CMIP7 Data Request: Impacts and Adaptation Priorities and Opportunities

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Abstract. The Coupled Model Intercomparison Project Phase 7 (CMIP7) undertook an extensive process to gather community input and refine data requests related to impacts and adaptation applications of Earth System Model (ESM) outputs. The Impacts and Adaptation (I&A) Data Request Team worked with CMIP7 leadership to distribute an open solicitation across many communities that use climate model outputs requesting inputs for new and existing variables, the most applicable temporal characteristics, and groupings of variables that together allow for specific application opportunities. This input was then collated and translated into CMIP7 standard templates for inclusion in the broader data request, leading to 13 I&A data request opportunities, 60 variable groups and 539 unique variables sought by vulnerability, impacts, adaptation, and climate services user communities. Here, we describe these opportunities and variable groups, as well as new insights into how ESM groups can prioritize outputs that set off a chain of further analyses, ultimately informing decisions impacting society and natural systems. These include an emphasis on high-resolution outputs to allow further modeling of climate impacts at regional and local scales, improved representation of extreme weather events, enhanced accuracy of downscaling and bias-adjustment techniques, and support for more detailed assessments for decision-making in adaptation and mitigation strategies. There is also broad interest in more extensive provisioning of two-dimensional variables at the Earth's surface, prioritizing experiments that enhance our understanding of both the recent past and future scenarios, and providing outputs that allow further downscaling and bias adjustment. We emphasize that variable groups are the fundamental level at which to engage with the I&A data request, matching the scale of input and the way output provision enables specific I&A applications. Given resource constraints, we applaud CMIP7 efforts to foster strong engagement and communication between ESM groups and the I&A team to build consensus around prudent compromises in priority variables, temporal resolutions, simulation experiments, time subsets, and ensemble members.

1 Introduction

1.1 Background

Recent climate extremes and record-breaking global temperatures emphasize that climate change is a present and urgent challenge to nature and nearly every aspect of society (Calvin et al., 2023). Mitigation and adaptation actions require clear-eyed insight into the ways that humans are altering the Earth's climate and modifying specific conditions that affect the systems we care about (Ruane et al., 2022). Climate change information must also be timely to enable proactive planning, implementation and system transitions.

The Coupled Model Intercomparison Project (CMIP) has served as the premier protocol-based community for understanding Earth System Models (ESMs) and coordinating ensemble-driven climate assessments. In its previous Phase 6 (Eyring et al., 2016), CMIP6 data requests emphasized the importance of producing data that would be useful for vulnerability, impacts, adaptation and climate services (VIACS) communities (Ruane et al., 2016). This reflected that a major motivation for building and running ESMs is to understand how climate changes affect natural and human systems (Eyring et al., 2019). Inputs from a number of impact sectors and climate services experts in the lead up to CMIP6 pointed to a set of prioritized climate variables (including several variables new since CMIP5) anticipated to be of primary interest to many communities and a number of variable groups tailored to the needs of select communities. In practice, there was a disconnect between the climate variables available from CMIP6 and the needs from various Impact & Adaptation (I&A) communities (Craig et al., 2022). This disconnect can be attributed to several factors: the mismatch between the spatial and temporal resolutions of CMIP6 outputs and the requirements of impact assessments, which often demand higher-resolution data to inform local adaptation strategies. Additionally, the lack of standardized data formats, bias correction and downscaling techniques, pre-computed ensembles and metadata has posed challenges for users attempting to integrate CMIP6 data into their models and decision-making processes. Addressing these gaps is crucial for enhancing the usability of climate model outputs in real-world applications.

CMIP7 (Dunne et al., 2024) features new and improved ESMs that take advantage of more powerful computational and data storage capabilities. Within the CMIP7 framework, data request processes have been conducted to prepare efficient and effective variable production for 35 registered Model Intercomparison Projects (MIPs) and other applications within the VIACS communities (which also extends well beyond CMIP7). The CMIP7 design recognizes that VIACS communities are rising in prominence given their critical role in climate action planning and implementation, and they are growing in expertise, organization, and engagement with both stakeholders and the physical climate science community.

1.2 ESMs in applications context

In practice, CMIP's relevance to impacts and adaptation planning is vital but not always direct. ESM outputs provide the fundamental climate response information that launches a long sequence of processing and analysis that supports risk management and adaptation planning (Figure 1) (Doblas-Reyes et al., 2021). This process is initiated by scenario inputs (e.g., emissions and land use information associated with socioeconomic and geopolitical pathways) provided by groups such as the integrated assessment models associated with ScenarioMIP (Van Vuuren et al., 2025). These outputs are then converted into greenhouse gas, aerosol, and land use forcing fields that will serve as driving conditions (as overseen by the CMIP7 Forcings Task team and input4MIPs). The ESMs then simulate the responses of the Earth system to these scenarios, generating foundational understanding of changes to the atmosphere, ocean, biosphere, cryosphere and land surface potentially including all of the variables requested by this CMIP7 I&A team. ESMs rely on some of the world's most powerful computing systems, yet they must remain efficient in order to simulate long time periods, large ensembles, multiple models, different model versions (with varying structures and physics), and a wide range of future scenarios. The importance of ESM efficiency can lead to coarse outputs that motivate further downscaling (Gutowski et al., 2016; Jones et al., 2024; Yu et al., 2022) and bias-adjustment (Karger et al., 2017; Lange, 2019; Thrasher et al., 2022) to capture important sub-grid-scale responses and reach decision relevant temporal and spatial scales, although these can also introduce delays into assessment planning. This information is often then passed into impacts models that represent the response of human and natural systems (e.g., agriculture, water resources, human health, infrastructure, energy, fisheries, ecosystems), further translating global change information into the units of asset risks and benefits that may govern stakeholder decisions. Outputs from all these models are then interpreted, translated, and communicated by experts, boundary organizations, climate services and practitioners, allowing for the design and implementation of climate responses (Doblas-Reyes et al., 2021). Climate services communities therefore depend on ESM outputs and help connect stakeholders with the climate information they need to inform risk management, adaptation, and mitigation on a variety of time horizons (e.g., World Meteorological Organization (WMO) Climate Services, NOAA, UK Met Office, the World Bank Climate Change Knowledge Portal, Copernicus Climate Services).

The flow of climate information from ESMs to adaptation-relevant decision-making is complex, non-linear, and increasingly flexible. Figure 1 illustrates that the processing pipeline is not a fully closed system; information can enter or exit at various stages. Many applications are designed to bypass certain steps to conserve resources or address methodological limitations. For instance, some workflows move directly from ESM outputs to bias-adjusted datasets without intermediate dyanmical downscaling. Other worksflows may utilize emulators as simplified, computationally efficient models approximating the behavior of full ESMs using statistical or machine learning methods trained on existing ESM outputs. While they cannot replace ESMs entirely, they allow users to explore additional scenarios or sensitivity analyses with reduced computational cost. While these shortcuts may introduce simplifications or degrade signal quality, emerging technologies—such as artificial intelligence and physics-informed machine learning—offer promising pathways to bridge gaps efficiently, provided they are applied with care (Molina et al., 2023; Kashinath et al., 2021).

The ESM step is critical to the entire processing and decision-making pipeline, motivating great interest in the CMIP7 variable request from many downstream communities. Lack of information from ESMs cuts off whole areas of downstream application, so it is critical that CMIP7 establish an early, close and sustained engagement with the VIACS communities. Even where emulators may be used to skip the ESM step, these would depend on foundational ESM simulations with robust outputs to train the emulators across all requested variables. Machine learning and other data-driven approaches are only as good as the underlying datasets, which underscores the importance of CMIP's original, physics-based information about climate response. The steps following the ESM simulations also take substantial time and effort, which emphasizes the need for timely production and sharing of CMIP outputs, particularly in light of pressing (though not yet finalized at time of writing) IPCC AR7 deadlines.

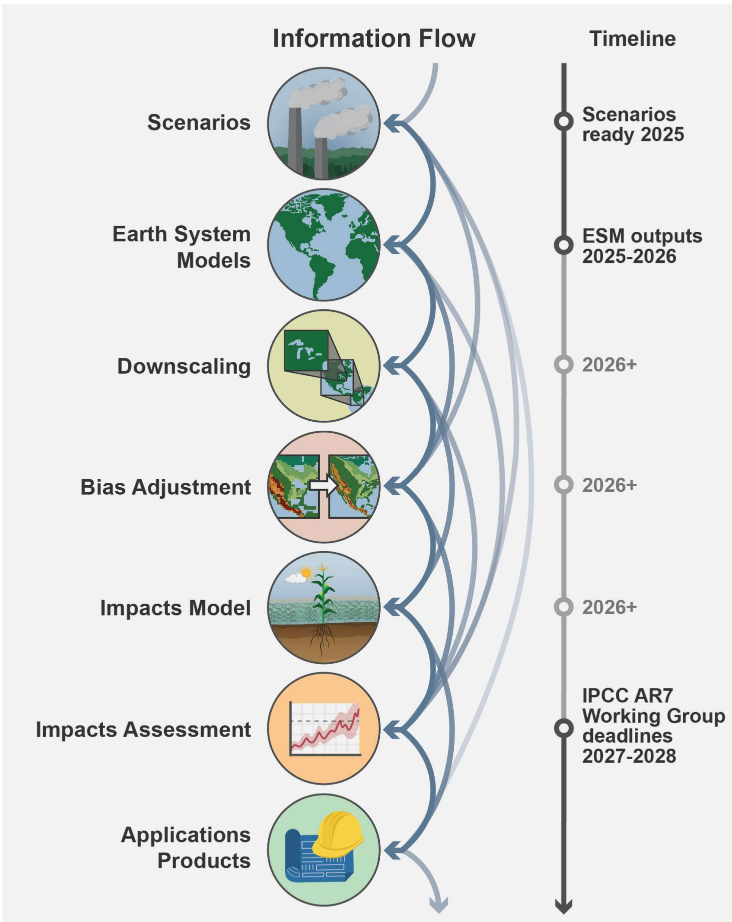

Figure 1: ESM outputs in the broader context of information flow and analysis for impacts and adaptation applications. Dark arrows indicate a direct chain of inputs and outputs for analyses developing scenarios into applications products, while lighter arrows indicate the potential for skipped steps utilizing methods such as artificial intelligence or emulators to accelerate the process and conserve resources. The timeline on the right indicates targeted milestones that puts time pressure on the larger process (although precise dates are not yet finalized by the IPCC and UNFCCC), with gray dates indicating reduced certainty given dependence on resources and the successful completion of previous steps and accessibility of outputs. Ruane and Kozlowski (2025).

2 Approach and methodology

The I&A Theme is unique within the CMIP7 Data Request because of its need to reach communities far beyond those developing and running ESMs. Work thus began by recruiting a team that could speak to the experience and practice of CMIP applications for nature and society. CMIP7 began by drawing from the foundation of the VIACS Advisory Board initiated in CMIP6 (Ruane et al., 2016), opening further with an open solicitation for participation that attracted dozens of applicants. The author team was selected based on expertise in the I&A application of CMIP outputs, an interest in covering major application sectors (e.g., water resources, cities, agriculture, ecosystems, infrastructure, health), community-led projects, and regions (Bernier et al., 2024). The team also selected ~~for~~ authors who could utilize established networks to reach the broader VIACS communities to maximize input and community representation in the CMIP data request process.

The I&A Team was especially interested in soliciting feedback from non-traditional CMIP partners and users of ESM outputs; however, this led to a larger gap in terms of familiarity with CMIP interfaces and data tools. Rather than asking the broader VIACS community experts to navigate the Climate and Forecasting (CF) Standard forms and CMIP7 AirTables, which define variables, variable groups and opportunities, the I&A team worked with the CMIP International Program Office (IPO) to establish a Mural Board web link for community input. Mural Board operates ~~that operated~~ like a white board for generating priority data requests, with space for respondents to leave notes indicating variables of interest, provide a short justification of prioritization, and to describe the community/perspective and application they were representing. This process allowed aggregating input into relatively broad opportunities, each covering inputs from several community expert groups, many of which are not (yet) as well organized as the ESM community. The Mural Board was divided into boards for 11 sectors (Climate Services, Agriculture, Cities, Fisheries, Human Health, Infrastructure, Marine Fisheries, Terrestrial and Freshwater Ecosystems, Peace and Socioeconomic Development, Water Resources, Energy) and a Miscellaneous/Other board. These Mural boards provided instructions, examples, and templates to make I&A data requests as easy and accessible as possible, while also collecting contact information associated with each entry to document reach and allow for follow-ups when clarification was necessary. The I&A Author team then sent out invitations to provide input across broad author and CMIP networks (**Figure 2**). Outreach followed a multi-pronged strategy to advertise the effort and solicit community input, including personal conversations, workshop and conference announcements and sessions, direct emails, messages on project and community list-servs, social media alerts, communications and special events organized by the CMIP IPO, and bulletins on WCRP websites (e.g., https://www.wcrp-climate.org/). In many cases, these advertisements were further disseminated through partner networks reaching thousands of impacts and adaptation experts (e.g., via CORDEX, AgMIP, ISIMIP). The I&A Author team also filled in data request needs determined by their own experiences, conversations with colleagues in their field, and information drawn from groups that have published data requirements in the literature (e.g., for the storm surge community;

Bernier et al., 2024). The co-development effort was also aided by web announcements, emails, and direct invitations from the CMIP IPO.

The overall I&A outreach response successfully included direct inputs on each sectoral Mural Board, with professional and scientific communities being the most common respondents, likely reflecting internal deliberations within groups already organized for collaboration in a climate applications realm. Where gaps were identified the team conducted more direct follow-on outreach, although it is likely that groups with additional inputs did not explicitly engage in the process. As inputs were public at the time of solicitation, some later inputs built on or clarified earlier inputs. The I&A Team tracked this iterative process to help determine shared priorities when combining variable requests.

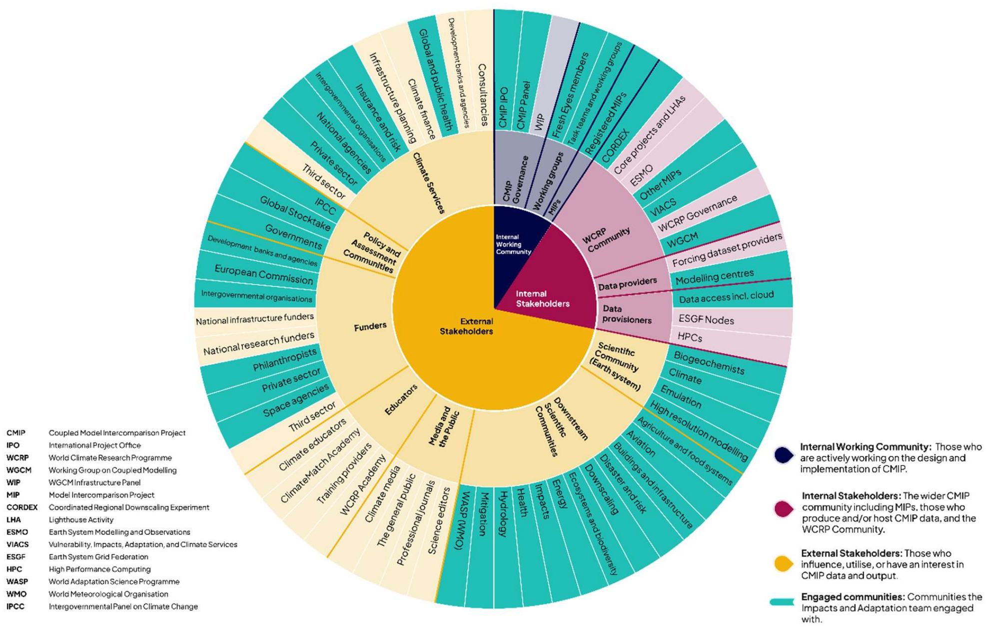

Figure 2: Categories of communities contacted and contributing to the I&A Data Request, with additional informal interactions furthering the reach of the input process. The bottom-right legend indicates the broad categories of stakeholders as colored in the innermost circle, with those categories elaborated outward and the final ring indicating which communities the I&A Team specifically engaged. Ruane et al. (2025)

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3 Information management and decision making

Inputs from the climate applications community allowed the I&A Team to summarize the VIACS perspective to engage ESM groups in planning output production. These contributions came both from individuals responding directly to the solicitation and from communities that had deliberated internally before submitting collective feedback. The vast majority of Mural Board inputs were akin to variable groups, providing a list of specific variables required to perform a given application, for example capturing the breadth of climatic impact-drivers needed to assess risks for a vulnerable asset, calculating an impacts-relevant metric, or driving an impacts model. In some cases, the same Mural Board input included several groupings of variables for distinct applications or indications of broad support for existing requests.

Harmonizing the I&A data request with the broader CMIP7 Data Request efforts required translating the Mural Board inputs into the CF Standard forms for proposing new variables and the CMIP7 AirTables for proposing variable groups and opportunities (Mackallah et al., 2025). This process began with an initial review of inputs and communication with community members to clarify any potentially confusing entries and to track down any missing information. The I&A team then merged similar variable groups according to the type of application that each group made possible. Finally, variable groups were clustered into coherent opportunities that generally aligned with the major impacts sectors. Reflecting the collaborative nature of the process, opportunities were named according to topic rather than for specific communities, projects, or models. Multiple opportunities were constructed in broad sectors like infrastructure, which had distinct output requirements for aviation and ground transportation applications. I&A opportunities were then scrutinized by independent CMIP7 data request authors, resulting in an additional round of consolidation to avoid overwhelming ESM groups deciding on their output targets (Appendix A). The details of the other thematic areas and variable groups included in the Data Request are provided in the companion manuscripts in Atmosphere (Dingley et al., 2025), Land and Land Ice (Li et al., 2025), Earth System (McPartland, 2025), and Ocean and Sea Ice (Fox-Kemper 2025) themes.

4 Results: Content included in the CMIP7 Data Request

4.1 I&A Opportunities and variable groups

The I&A Data Request process produced 13 I&A opportunities (Table 1) consisting of 60 variable groups.

Table 1: Overview of all opportunities associated with the Impacts and Adaptation data request (further details on variable groups provided in opportunity motivations below).

Section	ID	Opportunity title	#Variable Groups	Opportunity Description
4.1.1	19	Agriculture and Food System Impacts	10	Supports agricultural sector simulations and analyses of extreme event response, air pollution, water and land use for I&A planning in agriculture and food systems.
4.1.2	77	Bias-adjustment for impacts modelling and analysis	4	Enables bias reduction procedures that convert ESM outputs to more relevant scales for broad use by I&A applications.

4.1.3	16	Climate impacts on marine biodiversity and ecosystems	4	Supports marine biodiversity and ecosystem expert efforts to assess climate change impacts in marine ecosystems and for different ecological groups.
4.1.4	20	Core climate services	2	Baseline high-frequency output to support diverse communities working in climate services and climate impact modeling as a vital step in the value chain for understanding and managing the risks of a changing climate to society.
4.1.5	81	Dynamical Downscaling	7	High-resolution climate simulations performed with regional climate models (RCMs) and convection-permitting regional climate models (CPRCMs) are more and more used to feed regional climate services on a wealth of applications at fine spatial scales.
4.1.6	80	Empirical Statistical Downscaling and Emulators	4	Machine learning-based statistical approaches are now used to emulate the behavior of high-resolution climate models such as RCMs or CPRCMs. When trained, those tools have the capacity to replace the dynamical downscaling approaches for a variety of applications such as creating multi-member ensembles or emulating an emissions scenario not run with the emulated RCMs.
4.1.7	22	Energy system impacts	7	Supports energy sector simulations relating to, e.g., system operation, system planning, renewable power resources, use and availability of hydropower, transmission and storage planning, energy usage patterns, climate resilience of generation assets (including nuclear), and adaptation to extreme events.
4.1.8	37	Health impacts	6	Allows for further analysis of human health impacts across a range of major hazard types, including heat and humidity extremes, flooding, and air pollution.
4.1.9	41	Impacts of climate change on aviation	1	Supports studies focused on the impacts of climate change on the aviation sector. Tracks climate changes to upper tropospheric winds and temperature that govern jet streams and, in turn, affect wind shear and clear air turbulence as shown in multiple studies.
4.1.10	42	Impacts of climate change on transport infrastructure	1	Supports studies focused on the impacts of climate change on the transport sector (railways and roads, mainly). The sector is severely impacted by extreme weather events, through multiple hazards such as heat, flooding, extreme winds, coastal erosion and storm surges. Future climate projections are used to inform business planning, adaptation and regulatory submissions by the transport infrastructure sector.
4.1.11	11	Terrestrial Biodiversity	4	Supports model-based impact assessments and adaptation planning in the terrestrial biodiversity and ecosystem services sector. This spans a broad set of impact models from global to regional scales.
4.1.12	40	Vulnerability of urban systems, infrastructure and population	2	Enables studies focused on the impacts of climate variability and change on urban infrastructure and population. With more than half the global population living in cities and this number being projected to rapidly increase, understanding the projected changes in hazards to urban environments such as heat and flooding is of vital importance to support effective adaptation strategies.
4.1.13	67	Water security and Freshwater Ecosystem Services	16	Supports future projections of hydroclimatic hazards and their effects on freshwater ecosystems and water resources to plan adaptation actions and resilience building measures that ensure water security, ecosystem services and planetary health.

