Revised "Opinion Article" -- revisions directly following editors' suggestions
Re-Submission to EOS, AGU (10/27/00) -- *accepted*

GENERATING PROBABILITIES IN SUPPORT OF SOCIETAL DECISION MAKING

Alexander S.P. Pfaff, Dorothy M. Peteet

Keywords: science policy; climate change; probability

Earth-science predictions of natural phenomena are increasingly seen as valuable aids to improved societal decision making. Pielke et al. recently (EOS 7/13/99) argued persuasively that good predictions alone won't achieve better societal decisions. These authors' call to change the decision environments in which scientific predictions are used, though, may be more relevant to the daily activities of policy makers than to those of scientists. We see a role also for changing the information that scientists feed into those decision environments. In particular, scientists could better serve societal needs by generating not only possible scenarios, but also improved probabilities that decision makers need, including for decisions to be taken in the near future.

Below we use the case of abrupt climate change to illustrate this point, both because of current policy relevance and because it is a challenging case with respect to prediction. With costly policy actions being debated at Kyoto and elsewhere, all climate science may be of value for improving policy decisions, and attention is increasingly paid to the multiple timescales at which climate shifts. Recent scientific work has highlighted the possibility of abrupt climate changes, including drastic cooling, both as a basic feature of the climate system and as a local consequence of long-term global warming (Manabe and Stouffer 1995). Because such abrupt climate changes could have significant impacts, scientists have suggested that policy makers should take them into account.

However, if rough estimates of the probabilities that scenarios might occur are lacking, such work is of little value for current policy decisions. In the extreme, if informed probability estimates are not feasible, scientists' scenarios cannot guide rational policy choice. Or, more likely, non-scientists may use these scenarios in an ad hoc manner, which could worsen policy.

Improved, or any, scientifically-informed *current* probability estimates may be of great value for decisions to be taken *now or in the near future*. However, the gains to a scientist from estimating such probabilities may be small. Thus, publicly-provided incentives that promote scientists' *current* estimation of probabilities of abrupt climate change scenarios may be justified, alongside investments in basic research for improving such estimates in the long run.

Abrupt climate change

Recent studies of paleoclimatological records have indicated that the earth's climate can change drastically over a short period of time. A prominent example is dramatic evidence of past abrupt jumps from ice cores drilled in Greenland. The deep ice cores match each other very well down to the age of ~100ka BP and show abrupt changes in climatic indicators (Grootes et al. 1993). Further, paleoclimatic records from the North Atlantic correlate well with Greenland ice records, and confirm these past abrupt changes in the ocean (Bond et al., 1993).

During the last 12,000 years our climate has not been subject to such extreme changes in temperature as those during the last ice age. However, climate records do demonstrate several large and abrupt events. The most recent of these events is called the Younger Dryas (13-11.5 ka BP), named for fossils of the arctic-alpine flower, Dryas, that were found overlying tree remains in Europe. At the end of the Younger Dryas cold event in Greenland, snow accumulation rates doubled within 1-3 years (Alley et al. l993), European tundra changed to forest, and boreal forest disappeared in southern New England within 50 years. Pollen records throughout the world demonstrate that rapid YD/Holocene changes characterized many locations around the globe.

Of importance for policy, such events impact whole societies. The Preboreal cooling 8200 years ago and the Little Ice Age (1250-1900 AD) undoubtedly had major impacts on humans, contributing to abandonment of settlements in Greenland. Impacts of the Little Ice Age such as mass movements and floods, cod disappearance from European waters, and resulting famine and hardship are well-recorded (Grove l988).

Large and abrupt climatic events are equally notable in terms of precipitation, which is inherently more variable than temperature. Extreme and persistent droughts that occurred throughout the last few thousand years are known from lake level studies in California and Patagonia (Stine l994) and diatom records in the northwestern US (Laird et al. l997). Foraminiferal evidence for salinity changes in Chesapeake Bay suggest that 14 wet-dry cycles occurred in the last 500 years, including sixteenth and seventeenth century mega-droughts that exceeded twentieth century droughts in their severity (Cronin et al., 2000).

And again, such shifts affect societies. Major droughts have been correlated in time with the collapse of Mayan civilizations in Mexico (Hodell et al. 1995). Recent tree ring data from Virginia indicates extraordinary droughts that have been implicated in the demise of the Lost Colony and the extreme death rate in the Jamestown Colony from 1606-1612 (Stahle et al., 1998). Finally, of course floods have for a long time also severely impacted upon civilizations.

Thus, one feature of the earth's climate system appears to be the possibility of rapid mode switches, due to built-in instabilities, which involve climate shifts with societal impacts. A natural question is whether such switches might also be triggered by global warming, and thus perhaps by an atmospheric buildup of greenhouse gases. One possible scenario involving such a switch is a reorganization of the ocean's circulation, as proposed in ocean-atmospheric models. The potential magnitude and rapidity of such a "Younger Dryas"-type cooling is explored below.

