CMIPnext:
facilitating international climate science

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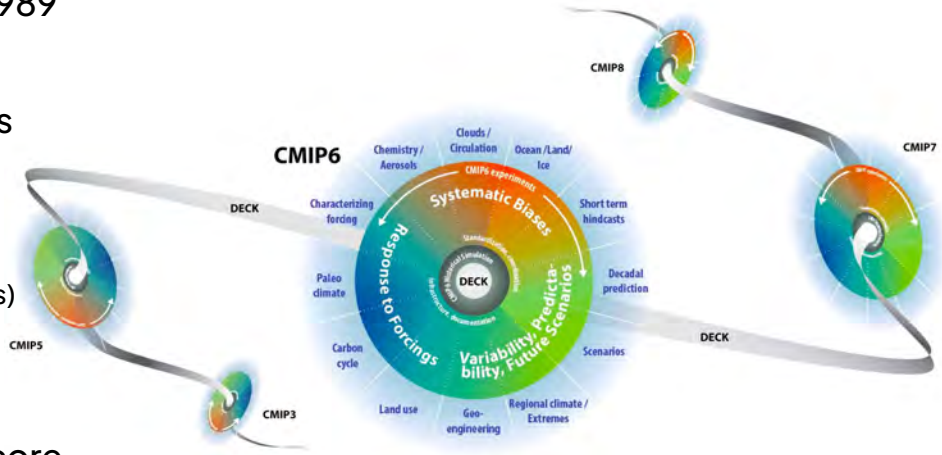
Overview

- Model Intercomparison Projects (MIPs) Overview
- CMIP6 status (current phase)
- CMIPnext planning
  - CMIP surveys; CMIP6Plus
- CMIP7
  - Forcing protocol (idealized/historical-proxy forcings); Data quantities, identities and formats
- CMEC
  - PCMDI Metrics Package (PMP); Collaborative activities in (climate) model evaluation

MIPs Overview

What are *MIPs

- Model Intercomparison Projects
- Started with Atmospheric-only MIP (AMIP) in 1989
- Coupled (atmosphere & ocean) MIP (CMIP) initiated 1995, evolved to Earth System Models (ESMs) in CMIP5
- Standardized protocols
  - Experimental (simulation length, model components)
  - Forcing (idealized, or historical-proxy forcings)
  - Data formats, identities and quantities
- Expanded for non-model activities servicing core modelling activities
  - **input4MIPs** – input (forcing) datasets for MIPs
  - **obs4MIPs** - observations for MIPs/model evaluation



Eyring *et al.* (2016) Overview of CMIP6, doi: 10.5194/gmd-9-1937-2016

CMIP

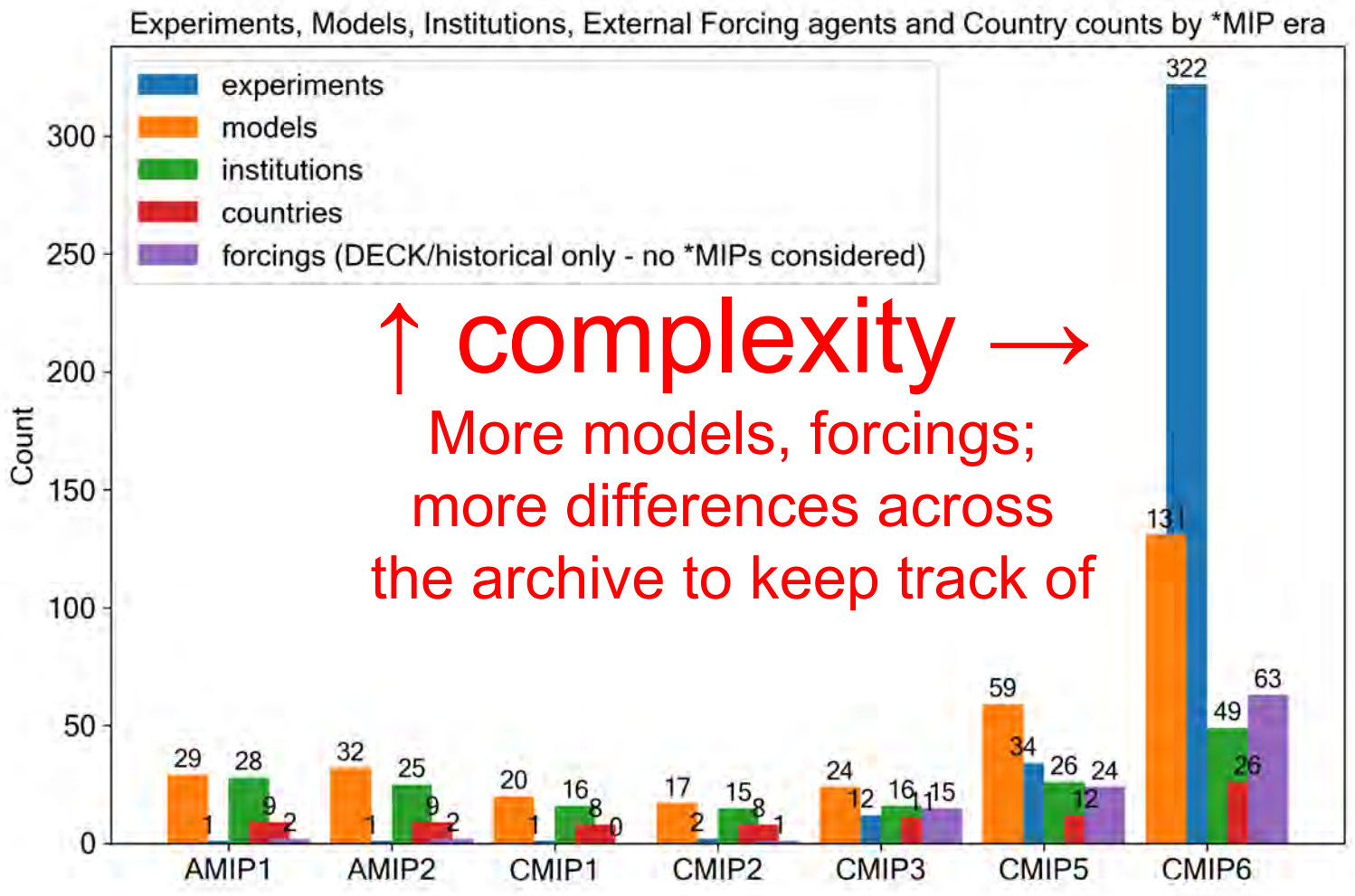
Timeline of *MIPs

Planning begins	**1989**	**1993**	**1995**	**1997**	**2003**	**2008**	**2014**
Simulations	AMIP1	AMIP2	CMIP1	CMIP2/ CMIP2+	CMIP3	CMIP5	CMIP6
Data Volumes	~1GB	~500GB	~1GB	~500GB	50TB	2PB	>20PB
Host Infrastructure	LLNL FTP*	LLNL FTP	LLNL FTP	LLNL FTP	LLNL FTP	ESGF 41# nodes	ESGF 30 nodes
Data formats	Fortran formatted binary	Fortran formatted binary, GRIB → DRS▽	GRIB → DRS	GRIB → DRS	CF netCDF-3	CF netCDF-4	CF netCDF-4
Operations begin	**1989**	**1995**	**1996**	**1999**	**2004**	**2011**	**2018**

* For some groups in addition to data distribution, LLNL computing facilities were used to run contributing simulations

▽ Data Retrieval and Storage (DRS) software library developed at PCMDI – pre-netCDF file format

The start of data federation - just 17 CMIP5 nodes remain, a ~50% loss from the CMIP5 peak - highlights tier 1 node importance for MIP data preservation


