The status of climate projections and their impact on practice

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Climate projections and their impact on policy and practice

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Abstract

This paper examines the history and current status of climate projections and explores their implications for practice and policy, particularly concerning adaptation to climatic change. It focuses on two aspects of climate projections that critically shape their impacts on decision-making and on the outcomes of such decisions. First, it discusses uncertainty and its role in shaping not only the production of climate projections but also their use by policy-makers. We argue that uncertainty critically affects the way climate projections move from useful to usable. We distinguish between these two concepts by proposing that usefulness is defined by scientists' perception of users' needs and usability by users' definition of what knowledge can be readily applied to their decision process. Second, the review explores the implications of climate projections for adaptation policy using examples from the seasonal climate forecasts applications literature as an analog. We examine constraints and opportunities for their application in policy and practice and find that over-reliance on science and technical "solutions" might crowd out the moral imperative to other solutions aiming at improving livelihoods and ecosystems' long-term sustainability. We conclude that, in the context of high uncertainty, rather than 'perfect' forecasts, decision-makers should seek to implement knowledge systems that integrate climate projections with other kinds of knowledge concerning the multiple stressors that shape adaptation policy.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC-AR4) published in 2007 has labeled climate change "unequivocal" (1). Yet, despite growing evidence that the climate is changing, there is still significant uncertainty regarding how people, ecosystems and structures will experience these changes. Part of the problem remains in the high level of uncertainty surrounding the projections of the changes in the physical climate of the Earth for the coming decades, including how much and how quickly the Earth will warm, sea level will rise, and the weather will change. This uncertainty varies both across scales (geographical and temporal) and across systems (human, environmental and physical). Because the consequences of these changes can be devastating to social, biological and physical systems around the world, there is great motivation on the part of decision-makers, both in the public and private sectors, to understand and acquire information that can inform their decisions. Even with such high motivation, there is relatively little empirical evidence of how decision-makers use climate predictions[1] in practice and with what results. What there is, however, is a good deal of conjecture about the positive value of climate predictions, especially from climate scientists and forecasters (2, 3). This hopeful view of the value of predictions is understandable since people often make decisions in a "predict-then-act" mode, that is, we evaluate the risk of making a decision by considering the information available to us, drawing on previous experience, and weighing the alternatives against the urgency of our needs (4). By carefully evaluating risk, we try to maximize gain and minimize costs. Whereas the conditions under which people make decisions vary with scale and context, it is often the case that decision-makers act under great level of uncertainty (4, 5).

Figure 1 describes how projections of global warming motivate responses and provides the context for this paper. The graph, top left, is from the IPCC-AR4 and shows the projection of the global surface warming in the year 2100 for a variety of emission scenarios. It is used symbolically to represent the products of scientific investigation. There are two products. The first is the knowledge that the Earth will warm. The second is the uncertainty associated with that warming projection. On the one hand, when scientific knowledge, societal and/or personal values, and political will coherently align, there is motivation to respond to this knowledge. On the other hand, doing nothing is a realistic and likely response when those elements are absent or weakly organized. The uncertainty surrounding scientific knowledge can **always** be used by stakeholders to justify their positions. In practice, knowledge and uncertainty from scientific investigation is only one element from a myriad of other sources and types of knowledge that inform decision-making.

Although climate scientists continuously affirm their commitment to improve the relevance of their predictions to decision-makers, in practice, progress has been slow. In general, research-based knowledge falls within a *range of usefulness* that starts with scientists' desire to study different phenomena and problems, and ends with decision-makers' need to make critical decisions to address the problems revealed by those studies. Within this range, in one extreme scientists produce research-based knowledge but decision-makers do not use it (either because they do not know it exists or because of a myriad of other reasons that constrain its utility). In the other extreme, decision-makers adopt research-based knowledge and incorporate it in their decision process. The way a problem is framed and knowledge moves within this range depends on specific actions from scientists and decision-makers who seek to interact with each other. It also depends on institutions and resources that shape their ability to do so (6, 7). Moving research-driven information from useful to usable is not easy, has many practical implications for information producers and users and may critically influence policy-making. In the next sections, we examine a few of these implications focusing especially in each of the following factors:

> 1) While in science uncertainty is part of the process, in practice, it can make decisions more complex. In response to perceived users' needs, there has been a focus on developing more powerful and scaled down climate predictions; this drive to improve climate predictions has shaped both atmospheric and social scientists' research agendas. Whereas the focus on improving predictions and decreasing uncertainty has been a priority in research funding programs, understanding issues of usability and improving the fit to decision-making needs has received less attention (6).

> 2) Uncertainty and climate predictions' lack of skill have been frequently used to justify policy paralysis and inaction. One argument is that policy systems, when confronted with the steep costs (both financial and political) of preventive action, are much more likely to resort to a "wait and see" position when predictions are uncertain and have low skill in relation to decision-markers' perceived needs. Other limitations to practical use include institutional mismatch and constraints, competing issues, lack of resources, and faulty communication (for a more detailed discussion, see below).

> 3) As prediction science matures and both scientists and users become more aware of the constraints and possibilities of climate projections, a new opportunity framing has emerged that focuses on co-producing knowledge and policy through interaction between knowledge producers (scientists) and users (decision-makers). In this context, there is growing awareness that climate predictions are but one among many kinds of knowledge necessary to support decision about climate adaptation. As such, rather than a source of paralysis, predictions should be integrated to a broader array of relevant information within a decision situation.

