WCRP 4
World Climate Research Programme #WCRP40

WORLD METEOROLOGICAL ORGANIZATION | UNESCO United Nations Educational, Scientific and Cultural Organization | Intergovernmental Oceanographic Commission | International Science Council

AGU100 ADVANCING EARTH AND SPACE SCIENCE

WCRP CLIMATE SCIENCE WEEK

AGU FALL MEETING, 7–13 DECEMBER 2019

The Coupled Model Intercomparison Project (CMIP) and interface with IPCC

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National Center for Atmospheric Research

Audience participation at: **www.sli.do**

#WCRP40

NSF | NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH | U.S. DEPARTMENT OF ENERGY Office of Science Biological and Environmental Research Regional and Global Climate Modeling Program

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The origins of CMIP can be traced to the formation of a World Climate Research Programme (WCRP) committee in 1990:

The Steering Group on Global Coupled Models (SGGCM)

First meeting in Geneva, November 1990

Larry Gates (chair), John Mitchell, Ron Stouffer, Ulrich Cubasch, Gerald Meehl

Other attendees: David Webb, Pierre Morel, Gordon McBean, Mike Manton, Dave Burridge

Larry Gates' charge to SGGCM: formulate a strategy for developing the **newly emergent global coupled climate models** (components of atmosphere, ocean, land and sea ice) being used for the first time for century timescale climate change simulations; organize coordinated experiments, and formulate standards (nothing about IPCC as it was viewed as a one-time activity that ended in 1990)

The first-ever WCRP Global Coupled Climate Model Workshop organized by SGGCM

(changed to CLIVAR NEG2 in late 1994; subsequently WGCM)

Scripps, October, 1994

Included representatives from modeling and analysis groups

The concept for a coupled model intercomparison project under the auspices of WCRP was first discussed here

The **Coupled Model Intercomparison Project (CMIP)**
approved by CLIVAR NEG2 in **September 1995**

The **Coupled Model Intercomparison Project (CMIP)** approved by CLIVAR NEG2 in **September 1995**

organized by the CMIP Panel (Gerald Meehl (chair), Ron Stouffer, George Boer, Curt Covey, Mojib Latif)

PCMDI agreed to archive model data and make available for analysis to the WCRP community

CMIP was organized in a progression of phases, starting with CMIP1 (model control runs, 1995) and CMIP2 (adding 1% per year CO2 transient increase, 1997)

CMIP1: Global coupled model simulation of present-day climate (1995)

CMIP1 Goals: 21 models from 9 countries; 10 analysis subprojects

1. Document systematic mean climate simulation errors of global coupled GCMs in atmosphere, ocean and cryosphere
2. Quantify effects of flux adjustment on coupled simulations of mean climate and climate variability
3. Document features of simulated climate system variability on a variety of time and space scales

CMIP2: Control run and climate sensitivity experiment with CO2 increasing 1% per year (limited fields, time average blocks, several monthly mean time series) (1997)

CMIP2 Goals: 18 models from 8 countries; 22 analysis subprojects

1. Document the mean response of the dynamically coupled climate system to a transient increase of CO2 in the models near time of CO2 doubling
2. Quantify the effects of flux adjustment on climate sensitivity in the coupled climate simulations
3. Document features of the simulated time-evolving climate system response to gradually increasing CO2

General CMIP description: Meehl, G.A., G.J. Boer, C. Covey, M. Latif, and R.J. Stouffer, 1997: Intercomparison makes for a better climate model. *Eos*, **78**, 445--446, 451.

As CMIP got started, SGGCM collected time series of globally averaged surface temperature change (1%/year CO2 increase) from 10 modeling groups and these data were assessed in the IPCC Second Assessment Report (1995)

From the IPCC Second Assessment Report (1995)
10 AOGCMs

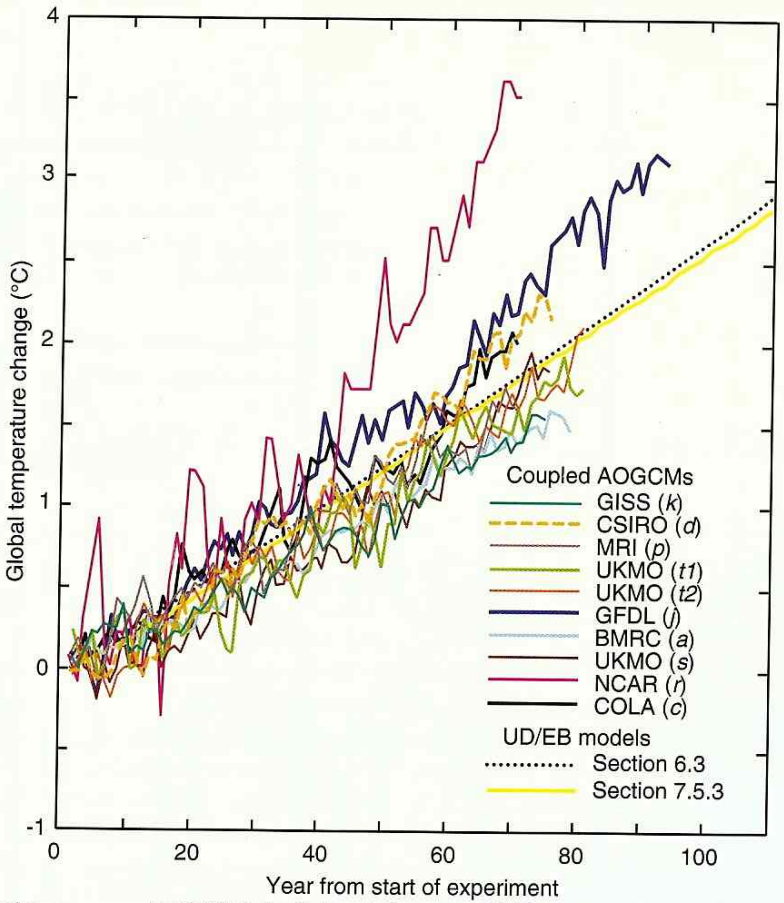
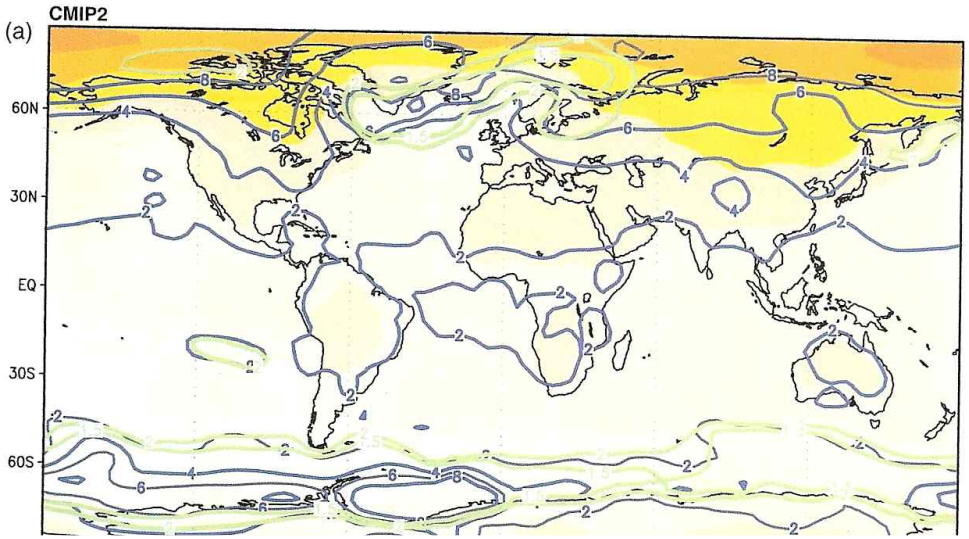


Figure 6.4: Comparison between several AOGCM simulations (climate sensitivities between 2.1 and 4.6°C), the UD/EB model of Section 6.3 (climate sensitivity 2.5°C) and the simple climate model of Section 7.5.3 (climate sensitivity of about 2.2°C). All models were forced with 1%/yr (compound) increase of atmospheric CO_2 concentration from equilibrium or near-equilibrium in 1990.

