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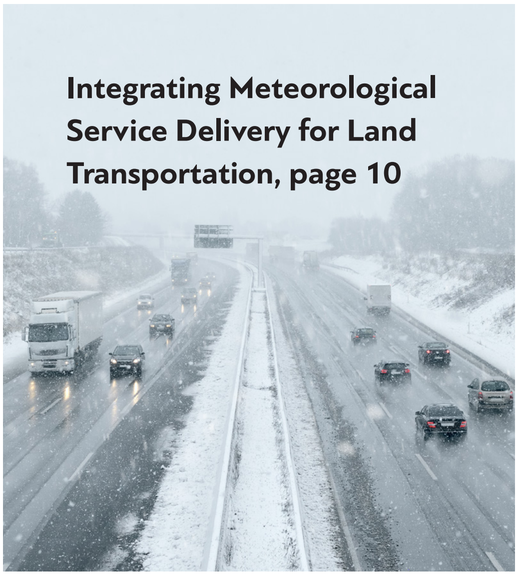
WEATHER CLIMATE WATER

(Un)Natural Disasters: Communicating Linkages Between Extreme Events and Climate Change



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Contributions to Climate Science of the Coupled Model Intercomparison Project

by David Carlson[1] and Veronika Eyring[2]

The World Climate Research Programme (WCRP) Coupled Model Intercomparison Project (CMIP) serves as a fundamental basis for international climate research. The process represents a remarkable technical and scientific coordination effort across dozens of climate modelling centres, involving some 1 000 or more researchers. A sequence of CMIP phases has underpinned and enabled a parallel sequence of Intergovernmental Panel on Climate Change (IPCC) Assessment Reports. The Fifth Assessment Report openly acknowledges a heavy reliance on CMIP phase 5. This brief overview of the design, intended capabilities and progress of the current sixth phase of CMIP (CMIP6) will demonstrate how it contributes to climate science.[3]

Motivation and benefits

Although model intercomparison projects now seem standard, the concept first arose when atmospheric modelling centres around the world started running coupled ocean and atmosphere models for climate. The need to share and intercompare outputs of those models was quickly recognized. But the tasks were easier said than done: a persistent organized set of protocols and mechanisms had to be defined along with a process to develop and support the coordination itself and the necessary intercomparison tools. In response, the WCRP Working Group on Coupled Modelling initiated CMIP. Early support from the Program for Climate Model Diagnosis and Intercomparison[4] (PCMDI) allowed CMIP to develop formats and standards and to establish effective mechanisms for model output availability.

Since 1995, CMIP has supported modelling centres and a broad range of model developers and users in the fundamental analysis and comparison of state-of-the-art climate model experiments under common protocols. While providing a useful and accessible basis for formal external assessments by IPCC and others, CMIP has, from the start, demonstrated two parallel benefits within the climate research community:

- Progress in the technical developments of the models themselves, fostered by exchange and intercomparison, and accompanied by agreed formats for exchange and metrics for intercomparisons;

- Ability to explore, in a systematic way through model diagnostics, ensemble means or careful cross-comparisons, specific scientific aspects of the climate system, from clouds to deep ocean circulation and the carbon cycle.

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1 Director, World Climate Research Programme, jointly sponsored by the Intergovernmental Oceanic Commission (IOC) of UNESCO (United Nations Educational, Scientific and Cultural Organization), ICSU (International Council for Science) and WMO

2 Deutsches Zentrum für Luft- und Raumfahrt

3 Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organisation by Eyring et al. (2015)

4 United States Department of Energy (DOE)

CMIP processes deliberately foster the sharing of hardware and software expertize and exchanges between model users and the research community. They have the additional valuable impacts of minimizing duplication of effort and reducing operational and computational resource demands. This is much appreciated by individual centres, as well as the collective community, in a resource-constrained environment.

CMIP6 Challenges

The need for CMIP and the challenges facing, in particular, CMIP6 have grown. More centres run more versions of more models, which are increasingly complex. A modern Earth system model might now have full atmospheric chemistry, active land processes – including vegetation growth and decay – and an interactive carbon cycle on land and in the ocean. It remains very challenging to run Earth system models with all amendments at highest resolution, but the list of necessary and desired model outputs for climate-related decision-making has grown enormously while basic resolution has improved.