Projections, prediction and the role of uncertainty

In this section, we briefly explore the history and nature of climate projections. In addition, we discuss the role and implications of uncertainty in the discovery and use of climate related knowledge. We argue that while in the world of policy uncertainty makes decision-making more complex, in science it is a motivation and intrinsic part of the process of study and discovery.

In his history of climate change prediction, Weart (7) points out that the basic projection that the Earth will warm in the presence of increasing greenhouse gases relies on physics that have been known for more than 200 years. We can calculate the heating of the Earth's surface—by gases that hold energy close to it, i.e. the greenhouse effect—with almost arbitrary accuracy for a gaseous atmosphere (8). Notable calculations and discussions of global warming prior to modern computationally-based model predictions included those by Arrhenius (9), Callendar (10) and Budyko (11). Hence, the history of climate change as a scientific problem is much older than its history as a social and public policy issue.

Predictions of weather and climate were one of the primary applications of early computers and remain a major application today. Weather and climate prediction still require the most powerful computers available and are limited by a lack of computational capacity and capability (3). The era of modern climate modeling can be traced to early models that were able to represent, explicitly, the transport of heat from equator to poles by the motions of the atmosphere and oceans (12). The response to incremental warming by greenhouse gases is complex because of the role of water as vapor, liquid, and ice. This complexity is in sharp contrast to the simple, underlying physics of greenhouse gas warming. This difference in complexity has important implications for policy because—while it was relatively easy to reach a consensus that climate is changing, it has been much more challenging for science to inform decision-makers about the character and magnitude of those changes.

At the global level, the Intergovernmental Panel on Climate Change (IPCC) is the main organization responsible for the assessment and dissemination of climate projections based on the scientific literature published in refereed journals. The Panel's process is well documented and transparent; in a recent review of its standards, Farber (13) argues that it raises the credibility of the projections of climate change above the normal standards of scientific research with enough certainty to have legal standing in the U.S. judicial system—something economic models have failed to accomplish so far.

The IPCC-AR4 basic projections of climate change for the year 2100 are summarized as follows:

> For the lowest projections of greenhouse gas emissions considered, the global average of the temperature at the surface of the Earth in 2100 will increase between 1.1 and 2.9 degrees centigrade. For the highest emission scenario considered, the temperature increase will be between 2.4 and 6.4 degrees centigrade.
>
> For the same emission scenarios, respectively as above, the global mean sea level will increase between 0.18 and 0.38 meters (lowest emissions) and 0.26 and 0.59 meters (highest emissions). The sea level rise predictions are qualified by the statement: "excluding future dynamical changes in ice flow."

The uncertainty associated with these predictions is an important quantity for determining whether the predictions are actionable information. Estimates of uncertainty are a fundamental product of scientific investigation on par with, in this case, the actual climate prediction. Indeed, uncertainty is in the language and culture of scientists, and its reduction is often posed as a motivation for new scientific research. Uncertainty is, however, hard to define and its quantification difficult to calculate. In the short and deceptively straightforward summary above, there are already four different nuances of uncertainty:

> The range of temperatures and sea level rise expresses uncertainties in the prediction of parameters intrinsic to the physical climate. These uncertainties are related to the formulation of climate models and evaluation of model performance with observations.
>
> The range of greenhouse gas emissions expresses uncertainties in our knowledge of the amount of greenhouse gases that will be emitted due to the enterprise of humans. These uncertainties are strongly tied to human behavior.
>
> The qualification of the sea level rise projections by the statement "excluding future dynamical changes in ice flow" expresses the fact that we know that there are processes in the climate models that are potentially important and poorly or unrepresented.

Farber's (13) argument represents a fourth evaluation of uncertainty. Namely, Farber concludes that the IPCC process increases the certainty of climate projections because its completeness and openness reduces the possibility of fundamental flaws in the conclusions of global warming. This type of external judgment is an important measurement of robustness of knowledge; it addresses the rhetorical question of, "Just how certain are you?" These distinct flavors of uncertainty just begin to span the spectrum of uncertainty that both scientists and decision-makers must face.

In the study of the Earth's weather and climate, the ability to predict what is going to happen is often used to verify the quality of knowledge or understanding of, for example, the atmosphere. The classic problem is weather prediction, in which a deterministic forecast is made of a set of environmental parameters. Temperature, pressure, wind, and rain are predicted for a particular place and a particular time and it is possible to verify these predictions with observations. There are uncertainties from a variety of sources in weather predictions, and these are communicated in, for example, probability of precipitation.

Whereas deterministic weather forecasts and simple statements of probability of precipitation are attractive to users, to the scientist, there is a far greater role that uncertainty can play in forecasting. One example is the concept of probabilistic predictions, where rather than a single deterministic forecast, ensembles of forecasts are used. These forecasts are combined with the idea that, in the least, the random component of the uncertainty can be reduced (14). In this case, uncertainty becomes a source of scientific information that provides a mechanism for improving the forecast, and potentially, the usability of the forecast. By investigating and managing uncertainty, a better forecast is generated. Based on this scientific practice, scientists have been motivated to provide more detailed information on uncertainty to increase its usefulness (15, 16).