The Younger Dryas

The Younger Dryas (YD) is the best-documented example of an abrupt climate change, primarily because of its millennial duration and its extensive geographic coverage. While the changes in Europe were discovered many decades ago, recent high-resolution analysis of annual layers in Greenland ice cores led to the discovery of just how rapidly the climate changed at the end of this event: temperatures warmed dramatically in Greenland within a decade, forests began to replace tundra in northern Europe and Canada, and spruce and fir in southern New England were replaced by pine and oak within decades.

An International Geological Correlation Project (IGCP) Working Group formed to study the YD(Peteet l995), and many scientists continue to examine whether or not the YD was a global event. The discovery that cooling occurred in the North Pacific region and other regions far from the North Atlantic indicates that perhaps rapid air-sea interactions took place, or even that the origin of the YD may have been outside of the North Atlantic. Certainly it is clear that a YD-type cooling today would have severe ecological and most likely also economic impacts, at the very least in Europe. Further, given our scant understanding of the underlying processes, several unforeseen effects are likely.

Informational needs for policy choices

In order to choose "rationally" (i.e., by weighing expected benefits and costs) between policies in the face of such climate uncertainty, a policy maker requires <u>all</u> of the following: (1) a list of scenarios, i.e. of potential physical shifts and their benefits and costs; (2) the probability of each of these scenarios; and (3) the effects of each policy on the probability of each scenario.

Consider the choice of whether to support emissions limitations in Kyoto, given concern about global warming (and the potential for an abrupt cooling). Limitations on driving and use of electricity would impose costs, e.g. shifts to alternative transport, appliances not used, trips not taken, etc.. Even assuming that the value of these costs of regulations is known, consider the expected benefits. As these include the avoidance of abrupt climate change, measuring these benefits necessarily involves an understanding of the costs of different abrupt climate scenarios.

It matters whether the scenarios involve thousands or billions of lives and dollars. For abrupt scenarios, though, predicting physical shifts (e.g., frozen-in ports) and net losses from the shifts can be difficult. The latter is complicated by large, rapid jumps between equilibria, and by the fact that the rapidity of change may increase the costs of transitions. Incentives exist for natural scientists to study physical shifts, and for social scientists to estimate impacts. However, such incentives appear to be lacking for estimating scenarios' *probabilities*.

Probabilities play a crucial role.

If an abrupt change scenario involving billions of dollars had roughly a fifty percent chance of occurring in the next twenty years, a limitation on driving that helped to avoid such a change might seem reasonable. If the same scenario had roughly a one in one million chance of occurring in the next five hundred years, however, while a little bit of climate research might seem worthwhile, limitations on driving might be out of the question. Or, if abrupt climate change could lead to flooding, consider a decision whether to move people permanently out of a coastal floodplain (or whether to insure them, as the U.S. disaster relief agency and private insurers must decide). Since the record of past changes suggests that future abrupt climate change is possible, moving people out would have positive expected benefits. However, should \$1000 or \$1,000,000 be spent? Should people be moved 1, 10, or 100 miles away, or at all? If even rough probabilities of possible scenarios do not exist, policy makers are restricted to relying on other sources of information (or perhaps none, i.e. judgement) in making such choices (and worse, at times only one or a very few of the possible scenarios are even conveyed at all).

Given the importance of probabilities, what sorts of probabilistic information may be needed? If policy makers adopt a relatively short time-horizon, the demand for probabilities far into the future may be small, but temporal resolution may be important. That a severe event is likely to occur within the next 50 years might be seen as importantly different from that same event being likely to occur between 50 and 100 years from now (and in fact, 0-4, 4-8, and 8-50 years may also be politically distinct time frames). Another demand for temporal resolution, this time within a year, arises from the desire to use agronomic knowledge. For some crops, even given an average temperature during the growing season, early or late cold can be important. Along another dimension, if international policy decisions are made by sovereign nations, there may be a demand for spatial resolution of scenarios and probabilities. Nations will want to know what to expect within their borders. For instance, there may be "winners" from a climate shift.

Scientific challenges and incentives

Why are such probabilities not provided more often? The fundamental reason is the difficulty of producing probability estimates *as rigorous as the evidence that a given scenario or change once occurred, and thus may re-occur*. Modeling abrupt climate change is complicated by a system which is dynamic, may feature rapid and dramatic shifts between states, and involves changes in ocean circulation and feedback among sea ice, greenhouse gases, and vegetation.

Given this complexity, "casual" estimation of probabilities could be done, but might be seen as unsatisfactory, and earn little respect from other scientists. Thus, natural scientists trained to be rigorous may avoid probability estimation until models improve (analogously, lacking reliable information on the future, and given large and rapid shifts between equilibria, economists may perceive little gain to “casual” numerical estimates of benefits and costs from climate shifts). However, while it may be natural for scientists of all types to choose a rigorous if slow road to “good” probability estimates through improved modeling, for policy this may be unfortunate, as some decisions must be taken *now or in the near future*. While policy makers’ staffs will surely fill the gaps by guessing the importance to assign to news of any given scenario, we suggest that trained scientists should be estimating improved probability weights to assign. Even better, scientists could do the estimation in direct communication with those needing the answers.

