From Global Climate Projections to Regional Planning: Matching What Science Can Supply With Decision Maker Demands**

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Summary

Access to high-quality and comprehensible climate information is key if policy makers are to make well-informed decisions on a range of topics. When considering 21st-century climate projections, the multistep process of transferring and translating information and knowledge from the realm of large-scale climate science to regional scale impacts, or other policy-relevant interests, poses several scientific and communication challenges. Communication hurdles exist not only between scientists and policy makers, but also between different science and engineering communities. While transferring data sets is relatively simple, reliably translating knowledge across disciplines so that strengths, limitations, and contexts are appreciated is more difficult. However, such transfers are needed if a stakeholder's information demands are to be matched with an appropriate supply of credible climate information. The quality of climate information available to policy makers can benefit both from improvements in the upstream source (i.e., climate science advancements in general, and especially improved projections) and from improved mechanisms that support cross-disciplinary information and knowledge exchanges. Accordingly, one can envision an increased role for policy-neutral boundary organizations — multidisciplinary entities designed to enhance collaboration, understanding, and communications among and between researchers and decision makers.

Current realities

In recent years, advances in climate observations, scientific understanding, and computer models of our planet's global climate system have contributed to three broad findings about multidecadal climate trends on large spatial scales — findings that have placed the topic of climate change on many policy makers' radar. The three key science-based messages are: (i) multiple lines of observational evidence detect that Earth's climate is warming; (ii) analyses of observations and models show that significant amounts of change in several observed large-scale climate features can be attributed to human activities; and (iii) climate model projections indicate that, for most plausible future greenhouse gas emissions scenarios, human-induced climate change will continue during the 21st century, quite possibly at a rate greater than that seen during the 20th century. The climate science community has delivered these messages in several forms, including international and national assessment reports, as well as statements and publications from numerous national academies and professional societies.

In some policy-making circles, the realization that past climate records alone are not necessarily reliable guides for the 21st century has led to demand for more specific information about future climate projections, including guidance regarding uncertainties. Currently, whether, and to what extent, the climate science community is able to supply credible information to meet the specific demands of various decision-making groups differs greatly. In the climate impacts arena, information sought from climate projections often vary by the application of interest (e.g., significance for agriculture, water resources, human health, ecosystems, national security). These projections also depend on the geography and the time line being considered. Even among those interested in how climate variations and trends impact Arizona's water resources, the relative importance of changes in multiyear averages, seasonality, or extreme events can differ greatly, and hence the requirements for climate information and guidance differ as well.

Global Climate Models (GCMs) are complex computer programs that simulate the Earth's threedimensional climate system (i.e., the physical atmosphere, ocean, land, and ice components, and increasingly, elements of the biosphere). GCMs are physics-based scientific tools used to generate climate projections on time scales extending over centuries. Originally developed as research tools, today's GCMs are used to advance climate science understanding and for decision-support purposes. Developing and running state-of-the-art GCMs requires multidisciplinary scientific teams and some of the most advanced, high-performance computing capabilities available. A 2012 National Research Council (NRC) report identified three global climate modeling efforts in the U.S., with similar groups existing in approximately 10 other nations. Additional climate modeling efforts, smaller in scope and often focusing on regional climate, exist at universities and other institutions.

Sources of uncertainty in GCM projections include, but are not limited to, questions about the rate that greenhouse gases will be emitted into the atmosphere over time and how the climate system will respond in detail to a given emissions scenario. An expression of these uncertainties is evident in the range of results generated by different combinations of GCMs and future emissions scenarios. While a large number of data files derived from dozens of climate model projections are freely available, for many climate impacts studies undertaken to support regional decision-making, the information contained in GCM output files is deemed inadequate due to a lack of spatial detail or systematic biases. Using GCM data files as input, a variety of processing methods referred to collectively as "downscaling" can be applied to generate climate projection products designed to be more suitable for climate impact studies. However, the dilemma for those seeking projections to aid in a decision-making process often is not the lack of projections, but rather "how to choose an appropriate data set, assess its credibility, and use it wisely."