These two types of forecasts, probabilistic and deterministic, provide brackets for the scientist. They lead to nuances in language; weather forecasts are often called predictions because of the deterministic nature of the problem. Estimates of how the climate will change are often labeled as projections or assessments, because deterministic forecasts of climate change are not formally possible. Nevertheless, as practitioners outside of the community of scientists use these projections, the word "prediction" is often used and the nuances based on the scientist's concept of uncertainty are lost.

The IPCC report recognizes the importance of uncertainty and discusses confidence and likelihood. Confidence is defined with well-known words like "very high" to mean 9 out of 10, "medium" 5 out of 10, etc. Something is "likely" to happen means there is a 66% probability of occurrence. These statements of uncertainty strive to incorporate the different sources and types of uncertainty that are suggested in the example of the IPCC predictions given above (17). In the world of relative uncertainties, it is safe to say that those associated with physical climate models are better known than the uncertainties due to greenhouse-gas emissions and socioeconomic impacts. The reason is that climate models are based on physics, which allows the investigation of cause and effect, supports predictions and can be verified with observations. The uncertainty related to known inadequacies, in the example above about the lack of dynamical ice sheet models, indicates known risks. The risks of the "unknown unknowns" are, yet, another type of uncertainty.

Returning more concretely to the IPCC projections – predictions of average surface warming and sea level rise are the most robust. The consistency of these predictions from one IPCC report to the next, on one hand, contributes to confidence that the physical processes in the models are reasonably represented. On the other hand, the fact that the range of the predictions does not get smaller with successive reports frustrates the users of climate predictions and the sponsors of climate research.

How precipitation will change and the impact of this precipitation on one region versus another is far less certain. Generally, as more and more spatial and temporal specificity are required, the less certain are the predictions. The impacts, that is, how climate change will affect social and ecosystems, agriculture, public health, etc. have a similar range of uncertainties dependent upon a different suite of complex factors.

When the IPCC-AR4 was published in 2007, there was nearly simultaneous publication of papers that expressed concern that the movement and melting of ice sheets had not been adequately included (for example, (18)). The overall perception was that the sea level rise could be much larger than predicted. This type of uncertainty, which follows from a known deficiency, exists for many reasons, ranging from a lack of knowledge, to overwhelming complexity, to theoretical assessments that the impact of the deficient process is small. When new knowledge shows that the process may be consequential or occur rapidly, there is an urgent reassessment of the reported uncertainty (see, for example: ice2sea, http://www.ice2sea.eu/ ; SeaRISE, http://websrv.cs.umt.edu/isis/index.php/SeaRISE_Assessment)

The prospect of rapid change from deficiently represented or unknown processes challenges the common view of climate change as a slow, incremental process that can be dealt with as it unfolds. There is evidence in the historical record and known processes that can lead to “abrupt” climate change. In many cases, the source of “surprises” in predictions is processes associated with phase changes of water. Recent examples are the roles of nitric acid and ice clouds in the Antarctic Ozone Hole and this decade’s rapid disappearance of sea ice (19, 20). In climate change science, researchers expect that fast melting of ice sheets and permafrost would lead to enormous impacts. These sources of uncertainty can be examined, quantified, and their risks and benefits assessed. Many of these considerations suggest that the IPCC estimates are “lower limits” rather than the best estimate of ranges (see, (13)). Addressing these uncertainties is an active discussion in the scientific community (see for example, Reducing the Uncertainty in the Prediction of Global Warming, http://www.as.huji.ac.il/workshops/global_warming/)

We are left, therefore, with daunting complexity in the quantification and specification of scientific uncertainty. We can conclude “unequivocally” that the Earth’s surface will warm due to increasing anthropogenic greenhouse gases. We can evaluate with similar confidence that this opens up risk of, for example, melting of ice sheets, which in turn, increases the risk of disruption to humans through rising sea level. Hence, we can assess the uncertainty well enough to know we need to reduce the emissions of greenhouse gases; that is, to motivate the development of mitigation policy. Yet, we still fall short from being able to inform policy-makers of how high the sea walls should be in the coastal areas of South America or the shores of the Cayman Islands.

Compared with mitigation policy, adaptation is far more complex. Adaptation is often reactive, regional, and dependent strongly on the specific application (for example, response to increased heat waves in cities, increased crop stress in savannah ecosystems, etc.). Many of the most critical socioeconomic, political and institutional determinants of vulnerability and adaptive capacity are poorly understood and assessments of the uncertainty associated with these processes are at their infancy. In adaptation, the challenges associated with the quantification and specification of uncertainty intersects with other sources of complexity that challenge the relationship between the scientist’s views of the usefulness of uncertainty and the decision-maker’s perception of usability.

In the next three sections, we examine the reasons behind the apparent disconnection between the expected potential value of climate predictions and the reality of inaction in preparing and offsetting climate-change-expected impacts. We then explore the implications of this disconnection to policy-making and, in particular, to adaptation action.

Useful, Usable, Desirable

We start by exploring the concepts of useful and usable and how they influence science, especially climate prediction production and use. In an environment of high uncertainty, high risk, no information or no previous experience, our ability to predict before we act can be very poor (4, 5). Often in these cases, the alternative is to adopt a wait-and-see approach, or inaction, until better information develops. Especially in the case of environmental policy-making, where many of the outcomes are irreversible or very difficult to correct (e.g. species extinction, lake eutrophication, etc), inaction can be, literally, the difference between life and death (21). The problem of climatic change, and its potential negative impacts, is among those in which the tradeoffs between uncertain predictions, evaluation of risk and inaction play a critical role in the ability of policy-makers to prevent, prepare and respond to these negative impacts.

