An evolving Coupled Model Intercomparison Project phase 7 (CMIP7) and Fast Track in support of future climate assessment

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Abstract. The vision for the Coupled Model Intercomparison Project (CMIP) is to coordinatecoordinates community- -based efforts to answer key and timely climate science questions and, facilitate delivery of relevant multi-model simulations through shared infrastructure for the benefit of the physical understanding, vulnerability, impacts and adaptations analysis, and support national and international climate assessments, and society at large. From its origins as a . Generations of CMIP have evolved through extensive community engagement from punctuated phasing of climate model intercomparison and evaluation, CMIP is now evolving through coordinated and federated planning into a more continuous climate modelling program. The activity is supported by the support for the design of experimental protocols, an infrastructure that supportsfor data publication and access, and the phasedpublic delivery or "fast track" of climate information for national and international climate assessments informing decision making. Key to these CMIP7 efforts are: an. We identify four fundamental research questions motivating a new phase coupled model intercomparison relating to: patterns of sea surface temperature change, changing weather, the

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Style Definition: Bullets: English (United States), Outline numbered + Level: 1 + Numbering Style: Bullet + Aligned at: 0.25" + Indent at: 0.5" water-carbon-climate nexus, and tipping points. Key CMIP7 advances include: expansion of ~~the Diagnostic, Evaluation and Characterization of Klima (DECK) to include historical, effective radiative forcing, and~~baseline experiments; focus on CO_2-emissions-driven experiments; sustained support for community MIPs; periodic updating of historical forcings and diagnostics requests; and a collection of prioritized experiments, or “Assessment Fast Track”, drawn from community MIPs to support ~~research towards the 7th Intergovernmental Panel on Climate Change Assessment Reporting cycle, or “AR7 Fast Track”, and climate~~climate research, assessment, and services goals across prediction and projection, characterization, attribution, and process understanding.

1 Introduction

The Coupled Model Intercomparison Project (CMIP) is an international research activity that develops coordinated experimental protocols within the World Climate Research Programme (WCRP) for global coupled atmosphere-ocean-land-ice ~~coupled~~ climate and Earth System Models (ESMs) and facilitates the distribution~~,~~ and interpretation~~, and use~~ of simulation output. ESMs represent the ~~time evolution of the climate and the~~ statistical characteristics of the weather and time evolution of climate through ~~a combination of the representation of the dynamical~~ the equations of motion ~~and equations describing the~~, physics, and thermodynamics ~~of~~and the interactions between radiation, clouds, and aerosols ~~and~~within the coupled hydrosphere, geosphere, biosphere, and cryosphere. Preceding phases of CMIP (Meehl et al., ~~1995~~1997; 2000; 2007;Taylor et al., 2012; Eyring et al., 2016) have ~~made evident how~~evidenced the evolution of ESMs ~~has~~for improved ~~the~~ representation of the Earth system through testing, evaluation, and comparison of models across generational increases in spatial resolution (initially tens of degrees to now around a quarter of a degree), comprehensiveness (including carbon cycle, atmospheric chemistry, aerosols, biogeochemistry, ecosystems, ~~ocean acidification~~cryosphere, land-hydrology interactions, sea level rise, and human drivers), and granularity (ensembles of models assessing structural uncertainty, detection and attribution, predictability, sensitivity to feedbacks, statistics of extremes, etc~~). There are, however, persistent model structural uncertainties and biases through the generations of CMIP that continue to require model development and assessment to ensure that these models are able to produce the most accurate predictions for the climate system moving forward.~~) (Figure 1). In addition to representing water and energy cycles and associated dynamics, ESMs coupling chemistry and the carbon cycle with the physical climate system have broadened model utility and applicability, for example, allowing exploration of interactions between anthropogenic emissions, climate, and the biosphere as mediated by biogeochemical cycles (Sanderson et al., 2024a). ~~As self-consistent representation of physics, biology, and chemistry on weather to climate time scales, each ESM contributing to past phases of CMIP has represented one combination of choices along the many dimensions of the multiverse of models (Figure 1). In particular, in addition to representing water and energy cycles and associated dynamics as in physical climate models, ESMs broaden the focus to questions in which the coupling between chemistry and/or the carbon cycle and the physical climate system plays a key role, for example exploring interactions between anthropogenic emissions and climate as mediated by biogeochemical cycles (Sanderson et al., 2024).~~

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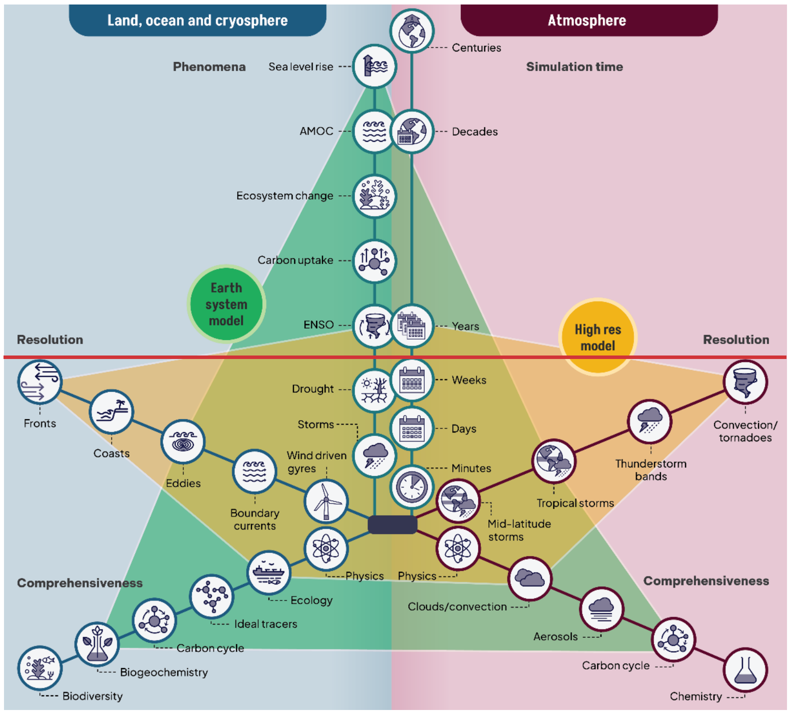
As an international research activity within WCRP,

CMIP supports the WCRP 2019-2028 science prioritiesobjectives of "Fundamental understanding of the climate system", "Prediction of near- term evolution of the climate system", "Long term response of the climate system", and "Bridging climate science and society." As described in Meehl (2023) and Stevens (2024), the origin of CMIP was to systematically assess coupled models – to characterize their biases, interactions, and response – and evaluate the effectiveness of ongoing model development efforts to address structural model issues or incorporate new processes. In early CMIP phases, the core CMIP experiments were those commonly performed by individual modeling centers during their model development cycles. A key to the scientific value of the model intercomparison research was that all models were run under the same experiment conditions. In particular, the same forcings were imposed on the models. With CMIP's early successes, the forcings were improved and extended for each of its successive phases. Equally important to CMIP's research appeal and impact were the strict standards imposed on the data produced by the models and the multi-model archive of all CMIP data, supported by a specially purposed software infrastructure (Durack et al., 2025). With all models providing publicly available results in the same format and structure, the same downloading tools and analysis code could be applied to all models without altering how the model output was ingested.

As a publicly available ensemble including state-of-the-art coupled model contributions from centers around the globe, CMIP collects simulations of varying levels of structural idealization from many physical climate models and ESMs. This international effort supports a wide range of science activities by providing a combination of idealized and single forcing experiments for the scientific community to interrogate and build a The range of CMIP experiments are instrumental to the research community's ability to build robust scientific literature underpinning mechanistic and process understanding of the complexities of climate change in the Earth system. More realistic (Durack et al., 2025). Realistic historical and projection simulations also support investigation into quantification of change and application to a broad range of societally relevant societal impacts.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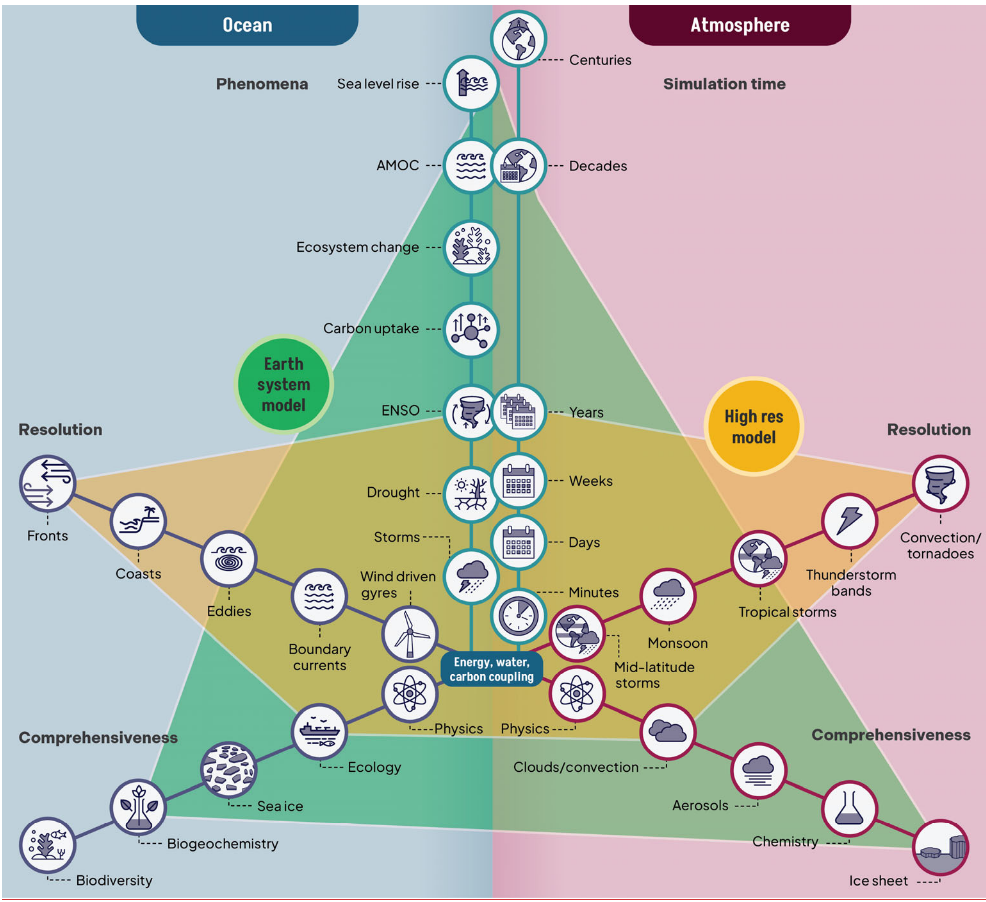

Figure 1: Earth system ~~modelling~~modeling as part of the multiverse of modeling approaches across resolution, comprehensiveness and simulation time. Atmospheric aspects are shown in red and ocean aspects in blue. Note that ensemble size, experiments/scenarios, precision, accuracy, availability and familiarity also come into play in the search for efficiency and robustness.

~~Beyond uncovering the systematic behavior~~The historical publicly availability of ~~coupled models and the associated uncertainty in climate behavior and the underlying response,~~ CMIP ~~simulations~~ensembles have ~~also proven useful across the scientific~~critically allowed the climate research community ~~for exploring~~to explore ideas without having to design unique experiments and run simulations in house ~~wherein the~~and advanced understanding of climate's fundamental underlying physics is elucidated through intercomparison. Examples are wide ranging including in such examples as tropical (Bellenger et al., 2014; Planton et al., 2021) and extra-tropical variability (Simpson and Polvani, 2016; Zappa and Sheppard, 2017), the behavior of temperature and precipitation extremes (Seneviratne and Hauser, 2020; Borodina et al., 2017), understanding the factors that influence modelleddriving modeled climate sensitivity (e.g., Zelinka et al., 20192020), and the connections between the representation of present-day climatology or processes and future projected change (e.g., Hall et al., 2019).

In addition to the systematic characterization of climate mechanisms,

CMIP has supported national and international assessments in the provision of climate responseresponses to first idealized forcing followed by selected community-developed scenarios of projected forcing and scenario-based projections of forcing has supported numerous national and international assessments (see **https://wcrp-cmip.org/cmip-use-in-policy/** for a partial list) and been considered in(Meehl et al., 2007). Projected climate change in coupled models due to increased greenhouse gas forcing has also been part of every Intergovernmental Panel on Climate Change (IPCC) report since its inception (Meehl et al., 2007). . The first climate change projections made with climate models used instantaneously doubled CO_2 concentrations to estimate what has become known as Equilibrium Climate Sensitivity (ECS; Manabe and Stouffer, 1980). A second idealized sensitivity experiment incorporated transient CO_2 forcing — increasing CO_2 1% per year to assess the Transient Climate Response (TCR; Mitchell et al., 1990) — followed as part of CMIP2 (Meehl et al., 1997) in support of the IPCC third (Cubasch et al., 2001) Working Group I assessments, respectively. Idealized simulations were complemented by sets of more realistic historical and projected scenarios in subsequent iterations of the protocol. One of the key roles of CMIP has been to provide one line of evidence on the likely range of CO_2 climate sensitivity in IPCC Assessments. The role for CMIP has broadened to general use for systematically sampling and characterizing model diversity as an element of uncertainty in a range of climate applications. These Scenario projections include not onlythe response to changes in CO_2 but alsoand other greenhouse gases, aerosols, and ozone, across a range of increasing and recovery trajectories via human perturbations to the carbon cycle and other aspects of the Earth system and others, and evolving. Analysis has evolved from an initial focus on the climatological response in temperature and precipitation to the response in: climate modes such as El Niño Southern Oscillation, extremes, such as drought, heat waves, monsoons and tropical storm statistics, and other a comprehensive suite of climate indicators such as snowpack, sea ice, ocean circulation and, sea level rise, withand ecosystems, and the implications across economic and societal sectors for agriculture, energy, transportation, infrastructure, and resilience among many others.

. Together, these activities support assessment and other climate services with increased understanding and projections across a suite of potential futures in support of climate resilience, adaptation and mitigation planning, policy analysis, and decision-making. Beyond direct contribution to national and international climate assessments, CMIP .

