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The Socioeconomic and Environmental Benefits of a Revolution in Weather, Climate and Earth-System Prediction

A Weather, Climate and Earth-System Prediction Project for the 21st Century

(Note: This paper fulfils the 2007 priority action in Climate Task CL-07-01 implementation)

Abstract:

This document was prepared by scientists from the World Meteorological Organisation (WMO)-World Weather Research Programme (WWRP), World Climate Research Programme (WCRP), International Geosphere-Biosphere Programme (IGBP), and the natural-hazards and socioeconomic communities. It is intended to inform policy makers, national academies of science and users of weather, climate and environmental information of the urgent necessity for establishing a *Weather, Climate and Earth-System Prediction Project* to increase the capacity of disaster-risk-reduction managers and environmental policy makers to make sound decisions to minimize and adapt to the societal, economic and environmental vulnerabilities arising from high-impact weather and climate. This endeavor is comparable in scale to the Apollo Moon Project, International Space Station, Genome Project and Hubble Telescope, with a socioeconomic and environmental benefits-to-cost ratio that is much higher. It will provide the capacity to realize the full benefits from the observational, modeling, prediction and early-warning system components of the Global Earth Observation System of Systems (GEOSS) and to accelerate major advances in weather, climate and Earth-system prediction and the use of this information by global societies. Delivering the benefits from this ambitious endeavor will require building upon the Group on Earth Observations (GEO) as an international organizational framework to coordinate the proposed *Project* across the weather, climate, Earth-system, natural-hazards and socioeconomic disciplines. Moreover, it will require investments in: i) maintaining existing and developing new observational capabilities; ii) advanced high-performance computing facilities with eventual sustained speeds of more than 10,000 times that of the most advanced computers of today, linked to a network of research and operational-forecast centers and early-warning systems world wide; iii) education, science and technology transfer projects to enhance the awareness and utilization of weather, climate, environmental and socioeconomic information; iv) infrastructure to transition *Project* research achievements into operational products and services.

1 RATIONALE

The socioeconomic, environmental and health impacts of recent extreme weather and climate events, such as: i) the destructive flooding rains over India, China, England, and the United States and the simultaneous southeastern Europe severe heat wave and drought during the summer of 2007; ii) the devastation of New Orleans by Hurricane Katrina in 2005; iii) the deadly European heat wave of August 2003; iv) the persistent multi-decadal African drought that ravaged the semi-arid regions of the Sahel, demonstrate the vulnerability of modern humanity, economies, and the environment to high-impact weather and climate (Fig. 1). Effective mitigation of, and adaptation to, such events requires accurate prediction of the likelihood of changing weather and climate at global, regional and local scales, combined with enhancing the capacity of disaster-risk-reduction managers and environmental policy makers to utilize this information to make sound decisions that minimize the societal vulnerability, economic and environmental losses and that maximize economic opportunities arising from high-impact weather, climate variability and climate change.



Fig. 1: The socioeconomic and environmental impacts of hazardous weather and climate. *Upper left:* Brush fire in Macedonia during the south-eastern European summer heat wave of 2007. *Upper right:* The town of Upton-upon-Severn in Worcestershire, England was surrounded by water during the devastating flooding of July 2007. *Lower left:* Father and son in flood ravaged Bangladesh, 2007. *Lower right:* An Ethiopian goat herder leads his livestock through the dust in the desert where severe drought in East Africa has forced overgrazing, which destabilizes the soil.

We stand at the threshold of providing and responding to major advances in observations, analysis and prediction of high-impact weather and climate events, and the complex interaction between the physical-biological-chemical Earth system¹ and global societies. This opportunity arises from the notable progress in our ability to monitor and predict short-term weather hazards and climate variability and change, and the utilization of this information by disaster-risk-reduction managers and environmental policy makers. For example: i) short-term regional forecasts (hours to 3 days) prepared on spatial scales of a few kilometers are currently capable of predicting the occurrence of flooding rainstorms, air-quality emergencies, coastal storm surges, severe wind events, hurricane track and land fall, with reasonable skill; ii) global-weather prediction has advanced to the point that national weather centers routinely provide useful forecasts with a 5-day forecast accuracy comparable to the 2-day forecasts of 25 years ago, including ensemble prediction systems that provide probability estimates of their expected level of skill for a week or more; iii) climate projections of global temperature and precipitation distributions over timescales from seasons to centuries provide the scientific underpinning for international treaties to limit activities that contribute to the emission of carbon dioxide and other greenhouse gases; iv) consequent assessment models have become increasingly important tools in evaluating the socioeconomic and environmental benefits and outcomes of different decisions. These accomplishments represent some of the most significant scientific, technological and societal achievements of the 20th century.

