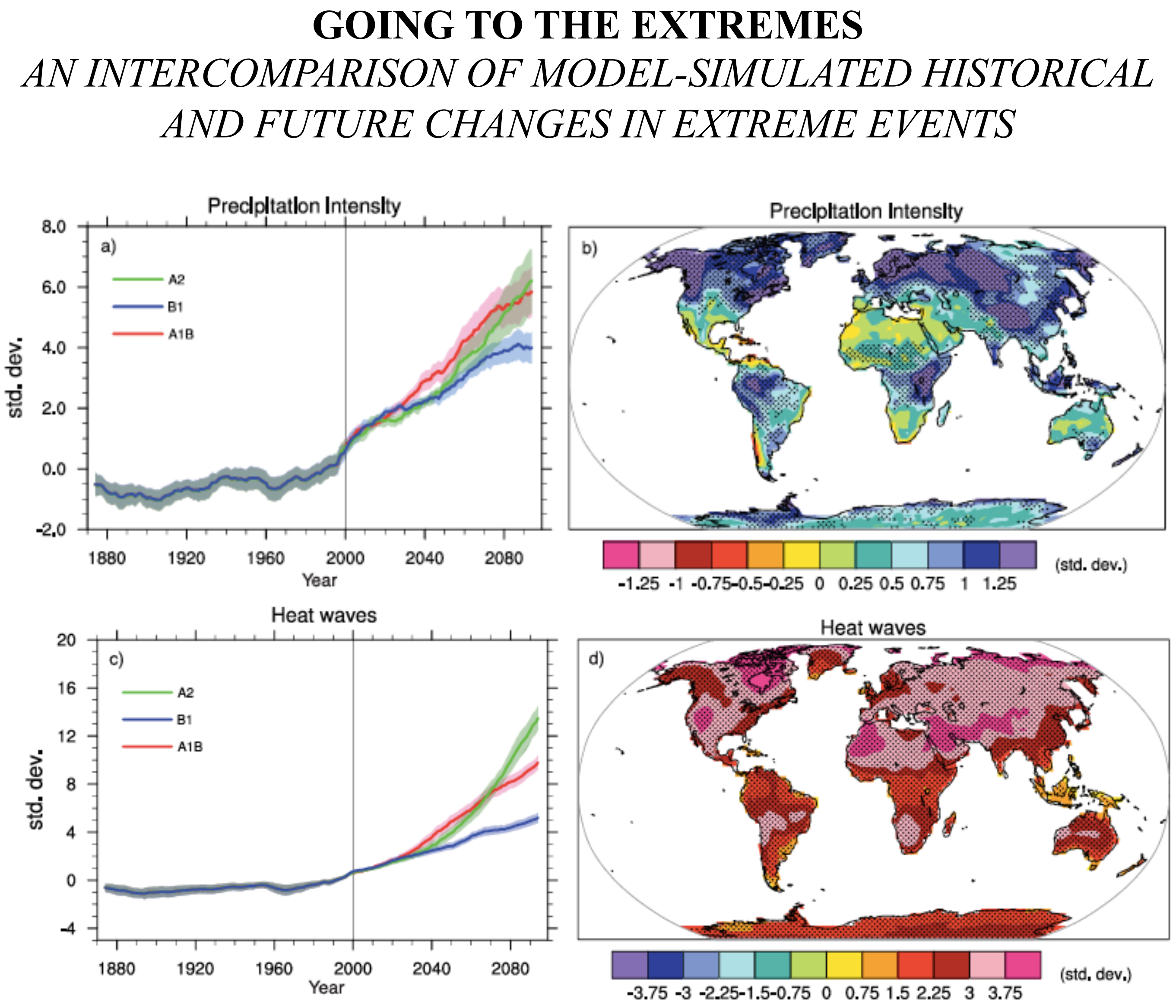
IPCC, 2013

Assessing future climate change - extremes

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

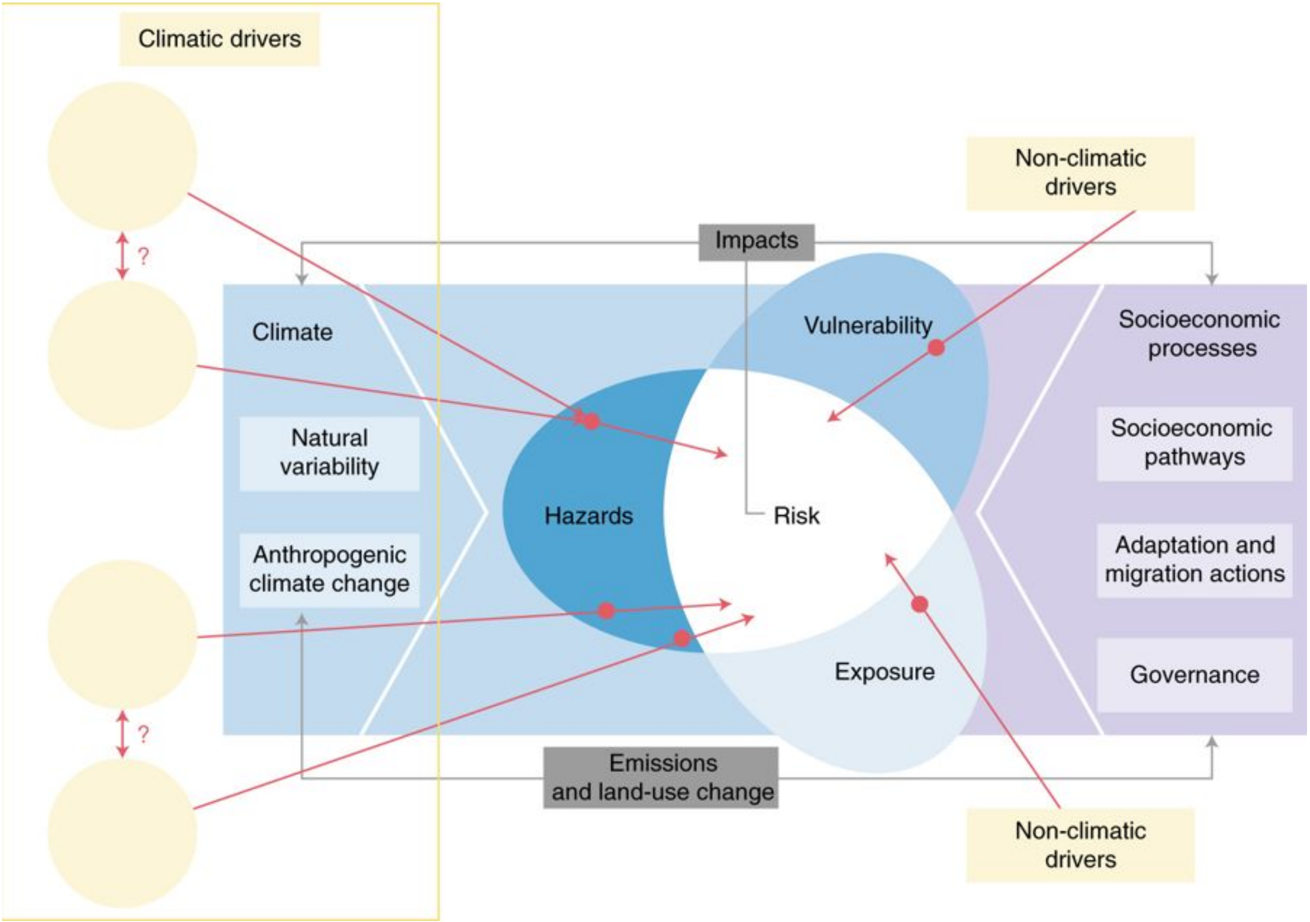
Focused on the robustness of the change in terms of sign and significance