Experiments, Models, Institutions, External Forcing agents and Country counts by *MIP era
experiments
models
institutions
countries
forcings (DECK/historical only - no *MIPs considered)
↑ complexity →
More models, forcings;
more differences across
the archive to keep track of
Count
0
50
100
150
200
250
300
AMIP1
AMIP2
CMIP1
CMIP2
CMIP3
CMIP5
CMIP6
29
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1
9
2
32
25
1
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2
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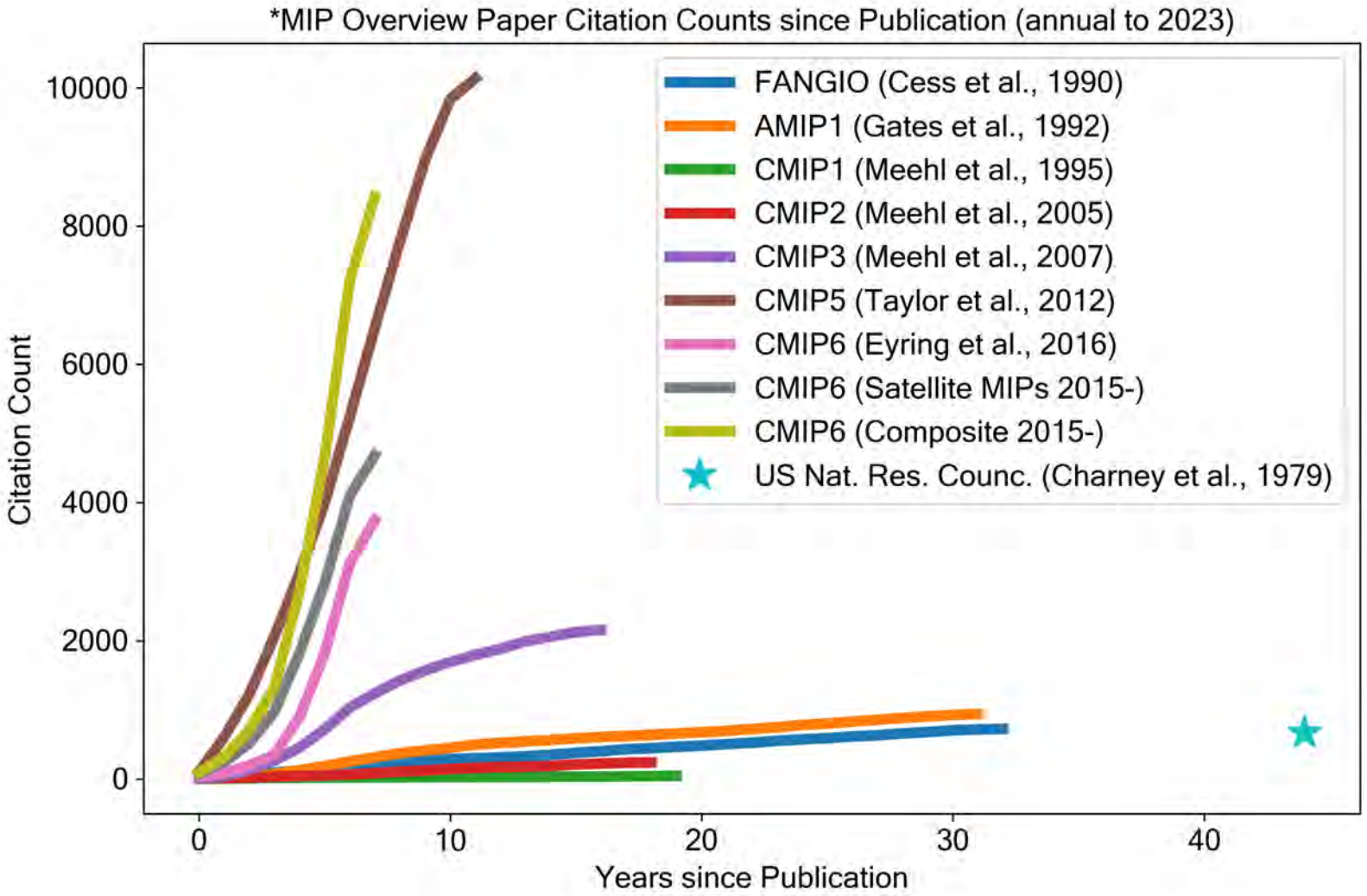
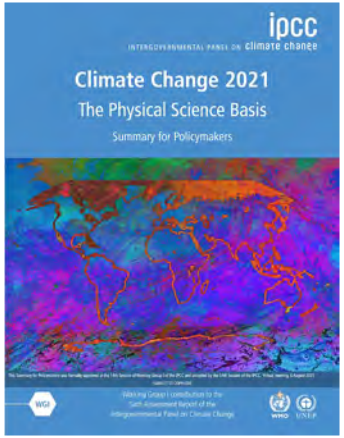
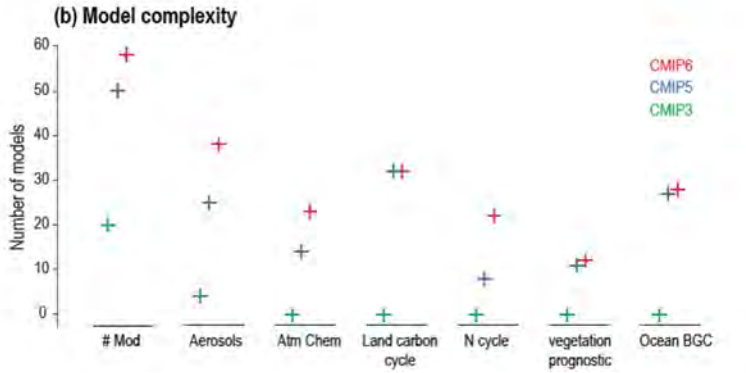

*MIP Overview Paper Citation Counts since Publication (annual to 2023)
Citation Count
Years since Publication
0
2000
4000
6000
8000
10000
0
10
20
30
40
FANGIO (Cess et al., 1990)
AMIP1 (Gates et al., 1992)
CMIP1 (Meehl et al., 1995)
CMIP2 (Meehl et al., 2005)
CMIP3 (Meehl et al., 2007)
CMIP5 (Taylor et al., 2012)
CMIP6 (Eyring et al., 2016)
CMIP6 (Satellite MIPs 2015-)
CMIP6 (Composite 2015-)
US Nat. Res. Counc. (Charney et al., 1979)

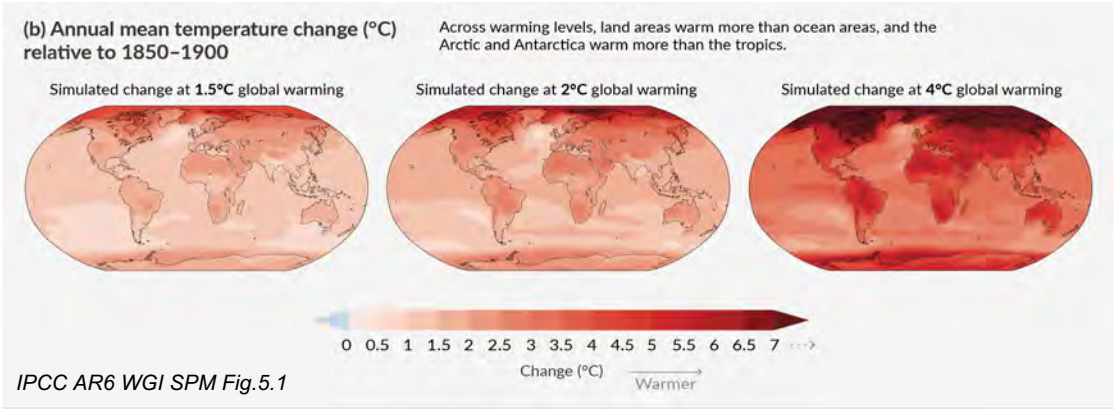
CMIP6 status

CMIP: driving science, informing policy





IPCC AR6 WGI TS Fig 2



IPCC AR6 WGI SPM Fig.5.1

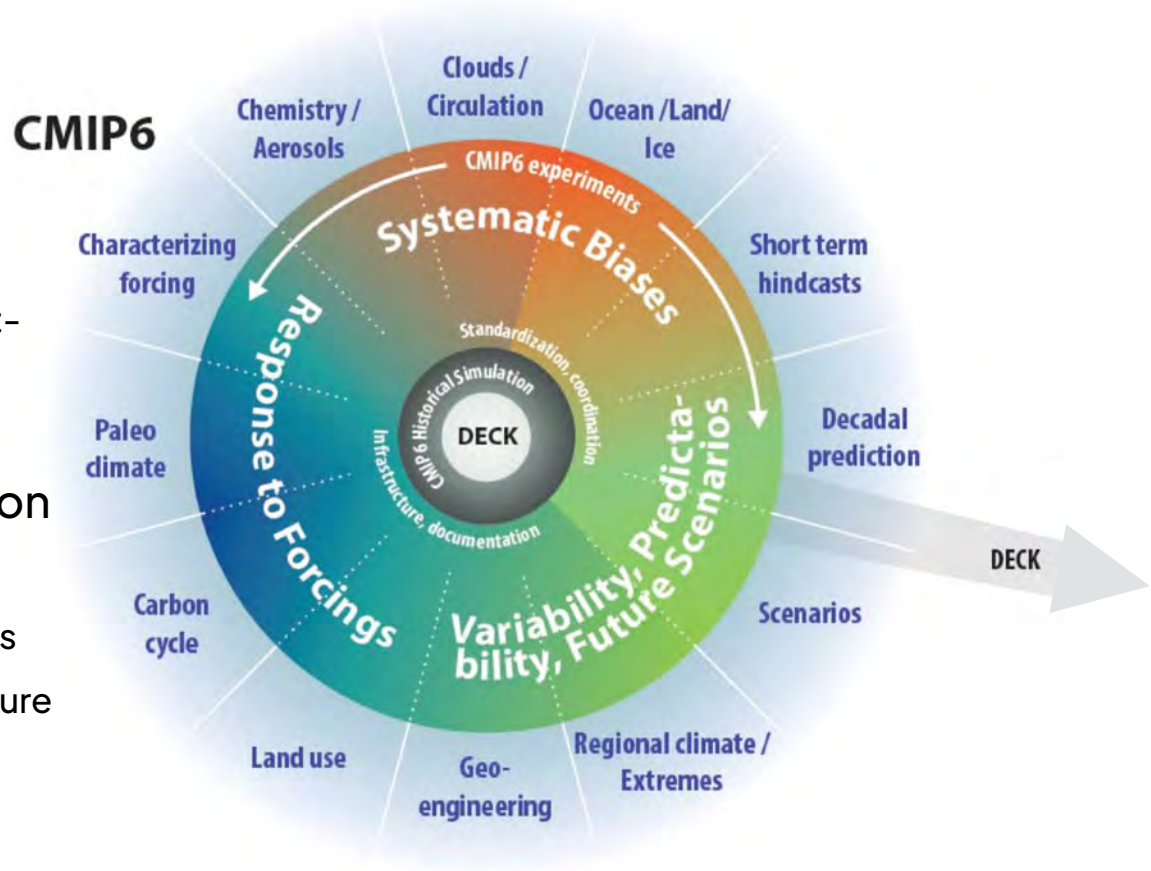
CMIP6: biggest yet!

- 24 endorsed MIPs
- 26 countries
- 48 institutions
- 130 models
- 322 experiments
- 8450 citations of CMIP6 and MIP design papers
- Nearly 26 PB of CMIP6 data
- 30+ ESGF data nodes

CMIP

CMIP6 – current phase

- DECK (core)
  - Diagnostic, Evaluation and Characterization of Klima
  - 4 experiments (1pctCO2, abrupt-4xCO2, piControl, AMIP) + historical + ESM variants
- 24 community MIPs focused on
  - ESM systematic biases
  - Forcing and feedback responses
  - Variability, predictability and future projections
  - Negative emissions pathways



Eyring *et al.* (2016) Overview of CMIP6, doi: 10.5194/gmd-9-1937-2016

CMIP structure

The DECK

The DECK (Diagnostic, Evaluation and Characterization of Klima) and CMIP historical simulations (1850 – near-present) that maintain continuity and help document basic characteristics of models across different phases of CMIP.

The MIPs

Model Intercomparison Projects (MIPs) address specific science questions across the climate and earth science communities. They are driven bottom up by the community.

