REVOLUTION IN CLIMATE PREDICTION IS BOTH NECESSARY AND POSSIBLE

A Declaration at the World Modelling Summit for Climate Prediction

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Thanks to the assessments by the IPCC, the world recognizes that humans are contributing to a global climate change that is among the most important threats we face. The climate science community now faces a major new challenge of providing society with reliable regional climate predictions. Adapting to climate change while pursuing sustainable development will require accurate and reliable predictions of changes in regional weather systems, especially extremes. Investments of trillions of dollars worldwide may be necessary to avoid the worst consequences of climate change. Yet, current climate models have serious limitations in simulating regional weather variations and therefore in generating the requisite information about regional changes with a level of confidence required by society. Use of high-resolution regional models to downscale regional climate change is questionable if the global models from which lateral boundary conditions are prescribed are not realistic. In short, the limitations of current modeling methods are forcing the climate science community to consider fundamental changes in its approach to meeting the urgent demands of a concerned society.

In this context, the World Climate Research Programme (WCRP) held a World Modelling Summit for Climate Prediction on 6–9 May 2008 in Reading, England, to develop a strategy to revolutionize prediction of the climate to address global climate change, particularly at regional scales.

The primary emphasis of the summit was on the simulation and prediction of the physical climate system. Since advances in climate modeling and prediction build strongly on those in weather forecasting, and because the inclusion of biogeochemical cycles in longer-term projections of climate change requires improved representations of the physical system, the summit was cosponsored by the World Weather Research Programme (WWRP) and the International Geosphere–Biosphere Programme (IGBP).

The deliberations by about 150 scientists from a number of disciplines embarked from the notion of climate and weather as a seamless problem. As such, use of numerical weather forecasting methods can help quantify and reduce uncertainty in climate predictions. Taking advantage of this experience to meet the demands of regional climate change information will require confronting the increasing challenges of resolution, complexity, length and numbers of simulations, and assimilating observational data.

The Japanese experience of simulating global climate with horizontal resolution of 3.5–10 km has established the basis for wider experimentation with—and application of—very high-resolution models. Thus, the experts at the summit concluded that climate modeling will need—and is ready—to move to fundamentally new high-resolution approaches to capitalize on the seamlessness of the weather–climate continuum.

This impending revolution raises issues of parameterization, regional modeling, and the balances