Many of the I&A opportunities cover a large number of applications appealing to broad audiences for use of CMIP7 outputs. Opportunities often align with IPCC Working Group II sectoral chapter topics, which in turn have a large number of sub-topics with unique variable groups and potential applications that could stand alone as their own opportunities. The I&A Data Request Team emphasizes that ESM groups should engage with the Opportunities first to determine the types of applications they would hope their model outputs would support, and then select among Variable Groups according to their own judgment balancing resource constraints, scientific interests, and motivation to support particular impacts and adaptation decision processes. As the I&A Team expects decisions operating on the Variable Group level, some variables are included in multiple variable groups to ensure internal coherence and sufficiency for the intended application (see also Section 5.1). Redundancies of output variables across variable groups are seen as highlighting a benefit given that it indicates multiple uses for the same output and a reduced overall burden for the ESM teams. The I&A Team also encourages ESM groups to avoid thinking that opportunities are all-or-nothing; even providing variables for one Variable Group (or a subset of those variables) is valuable.

In the following sections we describe the motivations for each I&A Data Request Opportunity and variable group, deepening the summaries and justifications provided in the CMIP7 Data Request AirTable.

4.1.1 Opportunity ID 19: Agriculture and Food Systems Impacts

Variables in this Opportunity support applications that help understand and prepare for risks to regional and global food systems, food security, and the livelihoods of many rural populations that rely on agricultural systems (Mbow et al., 2017; Pörtner et al., 2022). Agricultural systems, here focused on terrestrial practices including field crops, agroforestry, and animal agriculture, have great potential for adaptation and mitigation as the agricultural sector is a major emitter of greenhouse gases and driver of land cover change. Forewarning of future risks allows for proactive planning and the development of adaptation and mitigation strategies that will be effective, timely, and just, even when responses are non-linear or influenced by non-climatic factors (Ruane et al., 2024; Zhao et al., 2024)

Large communities of practice are well-established in using climate model outputs for agricultural applications. This requested received multiple inputs from the Agricultural Model Intercomparison and Improvement Project (AgMIP), which is an independent (non-CMIP7) community undertaking multi-crop-model ensemble projections of future agricultural yields, water requirements, and the downstream ramifications on food prices, food security, socioeconomic development, and geopolitical stability (Rosenzweig et al., 2013; Ruane et al., 2017; Hasegawa et al., 2018). AgMIP also coordinates global gridded crop model simulations (Jägermeyr et al., 2024) in collaboration with the Inter-Sectoral Impacts Model Intercomparison Project (ISIMIP; Frieler et al., 2024). Additional applications utilize empirical or machine learning models to anticipate crop risks or viability under different environments (Sweet et al., 2025).

The opportunity includes 10 variable groups (Table 2), beginning with an AgModelCoreDaily variable group that includes the most commonly required information to drive a process-based crop model. This core set also serves as a minimal dataset for a large number of additional agricultural indices and suitability analyses. The AgModelExpandedDaily variable group allows for more complex determination of evapotranspiration and drought conditions in agricultural lands. An AgModelHourly variable group adds sub-daily information for more complex agricultural modeling efforts (see Appendix B for more information on new variables from all I&A opportunities). The opportunity also features variable groups that explore specific aspects of agricultural systems in a changing world, including a focus on carbon stocks and fluxes, agricultural water resources (core and extended), air pollution impacts, and land use change. The AgTile variable group requests tile water and energy balance information corresponding to the agricultural components of a larger grid cell, and the AgImpactsMisc variable group includes additional variables related to wind gusts and monthly CO_2 concentrations.

Table 2: Motivation for variable groups associated with Agriculture and Food Systems Impacts

ID 19: Agriculture and Food System Impacts **Brief description:** Supports agricultural sector simulations and analyses of extreme event response, air pollution, water and land use for impacts and adaptation planning in agriculture and food systems.	
Variable group	**Reason for inclusion**
AgModelCoreDaily	Core daily variables needed to run majority of processed-based crop models such as those included within the Agricultural Model Intercomparison and Improvement Project (Rosenzweig et al., 2013; Ruane et al., 2017).
AgModelExpandedDaily	Additional variables that allow more complex agricultural modeling, including enhanced representation of radiation balances and evapotranspiration.
AgCarbon	Variables needed to assess carbon stocks and greenhouse gas exchanges on agricultural lands including crops and pastures.
AgWaterCore	Outputs that allow for evaluation of demand for water resources in agricultural lands.
AgWaterExt	Additional variables that allow more detailed evaluation of soil water balances and demand for water resources.
AgModelHourly	Sub-daily variables that are needed for more complex agricultural models and analyses, allowing for more precise resolution of diurnal cycles and agroclimatic extremes.
AgAirPollution	Conditions for aerosols and ozone that can damage agricultural systems.
AgTile	Indications of sub-grid-scale temperature, water, and energy balances for agricultural tiles that may be substantially distinct from the broader grid condition.
AgImpactsMisc	Surface wind and CO_2 concentration information requested by agricultural community.
AgLandUse	Variables describing land use classifications for agricultural lands

4.1.2 Opportunity ID 77: Bias-adjustment for impacts modeling and analysis

This opportunity requests variables that are critical to the pipeline of bias-adjustment for impacts model assessment (Figure 1). Variable groups were consolidated from community feedback from groups including ISIMIP (Frieler et al., 2024) and variables for the Climatologies at High-resolution for the Earth's Land Surface (CHELSA) project (Karger et al., 2016, 2017). ISIMIP produced bias-adjusted climate datasets from CMIP6 outputs (Lange, 2019) for coordinated use by impacts models across numerous sectors (e.g., agriculture, human health, forests, fisheries, water resources, energy). The requested ISIMIPMinimalAtmos variable group will enable the CMIP7 generation of ISIMIP climate projections allowing for analysis of multi-sectoral risk. ISIMIP also requested the ISIMIP3hourlyAtmos variable group given interest by regional models that operate at finer temporal resolution. The ISIMIP_deposition_variables group includes wet and dry deposition variables (NH3, NH4, NO_y) useful for ecosystems, agriculture, and water resources analyses. CHELSA utilizes mechanistic statistical downscaling to produce fine resolution (1km) mean climate statistics that have proven useful for analysis of biodiversity, wildlife and ecosystem services that may be highly sensitive to niche climate conditions in areas with complex topography, heterogeneous land use or coastlines. The CHELSA_land_daily provides outputs that would continue this work with CMIP7 outputs.

Variable groups included in this opportunity were developed with strong input from developers of ISIMIP and CHELSA (Table 3). Their established applications communities, many of whom have developed their own processing pipeline to convert climate projections into impacts model input datasets, make further application of CMIP7 outputs likely. These outputs will also enable other existing products (e.g., NASA NEX; Thrasher et al., 2024) and new bias-adjustment and statistical downscaling approaches that may emerge in the coming years, potentially including novel machine learning methods.

Table 3: Motivation for variable groups associated with Bias-adjustment for impacts modeling and analysis.

ID 77: Bias-adjustment for impacts modeling and analysis **Brief description:** Enables bias reduction procedures that convert ESM outputs to more relevant scales for broad use by impacts and adaptation applications.	
Variable group	**Reason for inclusion**
ISIMIPMinimalAtmos	Variables requested by the Inter-Sectoral Impacts Model Intercomparison Project (ISIMIP; Frieler et al., 2024) and likely to be of use for other downscaling methodologies. This minimal set is sufficient to drive bias adjustment for the bulk of impacts models across the ISIMIP sectors.
ISIMIP3hourlyAtmos	Sub-daily variables requested by the Inter-Sectoral Impacts Model Intercomparison Project (ISIMIP) in order to run subset of more complex impacts sector models.
ISIMIP_deposition_variables	These variables are used to track atmospheric NH_3, NH_4, and NO_y wet and dry deposition which can affect ecosystems, agriculture and water systems.
CHELSA_land_daily	Minimal set of variables needed as input for the CHELSA downscaling procedure (Karger et al., 2016), which is widely utilized by many ecosystems impact assessments and also feeds into part of the ISIMIP protocol.

4.1.3 Opportunity ID 16: Climate impacts on marine biodiversity and ecosystems

This opportunity provides outputs of interest to marine biodiversity and ecosystem modellers assessing climate change impacts on marine ecosystems for different ecological groups (Cooley et al., 2022). The variables and experiments in this opportunity provide input to a broad set of fisheries and marine ecosystem models within the Fisheries and Marine Ecosystem Model Intercomparison Project (FishMIP; Tittensor et al., 2018, 2021) and beyond. Mariculture is a growing industry expected to further expand as the need for protein increases globally. Fisheries models, which focus on both wild populations, ecosystems and mariculture, play a crucial role in fisheries management, conservation, and the understanding of marine ecosystems (Doney et al., 2012). For example, these models can evaluate the impact of temperature variability on fishery sustainability (Wang et al., 2020), helping to evaluate habitat suitability and population management strategies, ensuring sustainable practices. This opportunity provides critical data to enhance the models and assess future environmental shifts and corresponding effects on marine life. Daily resolution and extended variables can significantly enhance the accuracy of fish abundance estimates. Factors such as algal primary production, dissolved oxygen and the depth of the 17ºC isotherm can provide a more comprehensive understanding of fish distributions. By integrating these variables, the model can offer more insight into aquatic life population responses to changing climate.

The opportunity thus supports a broad set of use cases to model marine ecosystem services (Table 4). The variable group Marine_bgc_baseline is the baseline list of biogeochemical variables needed to fully characterise the marine ecosystem. The variable group biodiv_marine_daily is requested to provide inputs for marine biodiversity models. The variable group ISIMIP_oceanforcing_3hr is required for bias-adjustment of the oceanic forcings provided within ISIMIP. To date, oceanic forcing is typically not bias-adjusted although that is quite critical for the regional marine ecosystem and fisheries models that are calibrated by observational data (Frieler et al., 2024; Lengaigne et al., 2024).

Table 4: Motivation for variable groups associated with Climate impacts on marine biodiversity and ecosystems.

ID 16: Climate impacts on marine biodiversity and ecosystems **Brief description:** Supports marine biodiversity and ecosystem expert efforts to assess climate change impacts in marine ecosystems and for different ecological groups.	
Variable group	**Reason for inclusion**
Biodiv_marine_daily	Daily climate variables for biodiversity and ecosystem modeling in marine realm
ISIMIP_oceanforcing_3hr	The 3-hourly atmosphere-ocean surface fluxes (freshwater, heat, and momentum) will allow for a bias-adjustment of the oceanic forcings provided within ISIMIP.
Marine_bgc_baseline	This is the baseline list of variables that is needed to fully characterize the marine ecosystem. Each one plays an important role in validation, monitoring, comparison against observations, and understanding ecosystem services.
Marine_bgc_fishmip	Collection of data to support the modeling of marine ecosystem and fisheries to investigate changes and impacts

4.1.4 Opportunity ID 20: Core Climate Services

Kennedy et al. (2024) noted that the “delivery and use of climate information to enable climate action has never been more crucial”. Activities within cClimate service provision (and climate impact analyses modeling more generally) is tackle a diverse range of challengesactivity, spanning different sectors, scales, and actors. It is conducted both in public and private organizations, and may take the form of relatively general platforms (e.g., user interface platforms) or more bespoke activities for specific use cases. This field is rapidly growing - in 2024, at least 55 National Meteorological and Hydrometeorological Services provided climate services across 19 sectors (up from 45 in 2020; Kennedy et al., 2024). Provision of a base set of high-quality near-surface climate variables is thus expected to be taken up by a very large and diverse community to improve the understanding and assessment of climate risk and impacts on key sectors.

The need for high-quality climate information cuts across many areas from water and agriculture to energy, financial services and health. Climate services are vital steps in this chain, supporting the assessment, understanding and interpretation of climate change in the context of specific sectoral applications. The impacts considered are often highly complex and require fine-resolution modeling in both time and space. However, because of the nature of climate impacts work, but, by their nature, many different applications depend on a relatively small set of common surface/near-surface meteorological variables – for example, (e.g., health risks from heatwaves and the demand for energy are both strongly sensitive to near-surface temperatures and humidity (; Taylor and Buizza, 2003; Simpson et al 2023). In previous CMIP rounds, the availability of sub-daily input data relating to these fields has been patchy, inhibiting impact modeling for climate services by requiring compromises on the temporal resolution of impact modeling activities (i.e., use of daily or monthly rather than sub-daily resolution) and or the extent of inter-model comparison (e.g., restricting analysis to only the subset of only a few CMIP models providing relevant output at the required granularity)., or In more extreme cases, lack of available data may even preventing the use application of CMIP simulations in high-quality impact models completely (e.g., the absence of suitable high-frequency data for has stymied some energy-system applications; (Craig et al., 2022). This opportunity seeks to provide high-quality, high-frequency outputs to underpin a wide range of climate impact modeling activities to support enhanced climate service provision.

The Opportunity includes 2 variable groups (Table 5), both including high-frequency data, with both also requested in Opportunity 22 (Energy System Impacts) and enabling additional applications. The first group, impact_climserv_hourly_core focuses on a small set of sub-daily near-surface properties - temperature, wind-vectors, wind gusts, precipitation, humidity, insolation - which are suitable to support diverse applications in, e.g., health, energy, water, insurance. The second group, impact_climserv_hourly_expanded extends this to support a broader range of applications or more detailed impact models (e.g., building energy use, hydrological applications, splitting solar power between concentrating and PV types). Hourly frequency is indicated, but this is intended to be interpreted as a request for the "best possible" sub-daily resolution. Note that variable properties are selected according to the use case need (e.g., instantaneous sampling vs time-averaging, spatial sampling) and preserving these aspects is important for physical consistency and intercomparison. Experiments are selected to have most relevance to real-world challenges within the energy sector. Significant time subsets (with a minimum 20-30 years) and ensemble sizes (as many realizations as possible) are requested~~s~~ to ensure statistical robustness of analysis (e.g., to separate model uncertainty and internal variability). It is noted throughout that single-precision output is very likely sufficient for most impact applications.

Table 5: Motivation for variable groups associated with Core Climate Services.

ID 20: Core Climate Services **Brief description:** Climate services and climate impact modeling are a vital step in the value chain for understanding and managing the risks of a changing climate. This outlines a minimum variable set of high frequency outputs to support detailed process-based impact models to revolutionize climate projection data for service provision.	
Variable group	**Reason for inclusion**
impacts_climserv_hourly_core	Core sub-daily (ideally hourly or best available frequency) output to support onward modeling with sophisticated impact models across a range of sectoral applications.
impacts_climserv_hourly_expanded	Additional sub-daily (ideally hourly or best available frequency) output to support onward modeling with sophisticated impact models across a range of sectoral applications.

4.1.5 Opportunity ID 81: Dynamical Downscaling

High-resolution climate simulations using regional climate models (RCMs) are increasingly vital for informing climate services across a range of societal and environmental applications. Dynamical downscaling will play a crucial role in bridging CMIP7 global projections and the needs of the impacts, adaptation, and vulnerability communities. The 3D, model-level data requested from the historical and scenario experiments are essential to perform dynamical downscaling. Among the key initiatives providing such data, the Coordinated Regional Climate Downscaling Experiment (CORDEX), endorsed by the WCRP, is recognized for its standardized approach, delivering authoritative downscaled outputs over 14 nearly continental-scale domains, derived from ~~GCM~~ ESM simulations (Gutowski Jr et al., 2016). A global effort under CORDEX-CMIP6 has already produced over 250 simulations (with 600+ planned, https://wcrp-cordex.github.io/simulation-status), underlining the widespread demand for standardized boundary forcings.

Dynamical downscaling by means of RCMs (Giorgi, 2019), the core methodology in CORDEX, relies on high-frequency (typically 6-hourly) three-dimensional boundary conditions from ~~GCMs~~ESMs, spanning both historical and future scenario periods. To better capture the range of global warming levels (GWLs), particularly the pre-industrial baseline (GWL+0), an extension of the temporal coverage historical ~~GCM~~ ESM outputs would be needed. Specifically, we recommend extending the provision of lateral boundary conditions back to 1850 and forward to 2100 using scenario experiments; then at least up to 2125 using extension experiments. For standard CORDEX domains (10-25 km resolution), 6-hourly ~~GCM~~ ESM data suffice. However, higher-frequency outputs (e.g., 3-hourly) may be required for future km-scale nesting applications anticipated under CORDEX-CMIP7, particularly from higher-resolution ~~GCMs~~ ESMs (e.g., <40 km grid spacing) as envisioned in HighResMIP (Roberts et al., 2025).

Apart from the CORDEX output, this opportunity also merges requests from individual downscaling groups including those interested in regional ocean downscaling. The request has been divided into 7 variable groups (Table 6). The dynamical_downscaling_core group includes essential 6-hourly 3D atmospheric variables required for general downscaling. To address the growing demand for refined marine climate projections, the dynamical_downscaling_ocean_core group provides variables to force regional ocean models, including physics, biogeochemistry, and sea ice. The dynamical_downscaling_aerosols_chemistry group expands on traditional atmospheric variables by including aerosols and chemistry-related data, to be used by models including chemical components. For biogeochemical modeling, dynamical_downscaling_ocean_biogeochemistry_forcing and dynamical_downscaling_ocean_air_sea_biogeochemistry_forcing request monthly and daily 3D-global forcing fields, respectively. Meanwhile, dynamical_downscaling_ocean_air_sea_forcing considers hourly variables at the air-sea interface, critical for ocean-only model forcing. Finally, dynamical_downscaling_soil addresses the land component by requiring high-frequency 3D soil temperature and moisture fields.

Given the larger size of 3-dimensional, high temporal resolution variables included in the Dynamical Downscaling opportunity, we reiterate that ESM groups ~~supporting the Dynamical Downscaling opportunity are not mandated to provide all the requested variable groups. Contributors~~ can focus on the core variable groups and are encouraged to provide as many of the additional groups as they deem practical ~~can afford.~~ ~~to support the emerging components in regional Earth system modeling.~~ Note that variables provided for ~~the~~ RCM simulations also enable ~~can be~~ further downscaling~~ed~~ by CPRCMs to achieve ~~at even~~ higher resolution for specific regions.

Table 6: Motivation for variable groups associated with Dynamical Downscaling

ID 81: Dynamical Downscaling **Brief description:** Dynamical downscaling activity for CORDEX (and other RCMs and later CPRCMs) requires high-frequency lateral boundary conditions from ~~GCMs~~ ESMs for the historical and scenario periods.	
Variable group	**Reason for inclusion**
dynamical_downscaling_core	Downscaling is a key step in filling the gap between CMIP7 global climate model experiments and the activity of the communities dealing with vulnerability, impacts and adaptation studies. Dynamical downscaling requires 6-hourly 3D-global forcing fields for specific variables. This core variable group is the minimum requirement to perform dynamical climate downscaling.
dynamical_downscaling_ocean_core	There is an emerging need for regional downscaling of global climate models for the ocean (physics, biogeochemistry, sea ice) to provide refined and more regional-to-local

	information on marine environment past and projections changes, to support ocean climate services and for climate adaptation. This is the minimal set of variables needed to force regional ocean models at their lateral boundaries, and at the air-sea interface for forced models.
dynamical_downscaling_aerosols_chemistry	ESM outputs needed to drive regional climate models with enhanced atmospheric chemistry. Up to now, the variables needed were mainly limited to atmospheric variables (hus, ta, ua, va, ps) every 6 hours (6hrPlev) as well as some surface variables (tos, siconc...). This set includes variables associated with new aerosol and chemistry components of the climate system now included in more and more regional models.
dynamical_downscaling_ocean_air_sea_biogeochemistry_forcing	Dynamical downscaling of the ocean air-sea biogeochemistry requires daily 3D-global forcing fields for specific variables.
dynamical_downscaling_ocean_air_sea_forcing	Dynamical downscaling of the ocean requires hourly forcing fields at the air-sea interface for specific variables.
dynamical_downscaling_ocean_biogeochemistry_forcing	Dynamical downscaling of the ocean biogeochemistry requires monthly 3D-global forcing fields for associated variables.
dynamical_downscaling_soil	Includes variables required to drive a coupled land surface model (LSM) that implicitly solves the heat and mass exchanges between the atmosphere and the land surface, including those involving vegetation, which are central to the hydrological cycle. The use of LSMs in regional climate simulations, in turn, requires high frequency 3D fields of soil temperature and moisture at specified soil depths, which ideally should be sourced from the same global climate simulations used to force the atmospheric model.

4.1.6 Opportunity ID 80: Empirical Statistical Downscaling and Emulators

Empirical-statistical downscaling (ESD; Maraun et al., 2019) exploits the relationship between large-scale and local climate observations to convert coarse ESM output into regional-to-local climate projections. Mathematical models can also be trained on complex ESM and RCM outputs to reproduce key features at lower computational cost, thus statistically emulating its behaviour (Baño-Medina et al., 2024). Both ESD and RCM-emulators are increasingly important components of the CORDEX framework, enabling an efficient generation of high-resolution climate information tailored to regional and local needs. ~~Empirical-statistical downscaling (ESD) (Maraun et al., 2019) and emulation of dynamical models (Baño-Medina et al., 2024) are increasingly important components of the CORDEX framework, enabling an efficient generation of high-resolution climate information tailored to regional and local needs.~~ As in the previous case, this is an intermediate opportunity that is not sector-specific but enables a key step in the information pipeline described in Figure 1. These CORDEX techniques and similar ESD efforts can serve critical sectors such as agriculture, water management, energy, and urban planning, where timely, location-specific climate data is vital for decision-making. Stakeholders include national meteorological services, environmental agencies, infrastructure planners, and adaptation practitioners. Established communities, like the CORDEX-ESD group or the recently established CORDEX Task Force on Machine Learning, help coordinate efforts and improve methodological robustness.

