Update on CMIP5 and Opportunities for Assessing Model Reliability

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Outline

- CMIP5 overview
- Approaches to assessing model reliability
- "Long-term" experiments
- Decadal prediction experiments
- Atmosphere-only experiments
- Summary

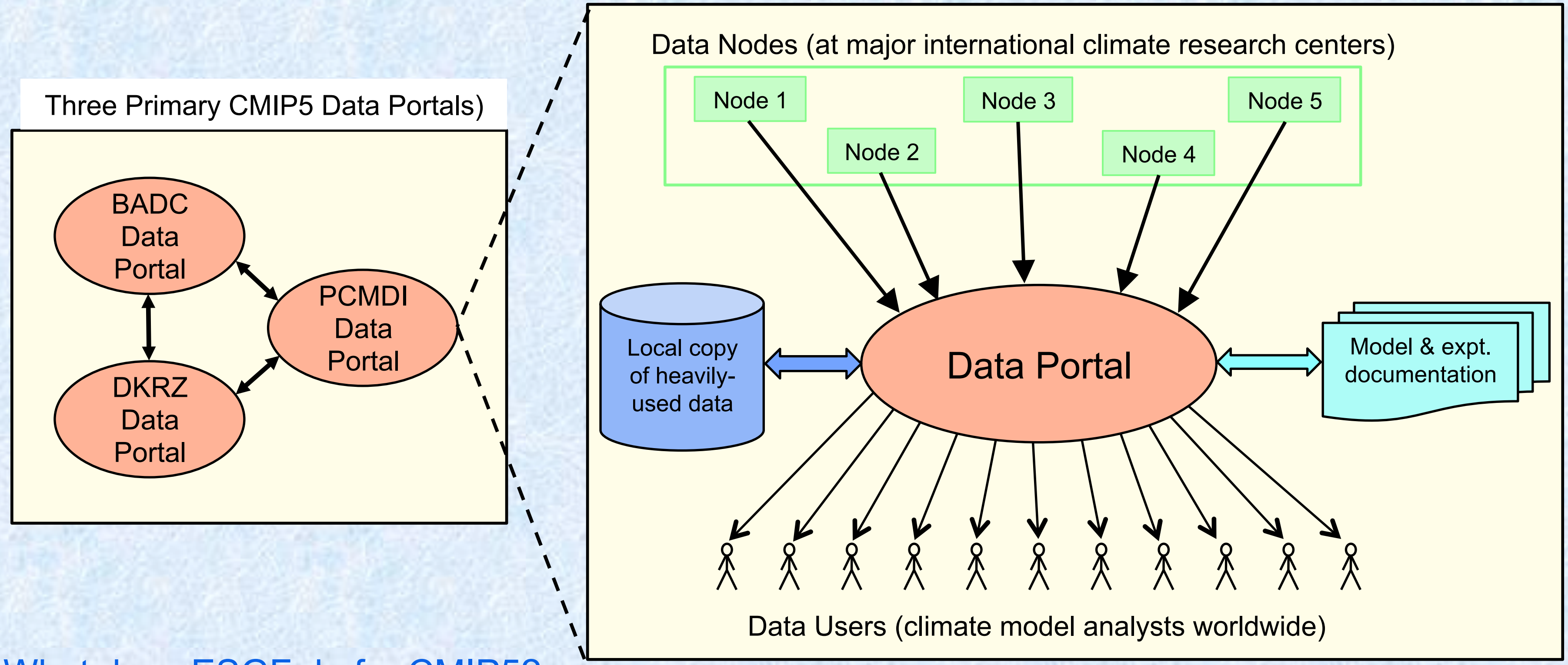
CMIP5 overview

- CMIP5 is organized by the WCRP's Working Group on Coupled Modeling (WGCM)
- It builds on but is much more ambitious than its predecessors
  - Addresses more research questions
  - Includes more comprehensive models
  - Produces more output fields
  - Calls for more complete documentation of models/experiments
  - Requires a new delivery system for data
- It is designed to
  - Meet the needs of the climate research community
  - Provide a basis for papers of interest to the IPCC's AR5

CMIP5 participating groups (23 groups; 50+ models; 17 Oct 2011: 24 models available from 13 centers)

Primary Group	Country	Model
CAWCR	Australia	ACCESS
BCC	China	BCC-CSM1.1
GCESS	China	BNU-ESM
CCCMA	Canada	CanESM2, CanCM4, CanAM4
CCSM	USA	CESM1, CCSM4
RSMAS	USA	CCSM4(RSMAS)
CMCC	Italy	CMCC- CESM, CM, & CMS
CNRM/CERFACS	France	CNRM-CM5
CSIRO/QCCCE	Australia	CSIRO-Mk3.6
EC-EARTH	Europe	EC-EARTH
LASG, IAP	China	FGOALS- G2.0, S2.0 & gl
FIO	China	FIO-ESM
NASA/GMAO	USA	GEOS-5
GFDL	USA	GFDL- HIRAM-C360, HIRAM-C180, CM2.1, CM3, ESM2G, ESM2M
NASA/GISS	USA	GISS- E2-H, E2-H-CC, E2-R, E2-R-CC, E2CS-H, E2CS-R
MOHC	UK	Had CM3, CM3Q, GEM2-ES, GEM2-A, GEM2-CC
NMR/KMA	Korea / UK	HadGEM2-AO
INM	Russia	INM-CM4
IPSL	France	IPSL- CM5A-LR, CM5A-MR, CM5B
MIROC	Japan	MIROC 5, 4m, 4h, ESM, ESM-CHEM
MPI-M	Germany	MPI-ESM- HR, LR
MRI	Japan	MRI- AGCM3.2H, AGCM3.2S, CGCM3, ESM1
NCC	Norway	NorESM1-M, NorESM-ME, NorESM1-L

PCMDI-led Earth System Grid Federation (ESGF) serves CMIP5 simulation output to analysts worldwide



What does ESGF do for CMIP5?

- For CMIP5, ESGF links together 13 data nodes
- Data holdings expanding from 100's to 1000's of Tbytes
- Serves 100's of users

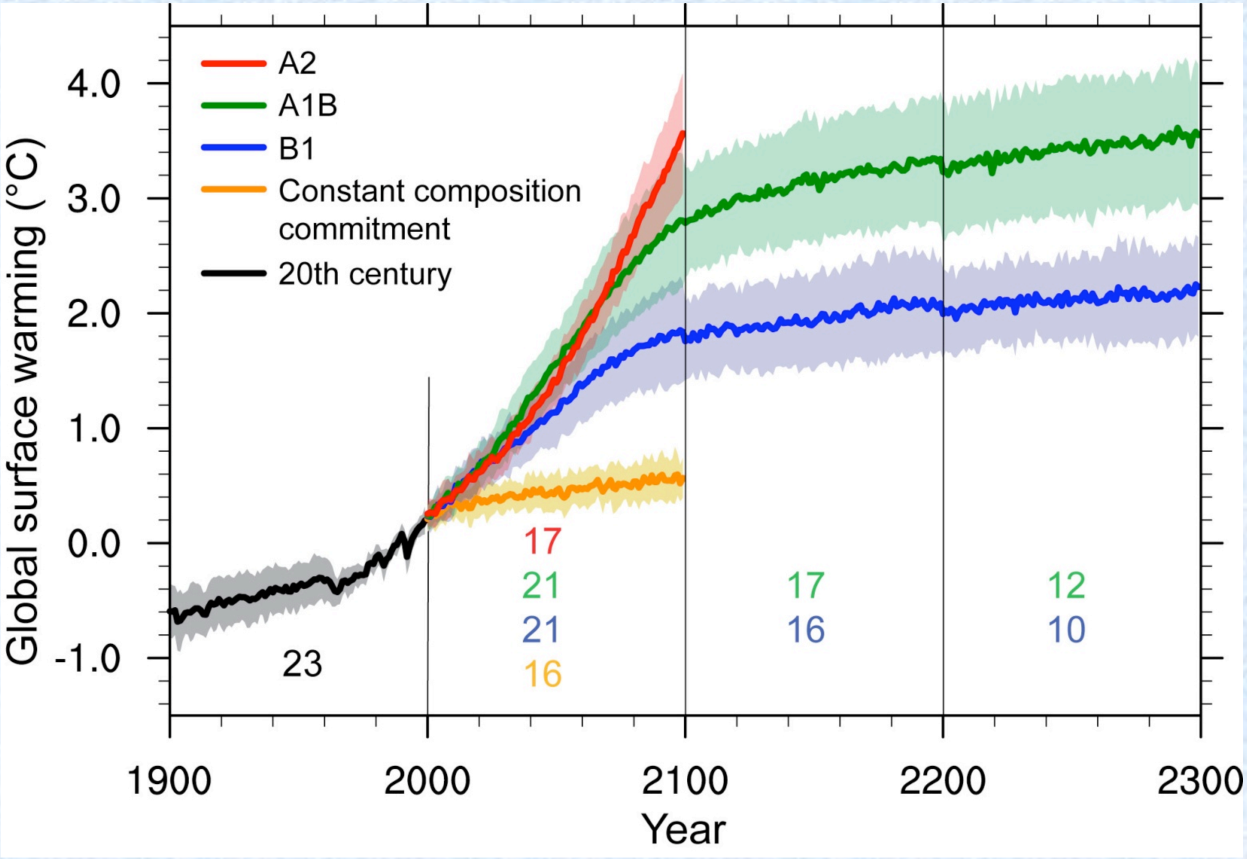
Approaches to assessing model reliability

- Seasonal to decadal forecasts: use hindcasts
- Ability to simulate important climate phenomena (e.g., seasonal cycle, ENSO, NAO, diurnal cycle, MJO)
  - Compare directly with observations: regional to global scale
- Ability to simulate important processes (e.g., radiative transfer, boundary layer clouds, convection, cyclones/ anticyclones)
  - Make use of specialized datasets (site-specific – e.g., ARM; and special observing periods– e.g., YOTC)
  - Compare with benchmark models
- Isolate and evaluate sub-components of the climate system

Reliability/uncertainty in climate projections on centennial and longer time-scales is difficult

- Observational record not long enough to quantify skill based on hindcasts (only 1 hindcast available)
- Attempt to build confidence that models accurately represent the physics (and dynamics) of the climate system
  - Ability to simulate important climate phenomena
  - Ability to represent individual processes
  - Ability to forecast weather and climate (on decadal and shorter time-scales)
  - Ability to simulate paleoclimates
- But we don't know the relationship between skill in simulating things we can observe and projection skill.
- So, we also consider model spread as a guide to uncertainty

The CMIP3 multi-model ensemble produced a range of responses even when forced similarly

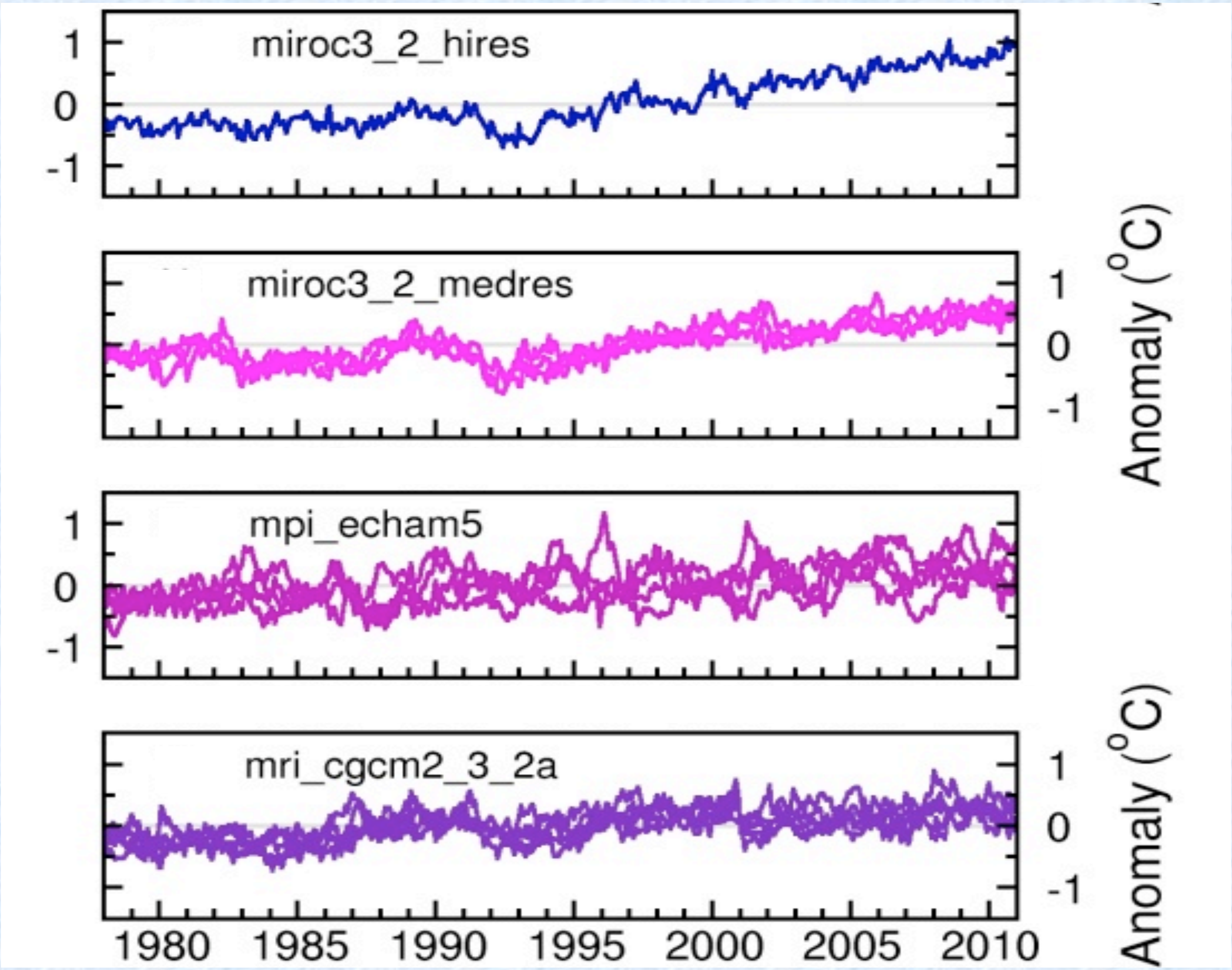


AR4 Summary for Policy Makers

Forced changes and unforced variability in global mean tropospheric temperature (TLT) in CMIP3 runs