CMIP increasingly also supportsprovides the source of climate serviceinformation for other large community research activities including downscaling through internationalthe WCRP projects such as the COordinated Regional Downscaling EXperiment (CORDEX; https://cordex.org/; Giorgi and Gutowski, 2015; Gutowski et al., 2016) and the Regional Information for Society (RIfS; https://www.wcrp-rifs.org/),2016) , Inter-Sectoral Impact Model Intercomparison Project (ISIMIP;

Warszawski et al., 2013), Sea Level projections via FACTS (Kopp et al., 2023), ~~Vulnerability, Impacts, Adaptation, and~~ the Copernicus Climate ~~Services (VIACS; Ruane~~Data Store (Buontempo et al., ~~2016~~2022) and ~~government services such as~~ the Copernicus Interactive Climate Atlas (https://atlas.climate.copernicus.eu/atlas~~) which resulted from previous atlases of the IPCC Reports (e.g.,~~; Gutierrez et al., 2021). ~~CMIP has been also applied to non-governmental, non-profit climate change attribution evaluation reports and real time diagnostics of high impact extreme events around the world such as World Weather Attribution (https://www.worldweatherattribution.org/; Otto, 2017, 2023) and Climate Central (https://www.climatecentral.org/; Gilford et al., 2022). CMIP results have been incorporated in climate vulnerability and readiness analyses for governmental policy, insurance, military preparedness, Non-Governmental Organizations, media communication, and commercial sector use, among others. CMIP~~

The CMIP protocols and resulting ensemble archive thus serves at least ~~three roles: a focal point for~~four roles: testing, evaluating, and comparing coupled models; scientific inquiry across a range of idealizations; ~~a source of information for the~~ exploration of plausible futures for climate attribution, downscaling and impacts contributions to climate services; policy-relevant assessment of ~~current understanding; and~~mitigation and adaptation options. Designing each CMIP phase as a ~~plausible representation of possible futures used both as a direct source of information or indirectly as a source of inputs through additional bias correction, sub-selection, climate attribution, downscaling or impacts modelling for climate services. Balancing~~research activity to balance the needs of ~~research,~~ evaluation, inquiry, service, and assessment~~, and~~ applications ~~has historically been one~~is challenged at times by lack of alignment between the ~~challenges~~burden of ~~designing CMIP phases because the burdens fall entirely~~investment falling mostly on the ~~research~~modeling community~~. Though~~ versus benefit for those credited for analysis in the subsequent scientific literature. Indeed, it has been argued that the assessment and service needs currently satisfied by CMIP might ~~well~~ be better met by a more sustained application of ESMs ~~to routinely updated forcings~~ (Schmidt et al., ~~2023~~2023a; Jakob et al. 2023; Stevens 2024~~), the~~). Unfortunately. the necessary ESM capabilities and associated infrastructure for such a sustained approach ~~is~~are not yet in place ~~at~~ either at any individual modeling center nor the national or international levels. ~~In the absence of non-research infrastructure for climate and Earth system modelling, the present~~ As a result, the experimental design for CMIP7 includes ~~some~~ components that might fruitfully be taken up outside the research community~~, but a set of immediate service needs remain an ongoing component of the project~~ in future phases of CMIP.

~~The design of CMIP7 responds to the experiences~~

The CMIP7 design provided here is informed both by cumulative participant experience obtained during CMIP6 and subsequent surveys and community feedback. Changes to the protocol and organization~~, described more fully below,~~ are intended to address community concerns by reducing ~~the~~contributor burdens of simulation and data provisioning ~~for contributors~~, facilitating more nimble community-driven ~~efforts~~MIPs, and ~~more clearly distinguishing among those aspects~~better supporting ~~science~~research, assessment, and service. The goals of CMIP7 are thus to ~~provide a framework supporting~~: 1) continue the rich diversity of ~~small~~multi-scale research built in CMIP6, 2) ~~continue to~~ enable episodic and punctuated participation and intercomparison and 3) facilitate more sustained participation with continuous and responsive support.

~~Though~~

Given a backdrop of multiple existing CMIP generations of ESM simulations ~~made for previous phases of CMIP have been a rich resource for developing understanding, it is worth asking whether the research community stands to benefit~~(Taylor et al., 2012; Eyring et al., 2026) and rapid development of alternative modeling approaches ranging from ~~another iteration of the project. The~~highly-resolved dynamical models to statistical emulators (Beusch et al., 2020; Mathison et al., 2024), the design presented here seeks to emphasize the value obtained from ~~an updated set of~~ new simulations by ~~Earth system~~ESMs within the multiverse of models~~.~~ (WCRP, 2023). That value arises from three main developments. First is the accumulation of a longer, richer observational record encompassing a wider range of conditions and the accelerating emergence of ~~the climate~~ change ~~signal~~ from climate variability. Second is the ongoing development and increasing comprehensiveness of ESMs aided by observational advances including increasingly diverse satellite observations of atmospheric composition, land characteristics, and ocean ecology~~. These~~ affording new opportunities for these models ~~need~~ to be evaluated, and their behavior understood ~~to interpret the results in the context of these new constraints.~~. Third is the formulation of new questions, four of which are articulated in the next section, about the co-evolution of natural systems and human ~~systems~~influence, especially as related to the trajectory of the carbon cycle ~~and its response to human activities, and the elaboration of models designed to address them. The design of CMIP7 is focused on four new research questions described in the next section for which understanding is evolving rapidly and new simulations promise to provide sharper insight. This section is followed by the CMIP7 guidance on protocols for the Diagnostics, Evaluation, and Characterization of Klima (DECK) and "AR7 Fast Track" experiments and their context in the evolving role of CMIP.~~.

~~**2 Guiding Research Questions**~~

~~The scientific component~~

This paper provides an overview of CMIP7 ~~focuses on~~ by first emphasizing four ~~guiding~~fundamental research questions (section 2) for which ~~moderately sized ensembles of~~ understanding is evolving rapidly and new ESM simulations ~~hold~~have great promise for sharper insight. The paper then describes guidance on protocols for the mandatory Diagnostics, Evaluation, and Characterization of Klima (DECK) and recommended "Assessment Fast Track" experiments (Section 3) distinguishing the more assessment and service focused prediction and projection experiments versus those aimed at process understanding through characterization, attribution before concluding with discussion of the evolving role of CMIP in the research community.

2 Fundamental Research Questions motivating Coupled Model intercomparison

Four questions emerged during initial planning for CMIP7 as areas in which a new ensemble of ESM simulations holds promise for substantial progress~~.~~ through the comprehensive approach of community engagement and wide range of different modeling approaches which only CMIP can deliver. These questions are ~~more~~ focused on the emergent capabilities of current ESMs — ~~and hence more timely and ephemeral —~~ consistent with but narrower than ~~those posed for CMIP6. A key opportunity permeating all~~ the WCRP 2019-2028 Science Objectives described above — as a synthesis by the CMIP Panel based on the experiments proposed by the broader community (section 3.3). While other pressing questions may be better addressed with different classes of models (e.g. cloud processes in global km-scale models, Merliset al., 2024), most experiments in the Assessment Fast Track (Section 3.4.5) address one or more of these questions ~~is~~. Underlying themes include the ~~ability~~opportunity to confront the ~~modelled~~modeled representation of historical trends with ~~a~~the seven years of further ~~eight years or more of the~~ observational record ~~past the 2014 termination from CMIP6 and new data constraints including the Earth radiative imbalance (Schmidt~~obtained since CMIP6, enhanced capabilities in modeling coupled carbon-chemistry-climate systems, and targeted experimental designs that leverage the multiverse of modeling tools (Hewitt et al., 2021; WCRP, 2023).

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2.1 Patterns of sea surface change: How will tropical ocean temperature patterns co-evolve with those at higher latitudes?

Description: The spatial pattern of sea surface temperature (SST) across the vast tropical Pacific has global implications through teleconnections and radiative feedbacks (e.g., Kang et al., 2020). ~~Models in earlier generations of CMIP consistently predicted that the global warming Sea Surface Temperature (SST) signal in the tropical Pacific would resemble El Niño~~SST evolution is intertwined with ~~an enhanced warming in the eastern equatorial Pacific (e.g., Cai et al., 2014; Wang et al., 2017). However, the AR6 report states that "there is no CMIP6 model consensus for a systematic change in intensity of ENSO SST variability over the 21st century," (Cai et al., 2022). Moreover, over the last several decades a signal of enhanced warming in the western Pacific and slight cooling in the eastern Pacific has emerged i.e., the opposite from that predicted by models on average (Coats and Karnaukas 2017; Seager et al., 2019). At the same time, a cooling has occurred in the Southern Ocean in the observational record in contrast to the expected warming based on CMIP simulations and there is growing evidence of a~~the fate of clouds which influence the global temperature response to increasing greenhouse gas concentrations (Armour et al., 2024) and feedback on local warming patterns (Myers et al., 2018; Erfani and Burls 2019; Rugenstein et al., 2023; Espinosa and Zelinka 2024). Growing evidence specifically suggests a two-way connection between trends in the Southern Ocean and those in the tropical Pacific (Dong et al., 2022; Kang et al., ~~2023). It is becoming increasingly clear that the SST trends observed~~ 2023), likely mediated by extratropical clouds (Kim et al. 2022) and unfolding over multi-year time scales. Models have helped elucidate some of the coupling mechanisms but struggle to reproduce important aspects of the historical SST patterns. Observed SST trends in both the tropical Pacific and the Southern Ocean are at ~~the very edge~~ or outside the range of those simulated by CMIP6 models (Wills et al~~.~~., 2022, Seager et al., 2022~~)~~), raising concerns that models are able to capture neither the externally forced trend nor the magnitude of internal variability ~~(or both)~~ in these regions (Watanabe et al., ~~2024). The~~

research community is now working to understand the origins of this discrepancy and there are now indications that unresolved processes such as ocean eddies (Yeager et al., 2023), melt water forcing (Dong et al. 2022, Schmidt et al, 2023), or recalcitrant biases, such as the double Intertropical Convergence Zone (Watanabe et al., 2024) or the cold bias in the equatorial cold tongue (Seager et al. 2019), may be playing a role. Transient or permanent shifts in SST patterns may also drive changes in the strength of some feedbacks (especially those mediated by clouds) and decadal changes in the Pacific (e.g., Li et al., 2023) with an impact on our understanding of the ongoing and future climate response with implications for climate sensitivity and time to 2C warming (Armour et al., 2024). Related to this key concern is the need for better joint understanding of historical and recent aerosol forcing and warming trends which appear to rule out high warming models in CMIP6, suggesting that the mechanisms behind both Earth's radiative balance and temperature changes may require a reassessment. In contrast to long-term trends, recent observational trends of the ocean heat content (OHC) of the upper 2000 m during 2005-2020 show significant warming in the tropical Pacific, subtropical oceans and the Southern Ocean, which reflect the El Niño-like structure and recent Pacific decadal shifts (Li et al., 2023). This study also documents a strong acceleration in global ocean warming since the 1990s, amounting to >25% increase in OHC during 2010–2020 relative to 2000–2010, and nearly a twofold increase during 2010–2020 relative to 1990–2000. This accelerated warming can have important implications for future SST trends and climate change.Observations of enhanced warming in the western Pacific and slight cooling in the eastern Pacific oppose modeled patterns on average (Coats and Karnaukas 2017; Seager et al., 2019).

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Why expect progress now? Research through CMIP7 on the sea surface warming patterns bolstered by a combination of advances including improved process understanding from the Tropics community (e.g., Ray et al., 2018; Planton et al., 2021), longer observational time series of historical forcings, improved forcings constrained by new satellite and in situ observations, better understanding of forcing uncertainty and internal variability, novel ideas about teleconnection mechanisms, potential reductions in biases in the double ITCZ, Walker circulation and ENSO through model improvements and increased resolution in the atmosphere and ocean (e.g. Yeager et al. 2023), may all help. Particular emphasis will be on the combination of improved and longer historical large ensembles in the context of the Detection and Attribution Model Intercomparison Project (DAMIP) and Aerosols and Chemistry Model Intercomparison (AerChemMIP) to further untangle the role of regional aerosol forcings.

Progress on this question will be facilitated by a longer observational record, especially one in which the forced signal has increased relative to internal variability, which will allow for more informative comparisons with observations (Schmidt et al., 2023a). Higher resolution and addition of new processes in ESMs, especially more refined treatments of mixing by ocean eddies (Yeager et al., 2023) and melt water input to the Southern Ocean (Dong et al., 2022, Schmidt et al, 2023b) from coupled ice sheet models, may mitigate model discrepancies and offer greater insight into local and teleconnecting mechanisms.

2.2 Changing weather: How will dangerous weather patterns evolve?

Description: Large scale patterns of climate play a critical role in maintaining background establishing the conditions that can trigger many weather extremes including hurricanes and other tropical storms, storm surges and, tornadoes, floods, droughts, atmospheric and marine heat waves, wind droughts, and monsoons whose frequency and/or intensity have started tomay change. Understanding how these large-scale patterns and the associated extremes will further respond to climate change is key to providing regional decisions with actionable regional information on climate change for adaptation. The CMIP6 largeLarge ensembles were of incredible value in highlightingfollowing CMIP6 protocols have highlighted the role of internal climate variability and in quantifying the level of discrepancyhelped quantify discrepancies between model behavior and the historical record (e.g., Wills et al,., 2022). The more active hydrological cycle projected under warming, for example, is expected to increase the potential for large storms. This is consistent with several recent examples of record-breaking storms such as the 2024 upper-tropospheric cut-off lows (known as DANA in Spanish) that produced severe floods in Valencia and other regions of Spain in November 2024, and rapid intensifying hurricanes, such as Otis in 2023 in the Eastern Tropical Pacific (Garcia-Franco et al., 2024) and Helene and Milton in 2024 in the southeastern United States (Clarke et al., 2024),). Anticipating and their increase attributedadapting to climate change (Bhatia et al., 2021; Clarke et al., 2024). There is a growing need to know how to adapt to rapid and unexpected changes, which in extremes will require more robust and finer resolution projections, and better understanding of the causes andcharacterization of shifts in spatial and temporal distributions of dangerous and impactful weather patterns for this information to be actionable. Given that. As many extreme events occur when climatic thresholds are threshold behavior basedexceeded (e.g. tropical cyclones, ice melt, coral bleaching, etc.), these priorities motivate improvements in the mean state of climate models to better match absolute historical temperatures as well as the changetheir changes will also benefit simulation of extremes.

Why expect progress now? Better statistics of rare events and extremes remain critical to meet the enormous research and societal challenges at hand. One key role of CMIP in the multiverse of modelling efforts is the running of multi-centennial coordinated simulations supporting characterization of frequency distributions of infrequent events. The CMIP7 focus on CO_2-emissions-forced models will allow for novel investigation of extremes under climate stabilization. Though the CMIP7 protocol does not specify large ensembles, some modelling centers may contribute large ensembles (as in CMIP6) allowing for better characterization of rare events. The considerable effort devoted to understanding the causes of the high ECS obtained in many models in CMIP6 may lead to improved representation of historical climate change (Meehl et al., 2020; Golaz et al., 2022). Finally, given anticipated modest enhancements in resolution for some models and how similar models behave across a range of resolutions (Roberts et al. (2024)), CMIP7 should include improved projections of extremes such as hurricane frequency. While full participation with km-scale ultra-high resolution simulations in which convection may be explicitly represented, known as convection-permitting (e.g., Coppola et al., 2020; da Rocha et al., Insights into this question are expected across the multi-model ensemble whose wide anticipated range address questions of structural uncertainty and more specifically from contributions of both single-model ensembles of key experiments addressing internal variability uncertainty and regional detail via higher resolution than previously available (e.g., HighResMIP2; Roberts et al., 2024). The increasing proportion of models driven by emissions rather than concentrations will allow for novel investigation of extremes under climate stabilization due to the demonstrated rigor of Transient Climate Response to Cumulative CO_2 Emissions (TCRE; Matthews et al., 2009) and climate stability under zero emissions commitment (MacDougall et al., 2020). ~~2024) remains in the future, CMIP7 simulations will also be complemented by regional downscaling efforts such as CORDEX.~~

2.3 Water-carbon-climate nexus: How will Earth respond to human efforts to manage the carbon cycle?

Description: State of the art coupled carbon cycle climate ~~modelling~~modeling sits at the intersection of climate, ecosystems, hydrology, biogeochemistry and ~~societal modelling~~socioeconomic modeling, with ~~the~~ future resilience of natural systems and ~~potentially~~ human-modulated carbon sinks ~~being the~~ key ~~uncertainty~~uncertainties in ~~relation to~~ climate stabilization and warming reversal. One of the main advances in CMIP7 is its focus on CO_2-emissions-forced models to explore dynamics climate-carbon coupling in idealized and realistic historical and future scenarios to quantify feedbacks (Sanderson et al., 2024a). Quantification of the land and ocean processes responsible for the historical carbon concentration response to ~~anthropogenic~~ CO_2 emissions constitutes an important step forward in demonstrating model robustness. ~~Critical to understanding the future carbon budget is quantifying how~~ Quantifying vegetation ~~responds~~responses to changing climate ~~and~~ -how soils respond to warming, moisture, and thawing in the context of a changing microbial communities (e.g., Chase et al., 2021~~)~~), and how ~~the processes that determine~~ vegetation growth ~~interact~~interacts with soil microbial functioning ~~and will respond to changing climate~~ (Lennon et al., 2024~~). Beyond this need for better historical and~~) - are critical to reducing uncertainty in future ~~natural system understanding, exploration~~carbon budgets. Exploration of the many proposed dimensions of Carbon Dioxide Removal (CDR) is critical to ~~understand the~~understanding vulnerabilities of ecosystems to natural and ~~anthropogenic~~human drivers such as climate variability, ecosystem management, land use fires, and pests. ~~While~~The societal context for understanding CDR is also rapidly changing: while previous carbon mitigation scenarios ~~have~~ placed a large reliance on the viability of BioEnergy with Carbon Capture and Storage (BECCS; ~~IPCC Special Report on Land, 2018~~Arneth et al., 2019), there remain deep ~~and~~, multidimensional uncertainties such as competition for water and land use between BECCS, afforestation, biodiversity protection and agriculture. ~~Constraining~~Because constraining historical land carbon uptake depends on knowledge of ~~the~~ ocean carbon uptake, ~~but with~~ the large ocean discrepancy between current surface estimates based on pCO_2 observations and prognostic biogeochemical models (RECCAP2; Friedlingstein et al., 2023) ~~recently increasing to 1 Pg/yr,~~limits our ability to confirm the effectiveness of prospective land or ocean CDR ~~is limited~~. Ocean CDR effectiveness, durability, vulnerability and overall additionality of proposed solutions such as iron fertilization, alkalinization, CO_2 injection, and carbon capture ~~in~~(e.g. seaweed) has only recently been explored. Also uncertain in the context of CDR is how ocean acidification will evolve ~~under continued stratification and will affect oceanic ecosystems in the context of CDR~~.

