Climate Science: An Empirical Example of Postnormal Science

Dennis Bray and Hans von Storch
Institute of Hydrophysics, GKSS Research Center, Geesthacht, Germany

ABSTRACT

This paper addresses the views regarding the certainty and uncertainty of climate science knowledge held by contemporary climate scientists. More precisely, it addresses the extension of this knowledge into the social and political realms as per the definition of postnormal science. The data for the analysis is drawn from a response rate of approximately 40% from a survey questionnaire mailed to 1000 scientists in Germany, the United States, and Canada, and from a series of in-depth interviews with leading scientists in each country. The international nature of the sample allows for cross-cultural comparisons.

With respect to the relative *scientific* discourse, similar assessments of the current state of knowledge are held by the respondents of each country. Almost all scientists agreed that the skill of contemporary models is limited. Minor differences were notable. Scientists from the United States were less convinced of the skills of the models than their German counterparts and, as would be expected under such circumstances, North American scientists perceived the need for societal and political responses to be less urgent than their German counterparts. The international consensus was, however, apparent regarding the utility of the knowledge to date: climate science has provided enough knowledge so that the initiation of abatement measures is warranted. However, consensus also existed regarding the current inability to explicitly specify detrimental effects that might result from climate change. This incompatibility between the state of knowledge and the calls for action suggests that, to some degree at least, scientific *advice* is a product of both scientific knowledge and normative judgment, suggesting a socioscientific construction of the climate change issue.

1. Introduction

The climate sciences have undergone significant changes in the past two decades. Originally the term “climate science” was little more than a blanket label for a number of related disciplines, including the likes of meteorology, oceanography, glaciology, some aspects of geography, and distinctive categories of earth sciences. For example, until the mid-1980s, the American Meteorological Society had no journal devoted specifically to climate. Papers addressing climate shared a common ground with applied meteorology, namely, the *Journal of Climate and Applied Meteorology*. Progress, however, was in the direction of a unified climate science: dynamical models of the atmosphere and ocean matured; global analyses techniques developed as conventional and remotely sensed data became available; and data sources became available from ice cores, from tree rings, and from lake characteristics. At times related issues were brought to public and political attention, as in the case of “rain making” or in the SST debates regarding the atmospheric impacts of large-scale supersonic transport. Typically, however, climate remained within the confines of academic pursuits. The products of the science were not politically or socially charged, and climate science might typically have been perceived as value-free curiosity driven research. If one considers the career of the Swedish scientist Svante Arrhenius,

Corresponding author address: Dr. Dennis Bray, Max-Planck-Institut fuer Meteorologie, Bundestrasse 55, D20146 Hamburg, Germany.
E-mail: bray@dkrz.de
In final form 2 November 1998.

however, interestingly enough, this has not necessarily been the historical case in climate sciences.[1]

> The historian of science and ideas Sven-Eric Liedman has referred to the Swedish professoriate after the turn of the century as civil servants close to the people (*folkliga ämbetsmän*). It was not uncommon for specialists to cultivate generalist ambitions and competence far beyond their own field. As the number of professors were few and their status made them part of the top of the elite, mingling freely with political and other elites, contact with public decision-making was an affair that needed no special organization. . . . Consider therefore his [Arrhenius's] role as "science advisor," a term that had not yet been invented during this time (Elzinga 1997).

It would seem then, at least in some cases, the interaction of science and politics has a long history, and climate science is no exception. According to Elzinga (1997) one can make the assumption that Arrhenius perceived science to have two sides: "one relating to method, the other to the role of scientists in society. These two aspects of an ideal science may be called internal and external dimensions."

This external dimension of climate sciences became more apparent in the 1970s (see Matthews et al. 1971) and the 1980s when climate and its anticipated changes became a political, public, and newsworthy topic. The dynamical models of oceans and atmosphere were coupled and a "changed" composition of the atmosphere was introduced. Historical data and satellite data were analyzed for the purpose of detecting anthropogenic-induced climate change and paleoclimatic data became a reference for comparison. Climate science—and the potential for climate change—became a public and political topic. Nightly news broadcasts and daily newspapers drew the attention of the public, and U.S. Senate Committees and the Enquete Commission of the Deutscher Bundestag (1988) put climate and climate change in the center of political attention, culminating in the formation of the Intergovernmental Panel on Climate Change. Consequently, climate scientists often found themselves with the opportunity for new roles, that of policy advisor or media personality, or both. The circumstances of the potential for global warming, that is, a high degree of uncertainty and perceived high stakes gave way to conditions of what has been termed "postnormal" science [as defined and characterized by Funtowicz and Ravetz (1985, 1990a, 1990b, 1992)].[2]