This request targets key variables needed for both traditional ESD methods and newer hybrid emulators. (Table 7) These tools are trained on large-scale atmospheric fields from reanalysis products or driving ~~GCMs~~ ESMs and can be applied to CMIP7 outputs, provided compatible variables are available. The statistical_downscaling_core_daily group includes essential daily variables (e.g., temperature, wind, moisture, geopotential height) on standardized pressure levels, supporting the main workflow of empirical-statistical methods that downscale historical and scenario simulations. In response to increasing user demand for high-frequency climate information, the statistical_downscaling_core_6hourly group covers the same set of variables at 6-hour resolution. These are crucial for applications such as hydrological modeling, sub-daily event analysis, and early warning systems. Maintaining consistency in pressure levels across both daily and sub-daily datasets ensures compatibility in training and deployment phases. The statistical_downscaling_extended group includes variables like monthly wet-day frequency and mean wet-day precipitation, which, while derivable from daily data, are computationally intensive to calculate. Their inclusion directly supports efficient modeling of 24-hour precipitation statistics and broader adoption of ESD by users with limited processing capacity. Finally, the global_emulators group provides variables for training AI-based emulators that replicate the behaviour of complex climate models. These emulators enable cost-effective, flexible projections, including under scenarios not originally simulated. AI-driven tools are also expected to play a transformative role in CMIP7 analysis by enabling rapid synthesis across multi-model ensembles.

Table 7: Motivation for variable groups associated with Empirical Statistical Downscaling and Emulators (CORDEX).

ID 80: Empirical Statistical Downscaling and Emulators **Brief description:** This opportunity covers empirical-statistical downscaling (ESD) activities in CORDEX, including hybrid downscaling (emulators).	
Variable group	**Reason for inclusion**
statistical_downscaling_core_daily	Core daily variables are used as large-scale fields for empirical statistical downscaling of climate projections (historical and scenario runs) which are typically at daily timescale and at multiple pressure levels.
statistical_downscaling_core_6hourly	Core 6-hourly variables are used as large-scale fields for empirical statistical downscaling of climate projections (historical and scenario runs) which are required for the increasingly demanded sub-daily timescale.
statistical_downscaling_extended	Additional variables requested for the convenience of users. They could otherwise be calculated by downloading several 3D fields the variables included in the high priority request. However, the latter would require downloading several 3d-fields.
Global_emulators	The requested variables will facilitate the creation of a family of foundation models to enable analysis of CMIP7 simulations using new Artificial Intelligence (AI) methods.

4.1.7 Opportunity ID 22: Energy System Impacts

The de-carbonization of the global energy system is central to climate mitigation, with investment in clean energy reaching US$2 trillion in 2024 (Giroud, 2024; Hassan et al., 2024, IEA, 2024). The scale of change is fundamentally transforming the nature of how energy systems operate. The CMIP outputs requested in this opportunity support a wide range of energy-sector applications seeking to understand, assess and manage climate risk within this complex and rapidly-evolving energy landscape, "overcoming the disconnect" that has previously existed between the energy- and climate- system science communities (Craig et al., 2022). Specific applications include the understanding and assessment of system operation, system planning, renewable power resources, use and availability of hydropower, transmission and storage planning, energy usage patterns, climate resilience of generation assets (including nuclear), and adaptation to extreme events.

There is an emerging international community of practice to support the uptake of energy systems-relevant ESM output, including its onward "conversion" to provide vital climate services to end-users and decision-making stakeholders (WMO, 2022). While no single, definitive WCRP-based "-MIP" exists (perhaps reflecting the aforementioned historic disconnect between energy- and climate- scientists;)(Craig et al., 2022), numerous overlapping groups draw in a wide community of research, industry and policy-makers. These include the Next Generation Challenges in Energy and Climate Modelling workshop community (NextGenEC; Craig et al., 2022), the International Conference on Energy and Meteorology (ICEM), the Open Energy Modelling Initiative (OpenMod), multiple long-running dedicated sessions at the American Geophysical Union and European Geophysical Union, established provision climate services and datasets (e.g, PECDv4, Dubus et al. 2022), and relevant parts of ISIMIP.

The Opportunity includes 7 variable groups, sharing a set of high-frequency variable groups with Opportunity 20 (Core Climate Services): impacts_climserv_hourly_core and impacts_climserv_hourly_extended (Table 8). These emphasize a small set of sub-daily output of near-surface fields pertaining to energy applications — ideally hourly but intended to request the “best possible” sub-daily resolution. The core set impacts_climserv_hourly_core provides the baseline information for detailed process-based energy modeling at the whole-system level (i.e., informing the integration of renewable generation and whole-system design), while impacts_climserv_hourly_expanded permits additional modeling refinements, making it possible to (e.g., distinction distinguish between types of solar power generation and providing , additional information for wind power and energy-use modeling). It is noted that the need for high-frequency output is dictated by both scientific necessity and convention. Scientific necessity tracks that (power systems require quasi-instantaneous matching of supply, demand and storage across a spatially extended transmission network, thus recommending complex data which maintains “realistic” multi-variate spatio-temporal co-variability that is essential and even as statistical downscaling is usually not possible.) and eConvention favors data for (detailed energy-system models typically “run” at hourly resolution, which thus its availability facilitates greater uptake by the energy modeling community). Variable properties are selected carefully according to need: e.g., instantaneous sampling of wind vectors is essential to avoid the smoothing (associated with time-averaging) that produces substantial biases in wind-power modeling applications. Sub-daily outputs (at least 3-hourly) are also required for: impact_river_temperature (risk to environment and/or curtailment of cooling systems for nuclear and fossil-fuel generation) or impact_energy_building_demand (use of energy in buildings), while daily outputs, including daily maxima, can be used for impact_energy_hydropower (hydropower availability); impact_energy_damaging_wind (wind storm damage to energy infrastructure); impact_energy_damaging_other (proxies for damage to energy infrastructure from other meteorological hazards). Experiments are selected to have most relevance to real-world challenges within the energy sector. Significant time subsets (min 20-30 years) and ensemble sizes (as many as possible) are requests to ensure statistical robustness of analysis (the sensitivity of energy system planning to climate variability on multi-annual timescales has been well established; Bloomfield et al 2016, Zeyringer et al 2018). It is noted throughout that single-precision output is very likely sufficient for most energy applications.

Table 8: Motivation for variable groups associated with Energy Systems Impacts.

ID 22: Energy System Impacts
Brief description: De-carbonizing energy systems is a central part of climate change mitigation. However, many of the changes needed - e.g. the shift to renewables - increase the exposure of the energy system to weather and climate. This opportunity supports detailed onward modeling for impacts and adaptation planning in the energy sector.

Variable group	Reason for inclusion
impacts_climserv_hourly_core	Baseline sub-daily (ideally hourly, else best available) information for detailed process-based energy modeling at the whole-system level, allowing evaluation of wind and solar integration, energy use, system operation and whole-system design.
impacts_climserv_hourly_expanded	Enhanced sub-daily (ideally hourly, else best available) information for detailed process-based energy modeling at the whole-system level. These variables permit additional modeling refinements over core list, for example distinguishing between types of solar power generation, and providing additional information for wind power and energy-use modeling.
impact_energy_hydropower	Additional daily variables to permit basic modeling of hydropower availability. Many energy systems around the world are heavily dominated by hydropower for electricity production (storage and run-of-river).
impact_energy_damaging_other	Additional monthly summary variables to quantify aggregate impact of damaging weather on energy system infrastructure (except wind).
impacts_energy_damaging_wind	Additional monthly summary variables to quantify aggregate impact of damaging wind storms on energy system infrastructure.
impact_energy_building_demand	Additional sub-daily variables to support enhanced modeling of building demand (including heat pumps). Electricity demand in buildings is expected to increase, both to support mitigation and to sustain the probably unavoidable increase in summertime cooling demand.
impact_energy_river_temperature	Additional sub-daily information needed to drive hydrological thermal models that can simulate how electricity generation through thermal power plants use a river for cooling. Excess river temperature leads to generator curtailment (unavailability) or environmental damage.

4.1.8 Opportunity ID 37: Health impacts

This opportunity facilitates applications of ESM outputs to gauge impacts and potential adaptation to climatic impact-drivers connected to human health (Ranasinghe et al., 2021) across 6 variable groups (Table 9). Climate change has both direct and indirect impacts on human health. Direct health impacts arise from a number of climatic impact-drivers, including pervasive mean conditions and extreme heat, cold, wind storms, flooding, and ice events, as well as ~~and precipitation, while indirect impacts are through impacts~~ changes to ~~on~~ atmospheric composition which influences the air pollution levels humans are exposed to (Im et al., 2022, 2023). Indirect health risks arise from climate's influence on the many natural and human systems that are linked to broader health systems, including effects on vector-borne diseases, food and water safety and security, malnutrition, and the consequences of malnutrition and displacement. The nature of these climate impacts heightens the interests of the general population and a large number of public, private, civil society and non-governmental organizations charged with reactive and proactive planning to reduce morbidity and mortality across complex health systems and diverse, vulnerable populations.

Three variable groups allow for deepening analysis of the effects of extreme heat and cold ~~on~~ risks for human populations including heat stroke, heat exhaustion, hyperthermia and hypothermia ~~(Table 9)~~. First, ~~These include~~ a core dataset of daily variables (HealthHeatCoreDaily) ~~that~~ includes both surface daily maximum temperature and relative humidity information given that many impacts are strongly connected with compound heat and humidity hazards that can challenge the body's ability to self-regulate temperature through perspiration (Staiger et al., 2019). These outputs are also useful for outdoor recreation and tourism applications. Daily resolution is essential, as heat waves are poorly represented by monthly outputs. In addition, minimum temperature data support the evaluation of cold-season hazards such as hypothermia and the calculation of wind chill indices (Kinney et al., 2015). Second, t~~T~~he HeatHealthExpandedDaily variable group is designed to meet the needs of health experts who have developed a large number of heat-health indices to understand risks to different demographic groups and populations exposed through outdoor labor (e.g., agricultural or construction work) (Vanos et al., 2020). This includes further information on the daily range of humidity, short- and longwave radiation and wind speeds that can drive extremes in body heat or dangerous wind chills. Third, t~~T~~he HeatIndices variable group requests that daily and maximum daily wet bulb globe temperature (Knutson and Ploshay, 2016) and NOAA Heat Index (Lin et al., 2012) be calculated within the model so that there is no methodological confusion in downstream impacts and adaptation applications.

Two variable groups in this opportunity focus on health risks associated with air pollution, which depends strongly on the type of air pollution and the duration and intensity of exposure (Orru et al., 2017). HealthPollutionDaily captures information related to mixing ratios for surface particulate matter at 1, 2.5, and 10 micron diameters, surface NO_2, and surface ozone on a daily scale. That set also includes temperature and humidity outputs as these govern the environment for chemical processes in the atmosphere that may convert precursors into dangerous air pollution constituents. Corresponding hourly outputs are also requested when possible in the HealthPollutionhourly variable group in order to gauge acute extremes and interactions with the diurnal cycle of temperature, humidity and precipitation. This information cannot be determined only from emissions data and projections.

HealthFloodingDaily requests variables important for developing engineering solutions to reduce risks to humans from inland flood waters. This includes details on maximum hourly precipitation rates, snow water equivalent, soil moisture, and runoff to describe the pre-conditioning and extent of flooding events. Additional variables relevant to indirect health CIDs are available in other I&A opportunities related to food systems (ID 19), water systems (ID 67), ecosystems (IDs 11 and 16), urban populations (ID 40), and broader climate services (ID 20).

Table 9: Motivation for variable groups associated with Health impacts.

ID 37: Health impacts	
Brief description: Allows for further analysis of human health impacts across a range of major hazard types, including heat and humidity extremes, flooding, and air pollution. Additional variables relevant for health systems are requested in opportunity IDs 11, 16, 19, 20, 40 and 67.	
Variable group	**Reason for inclusion**
HealthHeatCoreDaily	Variables in this group are very commonly used to understand the effects of extreme heat and cold on human health, including compounding events with high humidity.

HeatHealthExpandedDaily	Variables in this group allow for more in-depth analysis of the health impacts of heat and cold. Additional variables allow for more complex heat-health analyses (including humidity and radiation) and investigations of wind chill.
HealthPollutionDaily	Variables in this group allow health impacts and adaptation experts to track air pollution that are known to be hazardous to human health. Including these variables allows experts to track interactions between the climate system and pollutants that would not be available simply from emissions datasets.
HealthPollutionhourly	Impacts modelers are interested in hourly outputs to understand acute air pollution risks to human health.
HealthFloodingDaily	Variables in this group provide information about precipitation, soil moisture, snowpack, and runoff that can lead to dangerous flood conditions that can impact human health.
HeatIndices	Directly calculated heat indices that facilitate health risk management and adaptation planning for exposed populations.

4.1.9 Opportunity ID 41: Impacts of climate change on aviation

This opportunity was designed to support studies focused on the impacts of climate change on air travel and the broader aviation sector. Climate change causes changes on the jet streams that in turn affect wind shear and can cause clear air turbulence (Gratton et al., 2022; Lee et al., 2019; Williams and Joshi, 2013). The variables in this group allow experts to diagnose clear air turbulence that is of relevance for passenger safety concerns as well as planning of flight routes and times (Table 10). The 'essential' variable group unlocks the opportunity of diagnosing clear air turbulence from climate model output from 5 pressure levels (150, 175, 200, 225, and 250 hPa) in the upper troposphere/lower stratosphere (UTLS) region. These are standard model output variables (horizontal wind components and temperature) but requested at specific vertical levels.

Table 10: Motivation for variable groups associated with Impacts of climate change on aviation.

ID 41: Impacts of climate change on aviation **Brief description:** Tracks climate changes to jet streams that in turn affect wind shear and can cause clear air turbulence as shown in multiple studies.	
Variable group	**Reason for inclusion**
aviation_impacts_essential	The variables in this group allow to diagnose clear air turbulence that is of relevance for passenger safety concerns as well as planning of flight routes and times. This can be diagnosed using an essential set of 5 levels in the upper troposphere/lower stratosphere (UTLS) layer: 150, 175, 200, 225, and 250 hPa.

4.1.10 Opportunity ID 42: Impacts of climate change on transport infrastructure

This opportunity provides outputs of interest to the transport infrastructure communities looking to CMIP7 for projections in order to evaluate impacts, risks, and potential adaptations in the transport sector (railways and road, mainly) (Table 11). The sector is severely impacted by extreme weather events, through multiple hazards such as heat, flooding, extreme winds, coastal erosion and storm surges. Future climate projections are used to inform business planning, adaptation and regulatory submissions by the transport infrastructure sector. This is supported by substantial work in the topic focused on different regions of the world (de Abreu et al., 2022; Dooks, 2022; Nemry and Demirel, 2012; Palin et al., 2013, 2021). Climate resilience and efficiency of transport infrastructure also impacts mitigation efforts given transportation's role in current emissions.

Table 11: Motivation for variable groups associated with Impacts of climate change on transport infrastructure.

ID 42: Impacts of climate change on transport infrastructure **Brief description:** Provides outputs of interest to the transport infrastructure communities looking to apply CMIP7 projections for risk evaluation, business planning, adaptation, and regulatory submissions by the transport infrastructure sector.	
Variable group	**Reason for inclusion**
Transport_impacts_essential	Requested variables support studies focused on the impacts of climate change on the transport sector (railways and roads, mainly). The sector is severely impacted by extreme weather events, through multiple hazards such as heat, flooding, extreme winds, coastal erosion and storm surges.

4.1.11 Opportunity ID 11: Terrestrial Biodiversity

This opportunity includes variable groups providing information needed for model-based impact assessments and adaptation planning in the terrestrial biodiversity and ecosystem services sector relevant for initiatives such as the IPCC (Parmesan et al., 2022) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). The included variable groups will serve a broad range of biodiversity and ecosystem models aiming to understand past biodiversity and ecosystem changes as well as projecting future trends in biodiversity and ecosystem services. These are applied to evaluate impacts, risks, and potential adaptations that safeguard biodiversity and ecosystem services and ensure planetary health and human well-being.

Variable groups in this opportunity provide the minimal set of monthly variables essential for assessing broad-scale impacts of climate change on biodiversity and ecosystem services as well as advanced sets of variables with daily and sub-daily resolution essential for understanding long-term dynamics through process-based biodiversity, forest, and biophysical models (Table 12). Biodiv_land_monthly covers typical inputs needed for coarse-scale biodiversity and ecosystem services models as summarised in the BES-SIM protocols (Kim et al., 2018; Pereira et al., 2024). Additionally, these variables can be used to conduct impact assessments for different ecological groups and realms (Hof et al., 2018; Zurell et al., 2018). Biodiv_land_daily requests variables needed as input for advanced process-explicit and statistical biodiversity models and process-based forest models (Ferrier et al., 2016). These span models that predict spatiotemporal distribution and abundances of species or functional types, to models of avian species migration pathways and disease spread; thus supporting a broad set of use cases for modeling interactions between nature and people. Biodiv_land_daily_advanced provides additional input for process-based forest models (Grünig et al., 2024). Forests provide crucial ecosystem services to people, help mitigate climate change impacts, and are affected by synergistic global changes like climate extremes and disease spread. The variable group supports advanced process-based forest models through provision of variables related to extreme disturbances. Biodiv_microclim_hourly variables serve as input to biophysical models that help to understand and predict climate change impacts on species' behaviour, phenology, survival, distribution, and abundance (Briscoe et al. 2023). The variables in this variable group constitute typical input needed for microclimate and biophysical models. These biophysical models are uniquely suited to solve climate change biology problems that involve predicting and interpreting responses to climate variability and extremes, multiple or shifting constraints, and novel abiotic or biotic environments.

Table 12: Motivation for variable groups associated with Terrestrial Biodiversity.

ID 11: Terrestrial Biodiversity **Brief description:** Supports model-based impact assessments and adaptation planning in the terrestrial biodiversity and ecosystem services sector. This spans a broad set of impact models from global to regional scales.	
Variable group	**Reason for inclusion**
Biodiv_land_monthly	Monthly climate variables essential for biodiversity modeling used in many IPBES analyses.
Biodiv_land_daily	Daily climate variables essential for biodiversity modeling, including dynamic vegetation models. The daily resolution is required by several biodiversity models. This variable group also allows the calculation of additional indices relevant for impact assessments on terrestrial ecosystems, including the aridity index, fire weather index, and growing degree days.
Biodiv_land_daily_advanced	Advanced set of daily climate variables for biodiversity modeling, particularly relevant for process-based forest models.
Biodiv_microclim_hourly	Minimal set of variables needed as input for physics-based microclimate models essential for ecophysiological models of organisms' heat and water balances.

4.1.12 Opportunity ID 40: Vulnerability of urban systems, infrastructure and populations

This opportunity provides global multi-model output variables that are relevant to urban areas and built environments (Table 13). Cities are both hot spots of climate impacts and fundamental foci of adaptation strategies (Dodman et al., 2022), which has motivated a Special Report on climate change and cities in the IPCC Seventh Assessment Report (AR7) cycle. While only covering 2-3% of the Earth's land surface (Chakraborty et al., 2024; Schneider et al., 2009, 2010), cities accommodate over half of the world's population and contribute to a large proportion of carbon emissions (Creutzig et al., 2015; Seto et al., 2014) - a percentage projected to increase to 68% by 2050 (Birch and Wachter, 2011; Seto et al., 2013). They also respond differently to climate change compared to natural land covers. Due to heat islands, impervious surfaces and lack of arable land, urban environments are even more vulnerable to globally recognized climate risks including heatwaves, extreme precipitation, flooding, water scarcity, and food and energy insecurity (Cao et al., 2016; Georgescu et al., 2021; Li et al., 2024; Zhang et al., 2023; Zhao et al., 2018; Zheng et al., 2021). To address this grand global urban challenge, it is urgent to better understand urbanization and its complex two-way interactions with climate system across spatiotemporal scales. City and infrastructure resilience planning benefits from enhanced understanding of projected changes in physical climate impacts on urban environments, associated biophysical and biogeochemical processes, interconnections with urban microclimates, potential thresholds, and global and regional climate tipping points. Community groups such as the Urban Climate Change Research Network (UCCRN) share best practices in climate output application for impacts and adaptation planning around the world (Rosenzweig et al., 2018; Mahadevia et al., 2025).

The Urban_impacts_essential variable group is the highest priority for urban applications, indicating the minimal set needed to pursue main research and application tasks, with the Urban_impacts_additional variable group enabling deeper analyses of more climatic impact-drivers. Robust characterization of urban climate risks and effective urban planning under climate change relies on robust climate projections specific to built landscapes (Zheng et al., 2021). This opportunity will provide crucial information to robustly underpin those working in urban climate science and impacts assessment, urban governance, urban planning, and sustainable and resilient urban development amidst the challenges posed by a changing climate. This includes improving understanding of city-specific risks in the form of extremes, slow-onset events, and the compounding and cascading of risks in order to inform those working to reduce vulnerability and exposure across urban systems and sectors, including, but not limited to critical infrastructure, buildings, urban ecosystems and biodiversity, food, energy, water and population health. One manifestation of such impacts is the urban heat island (Zhao et al., 2014), which requires detailed sub-daily variables to be modelled. Finally, some requested variable support studies into the urban boundary layer height, which modulates the impacts of air pollution, clouds and precipitation. Furthermore, attribution of these events to rapid urbanization *vs* climate change, as well as the synergies between the two, is key in addressing future risks while navigating sustainable developments. An increasing number of ESMs and finer-scale models now have an urban representation and there is interest in tracking how each focuses on processes (ranging from atmospheric turbulence and wind to energy and water balance) and complexity (ranging from multi-layer parameterizations in the urban canyon to AI/ML), to robustly characterize uncertainty in global cities.

Table 13: Motivation for variable groups associated with Vulnerability of urban systems, infrastructure and populations.

ID 40: Vulnerability of urban systems, infrastructure and populations **Brief description:** This opportunity can support studies focused on the impacts of climate variability and change on urban population and the built environment.	
Variable group	**Reason for inclusion**
Urban_impacts_essential	Contains variables needed to analyze impacts to urban environments (both people and infrastructure) e.g. urban heat island, surface flooding, impacts of air pollution.
Urban_impacts_additional	Understanding projected feedback from and impacts to urban environments, for example urban heat island, surface flooding, and impacts of air pollution. Additional temporal resolution will enable analyses of onset and development of events.

