"Predicting the Climate of the Coming Decades: A Workshop Summary and Directions for Research"

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There is general scientific consensus that, because of increasing anthropogenic greenhouse gases, on average, by the middle of this century, the world will be warmer and sea level will be higher. However, because of natural fluctuations of the Earth system unrelated to greenhouse gases, the climate of each successive year may not be warmer than the previous one. Thus there may be clear and robust projections for anthropogenic influence in a particular region, but it is entirely likely (perhaps probable) that the climate in any given year or even decade between now and mid-century could be quite different from the projected anthropogenically forced trend. Given these dual 'natural' and anthropogenic influences on climate, how do we best plan on these different timescales?

To begin to tackle this inherently interdisciplinary challenge, we convened a workshop at the Rosenstiel School of Marine and Atmospheric Science of the University of Miami on January 11-14, 2010. The goal of the workshop was to bring together academics and practitioners who have shared interests in predicting the climate of the coming decades. This included researchers who were involved in developing climate prediction systems, studying decision making processes, developing applications of climate information, regional resource managers, and representatives from the insurance industry. This cross disciplinary approach to climate prediction and use is becoming increasingly important as the nations of the world develop national climate services. Presentations covered three general topics: (1) status of decadal climate prediction efforts, (2) assessing user needs of decadal timescale climate information and (3) constraints on decision making. Here we summarize the main points made during presentations and discussions for each of these topics (all presentations and a list of participants can be found at http://www.clivar.org/organization/decadal/rsmas_decadal/rsmas_talks.php), and suggest ways forward in preparing for the climate of the coming decades.

Status of decadal climate prediction efforts:

The decadal prediction problem represents a new 'frontier' in climate modeling. There is currently relatively high understanding and predictability at the seasonal to interannual timescales. On the longer end, we have a fairly good understanding of how the Earth will respond to greenhouse gas forcing, and have made projections of anthropogenic climate change that are generally consistent with the observed 20th century trends. The decadal timescale is a challenge because it contains both elements of natural fluctuations and anthropogenic change. This is largely uncharted territory in terms of climate prediction and includes a great deal of scientific uncertainty.

A number of presentations addressed the status of efforts to predict climate on a decadal timescale. There is currently a world-wide effort to examine whether including information about the present state of the climate (oceans, land, atmosphere and cryosphere) can introduce some predictability in the 'near-term' (i.e. the coming decades). This is coordinated through the Coupled Model Intercomparison Project (CMIP5), and results will be included in the next scientific assessment of the Intergovernmental Panel on Climate Change (IPCC). Many of the modeling centers involved in this effort were represented at the meeting, including those from the US (IRI, GFDL, NCAR, COLA, U. Miami), Australia, UK (Hadley Center), and Canada. The presentations generally focused separately on predictability in the Atlantic and Pacific basins. In the Atlantic, the source of predictability is thought to come from the Atlantic Meridional Overturning Circulation (AMOC) of the ocean. In some of the models, this produces patterns of the surface temperature of the North Atlantic basin, which may affect hurricanes, rainfall over North America and temperatures over much of Europe. In fact some presentations showed that experimental decadal prediction being made today indicate modest skill. In the Pacific, much of the discussion focused on the Pacific decadal oscillation, which, for example, has been shown to impact water resources in the western US.

While many of the talks focused on well known "modes of variability" (e.g., AMOC, PDO …), it was also recognized that much of the potential sources of predictability reside in capturing the thermal inertia associated with ocean heat content, and that predicting these modes of variability still requires additional mechanistic understanding. Overall the presentations suggested considerable optimism for decadal predictions that have useful information, yet significant scientific challenges remain and the community as a whole recognized the importance of emphasizing realistic expectations in terms of both what is achievable and that there are difficulties that lie ahead. These challenges include:

- Understanding the sources and mechanisms of decadal variability
- How to measure of skill in light of limit observational record
- How to quantify and identify the numerous sources of uncertainty including the limit of predictability
- Distinguishing between forced and natural variability
- How to best design observational networks for both forecast initialization and monitoring decadal variability
- How to develop models that provide information that can be used at regional scales and used in application models

Assessing user needs for decadal climate information:

Another set of presentations focused on the needs of various user groups for climate information. Several different sectors were discussed, including: insurance, water resources, agriculture, and public lands and marine ecosystems. In each of these sectors, there are existing tools for decision making in which climate information on different timescales can be explicitly included. In some cases these tools are already in use to incorporate climate predictions on seasonal to interannual timescales. However, there are decisions in many sectors that require a longer temporal perspective and therefore information about decadal climate fluctuations and anthropogenic climate change could become useful. Here we briefly summarize the key points of the presentations made in different sectors. A more thorough discussion of user needs that was compiled as part of the World Climate Conference 3 can be found at (http://www.wcc3.org/wcc3docs/pdf/WS9_WP_needs.doc.).

Several presenters noted that the insurance industry can play an important role in encouraging people to engage in adaptation measures that will reduce their vulnerability to climate fluctuations and extreme events, whatever the cause. One mechanism that was discussed was 'long-term' flood insurance in which insurance is tied to property and not individuals, and would hence encourage home improvement to reduce the vulnerability of a property to the impacts of flooding. Government can also play a role in using 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. A common concern that was reiterated was that premiums should reflect risk (not be subsidized). As such, there is a need for climate information in order to aid in quantification of the long-term risks of climate change and climate variability.