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SUMMIT STATEMENT: THE CLIMATE PREDICTION PROJECT

1. Considerably improved predictions of the changes in the statistics of regional climate, especially of extreme events and high-impact weather, are required to assess the impacts of climate change and variations, and to develop adaptive strategies to ameliorate their effects on water resources, food security, energy, transport, coastal integrity, environment, and health. Investing today in climate science will lead to significantly reduced costs of coping with the consequences of climate change tomorrow.
2. Despite tremendous progress in climate modeling and the capability of high-end computers in the past 30 years, our ability to provide robust estimates of the risk to society, particularly from possible catastrophic changes in regional climate, is constrained by limitations in computer power and scientific understanding. There is also an urgent need to build a global scientific workforce that can provide the intellectual power required to address the scientific challenges of predicting climate change and assessing its impacts with the level of confidence required by society.
3. Climate prediction is among the most computationally demanding problems in science. It is both necessary and possible to revolutionize regional climate prediction—necessary because of the challenges posed by the changing climate, and possible by building on the past accomplishments of prediction of weather and climate. However, neither the necessary scientific expertise nor the computational capability is available in any single nation. A comprehensive international effort is essential.
4. The Summit strongly endorsed the initiation of a Climate Prediction Project coordinated by the World Climate Research Programme, in collaboration with the World Weather Research Programme and the International Geosphere–Biosphere Programme, and involving the national weather and climate centers as well as the wider research community. The goal of the project is to provide improved global climate information to underpin global mitigation negotiations and for regional adaptation and decision making in the twenty-first century.
5. The success of the Climate Prediction Project will critically depend on significantly enhancing the capacity of the world's existing weather and climate research centers for prediction of weather and climate variations, including the prediction of changes in the probability of occurrence of regional high-impact weather. This is particularly true for the developing countries whose national capabilities need to be increased substantially.
6. An important and urgent initiative of the Climate Prediction Project will be a world climate research facility for climate prediction that will enable the national centers to accelerate progress in improving operational climate prediction at all time scales, especially at decadal to multidecadal lead times. This will be achieved by increasing understanding of the climate system, building global capacity, developing a trained scientific workforce, and engaging the global user community.
7. The central component of this world facility will be one or more dedicated high-end computing facilities that will enable climate prediction at the model resolutions and levels of complexity considered essential for the most advanced and reliable representations of the climate system that technology and our scientific understanding of the problem can deliver. This computing capability acceleration, leading to systems at least a thousand times more powerful than the currently available computers, will permit scientists to strive toward kilometer-scale modeling of the global climate system, which is crucial to more reliable prediction of the change of convective precipitation, especially in the tropics.
8. Access to significantly increased computing capacity will enable scientists across the world to advance understanding and representation of the physical processes responsible for climate variability and predictability, and provide a quantum leap in the exploration of the limits in our ability to reliably predict climate with a level of detail and complexity that is not possible now. It will also facilitate exploration of biogeochemical processes and feedbacks that currently represent a major impediment to our ability to make reliable climate projections for the twenty-first century.
9. Sustained, long-term, global observations are essential to initialize, constrain, and evaluate the models. Well-documented and sustained model data archives are also essential for enabling a comprehensive assessment of climate predictions. An important component of the Climate Prediction Project will therefore be an accessible archive of observations and model data with appropriate user interface and knowledge-discovery tools.
10. To estimate the quality of a climate prediction requires an assessment of how accurately we know and understand the current state of natural climate variability, with which anthropogenic climate change interacts. All aspects of estimating the uncertainty in climate predictions pose an extreme burden on computing resources, on the availability of observational data, and on the need for attribution studies. The Climate Prediction Project will enable the climate research community to make better estimates of model uncertainties and assess how they limit the skill of climate predictions.
11. Advances in climate prediction will require close collaboration between the weather and climate-prediction research communities. It is essential that decadal and multidecadal climate prediction models accurately simulate the key modes of natural variability on the seasonal and subseasonal time scales. Climate models will need to be tested in subseasonal and multiseasonal prediction mode also including use of the existing and improved data assimilation and ensemble prediction systems. This synergy between the weather and climate prediction efforts will further motivate the development of seamless prediction systems.
12. The Climate Prediction Project will help humanity's efforts to cope with the consequences of climate change. Because the intellectual challenge is so large, there is great excitement within the scientific community, especially among the young who want to contribute to make the world a better place. It is imperative that the world's corporations, foundations, and governments embrace the Climate Prediction Project. This project will help sustain the excitement of the young generation, build global capacity (especially in developing countries), and prepare humanity to adapt to—and mitigate the consequences of—climate change.

required and/or implied between the use of available computing power for higher resolution on the one hand and the inclusion of complex biogeochemical processes on the other.

Much higher resolution of the major model components (e.g., atmosphere, ocean, and land) is a fundamental prerequisite for a more realistic representation of the climate system and more relevant predictions (e.g., extremes, convection, and tropical variability), and thus regional and local applications. Improving the basic model physics is also important, whether through observationally inspired development, much higher resolutions, or stochastic concepts. Among the many advantages of very high-resolution studies is the improvement of the prediction of the tropical climate and its variability. This would dramatically improve predictions for some of the most populated and poorest areas of the globe.