4.1.13 Opportunity ID 67: Water Security and Freshwater Ecosystem Services

This opportunity identifies variable groups that allow hydrology and ecosystem analysis for water resources, hydropower and freshwater habitats (Table 14). Climate change increases the risk of floods and droughts and changes groundwater and river flow regimes with implications for water security, ecosystem services, natural hazards and human health (Caretta et al., 2022). Freshwater ecosystems have experienced severe habitat degradation and losses in biodiversity and urgent actions would be required to halt biodiversity loss and restore ecosystem health following climate-driven changes (Parmesan et al., 2022).

Future projections of hydroclimatic hazards and their effects on the ecosystems and water resources are essential for assessing what adaptation actions and resilience building measures are needed to ensure water security, ecosystem services and planetary health. Enhanced modeling, utilizing high resolution climatic data, will aid IPBES in understanding changes in freshwater biodiversity and ecosystem services and refining scenario development (Ferrier et al., 2016). Large ensemble simulations are also beneficial in capturing the plausible range of precipitation variability which is crucial for risk assessment and ensures well-informed adaptation actions (Mankin et al., 2020).

Table 14: Motivation for variable groups associated with Water security and freshwater ecosystem services.

ID 67: Water Security and Freshwater Ecosystem Services **Brief description:** Supports future projections of hydroclimatic hazards and their effects on freshwater ecosystems and water resources to plan adaptation actions and resilience building measures that ensure water security, ecosystem services and planetary health.	
Variable group	**Reason for inclusion**
WaterResources_daily	Flood and drought risk assessment at daily timescale. Future projections of hydroclimatic hazards at regional scale are essential for assessing adaptation actions and resilience building measures needed to ensure water security.
WaterResources_monthly	Flood and drought risk assessment at monthly timescale. The frequency required depends on the region; monthly data might suffice in some places (notably in the tropics where interannual variability is often more pronounced). Monthly data may also appeal to regions and experts with limited computational capacity.
WaterResources_subdaily	Flood and drought risk assessment at sub-daily timescale. Some high-impact hazards, such as flash flooding, occur at very short timescales.
hydro_modelling_daily	Minimum variable set for hydrological models at daily timescale. Hydrological models simulate the quantity and quality of water in terrestrial water bodies, allowing projections of water security and hazards which will enable assessment of adaptation actions.
hydro_modelling_subdaily	Minimum variable set for hydrological models at sub-daily timescale. Hourly precipitation is shown to enable more robust hydrological simulations.
impact_energy_hydropower	Many energy systems around the world are heavily dominated by hydropower for electricity production (storage and run-of-river).
WaterResourcesPET_daily	Daily variables for calculating potential evapotranspiration (PET).
WaterResourcesPET_Monthly	Monthly variables for calculating potential evapotranspiration (PET).
biodiv_freshwater_daily	Minimal variable set to allow model-based impact assessments on freshwater biodiversity and ecosystems

4.1.14 Other proposed opportunities with Impacts and Adaptation Relevance

An additional 16 opportunities proposed by other CMIP7 Data Request thematic teams have relevance for impacts and adaptation. In many cases these focus on dynamical structures, surface conditions, or extreme events that are often of great interest in VIACS applications. Cross-thematic evaluation of opportunities identified variable groups that could be combined or merged into opportunities focused on impacts and adaptation. The overall approach continued to recognize that some redundancy in variables across opportunities was acceptable as different variable groups request specific combinations of variables required for proposed analyses. Table 15 summarizes these I&A-adjacent opportunities, with the impacts and adaptation motivation for two opportunities provided to demonstrate their added relevance.

Table 15: Overview of all opportunities associated with the Impacts and Adaptation data request (further details on variable groups provided in example opportunity motivations below).

ID	Opportunity title	#Variable Groups	Impacts and Adaptation Relevance
24	Advancing Wind Wave Climate Modelling for Coastal Zone Dynamics, Impacts, and Risk Assessment	5	Addresses the need for detailed, accurate modeling and understanding of wind-driven ocean surface waves and how these evolve on global and regional scales, which is essential for predicting coastal hazards, erosion, and other wave-related impacts and supporting offshore renewable energy activities.
38	Assessments for Hydrological Processes, Water Resources, and Freshwater Systems	8	Input data for hydrology, lake, or glacier models, etc. and also variables to assess the usability of Earth system models for water resources applications. Variables also help efforts to evaluate whether these processes/systems are adequately represented in modeling frameworks.

69	Baseline Climate Variables for Earth System Modelling	4	This list reflects the most heavily used elements of the CMIP6 archive, which included many I&A applications. It is intended as a resource for ESM-MIPs developing requests to enable greater consistency among MIPs and as a reference for modeling centers to enhance consistency within MIPs.
44	Changes in marine biogeochemical cycles and ecosystem processes	8	Marine ecosystems are important for the Earth System and absorb around 50% of the atmospheric CO_2 in long-term sequestration of carbon. Marine systems are also susceptible to climate change impacts such as heat stress, ocean acidification, habitat loss, and other effects often connected to shifts in biogeochemistry. Relevant for ecosystem process tracking and downstream applications in marine food webs, food production, and tourism.
26	Detection and Attribution	3	Basic variables needed for quantifying changes to mean climate and its variability over time and for understanding the mechanisms involved. Essential for assessing the behavior of models and understanding the role of forcings in the climate system, opening up possibilities to extend detection and attribution into the human and natural impacts realm.
64	Diagnosing temperature variability and extremes	2	Variables requested to more completely diagnose temperature variability, particularly hot extremes, and the processes involved. Facilitates comparisons with observations and intercomparison across models.
68	Effects and Feedbacks of Wind-Driven Ocean Surface Waves Coupled Within Earth System Models	5	Wind-driven ocean surface waves influence air-sea interactions, coastal hazards, and ocean circulation, affecting climate predictions and extreme event modeling. Accurate representation of waves within Earth System Models improves impact assessments and adaptation strategies for coastal resilience and risk management.
35	Glacier changes, drivers, and impacts	5	Allows more detailed analysis of drivers for sea level rise, water resource provision for freshwater ecosystems, agriculture, and human settlements, as well as risk assessment for glacial lake outburst floods that can devastate downstream communities.
54	Multi-annual-to-decadal predictability of the Earth System and risk assessment of climate extremes	4	Variables requested for experiments that determine predictability within the climate system on different time horizons allow for further investigations of predictability in human and natural systems, particularly when including variables that allow further impacts modeling or calculation of climatic impact-driver indices related to actionable system outcomes.
47	Ocean Changes, Drivers and Impacts	20	Variables help to understand changes in ocean properties and circulations and to evaluate budgets of heat and salt. The Meridional Ocean Circulation (MOC), the Mixed Layer Depth (MKD) and the polar ocean properties are of specific interest and include variables also relevant for ocean ecosystem and fisheries applications.
49	Ocean extremes	6	Outputs to investigate the frequency and severity of extreme ocean conditions driven by climate changes, and support management strategies and adaptation measures to mitigate risks to marine ecosystems and coastal communities
55	Rapid Evaluation Framework	1	Variables requested for timely evaluation and benchmarking of newly available CMIP7 Assessment Fast Track (CMIP7 AFT) simulations as soon as they are uploaded to ESGF, which will help the VIACS communities get early indication of output utility and major findings. First version of the Rapid Evaluation Framework (REF) will be limited to a temporal resolution of monthly mean data and about five metrics/diagnostics per realm.
82	Robust Risk Assessment of Tipping Points	2	Allows for applications related to human and natural system consequences of exceeding tipping points in the climate system, including potential adaptations and adaptation limits.
31	Role of fire in the Earth system	2	Daily and/or hourly air pollutant outputs ($PM_{2.5}$, O_3, NO_2) to investigate the acute impacts of fires on human exposure and associated health, ecosystem, and agricultural impacts.
63	Synoptic systems	2	Variable groups allowing tracking of synoptic systems can help show how changing dynamical features such as storm tracks, blocking events and atmospheric rivers drive impacts and motivate adaptation planning.
5	Understanding the role of atmospheric composition for air quality and climate change	10	Air pollution levels and composition determine the chronic and acute impacts of air pollution ($PM_{2.5}$, O_3, and NO_2) on human health, ecosystems and agriculture. These pollutants are also among the short-lived climate forcers.

Opportunity ID 55: Rapid Evaluation Framework

The CMIP Rapid Evaluation Framework (REF) is cross-listed with the Earth System data request (McPartland et al., 2025). REF was created to evaluate and benchmark the newly available CMIP7 AFT simulations as soon as they are uploaded to the Earth System Grid Federation (ESGF) with metrics and diagnostics that are available through different open-source evaluation and benchmarking tools (Hoffman et al. 2025). This opportunity contains the set of variables that are needed for the planned diagnostics and metrics for the REF (Table 16; CMIP Model Benchmarking Task Team, 2024). The suggested REF metrics/diagnostics to be available for all CMIP7 AFT experiments are in the first instance very basic evaluations and are not expected to require very specific variables. The exact selection of variables was also made consistent with the model evaluation diagnostics in Working Group I Chapter 3 of the latest IPCC report (Eyring et al., 2021). Due to the fixed timeline for the CMIP7 AFT simulations there is only a short time period for technical implementation of the REF, and therefore the available metrics and diagnostics in this first version of the REF will be limited to a temporal resolution of monthly mean data and about five metrics/diagnostics per realm based on a community selection. REF variables and metrics will also support initial evaluation of formats and fundamental climatologies relevant for VIACS investigations, with broad findings helping to identify models, time periods, and conditions that merit more extensive investigations when more complete outputs become available. The realms were chosen specifically to be consistent with the realms used for the data request. Find more information about the REF opportunity in Dingley et al. (2025).

Table 16: Motivation for variable groups associated with the Rapid Evaluation Framework.

ID 55: Rapid Evaluation Framework **Brief description:** Evaluate and benchmark the newly available CMIP7 AFT simulations as soon as they are uploaded to ESGF. The first version of the REF will be limited to a temporal resolution of monthly mean data and about five metrics/diagnostics per realm.	
Variable group relevant to I&A	**Reason for inclusion**
ref_impacts_and_adaptation	There are 5 total variable groups in this opportunity, but this variable group is the set of variables requested for the planned I&A diagnostics and metrics for the Rapid Evaluation Framework. The variable group will be linked with the "Rapid Evaluation Framework" opportunity, and is essential for the evaluation of the new CMIP7 AFT simulations on a routine basis.

Opportunity ID 49: Ocean extremes

While the CMIP7 Ocean and Sea Ice paper Fox-Kemper et al. (2025) provides a detailed examination of ocean extremes and their underlying processes, it is important to also recognize them here due to their significant role in impacts and adaptation studies which are critical for improved understanding of future climate vulnerability and informing robust adaptation strategies. As the frequency and intensity of extreme ocean conditions - such as marine heatwaves, low-oxygen zones, extreme sea levels, and storm surges - continue to rise globally, they pose significant threats to marine and coastal ecosystems, coastal infrastructure and communities, human health, industries and global economies (Bernier et al., 2024; Fox-Kemper et al., 2021; Gruber et al., 2021; Holbrook et al., 2022). For example, ocean extremes can disrupt fisheries, degrade critical habitats like coral reefs, kelp forests, and seagrass beds, and intensify coastal flooding and erosion. Studying ocean extremes enables researchers, managers and policy makers to identify vulnerable regions, assess risks to infrastructure and ecosystems, and inform policy decisions aimed at building resilience in a rapidly changing climate. The Ocean Extremes opportunity was developed to request the critical climate model variables at the necessary spatial and temporal resolution that underpins impacts and adaptation modeling and assessments (Table 17). This, in turn, supports informed decision making, empowers stakeholders to develop proactive adaptation strategies, build resilience in vulnerable regions facing climate change and better understand their sensitivity to anthropogenic forcing through a wide range of climate scenarios. This information is critical to assess impacts of ocean extremes and accurately determine the extent and nature of required adaptation measures. In the coming decades, ocean extremes and associated floods and erosion are likely to remain a leading cause of natural disasters due to the effects of the increasing frequency and intensity of extremes combined with increased coastal development associated with greater exposure (Bernier et al., 2024). .

Table 17: Motivation for variable groups associated with Ocean extremes.

ID 49: Ocean extremes **Brief description:** Supports modeling and assessment of ocean extremes important for identifying vulnerable regions, designing coastal protection to appropriate levels, assessing infrastructure and ecosystem viability, and sensitivity testing adaptation measures.	
Variable group	**Reason for inclusion**
ocean_acidification_oxygen_extremes	Improves understanding of historic and projected changes in pH, oxygen, and salinity as well as associated interactions and impacts.
ocean_KE_vorticity_extremes	Enhances understanding of mesoscale eddies and their influence on ocean extremes
ocean_Temperature_extremes	Builds understanding of long-term trends and extreme events (marine heatwaves) in terms of historical and projected changes in horizontal (geographic) and vertical (depth layers) occurrence, drivers, frequency and intensity.
sea_level_extremes	Tracks ocean extremes, coastal inundation and erosion that can drive vulnerability and adaptation responses in coastal communities and ecosystems.
surgemip_variables	Enables analysis of storm surges, coastal inundation and erosion for coastal communities and ecosystems via direct analysis, using downstream/offline tools, or forcing high-resolution regional ocean-wave models, etc.
mixed_layer_extremes	Variables with enhanced focus on conditions within the well-mixed upper ocean column that include an abundance of marine life.

4.2 I&A Variables

These I&A opportunities and variable groups included 539 unique varabiles, including ~~required the I&A team to define~~ 93 new variables defined for CMIP7 (Appendix B). Several variables were not easily added given that they are not yet established in CF-standards, and were thus left for Data Request v2 (see further discussion in Section 5.4).

Most requested variables are similar to previous CMIP requests, but many new variables were existing physical parameters now defined at higher temporal resolution. This is motivated by the increasing complexity and precision of many impacts models, as well as by a strong interest in compound extremes that can result from conditions not resolved at the daily or monthly resolution. For example, with the growing share of intermittant renewable electricity generation, a precise analysis of flexibility and storage needs demand that sub-daily consideration of peak loads are balanced with the concomitant available generation. Therefore, electricity balance models work at a sub-daily resolution and generally use at least hourly observations or hourly reanalysis products for the current climate. Additionally, building and facilities design relies on regulations which require the estimation of extreme values, expressed in terms of return levels, and based on the highest values of each variable under consideration (for wind: extreme wind gust or daily maximum 10-min average wind speed). Information on humidity is of utmost importance for determining thermal comfort even in indoor environments with heating, ventilation and air conditions systems, with temperature and air quality also affecting system selection. Since extreme temperature and extreme humidity may not occur at the same time, detailed sub-daily evolutions of both variables are necessary.

5 Discussion

5.1 Prioritization Process

Given limited resources (in personnel, funding, computational systems, data storage and time) for ESM groups, the I&A team organized a set of direct consultations with ESM leaders to communicate VIACS community priorities for output data production. Operating under the assumption that resources would remain constrained, the I&A Team placed a strong emphasis on feasibility, striving to balance the need for comprehensive climate information with the practical limitations of data storage, processing capacity, and model complexity.

5.1.1 Core and extended variable groups

Many I&A opportunities include a core/minimum variable group that is of highest priority as determined by variables that (1) ESMs are likely to be capable of producing, and (2) impacts and adaptation communities will use for nearly all applications in this opportunity. An ESM contributing the core/minimum variable group will increase the likelihood of that ESM's outputs informing the broadest applications in that opportunity, while electing to skip these variables may result in that ESM's outputs being left out of prominent applications in that sector. Opportunities with core/minimum variable groups are accompanied by variable groups that serve to enhance or extend related applications. ESM groups are therefore encouraged to consider contributing these deeper variable groups (e.g., more variables, higher temporal resolution outputs) to increase the likelihood of that ESM's outputs being used in more complex applications and impacts modeling studies, some of which may provide critical levels of detail that elevate these studies in planning processes. ESM groups may be motivated to include more niche applications areas that are of particular interest for that ESM development team (e.g., carbon cycles, extreme events, atmospheric chemistry) or that allow for more tailored impacts and adaptation decision support. In many cases there are substantial overlaps and only a small number of additional variables are needed to create deeper understanding to enable concrete applications.

5.1.2 Temporal resolution

Many important extreme events happen on time scales finer than one day (e.g., extreme rainfall, heat extremes, acute air pollution exposure) or have important covariance on a sub-daily scale (e.g., heat and humidity extremes for drought), yet obtaining model outputs on these time scales is a common stumbling block for VIACS communities. This directly challenges the use of models and decision support metrics that require sub-daily data (Jägermeyr et al., 2021; Zabel and Poschlod, 2023) (e.g., crop models, biophysical models, ocean and wave models, river temperature models, models of energy demand in buildings, electricity system balance models.), as well as applications built around short-interval extreme events (e.g., storm water flooding that may be governed by maximum hourly rainfall rate). Without this high-resolution information experts have often employed various types of bias adjustment, turned to downscaling models, or resorted to imposing the climatological diurnal cycle or stochastic extreme events. In some cases – for example, certain electricity system planning applications where coherent sets of multivariate sub-daily time series across an extended geographical domain are essential - the absence of high-frequency output has been a complete barrier to the use of CMIP data outputs in I&A modeling. In requesting sub-daily outputs, the I&A Team is requesting the 'best possible' resolution: hourly is better than 3-hourly, but 3-hourly is better than 6-hourly which is better than daily. As will be discussed in Sect 5.1.4, modeling groups may find efficiency by using time slices on the highest resolution simulations.

Although some ESM groups may feel that their models were not designed for analysis on fine temporal time steps, this output would likely be bias-adjusted with a procedure that needs to know unique aspects of change for sub-daily variances, extremes and covariances that would not be available in daily and monthly outputs. For groups concerned about the data burden of high-resolution ESM outputs, we note that the I&A high resolution variable requests are mostly 2-dimensional variables with smaller sizes within the 3-dimensional ESM. We also emphasize that ESMs should not dismiss opportunities given calculations of overall data sizes, as an opportunity's size may be skewed by its largest variable group while a smaller core/minimal variable group should also be considered.

5.1.3 Experimental relevance

A large number of CMIP7 MIPs are directly relevant to impacts and adaptation (Dunne et al., 2024). While I&A opportunities and variable groups would be appreciated from any ESM in any of the MIPs, priority is placed on a smaller subset of MIP experiments. The Historical simulations and 21st century ScenarioMIP simulations (van Vuuren et al., 2025) simulations are by far the most desired for impacts and adaptation analysis given that they are most directly relevant to the recent past, the present, and planning procedures covering the coming decades. This information was also conveyed to the CMIP7 panel which helped motivate the inclusion of ScenarioMIP in the CMIP7 Fast Track which will support rapid analysis ahead of approaching deadlines for the Intergovernmental Panel on Climate Change Seventh Assessment Report (IPCC AR7)(Figure 1).

Many groups expressed interest in a 100 year outlook (out to 2125), noting that the last several CMIP experiments have kept 2100 as the distant time horizon even as that horizon gets ever closer. The 2125 time horizon is also important to understand the ramifications of overshooting in the coming century, which may require a combination of standard ScenarioMIP experiments (out to 2100) augmented with the first 25 years of the extensions (out to 2125). Several sectors have clear interest in longer-term scenarios out to 2500 (e.g., for modeling inert systems such as forest ecosystems within the terrestrial biodiversity sector and sectors at risk of impacts from cryospheric changes and sea level rise).

The growing scientific capabilities and public interest in detection and attribution put a spotlight on I&A outputs from the Detection and Attribution MIP (DAMIP) given direct implications for risk management, which also indicates applications within the Pre-industrial (Pi)Control experiment. Finer resolution outputs are also a shared interest of the I&A Theme, HighResMIP (Roberts et al., 2025) and the Decadal Climate Prediction Project (DCPP) (Boer et al., 2016). MIP experiments with relevance to a particular sector or dynamical process may be of particular interest (e.g., the Land Use Model Intercomparison Project (LUMIP) (Lawrence et al., 2016) for some agriculture and ecosystem variable groups) but are not as broadly used for application. There is also general interest in determining the sensitivity of climate impacts to uncertain ESM components, but this is at the discretion of the MIP leaders and we would recommend one or a very small number of MIP experiments producing extensive I&A variable groups beyond the historical and ScenarioMIP experiments (as resources allow).

5.1.4 Time subsets

ESM groups with resource constraints may elect to produce more extensive I&A variable groups for a limited time period, or time subset(s), rather than the entire historical and 21st century periods. This saves resources and provides I&A outputs that would not be possible if there was a requirement to produce all variables for all years, but begs the question as to which time subsets would be most desirable for VIACS communities. Engagement by the I&A Data Request Theme found greatest interests in understanding the climate of the most recent past, with 10 years likely the minimal number of years required to calculate important climate statistics even as 30 years matches WMO guidance for climatological analysis (WMO, 2017), More rare events typically benefit from longer climatological normals, although this is not always practical in a non-stationary climate. IPCC AR6 used 20-year time subsets to represent distinct global warming levels, with that time span also being more relevant within a non-stationary climate given that climate shifts are occurring on similar time horizons (IPCC, 2021). Time subsets for the recent past also benefit from alignment with modern-era satellite observations and retrospective analyses (Gelaro et al., 2017), for example the 1979-2025 period. Projections for the next 10 years are likely to only have a statistically-weak difference from the previous decades, so we recommend using future time subsets centered first on the 2050s (when many climate signals emerge) followed by a late century time subset centered on the 2080s (when scenarios are more distinct) (Ranasinghe et al., 2021). These time subsets also align with decision processes supported by the VIACS communities (Stuart et al., 2024). As in the historical period, future time subsets of 20, 30, or more years are helpful. The team also considered time subsets centered around targeted global warming levels (GWLs); however, this is less practical given that it would require an iterative process to run initial ESM simulations that determine the period corresponding to a given GWL, then re-running the ESM with more extensive I&A outputs in that time subset. Additionally, not all variables and climatic impact-drivers cleanly track GWLs (Tebaldi et al., 2024).