CMIP was fully functioning by 1997 and CMIP2 simulations and associated papers made significant contributions to the 2001 IPCC Third Assessment Report (TAR) in Chapters 8, 9,11, 12

For example, the multi-model temperature change in the IPCC TAR from CMIP2 1% runs, 11 models

546 *Projections of Future Climat*



Multi-model ensemble surface temperature change at time of CO2 doubling (colors), the range across models (blue contours), and multi-model mean change divided by the multi-model standard deviation (green contours)

Start of the concept of "MIPs" in CMIP2:

To access model data, short one page subproject proposals sent to the CMIP Panel for approval (these were informal to avoid overlap in analyses)

Following CMIP2 and the IPCC TAR in 2001:
--rapid development of the next generation of coupled climate models
--feasibility of running realistic scenarios for 21st century

The need for coordination of a new set of simulations for community analysis was greater than ever

WGCM approved CMIP3, September, 2003

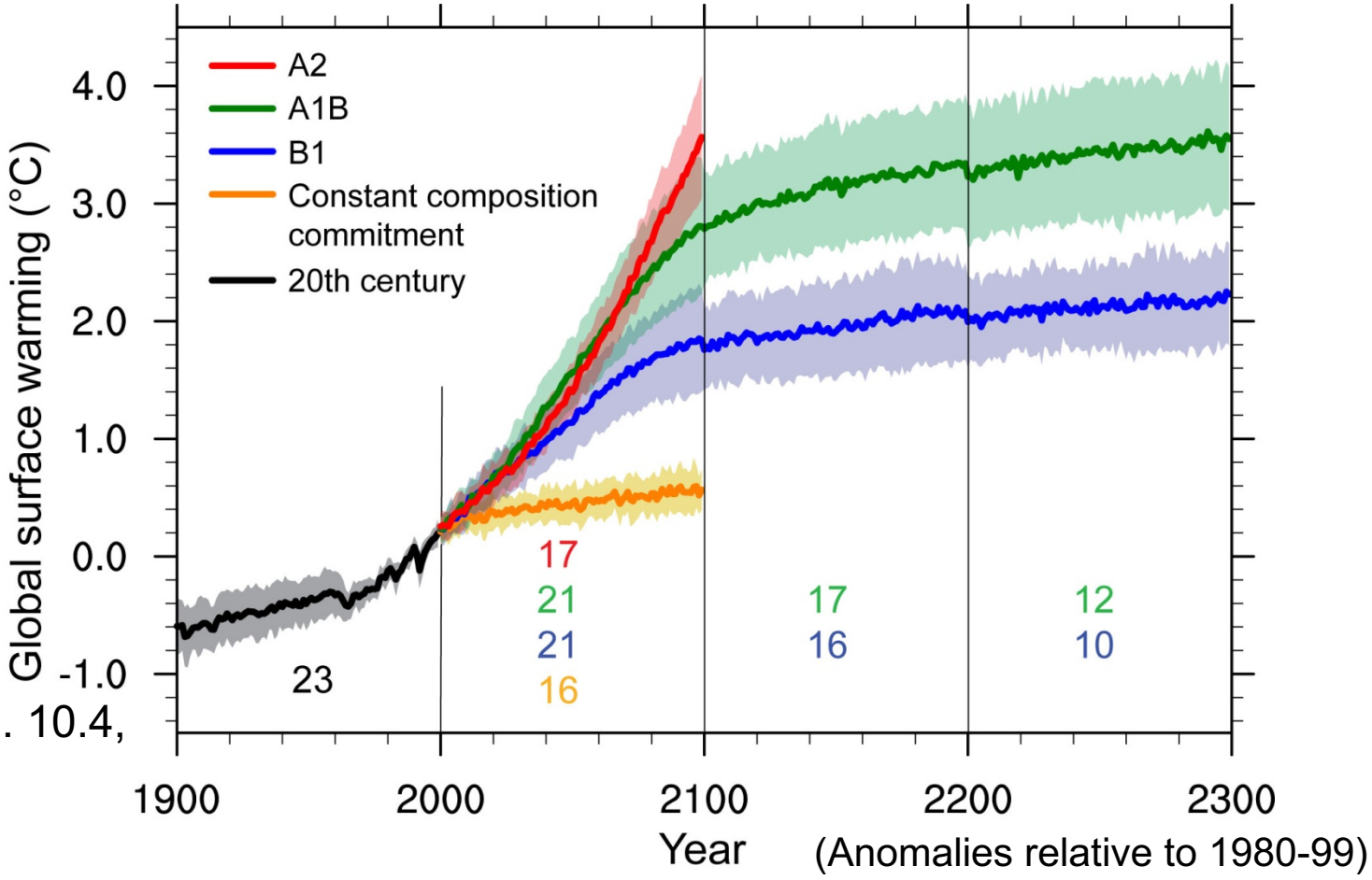
1. 20th century simulation to year 2000, then fix all concentrations at year 2000 values and run to 2100 (CO2 ~ 360ppm)
2. 21st century simulation with SRES A1B to 2100, then fix all concentrations at year 2100 values to 2200 (CO2 ~ 720ppm) (run one member to 2300)
3. 21st century simulation with SRES B1 to 2100, then fix all concentrations at year 2100 values to 2200 (CO2 ~ 550ppm) (run one member to 2300)
4. 21st century simulation with SRES A2 to 2100

PCMDI agreed to collect, archive and distribute a huge amount of model data to a potentially large number of users

(relied mainly on disks sent to modeling groups who filled them with data, and fedexed disks to PCMDI)

CMIP3 was the start of the modern era of open access to multi-model data via the internet

(Meehl, G. A., C. Covey, T. Delworth, M. Latif, B. McAvaney, J. F. B. Mitchell, R. J. Stouffer, and K. E. Taylor, 2007: The WCRP CMIP3 multi-model dataset: A new era in climate change research, *Bulletin of the American Meteorological Society,* **88**, 1383--1394.)



Ch. 10, Fig. 10.4, TS-32

CMIP3 took model intercomparison to the next level:

Unprecedented coordinated climate change experiments from 16 groups (11 countries) and 23 models collected at PCMDI (31 terabytes of model data), openly available, accessed by over 1200 scientists; over 200 papers

CMIP3 multi-model dataset and associated papers were assessed in the IPCC AR4 (2007); CMIP4 was informal collection of single forcing experiments

Late in CMIP3 during the IPCC AR4 process, it became clear that a profound paradigm shift for climate change science was about to happen

2007 and CMIP3 saw the end of 20 years of relatively coarse grid AOGCMs run with non-mitigation scenarios

The new paradigm:

decadal prediction with relatively high resolution AOGCMs (~50km) initialized for near-term climate change over the next 30 years

first generation **Earth System Models** (ESMs) with coupled carbon cycle and intermediate resolution (~200km) to study longer term feedbacks past mid-century with new mitigation scenarios

new **tangible linkages throughout the climate science community** (WCRP, IGBP, WG2 and WG3) are required to advance the science

A landmark Aspen Global Change Institute (AGCI) session: August, 2006, to formulate CMIP5

Participants were climate modelers, chemistry and aerosol modelers, land surface modelers, biogeochemistry modelers, IAM modelers, IAV researchers

"Firsts" in the 2006 AGCI CMIP5 session

(described by Hibbard, K. A., G. A. Meehl, P. Cox, and P. Friedlingstein, 2007: A strategy for climate change stabilization experiments. *EOS*, **88**, 217, 219, 221.)