A general prescription

For the long run, encouraging estimation of useful probabilities includes support for basic research on physical processes driving climatic scenarios. However, there is a constituency for basic research already, and some significant policy decisions need to be made *now or soon*. Thus, there is a need for greater incentives for *current* estimation of relevant probabilities. In sum: (1) faced with costly choices, societies need information about the likelihood of outcomes; (2) public incentives to focus scientists on probability estimates now may be worthwhile; (3) to balance extraction and use of helpful research results now with letting scientists do good long-term modeling requires both research and policy expertise (Pielke at al. 1999, Pfaff et al. 1999).

For abrupt climate change, current estimation might include best-guess probabilities calculated from historical records and researchers’ accumulated experience. Regional estimates of past temperature and precipitation changes, derived from stratigraphic sequences of sediment type and organic content, pollen, macrofossils, foraminifera, diatoms, midges, charcoal, and geochemistry, could be used to generate crude estimates of probabilities. For example, calculations could be based on the number of climate oscillations in North Dakota over the last 10,000 years. Tree rings also provide excellent histories of climate change in specific regions. Second, even lacking this data, again it seems desirable to have scientific experts working on basic research also be those estimating the probabilities for use in policy decisions. An example of one approach to this, for global warming, is Morgan and Keith 1995, which collected experts' probability distributions for the change in surface temperature expected from a doubling of CO_2, and then aggregated these opinions to produce a 'current-scientific-best-guess' probability distribution for use in policy.

Affiliations

Pfaff is at the School of International and Public Affairs, Department of Economics, and Center for Environmental Research and Conservation, Columbia University. Peteet is at NASA/Goddard Institute of Space Studies and the Lamont-Doherty Earth Observatory of Columbia University.

Acknowledgements

The authors thank Kenneth Broad, Wallace Broecker, Gideon Henderson, Margaret Kneller, Donald Pfaff, Jennifer Phillips, Stephanie Strickland, an anonymous referee, and this journal's editors for comments. We also acknowledge Wallace Broecker's and Niraj Kumar's initiation of multi-disciplinary discussions at Columbia regarding the valuation of socioeconomic impacts of abrupt climate change; those discussions led to the distinct discussions that yielded this paper. Finally, Pfaff gratefully acknowledges support from NOAA grant NA56GP0437.

REFERENCES

Alley, R.B. (1993). Abrupt increase in Greenland snow accumulation at the end of the Younger Dryas event. Nature 362, 527-529

Bond, G., Broecker, W., Johnsen, S., McManus, J., Labeyrie, L., Jouzel, J. and Bonani, G. (1993). Correlations between climatic records from North Atlanic sediments and Greenland ice. *Nature* 365, 143-147

Cronin et al. (2000). "Climate varibility in the eastern United States over the past millennium from Chesapeake Bay sediments". *Geology* 28: 3-6.

Grootes, P.M., Stuiver, M., White, J.W.C., Hohnsen, S., and Jouzel, J. l993. "Comparison of oxygen isotope records from the GISP2 and GRIP Greenland ice cores." *Nature* 366: 552-554.

Grove, J. l988. *Little Ice Age*. Metheun, NY.

Hodell, D.A., Curtis, J.H. and Brenner, M. (1995). "Possible role of climate in the collapse of Classic Maya civilization". *Nature* 375:391-394.

Laird, K.R., Fritz, S.C., Maasch, K.A. and Cumming, B.F. l996. "Greater drought intensity and frequency before AD 1200 in the Northern Great Plains, USA". *Nature* 384: 552-555.

Manabe, S. and Stouffer, R.J. (1995). "Simulation of abrupt climate change induced by freshwater input to the North Atlantic Ocean". *Nature*, v 378, 165-167.

Morgan, M.G. and D.W. Keith (1995). "Subjective Judgments by Climate Experts". *Environmental Science and Technology* 29:468A-476A.

Peteet, D. (1995). "Global Younger Dryas?" *Quaternary International* 28: 93-104.

Pfaff, Alexander S.P., Kenneth Broad and Michael H. Glantz (1999). "Who benefits from seasonal-to-interannual climate forecasts?" *Nature* 397(6721):645-646.

Pielke, R.A. Jr., Sarewitz, D., Byerly, Jr., and Jamieson, D. l999. "Prediction in the earth sciences and environmental policy making". *EOS* 28: 309-314.

Stahle, D.W., Cleaveland, M.K., Blanton, D.B., Therrell, M.D., and D. A. Gay. 1998. "The Lost Colony and Jamestown Droughts". *Science* 280: 564-566.

Stine, S. (1994). "Extreme and persistent drought in California and Patagonia during mediaeval time." *Nature*, v 369, 546-549