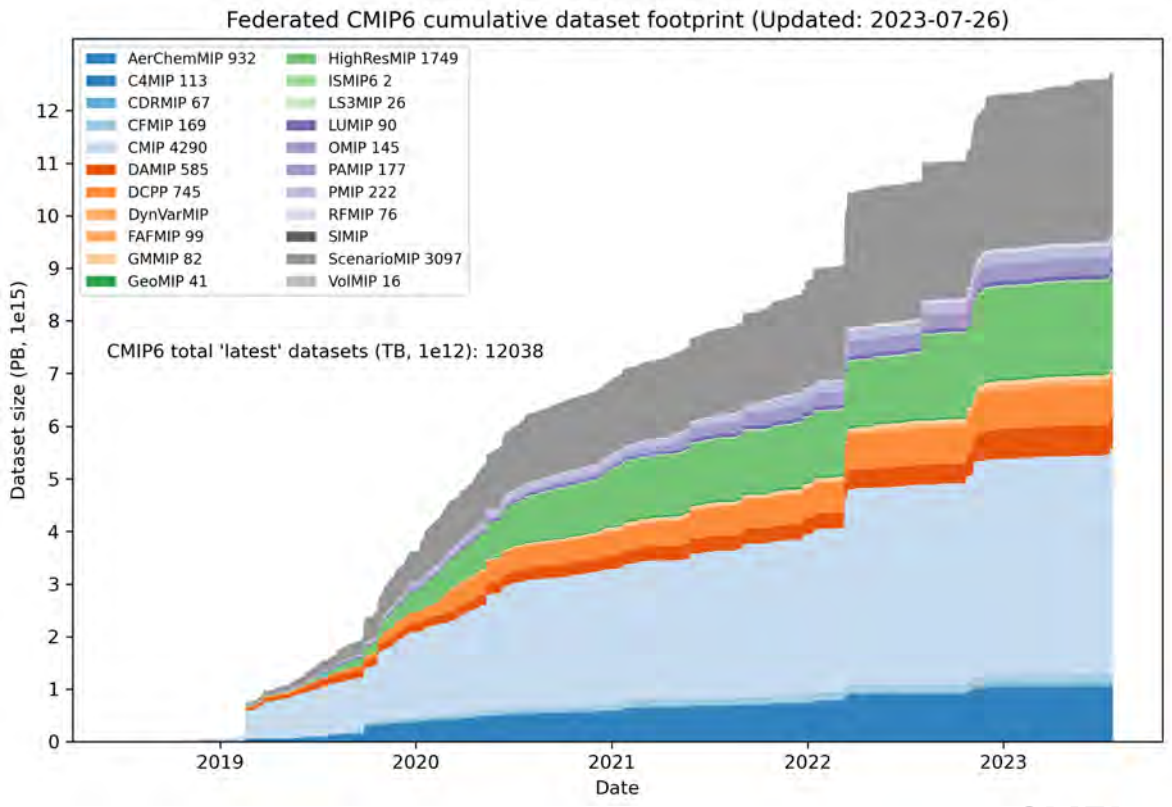
Participation in MIPs by individual modelling groups is at their own discretion and depends on their scientific interests and priorities.

Common standards and open access

Common standards: experimental, forcing, data; Allowing coordination on infrastructure and documentation that facilitates distribution of model outputs and the characterization of the model ensemble.

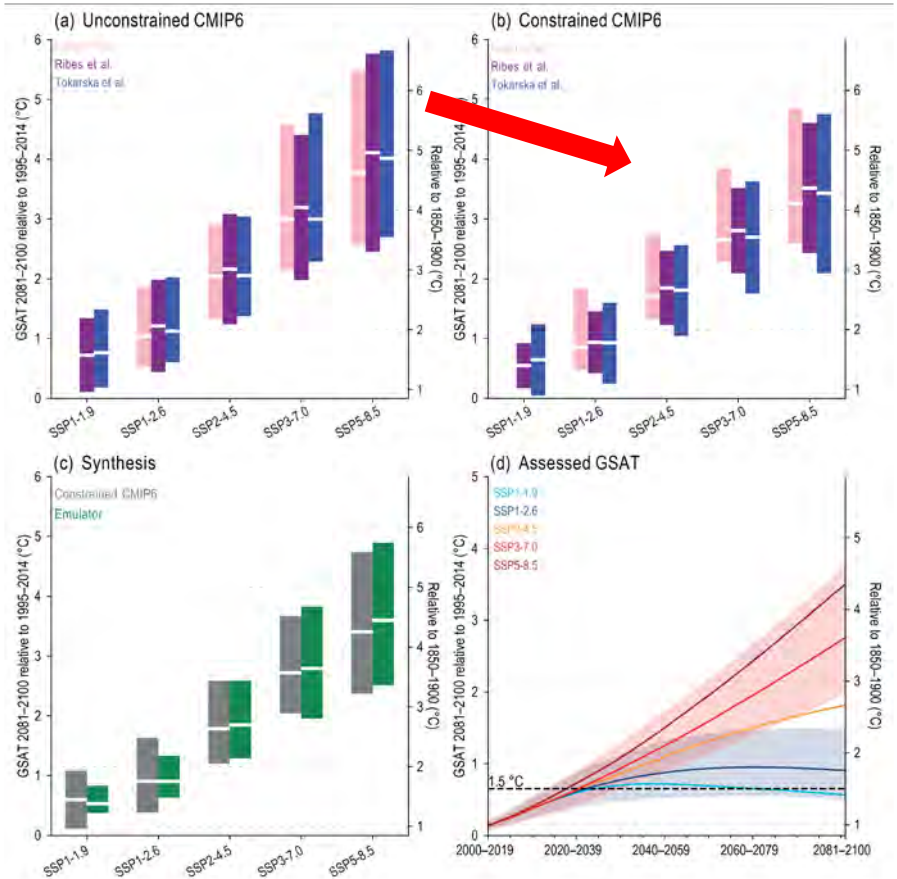
ESGF Published CMIP6 data

- Over 6.4 million CMIP6 ESGF datasets across activities/MIPs
- Seamless delivery – thanks to ESGF data challenges/stability testing
- Datasets - unique variable collections per experiment RIPF (unique simulations)
- Footprint – units of Petabytes



CMIP6 in AR6/IPCC

- CMIP6 “hot models” – climate sensitivity > Sherwood et al. (2020) and > AR6 assessed very likely range
- AR first “constrained projections” – models weighted by observational agreement – downward “correction”
- Getting forcing (and response!) right underpins observed climate change attribution, future projections utility
- Projection user community growing markedly
- Raises model evaluation importance – model projections use requires specialist guidance
- Operational “climate services” need next-level climate science guardrails



IPCC AR6 WG1, 2021, Summary for Policymakers, Fig 1.4 doi:10.1017/9781009157896.001

CMIPnext planning

CMIP – a team sport!

- PCMDI
  - U.S. DOE provided 34-years of *MIP support
- ESGF
  - Originated by U.S. DOE ~2007
  - Major recent contributions from numerous others
  - IS-ENES and ENES-RI follow-on
  - European contribution to ESGF & CMIP infrastructure
  - Numerous other projects and institutions, including DKRZ, IPSL, CEDA, ES-DOC, NASA, NOAA, …
  - CMIP6: 30+ ESGF nodes, 17 countries, 131 models, 48 institutions representing 26 countries, and many, many more…

The CMIP International Project Office

- CMIP expanded to point where coordination of elements requires dedicated administration and facilitation support.
- IPO established March 2022 at host institution, ESA's ECSAT site in Harwell, UK.
- IPO team consists of:
  - Director (*Eleanor O'Rourke*)
  - Programme Manager (*Briony Turner*)
  - Science & Communications Officer (*Beth Dingley*)
  - Technical Officer (*Daniel Ellis*)
  - Part-time administrative support (*Alice Kolesnikov*)

Staff from HE Space Operations under contract to ESA

CMIP6 Survey: Suggestions for CMIP7

- No big structural CMIP6 change but evolution.
- Retain IPCC alignment in some form.
- Reduce huge burden on modelling centres.
- Need for greater focus on climate impacts and adaptation relevant experiments (including updated scenarios).
- Need for operationalisation of critical elements (e.g., forcing) – delays in forcing had major CMIP6 delivery impacts.
- Build on substantial CMIP6 data infrastructure progress to facilitate science and support improved, and more user friendly, data access.
- Continue and enhance active community input to the experimental design process.
- Nurture the CMIP future community and promote young and global South scientists.

WCRP World Climate Research Programme

CMIP

Addressing community concerns

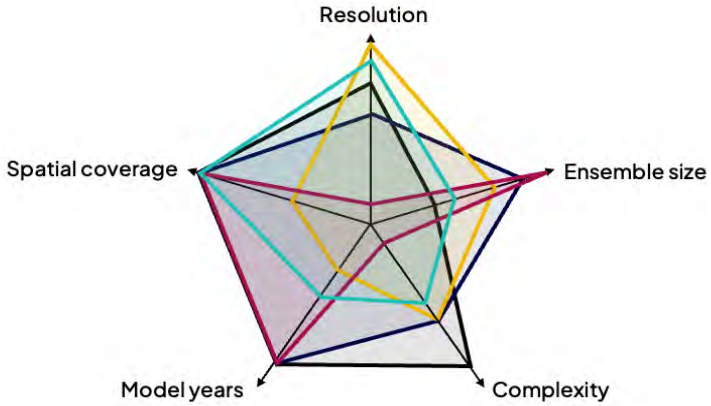
You said…. .	We are……
CMIP6 = burden on modelling centres	Reducing numbers of experiments.
IPCC timelines causes pressure	Proposing streamlined experiments on IPCC timeline. Freeing up community driven MIPs
Need for greater focus on climate impacts and adaptation relevant experiments	Seamless delivery across WGI, WGII and WGIII via updated scenarios tailored for mitigation and impacts policy applications with timely delivery to facilitate downscaling
Need for operationalisation of critical elements	Established Task Teams to deliver recommendations for sustainable delivery of near real time forcings.
Need sustainable funding of infrastructure to support improved, and more user friendly, data access.	Established Task Teams to deliver recommendations on requirements for future infrastructure and engaging with funders.
Continue and enhance active community input to the experimental design process.	Expanded CMIP Panel and established Task Teams through open calls plus rolling out extensive community engagement.
Nurture the future CMIP community and promote young and global South scientists.	Launched ECR group (Fresh Eyes on CMIP) and planning for CMIP Panel members from the global South.