--first time the future climate change problem was divided into **near-term and long-term timescales**, reflecting a shift of the science with the emergence of decadal climate prediction and the needs of the stakeholder community for near-term climate change information

--this session essentially launched the field of **decadal climate prediction** as a new area of climate science

--the first time **ESM experiments** were included in a CMIP phase, reflecting the rise of carbon cycle components being included in standard AOGCMs

--first time to **connect the Earth System Modeling Community with the Integrated Assessment Modeling community** in planning a CMIP phase

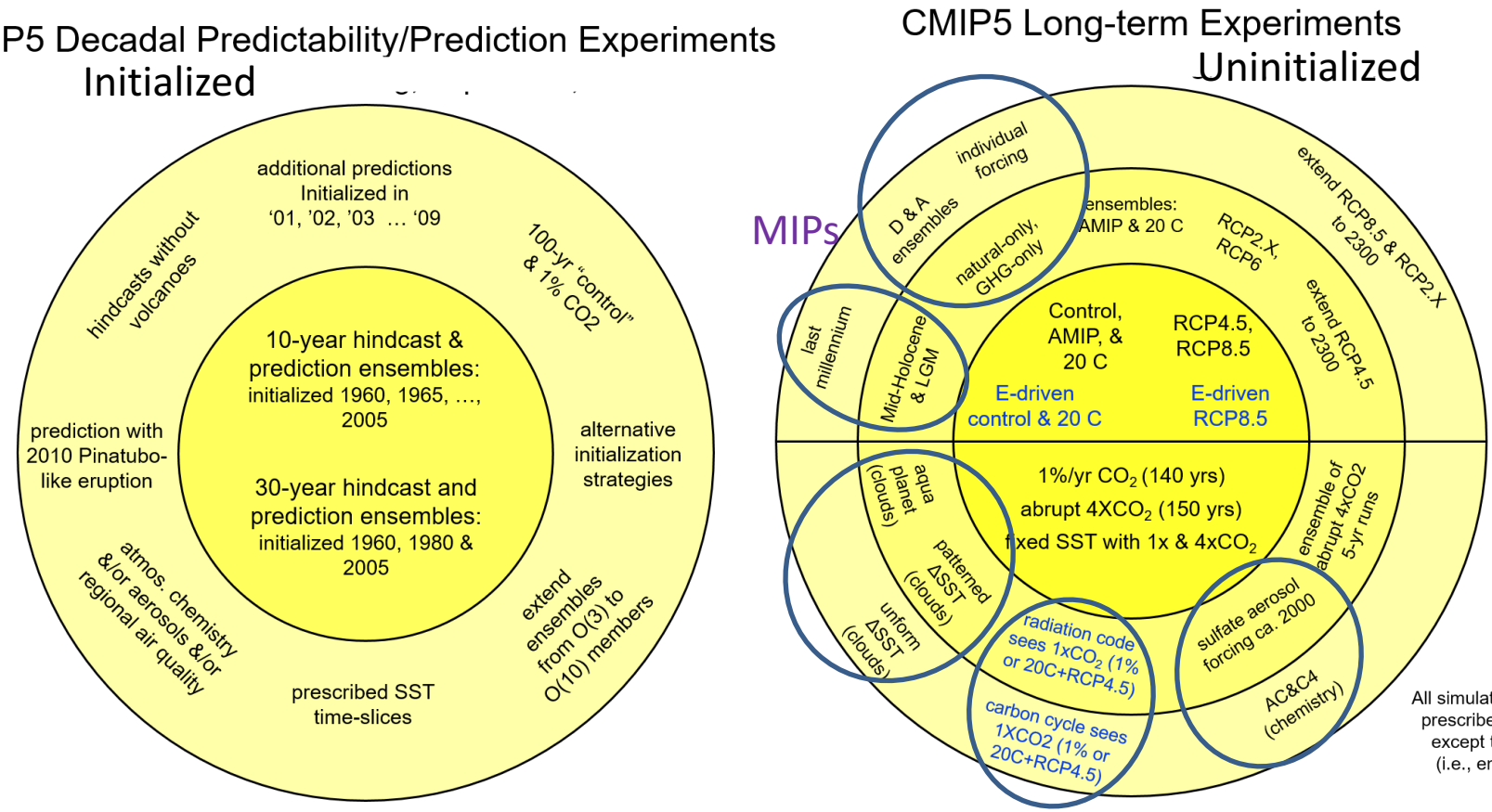
--the first time **idealized experiments proposed by MIPs** run to promote understanding of the climate system were formulated for inclusion in a CMIP phase

CMIP5 approved by WGCM, September 2008

CMIP Panel: Stouffer (Chair), Meehl, Latif, Covey, Taylor, Mitchell, Stockdale)

(Taylor, K.E., R.J. Stouffer, and G.A. Meehl, 2012: An overview of CMIP5 and the experiment design. *Bull. Amer. Meteorol. Soc.*, **93**, 485—498, doi: 10.1175/BAMS-D-11-00094.1.)

Two classes of models for two timescales and two different sets of science problems, and specified MIPs



All simulations are forced by prescribed concentrations except those "E-driven" (i.e., emission-driven).

IPCC AR5 2013:

2016-2035 assessed temperature range is less than from uninitialized projections in part due to results from initialized decadal predictions