~~*Why expect progress now?* Building on the introduction of Coupled Carbon-Climate ESMs in CMIP5 with more experiments added in CMIP6 towards process understanding, CMIP7 shifts the scientific focus to their response to CO_2 emissions and removals and the coupled mechanisms necessary to achieve climate stabilization. As such, CMIP7 is expected to include more comprehensive process representation of coupled carbon-climate in ESMs including the non-linear role of biogeography, land use, fires, permafrost and microbes. New experiments forced by CO_2 emissions (Sanderson et al., 2024) evaluate the robustness~~

of the Transient Climate Response to cumulative Emissions (TCRE) under net zero and net negative global emissions. Improved ESMs in CMIP7 will be better positioned to contextualize the assumptions and uncertainties associated with carbon cycle response and removals used to deliver climate forcings from Integrated Assessment Models, and characterize climate response and feedbacks.

2.4

Opportunities to address this question arise primarily from advances in 1) land process representation including the non-linear role of biogeography, land use, fires, permafrost and microbes, 2) improved representation of land and ocean biogeography though improvement in long standing climate biases such as double ITCZ, dry Amazon, and Southern Ocean warm bias, 3) new satellite CO_2, CH_4, land surface and other observational constraints and 4) new sets of experiments more explicitly targeting understanding of the carbon cycle.

2.4 Tipping Points of no return/ratcheting: What are the risks of triggering irreversible changes across possible climate trajectories?

Description: In AR6, the IPCC defined a Tipping Point as "AA tipping point is "a critical threshold beyond which a system reorganizes, often abruptly and/or irreversibly" and highlighted several possible tipping (IPCC, 2021). Wood et al. (2023) recently provided framing of high impact/low likelihood outcomes and the need for research spanning their various dimensions. Tipping elements includingcommonly cited in the climate system include collapse of Atlantic Meridional Overturning Circulation (AMOC) collapse,), Amazon die-back, poleward migration of temperate forests, Sahel greening, sea level rise/ice sheet collapse, and Arctic warming andwith associated loss of permafrost and carbon release (Lee et al., 2021). For example, as projected forest2021). Many tipping elements involve coupling between different components of the physical climate and/or the coupling of physical climate to biogeochemistry. Forest dieback and demography shifts -, for example, largely depend on the potential for drought and both thermal and hydrological factors (Drijfhout et al., 2015), making a representation of climate--vegetation interactions is key to robust characterization of potential change. In the case of the Amazon, for example, recent work focused on observations suggests that with resilience declines have already begun which could set the stage for major changepossibly declining in the Amazon (Boulton et al., 2022) while modeling suggests that). Wildfires are projected to increase in fire over this century under enhanced CO_2 and associated vegetation growth (Allen et al., 2024). In the case of potential Southern Ocean changes and Antarctic ice sheet collapse, the state of uncertainty remains extremely high withHowever, CMIP6 era models lackinglack fidelity in these and other key processes - such as representation of the Antarctic slope current and land-ice interactions or agreement in change- needed to project Southern Ocean changes and Antarctic ice sheet collapse (Fox-Kemper et al., 2021). Proposed mechanismsMechanisms of irreversible and potential sudden change are manifold across different tipping elements with considerable remaining uncertainties (Lenton et al., 2008; Drijfhout et al., 2015), and scientists and society alike are interested). There is great societal value in identifying early signs of tipping points and in designing early warning systems as an adaptation to climate warming, particularly as these tipping points influencewhen they induce further climate impacts.

Why expect progress now? Analysis of CMIP6

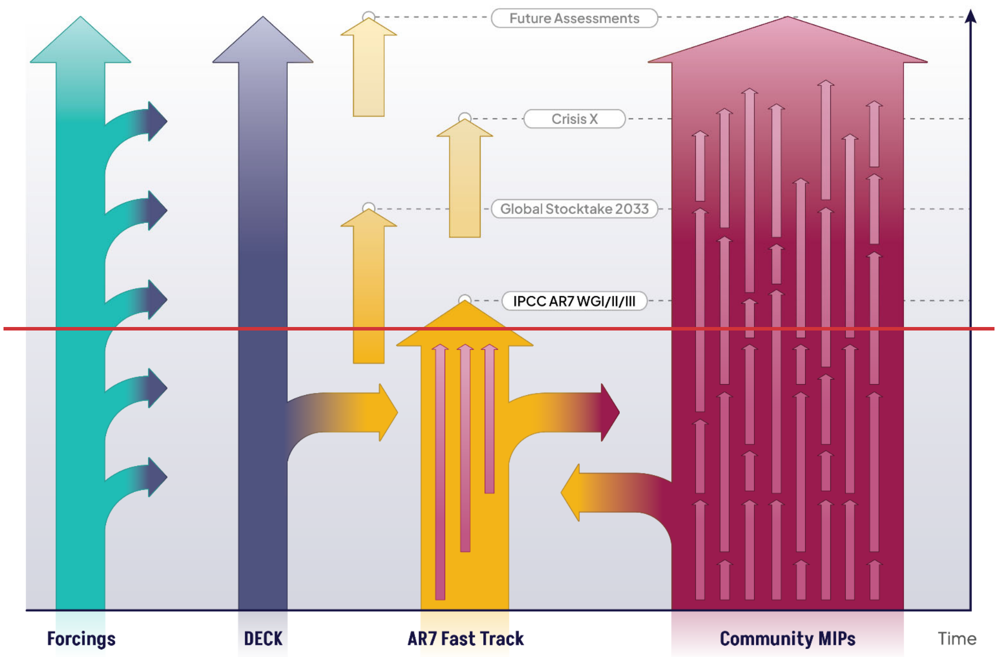
More robust insights can be expected with the shift to models has identified emerging advances of tipping processes such as fire (e.g., Allen et al., 2024) while application of Machine Learning (ML) methods has brought new insight into early detection of tipping points (e.g., Bury, et al., 2021). Ongoing improvements in historical simulations of warming and more constrained ECS will give greater confidence in results while the inclusion of more advanced ESMs forced by CO_2 emissions combined with the (allowing internally consistent carbon cycles and zero emission control experimentation) and by the coupling of more aspects of the climate system (e.g. ice sheets, biogeochemical processes). Additionally, provision of overshoot scenarios in CMIP7 from ScenarioMIP will provide the opportunitynew opportunities to explore the possibility of irreversible changes even with climate stabilization. Recent results fromCMIP7 also provides opportunities to explore process-driven storylines of how tipping points may occur through community paleoclimate studies such as exploration of the Green Sahara during the mid-holocene (Hopcroft and Valdes, 2021) also provide the opportunity to confront climate models with possible process-driven storylines of how tipping points may occur. New capabilities in CMIP7 models including coupled ice sheet models, expanded biogeochemical processes (including dynamic land use type) and higher resolution models will enable new insights on tipping points.).

3. CMIP7 Experimental Design: Expanded Baseline Experiments and the AR7Assessment Fast Track

The CMIP6 experiment design (Eyring et al., 2016) made great strides in decentralized scientific leadership through a new process of endorsing MIPs while retaining responsibility for defining a small number of simulations to characterize the basicbaseline behavior of each participating model through the mandatory Diagnostics, Evaluation and Characterization of Klima (DECK) and historical experiments. This led to a successfulThe resulting expansion of CMIP into new areas of science and new communities, including specific requests from supported a wide range of groups working on climate process understanding (e.g. Zelinka et al., 2020) and impacts (e.g., through VIACS, Ruane et al., 2016). Despite efforts to harmonize requests for experiments and data across MIPs,; however, this rapid expansion also led to significantconsiderably increased burdens on participating modellingmodeling centers. Efforts to present the requirements of the new MIPs in a consolidated form led to a perception of a monolithic request. This pressure of requests coming from many independent MIPs was exacerbated by the perceived needmodeling center eagerness to produce all simulations early enough to be included in the IPCC's Sixth Assessment Report (AR6) – conflating research, assessment, and service timelines. These and other issues highlighted in feedback from the modellingmodeling community, however, including responses to a CMIP6 community survey (https://zenodo.org/records/11654909) similar to the one after CMIP5 (Stouffer et al.,),2017), motivated an approach in CMIP7 planning of simultaneously less centralized coordination but more targeted recommendations on those CMIP7 experiments most likely to support the climate service and process understanding needs of the IPCCfor assessment versus the more general application of models in community MIPs.

The CMIP7 protocol responds to these ~~survey results~~experiences by more clearly distinguishing among simulations intended to: 1) systematically characterize model behavior and provide robust control simulations for a wide range of sensitivity studies, 2) establish ranges for future climate change under different emissions trajectories, and 3) target high priority scientific questions (Section 2~~) and 4) maintain explicit alignment with the IPCC assessment process.~~). To this end, the mandatory DECK is modestly expanded, community-driven and scientifically motivated MIPs are supported more broadly but encouraged to run on self-determined timelines, and ~~assessment reports~~assessments are supported by identifying and prioritizing ~~small thematic sets~~a sub selection of simulations~~,~~ drawn from the MIPs~~,~~ of particular relevance to informing such reports (Figure 2). This section includes a description of the first such ~~set, a "fast track" focused on the four motivating questions on a timeline allowing inclusion in the upcoming IPCC Seventh Assessment Report (IPCC-AR7). The design~~optional set, the CMIP7 Assessment Fast Track (AFT) that incorporates extensive community input and seeks to energize research inspired by emergent advances and ~~modelling~~modeling center priorities~~ rather~~. Rather than seeking to impose a single monolithic view from any single organizational perspective or stakeholder demand~~.~~

, each experiment within the AFT is explicitly optional - akin to participation in community MIPs. Acknowledging that details of the protocols described here are subject to modest change over time, the current (and all previous) versions, and the differences between them, will be made available as living documents through the CMIP website (https://wcrp-cmip.org/).


Future Assessments
Crisis X
Global Stocktake 2033
IPCC AR7 WGI/II/III
Forcings
DECK
AR7 Fast Track
Community MIPs
Time

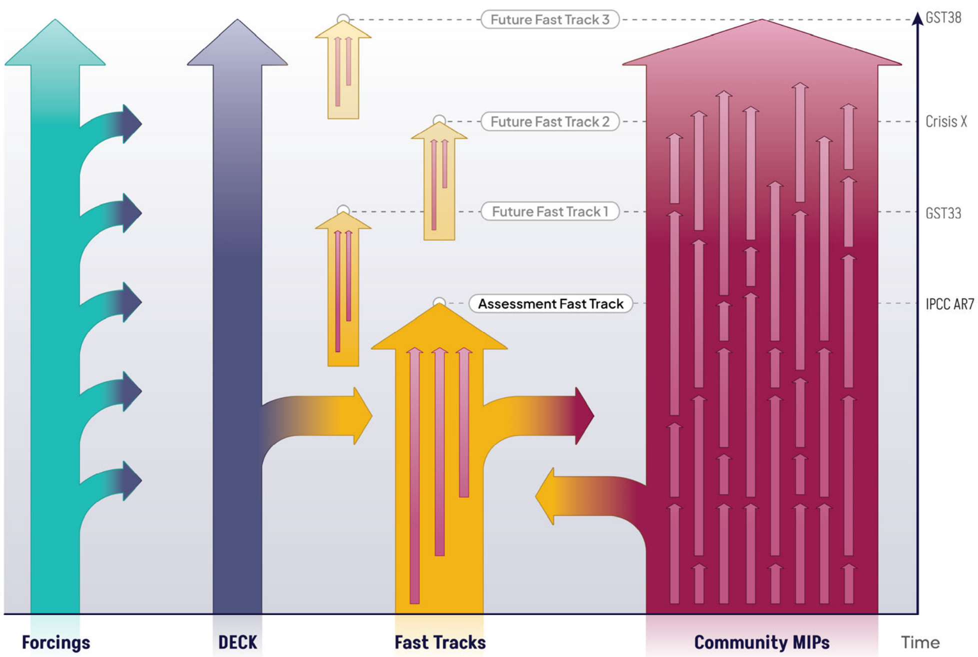


Figure 2: Schematic of the evolving CMIP design into an even more continuous approach with a continued DECK, regular updates and extensions of forcings, targeted "Fast Track" experiment sets starting with the "~~AR7~~Assessment Fast Track", and CMIP infrastructure, standards, and tools also supporting ongoing science activities through community MIPs.

3.1 Diagnosis, Evaluation and Characterization of Klima (DECK) Experiments

CMIP6 introduced ~~a~~the set of mandatory baseline experiments aimed at the Diagnosis, Evaluation and Characterization of Klima (German for Climate), all of which were performed for CMIP5 and most in prior iterations of CMIP (Eyring et al~~.,~~., 2016) and serve as the nominal CMIP "entry card" for participation. The CMIP7 DECK is based on the same experiments (Table 1, short names in italics) but is expanded modestly be adding a) the historical simulation, b) a small set of "fixed-SST" experiments to characterize effective radiative forcing, and c) an expanded protocol to facilitate participation with ESMs that close the carbon budget and are capable of running with interactive CO_2 forced by emissions (including positive, zero, and negative scenarios) in addition to prescribed concentrations.

