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.

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

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

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is highly geographically dependent, which adds a further 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., Table 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 uncer-
tainties 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 sci-
ence community will be able to provide far more reliable quantitative information about
future fine-scale climate change over differ-
ent regions of the globe.

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“Decision makers need information on how
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—JACK Fellows, University Corporation for Atmospher-
ic Research, Boulder, Colo.; Email: jfellows@ucar.edu

NEWS

Groups Call for Better Protection
From Climate Change and Severe Weather

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With a newly elected U.S. president tak-
ing office in January, eight leading profes-
sional organizations in the field of weather
and climate have called on the next admin-
istration and Congress to better protect the
United States from severe weather and cli-
mate change. The groups’ “transition docu-
ment,” which was provided to John McCain
and Barack Obama, includes five recom-
mandations 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 Admin-
istration and Congress: Actions to Make Our
Nation Resilient to Severe Weather and Cli-
mate 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 Advance-
ment 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 repre-
sent thousands of scientists, technology spe-
cialists, public policy analysts, and other

The document’s five recommendations are
as follows:
• Fully fund the nation’s Earth-observing
  system of satellite- and ground-based instru-
ments as recommended by the National
  Research Council.
• Greatly increase computing power availa-
  ble for weather and climate research, pre-
dictions, and related applications.
• Support a broad fundamental and
  applied research program in Earth sciences
and related fields to advance present under-
standing of weather and climate and their
impacts on society.
• Support education, training, and com-
  munication efforts to use the observations,
models, and application tools for the maxi-
mum benefit to society.
• Implement effective leadership, manage-
  ment, and evaluation approaches to ensure
that these investments are done in the best
interest of the nation.

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Ashraf S. Zakey, Abdus Salam ICTP

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