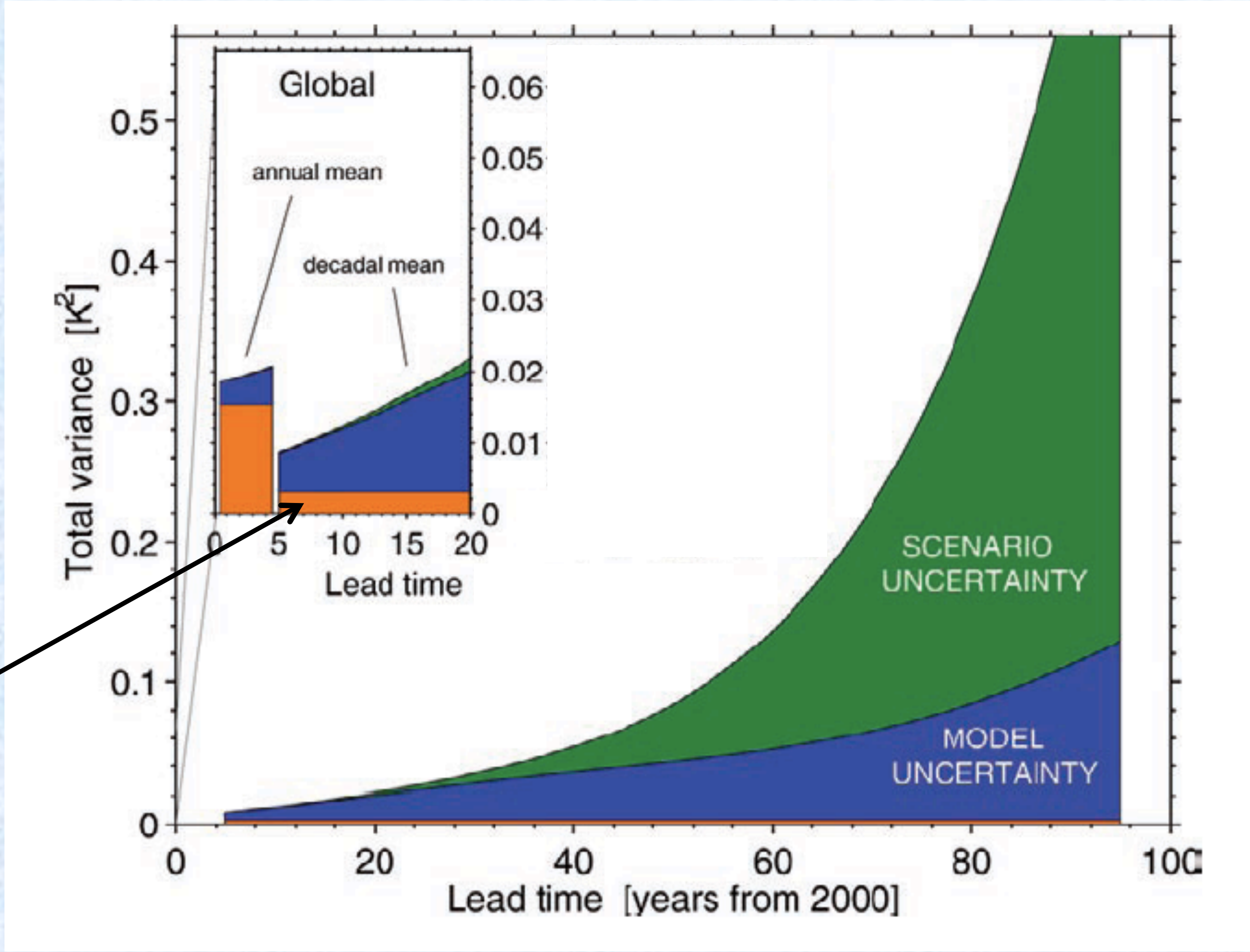
Single simulation

Ensembles of equally likely outcomes



Courtesy of B.Santer

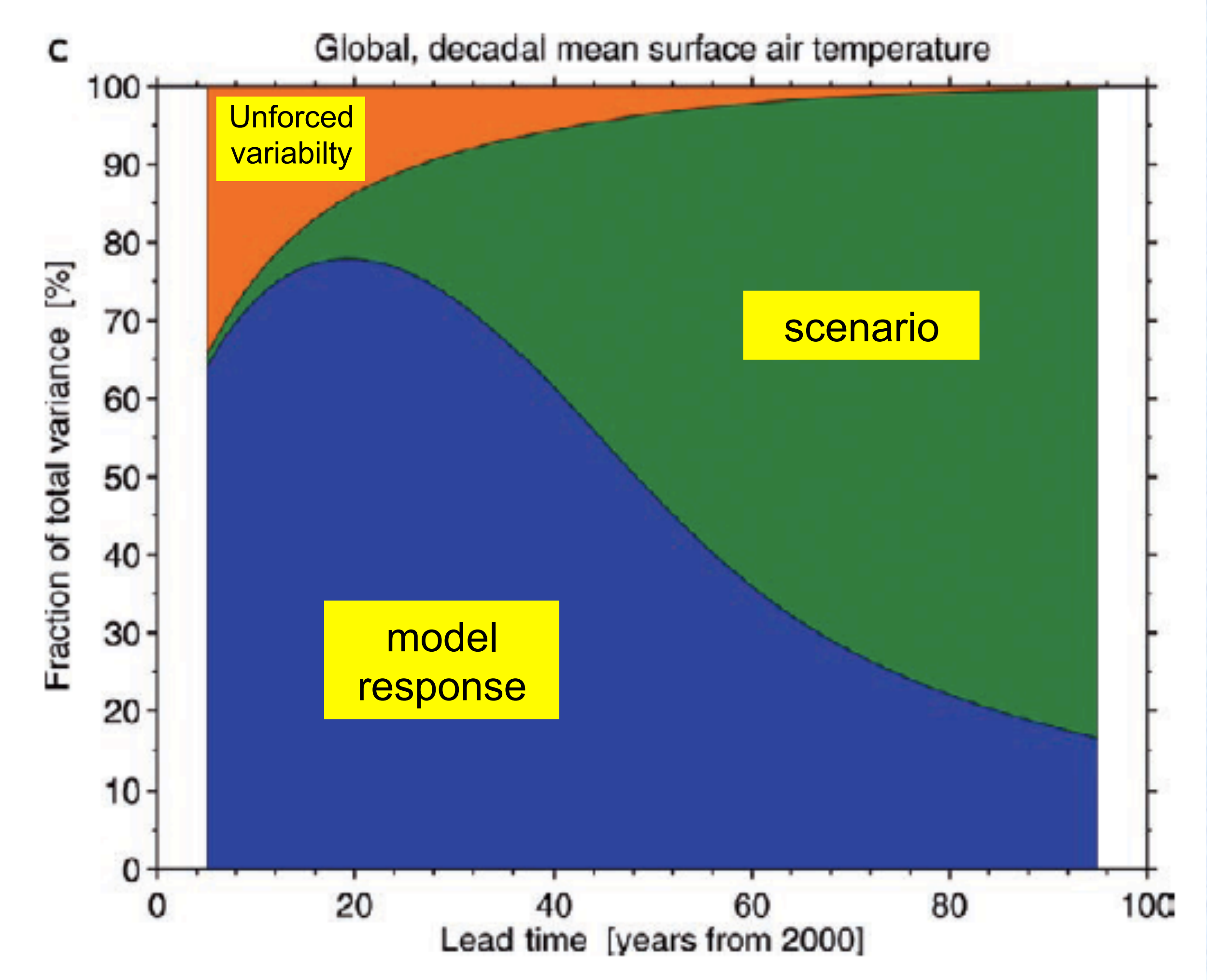
Total range of future climate change estimates depends on scenario, model, and unforced variability



Unforced variability is important only in the near-term.

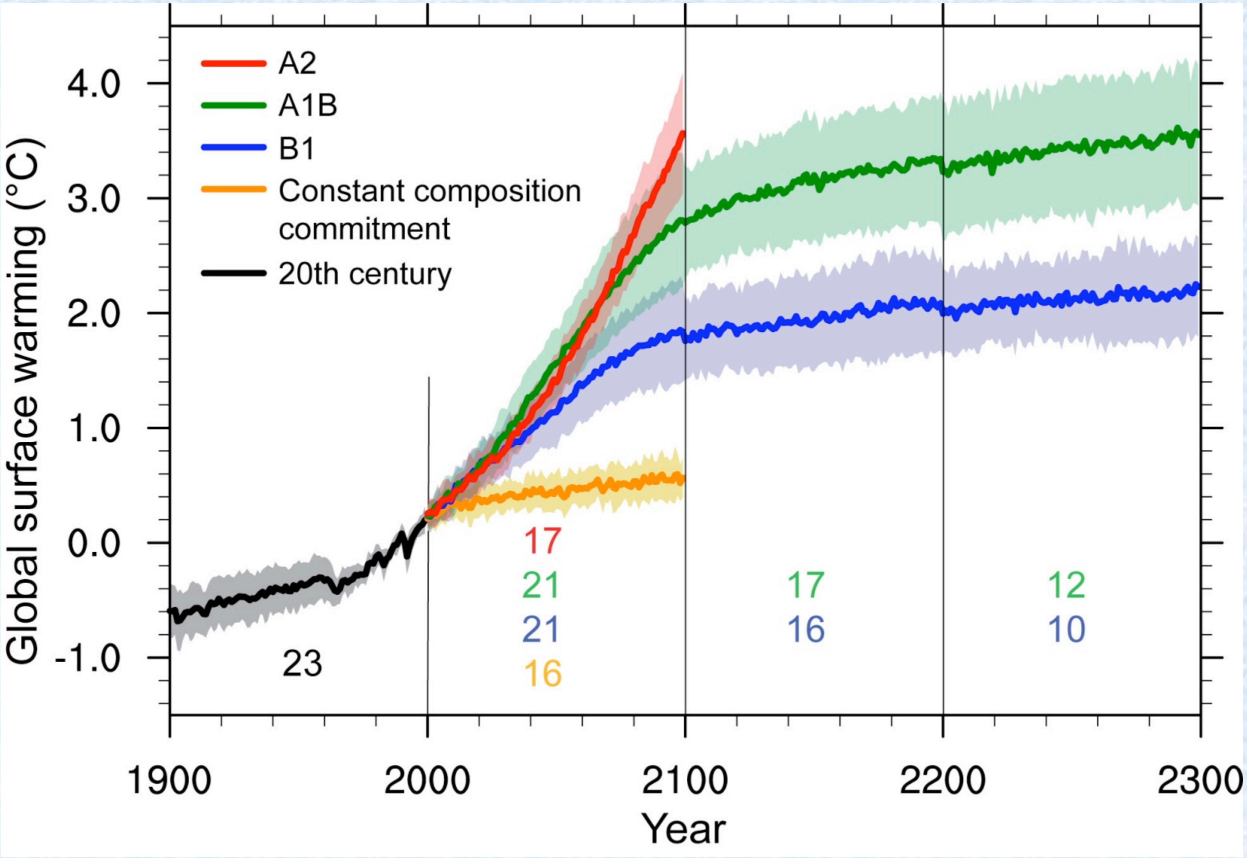
Hawkins & Sutton, *BAMS*, 2009

Projection ranges are initially dominated by model "uncertainty", but eventually are dominated by scenario



Hawkins & Sutton, *BAMS*, 2009

The CMIP3 multi-model ensemble produced a range of responses even when forced similarly



AR4 Summary for Policy Makers

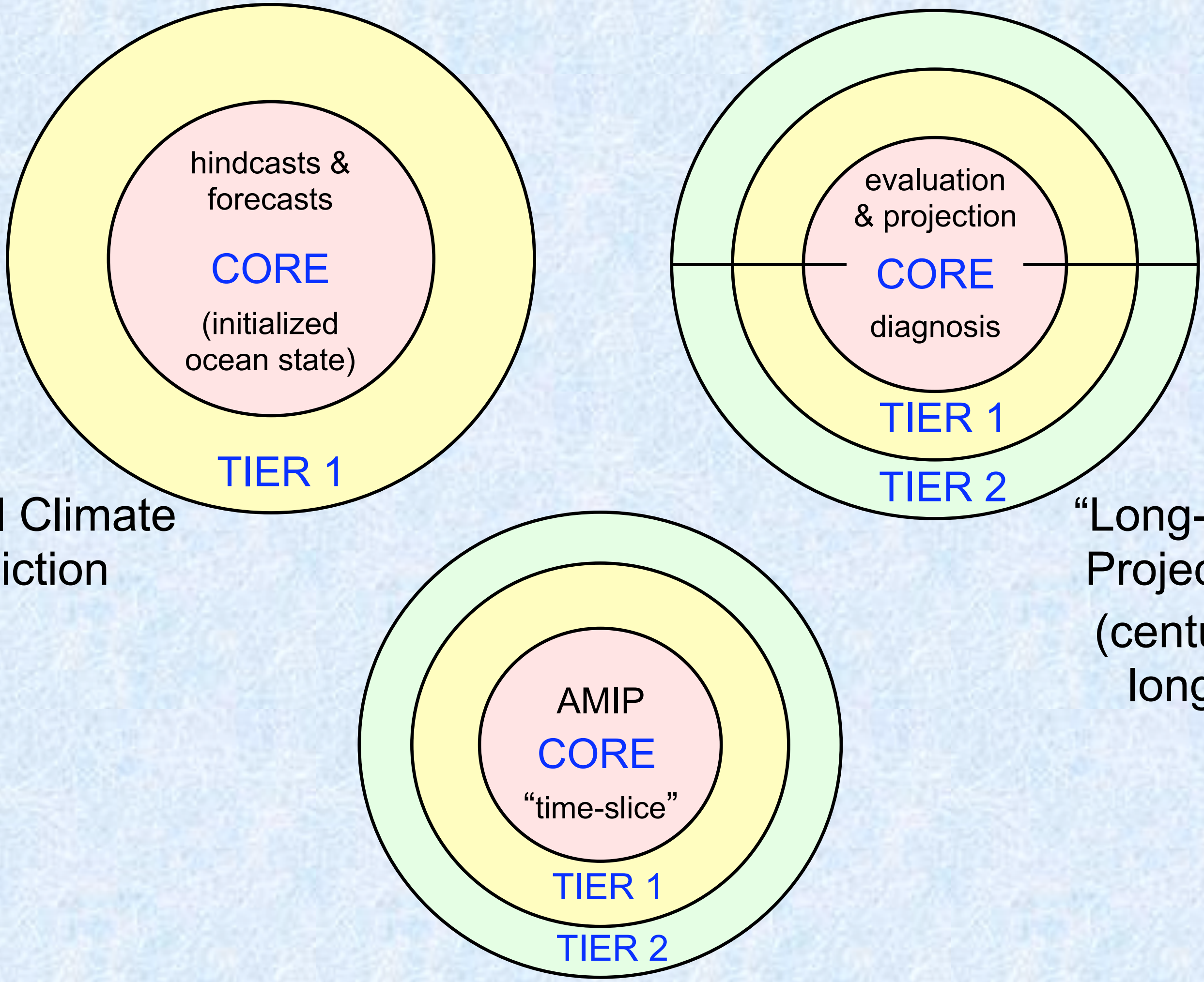
What is "model uncertainty"?