~~The~~

This expanded mandatory DECK is intended to allow for more complete description and characterization. Historical simulations (*historical* or *esm-hist*), which are most often interpreted in the context of more idealized experiments, are included in the DECK because they are key for characterizing model behavior over the observed historical record. Protocols remain formally unchanged from CMIP6 although more detailed guidance for models simulating biogeochemical mechanisms (and thus concentrations of CO_2 given emissions) and specifications of forcings (Table 1) is provided below.are provided below (Table 1). One change in CMIP7 is the explicit recommendation that modeling centers provide at least 100 years of pre-industrial control (*piControl*) and/or *esm-piControl* from before the corresponding branching points for *1pctCO2*, *abrupt-4xCO2* and historical perturbations to allow users to better characterize drift. Because physical and compositional perturbations, whether specified as a forcing or computed internally, do not fully specify radiative perturbations driving climate change (e.g., Soden et al.., 2018; Smith et al.., 2020), the CMIP7 protocol modestly expands the DECK with experiments to characterize model-specific effective radiative forcing (as wasincreasing their priority from being "strongly encouraged" in CMIP6). Three to mandatory in CMIP7). These three atmosphere-only experiments with fixed model-specific pre-industrial sea surface temperatureSST and sea ice concentration (SIC) fields are added to the DECK following protocols developed for CMIP6 by the Radiative forcing Model Intercomparison Project (Pincus et al.., 2016; Table 1). The abrupt 4xCO2*abrupt4xCO2* experiment protocol is further modified with a recommendation toto recommend extend the simulation out to 300 years, if possible, to provide a more robust estimate of the Equilibrium Climate Sensitivity than possible using only the first 150 years of simulation available in previous CMIP phases (Rugenstein et al., 20202019; Dunne et al., 2020).

While any

Table 1: Overview of the CMIP7 DECK with experiment short names, brief experiment descriptions, the forcing methods, as well as the start and end year and minimum number of years per experiment, and its main purpose. The DECK is used to characterize the CMIP model ensemble. Any size of ensemble is acceptable but the protocol requests submissions of least threeto meet the mandatory DECK compliance for submission to the Earth System Grid Federation (ESGF), submission of multiple ensemble members for the CMIP historical simulation as requested in DAMIP. Largeof *historical* and/or *esm-hist* simulations are highly encouraged as critical to a wide range of detection and attribution questions (see Sections 2.1, 2.2, and 3.3). Similarly, large ensembles of the Atmospheric Model Intercomparison Project (AMIP) simulations forced by SST and Sea Ice Concentrations (SIC) are also encouraged.

Table 1: Overview of In the "CMIP7 DECK with experiment short names, brief experiment descriptions, forcing methods" column, "All" means all natural, start and anthropogenic forcings including greenhouse gases, aerosolsend year, and land use as described in Table 2.main purpose. Experiments start on 1 January and end on 31 December of the specified years. The recommended *piControl* minimum experiment length is defined below; however, to ensure broad simulation data use, *piControl* temporal coverage should extend across the equivalent period (after initialization) to that in the full historical and future scenario (with extension) periods. The plus (+) sign indicates that beyond meeting the basic DECK requirements, the total number of simulated years would depend on the number of ensemble members, whether the *piControl* will follow the Fast Track guidance of 150 year abrupt-4xCO2 extension to 300 years and whether the scenarios and their extensions are being run. Further information of anthropogenic forcing for CO_2 emission- and concentration- forcing is provided in Section 3.1.1. Simulations with an Atmosphere General Circulation Model (AGCM) rather than a fully coupled model are noted.

Experiment short name	Experiment description	Anthropogenic Forcing	Volcanic Forcing	Solar Forcing	Start Year	End Year	Main purpose

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amip *(AGCM)*	ObservedAtmosphere with observed SSTs and SICs prescribed	Time-varying	Time-varying	Time-varying	1979	2021	Evaluation, SST/sea ice forced variability
piControl and/or *esm-piControl*	Coupled atmosphere-ocean pre-industrial1850 control	All 1850, CO_2 prescribed concentration or emissionzero emissions	Fixed mean radiative forcing matching historical simulation (i.e. 1850–2021 mean)	Fixed mean value matching first two solar cycles of the historical simulation (i.e. 1850–1873 mean)	1	400+	Evaluation, drift, unforced variability
abrupt-4xCO2	CO_2 prescribed to 4four times pre-industrialpreindustrial	Same as piControl except CO_2 concentration prescribed to 4four times piControl	Same as piControl	Same as piControl	1 (branching from year 101 or later of piControl)	150+ (300+ (1000)	Equilibrium climate sensitivity, feedback, fast responses
1pctCO2	CO_2 prescribed to increase at 1% yr-1	Same as piControl except CO_2 prescribed to increase at 1% yr-1	Same as piControl Time varying	Same as piControl Time varying	1 (branching from year 101 or later of piControl)	150	Transient climate sensitivity
historical and/or *esm-hist*	Simulation of the recent past	All time varying, CO_2 prescribed concentration or emission	Time varying Same as piControl	Time varyingSame as piControl	1850	2021	Evaluation, baseline for sensitivity studies and scenarios

piClim-Control (*~~amip~~AGCM*)	~~Preindustrial~~Pre-industrial conditions including SST and SIC prescribed	All 1850, CO_2 prescribed concentration	Same as piControl	Same as piControl	1	30	Baseline for model-specific effective radiative forcing (ERF) calculations
piClim-anthro (*~~amip~~AGCM*)	As *piClim-Control* except present-day anthropogenic forcing	All 2021, CO_2 prescribed concentration	Same as piControl	Same as piControl	1	30	Quantify present-day total anthropogenic ERF
piClim-4xCO2 (*~~amip~~AGCM*)	As *piClim-Control* except CO_2 set to four times 1850 concentrations ~~set to 4 times preindustrial~~	All 1850 except CO_2 prescribed at ~~4~~four times ~~preindustrial~~the 1850 concentration	Same as piControl	Same as piControl	1	30	Quantify ERF of 4 × CO_2

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3.1.1 Spanning CO_2 concentration- and emission-based simulations

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Given the increased prominence of science applications for coupled carbon-climate ESMs in climate stabilization and ~~their~~overshoot and the implications for carbon budgets (Sanderson et al., ~~2024~~2024a), the CMIP7 protocol has been re-designed to encourage participation with models driven with ~~both~~ CO_2 emissions as well as ~~the more traditional~~ specified CO_2 concentrations. The following guidelines seek to maximize comparability between the two sets of simulations:

For models running only with historical CO_2 concentrations (i.e. models that run *historical* only):

- run the *historical*, *abrupt-4xCO2*, and *1pctCO2* experiments, branching from year 100 or later of *piControl*.
- the requested length of *piControl* is enough to allow for comparison to all perturbations including future projections and extensions (if applicable) i.e. *piControl* should be as long as the longest perturbation experiment performed.

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For models running with BOTH historical CO_2 concentrations and emissions (i.e. models that run *historical* and *esm-hist*):

- run the *esm-hist* experiment, branching from year 100 or later of *esm-piControl.*
- the requirements for concentration-driven experiments (*piControl*, *historical, abrupt-4xCO2 and 1pctCO2)* as above.

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For models running with historical CO_2 emissions but NOT planning to run with historical CO_2 concentrations (i.e. models that run *esm-hist* only):

- run the *esm-hist* experiment, branching from year 100 or later of *esm-piControl.*
- run the ~~*piControl*,~~ *abrupt-4xCO2* and *1pctCO2* experiments, branching from year 100 (or later, as per ~~modelling center's~~modeling center preference) of *esm-piControl* with CO_2 concentrations as specified in Table 1, but using a pre-industrial value derived from the *esm-piControl* experiment (as discussed in the next paragraph). Note that a *piControl* simulation forced by the same CO_2 concentration is also encouraged to account for any carbon-climate coupling differences between esm-piControl.

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Within these general guidelines to accommodate both CO_2 emission- and concentration- driven simulations within the same experimental protocol, the CMIP Panel acknowledges that some additional flexibility in implementation remains necessary. For example, one approach to specifying CO_2 concentrations for *piControl*, *abrupt-4xCO2* and *1pctCO2* would be to take the average of the 30 years (i.e. years 70-99) of esm-*piControl*, with *abrupt-4xco2* and *1pctCO2* CO_2 concentrations also defined relative to the same level. Another approach could be to preserve model 3-D diurnal to seasonal spatial and temporal variability when forced with CO_2 concentrations. Additionally, some modeling centers apply CO_2 concentration forcing as a restoring term to the internal atmospheric tracer with a 1/year time scale (Dunne et al., 2020). As background, guidance is that ~~modelling~~modeling centers ~~should~~ seek to ~~match the observed CO_2 concentration in 1850 in their *esm-piControl* and~~ improve upon the historical CO_2 trend in their *esm-hist* ~~within ± 5ppm,~~relative to the CMIP6 ensemble which was found to be biased by -15 to +20 ppm CO_2 by 2014 (Gier et al., 2020) with ~~larger differences worthy~~the causal attribution and pathways for reconciliation with observations the topic of ~~attention.~~much recent research (e.g. Hajima et al., 2025).

3.1.2 Historical forcing data sets

~~Standardized data~~Data used to drive simulations has been referred to within CMIP as "forcings" (Durack et al., 2018). This includes specified values of certain variables (e.g. greenhouse gas concentrations) and/or fluxes at domain boundaries (e.g. emissions of carbon dioxide), depending on the experimental protocol. ~~Forcing~~CMIP7 forcing datasets ~~to be used in the~~for *historical* ~~simulation~~and *esm-hist* simulations are summarized in Table 2. Key changes with respect to CMIP6 include revisions of solar spectral partitioning and geomagnetic referencing (Funke et al., 2024), incorporation of revised volcanic aerosol model (Aubry et al., 2020), satellite ~~and~~ (Kovilakam et al., 2020), ice core (Toohey and Sigl, 2017; Fang et al., 2023), and geological (Aubry et al., 2021) records of historical ~~volcanic~~ activity ~~(Aubry et al., 2021,~~ across both small and large volcanoes between the pre- and post- satellite era (Chim et al., 2023), comparability of regional emissions of short-lived climate forcers (i.e. aerosols, aerosol precursors, and greenhouse gases) to observations (Hoesly et al., 2023), and refined land-use harmonization (Chini et al~~.~~., 2023; 2025). The end of the historical period for CMIP7 is ~~2022~~2021, driven by increased uncertainty in more recent estimates in emission of short-lived climate forcers. These and other forcing improvements will be described in the GMD Special Issue on Forcings as they become available. Models capable of interactive open biomass burning emissions of CO_2 are encouraged to run with these emissions ~~interactive~~interactively rather than prescribed from the available datasets except for CO_2 in all concentration-driven runs where CO_2 must be explicitly prescribed (*piControl*, *1pctCO2*, *4xabruptCO2*, and ~~*piclim* experiments).~~*piClim* experiments). Finally, while there is great interest in providing anomalous freshwater forcing (e.g. Schmidt et al., 2023b), possible datasets to provide such forcing were not able to be validated for formal recommendations at the time of this writing.

Table 2: ~~Historical forcings~~Forcings for *historical, esm-hist* and *amip* experiments by dataset, provider, short description, temporal range, and documentation. Further details on forcings are provided in papers in a separate collection of GMD/ESSD special issue. Note that modeling centers can ~~chose~~choose between CO_2 concentrations or emissions from the DECK suite of forcings depending on the simulations. Specification of all the other forcings remains the same between the two types of runs. ~~See~~See https://wcrp-cmip.org/cmip-phases/cmip7/cmip7-forcing-datasets/ for a general overview, https://input4mips-controlled-vocabularies-cvs.readthedocs.io/en/latest/dataset-overviews// ~~as a landing point for modelling teams~~for technical details, and https://github.com/PCMDI/input4MIPs_CVs for guidance on current versions of forcings.

Forcing dataset	~~Provider~~Documentation	Short description	Temporal range
Anthropogenic short-lived climate ~~forcer~~forcers (SLCF) and CO_2 emissions	~~Steven Smith, Rachel Hoesly (PNNL, USA)~~https://input4mips-cvs.readthedocs.io/en/latest/dataset-overviews/anthropogenic-slcf-co2-emissions/	Gridded monthly mean historical emission estimates by sector, and fuel for anthropogenic aerosol and precursor compounds, and CO_2, CH_4 and N_2O.	1750-~~2022~~2023
Open biomass burning emissions	~~Margreet van Marle (Deltares, Netherlands), Guido van der Werf~~	Gridded monthly estimates of open biomass burning emissions (forests,	1750-2022

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	(WUR, Netherlands)https://input4mips-cvs.readthedocs.io/en/latest/dataset-overviews/open-biomass-burning-emissions/	grasslands, agricultural waste burning on fields, peatlands).	
Land use	Louise Chini, George Hurtt (University of Maryland, USA)https://input4mips-cvs.readthedocs.io/en/latest/dataset-overviews/land-use/	Gridded annual estimates of the fractional land-use patterns, underlying land-use transitions, and key agricultural management information.	850-2023
Greenhouse gas historical concentrations	Zebedee Nicholls, Malte Meinshausen (University of Melbourne/Climate Resource, Australia)https://input4mips-cvs.readthedocs.io/en/latest/dataset-overviews/greenhouse-gas-concentrations/	Consolidated data sets of historical atmospheric (volume) mixing ratios of 43 greenhouse gases and ozone depleting substances.	1-2022
Stratospheric volcanic SO_2 emissions and aerosol optical properties	Thomas Aubry (University of Exeter, UK), Anja Schmidt (DLR, Germany), Mahesh Kovilakam (NASA, USA)https://input4mips-cvs.readthedocs.io/en/latest/dataset-overviews/stratospheric-volcanic-so2-emissions-aod/	Timeseries ofStratospheric volcanic SO_2 emissions and aerosol optical properties and volcanic SO_2 emissions.	1750-2023
Ozone concentrations	Michaela Hegglin (Forschungszentrum Jülich, Germany), David Plummer (Environment Canada, Canada)https://input4mips-cvs.readthedocs.io/en/latest/dataset-overviews/ozone/	This is toTo be determined but the expectation is that it will be expected to be - Gridded monthly mean 3-D ozone mixing ratios.	1850-2022

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Nitrogen deposition	https://input4mips-cvs.readthedocs.io/en/latest/dataset-overviews/nitrogen-deposition/	This is toTo be determined but the expectation is that it will be expected to be - Gridded monthly mean 2-D nitrogen deposition flux.- provided as dry/wet in the form of oxidised and reduced nitrogen species as in CMIP6	1850-2022
Solar	Bernd Funke (IAA, Spain)https://input4mips-cvs.readthedocs.io/en/latest/dataset-overviews/solar/	Daily and monthly mean reconstructed spectral solar irradiance (SSI) for spectral bins covering the wavelength range 10 – 100,000 nm.	1850-2023
Aerosol optical properties/MACv2-SPAMIP sea surface and sea ice boundary forcing	Paul Durack (PCMDI/LLNL, USA)https://input4mips-cvs.readthedocs.io/en/latest/dataset-overviews/aerosol-optical-properties-macv2-sp/	Anthropogenic aerosol optical properties for key plumes based on the MACv2-SP parameterization over the 1850-2022 period. Merged SST and sea ice concentration based on UK MetOffice HadISST and NCEP OI2	18701850-2022
AMIP sea surface and sea ice boundary forcingAerosol optical properties/MACv2-SP	Stephanie Fiedler (GEOMAR, Germany)https://input4mips-cvs.readthedocs.io/en/latest/dataset-overviews/amip-sst-sea-ice-boundary-forcing/	Merged SST and sea ice concentration based on UK MetOffice HadISST and NCEP OI2Anthropogenic aerosol optical properties for a number of key plumes based on the MACv2-SP parameterization over the 1850-2022 period. -	18501870-2022

3.1.3 PreindustrialPre-industrial control forcing

Forcings for the *piControl* experiment seek to establish a baseline climate against which the forced response can be assessed. The approach in CMIP7 follows CMIP6 although current forcing datasets are to be used. Greenhouse gases, anthropogenic and biomass burning aerosols, and land use forcing use constant 1850 values. Solar forcing uses a fixed mean over two solar cycles i.e. the average over 1 January 1850 to 28 January 1873 and volcano aerosol forcing for models that prescribe optical properties use the long-term historical 1850-20222021 average values of the historical forcing dataset (Table 2, see also Aubry et al., 2021 and Chim et al., 2023). Averaging is motivated by the observation that multiannual discrepancies in volcanic or solar forcing between *piControl* and *historical* and/or *esm-hist* simulations can lead to drifts (Gregory et al., 2013; Fyfe et al., 2021). Files with the correctly averaged solar and volcanic forcing are provided.