As an illustration of one sector's use of different time subsets, energy planning decisions are usually based on prospective studies targeting the next 5-10 years, although planning efforts are increasingly reaching 20-25 years. Those prospective studies generally rely on recent climate conditions, using 30-year time series of the required variables coming from station observations or reanalyses, representative of the current climatology (1991-2020 currently for example). Continuing climate change means that the recent past is no longer sufficient to anticipate even near future climate evolution, especially for heat wave frequency. Climate projections can provide a large scope of possible combinations of climate response to the human induced radiative forcing and decadal variability; however, decadal predictions may help reduce/specify this ensemble of possibilities for the next 5-10 years.

5.1.5 Ensemble members and gap filling

Robustness of ESM output for impacts and adaptation applications may also be improved by driving multiple initial condition ensemble members for a given experiment. This is particularly intriguing for VIACS applications given that initial condition ensembles provide more simulated years in a given climatological period or GWL within a non-stationary climate system that features a relatively larger range of internal variability than the climate change signal itself (Chan et al., 2022). VIACS applications manage uncertainty across ESM ensemble members, ESM groups, and model versions and physics packages within a given ESM. For the latter category, perturbed physics ensembles can provide important information about parameter uncertainty and model stability; however, these are of less interest for extensive I&A outputs given the likely high data volume. Large ensemble member experiments are particularly useful for infrequent extreme events that are at the forefront of impacts and adaptation concerns. When resources are constrained, artificial intelligence and other statistical approaches may help us fill in gaps when the full set of years, variables, time resolutions, ensemble members and experiments are not practical. It may therefore be helpful to simulate (at least) a subset of model ensemble members in a targeted time subset with more comprehensive variable outputs and sub-daily temporal resolution. These could then serve as a training dataset to emulate other ensemble members, models, time subsets, variables and time resolutions building off a less resource-intensive set of background simulations (e.g., monthly outputs of core variables over more years, models and ensemble members).

5.2 Gaps and opportunities across impacts and adaptation applications

The I&A Data Request process led to the identification of several gaps in earth system processes that support climate applications. While this effort has focused on the ESM component of the applications chain outlined in Fig. 1, in some cases the bottleneck for applications comes further down. The provision of impacts and adaptation ESM variables opens the door to many opportunities for research and improvement all along the chain. Downscaling is strongly influenced by the selection of RCMs, as well as resources required to operate high-resolution nested models spanning the world. Bias adjustment is built on a foundation of high quality and long period Earth observations that are not available for many impacts-relevant variables. Improved ESM resolution and process understanding will reduce the need for downscaling and bias-adjustment to reach current application scales, but will enable reach to even finer decision-relevant scales. Impacts models have their own biases and uncertainties and most can only represent responses to a subset of the climatic impact-drivers (Wang et al., 2024). Improved impacts models will therefore better translate climatic impact-drivers into projected impacts for natural and human systems, as well as allow evaluation of adaptation interventions.

Additional requested variables proved too challenging for the first version of the I&A Data Request given required shifts in model infrastructure and requirements around constructed indices, but these remain of great interest in the community and motivate future ESM capability improvements. To reduce the burden of high-resolution outputs, there remains a potential to save less frequent outputs that capture high-frequency statistics and characteristics. As noted also in the previous CMIP VIACS request, the impacts and adaptation community would benefit from ESM groups saving monthly outputs of event count or statistical distribution parameters related to daily or sub-daily events (Ruane et al., 2016), for example monthly counts of the number of rainy days, hourly precipitation rates exceeding a threshold, or the number of frost events. For CMIP7 there was an additional request for data that would provide information about the daily timing of extreme events, for example noting the time of day when maximum temperature was simulated. Additional variables like heat indices requested by the Health Impacts opportunity could be assembled by the applications expert if all ingredients to the index's numerical recipe are provided, but these indices were requested to reduce the burden on output users and also to minimize the likelihood that errors or slight methodological differences could affect applications. Calculating these variables within the ESMs also allows more efficient outputs, for example the maximum daily wet bulb globe temperature (WBGT) is a single key impacts relevant variable that spares modeling groups from having to provide its many individual variable components at hourly resolution. The I&A Team thus encourages models to develop new code and structures to make these outputs feasible, and encourages practitioners and data providers to share best practices, tutorials and guidelines as part of broader capacity building for CMIP7 applications. For example, we encourage continuing collaborations around CMIP7 data provision, access, further processing and applications between CMIP and the World Climate Research Programme's Regional Information for Society (RIfS) Joint Task Team on Responsible Data Use, as well as with the World Adaptation Science Program (WASP).

I&A requests for ESM outputs also set the stage for the rapidly evolving community of climate services. Recent efforts have increased the utility of climate information for many applications, including efforts to work directly with professional societies such as the International Actuarial Association working to manage changing insurance baselines in the face of rising seas and increased risk of coastal floods, fire weather, flooding, drought and heat waves (Connors et al., 2022).

5.3 Key reflections from data request process

The Impacts and Adaptation data request is unique within CMIP7 in having a mandate to reach far beyond the ESM groups that are at the center of the CMIP community. The web of applications stemming from CMIP work extends to a huge number of experts, policymakers, stakeholders, and practitioners across all aspects of society. This is truly a testament to the impact and ongoing legacy of the CMIP endeavor, and it is likely under-appreciated even by many who are directly involved. The VIACS communities are distributed and have unique networks and collaboration structures, and they are eager to be engaged.

CMIP7 has demonstrated a growing recognition of the importance of the VIACS communities; not just as model users, but as participants with helpful input into all phases of planning, conduct, sharing, and interpretation of results. Continuity of the VIACS Advisory Board between CMIP6 and CMIP7, as well as VIACS participation in CMIP panel meetings and workshops, helped ensure a continuation of institutional experience and networks that allowed the I&A Data Request Team to hit the ground running in recruitment, goal-setting, outreach, and translation of inputs into specific and practical data requests. The I&A Team also benefited from an open nomination and selection process that emphasized broad perspectives and strong networks to application communities, drawing from the VIACS Advisory Board but extending far beyond.

CMIP7 enables a process for community input and ESM group uptake that would not be feasible through independent outreach. I&A Team and CMIP7 IPO efforts to make the input solicitation process clear, accessible and easy through established and informal network outreach and the Mural Board proved invaluable given that CMIP was requesting voluntary contributions from busy community experts. The I&A data request author team, participating in a voluntary basis, also appreciated efforts by the CMIP7 Data Request Task Team participants to track details and translate technical information between subsequent versions of the AirTable.

CMIP7 also supports climate services and decision making beyond the information generation. Outreach must be cognizant of stakeholder fatigue, as each new round of projections and the subsequent updates to scientific literature do not necessarily match the investment or policy development cycles in private and public decision making. The Rapid Evaluation Framework and Diagnostic, Evaluation, and Characterization of Klima (DECK) Experiment Group analyses are critical to helping stakeholders build familiarity with the new sets of outputs, helping to motivate capacity investments and new analyses required to switch from planning based around CMIP5 or CMIP6 to planning based upon the state-of-the-science CMIP7 (Dunne et al., 2025). Improvements in accuracy and changes to the baseline context (e.g., land use changes and emissions of greenhouse gases and aerosols) would be particularly compelling in justifying stakeholders' shift to planning with the latest CMIP7 outputs and scenarios. CMIP7 and climate service organizations can increase uptake by making outputs more accessible. Examples may include the provision of outputs in decision-ready format that is directly ingestible by catastrophe models and optimization analysis, or pre-computed ensemble statistics that would allow users, such as practitioners in the financial sector, to consistently apply climate related impacts in a transparent and reproducible manner. CMIP7 efforts to standardize data taxonomy, spatial and temporal resolution, and metadata are therefore critical to early adoption.

6 Conclusions

The I&A Data request process aimed to establish consensus on output needs and priorities across a broad spectrum of ESM output users in the VIACS communities and the ESM groups, resulting in 13 I&A data request opportunities, 60 variable groups (Section 4) and 539 unique variables (Appendix B). The various opportunities and variable groups discussed here can inform decisions impacting systems across society and the natural world even as these systems are increasingly intertwined. This process required collaboration between climate scientists and impacts sector practitioners, with experts who can converse in both spheres providing especially helpful insights.

Throughout this data request the I&A Thematic team has endeavored to emphasize how different levels of resource commitments can maximize the impact of CMIP7 for some of society's most pressing challenges. This includes minimal or core variable groups that are likely to enable broad use (Section 4), the identification of smaller subsets of variables around targeted applications (Section 4), and time subset prioritization for focused analysis (Section 5). The I&A data request also invites ESM groups with more resources to drive larger scientific advances by meeting the rising demand for more variables, new variables, and high-resolution variables that can allow applications to match the complexity of the systems they aim to protect and help thrive. The overall process is enlightening for CMIP leadership, modeling groups producing ESM outputs, and ESM development priorities that will elevate the application and utility of ESM outputs. Even those groups that cannot meet this full CMIP7 request may consider ways to be better positioned to meet I&A requests for CMIP8.

Pressing deadlines from policymakers and an increasing appetite for systems-level knowledge emphasize the need for clear organization and communication of CMIP7 governance, data processing and dissemination of ESM outputs. This is especially true for impacts and adaptation applications that require additional information processing in the form of downscaling, bias-adjustment, impacts modeling, analyses, and decision making around implementation. Waiting to get perfect ESM outputs may leave these later phases of application without enough time to properly inform policymakers and stakeholders through initiatives such as the IPCC. The Rapid Evaluation Framework may help facilitate this process. It would be beneficial for CMIP7 modeling groups to provide clear communication on variable groups they intend to produce, allowing important preparation to set the stage for CMIP7 across the impact & adaptation sectors. Engagement up and down that pipeline is important to indicate priorities, communicate uncertainties, track error propagation, and give due credit to scientific contributors who may not be at the stakeholder interface.

The I&A Team also received feedback that clear documentation of outputs ~~are~~ is needed to facilitate broad use in applications. Lack of clarity or barriers to use would create the need for more intermediary organizations (e.g., consulting groups) that can navigate this space, but that would increase the distance between those who produce the data and those who use it, with the potential to lead to information degradation or misuse (particularly in the Global South). Public-private-academic collaborations hold great potential to provide open climate services for research that would enable a large number of applications and support pressing decisions around the world. The I&A Team thus encourages ESM teams to follow through and stretch to meet the needs of this important community, which carries key climate messages to the world with an emphasis on the specific points of contact whereby climate change affects the things that society cares about.

Appendix A. Data Request Opportunity Evaluation and P~~p~~rocessing

Table A.1: Actions taken in the processing of proposed opportunities for the I&A Data Request Theme. The processing of opportunities proposed in the open call of August 2024, including proposals from both within the author team and more widely, was carried out by revising the evaluation made within each thematic author team in the framework of a cross-thematic meeting in mid-September 2024. The meeting participants selected certain opportunities, rejected some, and merged others with shared scientific objectives and domain. In a subsequent step, an interactive discussion was held between members of our author team, opportunity proposal leaders, and the relevant domain communities. The goal was to harmonize the initially proposed opportunities and improve their description and data requirements. The following table summarises the key processing actions and decisions with specific reference to a working copy Airtable database available at the following link https://bit.ly/CMIP-DR-Opportunities.

ID	Meeting decision made	Notes from consultation	Notes from Author team
Accepted			
ID 5: Understanding the role of atmospheric composition for air quality and climate change	Author team meeting 2024-11-11	Checked with the Impacts and Adaptation theme if health impacts should be included here, or in a dedicated Opportunity. Decided to proceed with a dedicated health impacts Opportunity (ID 37, see Ruane et al., 2025). Discussion needed to ensure consistent pressure levels across Data Request.	Concern that all variable groups are listed as 'High priority'. In response, proposers highlighted that priorities were determined by the AerChemMIP community. Title was also shortened following review.
ID 11: Terrestrial Biodiversity	Author team meetings 23-09-2024 and 24-09-2024	Agreed to merge ID 2 (Advanced process-explicit forest models), ID 3 (Advanced process-explicit terrestrial biodiversity models), and ID 4 (Advanced high-resolution biophysical models for terrestrial biodiversity) into ID 11(BES-SIM standard scenarios for terrestrial biodiversity and ecosystem services) and rename.	Combination of several opportunities covering terrestrial biodiversity and ecosystems
ID 16: Climate impacts on marine biodiversity and ecosystems	Cross thematic review, October 2024	23/24-09-24: merge ID 21, 33, and possibly 44 and 16. Phase 1 consultation: merge ID 21, 33, 32 and 16. Cross thematic review (October 24): merge ID 21, 33, 32 into 44.	Combination of several opportunities covering marine ecosystems and fisheries. In the end, IDs 21, 32 and 33 were merged with ID44 rather than with ID 16.
ID 19: Agriculture and Food System Impacts	Author team meetings 23-09-2024 and 24-09-2024	Agreed to merge ID 7 (Agricultural water requirements), and ID 30 (Enhanced agricultural impacts) into	Includes opportunities that were merged into variable groups for agricultural modeling, water

		ID 19 (Core agricultural modeling) and rename. ID 6 (Agricultural carbon modeling) was also merged into the opportunity.	resources, air pollution, and carbon in agricultural systems.
ID 20: Core climate services			High resolution (sub-daily) outputs for use in multiple climate services applications across sectors.
ID 22: Energy system impacts	Author team meetings 23-09-2024 and 24-09-2024	Agreed to merge ID 25 (Damaging weather for energy systems), ID 45 (Modeling energy demand in built environment), ID 57(Risk assessment for off-shore wind farm installation), and ID 58 (River temperature modelling for thermal power plants) into ID 22(Core variables for energy system) and rename.	Combination of different opportunities devoted to energy system planning and adaptation in balancing generation and demand and ensuring resilience to extreme weather conditions
ID 24: Advancing Wind Wave Climate Modelling for Coastal Zone Dynamics, Impacts, and Risk Assessment	Author team meeting 19-09-2024	Noted need for high frequency surface conditions. Suggestion to merge ID 56 (Risk Assessment for offshore wind farm installation and ID 68 (Wind driven Ocean Surface Waves) - see below.	ID 56 merged into this opportunity. ID 68 to remain separate (see below).
ID 26: Detection and Attribution	Author team meeting 2024-11-11	Opportunity name revised to be more specific. Suggestion to add more biogeochemical variables and ocean grid variables.	Discussion needed to ensure consistent pressure levels across Data Request.
ID 31: Role of fire in the Earth system	Author team meeting 24-11-2024	A key Earth System Process and emerging area of science. Need to add more atmospheric variables.	A more descriptive title for this opportunity should be provided. Variable list may be reduced to focus more on fire related parameters.
ID 35: Glacier changes, drivers, and impacts	Author team meeting 25/10/2024	The cross-thematic review suggested investigating the need for a more specific variable group. It was also suggested to include mountain glaciers in the title and the possibility of merging with Hydrology and Fresh Water Systems (ID 38), Water Resources (ID 67) and Water Cycle (ID 66), which could be consolidated into two Opportunities.	Discussion of potential merger and decision to retain a distinct glacier Opportunity and to re-name (from original Glacier geometry changes and glacio-hydrology).
ID 37: Health impacts	Author team meetings 23-09-2024 and 24-09-2024	Merge ID 8 (Air pollution health impacts), ID 34 (Flooding health impacts) into ID 37 (Health impacts 2) and rename.	Combines multiple opportunities as variable groups related to heat and flooding, including daily and sub-daily outputs as well as heat indices.
ID 38: Assessments for Hydrological Processes, Water Resources, and Freshwater Systems	Author team meeting 25/10/2024	The cross-thematic review suggested consolidating this Opportunity (previously Hydrology and Freshwater Systems), the Water Resources (ID 67) and Water Cycle (ID 66) into two Opportunities, where one is focused on the water cycle and the other on land/water resources. The proposers of all three Opportunities were requested to make the necessary edits and a merge with ID 67 and Climate impact	After consideration of potential for proposed merges, author team decided, together with input from Impacts & Adaptation team that ID 67 (see below) be merged while ID 66, in discussion with and led by the Earth System team, should remain standalone as it is a fundamental component together with energy and carbon cycles. A soil temperature profile was also identified to be included for permafrost.

		assessments on freshwater ecosystems (ID 15) was requested.	
ID 40: Vulnerability of urban systems, infrastructure and population	Merge recorded in the I&A "Opportunities Being Merged" document, issued 19-09-2024	Merge ID 14 (Cities) into ID 40 (Impact of climate variability and change on urban population and infrastructure).	Combines several cities and infrastructure opportunities.
ID 41: Impacts of climate change on aviation	Discussed in author team meeting 19-09-2024	Identified as a high-volume data request due to misinterpretation of requested levels.	A specific set of levels (UTLS: upper troposphere/lower stratosphere) was created for the corresponding variable groups in March 2025.
ID 42: Impacts of climate change on transport infrastructure	Discussed in author team meeting 19-09-2024		Combines data requests from users focused on impacts on road and rail infrastructure.
ID 44: Changes in marine biogeochemical cycles and ecosystem processes	Author team meeting 02-10-2024 https://github.com/CMIP-Data-Request/Harmonised-Public-Consultation/issues/32	Potential to merge with other BGC opportunities - author team following up with proposers.	Revise original name, include additional marine variable groups and merge in other opportunities.
ID 47: Ocean Changes, Drivers and Impacts	Author sub-group meeting 03-02-2025	Deferred to thematic team pending further variables inclusion. Suggestion to merge ID 56 (see below). ID56 was merged with ID24.	Variable groups confirmed, refined and new variables added.
ID 49: Ocean extremes	Author team meeting 06-11-2024	Deferred to thematic team for further variable development and inclusion and merge with ID 62 (SurgeMIP storm surge intercomparison - see below)	Merge with ID62 completed and new physical parameters (and associated variables) added.
ID 54: Multi-annual-to-decadal predictability of the Earth System and risk assessment of climate extremes	Author team meeting 24-11-2024	This request has selected the entire fast track. If the data volume is a problem, I expect this can probably be narrowed down to a more refined set of experiments that are of most relevance.	This opportunity involves a broad list of variables, which may be split into separate and smaller groups by redesigning in favour of a subset of more specific opportunities.
ID 55: Rapid Evaluation Framework	Author team meeting 2024-11-11	Required variables confirmed across all themes following discussion. Opportunity ID 23 merged into this.	Added DECK experiment group and coordinated with Model Benchmarking TT on confirmed diagnostics for inclusion.
ID 63: Synoptic systems	Author team meeting 2024-11-11	Title changed to remove 'impacts' to avoid confusion with I&A theme work.	Variables gathered through community consultation.
ID 64: Diagnosing temperature variability and extremes	Author team meeting 2024-11-11	Suggestions to merge with other 'extremes' relevant Opportunities.	Decided not to merge, but title and description updated to make distinction clear.
ID 65: Uncertainty in changing net primary production	Author team meeting 27-09-2024 Merge in ID 44	Potential to merge with other BGC opportunities (changing net primary production, biological carbon sink in ocean and Marine BGC)	This could be coordinated/merged with the others marine biogeochemical opportunities.
ID 67: Water security and Freshwater Ecosystem Services	Author team meeting 21-11-2024	Merge ID 15 (Climate impact assessments on freshwater ecosystems) into ID 67 (Water Resources (Hydroclimatic hazards at regional scale for adaptation actions and resilience building.)) and rename.	Combines two opportunities with overlapping objectives involving freshwater resources
ID 68: Effects and Feedbacks of Wind-Driven Ocean Surface Waves Coupled Within Earth System Models	Author sub-group meeting 03-02-2025	Deferred to thematic team with suggestion to merge with ID 24	ID 24 concerns offline wave models, whereas the focus here is on coupled ESM wave components. Opportunity title updated from original Wind

			driven Ocean Surface Waves to reflect.
ID 69: Baseline Climate Variables for Earth System Modelling			Created for all data request with cross-cutting relevance to all themes.
ID 77: Bias-adjustment for impacts modelling and analysis	Author team meetings 23-09-2024 and 24-09-2024	Merge ID 17 (Climatologies at high resolution for the earth's land surface areas - CHELSA) into ID 77 (ISIMIP Inter-Sectoral) and rename.	Includes opportunities originating from CHELSA and ISIMIP. Daily deposition variables.
ID 80: Empirical Statistical Downscaling and Emulators			Key variables needed for both traditional ESD methods and newer hybrid emulators. With ID82, responds to increasing user demand for high-frequency climate information.
ID 81: Dynamical Downscaling	Recorded in update to the I&A Opportunities Being Merged document 09-10-2024	Merge ID 27 (Data for dynamical downscaling) and ID 28 (Atmospheric and Oceanic Dynamical downscaling) into ID 81 (Dynamical Downscaling).	Combines several opportunities independently requesting variable groups associated with higher resolution modeling of the atmosphere and ocean.
ID 82: Robust Risk Assessment of Tipping Points	Author team meeting 24-11-2024	TipMIP set of experiments will be added once available on the controlled vocabularies system.	The objectives are clear and the proposed set of variables is consistent.
Merged			
ID 2: Advanced process-explicit forest models	Author team meetings 23-09-2024 and 24-09-2024		Merged into the opportunity Terrestrial Biodiversity (ID 11) to group this impact sector
ID 3: Advanced process-explicit terrestrial biodiversity models	Author team meetings 23-09-2024 and 24-09-2024		Merged into the opportunity Terrestrial Biodiversity (ID 11) to group this impact sector.
ID 4: Advanced, high-resolution biophysical models for terrestrial biodiversity	Author team meetings 23-09-2024 and 24-09-2024		Merged into the opportunity Terrestrial Biodiversity (ID 11) to group this impact sector.
ID 6: Agricultural carbon monitoring	Author team meetings 23-09-2024 and 24-09-2024		Merged into Agriculture and Food System Impacts Opportunity (ID 19) to group alike requests.
ID 7: Agricultural water requirements	Author team meetings 23-09-2024 and 24-09-2024		Merged into Agriculture and Food System Impacts Opportunity (ID 19) to group alike requests.
ID 8: Air pollution health impacts	Author team meetings 23-09-2024 and 24-09-2024		Merged into Health Impacts Opportunity (ID 37) to group alike requests.
ID 14: Cities	Merge recorded in the I&A "Opportunities Being Merged" document, issued 19-09-2024		Merged into Vulnerability of urban systems, infrastructure and population (ID 40) to group alike requests.
ID 15: Climate impact assessments on freshwater ecosystems	Author team meeting 21-11-2024		Merged into Water security and Freshwater Ecosystem Services Opportunity (ID 67) to group alike requests.
ID 17: Climatologies at high resolution for the earth's land surface areas - CHELSA	Author team meetings 23-09-2024 and 24-09-2024		Merged into Bias-adjustment for impacts modeling and analysis Opportunity (ID 77) to group alike requests.
ID 21: Core fisheries modeling output	Author team meeting 27-09-2024 Merge in ID 44	Request proposers to merge with Fisheries board on additional fisheries modeling and impacts (ID32) and	Integrate with companion opportunities into joined Changes in marine biogeochemical cycles

