EOS
EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 89 NUMBER 45
4 NOVEMBER 2008
PAGES 445–456

The Regional Climate Change Hyper-Matrix Framework

PAGES 445–446

The accurate assessment of the potential impacts of climate change on societies and ecosystems requires regional and local-scale climate change information. This assessment is critical for the development of local, national, and international policies to mitigate and adapt to the threat of climate change. Characterizing uncertainties in regional climate change projections (RCCPs) is therefore crucial for making informed decisions based on quantitative risk analysis.

However, information about fine-scale climate change and associated uncertainties is lacking due to the absence of a coordinating framework to improve the characterization of such uncertainties. Here we propose the inception of such a framework.

Uncertainties in Regional Climate Change Projections

Figure 1 depicts interactions across different RCCP uncertainty sources, which stem from the intrinsic nature of the problem as well as from imperfect knowledge and modeling [*Giorgi*, 2005]. The human dimension of these interactions yields a range of possible future pathways of greenhouse gas (GHG) emissions, land use change, and aerosols ("forcing scenario" uncertainty). For any pathway, the Earth's biogeochemical cycles will help to determine the ultimate forcing of the global climate system, which produces a large-scale climate response (e.g., changes in El Niño–Southern Oscillation or storm tracks) that is modulated by fine-scale climate factors (e.g., topography and land cover). The public perception of climate changes and their impacts (e.g., on water resources, food and energy security, health, and biodiversity) ultimately drives policy decisions, adding further uncertainty.

By F. Giorgi, N. S. Diffenbaugh, X. J. Gao, E. Coppola, S. K. Dash, O. Frumento, S. A. Rauscher, A. Remedio, I. Seidou Sanda, A. Steiner, B. Sylla, and A. S. Zakey

Different tools are used to produce RCCPs [*Giorgi et al.*, 2001]. Coupled atmosphere-ocean general circulation models (AOGCMs) simulate the large-scale (10^2–10^4 kilometer) response to GHG changes. This response can be downscaled to fine spatial scales (1–100 kilometers) via regional climate downscaling (RCD) approaches, including uniform and variable-resolution atmospheric general circulation models (GCMs), regional climate models (RCMs), and statistical downscaling (SD) techniques, with each approach yielding various uncertainties [*Giorgi et al.*, 2001].

For example, climate models produce different responses to the same GHG forcing due to varying dynamics and physics parameterizations ("model configuration" uncertainty). Different initial conditions can produce different responses to the same GHG forcing because of nonlinearities within the climate system ("internal variability" uncertainty). Further, different downscaling methods (e.g., RCMs versus SD) yield an "RCD approach" uncertainty. Finally, the climate system response is highly geographically dependent, which adds a further