3.2 Ocean and Land Spin-up – characterizing model diversityland spin-up

Prior to starting a control experiment, climate and Earth System models must be tuned (e.g. Hourdin et al., 2017) and integrated to an a quasi-equilibrium initial state. This aspect of climate modelling has not traditionally been an issue for weather forecasting because atmospheric dynamics and physics has a relatively short memory of a couple of weeks. Climate, however, has such that responses in historical and idealized forcing perturbation experiments can be easily distinguished from the *piControl*. Challenging to achieving quasi-equilibrium initialization of the *piControl* include uncertainties in the state and trends of the 1850 Earth system, model biases, and long time scales out to millennia involved in reaching equilibrium in. There are many diverse both land (Sentman et al., 2011) and ocean (Irving et al., 2021; Séférian et al., 2016). The CMIP7 protocol described above, as with previous iterations, has no specific requirements for spin-up because the diversity of approaches to developing and spinning up pre-industrial simulations before finalizing the initial conditions for the *piControl* for both land (Sentman et al., 2011) and ocean (Irving et al., 2021; Séférian et al., their formal year 1 of the *piControl* mean that it would be difficult at this current moment to specify one amenable to all anticipated participants.2016). While the CMIP7 protocol described here keeps with past precedent in providing no specific requirements for spin-up, previous phases of CMIP provide some guidance on the limits of what is feasible, including the C4MIP (Jones et al., 2016) global land and ocean carbon drift tolerance metric of 10 PgC/century for ocean heat content analysis from CMIP6 (Irving et al., 2021) for which GFDL-CM4 demonstrated the highest *piControl* drift of $0.3x10^{24}$ J/century, or 0.06 C century^{-1}, corresponding to 0.4 W/m2. Similarly, drift in surface temperatures would ideally be kept well below historical warming rates of 1 °C century^{-1}. Participants are encouraged to provide detailed descriptions of their spin-up methodology and to monitor global energy, water and salinity e.g. via the integrated metrics listed in Appendix 1 and/or save the metricsmonthly variables from the *piControl* data request.

3.3 Support for community driven science

CMIP6 supported broad community engagement by soliciting proposals from self-organized MIPs, many of which had long histories themselves. Twenty-two MIPs were eventually endorsed (https://www.wcrp-climatecmip.org/modelling-wgcm-mip-cataloguemips/cmip6-endorsed-mips-article)/) and contributed to the CMIP6 request for data. As noted above, this centralized approach required synchronization of the diverse ensemble of MIP activities represented by the MIPs with the provisioning of forcingforcings provision and data request harmonization of the data request on a single timeline set by IPCC AR6.

CMIP7 also supports community driven model intercomparisons by providing baseline simulations for comparison, forcing data sets, technical specifications, centralized and distributed infrastructure to access data, and standardized open data access to facilitate model simulation and comparison. In CMIP7, however, the CMIP Panel will not endorse including ongoing logistical facilitation of novel community MIPs. Instead of endorsing entire MIPs but as was done in CMIP6, CMIP7 is instead drawdrawing on the existing community MIP experiments designed by community MIPs to assemble compact, targeted ESGF collections of both the mandatory DECK and optional endorsed "fast track" simulations to address specific needs. This change is intended to reduce the burden on modellingmodeling centers and community MIPs to deliver experimental designs and simulations on IPCC timelines. CMIP7 will thus move to a continuous approach of community MIP contributions supporting novel coupled model intercomparisons. The CMIP Panel, any single timeline. At the same time, the CMIP Panel, the Working Group on Coupled Modelling (WGCM) Infrastructure Panel, infrastructure providers, and IPO will provideremain committed to providing support to allow thefor both existing and novel community MIPs to bring fresh questions, hypotheses, and insight for new experiments, constraints, and applications to enrich CMIP community science.

A broad spectrum of modes is available for community MIPs. They, which may be tightly coupled to CMIP7, for example submitting standardized data to the Earth System Grid FederationESGF; or less tightly constrained by but compatible projects perhaps reusing standards or protocols, or activities which operate completely independently such as nationally and regionally supported research projects outside the auspices of WCRP. In the absence of centralized endorsement and harmonization of individual MIPs, the CMIP Panel and CMIP IPO play a community service role. This includes encouraging best practices in effective experimental design and execution through registration and offers guidelines on how best to developingdevelop and runningrun MIPs to conform with CMIP Practices in Appendix 2.

3.4 AR7Assessment Fast Track Experiments

The AR7Assessment Fast Track (AFT) is a set of recommended CMIP7 simulations drawn from Community MIPs intended to support both the direct needs of the climate research community for synthesis and physical science assessment as well as downstream climate services applications from the impacts, mitigation and adaptation communities, such as the ISIMIP and VIACS initiatives and contribute to the development of high temporal resolution forcing for regionally tailored information through dynamical and statistical downscaling efforts, such as CORDEX.. These first focused set of priority (but optional) recommendations for CMIP7 simulations include: *near-term prediction and long-term projection* experiments that support both the direct needs of the climate assessment as well as downstream use in climate services applications including providing data satisfying the needs ofwill provide information critical to satisfying the needs for both short- and long-term planning and for the impacts, mitigation and adaptation communities such as ISIMIP and VIACS as well as high temporal resolution forcing for regionally tailored information through dynamical and statistical downscaling such as CORDEX. CMIP7 goals also include the more classical aspects of systematic assessment with respect to *characterization* of model diversity, *attribution* of the quantitative role of particularspecific mechanisms in driving the forced response, and *process understanding* as per the four GuidingFundamental Research Questions described in Section 2 and listed in Figure 3. More information about the different experiments in Figure 3 is detailed above.below and in Table 3.

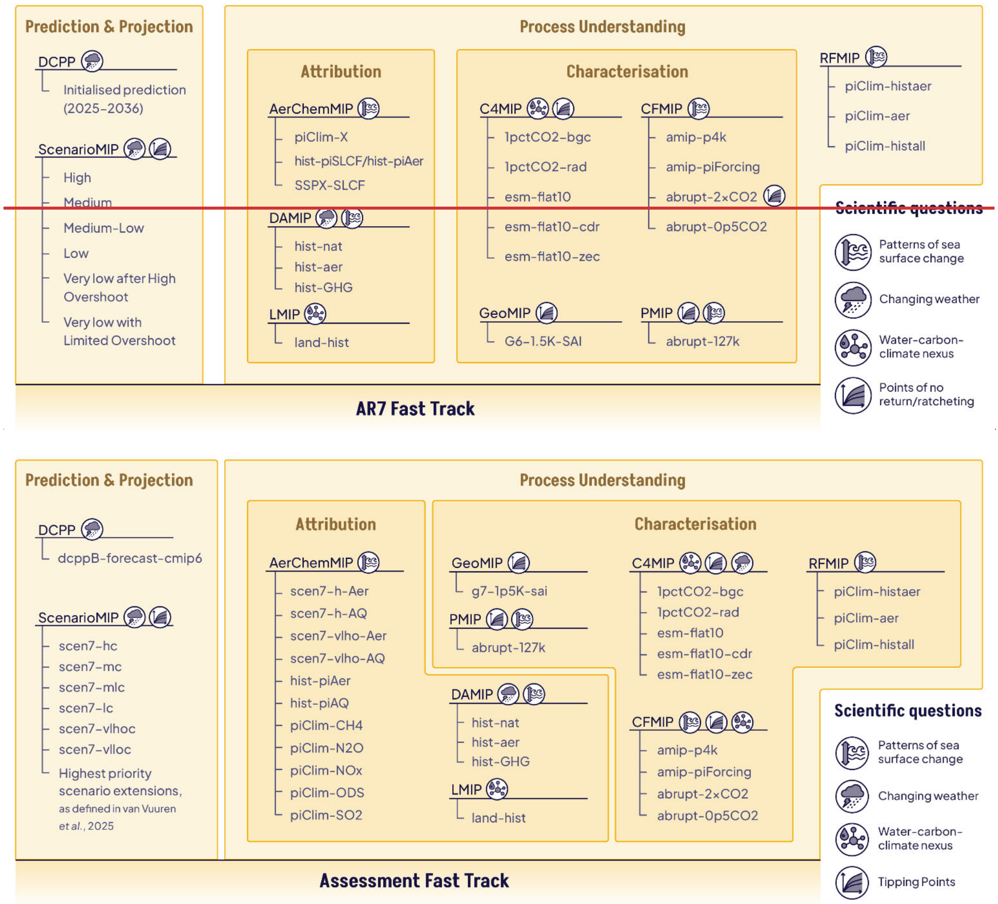

Figure 3: Schematic mapping the four ~~Guiding~~Fundamental Research Questions (Patterns of sea surface warming, Changing weather, ~~water~~Water-carbon-climate nexus, and Tipping points~~ of no return/ratcheting~~) and four topical areas (Prediction and Projection, Attribution, Characterization, and Process Understanding) onto ~~AR7~~Assessment Fast Track experiments.

3.4.1 Harmonization to projections

As in previous phases of CMIP, attention to optimize continuity, or "harmonization" of forcings is necessary across transition from the end of the historical forcing period heavily constrained by observations (Dec 2021 for CMIP7) into projected future scenarios from integrated assessment models through ScenarioMIP (van Vuuren et al., ~~in press~~2025). The Forcings Task Team's ~~harmonisation~~harmonization sub-group is working with the ScenarioMIP team on the details of this process, which will be ~~finalised~~finalized in ~~early~~ 2025. The specification of natural forcings in ScenarioMIP simulations include a projected solar cycle (Funke et al., in preparation) and a nine-year linear return to the constant background value for ~~volcanoes of [0.013 at 550 nm]~~stratospheric volcanic aerosol optical properties as in ~~the~~ *piControl*~~.~~ (0.014 at 550 nm).

3.4.2 Prediction and projection

Prediction experiments in the Decadal Climate Prediction Project (DCPP) and projections in ScenarioMIP provide important bounds on a range of possible near-term and future climate outcomes. While efforts aligned to DCPP exist as an ongoing effort outside of CMIP as the WMO Global Annual to Decadal Forecast (WMO Global Annual to Decadal Climate Update | 1 | World Meteorological Organization), there is great interest in generating ~~an AR7~~a recent "snapshot" of decadal prediction ensembles that would include a comprehensive suite of model diagnostics consistent with CMIP data standards beyond the five variables currently made available.

In each previous iteration of CMIP, the set of projection experiments included at least one high emissions scenario — initially viewed as the 1% idealized CO_2 increase (~~IPCC, 1992~~Washington and Meehl, 1989), then as a "business as usual" (SRES), then as an emissions-intensive scenario (RCP, ~~SCP~~SSP), and more recently as a mitigation policy failure scenario (AR6, WGIII Chapter3) — along with a range of emissions and concentrations scenarios based on moderate to extreme mitigation policy success. Projection scenarios ~~are being~~have been re-envisioned for the ~~AR7 Fast Track~~AFT by the ScenarioMIP community in close coordination with the CMIP Panel and WCRP~~. The focus of this effort is~~ to improve scenario practical viability and comprehensiveness~~ as well as changing~~. One important change is away from the reference frame ~~from a~~of previous generation CMIP emphasis on the null hypothesis of a high emission "business as usual" ~~to~~towards the "current policy" framework ~~developed through the IPCC Working Group III 6th Assessment informed by the Paris Agreement and ongoing Global Stocktake (https://unfccc.int/topics/global-stocktake~~(Riahi et al., 2022). In this reference frame, "current policy" keeps emissions roughly similar to present-day out to 2100 and provides for a convenient null hypothesis relative to high emissions "policy failure" versus lower emissions "mitigation policy success" futures (Riahi et al., 2022; Meinhausen et al., 2024). While these scenarios are driven by population and Gross Domestic Product data that only extends to 2100, each set of future forcings will be provided past 2100 as more idealized "Extensions" to at least 2150 and in some cases beyond to 2500. See van Vuuren et al. (~~in press~~2025) for a comprehensive discussion of these pathways and their technical implementation into scenario projections out to 2100 and extensions to 2500.

3.4.3 Attribution

One of the key aspects of ongoing CMIP efforts in systematic characterization of model behavior and its relationship to observations is in attributing the climate response to particular forcing changes, e.g., aerosol (AerChemMIP) and radiating forcing (RFMIP) for understanding how individual gases and aerosols affect the energy budget and Detection and Attribution MIP (DAMIP; Gillett et al., 2025) to quantify how different forcings influence climate. These experiments include a combination of single forcing changes and mechanism withdrawal experiments that allow for both the quantification of the impact of individual drivers and the combined responses to explore nonlinearity. From DAMIP,~~ the~~ greenhouse gas only, aerosol only, and natural only experiments are prioritized given their broad use in prior assessment reports. These will provide the opportunity to examine model response to historical forcings between 2015-2021 as opposed to the projected forcings used in CMIP6. They will also provide the opportunity to examine the ~~modelled~~modeled response to updated forcings prior to 2014, since such differences in forcings can impact on the representation of the historical climate evolution in individual models (e.g., Fyfe et al~~.~~., 2021; Holland et al~~.~~., 2023; Chemke and Coumou, 2024). Comparison of coupled historical simulations with those in LMIP (and AMIP) allows for attribution of component level biases. The increasing use of models with fully interactive carbon cycles also ~~opens the door to~~facilitates attribution of historical changes to emissions (as opposed to concentrations)~~ and~~ to understand the impact of individual forcings within the context of an interactive carbon cycle.

3.4.4 Characterization

This set of experiments similarly characterizes model ensemble systematic behavior towards understanding why models produce different outcomes and includes CFMIP for ~~cloud~~radiative feedbacks, C4MIP to assess carbon cycle-climate feedback strength, GeoMIP to assess geoengineering requirements and impacts of purposeful climate modification, and LMIP for the most direct comparison of land models with observations. As an example of the purpose and interconnectedness of all experiments, an example is provided for RFMIP that seeks to reduce the large uncertainty in effective radiative forcing due to aerosols in both observations (Bellouin et al., 2020) and across models (Smith et al. 2020). Experiment *piClim-aer* characterizes the model-specific effective radiative forcing at present-day (end of *historical*, or 2021 for CMIP7). ~~Understanding of present-day effective radiative forcing is augmented by experiments~~Experiments *piClim-histall* and *piClim-histaer*~~,~~, are small ensembles of atmosphere-only simulations with fixed sea surface temperatures and sea ice concentrations, ~~to~~which characterize the time-varying effective radiative forcing over the course of the historical period from all natural and anthropogenic forcings and from the temporal evolution of aerosols alone. Further ~~detail~~details on the motivation for each experiment and context within the MIP from which it is derived is provided in Table 3.

