CLIMATE LITERACY AS A FOUNDATION FOR PROGRESS IN PREDICTING AND ADAPTING TO THE CLIMATE OF THE COMING DECADES

by Amy Clement, Ben Kirtman, and Anna Pirani

There is general scientific consensus that because of increasing anthropogenic greenhouse gases the world will be warmer and sea level will be higher, on average, by the middle of this century. However, although there may be robust projections for anthropogenic influence in a particular region, it is entirely likely that the climate in any given year or even decade between now and midcentury could be quite different from the projected anthropogenically forced trend because of natural fluctuations of the Earth system unrelated to greenhouse gases. Given these dual natural and anthropogenic influences on climate, how can society (from the individual to the corporate scale) best adapt and plan mitigation strategies on these different time scales?

Researchers developing climate prediction systems, studying decision-making processes, and

WORKSHOP ON PREDICTING THE CLIMATE OF THE COMING DECADES

WHAT: Leading climate scientists met with stakeholders whose activities are inherently sensitive to predictions of climate variability to foster active dialogue and collaboration that will help prepare us for Earth's changing climate over the coming decades

WHEN: 11–14 January 2010

WHERE: Miami, Florida

developing applications of climate information convened a meeting at the Rosenstiel School of Marine and Atmospheric Science of the University of Miami to discuss three general topics: 1) the status of decadal climate prediction efforts, 2) assessing user needs of decadal time-scale climate information, and 3) constraints on decision making. This meeting was one of a series of workshops that took place throughout 2009 and 2010 within the climate science community that addressed different and complementary aspects of the decadal prediction problem (see www.clivar. org/organization/decadal/decadal.php). Here, we summarize the main points made during presentations and discussions for each of these topics and suggest ways forward in preparing for the climate of the coming decades. Presentations from the

workshop are available online (at www.clivar.org/rsmas_decadal.php).

STATUS OF DECADAL CLIMATE PREDICTION EFFORTS.

The decadal prediction problem represents a new "frontier" in climate modeling that includes a great deal of scientific uncertainty. The grand challenge of decadal climate prediction is to quantify sources of climate predictability on interannual to decadal time scales and to provide probabilistic regional forecasts with sufficient skill for planning and decision-making purposes. Overall, although there is considerable optimism that decadal predictions may provide useful information, significant challenges remain and the community as a whole recognizes the importance of emphasizing realistic expectations in terms of both what is currently achievable and the challenges that lie ahead. These include understanding the sources and mechanisms of decadal variability, quantifying and identifying sources of uncertainty including the limit of predictability, and detecting and attributing the forced signal of anthropogenic radiative forcing from low-frequency natural climate fluctuations. In terms of designing decadal prediction systems, issues include determining how to design observational networks for forecast initialization and monitoring, how to measure forecast skill in light of the limited observational record, what are the best initialization strategies for decadal prediction, and how to address model biases during initialization. Crucially for users of decadal prediction information, the major concerns are how to develop models of the climate system that provide information that can be used at regional scales as well as in application models and how much additional regional predictive skill can be obtained by resolving regional natural decadal variability mechanisms in addition to the climate change produced by changes in external forcing.

ASSESSING USER NEEDS FOR DECADAL CLIMATE INFORMATION.

Many different sectors, including insurance, water resources, agriculture, and public lands and marine ecosystems, are highly sensitive to climate variability on different time scales. In each of these sectors, there are existing tools for decision making in which climate information is explicitly included, most commonly for seasonal to interannual applications. However, there are decisions in many sectors that require a longer temporal perspective, and information about decadal climate fluctuations and anthropogenic climate change can become economically valuable by informing climate-sensitive decisions.

The insurance industry, for example, needs climate information to quantify the long-term risks of climate change and climate variability. This sector is well positioned to influence how society engages in adaptation measures that will reduce its vulnerability to climate fluctuations and extreme events, whatever the cause. Government can assist in using such insurance mechanisms to reduce losses associated with climate change by, for example, incorporating climate information into building codes or investing in natural infrastructure as a buffer to climate change. However, these measures can only be effective if premiums reflect risk and are not subsidized.