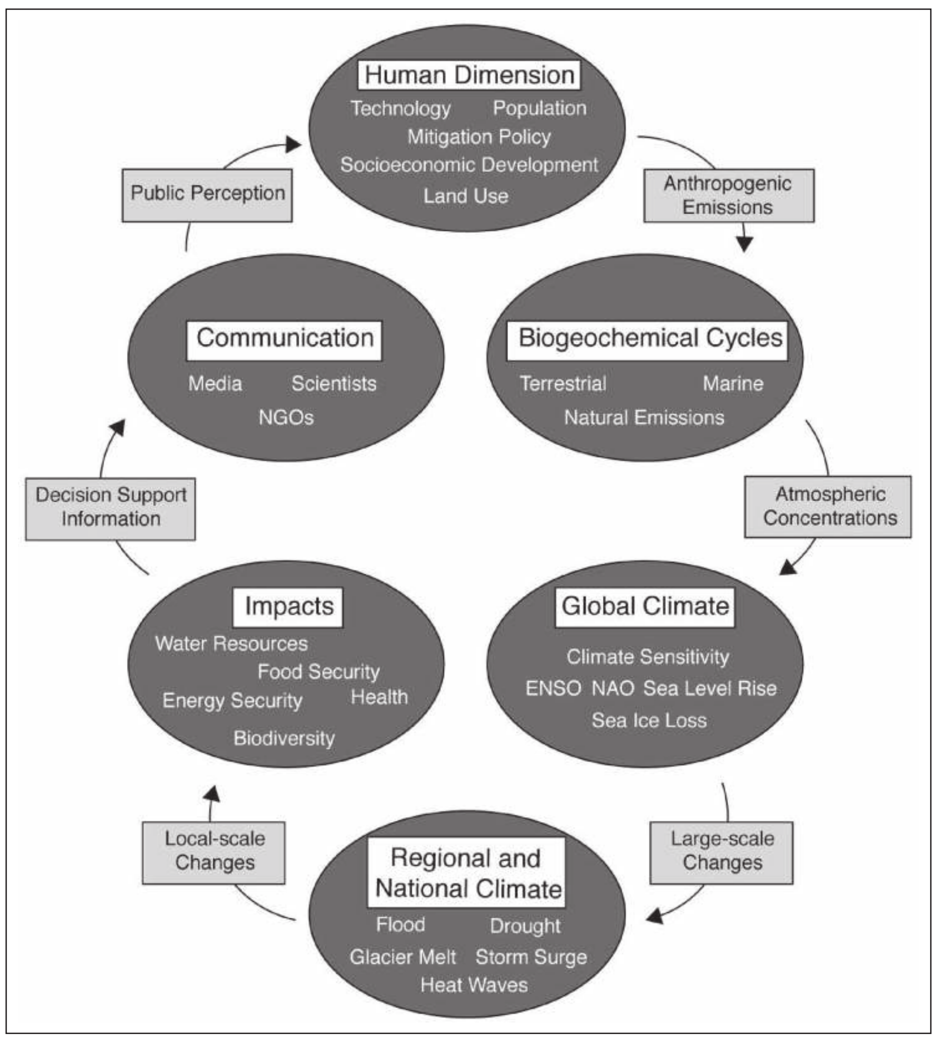

Fig. 1. Sources of uncertainty in regional climate change projections (RCCPs) and their connections.

level of regional uncertainty ("geographic uncertainty").

Previous work suggests that the forcing scenario and AOGCM configuration uncertainties dominate at the large scale [*Giorgi et al.*, 2001], while RCD configuration and approach uncertainties are more important at finer scales. The contribution of internal variability uncertainty remains relatively minor (Figure 2). It has long been recognized that the full characterization of regional climate change uncertainty requires large ensembles of experiments comprising multiple forcing scenarios, model configurations, initial conditions, and RCD approaches. To date, however, such fine-scale ensembles have been completed only for Europe [*Christensen et al.*, 2007]. Coordination is lacking for other regions, and existing projects [e.g., *Takle et al.*, 2007] have not provided a general framework for assessing RCCP uncertainties over multiple regions.

To help rectify this long-known problem, we propose the Regional Climate Change (RCC) Hyper-Matrix framework for systematically exploring multidimensional uncertainty in RCCPs (Figure 3). Dimensions are associated with geographic regions, forcing scenarios, and AOGCM and RCM configurations and initial conditions. A large multidimensional matrix—or "hyper-matrix"—of experiments is necessary to cover this uncertainty. While this matrix may be unfeasible given current knowledge and computing power, it is nonetheless useful to initiate a framework that can be incrementally populated.

First Phase of the Regional Climate Change Hyper-Matrix Framework

Our initial hyper-matrix framework is built on the Abdus Salam International Centre for Theoretical Physics (ICTP)–based regional climate network of scientists (RegCNET) [*Giorgi et al.*, 2006], the ICTP Regional Climate Model version 3 (RegCM3) [*Pal et al.*, 2007], and the AOGCM ensemble of the third phase of the Coupled Model Intercomparison Project (CMIP3) [*Meehl et al.*, 2007]. In the first phase of our project, we will investigate two of the largest sources of uncertainty. We will explore the geographic uncertainty dimension, with six continental-scale model domains (North and Central America, South America, Europe, Africa, Central Asia, and South and East Asia) at 25-kilometer grid spacing (a state-of-the-art resolution for long-term RCM experiments). We will then explore the AOGCM configuration dimension by sampling simulations with different AOGCMs from at least five models in the CMIP3 A1B scenario ensemble for RegCM3 boundary conditions.

In this first phase, we will focus initially on the near past (as a reference period and for model evaluation) and the near future (1980–2040), for which the scenario uncertainty is less relevant, and on the late 21st century/early 22nd century (2071–2100), for which the signal is larger [*Christensen et al.*, 2007]. The experiments and analyses will be conducted by RegCNET participants across the globe, thereby drawing on local knowledge and expertise. Targeted sensitivity experiments will explore other sources of forcing uncertainty, such as land use change and aerosols.