Tebaldi et al 2006 and AR4 Ch10

Assessing future climate change - extremes

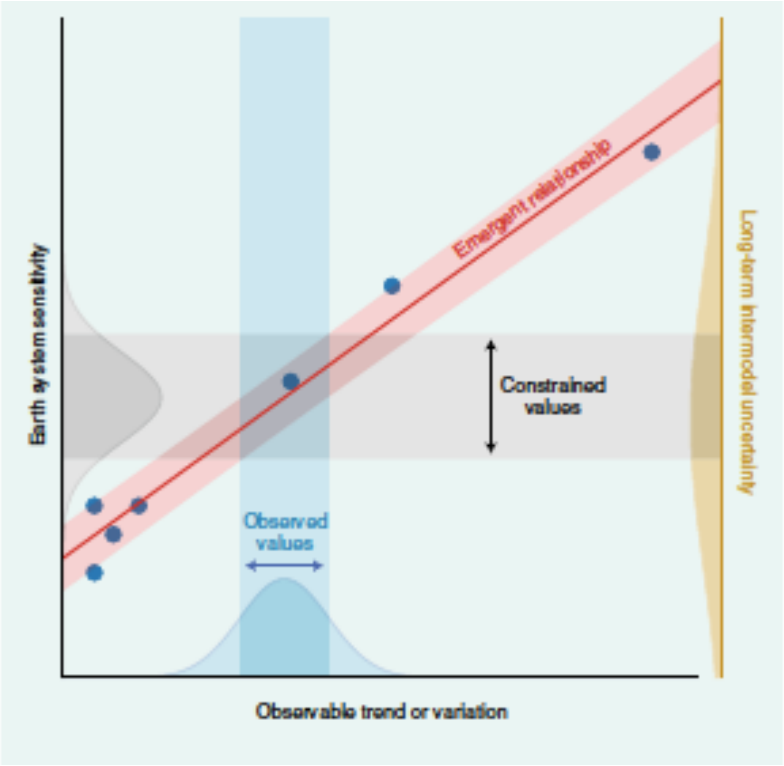
CMIP6 will provide many more models with high frequency output and large ensembles and new MIPs to better enable a process-based understanding of extremes in the multimodel context