Scientific opportunities and challenges

Significant challenges exist regarding the effective transfer and translation of high quality, policy-relevant climate science information from the realm of large-scale climate science to various decision-making applications. To provide policy makers an opportunity to make well-informed decisions, there is a need to better match an appropriate supply of credible climate science information with policy-relevant demands. Data servers and high-speed Internet connections allow large volumes of data to be shared, but data file transfers alone are insufficient to bridge transdisciplinary knowledge gaps. But to whom does the responsibility of filling those gaps fall?

Just as it is unrealistic to expect users of climate projections to become experts in the strengths, weaknesses, uncertainties, and nuances of climate model projections, it is likewise unrealistic to expect climate scientists to learn enough about various user needs to provide detailed guidance for particular applications. Within the U.S. government, some relatively modest department- or agency-level efforts exist that aim to enhance the use of climate science information in decision-making via the establishment of boundary organizations that straddle aspects of research, communications, and policy (e.g., U.S. Department of Interior Regional Climate Science Centers, National Oceanic and Atmospheric Administration Regional Science Integration and Assessments Program, U.S. Department of Agriculture Climate Hubs). The 2012-2021 strategic plan for the interagency U.S. Global Change Research Program encompasses aspects of this effort under the banner of advancing science and informing decisions. Efforts by universities, professional societies, and public and private sector entities similarly aim to initiate or encourage transdisciplinary dialogue and information exchange on climate science and policy issues. As noted in the 2012 NRC report, "addressing the wide spectrum of user climate information needs is outpacing the limited capacity of people within the climate modeling community."

Additional challenges include determining how enhanced information and knowledge exchange capabilities can be pursued without detracting from critical, ongoing climate science R&D efforts. Some climate scientists are wary of being perceived as being too closely linked to policymaking efforts, lest the scientist's objectivity be drawn into question.

Policy issues

The following items can contribute to developing a balanced portfolio that advances the production of high quality, policy-relevant climate science information while simultaneously promoting the effective communication to allow well-informed policy decisions.

- **Cross-disciplinary communications regarding policy-relevant climate projections:** This item is consistent with the 2012 NRC report's statement citing "the need for qualified individuals who can provide credible information to end users based on current climate models, wherever they work (public or private sector)." Key elements include collaborative development of boundary organizations capable of bridging gaps between decision-makers and climate scientists as well as between scientists and engineers in different disciplines. Promoting coordination among multiple boundary organization efforts could enhance consistency and reduce duplication of efforts. The rigorous implementation of policy-neutral practices could bolster the credibility of the process.

- **Development of the next generation of policy-relevant climate projections**: The climate modeling community continually seeks to improve climate model projections, especially on the regional spatial scales of interest to many stakeholders (e.g., the representation of El Niño in the tropical Pacific and the North American monsoon that have been linked to Arizona's precipitation). In the U.S., pursuit of this goal depends on the availability of advanced computing resources and personnel associated with the nation's major global climate modeling efforts, as outlined in the 2012 NRC report. Additionally, the downscaled climate projections used in many decision-support studies have not been analyzed as much as have the GCM projections from which they are derived. This suggests that increased efforts to systematically assess this less-studied segment of the climate information exchange chain could potentially reap sizable benefits.

- **Foundational climate science research and development:** The topic of human-induced climate change became a noteworthy policy issue only after decades of climate science research. Such foundational research was and continues to build upon several activities that are not directly associated with generating future climate projections. They include: gathering, improving and analyzing observations; developing and testing theories of how the myriad components of the climate system interact; and creating numerical models of the climate system (i.e., virtual Earths) that allow scientists to perform experiments that cannot be done in the real world. Improved policy-relevant projections and advancing the understanding of uncertainties will continue to depend upon broad-based advancements in climate science.

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