Expanding the Regional Climate Change Hyper-Matrix Framework

In this initial phase, our RegCNET-based effort necessarily covers a limited subspace (geographic and AOGCM configuration uncertainties) of the full RCC Hyper-Matrix. Figure 2 provides guidance for dimensions to explore in later phases. The scenario uncertainty is very important, and we plan to investigate it by sampling different scenario experiments from the CMIP3 data set and/or from new simulations generated for the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5). The RCD model configuration and approach uncertainties also contribute substantially to the overall RCCP uncertainty. These

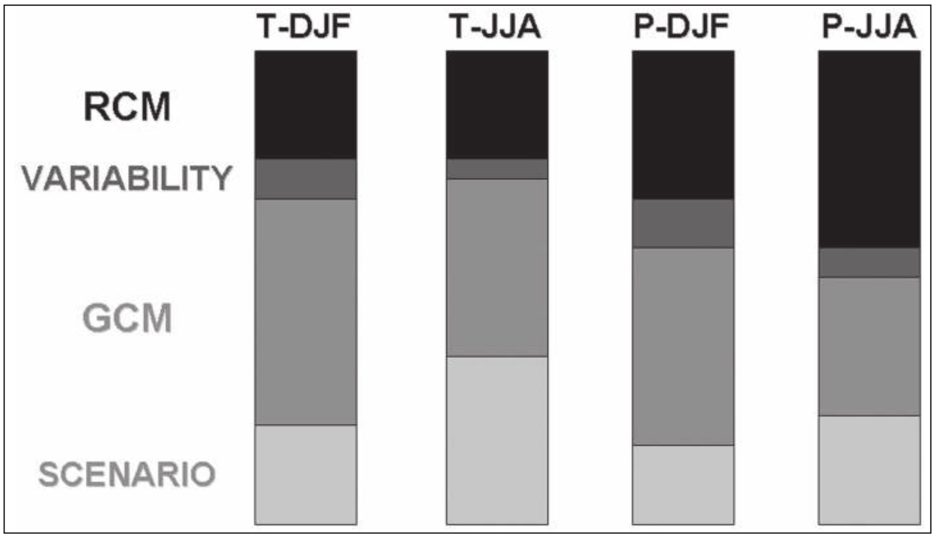

Fig. 2. Relative contribution of different sources to the uncertainty in the simulation of climate change over Europe as inferred from the Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects (PRUDENCE) ensemble of models. Black indicates use of different regional climate models (nine models). Dark gray indicates internal variability of general circulation models. Medium gray indicates use of different general circulation models (four models). Light gray indicates use of different scenarios (two scenarios covering about half of the Intergovernmental Panel on Climate Change scenario range). T is temperature; P is precipitation; DJF is winter; JJA is summer. Adapted from Déqué et al. *[2005].*

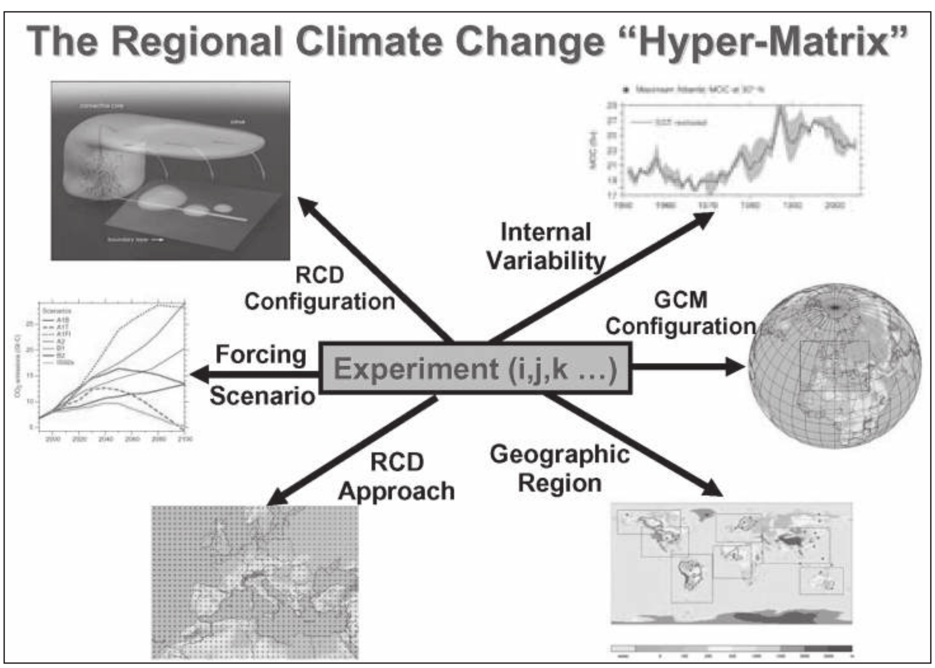

Fig. 3. Diagram of the proposed Regional Climate Change Hyper-Matrix framework. GCM is general circulation model and RCD is regional climate model. Original color image appears at the back of this volume.

uncertainties can be explored partially by running RegCM3 with different physics options or, optimally, by involving additional RCMs in the Hyper-Matrix framework.