3.4.5 Process understanding

The ~~AR7 Fast Track~~AFT experiments (Table 3) ~~promote~~were chosen as a practical balance among the ~~generation~~number of ~~ensembles with complementing available dimensions of experiment versus structure versus~~participating models, and the complexity, resolution~~ versus~~ , and number of ensemble ~~size~~members for each model (Figure 1) to help distinguish the role of different processes and interactions and local versus remote drivers. Links between the ~~guiding~~ research questions (Section 2) and DECK and ~~AR7 Fast Track~~AFT experiments include the following:

- Exploration of the patterns of sea surface warming and changing weather is supported through the updated and extended AMIP and historical experiments included in the DECK, set of projections and near-term predictions and associated diagnostics in Decadal Climate Prediction Project (DCPP), Cloud ~~Forcing~~Feedback (CFMIP) and Radiative Forcing (RFMIP) experiments. ~~CMIP~~The CFMIP and RFMIP experiments also allow exploration of atmospheric feedbacks and identify the role of SSTs in historical evolution and idealized response to forcing. Paleoclimate MIP (PMIP) ~~allow~~*abrupt-127k* experiment allows exploration of SST responses to orbital forcing. The single forcing experiments proposed through DAMIP can also help in interpretation of the role of individual forcings in regional historical trends. The linearity of ~~modelled~~modeled responses to rising CO_2 and feedbacks can be also ~~be~~ assessed through comparison of the CFMIP *abrupt-2xCO2* with *abrupt-0p5CO2* experiments. One particularly exciting application of the *esm-flat10-zec* experiment is the ability to conduct long simulations under climate stabilization to develop better understanding of the statistics of climate extremes.
- The *Water-Carbon-Climate Nexus* can be explored through ScenarioMIP projections, Coupled Climate Carbon-Cycle (C4MIP) and Geoengineering (GeoMIP) experiments. Some of the most ~~societally~~ pressing societal questions include implications of coupled carbon-climate interactions under a variety of carbon emissions trajectories, particularly under scenarios of climate mitigation (e.g., Carbon Dioxide Removal), interactions of short~~-~~-lived climate forcers under CH_4, H_2, and greenhouse gas and aerosol emissions trajectories, and advancing process understanding of Earth's radiation budget under purposeful climate modification (e.g., Solar Radiation Management). A series of idealized diagnostic "flat10" experiments in ~~CMIP7 fast track~~AFT will be used to derive emissions-driven estimates of Transient Response to Cumulative Emissions (TCRE; *esm-flat10*), Zero Emissions Commitment (ZEC; *esm-flat10-zec*) and climate reversibility under declining to negative emissions (*esm-flat10-cdr*; Sanderson et al. ~~(in review)).~~2024b).
- *Tipping Points*, ~~*of no return/ratcheting*~~ can be explored through both the ScenarioMIP projections (~~*High, Medium, Medium-low, Low, Very Low after High Overshoot*~~*scen7-h, scen7-m*, scen7-mlc, *scen7-l, scen7-vlho*, and ~~*Very Low after High Overshoot*~~*scen7-vllo*) and extended suite of idealized response to constant (*esm-flat10*), zero (*esm-flat10-zec*), and declining to negative (*esm-flat10-cdr*) emissions. Another particularly exciting application of the *esm-flat10-* ~~*zec*experiment is the ability~~*zec* experiment to conduct ensembles of simulations under climate stabilization to develop better understanding of the likelihood of tipping points. The PMIP *abrupt-127k* experiment ~~which~~ allows comparison to model response to last interglacial orbital parameters at which Arctic was free of sea ice and temperatures were close to present-day at ~~preindustrial~~pre-industrial CO_2.

~~Note that for all AR7 Fast Track experiments that require a historical, present day, or scenarios, the CMIP7 protocol requires slight modification of the original CMIP6 experimental design to be updated to CMIP7 historical (Section) and ScenerioMIP (van Vuuren et al., in press) forcing.~~

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3.4.6 Single model ensembles

Within the CMIP multi-model ensemble, the participating of single-model multi-member ensembles (e.g. Hawkins and Sutton, 2009) and even "large ensembles" (e.g. Kay et al., 2015) have been demonstrated critical for detection and attribution, notably in DAMIP (Gillett et al., 2025). Note that the DAMIP component of the AFT involves the request for at least three *historical* simulations to compare with three *hist-nat* and *hist-aer*. For CMIP7, the CMIP panel also strongly encourages the contribution of multiple ensemble members of *historical, esm-hist*, scenario projections and encourage modeling centers to adopt strategies for sampling *piControl* (and/or *esm-piControl*) states of low frequency climate variability (such as 20 year intervals) for the initial conditions of perturbation simulations as preferable to incremental perturbations or short intervals to avoid aliasing internal variability in the pre-industrial ensemble mean.

Table ~~3:~~3: Overview of the ~~AR7 Fast Track set of~~CMIP7 AFT experiments with experiment name, experiment primary goal, MIP short name from which it is derived, required model components, brief experiment overview description, primary goal of combined experiments in the MIP from which it is derived, minimum number of years per experiment, and its main purpose. Forcings include Greenhouse Gases (GHG), Short Lived Climate Forcers (~~SLCFs~~SLCF), Aerosols (AER), and carbon BioGeoChemistry (BGC). Superscripts on the experiment short name represent 1) Prediction & Projection, 2) Attribution, 3) Characterization and 4) Process Understanding. Superscripts on the MIP indicate applicability of the experiments to the ~~guiding~~synthesizing research questions (Section 2) of ~~1~~a) Patterns of sea surface warming, ~~2~~b) Changing ~~extremes, 4~~weather, c) The Water-Carbon-Climate nexus, and ~~4) Points~~d) Tipping points. The esm- prefix indicates experiments are forced by CO2 emissions rather than CO2 concentrations. Note that for all AFT experiments that require a historical, present day, or scenarios, the CMIP7 protocol requires slight modification of ~~no return/ratcheting~~the original CMIP6 experimental design to be updated to CMIP7 historical (Section 3.1.2) and ScenarioMIP (van Vuuren et al., 2025) forcing.

Experiment short name	Primary Goal of Experiment	MIP short name and protocol paper	Required model components	Experiment overview	~~Primary Goals of MIP~~	Years of simulation	~~Citation for protocol~~
~~Prediction and Projection~~							
~~Initialized prediction (2025-2036)~~	~~Predicting and understanding forced climate change and internal variability up to 10 years into the future~~	~~DCPP[2]~~	~~AOG~~	~~Initialized~~	~~Predicting and understanding forced~~	~~10 x 10 = 100 coupled~~	~~Boer et~~

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							CM	Prediction: 2025-2036	climate change and internal variability up to 10 years into the future through a coordinated set of skillful decadal predictions.	al., 2016
High; H-ext	Climate policy roll-back scenario with low renewable technology development and	ScenarioMIP[2,4]esm-scen7-h-AQ (esm-scen7-h-Aer for models wit	AOGCM	Future projections out to 2100 and extensions	(a) Facilitating integrated research on the impact of plausible future scenarios over physical and human systems, and on mitigation and adaptation options; (b)	79 + 200+ = 279+ coupled	van Vuuren nAerChemMIP[a] - Collins et al., 2017in press	AOGCM AER (plus CHEM for - AQ experiments)	Future scenario esm-scen7-vlho/h with high aerosol and tropospheric non-methane ozone precursor emissions	= 79 x 3 = 237 fixed SST

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	~~high emissions and extension to 2300-2500~~	hout interactive chemistry)[2,4]		~~out to 2300-2500 representing mitigation pathways of current policy, policy failure, policy success~~	~~addressing targeted studies on the effects of particular forcings in collaboration with other MIPs; (c) help quantifying projection uncertainties based on multi-model ensembles and emergent constraints.~~ Quantifying the role of future mitigation actions on SLCFs for climate and air quality responses.					

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		s and overshoot.	-					
Medium	Current policy scenario without further strengthening or roll-back						79 coupled	
Medium-Low, ML-ext	Modest mitigation policy scenario short of meeting Paris goals and extension to 2300-2500						79 + 200+ = 279+ coupled	
Low	Scenario consistent with staying likely below 2 deg C						79 coupled	
Very Low after High Overshoot, VLHO-ext	Delayed mitigation policy scenario with overshoot but rapidly intensifying CDR to return to 1.5 C and extension to 2300-2500 to return to preindustrial						79 + 200+ = 279+ coupled	
Very Low with Limited Overshoot	Rapid near-term emissions reduction scenario to limit warming to about 1.5 C						79 coupled	
Attribution								
hist-nat	Coupled response to natural solar and volcano forcing	DAMIP[1, 2] -	AOGCM	*piControl for*	(a) Estimating the contribution of	3 x 172 = 516 coupled	Gillett et	

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				- -	~~*cing for all except historically varying* solar and volcanoes~~	~~external forcings to observed global and regional climate changes; (b) observationally-constraining future climate change projections by scaling future GHG and other anthropogenic~~		~~al., 2016~~
~~hist-aer~~	~~Coupled response to anthropogenic aerosol forcing~~				~~*piControl forcing for all except his*~~	~~responses using regression coefficients derived for the historical period. (c) Understanding the contribution of~~	~~3 x 172 = 516 coupled~~	

				~~*torically varying aerosols*~~	~~individual forcings to inter-model spread over the historical record~~		
~~hist-GHG~~	~~Coupled response to anthropogenic GHG forcing~~			~~*piControl forcings for all except historically varying WMGHGs*~~		~~3 x 172 = 516 coupled~~	

land-hist	Evaluate land processes in DECK simulations to identify systematic biases and their dependencies and estimate terrestrial energy/water/carbon variability	LMIP[3] -	Land	Update on land forcing modified from ERA5	Atmospheric reanalysis forced experiment to compare with land satellite and field observations for land model evaluation and benchmarking	172 land only	Van den Hurk et al., 2016; D. Lawrence, personal communicati

							~~on~~
~~piClim-aer~~ -	~~Atmospheric response to present-day anthropogenic aerosols to attribute current warming and project committed future warming~~	~~RFMIP[1]~~ -	~~AGCM~~ - -	~~*preindustrial model SST and SIC and forcing for all except 2021 aerosols*~~	~~(a) Characterizing the global and regional effective radiative forcing for each model for historical and 4xCO2 simulations; (b) assessing the absolute accuracy of clear-sky radiative transfer parameterizations; (c) identifying the robust impacts of aerosol radiative~~	~~30 AMIP~~	~~Pincus et al., 2016~~
~~piClim-histaer~~	~~Atmospheric response to historical changes in anthropogenic aerosols to~~			~~*preindustria*~~	~~forcing during the historical period.~~	~~30 AMIP~~	

		attribute current warming and calibrate emulators			*l forcing for all except historically varying aerosols*			
	piClim-histall	Atmospheric response to historical changes in anthropogenic aerosols and WMGHG to assess why model warming differs from the observed record and estimate model forcing to compare with process models			*preindustrial model SST and SIC but*		30 AMIP	

				otherwise historically varying forcing			
piClim-X *(where X = Aer, CH_4, NOx, VOC, HC, and N_2O)*	Quantifying ERF climate feedbacks for individual SLCFs to assess their contributions to the radiation imbalance.esm-scen7-vlho-AQ (esm-scen7-vlho-Aer for models without interactive chemistry) [2,4]	AerChemMIP[1] -	AGCM AER	Single forcing AMIP experiments with model preindustrial SST and SIC	(a) Diagnosing forcings and feedback of tropospheric aerosols, ozone precursors and chemically reactive WMGHGs; (b) documenting and understanding past and future changes in atmospheric chemical composition; (c) estimating their	30 79 x 6 =1 80 3 = 23 7 AMIP	Collins et al., 2017

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				~~global-to-regional climate response~~			
hist-~~*piSLCF*~~piAQ (hist-piAer for models without interactive chemistry) [2,4]	Diagnosing climate and air quality responses to regionally inhomogeneous evolution of historical SLCF emissions to reduce uncertainty in our understanding of human-influenced climate change.		AOGCM AER CHEM	~~coupled simulations with historically evolving SLCFs~~Historical simulation with pre-industrial aerosol and tropospheric non-methane ozone		17 2 x 6 =1032 coupled	

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				precursors			
Process Understanding							
SSPXSST-SLCFpiClim-X (where X = Aer, CH4, NOx, VOC, HC, and N2O), NOX, ODS, SO2) [2,4]	Quantifying the role of future mitigation actions on SLCFs for ERF climate and air quality responsesfeedback for individual SLCFs to assess their contributions to the radiation imbalance.	AerChemMIP	AGCM CHEM (except piClim-SO2 where AER required instead of CHEM)	Single forcing AMIP experiments in AMIP with model future scenario SST and SICpre-industrial climatology with present-day	As above for AerChemMIP	30 43 x 6 = 180 AMIP258 fixed SST	Collins et al., 2017

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									CH_4, N_2O, NO_X, ODS, SO_2	
1pctCO2-bgcbgc[3,4]	Idealized biogeochemical response to CO_2 concentrations	C4MIP[2,3,4] -	AOGCM BGC - -	1pctCO2 for BGC but pre-industrial CO_2 for climate	Understanding and quantifying future century-scale changes in the global carbon cycle and its feedback on the climate system by isolating carbon-concentration and carbon climate elemen	150 coupled	C4MIP[b,c,d] Jones et al., 2016; Sanderson et al., 20242024a; Sanderson et al (in review)., 2024b	AOGCM BGC	Biogeochemically-coupled version of 1 percent per year increasing CO_2 experiment	150 coupled

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	ts of the global carbon feedbacks and climate change and enable calibration of coupled carbon-climate emulators.						
1pctCO2-radrad[3,4]	Idealized radiative response to CO_2 concentrations			1pctCO2 for climate but Radiatively-coupled version of 1 percent per year		150 coupled	

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				increasing CO_2 experiment pre-industrial CO_2 for BGC			
esm-flat10flat10[3,4]	Idealized coupled response to constant positive CO_2 emissions			10 PgC /yr-1 constant CO_2 emissione missions experiment		100+ coupled	
esm-flat10-edrcdr[3,4]	Idealized coupled response to reducing positive to negative CO_2 emissions after esm-flat10 to diagnose climate response and reversibility after all cumulative anthropogenic emissions are removed			CO_2 emission declining by 0.2 PgC yr-1 to -10		100+ coupled	

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				PgC yr-1 10 PgC/yr constant CO_2 removal / negative emissions experiment			
esm-flat10-zeczec[3,4]	Idealized coupled response to zero CO_2 emissions after esm-flat10 to diagnose the Zero Emissions Commitment (ZEC) - the additional warming after the cessation of emissions required to inform remaining carbon budget estimates.			Zero CO2 - emissions commitment CO_2 experiment		100+ coupled	
amip-p4kp4k[3,4]	Atmospheric response to idealized ocean warming	CFMIP[1] -CFMIP[a,c,d] -	AGCM	AMIP experiment with unifo	Diagnosis of atmospheric response to	30 43 AMIP	Webb et al., 2017

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		Webb et al., 2017		rm 4K SST plus 4Kincrease in ice-free regions	SST and sea-ice changes for comparison to feedbacks observed and modeled climate sensitivity.			
amip-piForcingpiForcing[3,4]	Atmospheric response to SST and SIC boundary conditionconditions without corresponding forcings			AMIP historically varying SST and SICexperiment but preindustrial otherfrom 1870 to the present with constant pre-industrial forcing levels (anthropogenic and natural).		153AMIP	30AMIP	
abrupt-2xCO22xCO2[3,4]	Idealized coupled response to doubled CO2 - similar to 21st century – and in some cases very different from scaled 4x response.	CFMIP[1, 4] -	AOGCM	2xCO2Abrupt doubl	Improving understanding	300co	Webb et al., 2017	

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				ing of CO2 concentration relative to piControl	of circulation, regional-scale precipitation, and non-	upled
abrupt-0p5CO20p5CO2[3,4]	Idealized coupled response to half CO2 concentration similar to LGM			0.5x CO_2 Abrupt halving of CO_2 concentration relative to piControl	linear changes.	300 coupled
hist-aer[2,4]	Coupled response to anthropogenic aerosol forcing	DAMIP[a,b] Gillett et al., 2025	AOGCM	Time evolving historical and then medium scenario aerosol forcings while all other forcings held at piControl levels.		3 x 172 = 516 coupled

