High-Resolution Earth System Global and Regional Modeling for Climate Assessment and Policymaking Require Advanced Computing Infrastructure

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Extremely high-resolution analyses with models of the Earth's climate system are needed to understand the impacts on a variety of sectors from recent and projected changes in climate resulting from human activities (e.g., from land use change and from the increasing levels of carbon dioxide and other heat trapping gases and particles in the atmosphere). Relevant impacts stretch across the fabric of human society and include human health, agriculture and food security, water resources, energy, transportation, urban systems and infrastructure, rural communities, indigenous communities, coastal regions, forests, ecosystems, and oceans and marine resources. Understanding these impacts are vital to assessing the needs for policymaking, including mitigation and adaptation considerations and emergency planning.

Global modeling studies of the changes in climate are needed at horizontal resolutions of at least 10-25 km across the planet and regional climate modeling studies (for a localized region like North America) at even higher resolution, perhaps more like 4-10 km. Although improvements in the representation of physical, chemical, and biological processes in the models are also important, high-resolution simulations are imperative because of the enhanced, detailed information they can give through better representation of orography and local processes, and resulting effects on synoptic scale weather structures across the planet. These studies are also needed for a range of time periods, for different assumptions of future human related activities, and for ensembles of model runs that allow scientists to better understand the role of natural variability. Such high-resolution modeling studies are likely to produce important findings that will further the understanding of climate change science, contribute to enhanced understanding of the resulting societal and ecosystem impacts, and provide insights for adaptation and mitigation policy-related analyses.

Still in its initial stages, CMIP6 (Coupled Model Intercomparison Project, phase 6) will be the next phase in the international coordination of special global climate modeling studies to analyze the past and projected future changes in the Earth's climate system. Since 1995, under the auspices of the World Climate Research Programme, CMIP has coordinated climate model experiments internationally, including the analysis and comparison of state-of-the-art climate model simulations to enhance understanding of the processes, mechanisms and consequences of climate variability and climate change. CMIP data sets promote and facilitate model validation and diagnosis of shortcomings, lead to improved understanding of key processes and feedbacks in the climate system, and enable evaluation of inter-model differences. As a result, CMIP has become the basis for the analyses of climate modeling studies in the international assessments of climate change by the Intergovernmental Panel on Climate Change (IPCC) and by national assessments such as the U.S. National Climate Assessment (NCA). Medium resolution climate models (e.g., about 1° latitude-longitude) or even lower resolution models were the basis for CMIP5 studies from about 40 models in the recent climate change assessments. The analyses of past, present, and future projections of climate from CMIP6 will provide important input into the next IPCC and NCA assessments as well as contribute extensively to impacts and policy related analyses. Our aim for CMIP6 is to have some global models run at as high a resolution as 1/4°

(25 km resolution). WCRP has organized a similar program called CORDEX for the coordination of regional modeling analyses that will also contribute to such assessments.

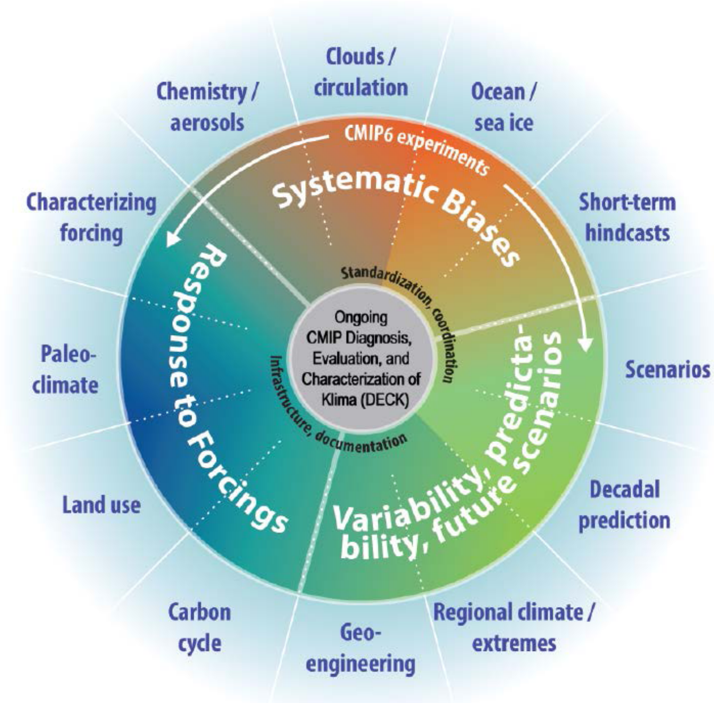

Figure 1. Schematic of the proposed experiment design for CMIP6. The inner ring and surrounding black text involve standardized functions of all CMIP, including ongoing Diagnosis, Evaluation, and Characterization of Klima (DECK) experiments (klima is German for "climate"). The middle ring shows science topics related specifically to CMIP6 to be addressed by the MIPs, with illustrative (and likely not complete) MIP topics shown in the outer ring. This framework is superimposed on the scientific backdrop for CMIP6—which encapsulate questions related to clouds, circulation, and climate sensitivity; changes in the cryosphere; climate extremes; regional climate information; regional sea level rise; and water availability (Meehl et al., 2014).

Over the rest of this decade and beyond, in addition to the many studies already needed as described above, advanced leadership-class computing infrastructures (e.g., NSF Track-1) will also be key to achieving even higher resolution for the atmosphere, eventually towards being able to fully represent cloud processes without parameterizations that add to current model uncertainties. The next generation goal is 1/8° (~12 km resolution), and improvements in methods would include atmospheric chemical tracers, indirect radiative balance, nested grids for regional impacts to properly calculate radiative heating rates dynamically within weather and climate models. We also need to increase the ocean/sea ice resolution to 0.1°, allowing for eddy-resolving ocean simulation within the modeling system. This resolution should enhance understanding of ocean feedbacks on climate and responses of the oceans to the changing climate. Striving for 1/16° (6 km) that resolve clouds should enhance understanding of seasonal prediction of water resources, and provide ultra fine-grain scale to tropical cyclones which would be highly beneficial to society.

Our studies have shown that a team comprised of both highly recognized experts in global climate modeling and analysis and experts in computer science and information technology are necessary to effectively using these advanced computational systems – these systems have become too complex for scientists to readily perform simulations in a turnkey manner. Comprehensive analysis and major revisions to the codes are necessary, including changing the core structure of the models in order to go to higher resolution for use on these systems.