		Fisheries board on advanced mariculture	and ecosystem processes opportunity (ID 44)
ID 25: Damaging weather for energy systems	Author team meetings 23-09-2024 and 24-09-2024		Merged with other opportunities into the energy system impacts opportunity (ID22)
ID 27: Data for dynamical downscaling	Recorded in update to the I&A Opportunities Being Merged document 09-10-2024		Merged into the opportunity Dynamical Downscaling (ID 81) to group alike requests.
ID 28: Atmospheric and Oceanic Dynamical downscaling	Recorded in update to the I&A Opportunities Being Merged document 09-10-2024		Merged into the opportunity Dynamical Downscaling (ID 81) to group alike requests.
ID 30: Enhanced agricultural impacts	Author team meetings 23-09-2024 and 24-09-2024		Merged into Agriculture and Food System Impacts Opportunity (ID 19) to group alike requests.
ID 32: Fisheries board on additional fisheries modeling and impacts	Author team meeting 27-09-2024 Merge in ID 44	Request proposers to merge with Core fisheries modeling output (ID21), and Fisheries board on advanced mariculture and species model (ID33) into one Opportunity.	Integrated with companion opportunities (ID21 and ID 33) into ID 44.
ID 33: Fisheries board on advanced mariculture and species model	Author team meeting 27-09-2024 Merge in ID 44	Request proposers to merge with Core fisheries modeling output (ID21) and Fisheries board on additional fisheries modeling and impacts (ID32) into one Opportunity.	Integrated with companion opportunities (ID21 and ID32) into ID 44.
ID 34: Flooding health impacts	Author team meetings 23-09-2024 and 24-09-2024		Merged into Health Impacts Opportunity (ID 37) to group alike requests.
ID 45: Modelling energy demand in built environment	Author team meetings 23-09-2024 and 24-09-2024		Merged with other opportunities into the energy system impacts opportunity (ID22)
ID 56: Risk assessment for offshore wind farm installation	Author team meeting 27-09-2024 Merge in ID24	Deferred to thematic team with suggestion to merge with ID 24	Merged into Merged into Ocean and Sea Ice Theme, Advancing Wind Wave Climate Modelling for Coastal Zone Dynamics, Impacts, and Risk Assessment opportunity (ID 24) to group alike requests.
ID 58: River temperature modelling for thermal power plants	Author team meetings 23-09-2024 and 24-09-2024		Merged with other opportunities into the energy system impacts opportunity (ID22)
ID 59: Robust risk assessments of extreme climate	Cross thematic review, October 2024	Merge with ID 54 (Multi-annual-to-decadal predictability of the Earth System and risk assessment of climate extremes).	Merged with ID 54
ID 62: SurgeMIP (storm surge intercomparison)	Cross thematic review, October 2024	Merge with ID 49 (Ocean Extremes)	Merged with Ocean Extremes (ID 49)
Rejected			
ID 36: Heat Health Impacts			Initial submission contained an error which led to an improved submission that is now included in Heat Impacts Opportunity (ID 37)

Appendix B. Description of new variables proposed by Impacts and Adaptation Data Request Theme

Table B.1: New variables proposed and variable formula updates by the Impacts and Adaptation Data Request Theme. The variables that are newly introduced in CMIP7 are tabulated below. The Coordinate Specifications column is lists special aspects of the temporal and spatial requirements for each variable. The full grid specifications can be found in v1.2 of the CMIP7 Data Request (Data Request Task Team, 2025a).

Variable CMOR name	**CF standard name**	**Description**	**Further detail to aid compute****	**Coordinate specifications**
bldep	atmosphere_boundary_layer_thickness	Boundary Layer Depth	existing physical parameter	3hrPt (3-hourly), E1hr (hourly)
cfc114	mole_fraction_of_cfc114_in_air	mole fraction of cfc114		AERmon (monthy)
clt	cloud_area_fraction	Total Cloud Cover Percentage	existing physical parameter	E1hr (hourly)
drynh3	minus_tendency_of_atmosphere_mass_content_of_ammonia_due_to_dry_deposition	Dry Deposition Rate of NH3	existing physical parameter	AERday (daily)
drynh4	minus_tendency_of_atmosphere_mass_content_of_ammonium_dry_aerosol_particles_due_to_dry_deposition	Dry Deposition Rate of NH4	existing physical parameter	AERday (daily)
drynoy	minus_tendency_of_atmosphere_mass_content_of_noy_expressed_as_nitrogen_due_to_dry_deposition	Daily Dry Deposition Rate of NOy	existing physical parameter	AERday (daily)
emich4	tendency_of_atmosphere_mass_content_of_methane_due_to_emission	total emission rate of CH4		AERmon (monthly)
epc1000	sinking_mole_flux_of_particulate_organic_matter_expressed_as_carbon_in_sea_water	Downward Flux of Particulate Organic Carbon at 1000m		Omon (monthly)
epcalc1000	sinking_mole_flux_of_calcite_expressed_as_carbon_in_sea_water	Downward Flux of Calcite at 1000m		Omon (monthly)
expcob	sinking_mole_flux_of_particulate_organic_matter_expressed_as_carbon_in_sea_water	Sinking Flux of Particulate Organic Carbon Reaching the Ocean Bottom		Oday (daily)
ficeberg	water_flux_into_sea_water_from_icebergs	Water Flux into Sea Water from Icebergs	existing physical parameter	3hr (3-hourly)
flandice	water_flux_into_sea_water_from_land_ice	Water Flux into Sea Water from Land Ice	existing physical parameter	3hr (3-hourly)
flashrate	frequency_of_lightning_flashes_per_unit_area	Lightning Flash Rate	existing physical parameter	Eday (daily)
friver	water_flux_into_sea_water_from_rivers	Water Flux into Sea Water from Rivers	existing physical parameter	Oday (daily), 3hr (3-hourly)
hcfc22	mole_fraction_of_hcfc22_in_air	Mole Fraction of HCFC22		AERmon (monthly)
hfc125	mole_fraction_of_hfc125_in_air	Mole Fraction of HFC125		AERmon (monthly)
hfc134a	mole_fraction_of_hfc134a_in_air	Mole Fraction of HFC134a		AERmon (monthly)
hfds	surface_downward_heat_flux_in_sea_water	Downward Heat Flux at Sea Water Surface	existing physical parameter	3hr (3-hourly)
hfls	surface_upward_latent_heat_flux	Surface upward latent heat flux	existing physical parameter	E1hr (hourly)
hfrunoffds	temperature_flux_due_to_runoff_expressed_as_heat_flux_into_sea_water	Temperature Flux Due to Runoff Expressed as Heat Flux into Sea Water	existing physical parameter	3hr (3-hourly)

hfss	surface_upward_sensible_heat_flux	Surface upward sensible heat flux	existing physical parameter	E1hr (hourly)
hurs	relative_humidity	Relative humidity at 2m above the surface	existing physical parameter	E1hr (hourly)
huss	specific_humidity	Specific humidity at 2m.	existing physical parameter	E1hr (hourly)
intpoc	ocean_mass_content_of_particulate_organic_matter_expressed_as_carbon	Particulate Organic Carbon Content	existing physical parameter	Oday (daily)
intpp	net_primary_mole_productivity_of_biomass_expressed_as_carbon_by_phytoplankton	Primary Organic Carbon Production by All Types of Phytoplankton	existing physical parameter	Oday (daily)
intppnano	net_primary_mole_productivity_of_biomass_expressed_as_carbon_by_nanophytoplankton	Vertically integrated total primary (organic carbon) production by nanophytoplankton.		Omon (monthly)
irrDem	surface_downward_mass_flux_of_water_due_to_irrigation	irrigation water demand		day (daily)
irrGw	surface_downward_mass_flux_of_water_due_to_irrigation	irrigation water withdrawal from groundwater		day (daily)
irrLut	surface_downward_mass_flux_of_water_due_to_irrigation	irrigation water withdrawal	existing physical parameter	day (daily)
irrSurf	surface_downward_mass_flux_of_water_due_to_irrigation	irrigation water withdrawal from surface water		day (daily)
mlotst	ocean_mixed_layer_thickness_defined_by_sigma_t	Ocean Mixed Layer thickness Defined by Sigma T	existing physical parameter	Oday (daily)
mrro	runoff_flux	Total Runoff	existing physical parameter	Eday (daily)
mrso10	mass_content_of_water_in_soil_layer	Soil moisture in the top 10 cm of the soil column		Eday (daily)
noaahi2m	heat_index_of_air_temperature	mean 2m daily NOAA heat index		day (daily)
noaahi2mmax	heat_index_of_air_temperature	max 2m daily NOAA heat index		day (daily)
o2200	mole_concentration_of_dissolved_molecular_oxygen_in_sea_water	Dissolved Oxygen Concentration at 200 meters	existing physical parameter	Oday (daily)
o2min	mole_concentration_of_dissolved_molecular_oxygen_in_sea_water_at_shallowest_local_minimum_in_vertical_profile	Oxygen Minimum Concentration	existing physical parameter	Oday (daily)
o2os	mole_concentration_of_dissolved_molecular_oxygen_in_sea_water	Surface Dissolved Oxygen Concentration	existing physical parameter	Oday (daily)
ph200	sea_water_ph_reported_on_total_scale	pH, negative log10 of hydrogen ion concentration with the concentration expressed as mol H kg-1.	existing physical parameter	Oday (daily)
phyc200	mole_concentration_of_phytoplankton_expressed_as_carbon_in_sea_water	Phytoplankton Carbon Concentration	existing physical parameter	Oday (daily)
phycalc	mole_concentration_of_calcareous_phytoplankton_expressed_as_carbon_in_sea_water	Mole concentration of calcareous phytoplankton expressed as carbon in sea water	existing physical parameter	Oday (daily)
Phydiat	mole_concentration_of_diatoms_expressed_as_carbon_in_sea_water	Carbon concentration of diatoms	Mole Concentration of Diatoms Expressed as Carbon in Sea Water	Oday (daily)
phydiaz	mole_concentration_of_diazotrophic_phytoplankton_expressed_as_carbon_in_sea_water	Carbon concentration of diazotrophs	Mole Concentration of Diazotrophs Expressed as Carbon in Sea Water	Oday (daily)
phymisc	mole_concentration_of_miscellaneous_phytoplankton_expressed_as_carbon_in_sea_water	Carbon concentration of miscellaneous phytoplankton	Mole Concentration of Miscellaneous Phytoplankton	Oday (daily)

			Expressed as Carbon in Sea Water	
phynano	mole_concentration_of_nanophytoplankton_expressed_as_carbon_in_sea_water	Carbon concentration of nanophytoplankton	Mole Concentration of Nanophytoplankton Expressed as Carbon in Sea Water	Oday (daily)
phypico	mole_concentration_of_picophytoplankton_expressed_as_carbon_in_sea_water	Carbon concentration of picophytoplankton	Mole Concentration of Picophytoplankton Expressed as Carbon in Sea Water	ODay (daily)
Ps	surface_air_pressure	Surface pressure	existing physical parameter	E1hr (hourly)
Rlds	surface_downwelling_longwave_flux_in_air	surface_downwelling_longwave_flux_in_air	existing physical parameter	E1hr (hourly)
rlus	surface_upwelling_longwave_flux_in_air	surface_upwelling_longwave_flux_in_air	existing physical parameter	E1hr (hourly)
rsdo	downwelling_shortwave_flux_in_sea_water	Downwelling Shortwave Radiation in Sea Water	existing physical parameter	Oday (daily)
rsds	surface_downwelling_shortwave_flux_in_air	downward solar radiation flux at the surface	existing physical parameter	E1hr (hourly)
rsdsdiff	surface_diffuse_downwelling_shortwave_flux_in_air	Surface Diffuse Downwelling Shortwave Radiation	existing physical parameter	E1hr (hourly)
rsntds	net_downward_shortwave_flux_at_sea_water_surface	Net Downward Shortwave Radiation at Sea Water Surface	existing physical parameter	3hr (3-hourly)
rsus	surface_upwelling_shortwave_flux_in_air	Surface upwelling shortwave radiation	existing physical parameter	E1hr (hourly)
sfcWind	wind_speed	surface wind speed	existing physical parameter	E1hr (hourly)
sfdsi	downward_sea_ice_basal_salt_flux	Downward Sea Ice Basal Salt Flux	existing physical parameter	3hr (3-hourly)
sfpm1	mass_fraction_of_pm1_ambient_aerosol_particles_in_air	PM1.0 mass mixing ratio in lowest model layer		AERday (daily), AERhr (hourly)
sfpm10	mass_fraction_of_pm10_ambient_aerosol_particles_in_air	PM10 mass mixing ratio in lowest model layer		AERday (daily), AERhr (hourly)
sfpm25	mass_fraction_of_pm2p5_ambient_aerosol_particles_in_air	PM2.5 Mass Mixing Ratio in Lowest Model Layer	existing physical parameter	AERday (daily)
so	sea_water_salinity	Sea water salinity	existing physical parameter	Oday (daily)
tas	air_temperature	temperature at 2m above surface	existing physical parameter	E1hr (hourly)
taUTLS	air_temperature	temperature in the UTLS region	6 hourly instantaneous temperature in the UTLS region (100, 150 and 225 hPa)	6hrPlevPt (6-hourly)
taUTLSadd	air_temperature	temperature in additional levels within the UTLS region	6 hourly instantaneous temperature in additional levels within the UTLS region (175 and 225 hPa)	6hrPlevPt (6-hourly)
tauuo	downward_x_stress_at_sea_water_surface	Sea Water Surface Downward X Stress. The stress on the liquid ocean from interactions with overlying atmosphere, sea ice, ice shelf, etc.	existing physical parameter	3hr (3-hourly)
tauvo	downward_y_stress_at_sea_water_surface	Sea Water Surface Downward Y Stress. The stress on the liquid ocean from interactions with overlying atmosphere, sea ice, ice shelf, etc.	existing physical parameter	3hr (3-hourly)
thetao200	sea_water_potential_temperature	Sea Water Potential Temperature at 200 meters	existing physical parameter	Oday (daily)
ts	surface_temperature	Surface temperature (skin for open ocean)	existing physical parameter	E1hr (hourly)

ua100m	eastward_wind	Eastward wind at 100m above the surface	existing physical parameter	E1hr (hourly), 3hr (3-hourly)
uas	eastward_wind	Surface wind speed Eastward Components at 10m above the surface	existing physical parameter	E1hr (hourly)
uaUTLS	eastward_wind	Eastward wind in the UTLS region.	6 hourly instantaneous Eastward wind at 5 pressure levels in the UTLS region (150, 175, 200, 225, and 250 hPa)	6hrPlevPt (6-hourly)
uos	surface_sea_water_x_velocity	surface prognostic x-ward velocity component resolved by the model.		Oday (daily)
va100m	northward_wind	Northward wind at 100m above the surface	existing physical parameter	E1hr (hourly), 3hr (3-hourly)
vas	northward_wind	Surface wind speed Northward Components at 10m above the surface	existing physical parameter	E1hr (hourly)
vaUTLS	northward_wind	Northward wind in the UTLS region	6 hourly instantaneous Northward wind at 5 pressure levels in the UTLS region (150, 175, 200, 225, and 250 hPa)	6hrPlevPt (6-hourly)
vos	surface_sea_water_y_velocity	surface prognostic y-ward velocity component resolved by the model.		Oday (daily)
wbgt2m	wet_bulb_globe_temperature	mean 2m daily wet bulb globe temperature. Wet Bulb Globe Temperature (WBGT) is a particularly effective indicator of heat stress for active populations such as outdoor workers and athletes.	WBGT = 0.567 * T_C + 0.393 * e/100 + 3.94, where T_C is temperature in degrees C, and e = huss * p * M_air / M_H2O, where "huss=specific humidity in kg/kg", M_H2O = 18.01528/1000 # kg/mol, M_air = 28.964/1000 # kg/mol for dry air and "P = surface pressure in Pa"	day (daily)
wbgt2mmax	wet_bulb_globe_temperature	maximum 2m daily wet bulb globe temperature. Wet Bulb Globe Temperature (WBGT) is a particularly effective indicator of heat stress for active populations such as outdoor workers and athletes.	WBGT = 0.567 * T_C + 0.393 * e/100 + 3.94, where T_C is temperature in degrees C, and e = huss * p * M_air / M_H2O, where "huss=specific humidity in kg/kg", M_H2O = 18.01528/1000 # kg/mol, M_air = 28.964/1000 # kg/mol for dry air and "P = surface pressure in Pa"	day (daily)
wetnh3	minus_tendency_of_atmosphere_mass_content_of_ammonium_dry_aerosol_particles_due_to_wet_deposition	Wet Deposition Rate of NH4	existing physical parameter	AERday (daily)
wetnh4	minus_tendency_of_atmosphere_mass_content_of_ammonium_dry_aerosol_particles_due_to_wet_deposition	Wet Deposition Rate of NH4	existing physical parameter	AERday (daily)
wetnoy	minus_tendency_of_atmosphere_mass_content_of_noy_expressed	Wet Deposition Rate of NOy	existing physical parameter	AERday (daily)

	_as_nitrogen_due_to_wet_deposition			
wfo	water_flux_into_sea_water	Water Flux into Sea Water	existing physical parameter	3hr (3-hourly)
wo	upward_sea_water_velocity	Sea Water Vertical Velocity	existing physical parameter	Oday (daily)
wsgmax10m	wind_speed_of_gust	Maximum Speed of Wind Gust at 10m	existing physical parameter	E1hr (hourly), Emon (monthly)
wsgmax100m	wind_speed_of_gust	Maximum Wind Speed of Gust at 100m	existing physical parameter	E1hr (hourly), Emon (monthly)
zg	geopotential_height	Geopotential height	existing physical parameter	6hrLev (6-hourly)
zmeso	mole_concentration_of_mesozooplankton_expressed_as_carbon_in_sea_water	Mole Concentration of Mesozooplankton Expressed as Carbon in Sea Water	existing physical parameter	Oday (daily)
zmicro	mole_concentration_of_microzooplankton_expressed_as_carbon_in_sea_water	Mole Concentration of microzooplankton Expressed as Carbon in Sea Water	existing physical parameter	Oday (daily)
zooc	mole_concentration_of_zooplankton_expressed_as_carbon_in_sea_water	Zooplankton Carbon Concentration	existing physical parameter	Oday (daily)
zos	sea_surface_height_above_geoid	Sea Surface Height above Geoid	existing physical parameter	Oday (daily)

**Note: Variables with existing physical parameters were requested at higher temporal resolution, including existing monthly variables requested at daily resolution, and existing daily resolution variables requested at sub-daily resolution (as fine as 1-hourly).

Code and data availability

The variables and their metadata included latest CMIP7 Assessment Fast Track Data Request can be accessed via the Data Request Task Team. At the time of this publication, the latest major release (v1.2) is accessible at Zenodo under https://doi.org/10.5281/zenodo.15116894 (Data Request Task Team, 2025a), and the latest minor release (v1.2.1) is accessible at Zenodo under https:/doi.org/10.5281/zenodo.15288187 (Data Request Task Team, 2025b).

Author contributions

ACR prepared the manuscript with contributions from all co-authors. ACR, MJ, BT and CLP provided conceptualization with inputs from CMIP Team. ACR and BT developed the outreach and input methods with help from the CMIP Team. CLP and MJ developed the methods for data inputs and oversaw opportunity evaluation as part of their roles on the CMIP Data Request team. ACR, CT, DJB, CB, ID, JF, PLMG, BH, VH, UI, DI, ILL, TL, XL, JM, NN, SP, IR, W-LT, AW, LZ, and DZ conducted outreach to I&A communities and then processed and summarized their inputs into original manuscript draft preparation. Data curation contributions were provided by ACR, CLP, DJB, JF, PLMG,VH, and BT and ACR and BT provided contributions to visualization. Review and editing was carried out by ACR, BT, CB, ID, DJB, VH, DI, ILL, IR, TL. XL, JM, NN, AW and DZ. BT provided resources and project administration support.