We pose that there are two elements to the disconnection between the perceived usefulness of climate predictions and their lack of use in developing adaptation policy. First, there is a range of perceptions between what scientists assume and hope is useful and what decision-makers know is usable. For example, within the Climate Assessment for the Southwest (CLIMAS) funded by The National Oceanic and Atmospheric Administration (NOAA), early on scientists focused on the production of a regional climate forecast tool, which they perceived as meeting stakeholders' needs. However, subsequent interactions with potential users revealed that what decision-makers wanted was a forecast evaluation decision support tool in addition to the forecast itself (22, 23).

While the differentiation between useful and usable has been theorized in the literature (24), these two concepts have often been used interchangeably rather than characterized as distinct points along a range of usefulness. Within this range, the difference between useful and usable is a material quality—to borrow from the language of marketing, usefulness is about functionality and desirability; usability is about application and fit, that is, what scientists ideally perceive as useful may not be applicable or fit decision-making processes and decision environments in practice. For example, seasonal climate forecasts (SCFs) are, in principle, useful for farmers since knowing in advance about how much it is likely to rain or not, is a good thing in agriculture. However for a subsistence rain-fed farmer in Africa with no options in terms of alternative technologies, it is not usable (25). The same forecast, however, can be valuable to a resource rich irrigated farmer in Australia planning their investment to the following season (26). Based on empirical evidence from CLIMAS, Lemos and Morehouse (23, p. 62) define usable science as that which "directly reflects expressed constituent needs, should be understandable to users, should be available at the times and places it is needed, and should be accessible through the media available to the user community."

Second, moving prediction science from useful to usable may depend on: a) technical factors (e.g. formatting, timing, skill, etc); b) cognitive factors that influence they way users perceive the science-generated information (e.g. communication, trust, credibility, accessibility, experience, etc); and c) institutional factors that facilitate or impede the adoption of new knowledge (22, 23, 27, 28, 29, 30, 31, 32). As we have mentioned earlier, within a range of usefulness, production of knowledge, including predictions, spans from knowledge-driven science, to applied science and decision support tools. Users in turn will choose what fits their needs (including inaction) and opportunities to use information from basic research to decision-support tools. On the one hand, the intervention of different mechanisms and the resolve of teams of interdisciplinary scientists and decision-makers to interact and produce usable science can work to the benefit of both science and policy systems (23). These mechanisms can be many different things. They can be, for example, the material conditions—financial, organizational and institutional—necessary to translate, disseminate, package and establish interacting structures that enable the co-production of science and policy. They can include boundary objects and organizations that facilitate the exchange between knowledge producers and users (33). For example, organizations such as the UK's Climate Impact Program (UKCIP) seek to play a pivotal role in facilitating the use of knowledge to inform adaptation action (for examples of numerous reports and technical papers see http://www.ukcip.org.uk/). On the other hand, the marriage between science and policy can either fail to happen or fall short from meeting the expectations of either system (34). In the example from CLIMAS mentioned above, Lemos and Morehouse (23, page 64), comment that in moving from useful to usable

> Researcher flexibility, in terms of willingness to think across the science-policy divide was essential; in particular, the project's success is in no small part attributable to the flexibility of the primary researcher (who began the task as her Ph.D. project and continues to work on it now as a research scientist) and of the researcher's disciplinary department to undertake this cross-disciplinary effort. Later, as the high costs of developing a web-based tool became increasingly apparent, assuring availability of sufficient resources became somewhat problematical, although not insurmountable, as the project was able to leverage funds from other sources. The resulting web-based forecast evaluation tool, currently in beta test mode, provides rigorous assessments of the accuracy and skill of climate forecasts across the United States and allows users to examine differences in the two variables over time and space.

We pose Figure 2 as a model for organizing effective use of climate projections in decision-making. As in Figure 1, the graph represents the products of scientific investigation. If there is to be effective response in, for example, building adaptive capacity, then it is necessary to reduce the problem at hand to manageable elements. Useful reductions are often aligned along a temporal axis as near-term and long-term. Spatially, there are often tensions between local and global factors. Not shown, but another useful axis is "wealth" which allows representation between rich and poor. With this problem reduction, interfaces between issues can be isolated, and the likelihood that tensions between competing issues can be rationalized is increased. This approach to problem solving is most likely to be successful when scientists and stakeholders cross their cultural boundaries, work on projects together and gain intuitive understanding of the role of uncertainties in their different communities.

In this section, we examined the relationship between science and policy with respect to the production and use of climate predictions. We argued that there is often a disconnection between what scientists perceive as useful and what decision-makers think is usable. We also review a few of the conditions that move predictions across the range of usefulness. Next, we explore different models of science and policy interaction and lay the groundwork to explore how uncertainty inherent to predictions has implications to decision-making, especially in justifying inaction.