We hope this framework will provide a template to facilitate the intercomparison of successive generations of RCD experiments performed with different models and approaches. As the RCC Hyper-Matrix is incrementally populated, the climate science community will be able to provide far more reliable quantitative information about future fine-scale climate change over different regions of the globe.

References

Christensen, J. H., et al. (2007), Regional climate projections, in *Climate Change 2007: The Physical Science Basis—Contribution of Working Group I to the IPCC Fourth Assessment Report*, edited by S. Solomon et al., chap. 11, pp. 847–940, Cambridge Univ. Press, Cambridge, U.K.

Déqué, M., et al. (2005), Global high resolution versus limited area model climate change scenarios over Europe: Quantifying confidence level from PRUDENCE results, *Clim. Dyn., 25*(6), 653–670.

Giorgi, F. (2005), Climate change prediction, *Clim. Change, 73*, 239–275.

Giorgi, F., et al. (2001), Regional climate information: Evaluation and projections, in *Climate Change 2001: The Scientific Basis—Contribution of Working Group I to the Third IPCC Assessment Report*, edited by J. T. Houghton et al., chap. 10, pp. 583–638, Cambridge Univ. Press, Cambridge, U.K.

Giorgi, F., et al. (2006), Introduction to the TAC special issue: The RegCNET network, *Theor. Appl. Climatol., 86*, 1–4.

Meehl, G. A., et al. (2007), The WCRP CMIP3 multimodel dataset: A new era in climate change research, *Bull. Am. Meteorol. Soc., 88*(9), 1383–1394.

Pal, J. S., et al. (2007), Regional climate modeling for the developing World: The ICTP RegCM3 and RegCNET, *Bull. Am. Meteorol. Soc., 88*(9), 1395–1409.

Takle, E. S., et al. (2007), Transferability intercomparison: An opportunity for new insight on the global water cycle and energy budget, *Bull. Am. Meteorol. Soc., 88*(3), 375–384.

Author Information

Filippo Giorgi, Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy; E-mail: giorgi@ictp.it; Noah S. Diffenbaugh, Purdue University, West Lafayette, Indiana; Xue J. Gao, National Climate Center, Beijing, China; Erika Coppola, Abdus Salam ICTP; Sushil K. Dash, Indian Institute of Technology, Delhi, India; Oscar Frumento, Centro National Patagonico, Puerto Madryn, Argentina; Sara A. Rauscher, Abdus Salam ICTP; Armelle Remedio, Manila Observatory, Manila, Philippines; Ibrah Seidou Sanda, University of Niamey, Niamey, Niger; Allison Steiner, University of Michigan, Ann Arbor; Bamba Sylla, Université Cheikh Anta Diop, Dakar, Senegal; and Ashraf S. Zakey, Abdus Salam ICTP

NEWS

Groups Call for Better Protection From Climate Change and Severe Weather

PAGE 446

With a newly elected U.S. president taking office in January, eight leading professional organizations in the field of weather and climate have called on the next administration and Congress to better protect the United States from severe weather and climate change. The groups' "transition document," which was provided to John McCain and Barack Obama, includes five recommendations to reverse declining budgets and provide tools and information that local and regional decision makers need in trying to prepare for weather- and climate-related impacts. The organizations also have been collecting from the community names that the next president should consider for key weather- and climate-related leadership positions in his administration.

The document, "Advice to the New Administration and Congress: Actions to Make Our Nation Resilient to Severe Weather and Climate Change," notes that the United States sustains billions of dollars in losses every year from disasters related to weather and climate, such as hurricanes, tornadoes, forest fires, floods, droughts, and snowstorms. More than a quarter of the U.S. gross national product (more than $2 trillion) is sensitive to weather and climate, according to the document. In 2008 alone, the country has experienced a record-setting pace of tornadoes, as well as many severe floods and wildfires.

Weather and climate risks can affect individual health and safety as well as the nation's economy, environment, transportation systems, and military readiness. "All 50 states are impacted by these events, and many of these events will be exacerbated by climate change," the document states.