Competing interests

Author ACR is Co-chair of the VIACS Advisory Board and an employee of NASA.
Author BT is an employee of HE Space Ltd which delivers the CMIP IPO service to the European Space Agency and is Vice Chair of the Chartered Institution of Building Services Engineers Knowledge Generation Panel
Author CT is Co-chair of the VIACS Advisory Board
Author CB is the director of the Copernicus Climate Change service at ECMWF
Author PLMG is employed by the Met Office, UK
Author VH is employed by CSIRO
Author SP is employed by EDF Lab, lab of an electricity company
Author AW is employed by Riskthinking.AI

Our authors making these declarations do so in accordance with the Competing Interests Policy but do not believe their positions have influenced their ability to provide complete and objective presentation of this research.

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984

References

Baño-Medina, J., Iturbide, M., Fernández, J., and Gutiérrez, J. M.: Transferability and Explainability of Deep Learning Emulators for Regional Climate Model Projections: Perspectives for Future Applications, Artificial Intelligence for the Earth Systems, 3, https://doi.org/10.1175/AIES-D-23-0099.1, 2024.

Bernier, N. B., Hemer, M., Mori, N., Appendini, C. M., Breivik, O., de Camargo, R., Casas-Prat, M., Duong, T.M., Haigh, I.D., Howard, T., Hernaman, V., Huizy, O., Irish, J.L., Kirezci, E., Kohno, N., Lee, J.-W., McInnes, K.L., Meyer, E.M.I., Marcos, M., Marsooli, R., Martin Oliva, A., Menendez, M., Moghimi, S., Muis, S., Polton, J.A., Pringle, W.J., Ranasinghe, R., Saillour, T., Smith, G., Getachew Tadesse, M., Swail, V., Tomoya, S., Voukouvalas, E., Wahl, T., Wang, P., Weisse, R., Westerink, J.J., Young, I., & Zhang, Y.J. 2024. Storm surges and extreme sea levels: Review, establishment of model intercomparison and coordination of surge climate projection efforts (SurgeMIP). Weather and Climate Extremes, 45, 100689. https://doi.org/10.1016/j.wace.2024.100689

Bloomfield, H. C., Brayshaw, D. J., Shaffrey, L. C., Coker, P. J., & Thornton, H. E. (2016). Quantifying the increasing sensitivity of power systems to climate variability. Environmental Research Letters, 11(12), 124025.

Bloomfield, H. C., Gonzalez, P. L. M., Lundquist, J. K., Stoop, L. P., Browell, J., Dargaville, R., M. De Felice, K. Gruber, A. Hilbers, A. Kies, M. Panteli, H. E. Thornton, J. Wohland, M. Zeyringer, and D. J. Brayshaw, 2021:. The importance of weather and climate to energy systems: a workshop on next generation challenges in energy–climate modeling. Bulletin of the American Meteorological Society, 102(1), E159-E167.

Briscoe, N. J.; Morris, S. D.; Mathewson, P. D.; Buckley, L. B.; Jusup, M.; Levy, O.; Maclean, I. M. D.; Pincebourde, S.; Riddell, E. A.; Roberts, J. A.; Schouten, R.; Sears, M. W. & Kearney, M. R. Mechanistic forecasts of species responses to climate change: The promise of biophysical ecology
Global Change Biology, 2023, 29, 1451-1470

Brönnimann, S., Franke, J., Valler, V. et al. Past hydroclimate extremes in Europe driven by Atlantic jet stream and recurrent weather patterns. Nature Geoscience (2025). https://doi.org/10.1038/s41561-025-01654-y
Cao, C., Lee, X., Liu, S., Schultz, N., Xiao, W., Zhang, M. & Zhao, L. Urban heat islands in China enhanced by haze pollution. Nat. Commun. 7, 12509 (2016).

Caretta, M.A., A. Mukherji, M. Arfanuzzaman, R.A. Betts, A. Gelfan, Y. Hirabayashi, T.K. Lissner, J. Liu, E. Lopez Gunn, R. Morgan, S. Mwanga, and S. Supratid, 2022: Water. In: Climate Change 2022: Impacts, Adaptation and Vulnerability.

Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 551–712, doi:10.1017/9781009325844.006.

Chakraborty, T., Venter, Z. S., Demuzere, M., Zhan, W., Gao, J., Zhao, L. & Qian, Y. Large disagreements in estimates of urban land across scales and their implications. Nat. Commun. 15, 9165 (2024).

Chan, W. C., Shepherd, T. G., Facer-Childs, K., Darch, G., and Arnell, N. W. (2022). Storylines of UK drought based on the 2010–2012 event. Hydrology and Earth System Sciences, 26(7), 1755-1777, https://doi.org/10.5194/hess-26-1755-2022.

CMIP Model Benchmarking Task Team. (2024). CMIP AR7 Fast Track Diagnostics list for the Rapid Evaluation Framework [Data set]. Zenodo. https://zenodo.org/records/14284375

Connors, S., M. Dionne, G. Hanák, R. Musulin, N. Aellen, M. Amjad, S. Bowen, D.R. Carrascal, E. Coppola, E. Dal Moro, A. Dosio, S.H. Faria, T.Y. Gan, M. Gomis, J.M. Gutiérrez, P. Hope, R. Kopp, S. Krakovska, K. Leitzell, D. Maraun, V. Masson-Delmotte, R. Matthews, T. Maycock, S. Paddam, G.-K. Plattner, A. Pui, M. Rahimi, R. Ranasinghe, J. Rogelj, A.C. Ruane, S. Szopa, A. Turner, R. Vautard, Y. Velichkova, A. Weigel, and X. Zhang, 2022: Climate Science: A Summary for Actuaries: What the IPCC Climate Change Report 2021 Means for the Actuarial Profession. International Actuarial Association.

Cooley, S., D. Schoeman, L. Bopp, P. Boyd, S. Donner, D.Y. Ghebrehiwet, S.-I. Ito, W. Kiessling, P. Martinetto, E. Ojea, M.-F. Racault, B. Rost, and M. Skern-Mauritzen, 2022: Oceans and Coastal Ecosystems and Their Services. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 379–550, doi:10.1017/9781009325844.005.

Craig, M. T., J. Wohland, L.P. Stoop, A. Kies, B. Pickering, H.C. Bloomfield, J, Browell, M. De Felice, C.J. Dent, A. Deroubaix, F. Frischmuth, P.L.M. Gonzalez, A. Grochowicz, K. Gruber, P, Härtel, M. Kittel, L. Kotzur, I. Labuhn, J.K. Lundquist, N. Pflugradt, K. van der Wiel, M. Zeyringer, and D.J. Brayshaw, 2022: Overcoming the disconnect between energy system and climate modeling. Joule, 6(7), 1405-1417. doi:10.1016/j.joule.2022.05.010.

Creutzig, F., Baiocchi, G., Bierkandt, R., Pichler, P.-P. & Seto, K. C. Global typology of urban energy use and potentials for an urbanization mitigation wedge. Proc. Natl. Acad. Sci. 112, 6283–6288 (2015).

Data Request Task Team. (2025a). CMIP-Data-Request/CMIP7_DReq_Content: Data request content for v1.2 (released 30 Jan 2025) (v1.1). Zenodo. https://doi.org/10.5281/zenodo.15116894

Data Request Task Team. (2025b). CMIP-Data-Request/CMIP7_DReq_Content: Data request content for v1.2.1 (released 30 Jan 2025) (v1.1). Zenodo. https://doi.org/10.5281/zenodo.15288187

de Abreu, V. H. S., Santos, A. S., & Monteiro, T. G. M. (2022). Climate change impacts on the road transport infrastructure: A systematic review on adaptation measures. Sustainability, 14(14), 8864.

Dingley, B., J.A. Anstey, M. Abalos, C. Abraham, T. Bergman, L. Bock, S. Fiddes, B. Hassler, R.J. Kramer, F. Luo, F.M. O'Connor, P. Šácha, I.R. Simpson, L.J. Wilcox, and M.D. Zelinka, CMIP7 Data Request: Atmosphere Theme. 2025, in preparation

Dodman, D., B. Hayward, M. Pelling, V. Castan Broto, W. Chow, E. Chu, R. Dawson, L. Khirfan, T. McPhearson, A. Prakash, Y. Zheng, and G. Ziervogel, 2022: Cities, Settlements and Key Infrastructure. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 907–1040, doi:10.1017/9781009325844.008.

Doney, S. C., Ruckelshaus, M., Emmett Duffy, J., Barry, J. P., Chan, F., English, C. A., ... & Talley, L. D. (2012). Climate change impacts on marine ecosystems. Annual review of marine science, 4(1), 11-37. https://doi.org/10.1146/annurev-marine-041911-111611

Dooks, T. C. (2022). Understanding climate risks to UK infrastructure-Evaluation of the third round of the Adaptation.Dunn, J.P., H.T. Hewitt, J. Arblaster, F. Bonou , O. Boucher, T. Cavazos, P.J. Durack, B. Hassle, M. Juckes, T. Miyakawa, M. Mizielinski, V. Naik, Z. Nicholls, E. O'Rourke, R. Pincus, B.M. Sanderson, I.R. Simpson, and K.E. Taylor (in review): An evolving Coupled Model Intercomparison Project phase 7 (CMIP7) and Fast Track in support of future climate assessment. Geoscientific Model Development, doi:10.5194/egusphere-2024-3874

Dubus, L., Brayshaw, D. J., Huertas-Hernando, D., Radu, D., Sharp, J., Zappa, W., & Stoop, L. P. (2022). Towards a future-proof climate database for European energy system studies. Environmental Research Letters, 17(12), 121001.

Dunne, J. P., Hewitt, H. T., Arblaster, J., Bonou, F., Boucher, O., Cavazos, T., ... & Taylor, K. E. (2024). An evolving Coupled Model Intercomparison Project phase 7 (CMIP7) and Fast Track in support of future climate assessment. EGUsphere, 2024, 1-51. https://doi.org/10.5194/egusphere-2024-3874, 2024

Eyring, V., Bony, S., Meehl, G.A., Senior, C.A., Stevens, B., Stouffer, R.J., Taylor, K.E., 2016. Overview of the coupled model intercomparison project phase 6 (CMIP6) experimental design and organization. Geosci. Model Dev. 9, 1937–1958. doi:10.5194/gmd-9-1937-2016.

Eyring, V., Cox, P.M., Flato, G.M. et al. Taking climate model evaluation to the next level. Nature Clim Change 9, 102–110 (2019). https://doi.org/10.1038/s41558-018-0355-y

Eyring, V., N.P. Gillett, K.M. Achuta Rao, R. Barimalala, M. Barreiro Parrillo, N. Bellouin, C. Cassou, P.J. Durack, Y. Kosaka, S. McGregor, S. Min, O. Morgenstern, and Y. Sun, 2021: Human Influence on the Climate System. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 423–552, doi: 10.1017/9781009157896.005, 2021.

Ferrier, S., Ninan, K. N., Leadley, P., Alkemade, R., Kolomytsev, G., Moraes, M., ... & Joly, C. Work programme of the Platform: scenarios* and models of biodiversity and ecosystem services Technical report of the methodological assessment of scenarios and models of biodiversity and ecosystem services (deliverable 3á (c)) Note by the Secretariat. https://www.ipbes.net/resource-file/5371

Fox-Kemper, B., Hewitt, H. T., Xiao, C., Adalgeirsdottir, G., Drijfhout, S. S., Edwards, T. L., Golledge, N. R., Hemer, M., Kopp, R. E., Krinner, G., Mix, A., Notz, D., Nowicki, S., Nurhati, I. S., Ruiz, L., Sallee, J.-B., Slangen, A. B. A., and Yu, Y.: Ocean, Cryosphere and Sea Level Change, in: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M. I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J. B. R., Maycock, T. K., Waterfield, T., Yelekçi, O., Yu, R., & Zhou, B., pp. 1211–1362, Cambridge University Press, United Kingdom and New York, NY, USA, https://doi.org/10.1017/9781009157896.011, 2021.

Fox-Kemper, B., P. DeRepentigny, A.M. Treguier, C. Stepanek, E. O'Rourke, C. Mackallah, A. Meucci, Y. Aksenov, P.J. Durack, N. Feldl, V. Hernaman, C. Heuzé, D. Iovino, G. Madan, A.L. Marquez, F. Massonnet, J. Mecking, D. Samanta, P.C. Taylor, W.-L. Tseng, and M. Vancoppenolle: CMIP7 Data Request: Ocean and Sea Ice Priorities and Opportunities. Geosci. Model Dev. [in preparation]

Frieler, K., Lange, S., Piontek, F., Reyer, C. P. O., Schewe, J., Warszawski, L., Zhao, F., Chini, L., Denvil, S., Emanuel, K., Geiger, T., Halladay, K., Hurtt, G., Mengel, M., Murakami, D., Ostberg, S., Popp, A., Riva, R., Stevanovic, M., Suzuki, T., Volkholz, J., Burke, E., Ciais, P., Ebi, K., Eddy, T. D., Elliott, J., Galbraith, E., Gosling, S. N., Hattermann, F., Hickler, T., Hinkel, J., Hof, C., Huber, V., Jägermeyr, J., Krysanova, V., Marcé, R., Müller Schmied, H., Mouratiadou, I., Pierson, D., Tittensor, D. P., Vautard, R., van Vliet, M., Biber, M. F., Betts, R. A., Bodirsky, B. L., Deryng, D., Frolking, S., Jones, C. D., Lotze, H. K., Lotze-Campen, H., Sahajpal, R., Thonicke, K., Tian, H., and Yamagata, Y., 2017: Assessing the impacts of 1.5 °C global warming – simulation protocol of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP2b), Geosci. Model Dev., 10, 4321–4345, https://doi.org/10.5194/gmd-10-4321-2017.

Frieler, K., Volkholz, J., Lange, S., Schewe, J., Mengel, M., del Rocío Rivas López, M., Otto, C., Reyer, C. P. O., Karger, D. N., Malle, J. T., Treu, S., Menz, C., Blanchard, J. L., Harrison, C. S., Petrik, C. M., Eddy, T. D., Ortega-Cisneros, K., Novaglio, C., Rousseau, Y., Watson, R. A., Stock, C., Liu, X., Heneghan, R., Tittensor, D., Maury, O., Büchner, M., Vogt, T., Wang, T., Sun, F., Sauer, I. J., Koch, J., Vanderkelen, I., Jägermeyr, J., Müller, C., Rabin, S., Klar, J., Vega del Valle, I. D., Lasslop, G., Chadburn, S., Burke, E., Gallego-Sala, A., Smith, N., Chang, J., Hantson, S., Burton, C., Gädeke, A., Li, F., Gosling, S. N., Müller Schmied, H., Hattermann, F., Wang, J., Yao, F., Hickler, T., Marcé, R., Pierson, D., Thiery, W., Mercado-Bettín, D., Ladwig, R., Ayala-Zamora, A. I., Forrest, M., and Bechtold, M., 2024: Scenario setup and forcing data for impact model evaluation and impact attribution within the third round of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP3a), Geosci. Model Dev., 17, 1–51, https://doi.org/10.5194/gmd-17-1-2024.

Gelaro, R., and Coauthors, 2017: The Modern-Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2). J. Climate, 30, 5419–5454, https://doi.org/10.1175/JCLI-D-16-0758.1

Georgescu, M., Broadbent, A. M., Wang, M., Krayenhoff, E. S. & Moustaoui, M. Precipitation response to climate change and urban development over the continental United States. Environ. Res. Lett. 16, 044001 (2021).

Giorgi, F.: Thirty Years of Regional Climate Modeling: Where Are We and Where Are We Going next?, Journal of Geophysical Research: Atmospheres, 124, 5696–5723, https://doi.org/10.1029/2018JD030094, 2019.

Giorgi, F., Jones, C., Asrar, G. R.: Addressing climate information needs at the regional level: the CORDEX framework, World Meteorological Organization (WMO) Bulletin, 58, 175–183, 2009.

Gratton, G. B., Williams, P. D., Padhra, A., & Rapsomanikis, S. (2022). Reviewing the impacts of climate change on air transport operations. The Aeronautical Journal, 126(1295), 209-221.

Gruber, N., Boyd, P.W., Frölicher, T.L., & Vogt, M. Biogeochemical extremes and compound events in the ocean, Nature, 600, 395–407, https://doi.org/10.1038/s41586-021-03981-7, 2021.

Grünig, M.; Rammer, W.; Albrich, K.; André, F.; Augustynczik, A. L.; Bohn, F.; Bouwman, M.; Bugmann, H.; Collalti, A.; Cristal, I.; Dalmonech, D.; De Caceres, M.; De Coligny, F.; Dobor, L.; Dollinger, C.; Forrester, D. I.; Garcia-Gonzalo, J.; González, J. R.; Hiltner, U.; Hlásny, T.; Honkaniemi, J.; Huber, N.; Jonard, M.; Maria Jönsson, A.; Lagergren, F.; Nieberg, M.; Mina, M.; Mohren, F.; Moos, C.; Morin, X.; Muys, B.; Peltoniemi, M.; Reyer, C. P.; Storms, I.; Thom, D.; Toïgo, M. & Seidl, R. A. harmonized database of European forest simulations under climate change Data in Brief, Elsevier BV, 2024, 54, 110384

Gutowski Jr., W. J., Giorgi, F., Timbal, B., Frigon, A., Jacob, D., Kang, H.-S., Raghavan, K., Lee, B., Lennard, C., Nikulin, G., O'Rourke, E., Rixen, M., Solman, S., Stephenson, T., and Tangang, F.: WCRP COordinated Regional Downscaling EXperiment (CORDEX): a diagnostic MIP for CMIP6, Geoscientific Model Development, 9, 4087–4095, https://doi.org/10.5194/gmd-9-4087-2016, 2016.

Hasegawa, T., Fujimori, S., Havlík, P., Valin, H., Bodirsky, B. L., Doelman, J. C., Fellmann, T., Kyle, P., Koopman, J. F. L., Lotze-Campen, H., Mason-D'Croz, D., Ochi, Y., Pérez Domínguez, I., Stehfest, E., Sulser, T. B., Tabeau, A., Takahashi, K., Takakura, J., van Meijl, H., ... Witzke, P. (2018). Risk of increased food insecurity under stringent global climate change mitigation policy. Nature Climate Change, 8(8), 699-703. https://doi.org/10.1038/s41558-018-0230-x

Heilig, G. K. World urbanization prospects: the 2011 revision. U. N. Dep. Econ. Soc. Aff. DESA Popul. Div. Popul. Estim. Proj. Sect. N. Y. (2012).

Hof, C.; Voskamp, A.; Biber, M. F.; Böhning-Gaese, K.; Engelhardt, E. K.; Niamir, A.; Willis, S. G. & Hickler, T. Bioenergy cropland expansion may offset positive effects of climate change mitigation for global vertebrate diversity Proceedings of the National Academy of Sciences, Proceedings of the National Academy of Sciences, 2018, 115, 13294-13299

Hoffman, F., Hassler, B., Swaminathan, R., Lewis, J., Andela, B., Collier, N., Hegedűs, D., Lee, J., Pascoe, C., Pflüger, M., Stockhause, M., Ullrich, P., Xu, M., Bock, L., Chun, L., Gier, B. K., Kelley, D. I., Lauer, A., Lenhardt, J., Schlund, M., Sreeush, M. G., Weigel, K., Blockley, E., Beadling, R., Beucher, R., Dugassa, D. D., Lembo, V., Lu, J., Brands, S., Tjiputra, J., Malinina, E., Mederios, B., Soccimarro, E., Walton, J., Kershaw, P., Marquez, A. L., Roberts, M. J., O'Rourke, E., Dingley, B., Turner, B., Hewitt, H., and Dunne, J. P.: Rapid Evaluation Framework for the CMIP7 Assessment Fast Track [submitted to GMD]

Holbrook, N.J., Hernaman, V., Koshiba, S., Lako, J., Katjar, J.B., Amosa, P., & Singh, A. 2022. Impacts of marine heatwaves on tropical western and central Pacific Island nations and their communities. Global and Planetary Change 208: 103680. https://doi.org/10.1016/j.gloplacha.2021.103680

IEA (2024), World Energy Investment 2024, IEA, Paris https://www.iea.org/reports/world-energy-investment-2024, Licence: CC BY 4.0

Im, U., Bauer, S.E. Frohn, L.M., Geels, C., Tsigaridis, K., Brandt, J., 2023. Present-day and future PM2.5 and O3-related global and regional premature mortality in the EVAv6.0 health impact assessment model, Environment Research, 216, 4, 114702. doi: 10.1016/j.envres.2022.114702

Im, U., Geels, C., Hanninen, R., Kukkonen, J., Rao, S., Ruuhela, R., Sofiev, M., Schaller, N., Hodnebrog, Ø., Sillmann, J., Schwingshackl, C., Christensen, J.H., Bojariu, R., Aunan, K., 2022. Reviewing the links and feedbacks between climate change and air pollution in Europe. Front. Environ. Sci. 10:954045. doi: 10.3389/fenvs.2022.954045

IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3–32, doi:10.1017/9781009157896.001.

IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change, Cambridge University Press, doi:10.59327/IPCC/AR6-9789291691647.

Jones, C. G., Adloff, F., Booth, B. et.al. (2024). Bringing it all together: Science priorities for improved understanding of Earth system change and to support international climate policy.. Earth Syst. Dynam.. 15: 1319–1351; DOI: https://doi.org/10.5194/esd-15-1319-2024

Jägermeyr, J., C. Müller, A.C. Ruane, J. Elliott, J. Balkovic, O. Castillo, B. Faye, I. Foster, C. Folberth, J.A. Franke, K. Fuchs, J. Guarin, J. Heinke, G. Hoogenboom, T. Iizumi, A.K. Kain, D. Kelly, N. Khabarov, S. Lange, T.-S. Lin, W. Liu, O. Mialyk, S. Minoli, E.J. Moyer, M. Okada, M. Phillips, C. Porter, S. Rabin, C. Scheer, J.M. Schneider, J.F. Schyns, R. Skalsky, A. Smerald, T. Stella, H. Stephens, H. Webber, F. Zabel, and C. Rosenzweig, 2021: Climate impacts on global agriculture emerge earlier in new generation of climate and crop models. Nat. Food, 2, no. 11, 873-885, doi:10.1038/s43016-021-00400-y.