Science-policy interactions

Carol Weiss (35) proposes two basic models for the use of basic research in policy-making. In the decision-driven model (or transfer-and-translate model), policy-makers when faced with a problem, either look for solutions in the pool of pre-existing research products or commission new research to meet their needs. In the first case, existing research might be only marginally applicable to the problem and a certain adjustment is necessary. Commissioned research in turn is expected to have direct application in decision-making. In the second knowledge-driven (or trickle down) model, “research is sometimes used for policy-making not so much because an issue requires elucidation but because research has uncovered an opportunity that can be capitalized upon” (35, p. 29). This model assumes that the “sheer existence of knowledge presses it toward development and use” (p. 30). Although much has been written criticizing the tenets of the knowledge-driven model (see for example (36) many of its assumptions remain influential, including the belief that science holds the promise of neutral and rational knowledge that can inform better policy design. However, what we know about the production of both science and policy is that neither is rational nor straightforward and that knowledge is increasingly co-produced within a ‘‘culture of research’’ in which science and society come together to ask questions and search for solutions collectively (37). (For a detailed discussion of different models of science-policy interaction see (38)).

Within the range of usefulness, the mode of production of climate prediction began as trickle down and has been moving towards transfer-and-translate. Empirical evidence from the seasonal climate forecast (SCF) application literature suggests that success is mostly associated with scientists having gone beyond the physics of prediction to engage on research and practice designed to understand what it takes to make predictions usable (see section below). This effort has often been carried out by interdisciplinary teams of scientists (physical and social) working together with stakeholders in the context of integrated assessments and participatory models of science policy interaction (23, 30).

Because, as a problem, climate change originated outside the experience of decision-makers and because it involves high-stakes policy in a context of complex uncertainty, the transition from usefulness to usability has been slow. Yet, in climate policy there is increasing awareness that in order to solve the potential problems related to climate impacts, scientific priorities and practices need to change to include decision-support—that is “organized efforts to produce, disseminate, and facilitate the use of data and information in order to improve the quality and efficacy of climate-related decisions.” In addition, “the information that is needed is not only about climate, but also about changes in social and economic conditions that interact with climate change and about the state of knowledge and uncertainty about these phenomena and interactions.” (39, p. S1).

Climate predictions and implications for science and policy

As argued above, part of the difficulty with current models of science-policy interaction can be traced back to the definition and framing of the problem. When a problem exists first in the realm of science and is not readily experienced by the public, the way it gets inserted in the policy agenda may critically define the kind of action policy-makers take to solve it (21). This may be especially true for public policy-makers since they have the responsibility to solve the problem in the public’s interest. Occasionally the decision to apply untested scientific knowledge such as climate predictions and seasonal climate forecasts in policy-making can be haphazard, may backfire and even lead to undesirable outcomes. On the one hand application may lead to a period of “new technology blues” (40) that is, when the tribulations of implementing a new technology may result in its discredit, even before new and better applications can be uncovered. For example, in Northeast Brazil farmers’ perception that climate forecasts were “wrong” despite their probabilistic character contributed to discredit not only the forecasts but the forecasters and the agency releasing them as well (40). On the other hand, undesirable outcomes motivate further adjustment to either get it right or discard it as a desirable solution. In the best-case scenario, when this process is carefully monitored and examined, policy systems learn and adapt accordingly (5, 41). In the worst, mistakes persist and propagate, and their consequences defy public interest (5).

In some instances, policy can be successful even if decision-makers have had little experience in solving the same kind of problem before (e.g. the ozone layer hole; for more details, see (42)). In others, decision-makers' lack of experience can be critical in defining the range of action they are willing to take. Climate change, for example, was first framed by science and then it became a public policy problem. And partly because neither the public nor policy-makers could experience many of its negative consequences directly, acting preventively has been at best challenging and at worst virtually impossible. Moreover, the ideal that policy-makers can continue to make incremental changes to policy and adjust it as needed may be hard to operationalize in climate change policy because of the potential for catastrophic and "dangerous" changes (43, 44).

Sarewitz and Pielke Jr. (45) have argued that the early marriage between climate change and science has been critical in defining climate policy. On the one hand, pegging climate change to science gave the environmental movement its first impetus to link many of the problems that they were interested in solving (such as pollution, loss of forests, etc) to something global and urgent. On the other hand, it alienated decision-makers because it placed the problem outside their experience (45). As a scientific problem, climate change has had a hard time galvanizing support among the public. This is in part due to the "scientific controversy" surrounding its causes and effects that did little to attract and accumulate the necessary political capital to back up unpopular and costly policy to mitigate and prepare for its negative consequences. For decision-makers reluctant to commit to concrete policies, the uncertainty and controversy in scientific investigation means that investing in more research provides the perfect pretext to appear to be doing something without ever risking making the "wrong" decision. Scientists, in turn, welcome the possibility of more money for research. Yet, the over-reliance on science may also have sidestepped the moral imperative of doing what is right. The way the problem was framed provided the perfect opportunity for policy gridlock while ignoring the things that actually had to be addressed to decrease vulnerability to climate impacts (45). Indeed the technical "solution" crowded out the moral imperative to do what is needed to improve livelihoods, conserve natural resources and increase the resilience of human and ecosystems (46, 47). In NE Brazil for example, rather than addressing structural deficits at the heart of vulnerability to drought such as unequal income and land distribution, lack of education, health, political power, etc., local technocrats and politicians often opted to invest in less costly (both politically and financially) technical solutions such as cloud seeding to 'produce' rain or seasonal climate forecasts to respond to drought (47).