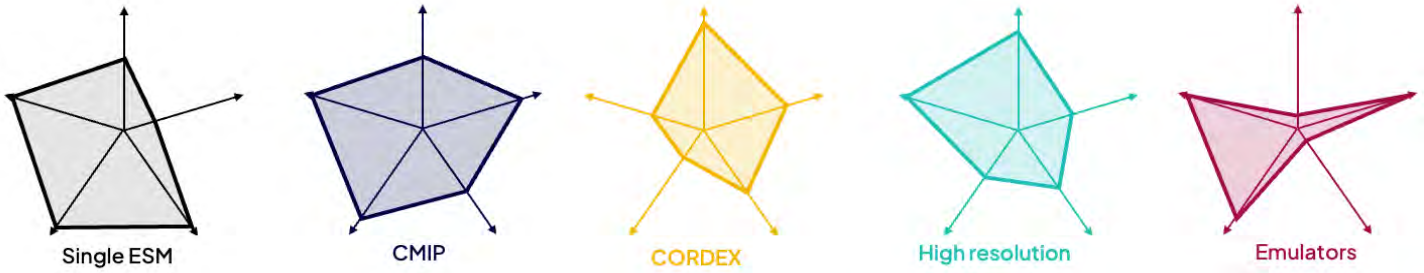
The Task Teams

CMIP Task Teams have been established to drive forward definition of CMIP7 in an open and collaborative manner.

- Data access (*Robert Pincus and Atef Ben-Nasser*)
- Data citation (*Martina Stockhause and Sasha Ames*)
- Data request (*Martin Juckes and Chloe Mackallah*)
- Forcings (*Paul Durack and Vaishali Naik*)
- Model benchmarking (*Birgit Hassler and Forrest Hoffman*)
- Model documentation (*David Hassell and Guillaume Levavasseur*)
- Strategic ensemble design (*Ben Sanderson and Isla Simpson*)
- Fresh Eyes on CMIP (*currently under evaluation*)

The role of CMIP within the Modelling Multiverse





CMIP

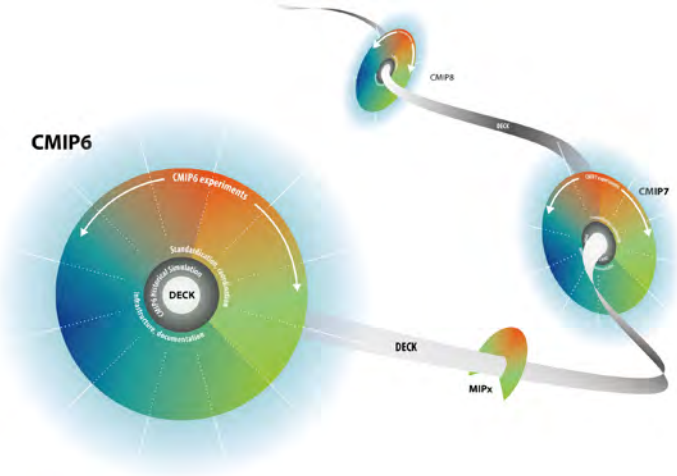
Need for multi-model ensembles beyond CMIP6

- CMIP – provides proven method for testing/validating climate models.
- Enhanced process understanding enabled by improved model fidelity, increased complexity and resolution (e.g., emergent properties).
- Hypothesis testing using climate change projections based on new, updated, and extended scenarios. CMIP infrastructure enables this.
- New observational comparison opportunities emerged that motivate new diagnostics and MIPs (e.g., SWOT, EMIT, BGC Argo – also obs4MIPs).
- CMIP – key international climate service (serves IPCC, policymakers).
- An extended 'gap' in CMIP delivery could result in poorer quality climate information being used by the policy and downstream user community.

CMIP

WCRP World Climate Research Programme

CMIP Infrastructure

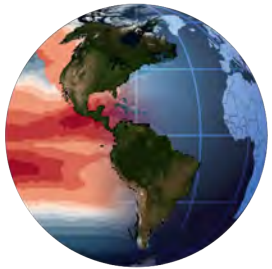


- Leveraging the CMIP6 infrastructure to benefit wider WCRP activities (CMIP6Plus).
- New and ongoing MIP activities can request guidance and limited support.
- Enable responsive activities (e.g., CovidMIP, ZECMIP, LESFMIP, CERESMIP, RAMIP, …).
- Support CMIP and wider activities' evolution and potential operationalisation of components (e.g., testing next generation forcings)
- Determining a sustainable funding model for CMIP infrastructure.

CMIP6Plus: facilitating and enabling science

Can we leverage existing infrastructure investments, while not waiting?

- Agile, responsive evolution
  - Continuous DECK is a start
  - Facilitate, respond and enable science opportunities – CovidMIP, ZECMIP/C4MIP
- Allow CMIP to evolve and "operationalise"
  - Incremental change (e.g., maintain ESGF dependence)
  - Next generation forcings and observations
  - Change little, increment and allow modelling groups to focus on science
- Best prepare CMIP for exascale and the AI/ML onslaught.



CMIP6+

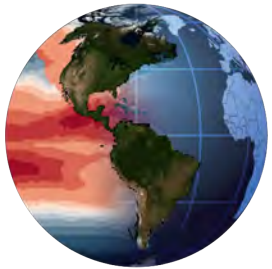
Coupled Model Intercomparison Project next phase

CMIP

CMIP6Plus: facilitating and enabling science

Can we leverage existing infrastructure investments, while not waiting?

- Continue beyond CMIP6 with few changes as CMIP7 is planned
  - Reduce time pressures – loosen CMIPx to IPCC ARx linkage
  - Continuous CMIP science – move away from monolithic ~7 year phases
- Facilitate and recognise contributors
  - Ensure all contributions are recognised
  - How can we support forcing data providers?
  - Funding? (“CMIP endorsed” data provider)
  - Infrastructure support?



CMIP6+

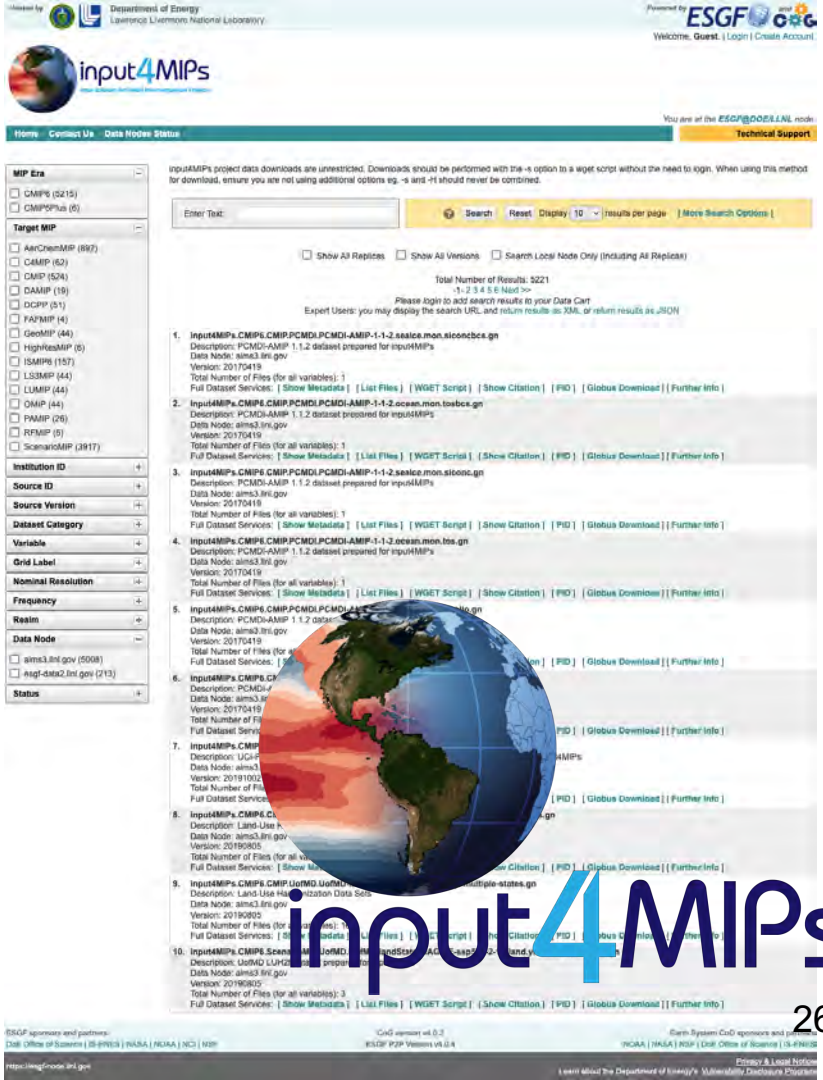
Coupled Model Intercomparison Project next phase

Looking forward: CMIPnext ideas

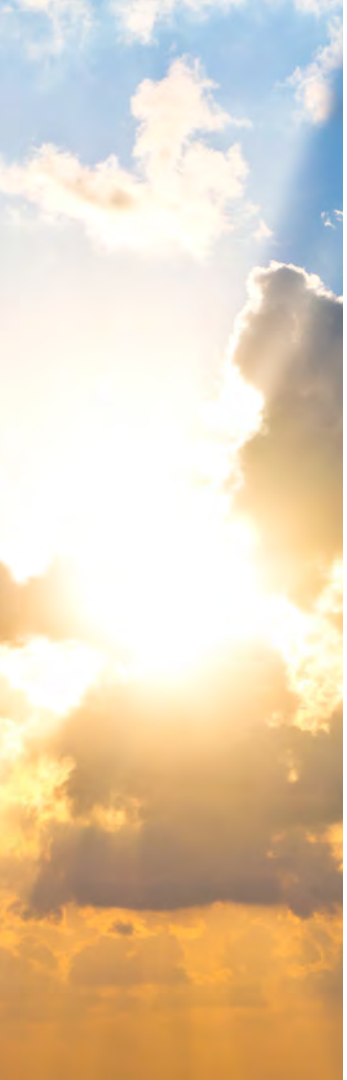
Can we optimise to meet science goals without bloating the archive?