To achieve such advances, summit discussions converged on a proposal for a world Climate Prediction Project and associated climate research facility (see sidebar). The overwhelming view of the group was that the project must have a strong focus on the scientific aspects of climate prediction, and the facility should have the character of a scientific enterprise. Such a project could dramatically accelerate progress by focusing on experiments that are two or more generations ahead of national efforts and that cannot be carried out by individual centers. Among the features of the project would be:

- *Hardware*—Flexible hardware that can support research on developing models with much higher resolution is needed. The cost and power requirements for a multipetaflop climate computer are such that an "off the shelf" supercomputer could be sufficient for the community's needs. On the other hand, the use of probabilistic chips now in development might introduce stochastic processes into models at the chip level. A radical new design based on cell phone chip technology may also be of interest for climate modeling. These intriguing developments should be monitored, but tailoring a specific machine for a particular class of algorithm should not be emphasized, because the development cost is very high.
- *Software*—Because supercomputers of the next generation will contain millions of processors, new methods of highly parallel programming will be required. The project will require more software engineers in the field.
- *Models*—During the past 30 years, computational power has increased by a factor of 1 million, but the resolution of climate models has increased only by a factor of two. There are atmospheric GCMs currently in use at 50-km resolution that can run 1,000 times faster than real time. With the existing and projected technology, models with 25-km resolution are within reach in the next 3 years or so. However, multidecadal climate simulation with global nonhydrostatic cloud system resolving models of the atmosphere using 2–5-km grids (with comparable resolution in the ocean) are not likely to be attained within the next 5 years. As models reach 2–5-km-scale resolutions, they will generate aggregate output data on the order of hundreds of exabytes, stored at widely distributed modeling centers.

The summit tried to identify issues that required computing resources significantly beyond what is currently available. These grand (computational) challenges can be grouped into the following areas:

- *Process-based model evaluation*—The effects of using different cloud parameterizations and varying the parameters in those parameterizations should be evaluated not only against global-scale satellite data, but also against what is known about basic cloud processes. High-resolution model experiments are required for developing and testing parameterizations.
- *Data assimilation, analysis, and initialization*—The methods of data assimilation and initialization, which have been crucial for the success of numerical weather prediction, must be extended to coupled models to obtain physical consistency. Observing system experiments are required to develop rational strategies for defining the most effective and efficient data streams. Model bias must be reduced and corrected in assimilation.
- *Detection and attribution of climate events*—Do climate models correctly simulate major climate signals, and if not, how much is due to inherent unpredictability rather than model deficiencies? The mechanisms for observed climate signals should be well understood, and metrics that quantify the fidelity of climate prediction models should be defined, so that we can assess the reliability of climate predictions.
- *Ensembles*—Large ensembles of high-resolution simulations are required for the quantification of

forecast skill. This computing challenge is particularly acute at the decadal prediction scale.

The challenge of providing improved information on extremes and high-impact climate and weather variations requires a concerted, international response to significantly increased model resolution. While the proposal for a Climate Prediction Project intends to expedite computing capabilities of 2–3 orders of magnitude above what is currently available nationally, the summit underscored strong support for national centers and for maintaining model diversity—a healthy element of competition.

A global facility could provide substantial benefits to national activities by developing the next-generation numerical cores and by providing a significantly enhanced computing capacity to scientists around the world to perform climate predictions with a range of models at resolutions that are not possible using national facilities. A global facility can also provide a focal point for advanced computational science and support a program of training and capacity building for developing countries.

There was some limited discussion on how to obtain resources for the project. The private sector and nonprofit foundations were proposed as possible sources. The importance of stressing the global, humanitarian aspects was noted when making the case for new and substantial investment. Based on the summit deliberations, the theme leaders (B. Hoskins, J. Kinter, J. Marotzke, M. Miller, and J. Slingo), with substantial input from R. Hagedorn, T. Palmer, J. Shukla, and other members of the organizing committee (M. Beland, C. Bitz, G. Brunet, V. Eyring, C. Jakob, H. LeTreut, T. Matsuno, G. Meehl, J. Mitchell, A. Navarra, C. Nobre, V. Ramaswamy, D. Randall, and K. Trenberth), prepared a Summit Statement. To realize the revolution in climate prediction that is both necessary and possible, the Summit Statement proposes a Climate Prediction Project and a world climate research facility (see sidebar).