- The "spread" of model results for any given scenario is loosely referred to as "model uncertainty"

- It sometimes is assumed to be an estimate of the range of "possible outcomes" produced by some scenario, with the "truth" presumably contained within the range

- Remember, the spread can result from several factors:
  - Differences in "forcing" and "climate sensitivity"
  - Differences in the (equally likely) paths of unforced variability exhibited by simulations forced in the same way
  - In CMIP5 emission-forced simulations, differences in carbon cycles

CMIP5 is organized around three types of simulations



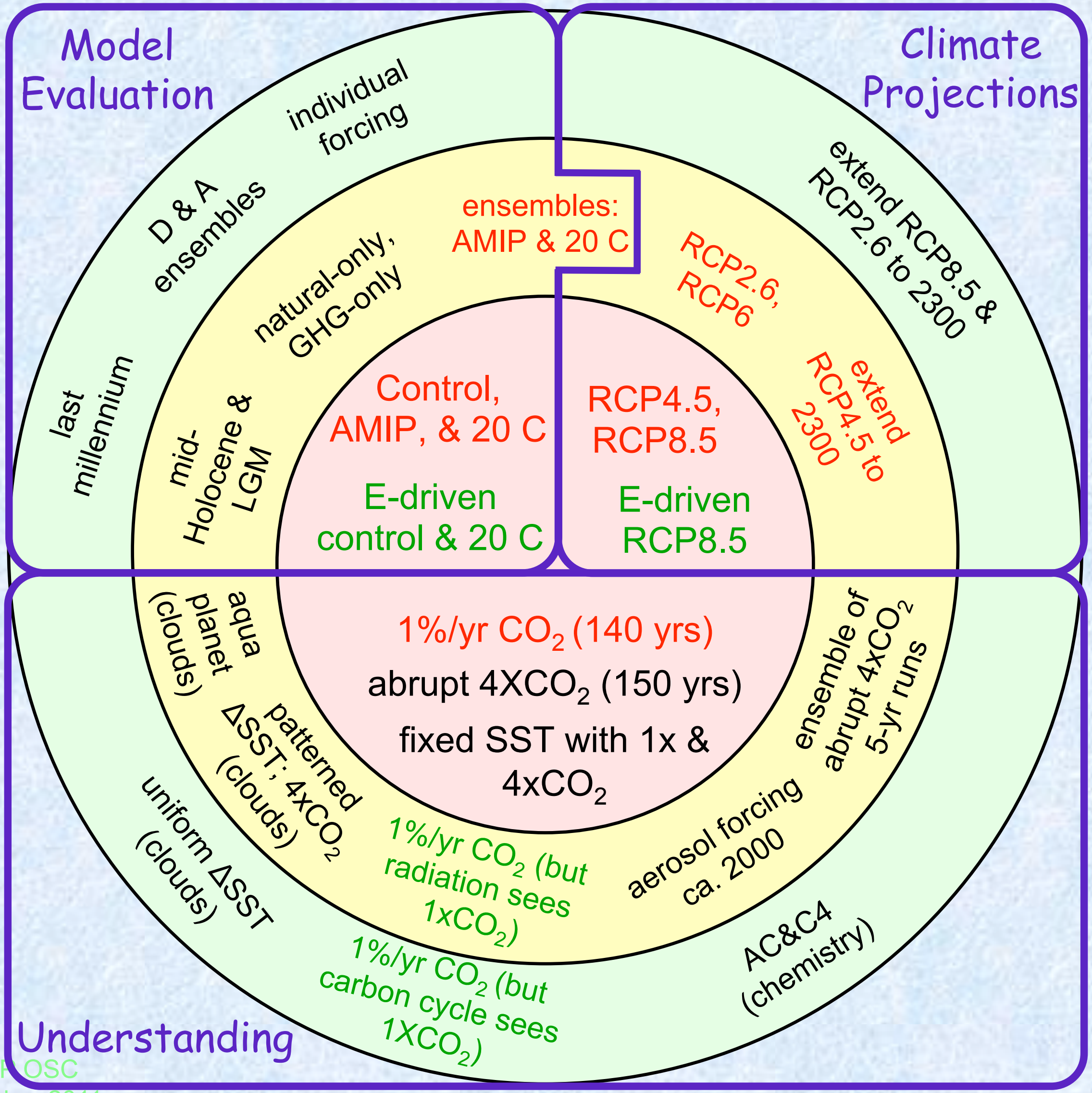
Decadal Climate Prediction

“Long-Term” Projections (century & longer)

Atmosphere-Only Simulations

(for computationally demanding and NWP models)

A rich set of CMIP5 experiments, drawn from several predecessor MIPs, focuses on model evaluation, projections, and understanding

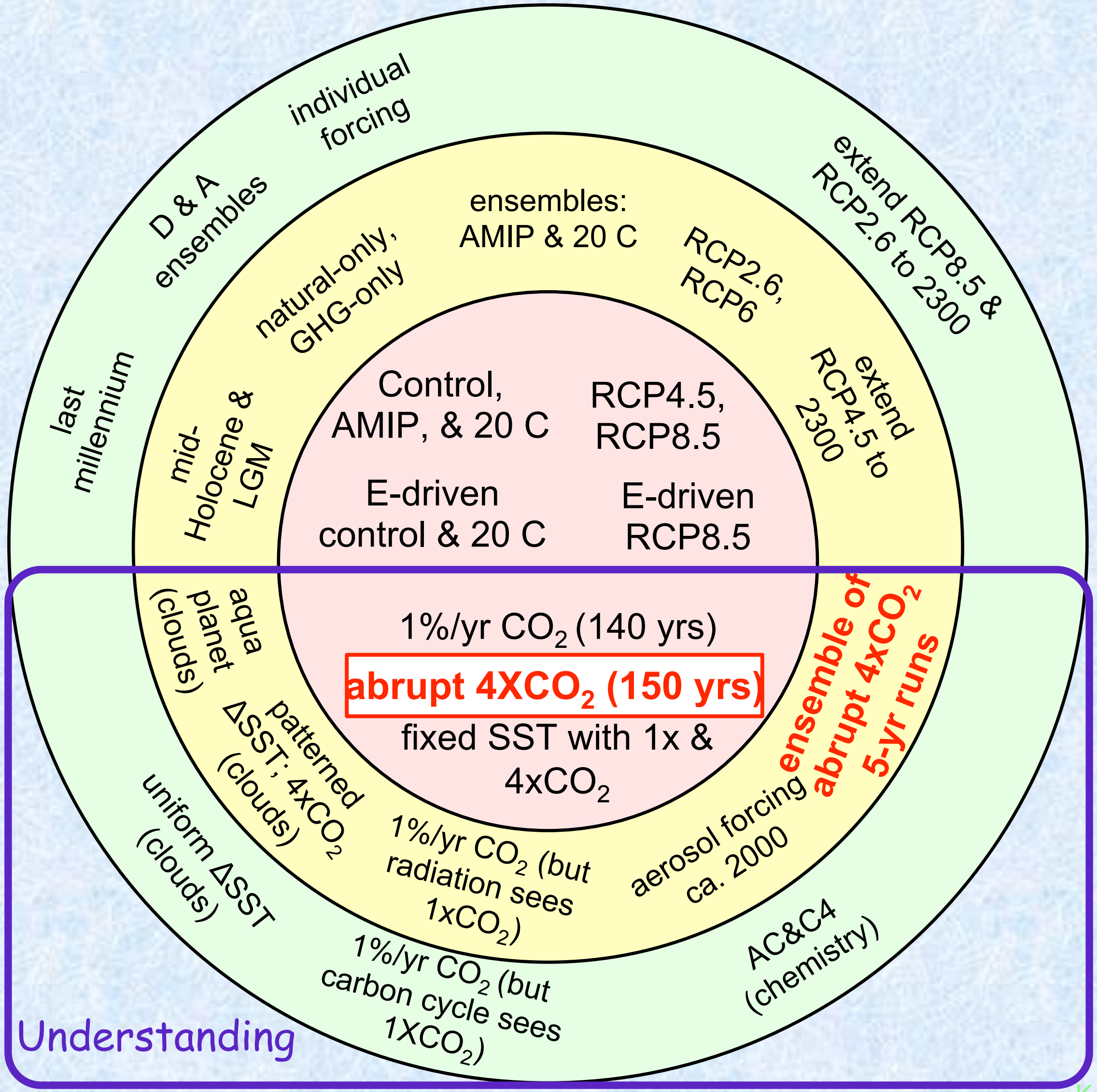


Red subset matches the entire CMIP3 experimental suite

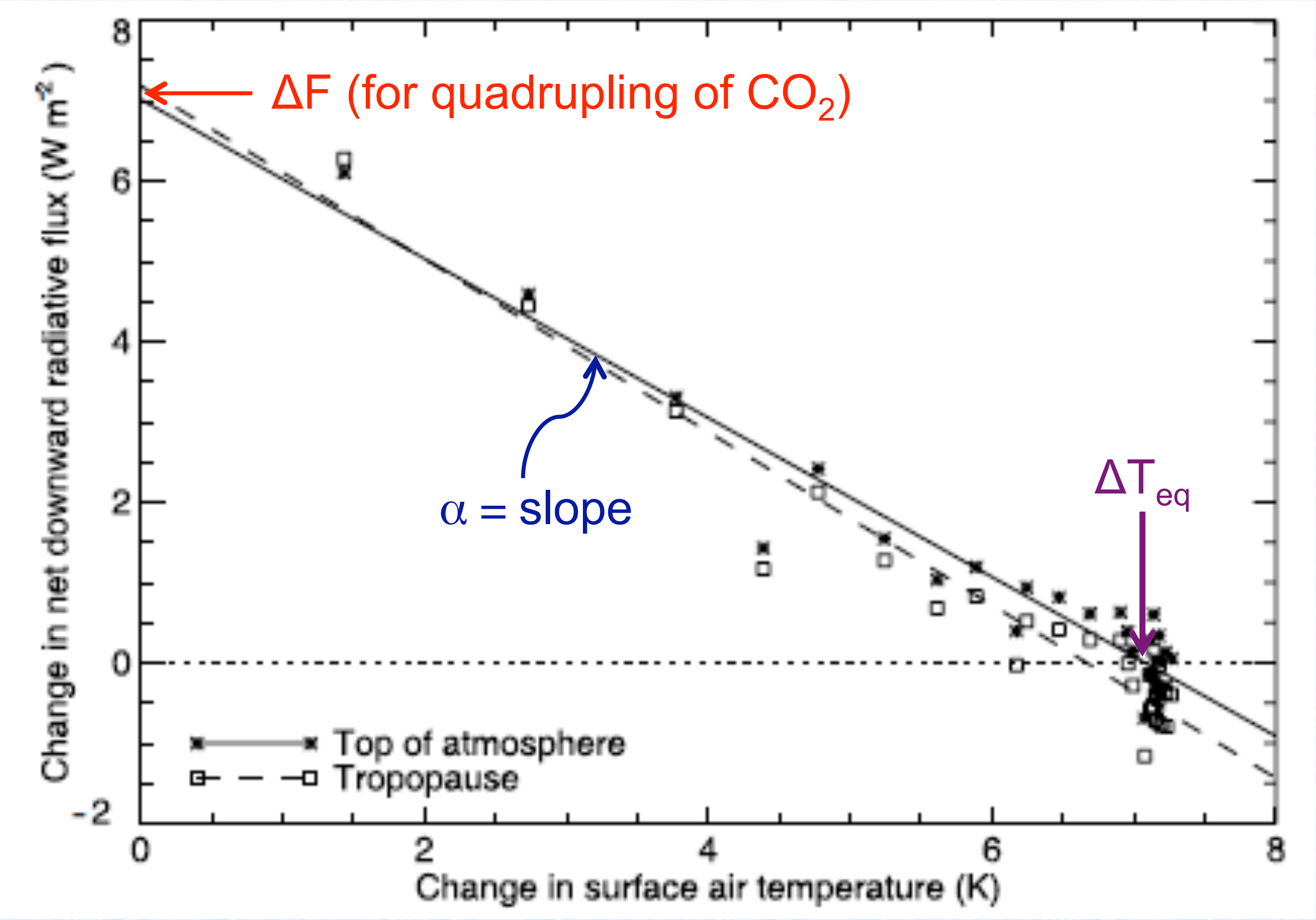
Green subset is for coupled carbon-cycle climate models only

Adapted from Taylor *et al.*, BAMS, 2011

Abrupt 4xCO2 simulation yields estimates of model differences in climate "sensitivity" and "forcing"