Building on the advances in observing systems and predictive skill over of the past three decades, we foresee the potential for further major scientific breakthroughs that will enable governments to achieve a more effective mitigation of, and adaptation to, extreme weather and climate and to realize higher levels of societal, economic and environmental benefits. The high priority of expanding our weather, climate and Earth-system observation, analysis, and prediction capability is justified by both evidence of the increasing incidence of weather and climate extremes, as reported by the Intergovernmental Panel for Climate Change (IPCC, 2007) and by the ever increasing vulnerability of society, economies and the environment to high-impact weather, and climate variability and change. More than 75 percent of the natural disasters around the world are triggered directly or indirectly by weather and climate events.

The artificial distinction between weather, climate and Earth-system prediction, and the link with its socioeconomic and natural-hazards mitigation applications, is transitioning into a seamless suite of models applicable over all relevant decision-making spatial and temporal scales. Within this paradigm shift, socioeconomic and environmental demands are an integral component in the design and implementation of a new generation of science-based global to regional early warning systems that will enable major advances in mitigation and adaptation to daily through multi-decadal hazards of high-impact weather, and climate variability and change. In the same way that the atmosphere encompasses the Earth, the expertise to exploit further advances in observations, monitoring and prediction of the physical-biological-chemical Earth system and its interaction with the global socioeconomic system, resides across many nations, international organizations and diverse scientific disciplines. Advancing the skill of weather, climate and Earth-system prediction to enable sound decisions to minimize and adapt to the societal, economic and environmental vulnerabilities arising from high-impact weather and climate is a global enterprise for the 21st century.

¹ The Earth-system encompasses the atmosphere and its chemical composition, the oceans, land/sea-ice and other cryosphere components; the land-surface, including surface hydrology and wetlands, lakes; and short-time scale phenomena that result from the interaction between one or more components, such as ocean waves and storm surges. On longer time scales (e.g., climate), the terrestrial and ocean ecosystems, including the carbon and nitrogen cycles and slowly varying cryosphere components (e.g., the large continental ice sheets and permafrost) would also be considered to be part of the Earth-system.

2 RECENT PROGRESS

Global societies of today derive substantial benefits from weather and climate observations, analyses and predictions. These benefits include: i) early warning systems to assess risk and reduce vulnerability arising from weather, climate, and air-quality hazards; ii) weather, climate, and complex Earth-system prediction systems tailored for the specific needs of societal, economic and environmentally sensitive sectors, e.g., energy, water-resource management, health, air and water quality, transportation; agriculture, fisheries, leisure industries, ecosystems, biodiversity and national security; iii) quantitative measures of the probability of occurrence and potential severity of a given socioeconomic or environmental outcome. It is recognized that mitigation and adaptation strategies require predictions of the probability and uncertainty of occurrence of extreme events on both weather and climate time scales. The occurrence of extreme weather and climate events may be infrequent, but the consequences can be catastrophic to those societies and ecosystems affected.

Recent progress in the atmospheric, oceanographic, Earth-system, and socioeconomic sciences, observations, computer technology and global communication systems affords the opportunity to accelerate further advances in the accuracy of weather, climate prediction information and its utilization. These advances include: i) greatly expanded observations of the atmosphere, oceans, land and ice surface, including their bio-geochemical properties; ii) increasingly accurate weather, climate and Earth-system prediction models, aided by improvements in numerical methods, representations of physical processes, probabilistic (ensemble) prediction systems and the continuous increase in the capacity of high-performance computers; iii) advanced knowledge of the theoretical and practical limits of atmospheric and oceanic predictability, including the influence of climate variability and change on high-impact weather events; iv) the societal, economic and environmental utilization of weather, climate and Earth-system information to assess, mitigate and adapt to natural and human-induced environmental disasters.