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hist-GHG[2,4]	Coupled response to anthropogenic GHG forcing			Historical simulation with time evolving greenhouse gas forcing only and all other forcings at pre-industrial levels.	3 x 172 = 516 coupled
hist-nat[2,4]	Coupled response to natural solar and volcano forcing			Natural-only historical simulations (solar irradiance, stratospheric aerosol)	3 x 172 = 516 coupled
dcppB-forecast-cmip6[1]	Predicting and understanding forced climate change and internal variability up to 10 years into the future	DCPP[b] - Boer et al., 2016	AOGCM	Forecast initialized from observations with forcing from ssp245 (2025-2036)	10 x 10 = 100 coupled
G6-1.5K-SAIg7-1p5K-sai[3,4]	Coupled response to idealized stratospheric aerosol injection to arrest warming to better understand possible consequences of purposeful solar radiation modification	GeoMIP[d] - Visioni et al., 2024GeoMIP[4] -	AOGCM	Stratospheric SulphurSulfur forcing held constant to stabil Assessing the climate system response (including on extreme events) to	50 coupled Visioni et al., 2024

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				ize climate at 1.5C warming starting from year 2035 of Medium Projection Scenario	proposed radiation modifieation geoengineering schemes by evaluating their efficacies, benefits, and side effects.	
land-hist[2,4]	Evaluate land processes in DECK simulations to identify systematic biases and their dependencies and estimate terrestrial energy/water/carbon variability	LMIP[c] - Van den Hurk et al., 2016; D. Lawrence, personal comm	LAND	Land-only historical simulation from 1850 to 2022.		172 land only

							unication			
abrupt-127k127k[3,4]	Coupled response to orbital changes associated with last interglacial leading to Arctic warming and sea ice loss and transl	PMIP[1,4]	AOGCM	Preindustrial forcing except for solar forcing from orbital parameters set for	Analyzing the response to forcings and feedback for past climates outside recent variability and assessing the credibility of climate models	100 coupled	PMIP[a,d] Otto-Bleisner et al., 2017 Sime et al. (2023)	AOGCM	Abrupt orbit and greenhouse gases of 127 ka before present	100 coupled

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	ation of high latitude climate forcing to lower latitudes ~~127Kago~~				
piClim-aer[3,4]	Atmospheric response to present-day anthropogenic aerosols to attribute current warming and project committed future warming	RFMIP/ AerChemMIP[a]	AGCM	Effective radiative forcing by present-day aerosols	30 fixed SST
piClim-histaer[3,4]	Atmospheric response to historical changes in anthropogenic aerosols to attribute current warming and calibrate emulators	RFMIP[a] Pincus et al., 2016		Historical and future transient effective radiative forcing from aerosols	251fixed SST
piClim-histall[3,4]	Atmospheric response to historical changes in anthropogenic aerosols and WMGHG to assess why model warming differs from the observed record and estimate model forcing to compare with process models	Smith et al., 2020		Historical and future transient effective radiative forcing from all forcers	251 fixed SST
scen7-h, and/or esm-scen7-h[1]	Climate policy roll-back scenario with low renewable technology development and high emissions	ScenarioMIP[b,d]	AOGCM	Future projected simulations out to 2100	79 coupled

scen7-m and/or esm-scen7-m[1]	Current policy scenario without further strengthening or roll-back	van Vuuren et al., 2025		representing mitigation pathways of current policy, policy failure, policy success and overshoot.	
scen7-ml, and/or esm-scen7-ml[1]	Modest mitigation policy scenario short of meeting Paris goals				
scen7-l and/or esm-scen7-l[1]	Scenario consistent with staying likely below 2 deg C				
scen7-vlho, and/or esm-scen7-vlho[1]	Delayed mitigation policy scenario with overshoot but rapidly intensifying CDR to return to 1.5 C				
scen7-vllo and/or esm-scen7-vllo[1]	Rapid near-term emissions reduction scenario to limit warming to about 1.5 C				
Scenario extensions[1]	Please refer to van Vuuren et al, 2025 for selection of high priority extensions.			Future projected simulation extensions out to 2150-2500 representing mitigation pathways of current policy, policy failure, policy success and overshoot.	Minimum 50 to maximum 400 coupled

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3.5 Pre-selection and sub-sampling of models

The number of models contributing results to CMIP has grown substantially over time, such that more than 100 separate models contributed to CMIP6. A dedicated task team (see section 4.1) considered how best to balance insight with a characterization of diversity by considering available approaches to narrow *a-priori* the number of models contributing to each experiment (pre-selection) and the *a-posteriori* narrowing of models having contributed to each experiment (sub-sampling). Many models are closely interrelated, often via shared implementations and more often via shared conceptual bases. Many sets of simulation results are also similar, though similarity of model structures or genealogies is not an especially good predictor of similarity in results. Similarity between models and between results suggests both that results weighted in some way (e.g. Lee et al., 2021) might be more informative than a raw average, and that having every model contribute to every experiment might be wastefully redundant. The major issues considered and resulting insights drawn from this effort are summarized in Appendix 3. The end result is that CMIP7 protocols do not include *a-priori* matching of models or configurations to specific experiments but that CMIP and the Earth System Grid Federation (ESGF) should strive to enhance opportunities for both model and ensemble – based evaluation. Recommendations for pre-selection and sub-sampling include the following strategies for improving the efficiency of building model diversity in the ensemble:

- Modeling centers consult first the CMIP7 DECK followed by the AR7 Fast Track in their initial prioritization of CMIP7 simulations.
- Researchers interested in assessing the state of the ensemble and Modeling centers wishing to identify gaps in model diversity to further prioritize experiments may consult the proposed Rapid Evaluation Framework (REF; https://wcrp-cmip.org/rapid-evaluation-framework).
- Potential community MIPs looking to build from the CMIP7 DECK and AR7 Fast Track should look at the scope of DECK and AR7 Fast Track experiments supplied on ESGF and analyzed in the REF to identify potential points of collaboration towards targeted community science goals.

4. Evolving CMIP to meet changing needs and opportunities

4.1 The CMIP International Project Office and associated Task Teams

The process leading to thisthe CMIP7 experimental design differs substantially from past iterations of CMIP. Until CMIP6 the experimental suite was designed almost entirely within the small, researcher-led CMIP Panel relying on volunteer coordination efforts from individual nations facilitated by WCRP. While CMIP6 evolved the research scope considerably, CMIP has also been shaped by growing and evolving institutional, national, and international needs for assessment and climate services. In light of CMIP's widening roles, and in response to the increasing demands of thea growing user base, WCRP

secured the establishment of a CMIP International Project Office (CMIP IPO) in 2020 through WMO Resolution 67 (https://www.wcrp-climate.org/images/modelling/WGCM/WGCM23/Presentations/5b_WGCM23-WMO-Res67_CMIP-IPO.pdf). ~~The European Space Agency successfully bid to host the CMIP IPO, which started operations in March 2022 at their UK site.~~ The provision of full-time staff supports the development and delivery of CMIP consistent with the level of international investment and use. With the IPO in place, the CMIP process is institutionally organized and increasingly consistent with ~~WCRP~~the professional standards of transparency, inclusiveness, and equity. The IPO also brings the capacity for full documentation of discussions and decisions, coordination of the various panels and task teams (https://wcrp-cmip.org/cmip7-task-teams/) ~~with explicit terms of reference, and a more open culture~~ allowing many more scientists (including early career researchers) to ~~be engaged.~~
~~With staff in place to manage WCRP and stakeholder requests and meeting logistics, the IPO has also enabled more community consultation such as limited term (months to years) task teams formulated to solve particular problems and~~ engage ~~with relevant stakeholder groups~~. Thus far, seven task teams each involving about a dozen people have contributed to the planning of CMIP7 to date. These include task teams on climate forcings, data access, data citation, data request, model benchmarking, model documentation, and strategic ensemble design as well as smaller working groups on spin-up, harmonization of historical and projection forcing datasets~~,~~. There are also thematic diagnostic groups~~,~~ and sustained mode conceptualization with teams on the CMIP carbon footprint, controlled vocabularies, and quality control/quality assurance being established. The IPO has also facilitated broader community engagement and consultation ~~across the spectrum of time zones with morning, afternoon, and evening virtual information and drop-in sessions plus in person participation in meetings across the globe. While perhaps not as nimble as the previous small group in-person trusted relationships built over many years, this added layer of organization and associated formality has allowed CMIP to become more transparent, inclusive, and facilitative of robust community engagement~~.

4.2 Maturing infrastructure and support capabilities

Key CMIP7 efforts to improve the utility and interpretation of CMIP data have focused on open community consultation processes for revised standards for model documentation, the output data request, and benchmarking. The widening use of CMIP data ~~and IPO ability to accumulate, synthesize, and respond to community feedback~~ has underscored ~~several priorities for development of increasing infrastructure and support capabilities in CMIP7. One area of needed improvement is the~~ the uneven ~~availability~~nature of model documentation ~~across the ensemble~~. Downstream users in particular report frustration with descriptions diffused across model description and intercomparison journal articles, web sites, databases, and technical documents. ~~Modeling centers, on the other hand, are not generally prepared or able to invest substantially in documentation for widespread use.~~ To balance ~~these needs~~the needs of users with the limited resources at modeling centers for documentation, the CMIP7 Model Documentation Task Team has developed a protocol for Essential Model Documentation (EMD): ~~-~~a high-level description required of ~~a~~all participating ~~model. It~~models. Building from similar efforts in previous CMIP phases, it contains questions soliciting information and associated references on formulation ~~that can~~to allow differences between models be easily compared between different models and allows model outputs to be better and understood. More detailed model documentation is expected to be available via references given as part of the EMD. Model participation in CMIP7 is contingent on providing this documentation.

The process of collating and reviewing community input into the model output data request has also been extensively been revised. The content of the CMIP7 Data Request starts from a set of 132 Earth System Model Baseline Climate Variables (Juckes et al., 2024) identified as being of high general utility. This list includes just 132 out 2062 variables in the CMIP6 data request and defines the core of the CMIP7 Data Request. To enable broader and more transparent access while also scrutinizing and constraining the size and complexity of the request, author teams andTo enable broad access and scrutiny, scientific steering groups in five thematic areas (atmosphere, ocean & sea-ice, land & land-ice, impacts & adaptation, and Earth system) have beenwere convened with representation from 106 authors from 25 countries). The impacts & adaptation theme has played a critical role in enabling greater engagement with users outside the physical climate science. These teams, working with the CMIP IPO, Data Request Task Team, and WGCM Infrastructure Panel, are consolidatingconsolidated data requirements from MIPs and public consultation into a single comprehensive, or "harmonized" request for the AR7 Fast Track. The CMIP AR7 Fast Track data request will befor the CMIP7 AFT issued in three major releases, starting with version 1.0 in November 2024 (see https://wcrp-cmip.org/cmip7/cmip7-data-request/).https://wcrp-cmip.org/cmip7/cmip7-data-request/), version 1.1 in January 2025, and version 1.2 in April 2025.

One of the difficulties in realizing the more routine benchmarking and evaluation of the models as envisioned in Eyring et al. (2016) was the challenges met in

To better support automation of diagnostic evaluation— both the difficulty in maintaining and providing to modelling centers the software for doing the analysis and lack of uniformity in metadata and data formats. The, Model Benchmarking Task Team has been working to incorporate available open-source evaluation and benchmarking packages into the Rapid Evaluation Framework (REF) and into ESGF to support public analysis and for incorporation into modelling center workflow to internally evaluate developing models in the same more comprehensive way before their models are evaluated publicly on theseassessment of model performance and simulation for various potential end users and applications. This community metrics. Several of such packages widely used in theowned evaluation framework, built upon, and compatible with, existing community for the evaluation and analysis of CMIP6 data have been identified by the task team to providepackages incorporates an application programming interface for executing metrics generation from a "first data check" for newly developed simulations. An overview of the currentsuite of community evaluation packages is available on a dedicated subpage of the official . The REF allows the full integration of the evaluation tools into the CMIP webpage (https://airtable.com/applbQetZtl09L2Ga/shrzOD0Hif0PY6XJI/tbl3p5dTJjQ6xLiWx).publication workflow, and their diagnostic outputs to be published alongside the model output on the ESGF through an easily accessible website. (see https://wcrp-cmip.org/cmip-phases/cmip7/rapid-evaluation-framework/ for more information). Another dimension of expanded access and coordinated activity in CMIP7 is the Fresh Eyes on CMIP - an early career researcher activity coordinated through the IPO.

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5. Summary

CMIP7 continues the pattern of evolution and adaptation ~~to science priorities and community needs~~ building from CMIP6, keeping minimal requirements of DECK and flexibility of infrastructure but switching from ~~officially reviewing and~~ endorsing a ~~broad~~broadly unconstrained suite of MIPs in favor of only a targeted set of experiments. As a means of clarifying some of the unifying science challenges motivating model intercomparison, CMIP7 science priorities ~~(Section 2)~~ are planned to address ~~guiding~~the following fundamental research questions (Section 2) relating to: 1) Patterns of sea surface warming, 2) Changing extremes, ~~4~~3) The Water-Carbon-Climate nexus, and 4) Tipping Points ~~of no return/ratcheting~~ which are well-aligned with the ~~WCRP's four~~WCRP2019-2028 Science Objectives. The ~~AR7~~CMIP7 Assessment Fast Track (AFT) experiments (~~Section 3.7;~~ Table 3) ~~endorsed in CMIP7 were chosen~~are proposed to both ~~to~~ help answer these guiding research questions and address the requirements of prediction and projection (3.7.1), attribution (3.7.2), characterization (3.7.3), and process understanding (3.7.4~~) towards assessment of state-of-the-art Earth system models~~). CMIP continues to serve at the heart of internationally coordinated climate and Earth system science within the WCRP, but a significant part of the AFT is also intended to support the emerging communities focused on Climate Service activities.

CMIP has striven to meet increasing and broadening scientific and service demands while remaining responsive to the individual priorities and resource limitations of the modeling centers. The revised DECK and AFT recommendations (Section 3) are provided as guidance to modeling centers as they prioritize application of limited computational and human resources for CMIP7 participation. Particularly exciting among the CMIP7 opportunities is the ability to leverage growing model comprehensiveness and maturity of CO_2 emissions-forced ESMs to explore proposed carbon and climate mitigation solutions and the Earth system consequences of stabilization and overshoot and role of changing atmospheric composition, extremes and tipping points.

From consultations with ~~modelling~~modeling centers and forcings providers, the CMIP Panel anticipates the CMIP7 generation of models and forcings to have improved representation of historical climate changes in addressing ~~CMIP6 deficiencies in the improbably high climate sensitivity (Meehl et al., 2020; Lee et al., 2021) and anomalous cooling in the 1960s (Zhang et al., 2021).~~some CMIP6 deficiencies. The inclusion in HighResMIP2 (Roberts et al., 2024) of models capable of representing tropical cyclones, mesoscale weather systems and eddying ocean interactions brings exciting new potential for characterization of extremes, while the re-characterization of future pathways into mitigation policy "success" and "failure" relative to "current policy" provides a path for simplifying communication of the Earth system consequences under different policy options. ~~Particularly exciting among the CMIP7 opportunities is the ability to leverage growing model comprehensiveness and maturity of CO_2 emissions-forced ESM's to explore proposed carbon and climate mitigation solutions and the Earth system consequences of stabilization and overshoot and role of changing atmospheric composition and extremes.~~

~~CMIP has striven to meet increasing and broadening scientific and service demands, expectations of transparency, diversity, equity, and inclusivity. One dimension of expanded access is Fresh Eyes on CMIP - an early career researcher activity coordinated through the IPO. To remain sensitive and responsive to the diversity priorities and resource limitations of the modelling canters, CMIP7 provides the revised DECK and AR7 Fast Track recommendations (Section 3) as guidance to modeling centers as they prioritize application of limited computational and human resources. While this initial CMIP7 AR7 Fast Track is aimed at fulfilling the needs of the forthcoming IPCC physical climate and impacts assessment, CMIP also stands ready to consider future targeted sets of experiments developed to suit future needs. This 7th phase of CMIP thus continues at the heart of internationally coordinated climate and Earth system research within the WCRP and supporting the emerging Climate Service communities.~~

As the applications of CMIP data continues to widen into new contexts such as machine learning (ML) and new communities including the private sector, the question of assuring "fitness-for-purpose" and the limitations of appropriate use of model contributions grows in importance. ~~There~~CMIP is ~~a~~working to address the growing pressure from stakeholders involved in adaptation and risk mitigation to provide guidance on appropriate use of individual models and the ~~simulation~~multi-model ensemble ~~as a whole. This is one of the motivations behind CMIP efforts in selection and sub-sampling and deployment of~~through the Rapid Evaluation Framework (REF; Section ~~3.5~~4.2; Appendix 3; https://wcrp-cmip.org/rapid-evaluation-framework). ~~Such community pressure will surely grow as~~As emulators based on ML techniques mature and compete with classical physical climate and Earth system models to run large ~~ensembles and~~ensemble or downscale information~~. Emulators~~ to a more local scale, they may ~~soon~~ enable the construction of more structured ensembles from selected models such that a priori model pre-selection and sub-sampling (~~Section~~Appendix 3~~.8) becomes~~) become more viable in future phases of CMIP.