Karger, D. N., Conrad, O., Böhner, J., Kawohl, T., Kreft, H., Soria-Auza, R. W., Zimmermann, N. E., Linder, H. P., and Kessler, M.: Climatologies at high resolution for the earth's land surface areas, Sci. Data, 4, 170122, https://doi.org/10.1038/sdata.2017.122, 2017.

Kashinath, K., M. Mustafa, A, Albert, J. L. Wu, C. Jiang, S. Esmaeilzadeh, K. Azizzadenesheli, R. Wang, A. Chattopadhyay, A. Singh, and A. Manepalli, 2021. Physics-informed machine learning: case studies for weather and climate modelling. Philosophical Transactions of the Royal Society A, 379(2194), p.20200093. doi:10.1098/rsta.2020.0093

Kerr, R. B., Hasegawa, T., Lasco, R., Bhatt, I., Deryng, D., Farrell, A., et al. (2022). Food, Fibre, and other Ecosystem Products. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, et al. (Eds.), Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Intergovernmental Panel on Climate Change Sixth Assessment Report. (pp. 713–906). Cambridge University Press. https://doi.org/10.1017/9781009325844.007

Kim, H., Rosa, I. M. D., Alkemade, R., Leadley, P., Hurtt, G., Popp, A., van Vuuren, D. P., Anthoni, P., Arneth, A., Baisero, D., Caton, E., Chaplin-Kramer, R., Chini, L., De Palma, A., Di Fulvio, F., Di Marco, M., Espinoza, F., Ferrier, S., Fujimori, S., Gonzalez, R. E., Gueguen, M., Guerra, C., Harfoot, M., Harwood, T. D., Hasegawa, T., Haverd, V., Havlík, P., Hellweg, S., Hill, S. L. L., Hirata, A., Hoskins, A. J., Janse, J. H., Jetz, W., Johnson, J. A., Krause, A., Leclère, D., Martins, I. S., Matsui, T., Merow, C., Obersteiner, M., Ohashi, H., Poulter, B., Purvis, A., Quesada, B., Rondinini, C., Schipper, A. M., Sharp, R., Takahashi, K., Thuiller, W., Titeux, N., Visconti, P., Ware, C., Wolf, F., and Pereira, H. M.: A protocol for an intercomparison of biodiversity and ecosystem services models using harmonized land-use and climate scenarios, Geosci. Model Dev., 11, 4537–4562, https://doi.org/10.5194/gmd-11-4537-2018, 2018.

Kinney, P.L. et al., 2015: Winter season mortality: Will climate warming bring benefits? Environmental Research Letters, 10(6), 064016, doi:10.1088/ 1748-9326/10/6/064016.

Knutson, T.R. and J.J. Ploshay, 2016: Detection of anthropogenic influence on a summertime heat stress index. Climatic Change, 138(1–2), 25–39, doi:10.1007/s10584-016-1708-z.

Lange, S. (2019). Trend-preserving bias adjustment and statistical downscaling with ISIMIP3BASD (v1.0) [dataset]. Geoscientific Model Development, 12(7), 3055–3070. https://doi.org/10.5194/gmd-12-3055-2019

Lee, S. H., Williams, P. D., & Frame, T. H. (2019). Increased shear in the North Atlantic upper-level jet stream over the past four decades. Nature, 572(7771), 639-642.

Li, X. 'Cathy', Zhao, L., Qin, Y., Oleson, K. & Zhang, Y. Elevated urban energy risks due to climate-driven biophysical feedbacks. Nat. Clim. Change 14, 1056–1063 (2024).

Li, Y., Tang, G., O'Rourke, E., Minallah, S., Mas e Braga, M., Nowicki, S., Smith, R., Lawrence, D.M., Hurtt, G.C., Peano, D., Meyer, G., Hassler, B., Mao, J., Xue, Y. and Juckes, M. 2025.CMIP7 Data Request: Land and Land Ice Priorities and Opportunities, in preparation.

Lin,Y.-K., C.-K. Chang, M.-H. Li,Y.-C.Wu, and Y.-C.Wang, 2012: High-temperature indices associated with mortality and outpatient visits: Characterizing the association with elevated temperature. Science of The Total Environment, 427–428, 41–49, doi:10.1016/j.scitotenv.2012.04.039.

Mackallah, C., Juckes, M., Anstey, J., Pascoe, C., Rigoudy, G., Moine, M.-P., Lovato, T., Pamment, A., Kawamiya, M., Bergman, T., Schupfner, M., Koven, C., Lam, T., Dingley, B., O'Rourke, E., Turner, B., Ellis, D., and Mizielinski, M.: CMIP7 Data Request: a transparent community-led approach leveraging interactive web tools and enhanced CMIP governance [in preparation]

Mahadevia, D., G.C. Delgado Ramos, J. Barnes, J. Fitzgerald, M. Kamei, and K. Lanza, 2025: Learning from COVID-19 for Climate-Ready Urban Transformation. In Solecki, W., M. Pathak, M. Barata, A. Barau, M. Dombrov, and C. Rosenzweig (Eds.), Climate Change and Cities: Third Assessment Report of the Urban Climate Change Research Network. Cambridge: Cambridge University Press. doi:10.1017/9781009527279

Mankin, J. S., Lehner, F., Coats, S., & McKinnon, K. A., 2020: The value of initial condition large ensembles to robust adaptation decision-making. Earth's Future, 8, e2012EF001610. https://doi.org/10.1029/2020EF001610

Maraun, D., Huth, R., Gutiérrez, J. M., Martín, D. S., Dubrovsky, M., Fischer, A., Hertig, E., Soares, P. M. M., Bartholy, J., Pongrácz, R., Widmann, M., Casado, M. J., Ramos, P., and Bedia, J.: The VALUE perfect predictor experiment: Evaluation of temporal variability, International Journal of Climatology, 39, 3786–3818, https://doi.org/10.1002/joc.5222, 2019.

Matthieu Lengaigne, S Pang, Y Silvy, et al. An ocean-only framework for correcting future CMIP oceanic projections from their present-day biases. ESS Open Archive . July 05, 2024. doi:10.22541/essoar.172019498.89258365/v1

Mbow, C., Rosenzweig, C., Barioni, L. G., Benton, T. G., Herrero, M., Krishnapillai, M., et al. (2019). Food Security. In P. R. Shukla, J. Skea, E. C. Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, et al. (Eds.), Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.

McPartland, M.Y., T. Lovato, C. Koven, J.D. Wilson, B. Turner, C.M.. Petrik, J. Licón-Saláiz, F. Li, F. Lhardy, J.C. Kinney, M. Kawamiya, N.P. Gillett, C.M.N. Fall, C. Danek, C.M. Brierley, A. Bastos, and O. Andrews, 2025: CMIP7 Data Request: Earth System Priorities and Opportunities. [in preparation]

Molina, M. J., T. A. O'Brien, G. Anderson, M. Ashfaq, K. E. Bennett, 2023: W. D. Collins, K. Dagon, J. M. Restrepo, and P.A. Ullrich, 2023. A review of recent and emerging machine learning applications for climate variability and weather phenomena. Artificial Intelligence for the Earth Systems, 2(4), p.220086. doi:10.1175/AIES-D-22-0086.1

Nemry, F., & Demirel, H. (2012). Impacts of Climate Change on Transport: A focus on road and rail transport infrastructures. European commission, joint research centre (JRC), institute for prospective technological studies (IPTS), 89.

Orru, H., K.L. Ebi, and B. Forsberg, 2017: The Interplay of Climate Change and Air Pollution on Health. Current environmental health reports, 4(4), 504–513, doi:10.1007/s40572-017-0168-6.

Palin, E. J., Thornton, H. E., Mathison, C. T., McCarthy, R. E., Clark, R. T., & Dora, J. (2013). Future projections of temperature-related climate change impacts on the railway network of Great Britain. Climatic Change, 120, 71-93.

Palin, E. J., Stipanovic Oslakovic, I., Gavin, K., & Quinn, A. (2021). Implications of climate change for railway infrastructure. Wiley Interdisciplinary Reviews: Climate Change, 12(5), e728.

Parmesan, C., M.D. Morecroft, Y. Trisurat, R. Adrian, G.Z. Anshari, A. Arneth, Q. Gao, P. Gonzalez, R. Harris, J. Price, N. Stevens, and G.H. Talukdarr, 2022: Terrestrial and Freshwater Ecosystems and Their Services. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 197–377, doi:10.1017/9781009325844.004.

Pereira, H. M.; Martins, I. S.; Rosa, I. M. D.; Kim, H.; Leadley, P.; Popp, A.; van Vuuren, D. P.; Hurtt, G.; Quoss, L.; Arneth, A.; Baisero, D.; Bakkenes, M.; Chaplin-Kramer, R.; Chini, L.; Marco, M. D.; Ferrier, S.; Fujimori, S.; Guerra, C. A.; Harfoot, M.; Harwood, T. D.; Hasegawa, T.; Haverd, V.; Havlík, P.; Hellweg, S.; Hilbers, J. P.; Hill, S. L. L.; Hirata, A.; Hoskins, A. J.; Humpenöder, F.; Janse, J. H.; Jetz, W.; Johnson, J. A.; Krause, A.; Leclère, D.; Matsui, T.; Meijer, J. R.; Merow, C.; Obersteiner, M.; Ohashi, H.; Palma, A. D.; Poulter, B.; Purvis, A.; Quesada, B.; Rondinini, C.; Schipper, A. M.; Settele, J.; Sharp, R.; Stehfest, E.; Strassburg, B. B. N.; Takahashi, K.; Talluto, L.; Thuiller, W.; Titeux, N.; Visconti, P.; Ware, C.; Wolf, F. & Alkemade, R. Global trends and scenarios for terrestrial biodiversity and ecosystem services from 1900to2050 Science, 2024, 384, 458-465

Ranasinghe, R., A.C. Ruane, R. Vautard, N. Arnell, E. Coppola, F.A. Cruz, S. Dessai, A.S. Islam, M. Rahimi, D. Ruiz Carrascal, J. Sillmann, M.B. Sylla, C. Tebaldi, W. Wang, and R. Zaaboul, 2021: Chapter 12: Climate change information for regional impact and for risk assessment. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. V. Masson-Delmotte, P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou, Eds., Cambridge University Press, pp. 1767-1926, doi:10.1017/9781009157896.014.

Roberts, M.J., et al., 2025: High-Resolution Model Intercomparison Project phase 2 (HighResMIP2) towards CMIP7. Geosci. Model Dev., 18, 1307–1332, 2025. doi:10.5194/gmd-18-1307-2025

Rosenzweig, C., J.W. Jones, J.L. Hatfield, A.C. Ruane, K.J. Boote, P. Thorburn, J.M. Antle, G.C. Nelson, C. Porter, S. Janssen, S. Asseng, B. Basso, F. Ewert, D. Wallach, G. Baigorria, and J.M. Winter, 2013: The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and pilot studies. Agric. Forest Meteorol., 170, 166-182, doi:10.1016/j.agrformet.2012.09.011.

Rosenzweig, C., Solecki, W., Romero-Lankao, P., Mehrotra, S., Dhakal, S., & Ali Ibrahim, S. (Eds.), 2018: Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network. Cambridge University Press. doi:10.1017/9781316563878.007

Roy I, Mliwa M, Troccoli A (2023), Important drivers of East African Monsoon variability and improving rainy season onset prediction, Natural Hazards, Springer, https://doi.org/10.1007/s11069-023-06223-3

Roy, I and Troccoli, A (2024) Identifying Important drivers of East African October to December rainfall season. Science of the Total Environment (STOTEN), Elsevier, https://doi.org/10.1016/j.scitotenv.2023.169615

Ruane, A.C., & Kozlowski, N. (2025). Climate Information Flow for Impacts and Adaptation (Version 6). Zenodo. https://doi.org/10.5281/zenodo.15888031.

Ruane, A.C., C. Teichmann, N. Arnell, T.R. Carter, K.L. Ebi, K. Frieler, C.M. Goodess, B. Hewitson, R. Horton, R.S. Kovats, H.K. Lotze, L.O. Mearns, A. Navarra, D.S. Ojima, K. Riahi, C. Rosenzweig, M. Themessl, and K. Vincent, 2016: The Vulnerability, Impacts, Adaptation and Climate Services Advisory Board (VIACS AB v1.0) contribution to CMIP6. Geosci. Model Dev., 9, 3493-3515, doi:10.5194/gmd-9-3493-2016.

Ruane, A.C., C. Rosenzweig, S. Asseng, K.J. Boote, J. Elliott, F. Ewert, J.W. Jones, P. Martre, S. McDermid, C. Müller, A. Snyder, and P.J. Thorburn, 2017: An AgMIP framework for improved agricultural representation in IAMs. Environ. Res. Lett., 12, no. 12, 125003, doi:10.1088/1748-9326/aa8da6.

Ruane, A.C., R. Vautard, R. Ranasinghe, J. Sillmann, E. Coppola, N. Arnell, F.A. Cruz, S. Dessai, C.E. Iles, A.K.M.S. Islam, R.G. Jones, M. Rahimi, D. Ruiz Carrascal, S.I. Seneviratne, J. Servonnat, A.A. Sörensson, M.B. Sylla, C. Tebaldi, W. Wang, and R. Zaaboul, 2022: The Climatic Impact-Driver framework for assessment of risk-relevant climate information. Earth's Future, 10, no. 11, e2022EF002803, doi:10.1029/2022EF002803.

Ruane, A.C., M. Phillips, J. Jägermeyr, and C. Müller, 2024: Non-linear climate change impacts on crop yields may mislead stakeholders. Earth's Future, 12, no. 4, e2023EF003842, doi:10.1029/2023EF003842.

Ruane, A.C, Dingley, B., & Turner, B. (2025). Community engagement during Impacts and Adaptation CMIP7 Data Request process. Zenodo. https://doi.org/10.5281/zenodo.15834319

Schneider, A., Friedl, M. A. & Potere, D. A new map of global urban extent from MODIS satellite data. Environ. Res. Lett. 4, 044003 (2009).

Schneider, A., Friedl, M. A. & Potere, D. Mapping global urban areas using MODIS 500-m data: New methods and datasets based on ‘urban ecoregions’. Remote Sens. Environ. 114, 1733–1746 (2010).

Seto, K. C. et al. Human settlements, infrastructure and spatial planning. Clim. Change 2014 Mitig. Clim. Change Contrib. Work. Group III Fifth Assess. Rep. Intergov. Panel Clim. Change (2014).

Simpson, C.H., Brousse, O., Ebi, K.L. *et al.* Commonly used indices disagree about the effect of moisture on heat stress. npj Clim Atmos Sci 6, 78 (2023). https://doi.org/10.1038/s41612-023-00408-0

Sweet, L.-B., I.N. Athanasiadis, R. van Bree, A. Castellano, P. Martre, D. Paudel, A.C. Ruane, and J. Zscheischler, 2025: Transdisciplinary coordination is essential for advancing agricultural modeling with machine learning. One Earth, 8, no. 4, 101233, doi:10.1016/j.oneear.2025.101233.

Staiger, H., G. Laschewski, and A. Matzarakis, 2019: Selection of Appropriate Thermal Indices for Applications in Human Biometeorological Studies. Atmosphere, 10(1), 18, doi:10.3390/atmos10010018.

Taylor, J. W., & Buizza, R. (2003). Using weather ensemble predictions in electricity demand forecasting. International Journal of forecasting, 19(1), 57-70.https://doi.org/10.1016/S0169-2070(01)00123-6

Thrasher, B., Wang, W., Michaelis, A. et al. NASA Global Daily Downscaled Projections, CMIP6. Sci Data 9, 262 (2022). https://doi.org/10.1038/s41597-022-01393-4

Tittensor, D. P.; Eddy, T. D.; Lotze, H. K.; Galbraith, E. D.; Cheung, W.; Barange, M.; Blanchard, J. L.; Bopp, L.; Bryndum-Buchholz, A.; Büchner, M.; Bulman, C.; Carozza, D. A.; Christensen, V.; Coll, M.; Dunne, J. P.; Fernandes, J. A.; Fulton, E. A.; Hobday, A. J.; Huber, V.; Jennings, S.; Jones, M.; Lehodey, P.; Link, J. S.; Mackinson, S.; Maury, O.; Niiranen, S.; Oliveros-Ramos, R.; Roy, T.; Schewe, J.; Shin, Y.-J.; Silva, T.; Stock, C. A.; Steenbeek, J.; Underwood, P. J.; Volkholz, J.; Watson, J. R. & Walker, N. D. A protocol for the intercomparison of marine fishery and ecosystem models: Fish-MIPv1.0. Geoscientific Model Development, 2018, 11, 1421-1442

Tittensor, D. P.; Novaglio, C.; Harrison, C. S.; Heneghan, R. F.; Barrier, N.; Bianchi, D.; Bopp, L.; Bryndum-Buchholz, A.; Britten, G. L.; Büchner, M.; Cheung, W. W. L.; Christensen, V.; Coll, M.; Dunne, J. P.; Eddy, T. D.; Everett, J. D.; Fernandes-

Salvador, J. A.; Fulton, E. A.; Galbraith, E. D.; Gascuel, D.; Guiet, J.; John, J. G.; Link, J. S.; Lotze, H. K.; Maury, O.; Ortega-Cisneros, K.; Palacios-Abrantes, J.; Petrik, C. M.; du Pontavice, H.; Rault, J.; Richardson, A. J.; Shannon, L.; Shin, Y.-J.; Steenbeek, J.; Stock, C. A. & Blanchard, J. L. Next-generation ensemble projections reveal higher climate risks for marine ecosystems . Nature Climate Change, 2021, 11, 973-981

Vanos, J.K., J.W. Baldwin, O. Jay, and K.L. Ebi, 2020: Simplicity lacks robustness when projecting heat-health outcomes in a changing climate. Nature Communications, 11(1), 6079, doi:10.1038/s41467-020-19994-1.

van Vuuren, D., O'Neill, B., Tebaldi, C., Chini, L., Friedlingstein, P., Hasegawa, T., ... & Ziehn, T. (2025). The Scenario Model Intercomparison Project for CMIP7 (ScenarioMIP-CMIP7). EGUsphere, 2025, 1-38.

Wang, B., J. Jägermeyr, G.J. O'Leary, D. Wallach, A.C. Ruane, P. Feng, L. Li, D.L. Liu, C. Waters, Q. Yu, S. Asseng, and C. Rosenzweig, 2024: Pathways to identify and reduce uncertainties in agricultural climate impact assessments. Nat. Food, 5, no. 7, 550-556, doi:10.1038/s43016-024-01014-w.

Wang, HY., Shen, SF., Chen, YS. et al., 2020 Life histories determine divergent population trends for fishes under climate warming. Nat Commun 11, 4088. doi:10.1038/s41467-020-17937-4

Williams, P. D., & Joshi, M. M. (2013). Intensification of winter transatlantic aviation turbulence in response to climate change. Nature Climate Change, 3(7), 644-648.

Williams, P. D., & Joshi, M. M. (2016). Clear-air turbulence in a changing climate. Aviation Turbulence: processes, detection, prediction, 465-480.

WMO, 2017: WMO guidelines on the calculation of climate normals. WMO-1203, 29 pp. https://library.wmo.int/records/item/55797-wmo-guidelines-on-the-calculation-of-climate-normals. ISBN: 978-92-63-11203-3

WMO, 2022. 2022 State of Climate Services: Energy. World Meteorological Organization (WMO). WMO No. 1301, 52pp., https://library.wmo.int/records/item/58116-2022-state-of-climate-services

Yu, Y., Mao, J., Wullschleger, S.D. et al., 2022: Machine learning–based observation-constrained projections reveal elevated global socioeconomic risks from wildfire. Nat Commun 13, 1250. doi:10.1038/s41467-022-28853-0

Zabel, F. and B. Poschold, 2023: The Teddy tool v1.1: temporal disaggregation of daily climate model data for climate impact analysis. Geophysical Model Development, 16, 5383–5399, doi: 10.5194/gmd-16-5383-2023

Zeyringer, M., Price, J., Fais, B., Li, P. H., & Sharp, E. (2018). Designing low-carbon power systems for Great Britain in 2050 that are robust to the spatiotemporal and inter-annual variability of weather. Nature Energy, 3(5), 395-403.

Zhao, L., Lee, X., Smith, R. B. & Oleson, K. Strong contributions of local background climate to urban heat islands. Nature 511, 216–219 (2014).

Zhao, L., Oppenheimer, M., Zhu, Q., Baldwin, J. W., Ebi, K. L., Bou-Zeid, E., Guan, K. & Liu, X. Interactions between urban heat islands and heat waves. Environ. Res. Lett. 13, 034003 (2018).

Zhao, L., Oleson, K., Bou-Zeid, E., Krayenhoff, E. S., Bray, A., Zhu, Q., Zheng, Z., Chen, C. & Oppenheimer, M. Global multi-model projections of local urban climates. Nat. Clim. Change 11, 152–157 (2021).

Zhang, K., Cao, C., Chu, H., Zhao, L., Zhao, J. & Lee, X. Increased heat risk in wet climate induced by urban humid heat. Nature 617, 738–742 (2023).

Zheng, Z., Zhao, L. & Oleson, K. W. Large model structural uncertainty in global projections of urban heat waves. Nat. Commun. 12, 3736 (2021).

Zurell, D.; Graham, C. H.; Gallien, L.; Thuiller, W. & Zimmermann, N. E. Long-distance migratory birds threatened by multiple independent risks from global change. Nature Climate Change, 2018, 8, 992–996