Previous experience and institutional constraints also play a critical role in the way policy-makers make decisions to use science (27, 28, 38). Despite the fact that decision-makers frequently make decisions that involve difficult to predict human behavior (or use predictions that are often wrong)—they may have difficulty in extending the same experience to climate change for they perceive it as natural science-driven and therefore predictable. Moreover, as mentioned before, scientists have often expressed their faith not only on the usefulness of climate predictions but also on their ability to continuously progress in producing "better" information (2, 3). This faith, in turn, might have encouraged decision-makers to believe that a wait-and-see approach would be reasonable, especially considering powerful opposition from special interests (e.g. oil and coal industry) and the lack of political capital to make tough decisions about climate change under high levels of uncertainty. Paradoxically, what decision-makers initially may have liked about climate change as a problem—that it was predictable scientifically—is precisely what now they offer as a reason to delay action. However, while inaction may be convenient, "the argument, that scientific uncertainty must be resolved before action should be taken, disregards the fact that no amount of data or theory will be able to eliminate all uncertainty regarding future temperature changes" (5, p. 438). Since climate change became a public policy problem mostly because of scientific investigation, it may defy the qualifications of even the most seasoned public policy-makers as they cannot draw either on their expertise or on their previous experience. In other words, because decision-makers might not have previous experience with a problem like climate change, or feel they might not understand it well enough to make sound decisions, or may believe it can be eventually solved by science, they are happy to defer action to whenever the information is "right." In this case, uncertainty may become a pretext for inaction, a rationale for self-serving selection of scientific opinion, or a license to ignore scientists (5).

The level of uncertainty of predictions, however, is not a "one size fits all" proposition; different policy decisions can tolerate different levels of uncertainty. For example, surprisingly to many, the decision to protect the ozone layer was achieved relatively fast and efficiently despite considerable uncertainty and lack of scientific consensus (48). As described in the previous section, there are many kinds of uncertainty and they may affect the use of predictions in decision-making differently. In moving climate change predictions from useful to usable, scientists have to consider three kinds of significant complexity: a) that of science itself as a source of information for decision-making (e.g. deterministic vs. probabilistic information, uncertainty, lack of consensus, methodological and intellectual constraints, etc.); b) that of user and policy-making systems and their capacity to make decisions (e.g. interest group politics, conflicting and faulty institutions, lack of material and social resources, cognitive limitations, etc), and c) that specific to the interaction between science and policy and defined by these two systems' divergent cultures and modi operandi.

Yet, uncertainty of predictions has often been used to justify inaction including regarding adaptation policy. In the best-case scenario inaction is the result of a wait-and-see approach in which decision-makers postpone action expecting the quality of predictions to improve. In the worst, uncertainty is manipulated into 'selective doubt' to avoid action perceived as undesirable by certain interests (49, 50). For example, in the 1990s, industrial interests who became significantly prominent in the global change debate in the years leading to the Kyoto Conference used the uncertainty argument to advocate against 'policy that would hurt the US's economy' (48). In the mid 2000s, the Bush administration was able to "[enlist] an outspoken skeptic of global warming" in a fight regarding overseas energy projects (Kintisch 2005:482 cited by (50)).

Finally, scientists and decision-makers had difficulty communicating not only about the uncertainty of predictions (31, 51, 52, 53) but also about whether and how fast the science behind it would progress to a level decision-makers would perceive as usable (53). Throughout, climate modelers have persisted in justifying further funding for prediction research on its potential for usability (2, 54). However, evidence from the seasonal climate forecast literature (see section below) shows that there are many constraints to the use of seasonal climate forecast in decision-making, not all of them related to the level of skill of the forecasts (29, 55, 56).

Prediction in practice: lessons from seasonal climate forecast application

Seasonal climate forecasts (SCF) have, in principle, many applications. For the past fifteen years, a rich empirical literature focusing on the use of SCFs in different sectors in different parts of the developed and developing worlds has emerged both in the social and natural sciences (29, 32, 55, 56, 57, 58, 59, 60, 61). Findings from this literature suggest that successful application of SCF tends to follow a systems approach where SCF is contextualized to the decision situation and embedded within an array of other information relevant for risk management. For example, in Australia, users and producers of SCF have created knowledge systems for action in which the forecasts are part of a broader range of knowledge that informs farmers' decision-making (23). In Arizona, forecast producers interacted closely with potential users to customize information to their needs, including formatting, frequency and focus (28, 29). In contrast, in other cases, evidence shows that there might be opportunity costs to the application of forecasts, ranging from the crowding out of more sustainable and robust alternatives to outright harm to users whose decisions forecasts were meant to improve (29, 47, 62). For example, in Peru, a forecast of El Niño and the prospect of a weak season gives fishing companies incentive to accelerate seasonal layoffs of workers (62) In Zimbawbe, forecast of a bad season resulted in reduced credit availability and planted areas (63).