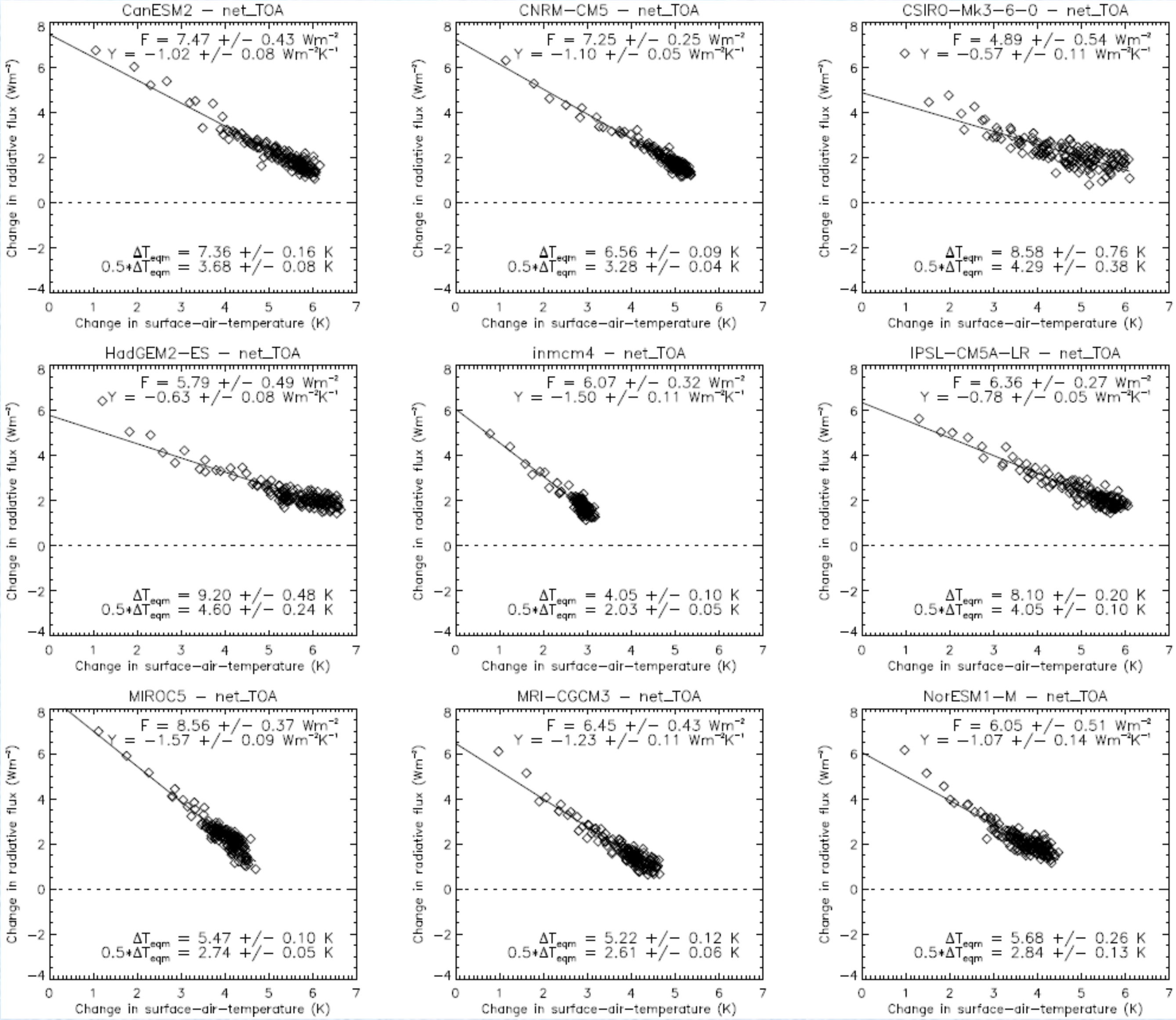


CMIP5 idealized experiments designed to quantify differences in model forcing and global climate sensitivity



Gregory *et al.*, 2004

Preliminary results from 9 CMIP5 models



Ranges

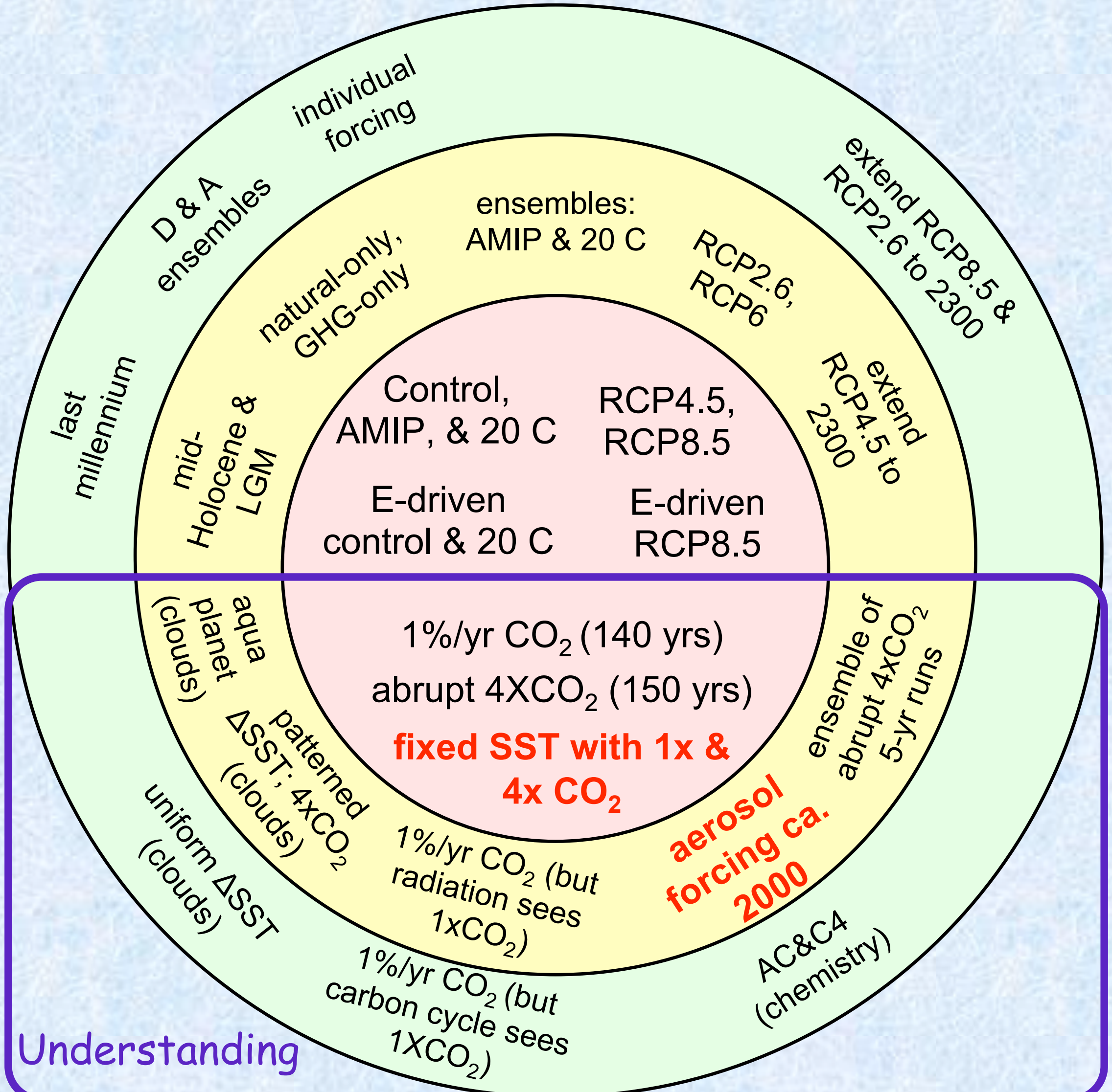
Climate fdbk (α) = 0.6 – 1.6 W m^{-2} / K

Forcing = 4.9 – 8.6 W m^{-2}

2xCO_2 equilibrium climate sensitivity = 2.0 – 4.6 K

Courtesy of T. Andrews

CO2 forcing and aerosol forcing can be quantified using an alternative method.



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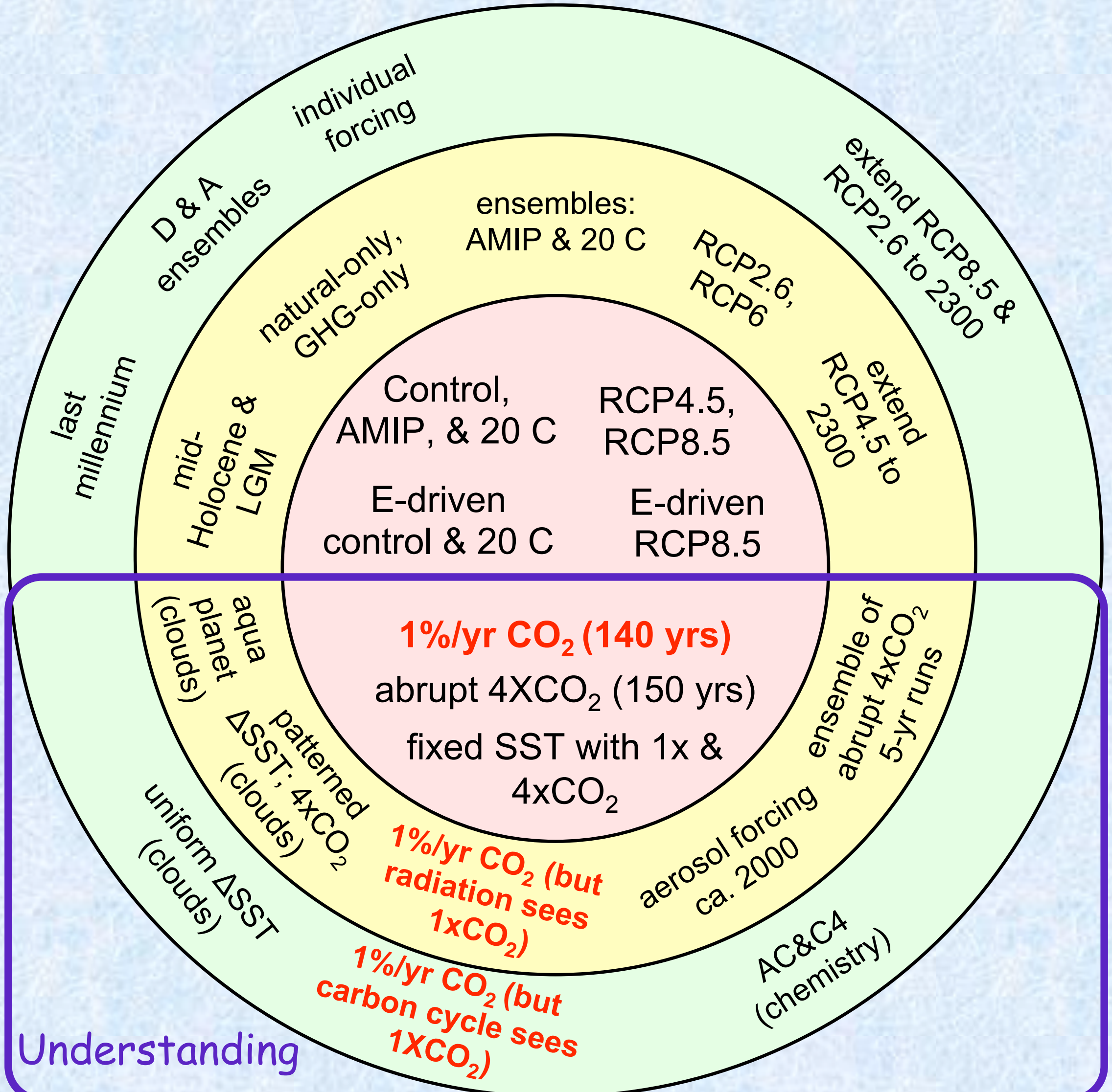
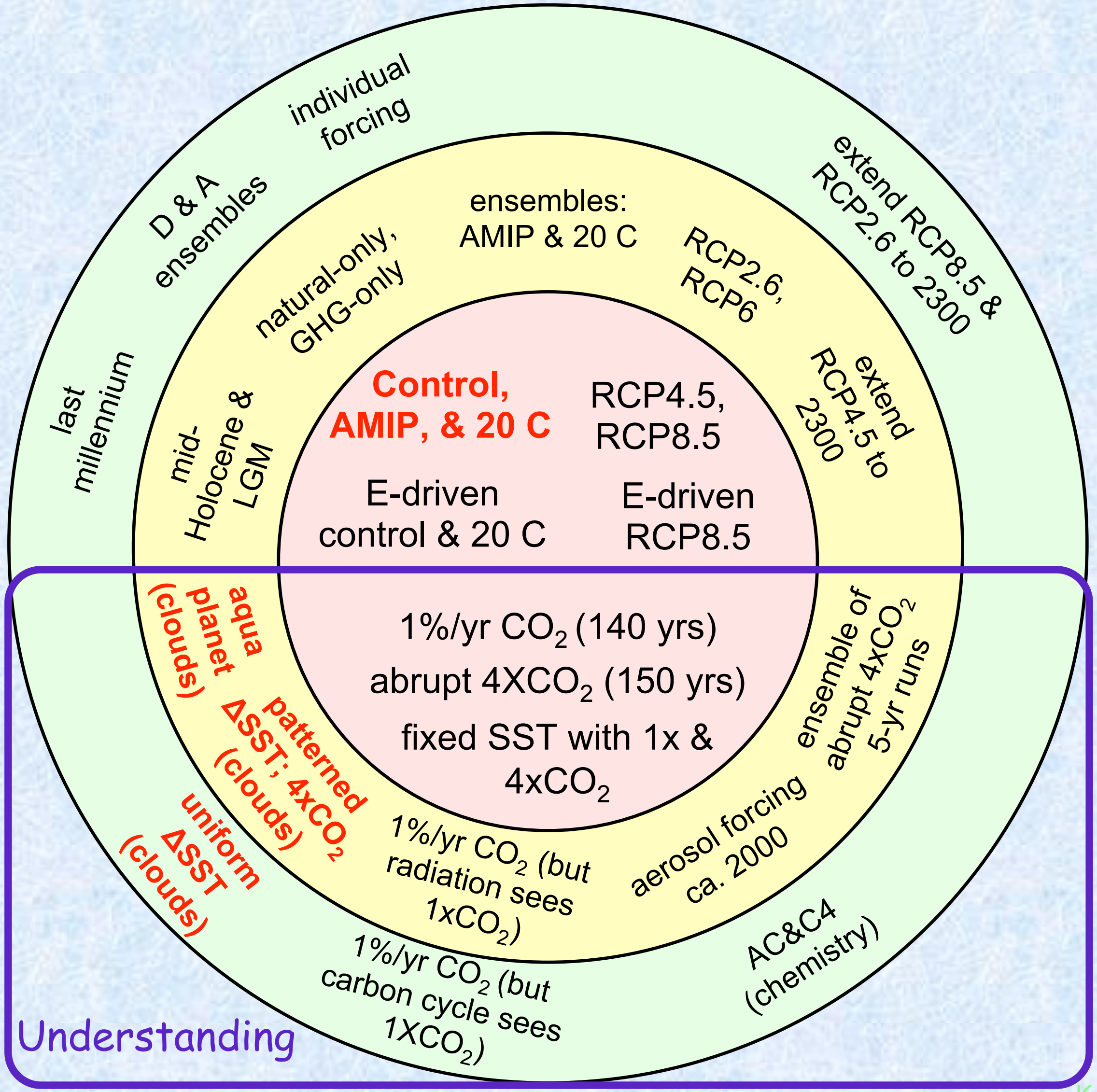
Carbon cycle feedbacks can be diagnosed