The document was developed by the Alliance for Earth Observations, AGU, the American Meteorological Society (AMS), the Consortium for Ocean Leadership, the Consortium of Universities for the Advancement of Hydrologic Science, the National Association of State Universities and Land-Grant Colleges, the University Corporation for Atmospheric Research, and the Weather Coalition. Collectively, the groups represent thousands of scientists, technology specialists, public policy analysts, and other experts.

The document's five recommendations are as follows:

- Fully fund the nation's Earth-observing system of satellite- and ground-based instruments as recommended by the National Research Council.
- Greatly increase computing power available for weather and climate research, predictions, and related applications.
- Support a broad fundamental and applied research program in Earth sciences and related fields to advance present understanding of weather and climate and their impacts on society.
- Support education, training, and communication efforts to use the observations, models, and application tools for the maximum benefit to society.
- Implement effective leadership, management, and evaluation approaches to ensure that these investments are done in the best interest of the nation.

The organizations estimate that the recommendations would cost roughly $9 billion above the current federal investments being planned for 2010–2014.

"Our concern is that the United States is not preparing properly for severe weather or climate change because of declining research budgets and lack of attention to these threats over the past few years," said John Snow, dean of the College of Atmospheric and Geographic Sciences at the University of Oklahoma and cochair of the Weather Coalition's executive committee. "Adequate research funding is essential for improving our nation's ability to respond to severe weather events and for mitigating the impacts of climate change that will undoubtedly occur over the next several decades."

"Decision makers need information on how climate change will affect their local areas, but our community has been hampered by a lack of funding for more research, observations, and computing power to provide information at this local level," said AMS Executive Director Keith Seitter. "This information is also needed to help implement and monitor carbon emission reduction proposals like cap and trade, contribute to the development of a prosperous carbon-free economy (such as forecasting for wind and solar industries), reduce the uncertainties of climate change impacts that could have severe consequences for human civilization (such as rapid release of enormous amounts of carbon in a warming Arctic region), and provide for effective adaptation to climate change. Clearly, there is more science to be done."

The document, available at http://www.ucar.edu/td, provides detailed implementation guidance—including specific management actions and budget estimates—and a place to submit names of weather and climate leaders whom the next president should consider for his administration.

—JACK FELLOWS, University Corporation for Atmospheric Research, Boulder, Colo.; E-mail: jfellows@ucar.edu

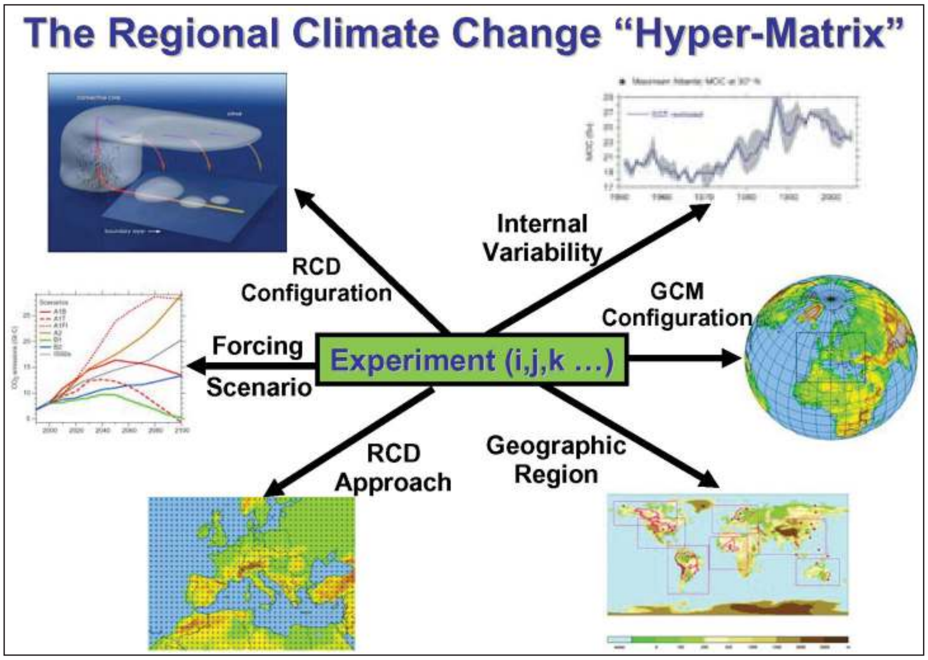

Fig. 3. Diagram of the proposed Regional Climate Change Hyper-Matrix framework. GCM is general circulation model and RCD is regional climate model.

Page 445