More recent scholarship, which seeks to apply the lessons from the SCF application to inform climate adaptation policy, similarly argues for integration of predictions within broader decision contexts. These should take into consideration not just the magnitude and dimension of exposure to climate impacts (to which impacts predictions may be more relevant) but also to characterize sensitivities related to livelihoods, institutions, politics, cultures, etc. (56, 58, 59, 64). Particularly in countries and communities where lack of resources critically defines vulnerability, adaptation policy should not be dependent on predictions since building capacity ought to be precisely about enabling flexible and robust human, environmental and physical systems to withstand a wide range of impact. In these contexts, climate hazard such as storms, sea level rise and warmer temperatures is only one aspect of vulnerability. Thus, rather than 'perfect' forecasts, integrated assessments and participatory approaches that contextualize the information to the users' multiple stresses and needs make more sense. To jump start policy action, policy-makers need "plausible representations of future climate" that can help them understand where vulnerabilities lie and what to do to decrease these vulnerabilities (46). Relative to uncertainty, climate is only one in a cascade of uncertainties that aggregate across physical, social, cultural and political factors (65). And uncertainty introduced by climate predictions themselves remains an issue, that is, human behavior influenced by this kind of information remains largely intractable in the context of prediction (66).

In the context of compounded or irreducible uncertainty, it seems more sensible to search for resilient and robust approaches that seek to identify strategies that are less sensitive to wide ranges of uncertainties (53, 67, 68). For example, ten years of experience with climate forecasting application in Africa suggests that incorporating forecasts within broader sustainability approaches are likely to produce better results than isolated attempts to inform action by the use of forecasts alone (63) . Other strategies may include "no-regrets" or precautionary approaches that allow for future adjustment as the dimension of climate impact and response evolve. They may also include the support of powerful computational resources, which rather than decreasing uncertainty, help to better uncover them so that decision-makers "have better discovery of all issues bearing on the decision" (4, 53). These alternatives may be even more straightforward in less developed countries where vulnerability, sensitivity and adaptive capacity are intrinsically connected to development and sustainability. Most importantly, the application of climate predictions and projections should not crowd out other approaches that are likely to enhance the adaptability of people and systems to climate impact. Hulme and Dessai nicely summarize the issue:

> Effective and robust adaptation strategies are not significantly limited by the absence of accurate and precise regional climate predictions. They are limited more by a multitude of technological, institutional, cultural, economic and psychological factors that lie beyond the reach of climate models — and always will. The epistemological limits to predicting future climates with accuracy and precision must not be used as a reason to limit adaptation to climate change.(54, p. 979).

As the reality of climate change as a problem becomes universally apparent, the need for adaptation policy has risen in many countries' public policy agendas. What we do not know about both physical and social determinants of vulnerability and adaptive capacity is large. However, what we do know is enough to jump start action that will allow for future adjustment and learning.

Conclusion

This article has reviewed both the sources of uncertainty in the predictions of climate change and the use of uncertainty of the predictions by decision-makers. We have explored the gap between the potential usefulness of uncertainty as advocated by scientists and the usability of information from predictions by policy- and decision-makers.

Like predictions, uncertainty is a fundamental product of the scientific investigation of climate; uncertainty will not be eliminated and in many cases will get even larger. In a complex system, such as that which represents the Earth's climate, scientific investigation will continue to reveal new sources of uncertainty. Systematic reduction of uncertainty by continued scientific investigation is not, a priori, expected. In fact, the emergence of ensemble forecasts as a new technology, explicitly, manages the uncertainties in the forecast system to provide improved, presumably more usable, forecasts.

Scientists' statements that "better" predictions are necessary are sensible in terms of the practice of science and in terms of their experience. It is reasonable to expect that improved predictions will lead to improved usability. Similarly, for those making difficult decisions with high stakes, it is reasonable to hope that support from science would streamline the policy process and clarify their decision options. However, a great deal of what we know of both the production of scientific knowledge and its application in decision-making suggests that neither process is rational or straightforward. In addition, progress in the science of climate prediction has been slower than both scientists and decision-makers expected and hoped. By ignoring the complexities of each other's tasks, both scientists and policy-makers are shortchanging society of better solutions to the climate change problem. Climate prediction sits in relationship to many other competing sources of information and interests. Understanding how to use them to boost the range of decisions that improve adaptation is what will move predictions from useful to usable.

The existence of climate change as a public policy concern following from scientific investigation and the fact that policy-makers do not have a strong experience base with similar problems helps to frame the disconnection between what is useful and what is usable. The high stakes character of climate policy and the costs and political capital associated with its implementation amplify this gap and invites inaction. It also enables 'selective doubt' in arguments about policy development for both mitigation and adaptation. The impact on adaptation policy is greater because the specific questions of adaptation introduce complexity that further challenges the definition of climate change uncertainty.

With regards to the practice of scientific investigation, our arguments reveal an uncertainty fallacy, that is, the idea that the systematic reduction of uncertainty will lead to development of policy and the rationalization of decision-making. Aside from not recognizing the fundamental nature of uncertainty and the complexity of uncertainty in scientific investigation, this notion does not recognize how scientific uncertainty affects the decision-making process. In the absence of ‘clear and present danger’, those who rely on ‘selective doubt’ are able to sustain their arguments.

The usability of uncertainty requires that there be convergence at the interface of different communities; in our discussion between the scientific and policy- and decision-making communities. This requires focus on real problem solving that crosses disciplines. The complexities, of both the specification of scientific uncertainties and the tensions between priorities in the decision-making process, require concrete objectives to define the usability of uncertainty.