Some configurations of CMIP6 models will run at global resolutions of 25 km, which is better than the regional resolutions of only a few years ago. Running these models requires enormous computational resources, while archiving, documenting, subsetting, supporting and distributing the terabytes (and increasingly petabytes) of model output challenges the capacity and creativity of the biggest data centres and fastest data networks.

In designing CMIP6, the CMIP Panel – an oversight group of international scientists – undertook a rigorous assessment of past performance and future needs. It listened carefully to customers, in this case, modelling centres and research users. Based on prior CMIP phases, particularly the increment from CMIP3 to CMIP5, it assessed which strategies and practices had aided or limited substantial progress in model skill and scientific understanding. From this consultation, the Panel defined five design goals for CMIP6:

- To facilitate relationships between and intercomparisons among various Model Intercomparison Projects within CMIP6 and to ensure consistency across CMIP phases;
- To enable the research community to provide modelling centres with a science-based priority outline of CMIP6 preferred activities;
- To allow modelling groups to implement self-determined development schedules and research experiments uncoupled from, but still relevant to, a single IPCC deadline;
- To strengthen overall Model Intercomparison Project activities by embedding them within a coherent scientific framework, leading to an enhanced collective outcome; and
- To achieve all of the above through an open and inclusive process.

The CMIP6 design as it evolves, and as implemented to date, achieves these goals through fundamental changes in process and procedure and by adopting the WCRP Grand Science Challenges[5] as an encompassing scientific framework.

Continuous and flexible operations

To avoid alternating haste and delay in the lead-up to a fixed deadline, CMIP6 allows modelling centres to implement improved model versions and to run various CMIP experiments as ready and as convenient. They can do so as long as they also complete and submit the Diagnosis, Evaluation, and Characterization of Klima experiments (DECK) and the CMIP6 historical simulation according to guidelines, as certification of their CMIP capabilities and intents and as "entry cards" to CMIP6.

For CMIP6, historical forcing datasets – including emissions and concentrations of greenhouse gases, land use changes, solar and stratospheric (volcanic aerosol, ozone) variations – became available in April 2016. This will allow modelling centres to start running CMIP6 entry card experiments very soon.

Forcing datasets for future climate projections will become available by the end of 2016 from the Integrated Assessment Modelling (IAM) community, allowing clim-

[5] www.wcrp-climate.org/grand-challenges

Members of the CMIP Panel

- Veronika Eyring (Chair, Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Centre))
- Sandrine Bony (Centre national de la recherche scientifique, (National Centre for Scientific Research), France)
- Jerry Meehl (National Center for Atmospheric Research, U.S.)
- Catherine Senior (MetOffice, United Kingdom of Great Britain and Northern Ireland)
- Bjorn Stevens (Max-Planck-Institute for Meteorology, Germany)
- Ron Stouffer (Geophysical Fluid Dynamics Laboratory, U.S.)
- Karl Taylor (Program for Climate Model Diagnosis and Intercomparison, U.S.)

ate projection experiments to start at that point. The majority of the CMIP6-endorsed Model Intercomparison experiments will occur during the period 2017–2018. Research based on analysis of the CMIP6 output will start to emerge in 2018–2020, in time to contribute to the IPCC Sixth Assessment Report.

Consistent and persistent model protocols

DECK and the CMIP6 historical simulation extend from the sound basis of prior CMIP phases. They are also very likely to represent exactly the experiments that most modelling groups use, or will use, to test and evaluate their newest model versions. Note that for the purpose of CMIP6, future climate began in 2015. We expect that the protocols for DECK and the CMIP historical simulation will remain quite consistent for future CMIP phases. In this way, rather than imposing performance or computational barriers, DECK and the historical simulation encourage consistency among models and across phases.

Improved standards and documentation

The push for improved standards and documentation arises internally due to the growing complexity of the models and externally in recognition that an increasing number of users outside the climate modelling community want access to CMIP data. CMIP works closely with the WCRP Working Group on Coupled Modelling Infrastructure Panel to establish and promulgate requirements, formats and specifications for output products, model and simulation documentation, and archival and access systems. These guidelines and standards, coupled with the long-term viability of the overall CMIP process, have allowed and encouraged the parallel evolution of data and evaluation infrastructure. One new effort will facilitate the execution of accepted analysis packages whenever an archive site registers a new CMIP product.