CMIP5 Uninitialized

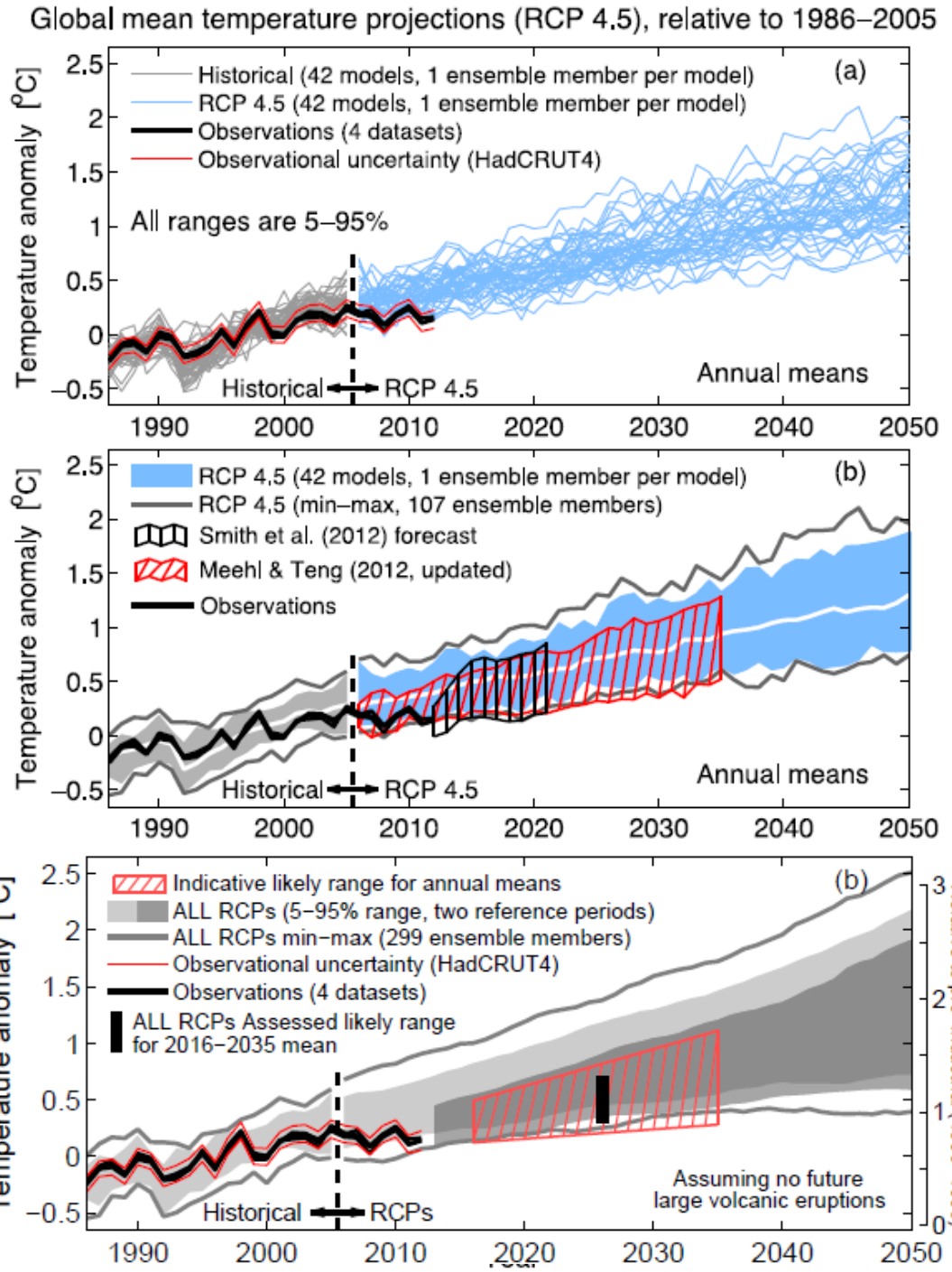
Figure 11.9a from IPCC AR5, ch 11

CMIP5 Initialized

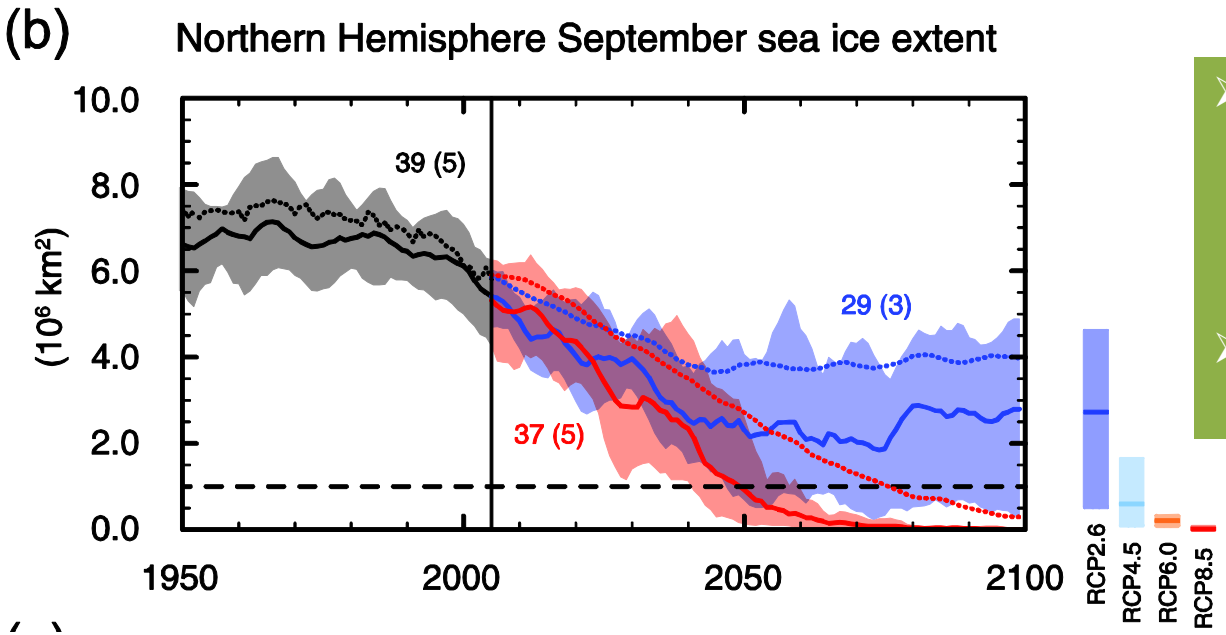
Figure 11.9b from IPCC AR5, ch 11

Assessed Temperature change

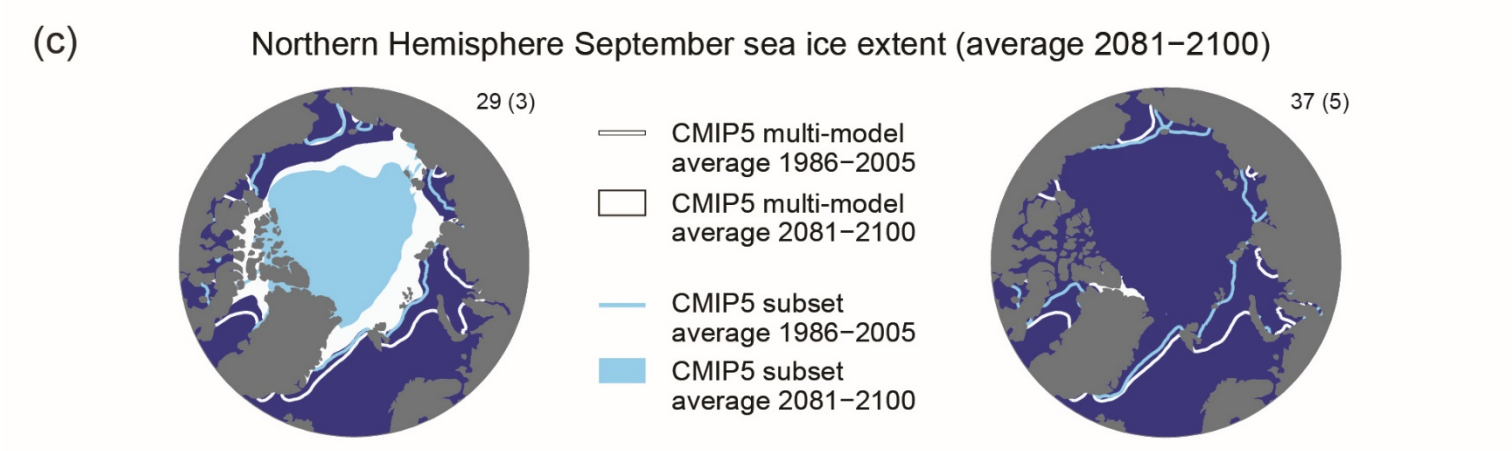
Figure 11.25b from IPCC AR5, ch 11



IPCC AR5 2013: CMIP5 multi-model mean results for sea ice projections



- It is *very likely* that the Arctic sea ice cover will continue to shrink and thin during the 21st century as global mean surface temperature rises.
- Global glacier volume will further decrease.



CMIP6 Experimental Design

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

- Summer 2013 CMIP5 survey and Aspen Global Change Institute & WGCM/AIMES 2013 mtgs
- Initial proposal for the design of CMIP6 (Meehl et al., EOS, 2014).
- Feedback on this initial CMIP6 proposal solicited until September 2014.
- **The WGCM and the CMIP Panel finalized the CMIP6 design at the WGCM 18th session (October 2014, Grainau) in consultation with the model groups and MIP co-chairs**
- CMIP6 to run for a nominal 5 years, from 2015 to 2020, but simulations and analyses will extend beyond that time frame

CMIP6 Organization

- **CMIP Panel** (Veronika Eyring (chair), Gerald Meehl, Cath Senior, Ron Stouffer, Karl Taylor, Greg Flato) 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).