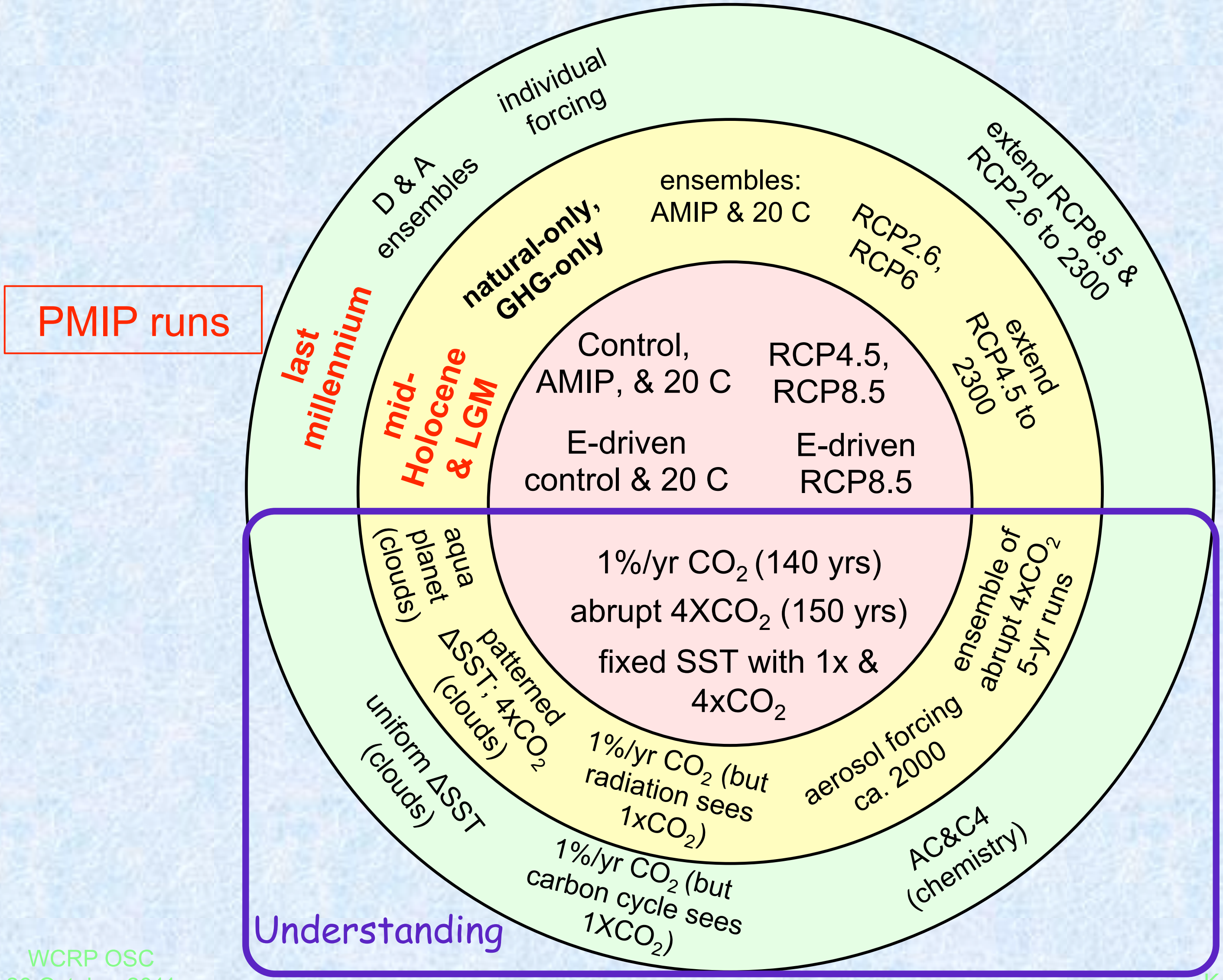
PCMDI

Representation of clouds and cloud processes can be studied under realistic and idealized conditions with help of "satellite simulator" output (CFMIP)

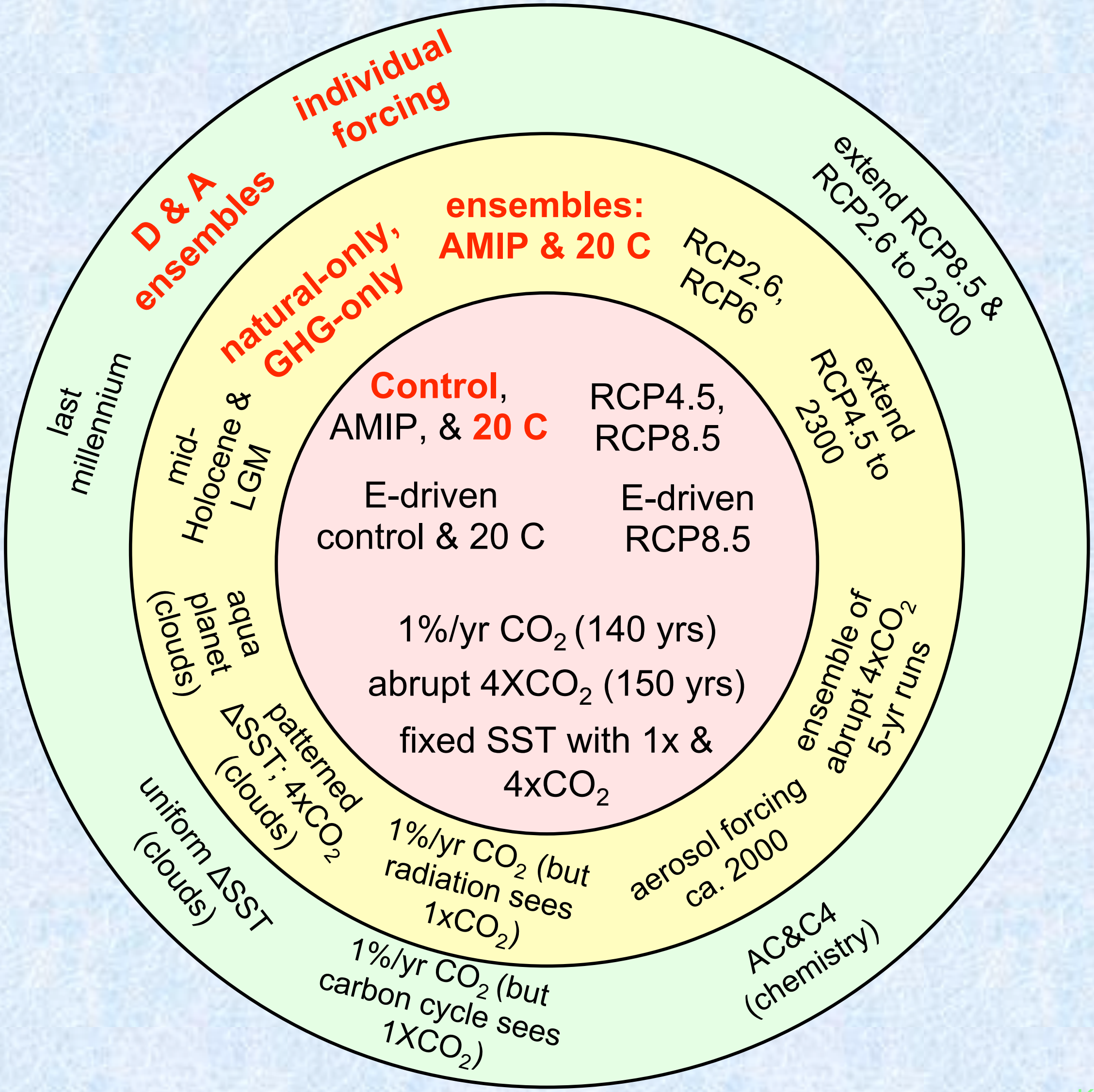


PCMDI

Ability to simulate climates of the past that are substantially different from today can be assessed



Ability to simulate trends can be evaluated with "detection and attribution" focused simulations



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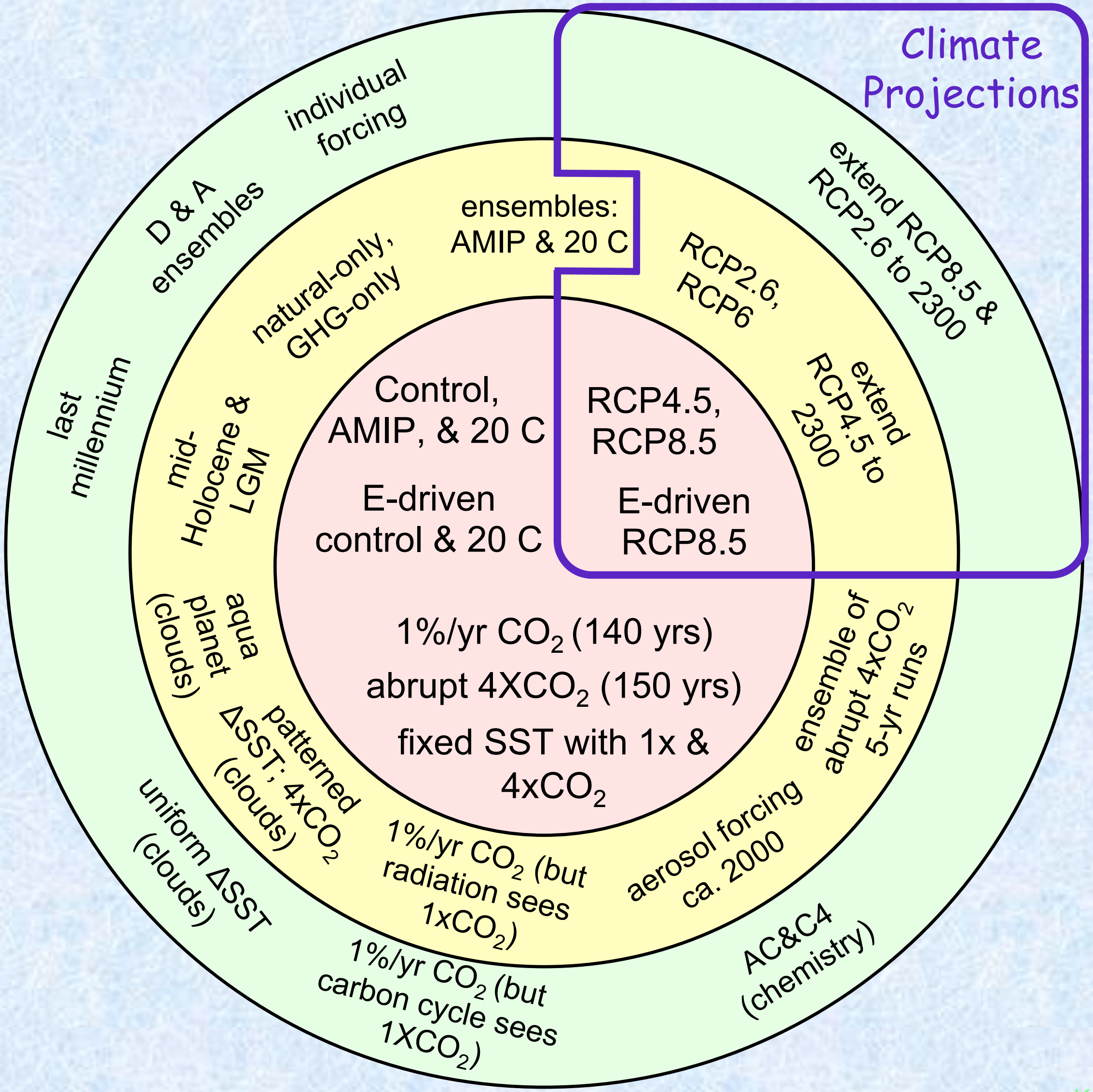
Climate projections



“Long-term” experiments: contributions

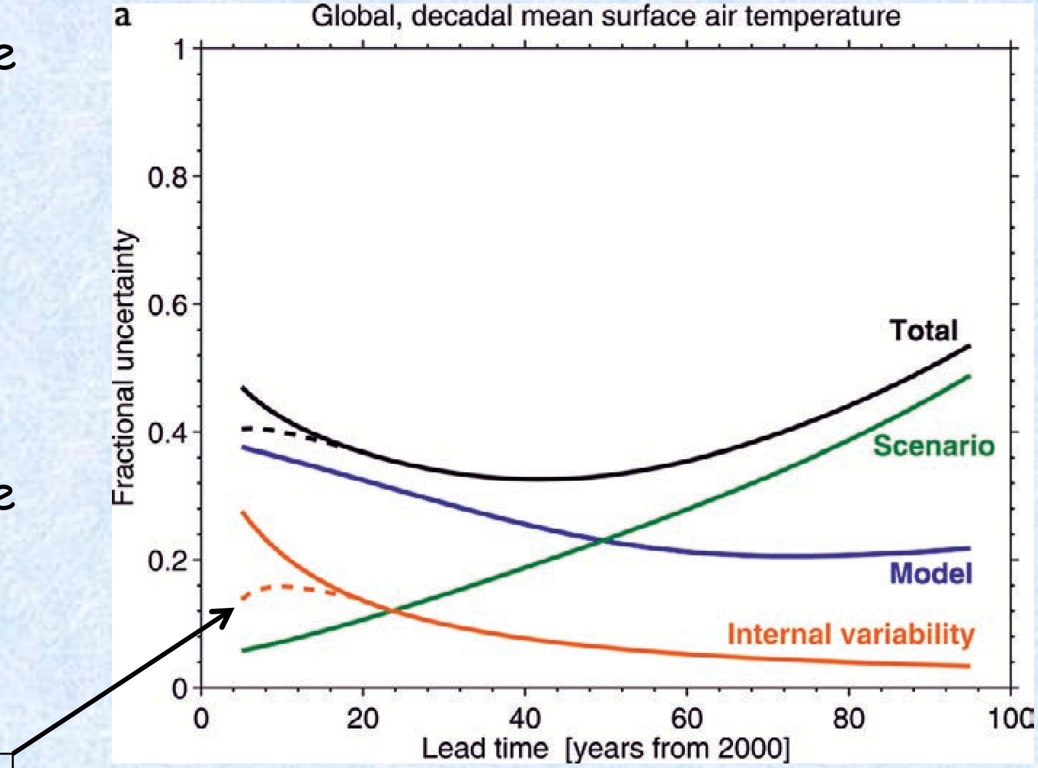
* Core simulations (# available as of 17 Oct 2011)

Experiment(s)	# of models
* Control & historical	35 (14)
* AMIP	26 (9)
* RCP4.5 & 8.5	29 (15)
RCP2.6	18 (12)
RCP6	13 (10)
RCP’s to year 2300	10 (?)
* 1% CO2 increase	28 (11)
* Fixed SST CO2 forcing diagnosis	16 (8)
* Abrupt 4XCO2 diagnostic	22 (11)

Experiment(s)	# of models
Fast adjustment diagnostic	9 (?)
Aerosol forcing	9 (5)
*ESM control, historical & RCP8.5	18 (4)
Carbon cycle feedback isolation	9 (3)
Mid-Holocene & LGM	11 (4)
Millenium	7 (0)
CFMIP runs	~8 (~4)
D & A runs	15 (8)

CMIP5 will also include models initialized with the observed climate state (particularly, the upper ocean)