CMIP has evolved over its several phases to provide critical services to ~~a broad~~the broader scientific ~~and stakeholder~~ community through support for protocols including forcing/input data, output conventions, contributions from ~~modelling~~modeling centers, and mechanisms for data distribution. This chain of end-to-end solutions necessary for coupled model intercomparison is a facility useful for answering a multitude of questions for which CMIP standards, protocols, infrastructure, and experiments provide ~~the basis~~context. Given this established and ongoing importance of CMIP, it is important to recognize ~~not only the successes but also its~~ the ongoing challenges to sustainability of the CMIP process. While CMIP has benefited handsomely from the creation of the dedicated IPO, the lack of structural funding for forcings providers, ~~modelling~~modeling centers, infrastructure providers, and data users forces ad hoc participation based on national funding with diverse priorities. While this mode of funding has proven exceedingly successful in keeping research quality at the forefront, its highly episodic nature has proven challenging to transition to more continuous or sustained modes of information provision.

While the effort described above for CMIP in its 7th phase continues as a fundamentally research driven activity, efforts are also underway to build on aspects of CMIP into a more sustained mode. With the ever-increasing urgency of robust and actionable information for climate change assessment, adaptation and mitigation and predictions on seasonal to decadal timescales, however, the climate community in general (e.g. Schmidt et al., ~~2023~~2023a; Jakob et al., 2023; Stevens, 2024) and CMIP specifically (Hewitt et al., in preparation) have been pursuing ways to support sustained extension of historical forcings, applications of models, and their data provision. CMIP has also identified challenges in the transition of the research mode of funding, human and computational resources, cultures and reward systems along the path to sustained activity and seeks broad community engagement through WCRP and WMO to continue pressing forward on next generation solutions. These efforts include a recent workshop in October 2024 to explore a "Pathway to regular and sustained delivery of climate forcing datasets" ~~(https://wcrp-cmip.org/event/forcings-workshop/).~~(https://wcrp-cmip.org/event/forcings-workshop/).

~~In summary~~

Moving forward, CMIP is evolving to support the ever-increasing diversity of climate and Earth system questions that require a multiverse of models across resolution and comprehensiveness (Figure 1). As this diversity in model structure and applications expands, CMIP strives to offer a platform that enables intercomparison and hybridization of these approaches to support the international coupled modeling community to understand our present and future climate and their changes and impacts on the Earth system.

Appendices

Appendix 1

To ~~characterise~~characterize any model simulation performed before the initial year of piControl (spin-up; Section 3.2), it is recommended that ~~modelling~~modeling centers save model initial conditions as well as the following integrated annual metrics for provision to the CMIP IPO for ~~curation~~public dissemination.

Metric	Justification
~~TOA~~Top Of Atmosphere radiative imbalance and albedo [rsdt, rsut, rlut]	Interpretation of the evolving energy input into the system
Global mean SST [tos]	SST stability is essential
Ocean heat content – upper and lower if possible [thetaoga, bigthetaoga]	To first order, TOA and ocean heat content change should balance. Upper and lower ocean heat content is preferable – if not total.
Total ocean salt content [soga]	Check that the ocean is conserving salt
Total ocean mass and volume [masscello, volcello]	

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Net surface heat flux (into ocean) [hfds, hfcorr]	Check with TOA and heat content (but need to think about ice)
Net surface freshwater flux into ocean and/or global mean precipitation	Check with ocean volume (but need to think about ice)
Northern and southern hemisphere sea ice volume/mass min and max [sivoln, sivols]	
AMOC [msftyrho, msftyz]	Maximum of MOC in Atlantic
Global mean albedo [rsdt, rsut]	
Snow cover – total area? [sncls]	
CO2mass	Integral of atmospheric CO2 concentration
net carbon flux atmosphere-ocean (global integral fgco2)	Understand if any remaining C relocation between the reservoirs is present at the end of spin-up, can be calculated from deltas from total land/ocean/permafrost carbon pools. This can be further detailed. e.g., Land carbon can be distinct between soil/vegetation/permafrost, ocean carbon can be distinct between DIC/DOC/POC/surface ocean/deep ocean, ...
net carbon flux atmosphere-land (nbp)	This may need to be derived if terms like fire and land use are treated separately
Net permafrost carbon flux	
Sediment weathering flux / riverine C flux (icriver, ocriver, fric, froc)	Necessary for mass balance within the ocean. There are separate terms for inorganic and organic carbon
Diagnosed CO_2 emissions	In case of CO_2 concentration or emissions driven spin-up, respectively, to assess the total C balance of the model.
intCVeg	Integral of Carbon in Vegetation (Three of these four land carbon metrics would be useful to track drift in stocks)
intCsoil *	Integral of Carbon in soil
intCLitter	Integral of Carbon in litter
intCLand	Integral of Carbon on Land

intdic	Integral dissolved inorganic carbon concentration
intCProduct	Integral of harvested Carbon from land use (cLand=cVeg+cLitter+cSoil+cProduct)
intAlk	Integral dissolved alkalinity concentration
$intO_2$	Integral dissolved oxygen concentration
$intNO_3$	Integral dissolved nitrate concentration
Total water storage	sum of snow water equivalent and soil moisture in all layers, useful to track drift in water budget

Appendix 2

General guidance on setting up a MIP

CMIP's long experience in coordinating model intercomparisons has helped identify a set of practices (up to date version can be found at https://doi.org/10.5281/zenodo.10572155) that allow broad participation and efficient use of resources, which are summarized here.

1. Articulate the hypothesis: Clearly define what new knowledge will be gained by the experiments. MIPs that define key metrics that can be calculated and compared with observed quantities are particularly useful in this regard.
2. Clarify the experimental design and data requirements: Experimental designs are most effective when they ~~elucidate~~are able to distinguish areas of robust model agreement and ~~inform on areas of~~ inter-model differences. Clear design and description of ~~a MIP and its~~ individual experiments~~, articulation of~~ and data requirements~~, and resource planning~~ is essential to ensure uniform conformance to protocols ~~by contributors~~ and ~~the~~ production of comparable results~~ that meet the design goals~~. Targeted sizing of the experimental design (in terms of both runs and data requirements) helps limit the environmental footprint of performing the MIP simulations.
3. Leverage past experience: An awareness of previous model experiments and care in avoiding unnecessary duplication frees resources and focuses effort on novel questions. Designs explicitly taking into account the extent to which modestly different forcings, experiments, or model versions can provide compelling motivation for new experiments.
4. Develop prototype experiments: Performing prototype experiments with at least one model prior to proposing MIP experiments provides critical justification of why initial results are insufficient and need to be augmented with results from a multi-model ensemble. Identification of dependencies or links to existing (or proposed) experiments and associated available simulations provides a comprehensive perspective on the full requirements for participation.
5. Foster transparent and inclusive collaboration: MIPs co-designed by a wide range of individuals, communities, and institutions contributing ideas, simulations, results, or analysis help move the field forward. Reaching out early to ~~modelling~~modeling centers and/or other participants can help secure sufficient commitments to assure the

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6. Coordinate with other MIPs: Consider registering the MIP. This includes a brief description of initial plans and is meant to identify potential duplications and foster opportunities to coordinate across MIP activities. Such coordination is particularly helpful for avoiding naming clashes, which can create confusion for modelling teams and downstream data users alike.
7. Document the approach comprehensively: Description papers subject the MIP design to a process of peer review. Such papers provide the goals of the MIP and the rationale for each of the planned experiments. Defining the experiment protocols as clearly as possible helps avoid confusion and highlight possible areas of departure between modeling center ~~implementation.~~implementations. "Living" experiment documentation on a website or other easily accessible platform can ensure that up-to-date information is readily available for those seeking to conduct the experiments.
8. Prioritize anticipated experiments: Explicit prioritization ("tiers") of experiments allows contributors to usefully participate at whatever level of effort best suits them for a spectrum of levels of engagement.
9. Support contributors and users: Anticipate how the data will be prepared and distributed so that the scientific findings can be published including testing diagnostics across models to assure data comparability.
10. Acknowledge contributions: Where MIP analysts are distinct from the groups contributing results encourage inclusion of data providers as co-authors (especially in early publications). Data citation is a further mechanism of ~~acknowledgement~~acknowledgment.

Conforming with CMIP Practices

In addition to following the above "best practices", a MIP may want to take advantage of the data standards and infrastructure that support the most recent phase of CMIP. In some cases, the CMIP panel and IPO may be able to provide additional input and services that may increase the potential scientific impact of a MIP. Insistence on the latest standards and adoption of the same controlled vocabularies used in previous CMIP phases can reduce the overhead on modeling group participation and facilitate community analysis of MIP results. While the CMIP7 technical specifications are still under development, they will rely heavily on the CMIP6 requirements which were discussed generally in Balaji et al. (2018) and were fully detailed on the CMIP6 website in the Guide to CMIP6 Participation.

Appendix 3: Model sub-selection

Noting that the number of models contributed to CMIP has grown substantially from CMIP3 to officially over 100 models in CMIP6 and that the computational, energy, and human resources available for CMIP-related activities is limited, the design phase for CMIP7 explored options for sub-sampling the ensemble by pre-selecting models for individual experiments with an eye towards optimizing computational efficiency. The final design, however, does not include a pre-selection of models. The reasons for this decision are laid out in this appendix.

Support for pre-selection of models comes from several bases, including the recent weighting of CMIP6 model output conducted in multiple studies and applications. One of the important departures of the IPCC 6th Assessment from those previous was a shift towards a synthesis of multiple lines of evidence to inform future climate uncertainty ranges (using a combination of ESM ensembles, observations and emulators). This~~,~~ was in part ~~was~~ due to a subset of models which were deemed to exhibit historical warming ~~which was~~ inconsistent with observations (Hausfather et al., 2023). Potential mechanisms for direct model weighting on global warming response have been proposed by some authors (Massoud et al., 2023), while others propose multivariate weighting of models based on aggregate skill and independence (Sanderson~~,~~ et al., 2017, Brunner et al., 2020). It is also recognized in extensive literature (Knutti et al., 2013) that the diversity of current models arises from a smaller number of lineages which ~~maintains~~maintain dependency between them in the algorithmic structure and behavior (e.g., CESM to NorESM, E3SM, CCMC, BCC-CSM), which some studies have recommended as a strategy for weighting (Kuma et al~~.~~., 2023).

There are also several strong arguments against pre-selection of models. In many cases, ~~despite their common ancestry, seemingly similar~~similarly structured models can behave very differently despite often common ancestry. For example, in CMIP6, the atmospheric component of NorESM2 is very close to that of CESM2, yet CESM2 had one of the highest equilibrium climate sensitivities at 5.2K and NorESM2-LM had one of the lowest at 2.5K (Meehl et al~~.~~., 2020, Table 2). Results from Perturbed Parameter Ensembles also demonstrate that small changes in parameter tuning can yield strongly differing results from the same model (Yamazaki et al~~.~~., 2021), which makes it challenging to determine how to balance ensuring independence with spanning as broad a range of uncertainty space as possible. While many models participating in CMIP include different configurations of the same trunk model (ESM, high resolution, alternative physics), this potential source of duplicity often provides valuable dimensions of diversity include not only the most comprehensive and high-resolution models but also more computationally efficient models which generally participate in targeted community science activities within CMIP. Further, even if it is feasible to choose the "best" models for a particular task, there are several benefits to a diverse ensemble which spans a wide range of plausible behavior. Insights into mechanisms and constraints on future projections such as "emergent constraints" benefit from the full range of responses that can allow linkages between aspects of the model representation and forced response to be identified. For example, Swaminathan et al. (2024) shows that many metrics of crucial interest are uncorrelated with Equilibrium Climate Sensitivity (ECS) such that many high ECS models in CMIP6 considered outside of the "probable" range have very good evaluation scores on many metrics and that having a lower ECS is not necessarily a measure of quality.

Model spread in future climate response cannot be not known in advance, and only in ensemble post-processing is it evident how process and technical improvements translate into ensemble performance and projection spread. —While immensely valuable in combining multiple lines of evidence to constrain the global temperature response once the ensemble is mature, these approaches cannot be used a priori to select models to participate in CMIP experiments because model simulations are not yet available, making objective pre-selection of CMIP7 model variants effectively impossible. Further, such techniques are highly dependent on the metric chosen - two models may exhibit highly similar warming patterns, but different precipitation or carbon cycle responses - for example. Any attempt to pre-select independent models would require a highly multivariate approach. Studies such as Peatier (~~2023~~2024) and Sanderson (2017) also suggest that as the number of metrics included in an assessment increase, the ability to distinguish skill and similarity in that space weakens (even post-hoc) such that the more metrics are considered, the less significant the differences between models becomes in terms of overall performance and the more arbitrary the weighting. As such, it is not desirable to filter potentially useful and unique models until their historical performance and basic metrics of future climate response are known.

In contrast, post-selection and model weighting strategies have proven immensely useful for downstream and targeted community science activities which are able to select models based on simulations in the CMIP7 DECK and ~~AR7~~Assessment Fast Track in cases when desired diagnostic behavior is well defined. There are several examples of frameworks developed through CORDEX for sampling based on metrics for different regions (e.g., Grose et al., 2023, Nguyen et al., 2024). In many cases, however, these configuration-specific model variants are already effectively designed for specific parts of CMIP (e.g., high resolution for HighResMIP, interactive chemistry for AerChemMIP, interactive carbon cycle for C4MIP).

In the absence of pre-selection modeling centers might help fill uncertainty space by consulting results from the Rapid Evaluation Framework (REF), identifying gaps in model diversity across dimensions such as CO_2 and aerosol sensitivity, temperature and precipitation bias patterns, carbon response patterns, etc., and contributing simulations to fill uncertainty space towards yielding new information to robustly fill out the ensemble.

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~~**Code availability**~~

~~While no code was used in the present study, CMIP best practices are for modeling centers to make the code for models used for the DECK and AR7 Fast Track simulations described here be made available as part of the documentation of their models.~~

Data availability

~~While no data was used in the present study, the~~The model output from the DECK and ~~AR7~~Assessment Fast Track simulations described in ~~here~~this paper will be distributed through the Earth System Grid Federation (ESGF). As in CMIP6, the model output with associated metadata and documentation will be freely accessible through data portals.

Author contribution

JD prepared the manuscript with contributions from all the co-authors.

Competing interests

The authors declare that they have no conflict of interest.

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