3 CORE ELEMENTS OF AN INTERNATIONAL WEATHER, CLIMATE, AND EARTH-SYSTEM PREDICTION PROJECT

The core elements of an international *Weather, Climate and Earth-system Prediction Project* will build upon the above achievements (Section 2) and will include:

High-resolution observations and models – High-resolution observations and models of the atmosphere, ocean, land and biogeochemical processes that: i) monitor and predict the seamless interaction among weather, climate, the Earth system and global socioeconomics; ii) resolve the detailed properties of the atmosphere, oceans, land, ice, atmospheric composition, bio-geochemistry, and energetic oceanic eddies and boundary currents, with computational resolution consistent with the spatial scale of the applications (Fig. 2); iii) address daily, seasonal, inter-annual and multi-decadal prediction for short-term societal functions and long-term policy decisions; iv) provide scientifically-based assessments of the impacts of predicted changes and the actions required to mitigate them. This includes assessments of the potential consequences of emerging geo-engineering intervention hypotheses designed to modulate climate variability and change and associated high-impact weather.

High-resolution data-assimilation and analysis – High-resolution global and regional data-assimilation and analysis systems that enhance the utility of the full spatial and temporal resolution of observations from space, land/ice surfaces and oceans. This requires the development of advanced data-assimilation systems which incorporate weather, climate and Earth-system prediction models as an integral component in the analysis of the observations and so provide a sensor-integrated synergy for the monitoring, prediction and forecast verification of weather, climate, and biochemical properties of the Earth system.

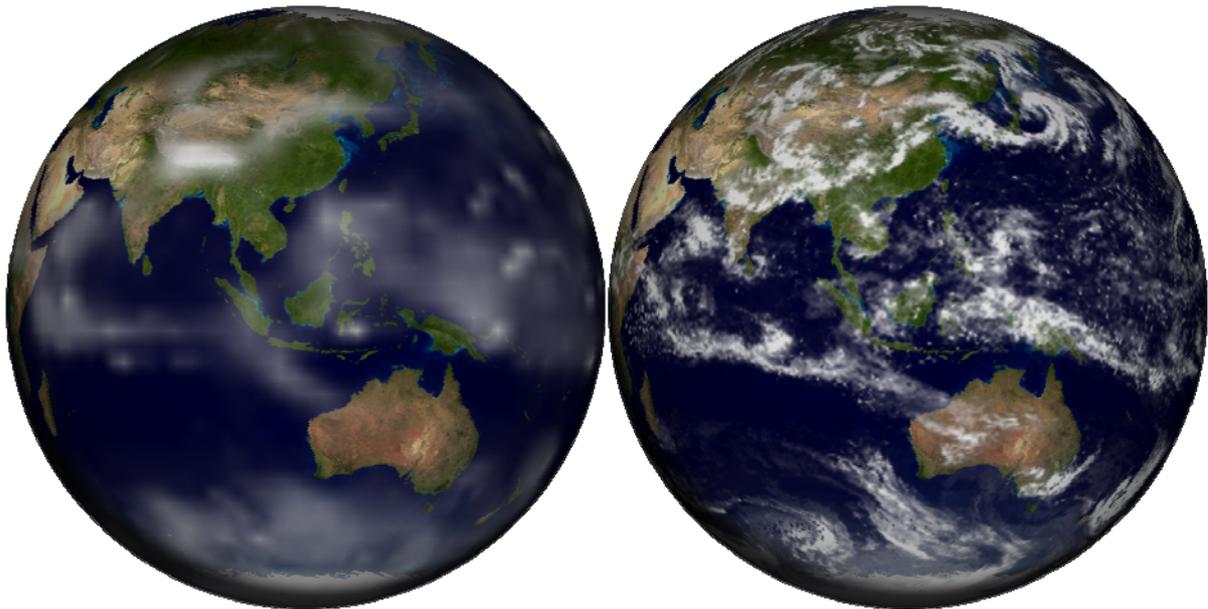


Fig. 2: An illustration of the limitation of present-day coarse-resolution, multi-decadal climate-projection models to resolve regional high-impact weather events routinely predicted by today's 14-day higher-resolution operational forecast systems. *Left panel*, global cloud distribution in a 320-km resolution climate simulation experiment. *Right panel*, same as left panel, but for a 20-km resolution simulation with the same model, comparable in resolution to the most advanced operational weather forecast models of today. The proposed *Project* will provide high-resolution climate models that capture the properties of regional high-impact weather events, such as tropical cyclones; heat waves; sand and dust storms, associated within multi-decadal climate projections of climate variability and change (Courtesy of Takeshi Enomoto, Earth Simulator Center/JAMTEC).