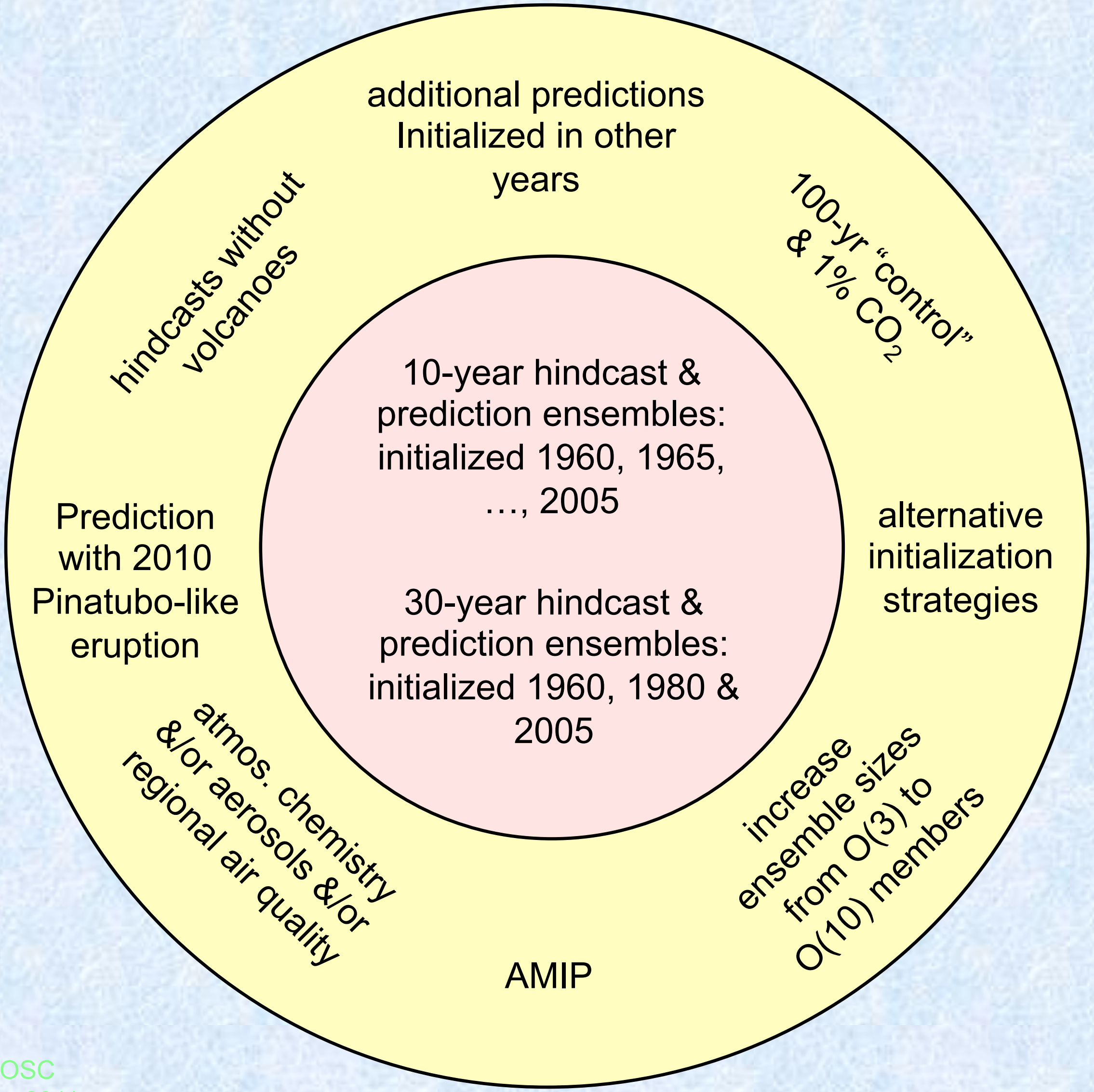
- The hope is that through initialization the models will be able to predict the actual trajectory of “unforced” climate variations.
- The hypothesis is that some longer time-scale natural variability is predictable if the initial state of the system is known



The deviation from observations caused by unforced variability can potentially be reduced through initialization.

Hawkins & Sutton, 2009

The new "near-term" experiments attempt "predictions" of the climate state, including "unforced" variations, by initializing models with observations.



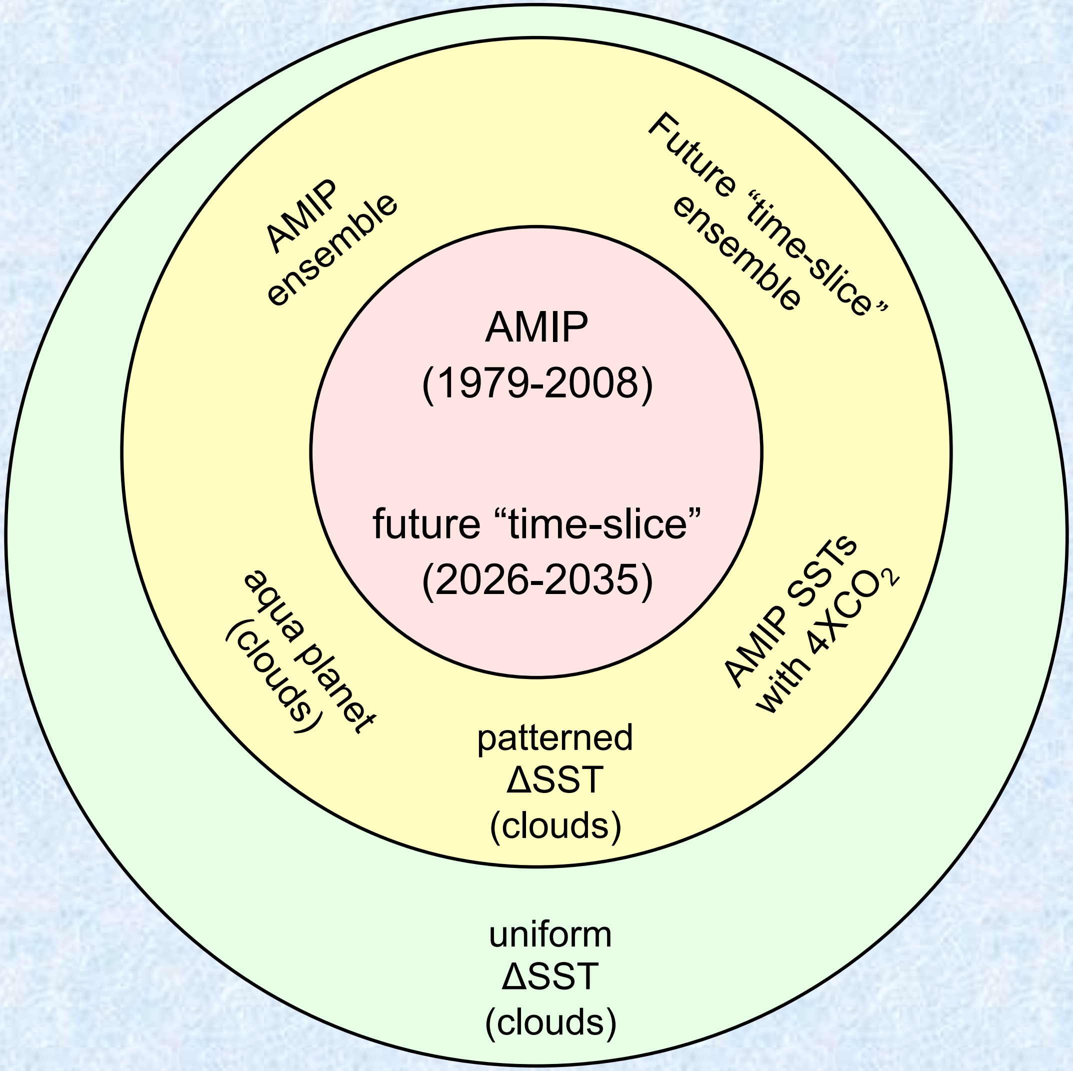
Adapted from Taylor *et al.*, BAMS, 2011

“Decadal” experiments: contributions

* Core simulations simulations (# available as of 17 Oct 2011)

Experiment(s)	Number of models
*Hindcasts and predictions	18 (6)
AMIP	3 (3)
Volcano-free hindcasts	3 (0)
2010 “Pinatubo-like” eruption	1 (0)
Initialization alternatives	5 (?)
Pre-industrial control	10 (4)
1% CO2 increase	9 (3)

CMIP5 Atmosphere-Only Experiments
(targeted for computationally demanding and NWP models)



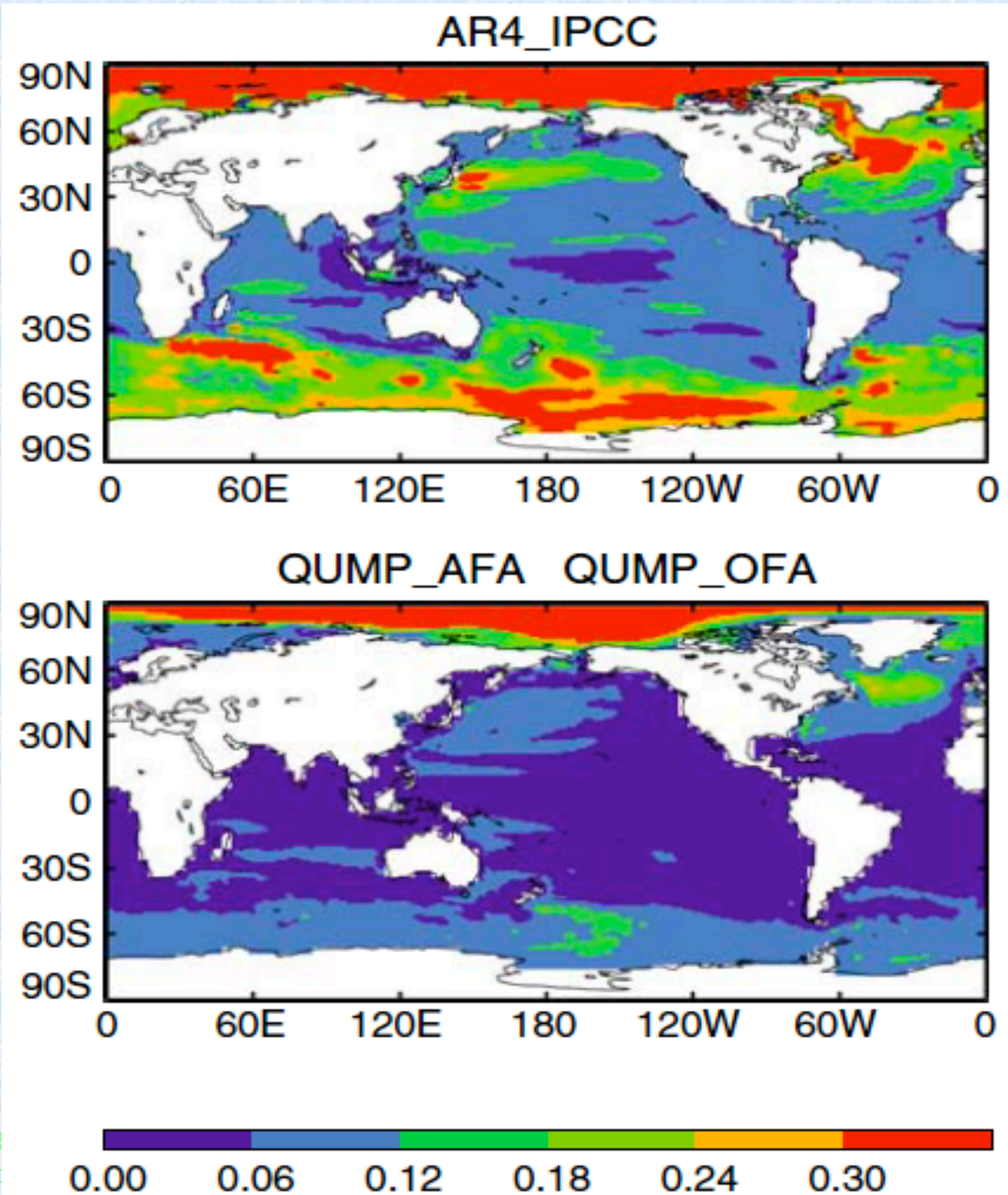
~14 models plan to do core runs

(10 of these will also do long-term and/or decadal simulations)

Is "uncertainty" based on spread of model results misleading?

- It doesn't include possibility of a common bias across models
  - If the bias is not zero, the truth may lay outside model results
- It assumes that existing models constitute a "representative sample" of all possible models that are equally consistent with physical laws and observations.
  - If some of the models are inconsistent with observations, then eliminating/ down-weighting those models should improve uncertainty estimation
  - If "social pressures" decrease the spread of model results, "model uncertainty" will be unjustifiably perceived as being reduced
- The common (but not rigorously grounded) aspects of model formulation may (misleadingly) limit the spread

Structural uncertainty may be underestimated in perturbed physics ensembles (perhaps also in multi-model ensembles)



← CMIP3 ensemble

Sea level rise pattern (with global mean removed)

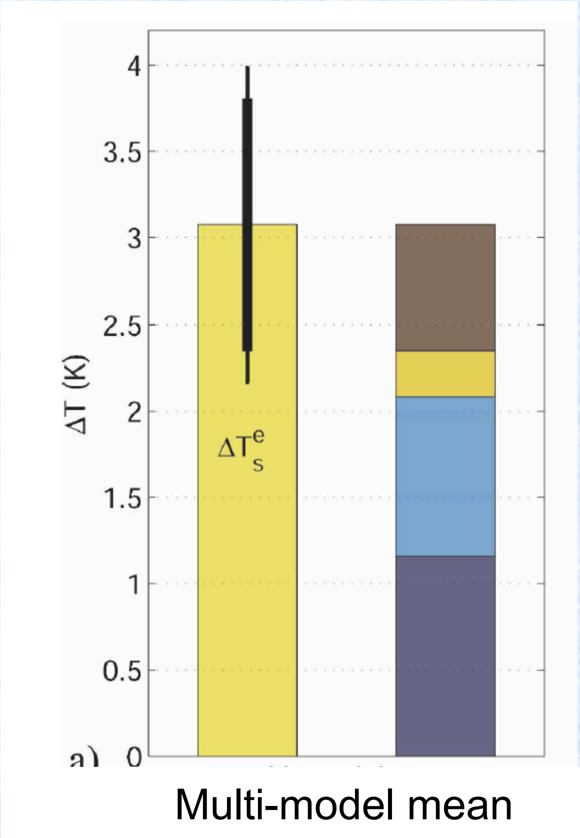
← Perturbed physics ensemble

Pardaens, Gregory, and Rowe, *Clim. Dyn.*, 2010

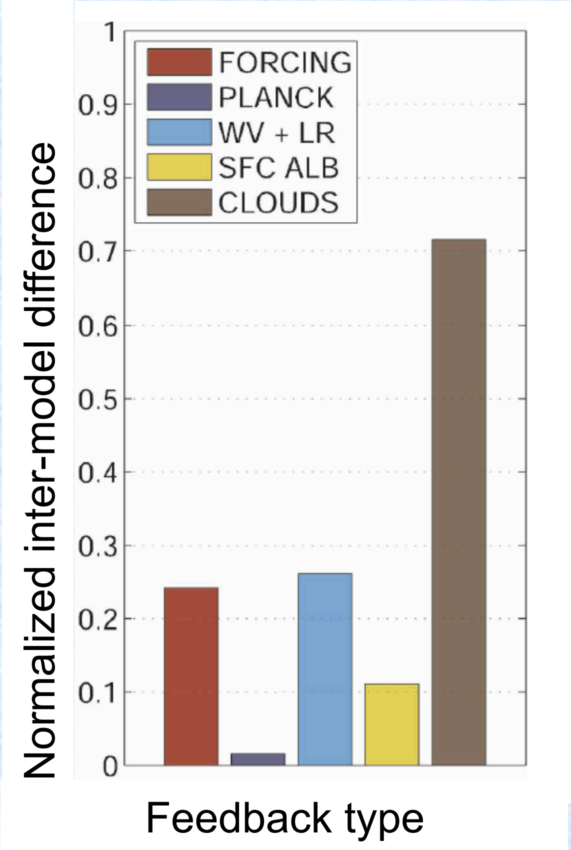
If the multi-model ensemble can't provide rigorous estimates of the total uncertainty, what *can* it do?