- Not just data request – rather, MIPs provide diagnostics/code to implement
  - Rather than requesting data, request the targeted diagnostic
  - Plus = less data, minus = locks out spontaneous science opportunities
- MIPs define diagnostics to implement within models
  - Advance the inclusion of key simulators (e.g., COSP)
  - Encourage MIP diagnostic team development – move workload to MIP chairs, not modellers
- How to best leverage community diagnostics
  - ESMValTool, CMEC (Coordinated Model Evaluations Capabilities), NOAA-MDTF
- Amalgamate efforts to reduce overheads (e.g., input4MIPs, obs4MIPs)

CMIP

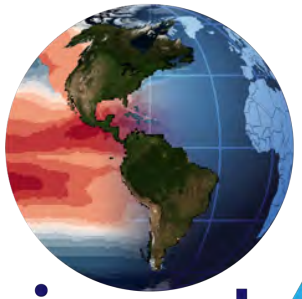


obs4MIPs input4MIPs



Climate forcing

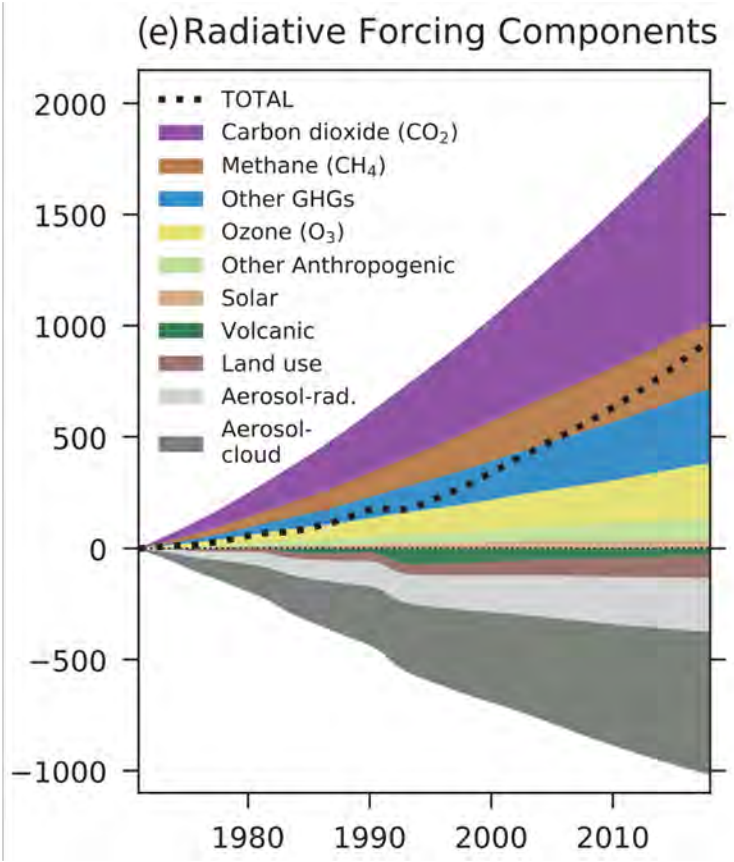
- *MIP history proved external climate forcing matters
- Historical forcings are keys to climate change attribution
- Future forcing will determine future state (accurate projection/predictions)
- input4MIPs began the process
  - CMIP forcing dataset coordination
  - Version control and documentation
- Beyond CMIP6
  - Evaluate, quantify and better understand uncertainties
  - Dataset harmonization across products
  - Quantify, version control and document forcings
  - Feedback on MIP experimental design through forcing evaluation

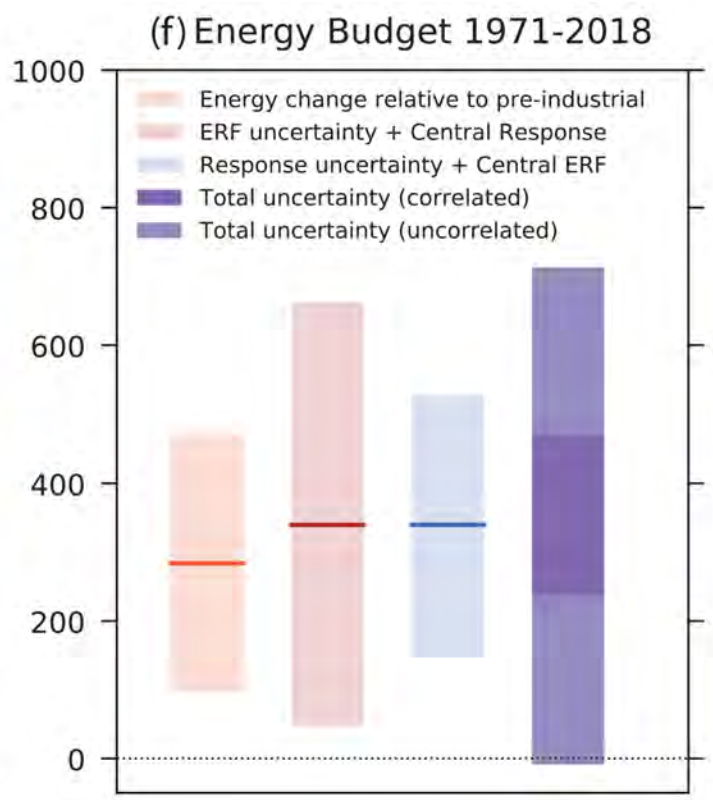


input4MIPs

CMIP

Climate forcing





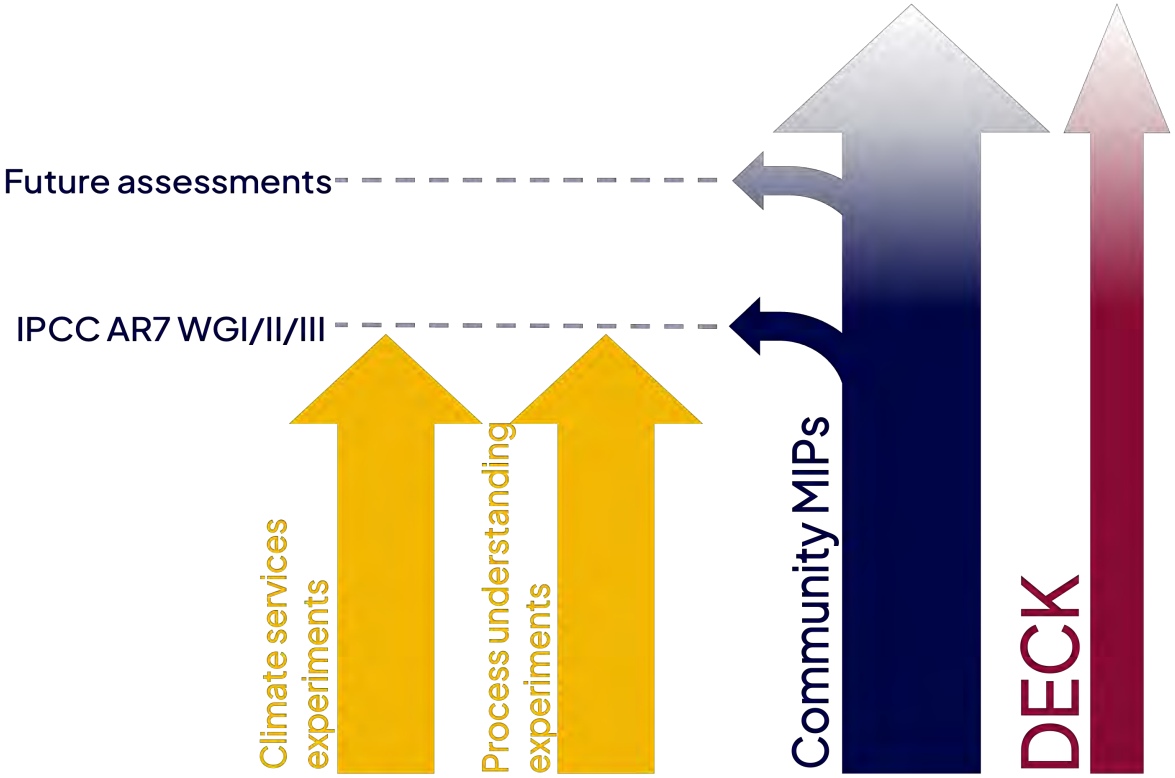
IPCC AR6 WG1, 2021, Box 7.2 Fig 1 doi:10.1017/9781009157896.009

Forcings provision (including scenarios)

- Delays in forcing dataset provision were highly problematic during CMIP6.
- There is a need to update, and develop new forcing datasets with adequate time for robust evaluation before CMIP7 commences.
- Scenario development is increasingly important to ensuring policy makers have the information they will need to address post 2030 mitigation and adaptation planning.
- Forcings session at AGU23 in December 2023.

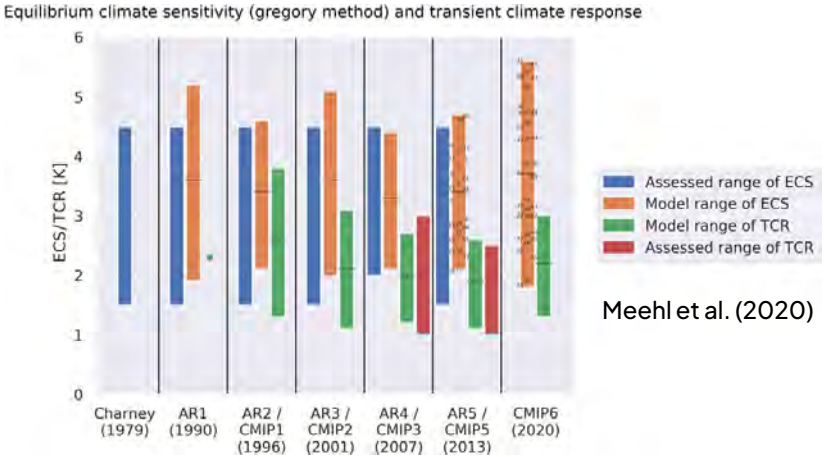
CMIP7

Evolving CMIP7 structure



CMIP7 will address WCRP science objectives

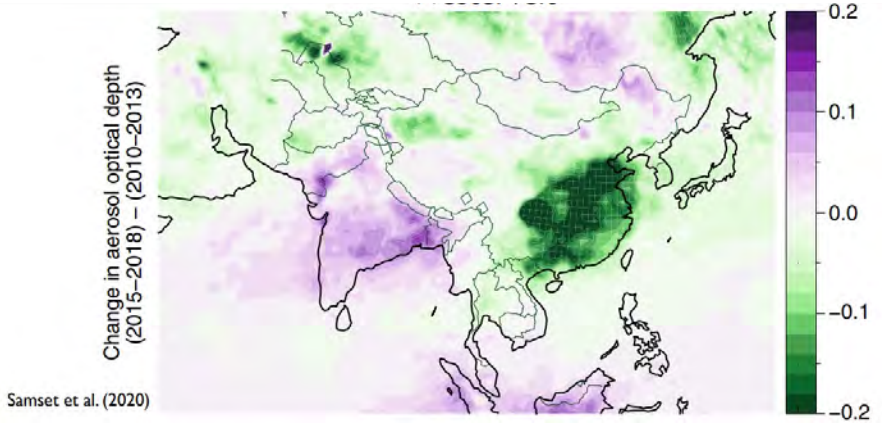
1 *Fundamental understanding of the climate system*



Meehl et al. (2020)

Help reconcile the observational refutation of high ECS models and their continued prevalence in the ensemble.