Water resources managers in many regions are faced with large decadal time scale swings in hydroclimate. Managers have developed operational guidelines in which climate information can be used. Water planners have developed partnerships (such as the U.S. Water Utility Climate Alliance) to assess the impact of climate on their natural resources. Agriculture is another sector that can be strongly affected by decadal climate fluctuations. Farmers are interested in climate information, but determining how this gets used at the farm level then scaling up to the regional level—such as how aggregate land use impacts occur as individual farmers respond to decadal climate fluctuations—is quite complex.

Public lands and marine ecosystem managers are responding to climate change with various approaches. The U.S. National Parks Service, for example, uses a "strategic framework" for long-term planning that allows a wide range of climate-related scenarios. Monitoring has also been emphasized, and there are ongoing projects that monitor climate-related variability and changes on land (the National Park Service Vital Signs Network) and in the ocean [National Oceanic and Atmospheric Administration's (NOAA) Coral Reef Watch]. Additionally, advances in biophysical modeling are important in evaluating and attributing the possible impacts of climate change on marine ecosystems.

CONSTRAINTS ON DECISION MAKING.

Decision science is the study of how individuals and groups make decisions utilizing probabilistic information. This field has a long history in anthropology, psychology, and economics but has more recently been applied to environmental decision making. The way that information is interpreted and used is complex because of individual cognitive biases as well as conflicting group social goals, and this can lead to unexpected outcomes. Another set of challenges involves cognitive biases in processing information. Research on "low probability–high

impact" events, such as hurricanes, has shown that, even when the public is quite savvy about weather information, people tend to misinterpret the information and underinvest in a response. This is a particular challenge for decadal time-scale climate fluctuations where the "trial and error" mode of learning is not particularly robust. One clear challenge is gaining a better understanding of how individuals and groups weight (or "discount") future events in terms of trading off short- and longer-term gains and losses. This has major implications for designing better information products and processes for decision making.

SYNTHESIS/OUTLOOK. The science of decadal climate prediction is still in its early days. Although it is clear that there is a gap between the information that people need and what the scientific community can currently provide, there is the opportunity to develop applications that use decadal climate information in collaboration with stakeholders. Involvement of the end users from the start of the process of developing climate services is essential to gain trust, focus on the right information for decision making, and develop mechanisms for feedback between different communities.

A major recommendation that emerged from the workshop was that the efficacy of such an engagement depends on the advancement of "climate literacy." We define climate literacy in the most general sense to include both scientific and public understanding of the causes and consequences of climate change on different time scales (see sidebar). A framework in which there is a focus on climate literacy across disciplines would help increase societal resilience to climate fluctuations on any time scale.

CONCLUSIONS. Although much of this work is ongoing and can in effect continue quite indepen-

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DEVELOPING CLIMATE LITERACY

There are a number of key elements that need to be understood to effectively communicate climate change at a level everyone understands:

Climate models are tools for climate literacy to assess the potential for and sources of predictability on decadal time scales and for attribution studies, because users of climate information have a need to have some understanding of the causes of climate change as well as whether they are natural or anthropogenic.

Climate observations are important in a number of ways. The global observing system is essential for establishing the initial conditions for climate model prediction studies, as well as for climate monitoring. The latter is important for detecting climate change but also for assessing the range of variability in a given region. Additional research is needed to assess the optimal configuration for such an observing system. Paleoclimate archives are a key element here because there are climate fluctuations at a number of different time scales, many of which are not fully covered by the modern instrumental record.

Transparency in communicating uncertainty (i.e., in detailing both the limits and usability of information as well as describing overall uncertainty levels) needs to be clear to maintain standards for proper use and interpretation of climate model predictions.

Decision science can be effectively used to establish better guiding approaches for incorporating climate information into decision making. Institutional frameworks and educational products can be developed for "robust decision making" that induces decision makers to consider implications of a range of decisions across multiple time scales, which may reduce some of the more pervasive biases that occur.

Partnerships in the long term to achieve all of the above, as well as user involvement from the onset in product and program design, are required.

Metrics should be in place from early on to learn how well we are doing at using climate information and to identify problems that we can learn from.

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dently, there is perhaps an opportunity to coordinate, or "package," these elements for application. There has been much discussion of climate services at many levels of government. The findings of this workshop indicate that developing partnerships that include forecasting as one element of a broader climate literacy strategy could be an important part of that effort.