Rough explanations for differences in model responses can sometimes be identified and used to set research priorities

Response



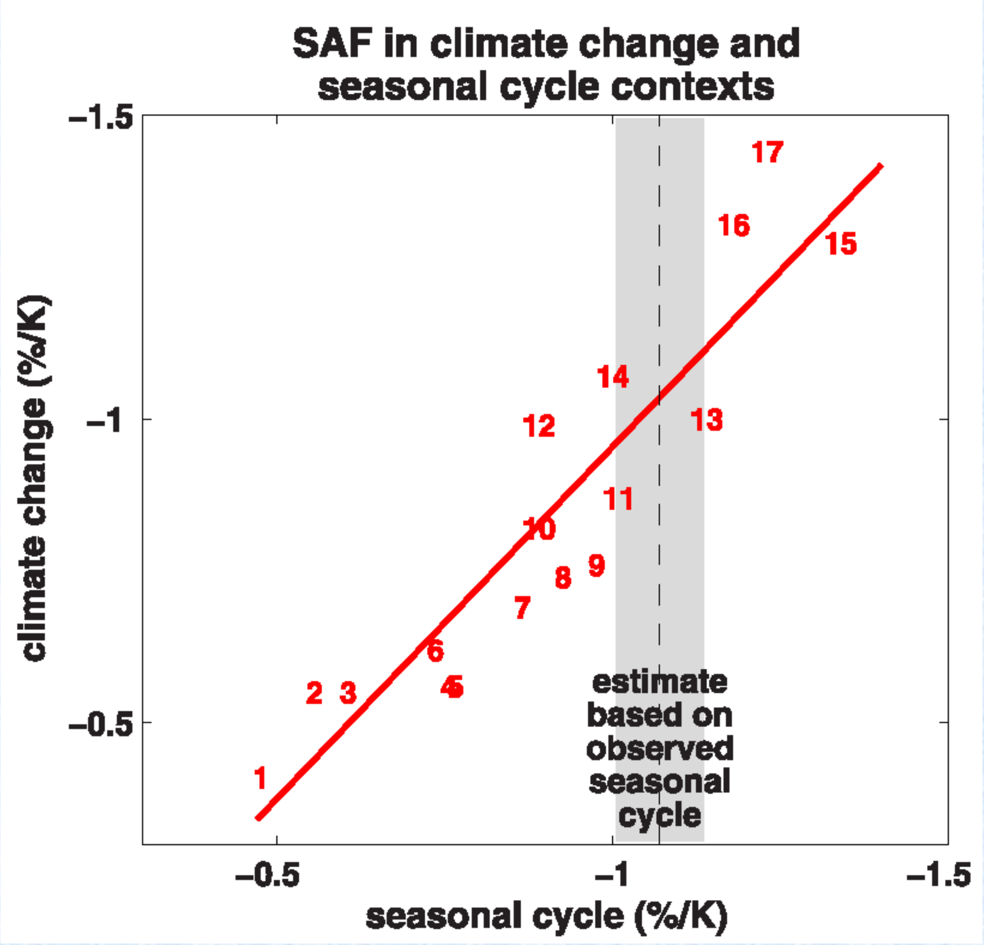
Model Agreement



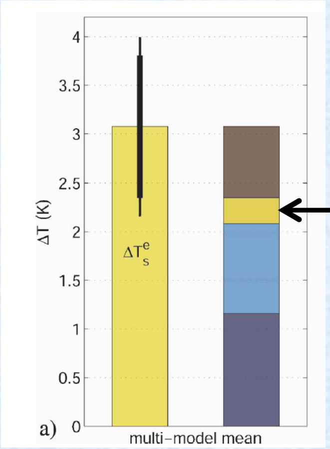
Cloud feedbacks are responsible for largest fraction of model response differences

Dufresne and Bony, J. Climate, 2008

Relationships between observables and projected climate responses can sometimes be discovered



Response of snow cover to global warming in models is related to their snow response to spring warming



But recall that surface albedo feedback is relatively weak

Hall and Xu, GRL, 2006

CMIP5 provides a number of opportunities to evaluate models

Most relevant
Experiments

- Forced responses
  - Seasonal cycle
  - Diurnal cycle
  - Volcanic eruptions
  - Historical warming

historical & AMIP

single-forcing
"detection & attribution"

  - Paleoclimates

LGM, mid-Holocene, last millenium

- Unforced variability

Control & AMIP

  - ENSO
  - Madden-Julien Oscillation
  - NAO

CMIP5 provides perspectives on uncertainty in projections

- The spread indicates that there ***is*** uncertainty in model projections
- Reduced spread may give us more confidence in a result, ***but***
- The spread of model results cannot provide a rigorous estimate of uncertainty

CMIP5 timeline reminder:

- Late 2013: IPCC AR5 published
- Journal articles accepted – 15 March 2013
- Journal articles submitted – 31 July 2012
- April 2012: Data not already in the CMIP5 archive will probably not be included in publications cited by the AR5
- March 2011: First model output became available to users

Advertisements

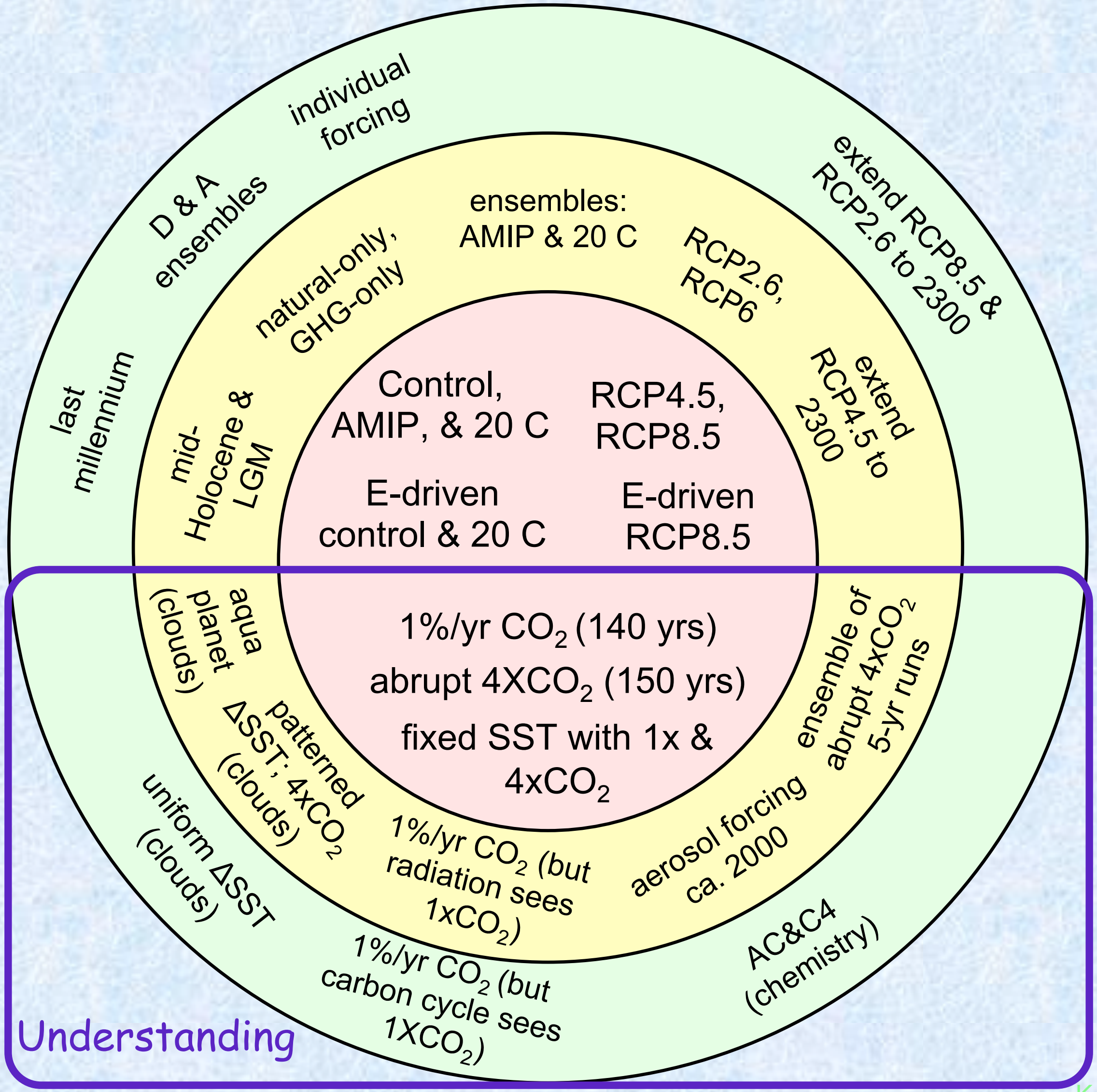
- WCRP's WGCM has planned a CMIP5 science conference:
  - IPRC, University of Hawaii, Honolulu
  - March 5-9, 2012
  - Watch WGCM website:

    http:www.clivar.org/organization/wgcm/wgcm.php

- CMIP website: http://cmip-pcmdi.llnl.gov

  (or search on "CMIP5")

Abrupt 4xCO2 simulation yields estimates of model differences in climate "sensitivity" and "forcing"