Water resources managers in many regions are faced with large decadal timescale swings in hydroclimate. Two examples raised in the meeting were South Florida and the American Southwest. In Florida, precipitation amounts are known to fluctuate with Atlantic Ocean temperatures, and GHG forcing is likely to influence water resources both through changes in precipitation and also through sea level rise. Managers have developed operational guidelines in which climate information can be used. For example, the South Florida water management district uses a decision tree in which a multi-seasonal outlook can be used to make discharge decisions. This outlook indicates whether coming years/decade will be 'wet to very wet' or 'dry to normal.' Western water planners also contend with large decadal timescale fluctuations in hydroclimate, and the possibility of GHG gas induced drying. There is an extremely wide range of stakeholders that use common resources and a complex terrain. Water planners have developed partnerships in order to assess the impact of climate on the resource, an example of which is the Water Utility Climate Alliance.

Agriculture is another sector which can be strongly affected by decadal climate fluctuations. One example presented at the meeting was farming in Argentina. There are large decadal fluctuations in soil moisture, causing conditions to range from semi-arid conditions to near complete inundation. Farmers there are interested in climate information, but determining how this gets used at the farm level and then scales up to the regional level is quite complex. Researchers are developing models ('social simulation') to analyze this, including what aggregate land use impacts may occur as farmers respond to decadal climate fluctuations. These models are intended to provide a framework for assessing the use and utility of climate information in decision-making.

Public lands and marine ecosystem managers are responding to climate change with various approaches. The U.S. National Parks Service, for example, has taken on the issue of long-term planning for climate change by using a 'strategic framework.' Such a framework allows one to examine a wide range of possible scenarios in the most important and most uncertain phenomena. An example was given of climate change scenarios for future sea level rise (moderate to significant) and storm activity (status quo/decreased frequency to increase frequency and intensity), and the possible effects on a barrier island. It seems clear that decadal swings in climate (unrelated to GHG forcing) could also be incorporated into these scenarios. Monitoring was also emphasized, and there are ongoing projects on land (National Park Service Vital Signs Network) and in the ocean (e.g. NOAA's Coral Reef Watch). Presentations also showed advances in bio-physical modeling which is an important in evaluating and attributing the possible impacts of climate change on marine ecosystems.

Constraints on decision making

Another area of focus was decision science, which 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 only recently been applied to environmental decision making with concerted focus. Many of the examples drew on experiences from application of forecasts of seasonal to interannual information (eg, El Nino) and extreme events (eg, hurricanes). A number of presenters pointed out that the way that information is interpreted and used is complex because of individual cognitive biases as well as conflicting group social goals, and can lead to unexpected outcomes. These "surprises" may result from the strategic use of uncertainty for private or political gain by one group over another. Another set of challenges revolves around cognitive biases in processing information. One example given is hurricane predictions. Research on these 'low probability- high impact' events has shown that, even when the public is quite savvy about weather information, people tend to misinterpret the information, under-invest, learn slowly, and forget quickly. This is a particular challenge for decadal timescale climate fluctuations where our 'trial and error' mode of learning is not particularly robust. Several presenters also emphasized the important role for media in the exchange of information between the scientific community and the public. An important consideration in this is trust in the provider of information, which the media has, in the past, both helped to establish and also played a role in its reduction. One clear challenge is gaining a better understanding how individuals and groups weight (or "discount") future events in terms of trading off short and near term gains and losses. This has major implications for designing better information products and processes for decision making.

Examples of tools that incorporate climate information into decision support systems were provided from work being done in agriculture (NOAA's Regional Integrated Scientific Assessments) and small scale insurance in developing countries (IRI and Center for Research on Environmental Decisions). These efforts emphasized the need to work on developing these decisions tools with the end users from the start of the process in order to gain trust, focus on the right decisions, and develop a continuous feedback loop.

Synthesis/Outlook:

Given the state of the science of decadal climate prediction, it seems clear that there is a gap between the information that people need (and are increasingly requesting), and what the scientific community can currently provide. Thus it appears to be premature to develop specific applications using decadal climate predictions. However, it is not premature to engage these communities, and one theme that emerged from the workshop was that a primary objective of this engagement could be simply to start to develop '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 timescalses. A focus on climate literacy would provide a more robust framework for developing resilience to climate fluctuations on any timescale. The findings presented at the meeting suggest that there are a number of key elements in developing climate literacy, which are described below:

- ***Climate models*** can be used as tools for climate literacy in a number of different ways. Firstly, models can be used to assess the potential for, and sources of predictability on decadal timescales. This research is already ongoing in a coordinated fashion. Models can also be used to do attribution studies since users of climate information have a need to have some understanding of the causes of climate change, and whether they are natural or anthropogenic.
- ***Climate observations*** have a role to play in a number of ways. First, observing networks for the ocean, atmosphere and cryosphere are essential for establishing the initial conditions for climate model prediction studies. Additional research is needed to assess the optimal configuration for such a network, and how close (or far) we are from having such a network. The second is for monitoring. This is important for detecting climate change, but also for assessing the range of variability in a given region. A key element in this is paleoclimate archives, since there are climate fluctuations at a number of different timescales, many of which are not fully covered by the instrumental record.
- ***Decision Science*** can play a role in establishing better guiding approaches for incorporating climate information into decision making. Institutional frameworks and educational products can be developed for 'robust decision making' hat induces decision makers to consider implications of a range of decisions across multiple timescales may reduce some of the more pervasive biases that occur.

- To achieve all of the above, long term ***partnerships*** based on transparent presentation of the uncertainty in forecasts and data, and user involvement in product and program design is required.
- Finally, a system of ***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.

While much of this work is ongoing, and can in effect, continue quite independently, 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.