Routine use of these tools and diagnosis patterns will greatly facilitate systematic model evaluations as part of subsequent assessments. The CMIP standards and guidelines have also enabled a substantial data assembly effort, focused on gathering and converting observations and reanalysis products into accessible and CMIP-like formats for use in model evaluation. Both of these model evaluation efforts will broaden and accelerate during CMIP6. Fundamentally, these community-based CMIP tools and data sources encourage progress on model development and on scientific exploration.

Deliberate science focus

In the face of the increasing complexity of individual models, more versions running at more modelling centres and the share number of Model Intercomparison Projects within and outside of CMIP, the CMIP Panel wanted to ensure the dual roles of CMIP: to advance model development and to facilitate and advance climate research.

In evaluating more than 30 Model Intercomparison Projects proposed for CMIP6, the Panel considered the relevance of each to the three fundamental science questions of CMIP6:

- How does the Earth system respond to forcing?
- What are the origins and consequences of systematic model biases?

- How can we assess future climate changes given climate variability, predictability and uncertainties in scenarios?

These questions serve as the model improvement basis for seven WCRP Grand Science Challenges. The Panel merged, adjusted and revised the 30 proposals to come up with a "final" list of 21 CMIP6-endorsed Model Intercomparison Projects. All of these earned a commitment from 10 or more modelling centres, which committed to run all the top priority (tier 1) experiments specified by the Model Intercomparison Project and to produce all requested diagnostic outputs and information.

This convergence of Model Intercomparison Project goals with modelling centre commitments did not occur automatically or spontaneously. It is a clear signal that the CMIP process does, and will continue to, focus on highly relevant science questions extracted from, and contributing to, the WCRP Grand Science Challenges. Obviously, the Model Intercomparison Projects tailored their goals and requests to expected model capabilities and capacities, but through this process, modelling centres participated directly in designing the scientific focus and size of CMIP6.

To gain endorsement, and to help CMIP6 and the modelling centres set priorities and monitor progress, all of the Model Intercomparison Projects specify top priority tier 1 activities. Most also contain longer lists of optional and encouraged experiments. Working together with the IAM community, CMIP6 will specify Shared Socioeconomic Pathways with close (and quantitative) connection to the Representative Concentration Pathways of CMIP5. CMIP6 also takes a deliberate step towards improved communication with the assessments, adaptation and services communities through the establishment of a vulnerability, impacts and adaptation, and a climate services advisory board.

Available computing resources do not meet the full expected analytical and experimental desires of CMIP6. WCRP hopes that an orderly CMIP process encourages efficiency but also stimulates additional interest and resources. Circa 2011, Jerry Meehl of NCAR (National Center for Atmospheric Research) wrote that CMIP5 represented "the most ambitious coordinated multi-model climate change experiment ever attempted."

Today, the breadth and ambition of CMIP6 offers an extraordinary new standard of multidisciplinary climate science and a new level of coordination challenges.

Summary

CMIP6 envisions and encourages a consistent and persistent set of core activities, enhanced tools and mechanisms for access and analysis, and a simultaneously broad but focused scientific impact. It sets a notable example for inclusivity, for transparency and for open access of its information and products. It functions almost entirely through coordination, collaboration and cooperation. Although the meteorological community understands global (atmospheric) models and rapid exchange of high-quality data and model outputs, the CMIP endeavour almost certainly exceeds numerical weather prediction in complexity and data volumes.

Most of the coordination and collaboration occurs through the volunteered time of climate researchers. We know of no other community of models, modellers and researchers in the worlds of physics, medicine, economics, energy or weaponry, that puts such a large effort into intercomparison and exchange and which sustains such a remarkable effort through community motivation.

The CMIP response deserves appreciation and admiration within the scientific community. The breadth and ambition of CMIP6 offer an extraordinary new standard of multidisciplinary climate science and a new level of coordination challenges. As attention turns increasingly to the impacts of a changing climate, the CMIP process and products will represent one of society's most important sources of robust and reliable climate information.

References available in the online version.

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