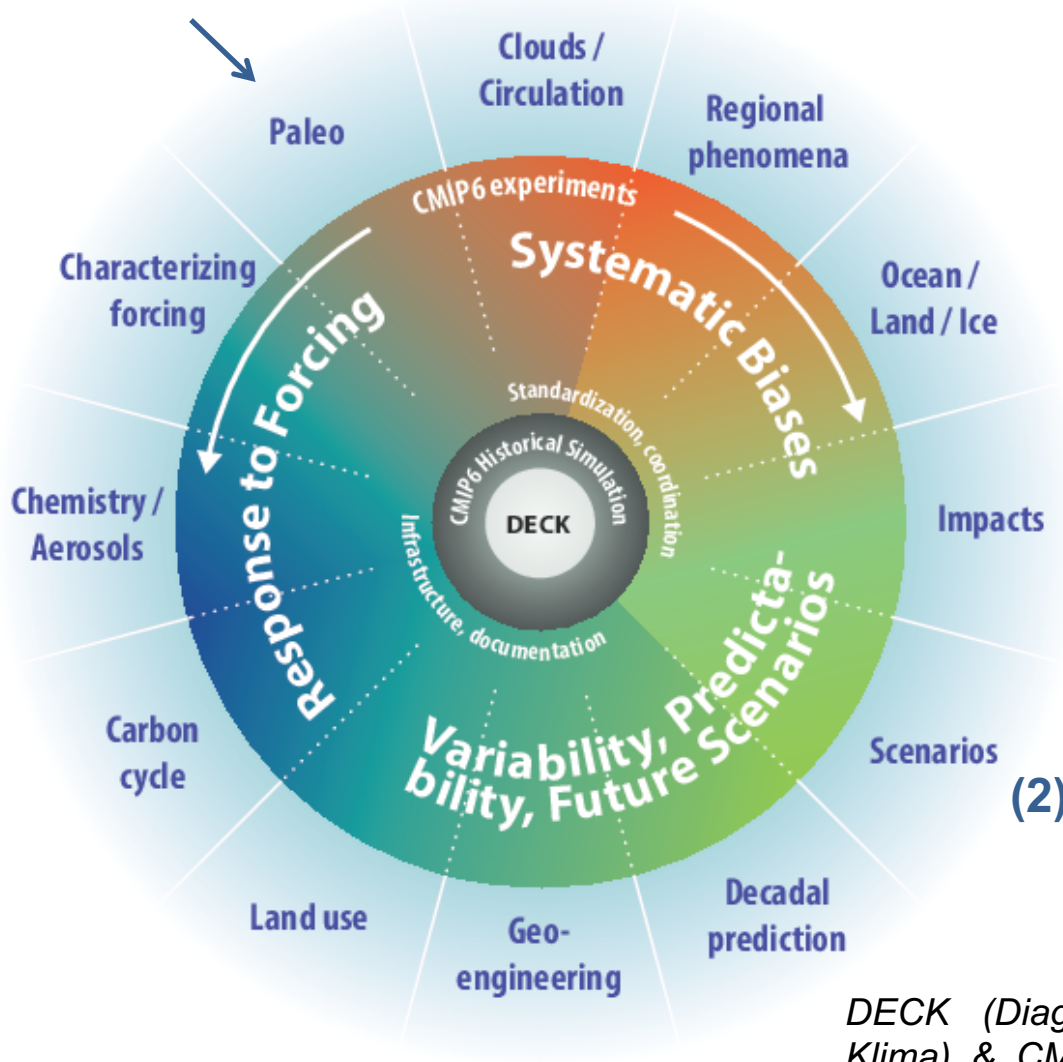
- **input4MIPs:** infrastructure for forcing data (Chair: P. Durack)
- **ESGF** supports a federated data archive hosting the CMIP6 data
- **Infrastructure support components are the responsibility of multiple, independently-funded projects (e.g., ES-DOC, data citation service, errata services)**
- **Routine evaluation** of the models with newly available tools is now available for the first time

WCRP
World Climate Research Programme

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

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)

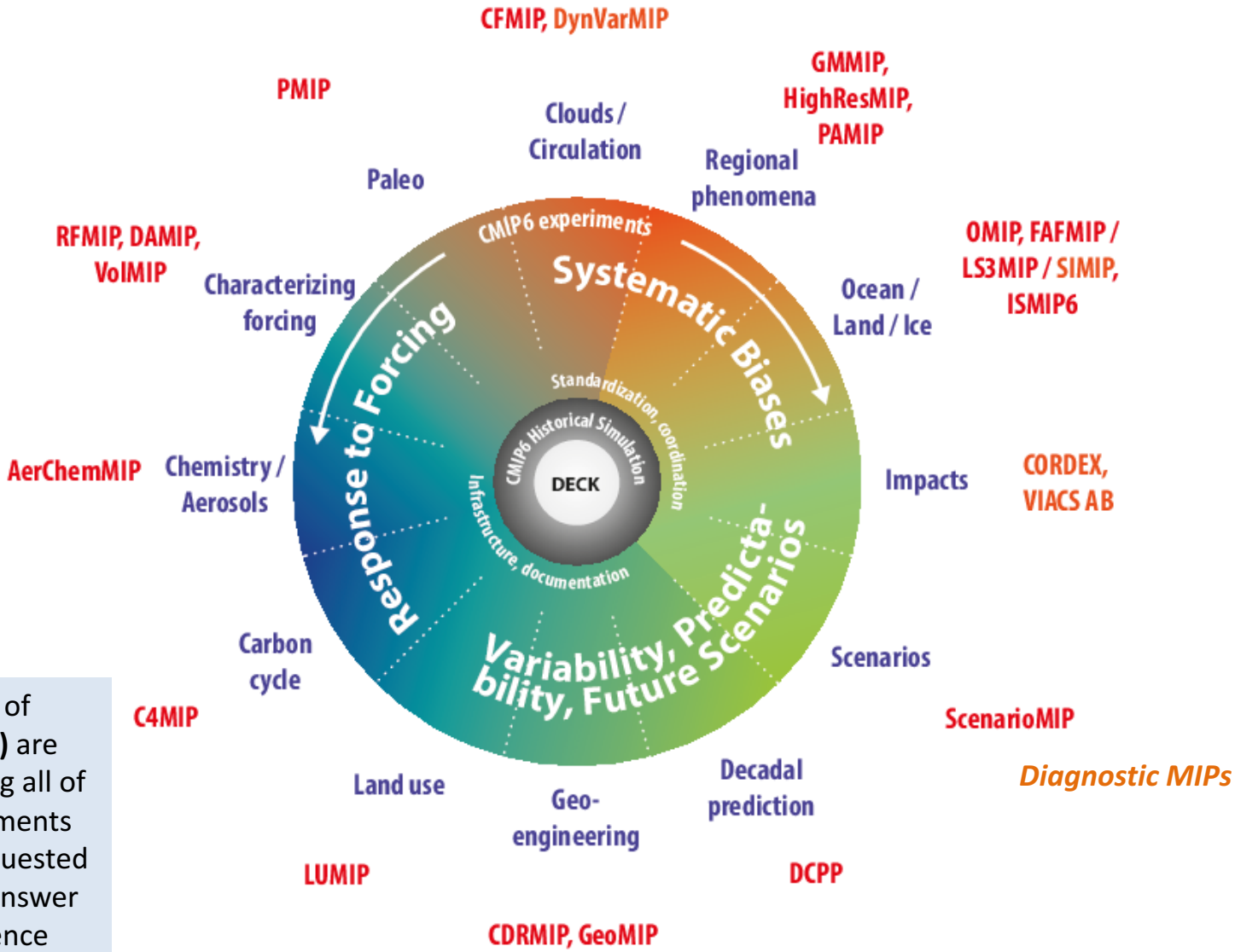
v. Historical simulation using CMIP6 forcings (1850-2014)

(2) Standardization, coordination, infrastructure, documentation: WGCM Infrastructure Panel (WIP)

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

23 CMIP6-Endorsed MIPs formulated by volunteer groups of scientists to address compelling science questions

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.

Coupled Model Intercomparison Project (CMIP)

- CMIP is a project of the World Climate Research Programme (**WCRP**)'s Working Group on Coupled Modelling (**WGCM**).
- Since 1995, **CMIP** has coordinated climate model experiments involving multiple international modeling teams worldwide.
- CMIP has led to a better understanding of past, present and future climate change and variability in a **multi-model framework.**
- CMIP defines **common experiment protocols, forcings and output.**
- CMIP has developed in phases, with the sixth phase, CMIP6, in progress.
- Individual "MIPs" proposed by volunteers from the community to look at specific science questions
- The data challenge: CMIP1-CMIP2: several TB; CMIP3: 31 TB;

  CMIP5: 2 PB; CMIP6: 5+ PB
- **CMIP's goal is to advance scientific understanding of the Earth system**
- **CMIP is not done for the IPCC, or run by the IPCC, but is formulated by the climate science community through WCRP**
- CMIP model simulations, constituting the current state-of-the-art of climate science, are assessed as part of the IPCC Climate Assessment Reports and various national assessments.