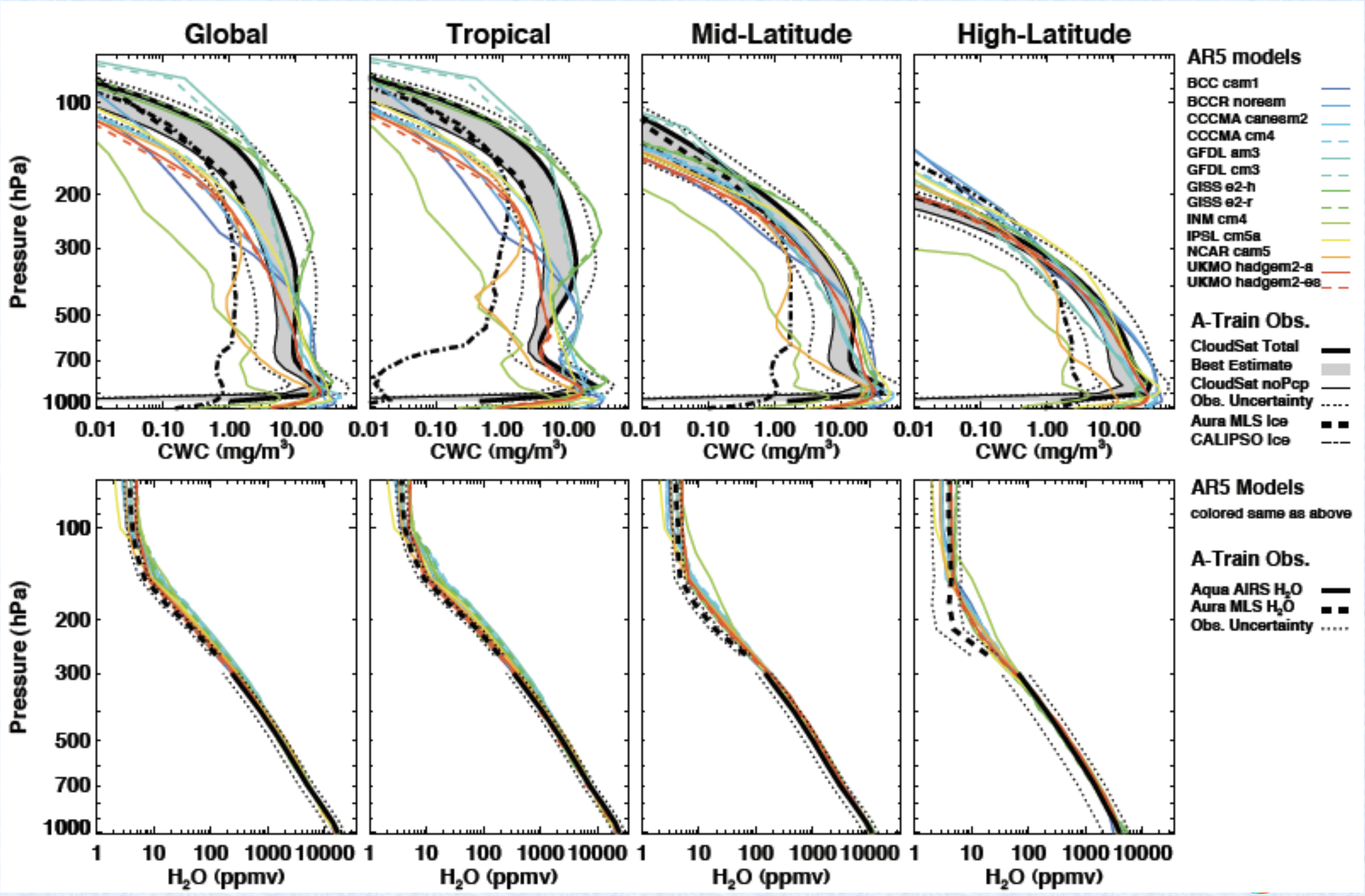


PCMDI

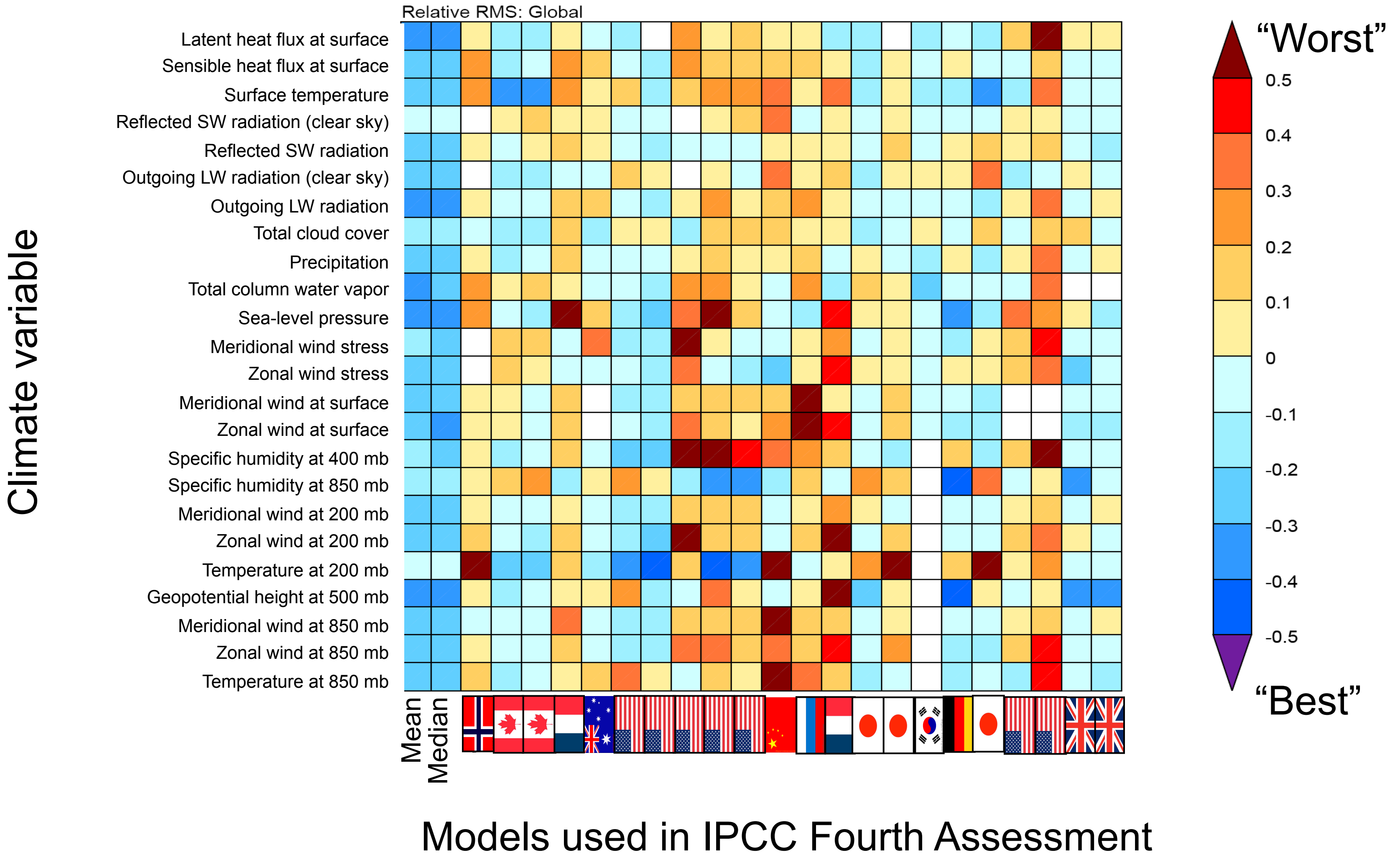
Coordinated with CMIP5 is a parallel effort to collect and make available observations

- Promoted by Duane Waliser and others at JPL with cooperation from PCMDI and encouragement by the WGCM
- Short name: Obs4MIPs
- Data written in same structure and format as CMIP5 model output
- Not only satellite data but also ARM data and reanalysis

"Obs4MIPs" is providing datasets useful in evaluating CMIP5 models (preliminary results courtesy of Jonathan Jiang)

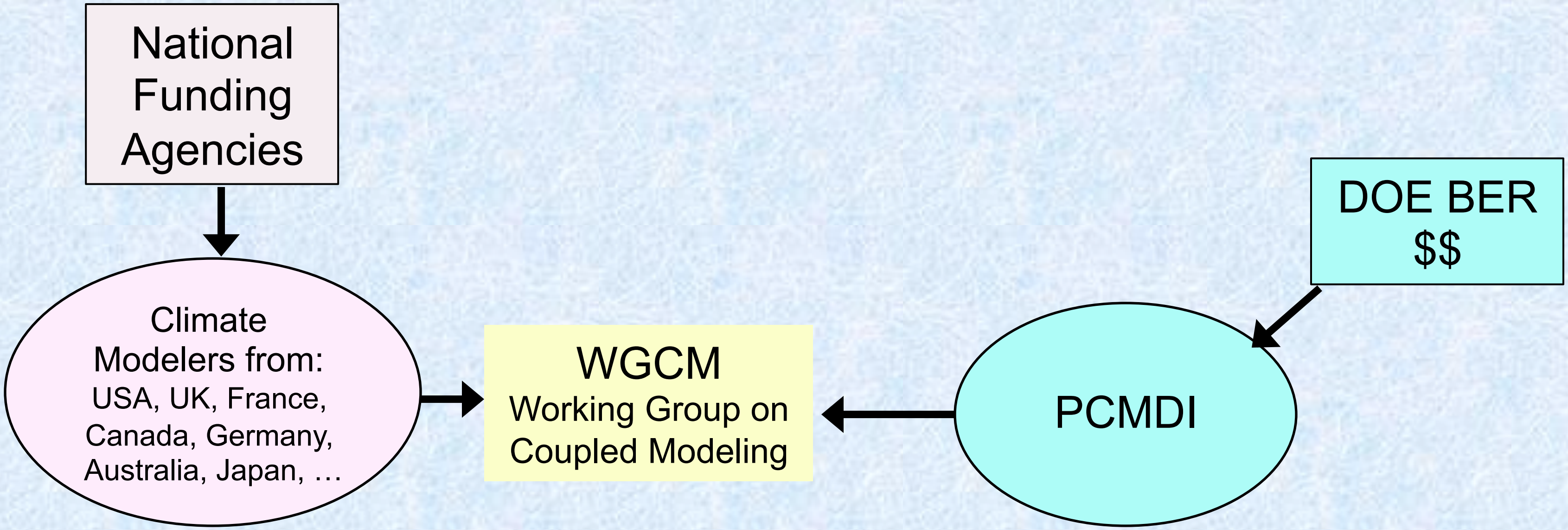


The "mean" model simulates climatology better than individual models, and some believe the consensus projection is also superior

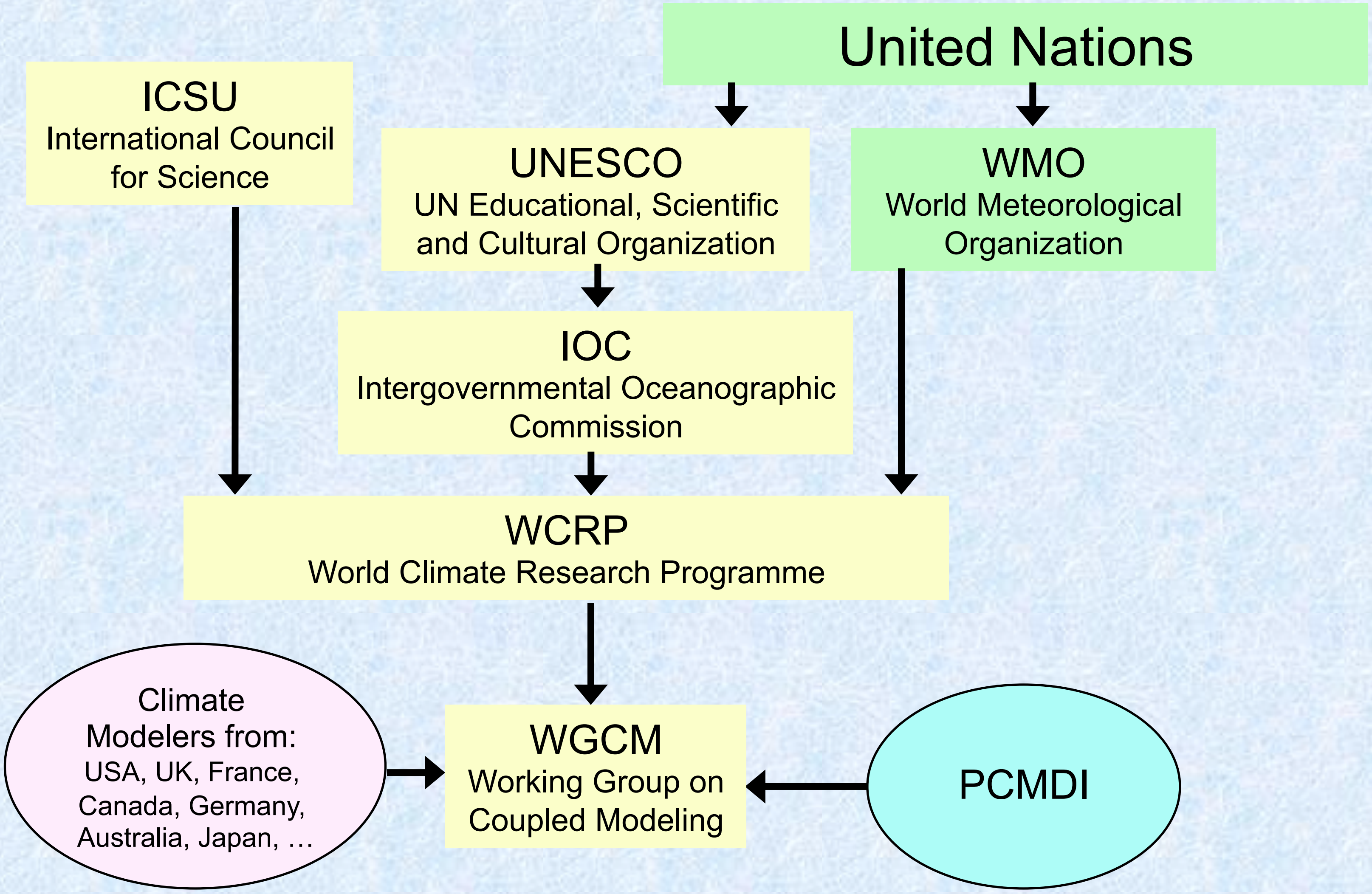


Gleckler, Taylor and Doutriaux, *J.Geophys.Res.* (2008)

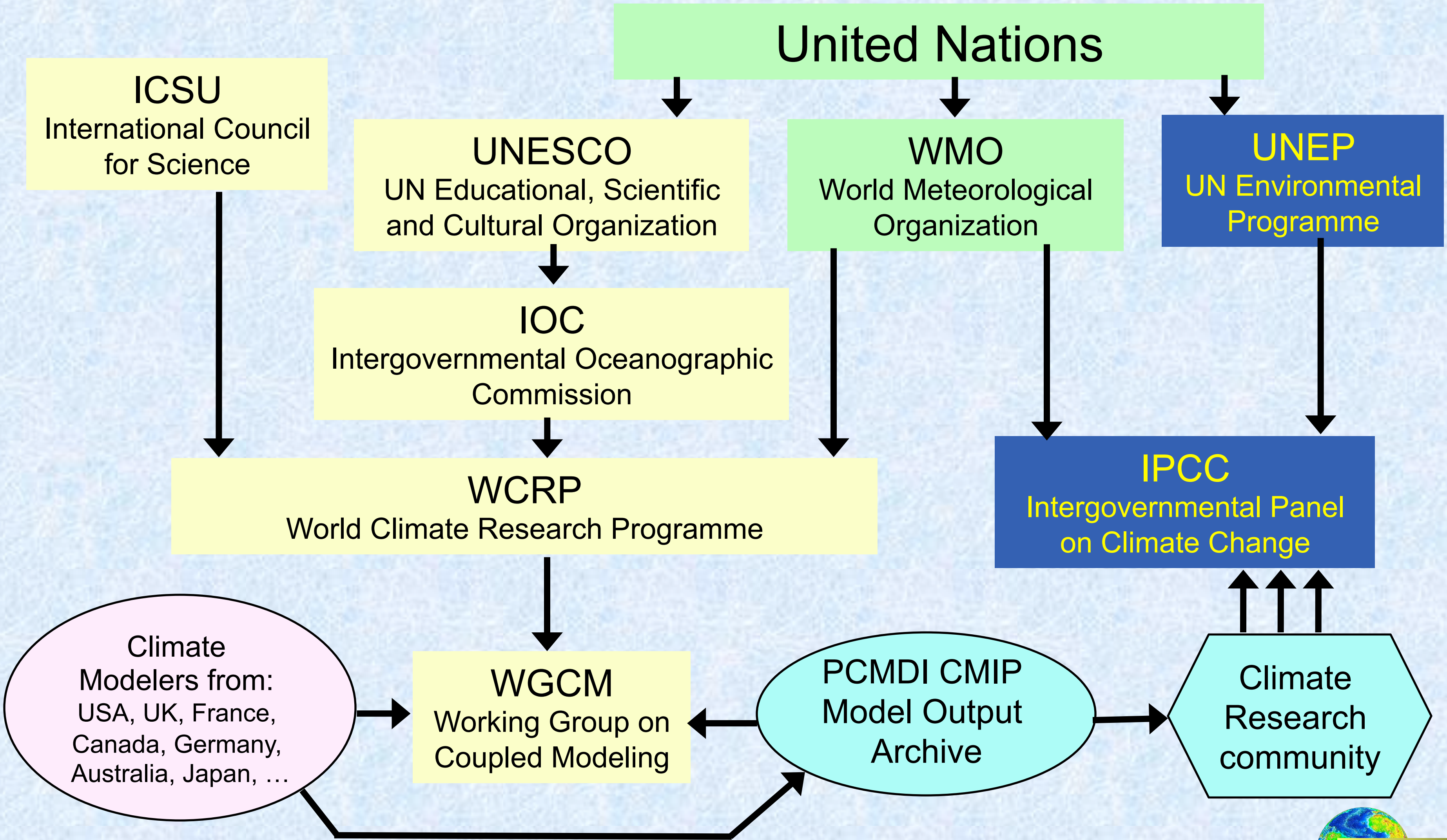
CMIP: A grass-roots collaborative effort



CMIP: Under the umbrella of an internationally-coordinated research program



IPCC assessments are separate from the international climate research programs



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