Advanced High-Performance Computing (HPC) capabilities – To enable the implementation of: i) next-generation weather, climate, and Earth system monitoring, assessment, data-assimilation, and prediction systems; ii) ensemble-prediction systems that include many possible projections for the future, thereby allowing probabilities of high-impact events to be deduced that are performed with high-resolution models for weather, climate variability, and Earth-system prediction; iii) long-term (multi-decadal) integrations for climate models with a high degree of Earth-system complexity for climate variability prediction and climate change projections. It is envisioned that these three elements (i-iii) will require access to dedicated HPC facilities with sustained speeds of at least 10,000 times that of the most advanced computers of today (achievable within 10-20 years), each supported by a critical mass of scientific and technical effort. Each facility could be supported by a cluster of countries with common interest in high-resolution prediction of weather, and climate variations and change. Advanced data processing, visualization methods, and user-friendly, high-speed and high-bandwidth, common data format, and integrated data-distribution system that allows access to most information in near real time are required to fully realize the research and operational benefits of the high-resolution analyses and predictions that will be generated by high-performance computing.

Data and forecast-information-system archive – Establishment of an internationally-coordinated weather, climate, Earth-system and socioeconomic data and forecast information-system archive that: i) provides universal access to observational, experimental and operational global data bases, commensurate with the highest resolution achievable, given near-term observational and computational constraints; ii) facilitates advanced analysis and visualization representations of observed and predicted weather, climate Earth-system events and their impacts.

Underpinning research – To improve the performance and application of models, thus providing the basis for better predictions with known confidence through improved knowledge of weather, climate and Earth-system processes and their past, present and future fluctuations and change. As an example, one of the foremost research challenges, with major implications for forecast capability, is to improve the ability of weather and climate models to initiate and maintain the organisation of precipitating cloud systems in the tropics on space-scales of thousands of kilometres and time-scales of hours to weeks. Underpinning research will also include: i) the diagnosis of observed weather, climate and Earth system phenomena using routinely analysed data and data from special multidisciplinary field campaigns; ii) performance and analysis of detailed numerical simulations of particular weather, climate and Earth system processes; iii) development and application of advanced data-assimilation methods; iv) performance and analysis of weather, climate and Earth system simulations and predictions; v) studies to assess and advance the socioeconomic use of advanced observations and prediction systems for weather, climate and the Earth-system.

Decision information – The production of information for policy makers and stakeholders is crucial in assisting critical decision-making processes regarding, adaptation to and mitigation of, weather and climate events, and sustainable development by exploiting advances in: i) forecasts of short-term weather hazards; ii) observations and analyses of changes that have occurred; iii) predictions of climate variability and change at the regional and local scale and of their inherent uncertainties, including predictions of the climatology of extreme events, e.g., tropical cyclones, winter storms, regional floods, droughts, dangerous air quality; iv) consequence assessment tools, which can utilize environmental, economic and social information to predict societal and environmental outcomes.

4 REQUIRED INVESTMENTS

Delivering the benefits from this ambitious endeavor will require building upon GEO as an international organizational framework to coordinate the proposed *Weather, Climate and Earth-system Project* across the weather, climate, Earth-system, natural hazards and socioeconomic disciplines, including the infrastructure required to support the *Project* elements described in Section 3. The effort will also require:

- Stemming the current decline in surface and upper-air global observing networks and the development and implementation of a new generation of *in-situ* and space-based observing systems to meet the ever-increasing observational demands of today's and future generations of prediction and early-warning systems.
- High-performance computing facilities with sustained speeds of more than 10,000 times the most advanced computers of today (achievable within 10-20 years), including advanced data-processing, information-distribution and visualization systems; each facility staffed with a critical mass of scientists and linked to a global network of research, forecast and early-warning centers.
- Education, science and technology transfer projects to enhance awareness and utilization of weather, climate, environmental and socioeconomic information.
- Infrastructure to transition *Project* achievements into operational products and services.

5 THE WAY FORWARD

The proposed *Weather, Climate and Earth-System Prediction Project* will be comparable in scale to the Apollo Moon Project, Genome Project, International Space Station and Hubble Telescope, with socioeconomic and environmental benefits-to-cost ratio that is much higher. It will provide the capacity to realize the full benefits from the observational, modeling, prediction and early-warning system components of GEOSS and to accelerate major advances in weather and climate prediction and their socioeconomic and environmental applications. It will require unprecedented international collaboration and good will, but the global scope of the problem makes this inescapable, as no single nation possesses the scientific capacity and infrastructure to meet the challenges set forth in this document. As nations, we have collaborated in the advancement of weather forecasting, climate prediction and global-observing systems. As the Group on Earth Observations, we must now extend this collaboration to embrace the Earth-system and the socioeconomic and environmental applications of our science. It is a task that must be undertaken.