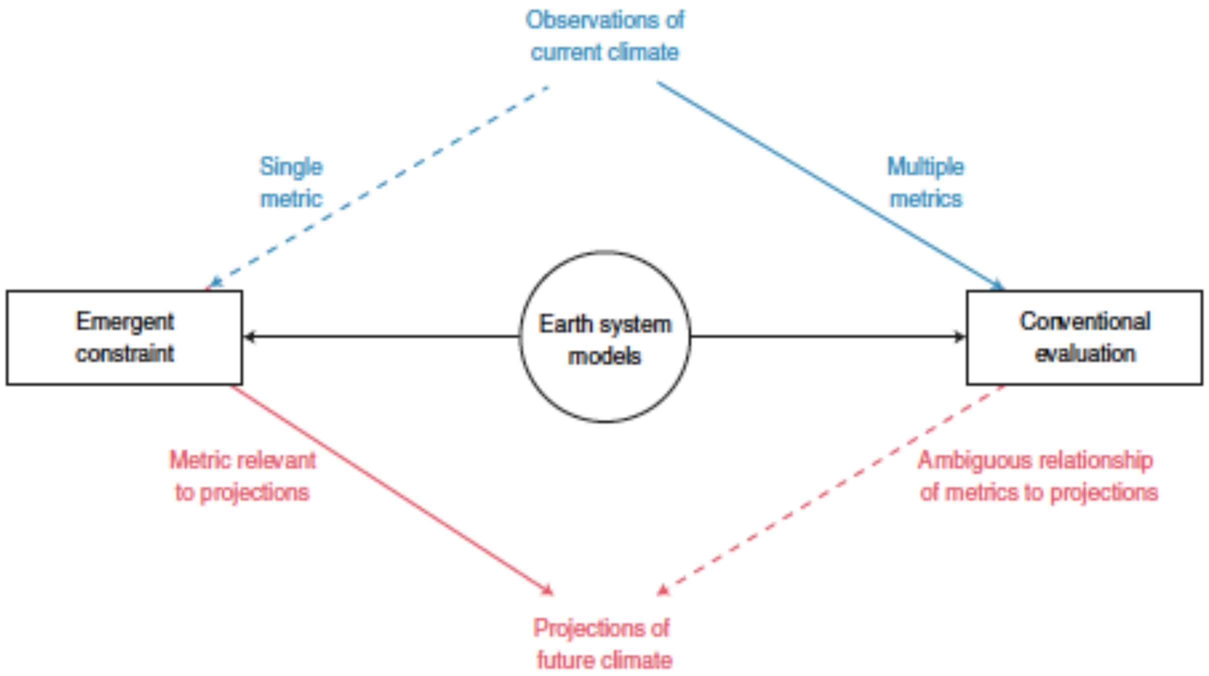


IPCC, 2012; Zscheischler et al., 2018

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

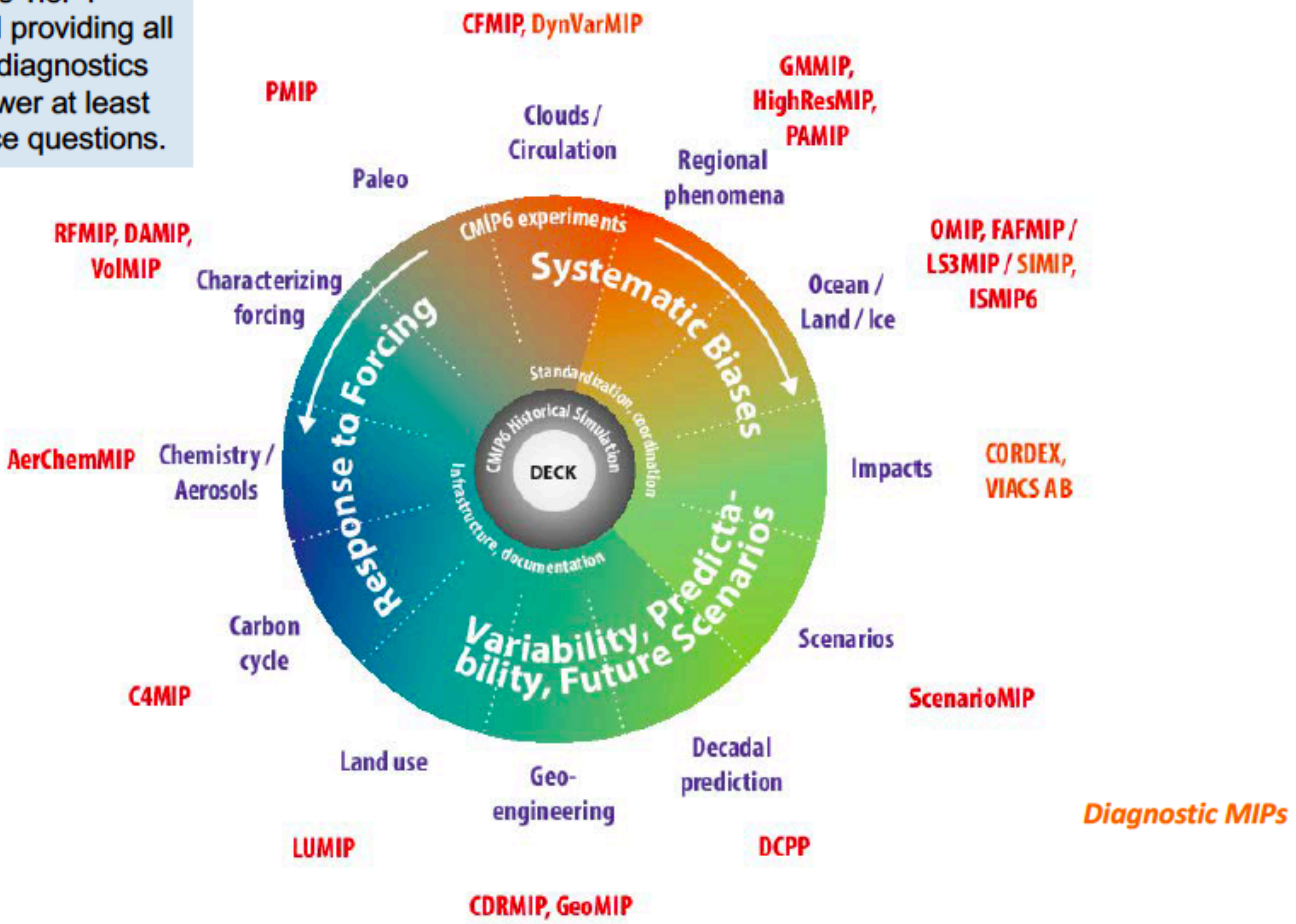




Eyring et al 2019; Hall et al 2019

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.

23 CMIP6-Endorsed 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

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:

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?

TOGA 95 conference: Melbourne 1995

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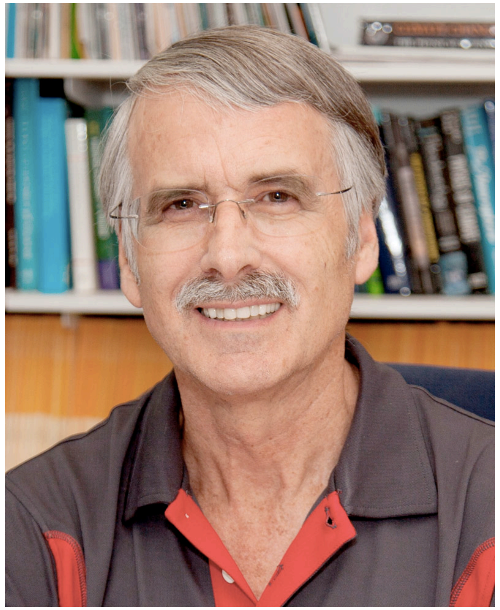
My first exposure to WCRP was as an undergraduate student during the Tropical Oceans and Global Atmosphere (TOGA) conference held in Melbourne in 1995

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