WCRP 40 World Climate Research Programme #WCRP40

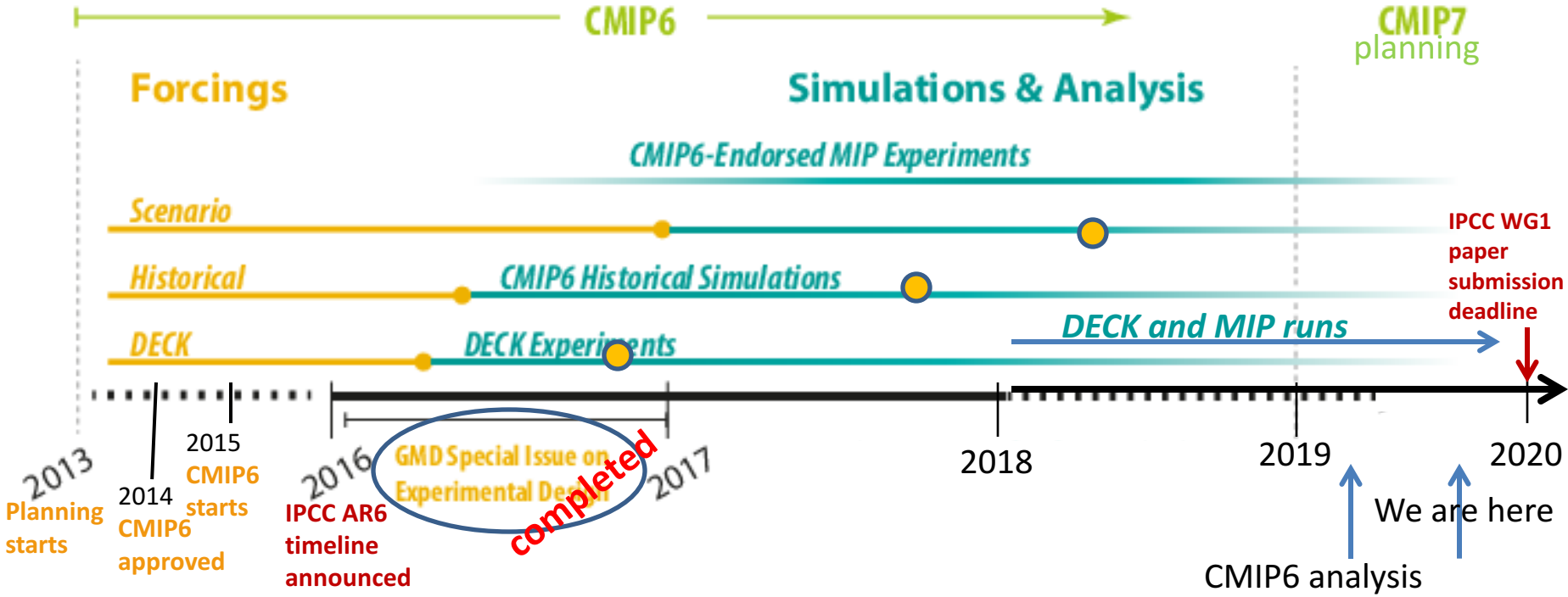
CMIP The World Climate Research Programme's Coupled Model Intercomparison Project

CMIP6 Timeline
(as of October, 2019)

Modeling groups thought they would start the DECK experiments in early 2017

But…most modeling groups ran at least a year late in the model development process

DECK experiments and CMIP experiments run in 2018-2019



--CMIP6 finalized late 2014

--CMIP6 starts in 2015 too run a nominal 5 years (2015-2020) but simulations and analyses to extend beyond that time frame

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

CMIP6: 48 participating Model Groups from 16 countries

	Institution	Country		Institution	Country		Institution	Country
1	AWI	Germany	12	DOE	USA	23	MRI	Japan
2	BCC	China	13	EC-Earth-Cons	Europe	24	NASA-GISS	USA
3	BNU	China	14	FGOALS	China	25	NCAR	USA
4	CAMS	China	15	FIO-RONM	China	26	NCC	Norway
5	CasESM	China	16	INM	Russia	27	NERC	UK
6	CCCma	Canada	17	INPE	Brazil	28	NIMS-KMA	Republic of Korea
7	CCCR-IITM	India	18	IPSL	France	29	NOAA-GFDL	USA
8	CMCC	Italy	19	MESSY-Cons	Germany	30	NUIST	China
9	CNRM	France	20	MIROC	Japan	31	TaiESM	Taiwan, China
10	CSIR-CSIRO	South Africa	21	MOHC	UK	32	THU	China
11	CSIRO-BOM	Australia	22	MPI-M	Germany	33	Seoul Nat.Uni	Republic of Korea

New in CMIP:

2 new model groups from Germany (AWI, MESSY-Consortium)
4 new model groups from China (CAMS, CasESM, NUIST, THU)
1 new model group from Brazil (INPE)
1 new model group from India (CCCR-IITM)
1 new model group from Taiwan, China (TaiESM)
1 new model group from USA (DOE)
2 new model group from Republic of Korea (NIMS-KMA, SAM0-UNICON)
1 new model group from South Africa / Australia (CSIR-CSIRO)

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More models (>70)
New models
More complex models
Higher resolution models

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

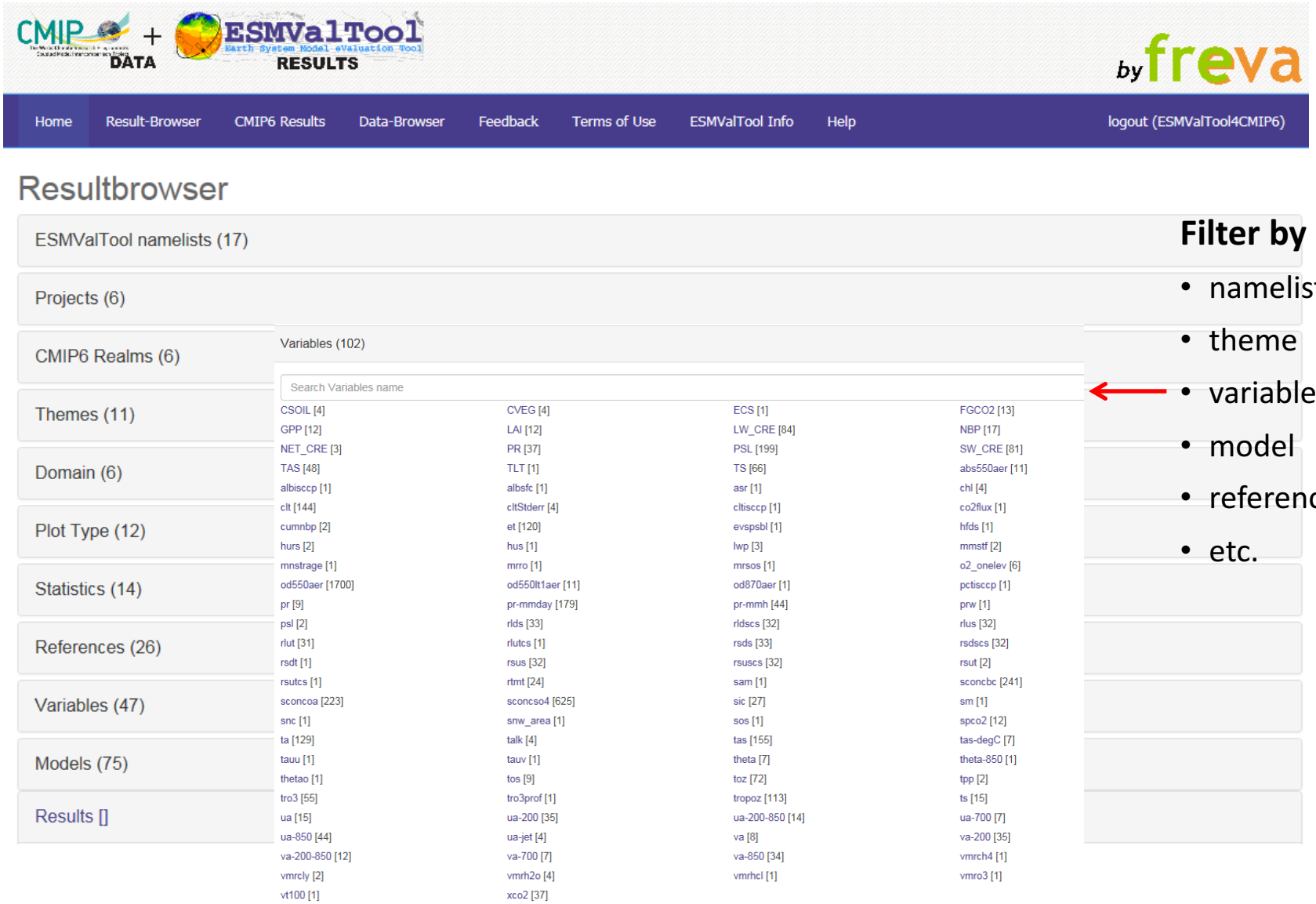
⇒ **13 new model groups so far;**

⇒ **Total of 16 countries: Australia, Brazil, Canada, China, France, Germany, India, Italy, Japan, Korea, Norway, Russia, South Africa, Taiwan, U.K., U.S.A.**