Notes

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1. While the term climate projections more closely reflects current attempts to predict future impacts of climate change, hereafter we use the more commonly utilized climate predictions recognizing that the discrepancy between the two terms has itself political and policy implications.

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Cross-References

CC-0094: Skill and uncertainty in models

CC-0266: Policy integration and climate adaptation

CC-0224: Barriers to engagement

Supplementary Information

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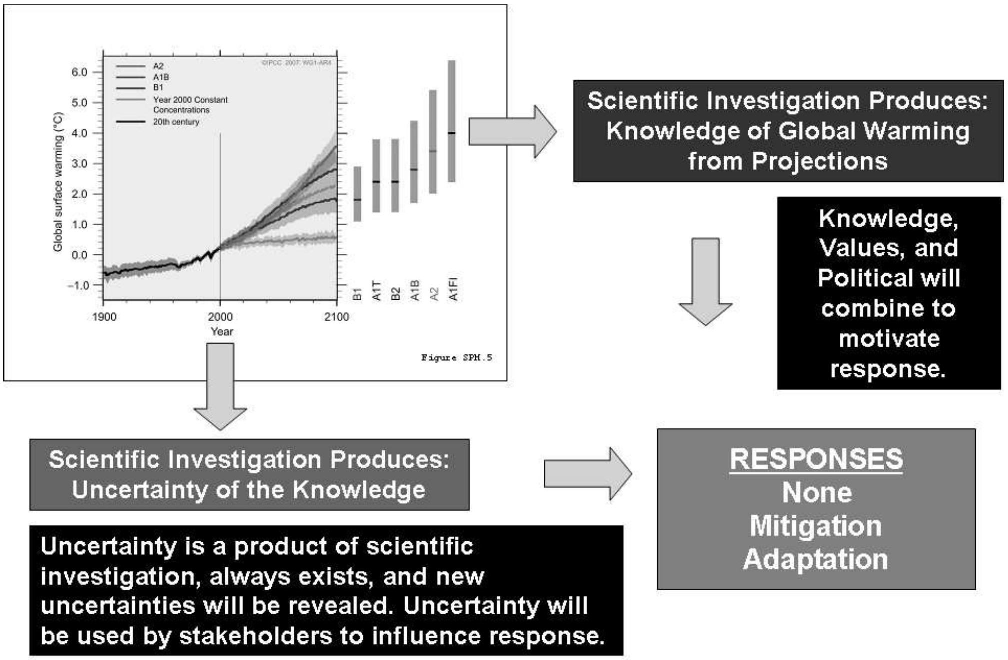

Scientific Investigation Produces: Knowledge of Global Warming from Projections

Knowledge, Values, and Political will combine to motivate response.

Scientific Investigation Produces: Uncertainty of the Knowledge

Uncertainty is a product of scientific investigation, always exists, and new uncertainties will be revealed. Uncertainty will be used by stakeholders to influence response.

RESPONSES
None
Mitigation
Adaptation

Figure 1: The relationship between the products of scientific investigation of the Earth's climate and responses in policy and practice.

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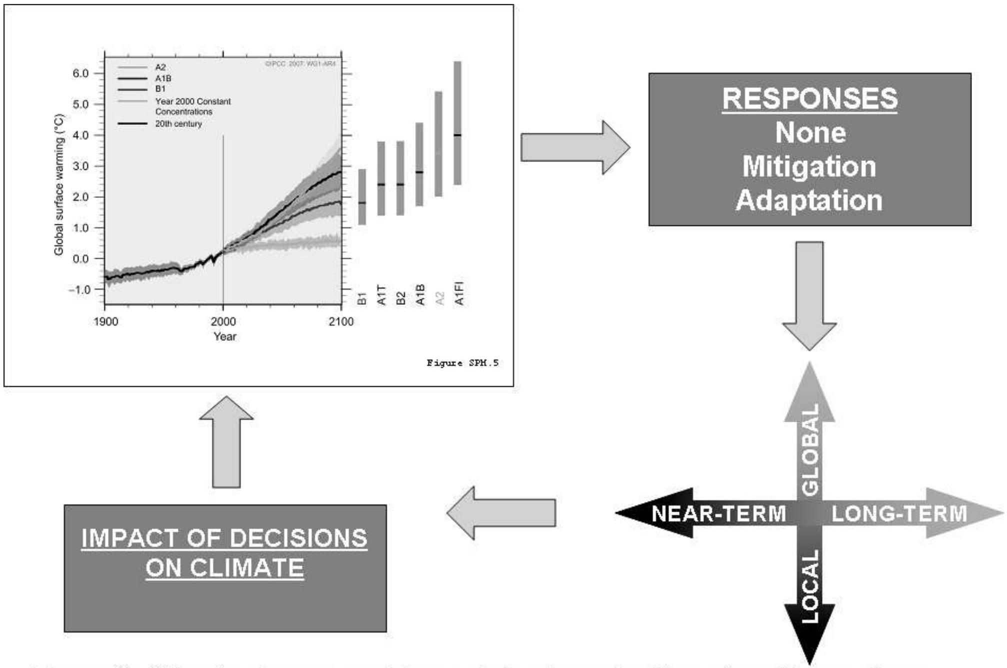

Figure 2: Climate-change problem solving by reduction of problems along temporal and spatial axes. A third axis for wealth, rich and poor, is also needed. The process is closed by evaluation of the decisions on the climate.

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