2 *Prediction of the near-term evolution of the climate system*

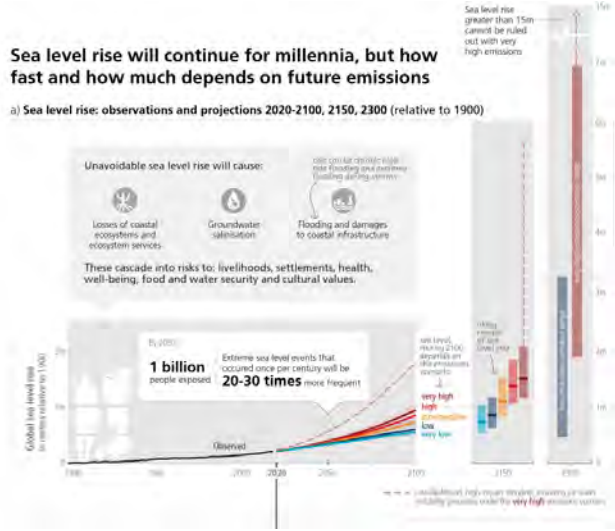


Assess forcing uncertainty e.g., the potential to explore sensitivity to high aerosol forcing.

CMIP

CMIP7 will address WCRP science objectives

3 *Long-term response of the climate system*

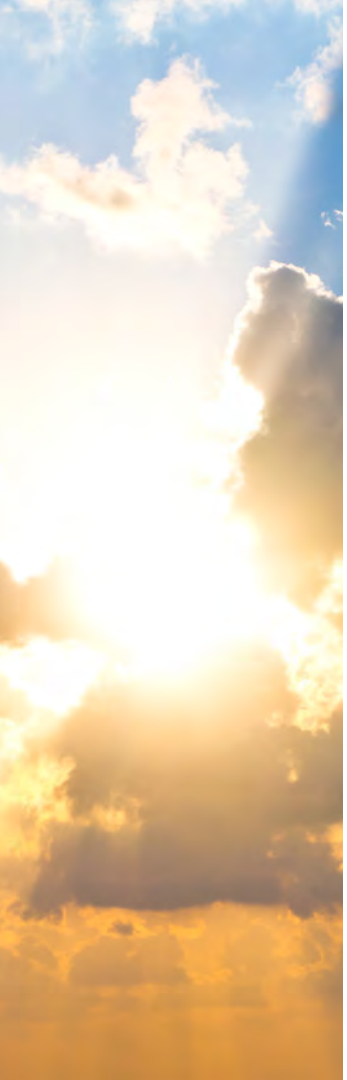


IPCC AR6 SYR

Focus beyond 2100 including overshoots and e.g., how to better constrain sea level rise "deep uncertainty" under >3°C warming.

4 *Bridging climate science and society*

WCRP CORDEX CMIP



CMIP7 preliminary timeline

For the subset of CMIP7 experiments aimed at IPCC alignment, engagement with the new IPCC leadership is underway. Planning will coalesce in late 2023. Community MIPs do not need to align with that timeline, although they may choose to do so. Current estimates suggest:

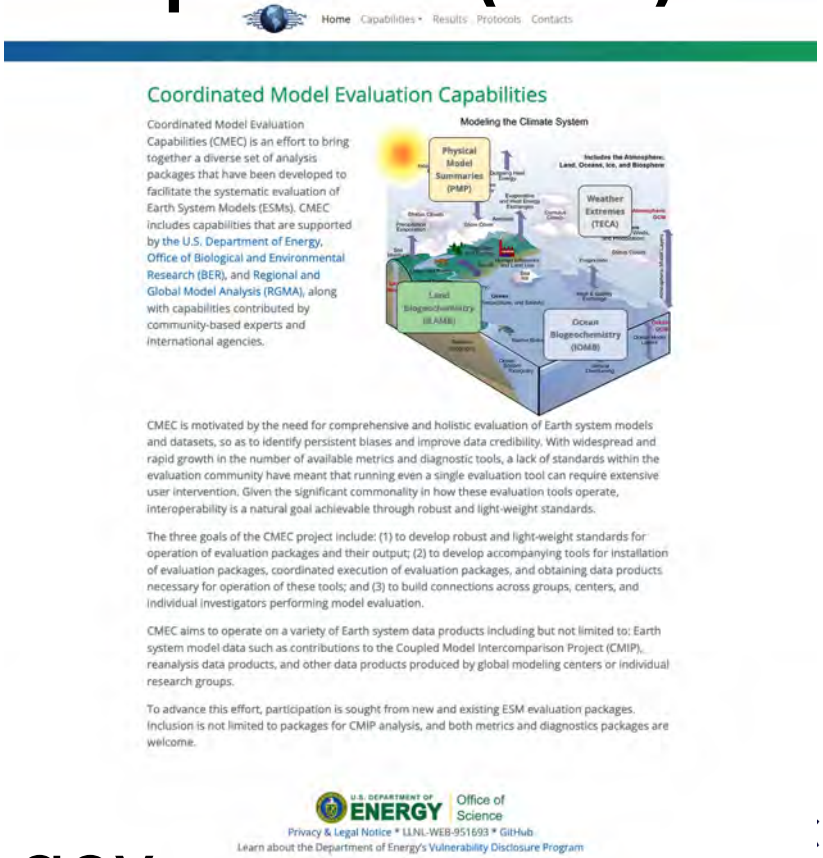
- Historical forcings: Update expected, with data extending until December 2021 available by mid-2024 and revised in 2026 (CMIP Forcings timeline – current status).
- Scenario forcings: late 2026 (link to ScenarioMIP pages)
- Data request: Initial production versions expected early to mid-2025, with regular updates thereafter.
- Modelling centres: Consulting on expectations for when new models and associated infrastructure will be ready.
- ESGF nodes: ESGF needed to collate and serve the data. Ongoing discussions led by the WIP and ESGF community.
- CMIP7 description paper: Intention for submission in 2024.

CMIP

CMEC

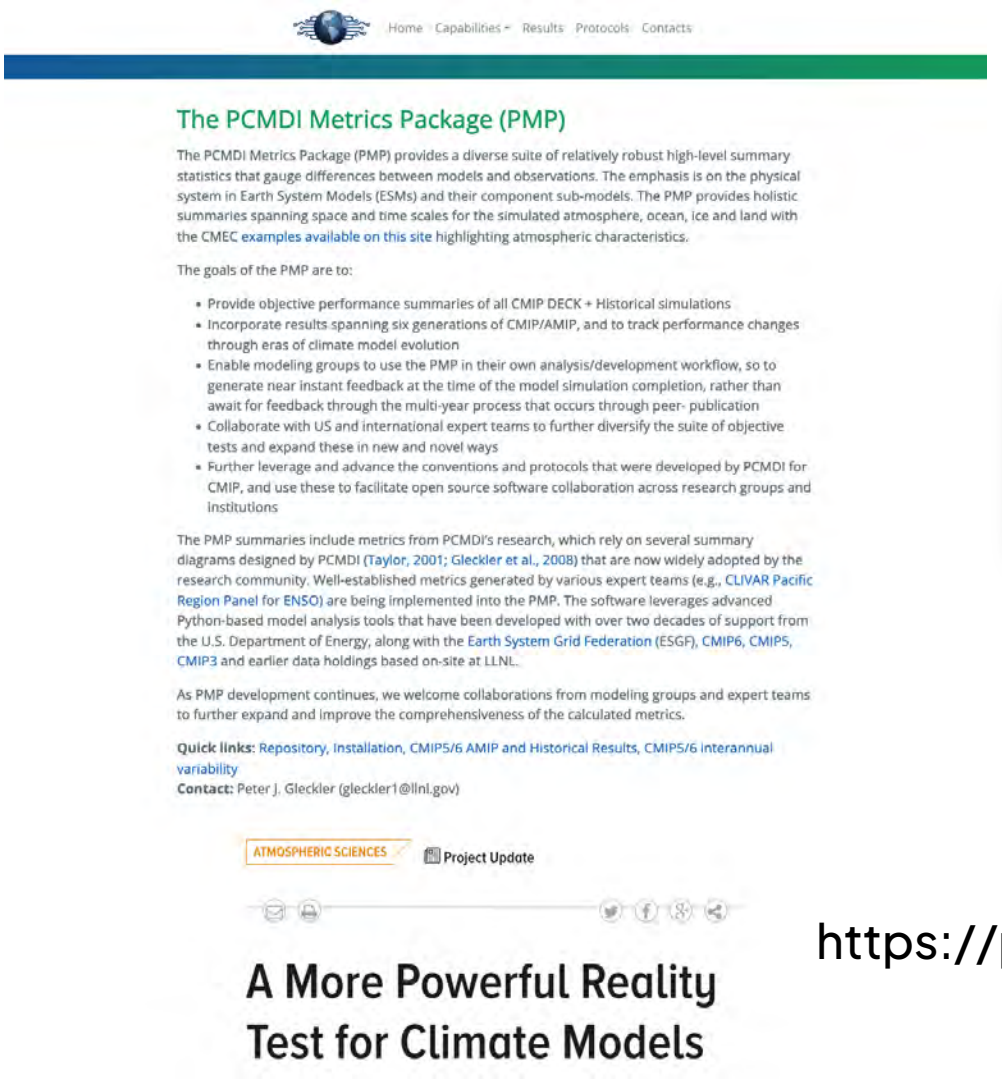
Coordinated Model Evaluation Capabilities (CMEC)