* Other models can join providing DECK and historical simulations are submitted

First CMIP6 Results from ESMValTool incl. NCAR CVDP at DKRZ

(Password restricted website and watermarked for quality control)



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

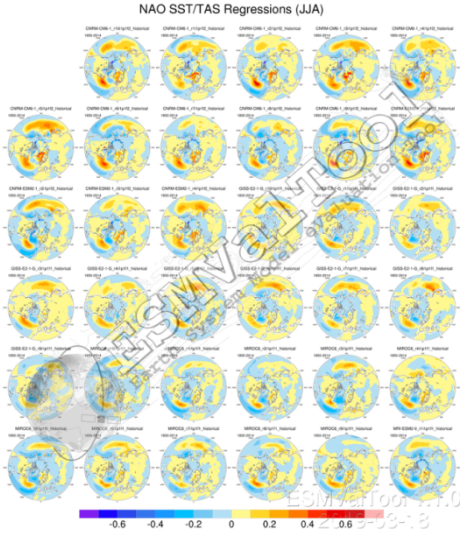
Filter by

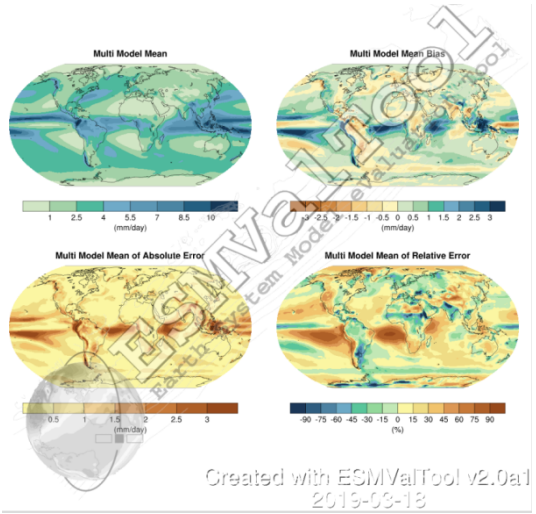
- namelist
- theme
- variable
- model
- reference
- etc.

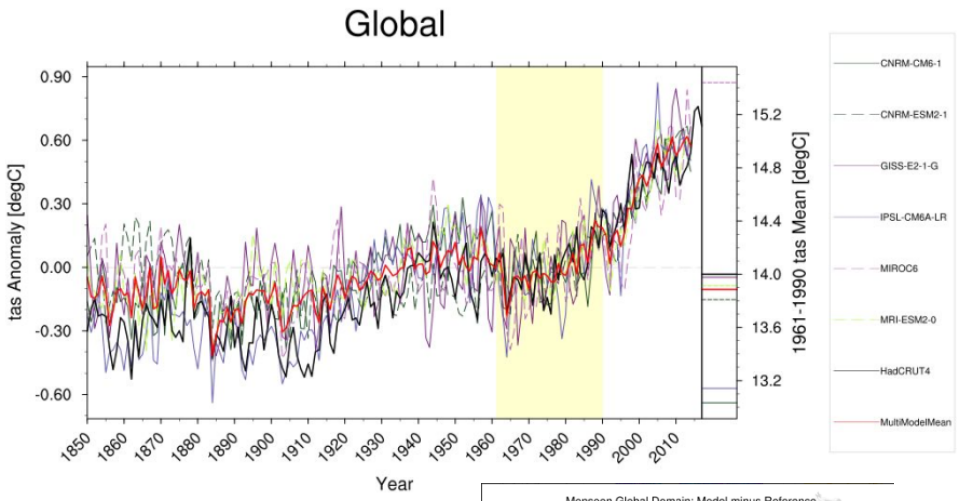
First CMIP6 Results from ESMValTool incl. NCAR CVDP

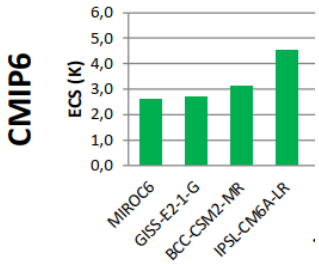
(Password restricted website and watermarked for quality control)

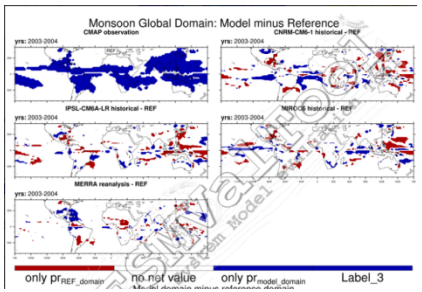
http://cmip-esmvaltool.dkrz.de/











Namelists include for example

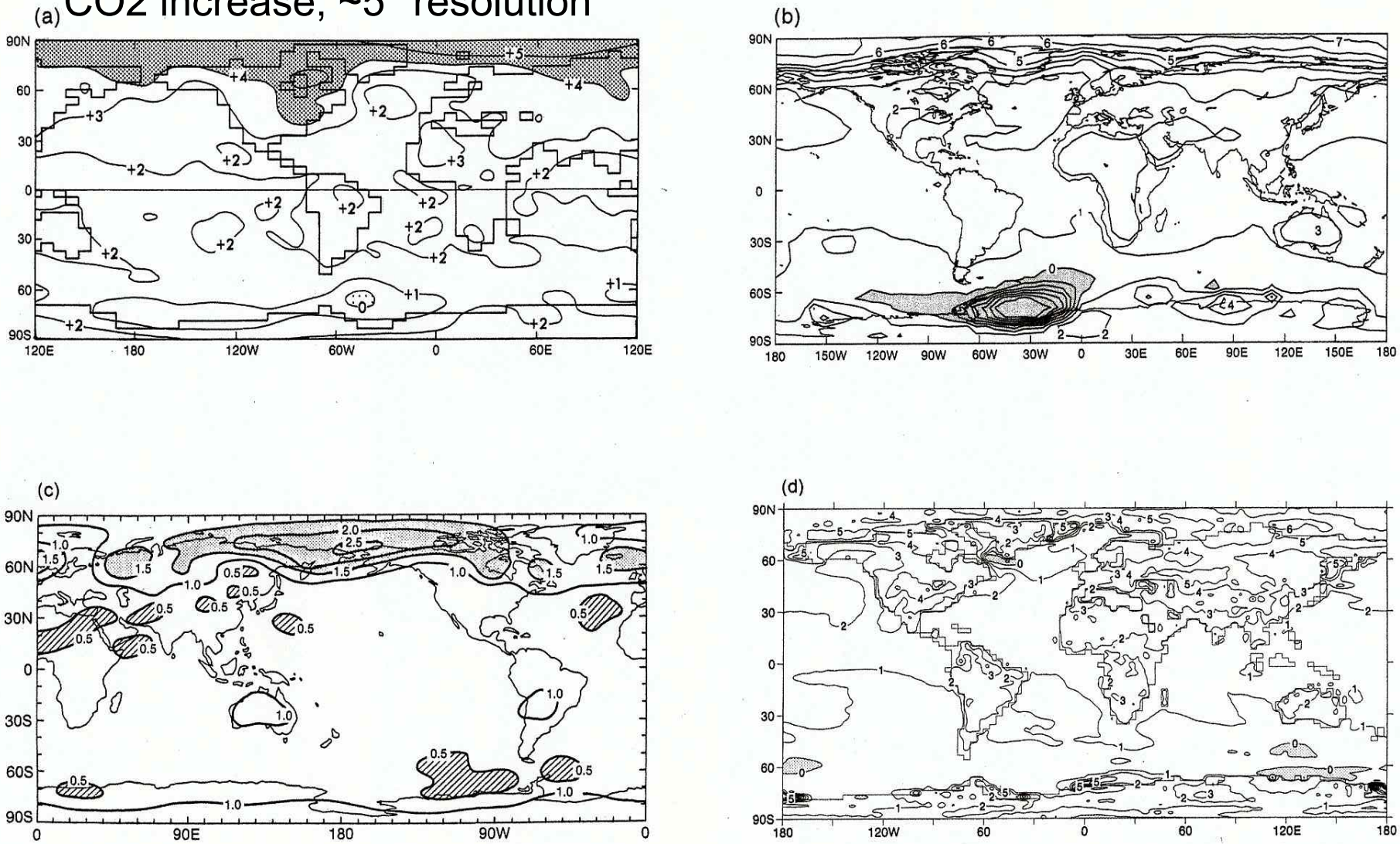
- AR5 Chapter 9 Model Evaluation
- Modes of Variability (CVDP)
- Monsoon, evapotransporation, carbon cycle
- ECS, ozone, aerosols