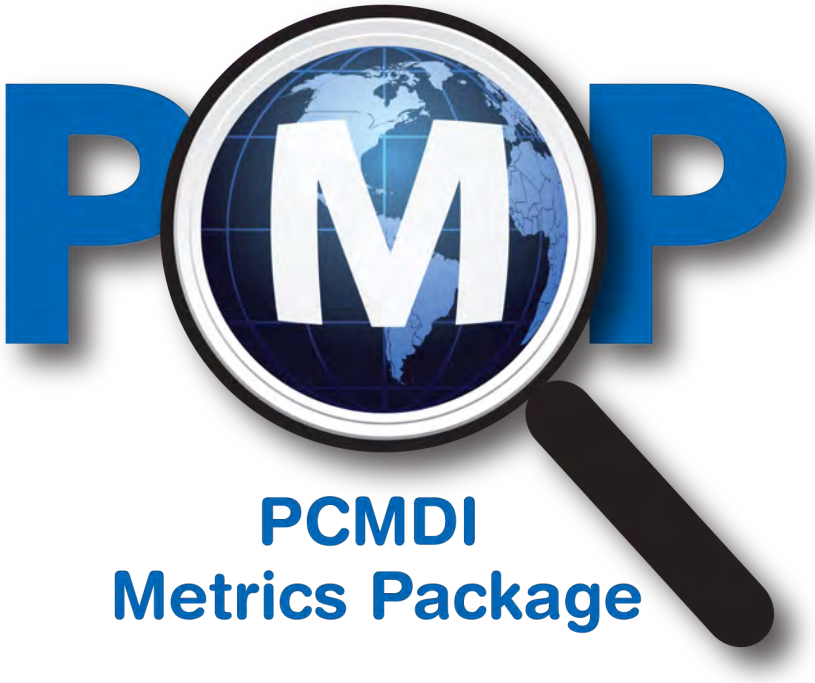
- Effort to bring together a diverse set of analysis packages developed to facilitate Earth System Model systematic evaluation
  - PCMDI Metrics Package (PMP)
  - International Land Model Benchmarking Package (ILAMB)
  - Toolkit for Extremes Climate Analysis (TECA)
- Technical alignment, providing a simple and consistent driver interface across all contributing modules
- Coordinates and organizes output data produced by CMEC packages



https://cmec.llnl.gov

MIP

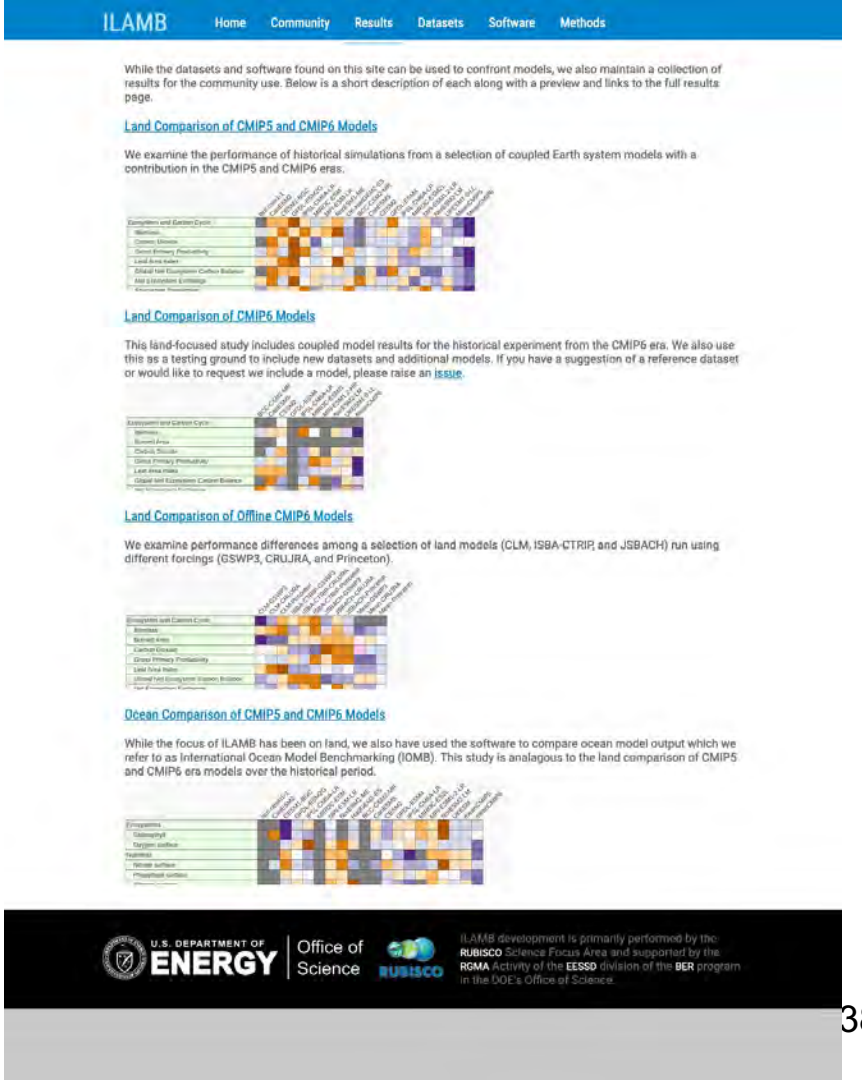


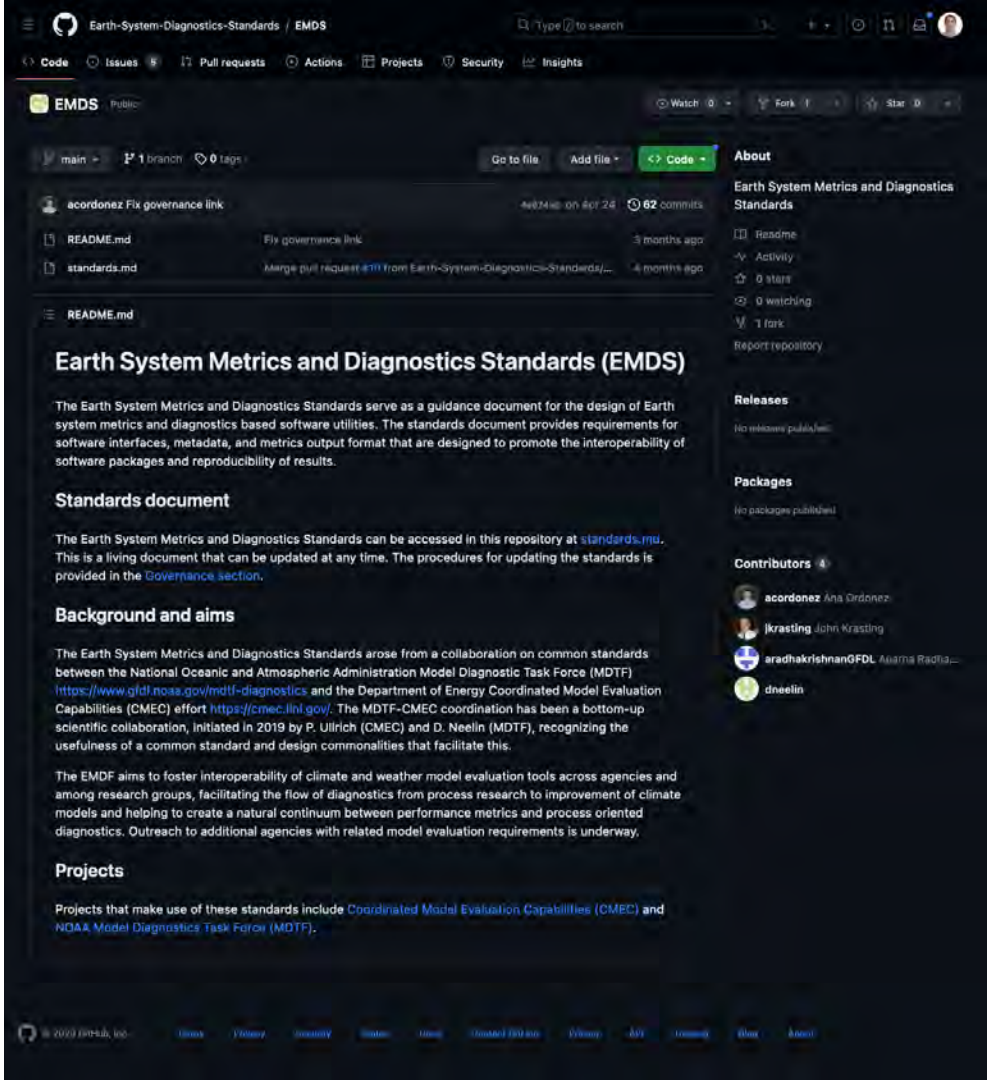


https://pcmdi.llnl.gov/research/metrics/

ILAMB | International Land Model Benchmarking

https://www.ilamb.org





CMEC
LLNL, ORNL, LBNL
Dept of Energy

NOAA-MDTF
NOAA-GFDL, UCLA, U/NCAR, PNNL, Colorado State, Florida State, UCD, UW
Dept of Commerce/NOAA

https://github.com/Earth-System-Diagnostics-Standards

Thank You!

Questions, suggestions..?