ESMValTool
Earth System Model eValuation Tool

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

The start of the modern era of intercomparison of multi-model global coupled climate model simulations (IPCC 1992 update to the First Assessment Report); results collected by SGGCM members

GFDL (USA), MPI (Germany), NCAR (USA), UKMO (UK); 1% per year CO2 increase, ~5° resolution



The first MIP: "AMIP" (late-1980s) (Atmospheric Model Intercomparison Project)

Run the same atmosphere-only model experiment set up in the same way for a time period in the 20th century using the same time-evolving SSTs across a number of different models so the simulations can be directly compared to see where they agree and disagree

Success of AMIP pointed to a Coupled Model Intercomparison Project (CMIP)

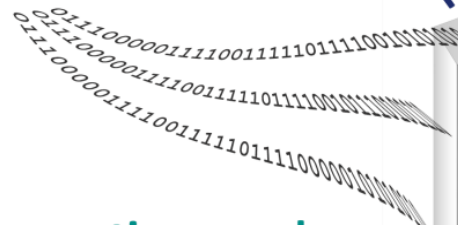
Envisaged Workflow for Routine Evaluation in CMIP

- Ensuring traceability and provenance of the results -

Well-Established Analysis
Sharing of Diagnostic Code
Guidance and support from CMIP Panel,
WGNE/WGCM Climate Model Metrics
Panel and , CMIP6-Endorsed MIPs

Model Output

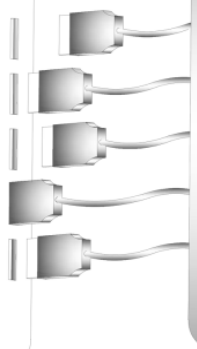
CMIP
The World Climate Research Programme's Coupled Model Intercomparison Project



Processing Capability

Data Archive

Standardised Interfaces



Community-tools for Routine ESM Evaluation

Visualization & documentation of evaluation results
Record of provenance
Scientific interpretation
Additional in-depth analysis

Observations and Reanalyses

obs4MIPs
ana4MIPs

Analysis computing environment integrated with the ESGF

State evaluation of ECVs
(climatology, trends, …)
Process and phenomena evaluation
Link to projections
(MMM analysis and emergent constraints)
Performance metrics

ESMValTool
Earth System Model eValuation Tool

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

PCMDI Metrics Package (PMP)
Others

Eyring et al., ESD (2016)

2013: Given the success of the 2006 AGCI session in formulating CMIP5, it was decided to convene an AGCI session in 2013 to plan CMIP6 bringing together climate scientists, IAM modelers and IAV researchers

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EOS

EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

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PAGES 77–84

Climate Model Intercomparisons: Preparing for the Next Phase

PAGES 77–78

Since 1995, the Coupled Model Intercomparison Project (CMIP) has coordinated climate model experiments involving multiple international modeling teams. Through CMIP, climate modelers and scientists from around the world have analyzed and compared state-of-the-art climate model simulations to gain insights into the processes, mechanisms, and consequences of climate variability and climate change. This has led to a better understanding of past, present, and future climate, and CMIP model experiments have routinely been the basis for future climate change assessments made by the Intergovernmental Panel on Climate Change (IPCC) [e.g., IPCC, 2013, and references therein].

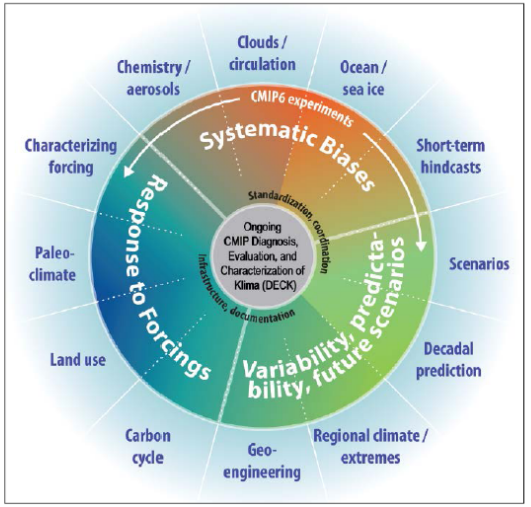
CMIP has developed in phases, with the simulations of the fifth phase, CMIP5, now mostly completed. Though analyses of the CMIP5 data will continue for at least several more years, science gaps and outstanding science questions have prompted preparations for the sixth phase of the project (CMIP6). This brief overview of the initial proposed design of CMIP6 is meant to inform interested research communities and to encourage discussion and feedback for consideration in the evolving experiment design (see Figure 1). A more complete description and further information are available at http://www.wcrp-climate.org/index.php/wgcm-cmip/wgcm-cmip6 and in the additional supporting information in the online version of this article.

Scientific Focus and Structure

The proposed scientific backdrop for CMIP6 consists of the six grand challenges of the World Climate Research Programme and feedbacks. The specific experiment design would focus on three broad questions: How does the Earth system respond to forcing? What are the origins and consequences of systematic model biases? How can we assess future climate changes given climate variability, climate predictability, and uncertainties in scenarios?

Within this scientific framework, a more distributed organization for CMIP6 than in previous phases of CMIP is proposed. This would fall under the oversight of the CMIP Panel (see Figure 1), wherein an ongoing activity, CMIP, is distinguished from a particular phase of CMIP, now CMIP6. This structure involves two basic components.

First, CMIP (inner part of Figure 1) would be composed of two elements: in one, researchers would run a small set of standardized



Global coupled climate models (atmosphere, ocean, land, sea ice) were being formulated in the 1970s, but limited computing power hindered development

(e.g. sector formulations, idealized geography, “asynchronous coupling”)

The first fully coupled global climate models with realistic geography were starting to be run for multi-decadal simulations in the late 1980s

In the first IPCC assessment (1990), there was one fully coupled AOGCM run in a control run and a 1% per year CO2 increase experiment

2008: growing directly from the 2006 AGCI session that defined the decadal climate prediction problem, the 2008 AGCI session formulated the first-ever coordinated set of decadal climate prediction experiments for the CMIP5 experimental design

Article in Bull. Amer. Meteorol. Soc., 2009 describing outcomes of AGCI session

ARTICLES

DECADAL PREDICTION

Can It Be Skillful?

BY GERALD A. MEEHL, LISA GODDARD, JAMES MURPHY, RONALD J. STOUFFER, GEORGE BOER, GOKHAN DANABASOGLU, KEITH DIXON, MARCO A. GIORGETTA, ARTHUR M. GREENE, ED HAWKINS, GABRIELE HEGERL, DAVID KAROLY, NOEL KEENLYSIDE, MASAHIDE KIMOTO, BEN KIRTMAN, ANTONIO NAVARRA, ROGER PULWARTY, DOUG SMITH, DETLEF STAMMER, AND TIMOTHY STOCKDALE

A new field called "decadal prediction" will use initialized climate models to produce time-evolving predictions of regional climate that will bridge ENSO forecasting and future climate change projections.