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Contact cmip-ipo@esa.int with any questions or feedback.
More information can be found at wcrp-cmip.org

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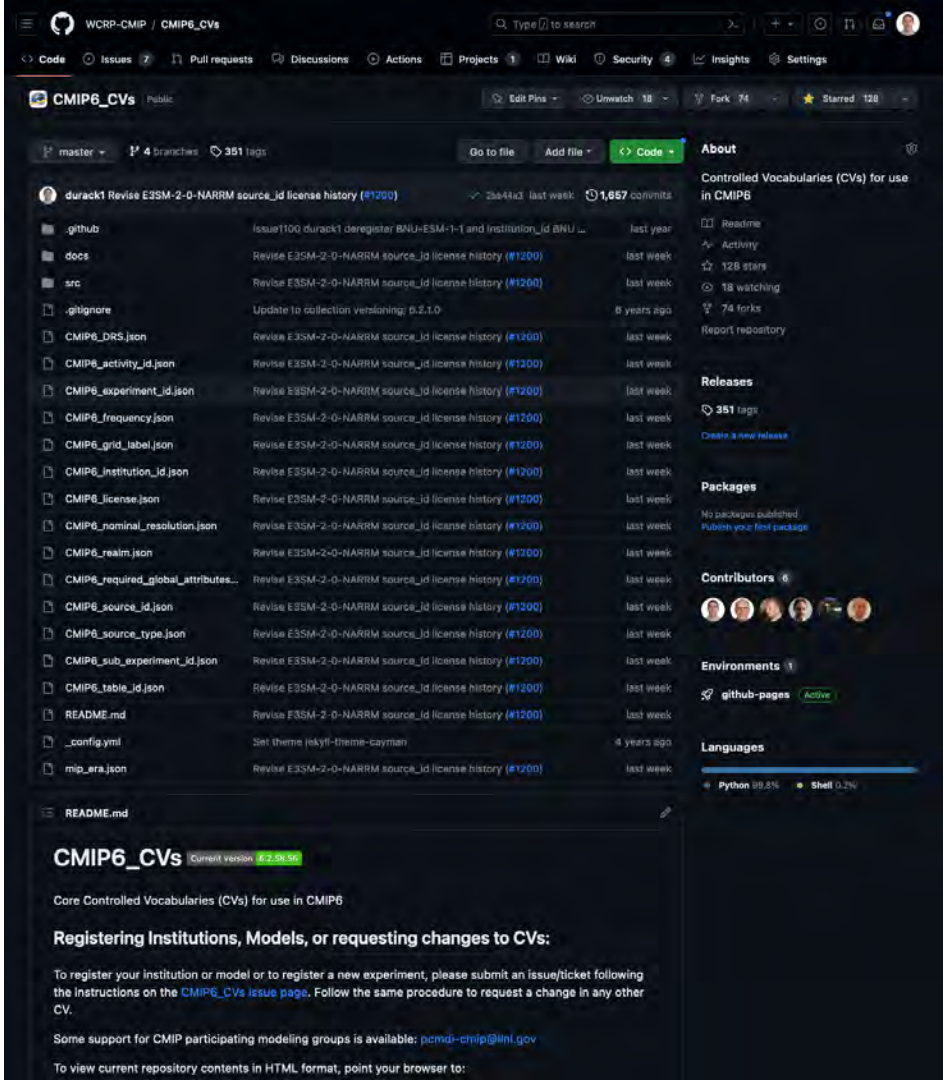
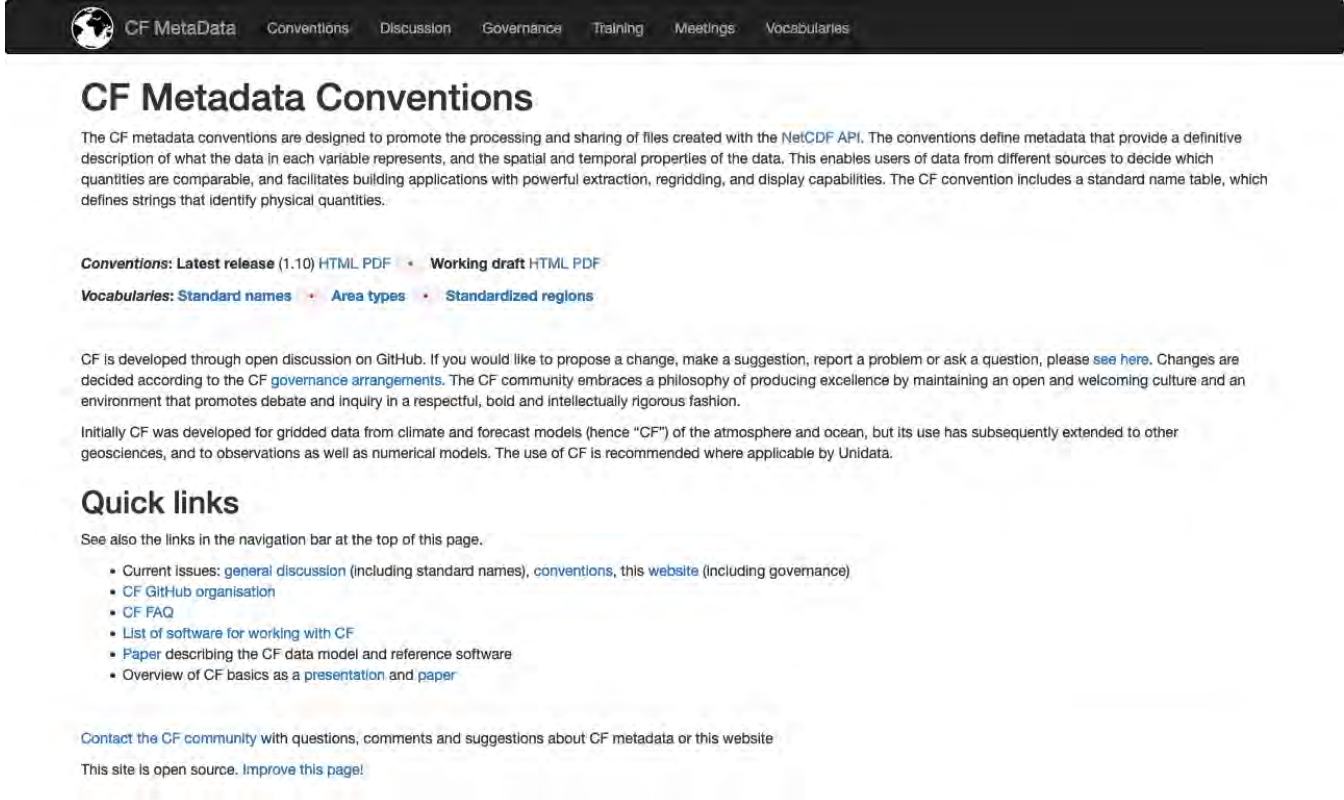
Lawrence Livermore National Laboratory

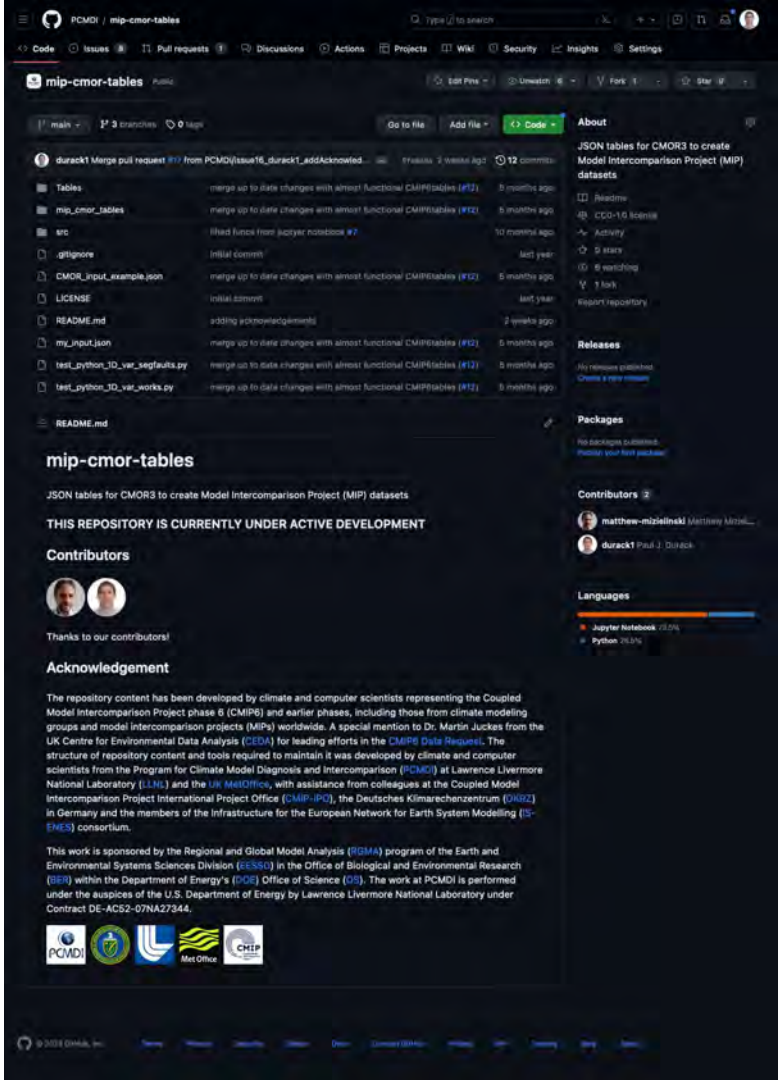
Extra slides



https://github.com/WCRP-CMIP/CMIP6_CVs



http://cfconventions.org



https://github.com/PCMDI/mip-cmor-tables/

Time-evolving *MIP external forcing

Forcing/MIP era	AMIP1	AMIP2	CMIP1	CMIP2	CMIP3[a] 20c3m	CMIP5[b] historical	CMIP6[c] historical
SST & sea ice	Y	Y			Y (AMIP)	Y (AMIP)	✓ (AMIP)
Greenhouse gases		Y (fixed: CO_2, CH_4, N_2O)	Y (fixed)	Y (fixed and 1% idealized)	Y (~5 species)	Y (~9 species)	✓ (46 species)
Ozone		Y?	Y (fixed)	Y (fixed)	½	Y	✓
Sulphate aerosols (in/direct)					½ / Y	⅖ / Y	✓
Black/Organic carbon					½ / ½	⅘	✓
Land use change					⅓	¾	✓ (4 states)
Solar irradiance		Y(fixed)	Y (fixed)	Y (fixed)	½	9/10	✓
Volcanic aerosols					½	9/10 (3 variants)	✓
Nitrogen deposition							✓ (4 species)
Total varying forcings	**2**	**2**	**0**	**1 (idealized)**	**~15**	**~24**	**~63**