Whereas Kuhn (1962) proposed the transition from preparadigmatic science (in which the science has several competing hypotheses with none being deemed more valid than the other) to normal science (in which one hypothesis or theory comes to dictate the epistemic regime[3] in which a particular science is conducted) the extension of the discussion to postnormal science addresses the issue at hand when there is a considerable amount of knowledge generated by normal science in different disciplines and there is a high degree of uncertainty and the potential for disagreement due to empirical problems and political pressure. This characterization is consistent with the present state of climate sciences.[4] The concept of postnormal science, then, incorporates social and epistemic relationships that exist outside of the scientific communities but that act upon programs of research. Both Elzinga (1997) and Funtowicz and Ravetz (1990b) and others have referred to the contemporary attributes of climate science as reflecting postnormal science. In this paper we explore with empirical means Ahrrenius's elements of internal and external dimensions of science in the contemporary context of the global warming issue leading us to conclude that contemporary climate science is a good example of postnormal science at play.

One aspect of the concept of postnormal science (Funtowicz and Ravetz 1992) tends to focus on the internal dynamics of science (as does our following analysis). According to such a system,

[1]For a full account see Elzinga (1997).

[2]Jasanoff and Wynne (1998) in *Human Choice and Climate Change* note "this particular model is problematic under either of two assumptions: either it assumes that the uncertainty and decision stakes axes are independent of each other, conflicting with findings that show uncertainty rising with the increase in stakes and attendant political scrutiny of competing claims (Wynne 1980; Collingridge and Reeves 1986; Jasanoff 1991) or else it presupposes that reducing the uncertainty dimension of postnormal science simultaneously reduces decision stakes." It is not our intention here to debate the concept of postnormal science, rather it is to employ it as a logical directive for the discussion.

[3]The term "epistemology" is used here in reference to the theory of knowledge, the theory of how it is that a person comes to have knowledge of the external world and to the methods of scientific procedure, which lead to the acquisition of knowledge.

[4]In the survey employed throughout this paper the response to the open-ended statement "my academic training is mostly in . . ." resulted in claims of 18 different disciplines.

> policy option or problem-solving strategies, arise as functions of *system uncertainties* on the one hand and *decision stakes* on the other. When both variables are low, the puzzle-solving approaches of Kuhnian normal science are adequate to produce consensus. If either variable rises to the medium level, unresolved methodological debates come to the fore, and new actors and skills must be brought into play to forge solutions to policy problems. Funtowicz and Ravetz characterized this middle region of scientific activity as professional consultancy. Finally, when both variables are high, they saw a region of *postnormal science,* where scientific experts share the field of knowledge production with amateurs, such as stakeholders, media professionals, and even theologians or philosophers. (Jasanoff and Wynne 1998).

The roles of scientists under such conditions often demand "social" or "political" comment well beyond the expertise of the climate scientist, and these comments are often presented, or at least interpreted, as "facts." However, one might suggest here, contrary to the claim of Jasanoff and Wynne, that *knowledge production,* the internal dimension of science, at least in the context of scientific knowledge, is not necessarily as contestable an area as *knowledge diffusion.* It is possibly the case that advocates (in some instances) and lay persons are not skillful at assessing subjective probabilities of complex outcomes. One should also note, however, that scientists have no special skill beyond assessing events, their dynamics, and their probabilities.

Before proceeding, it is necessary for the sake of clarity to provide an operational definition of "expertise." Expertise could, for example, refer to Popper's criterion for the evaluation of scientific authenticity, namely the ability to falsify results, distinguishing true science from pseudoscience. However, such a definition is open to multiple critiques. For example, "falsifiability is a self-referential concept in science, inasmuch as it appeals to those normative codes of science that favor authentication of evidence by a supposedly dispassionate observer" (Ross 1990). For our purpose, the concept of expertise is not so formal. Rather we refer to expertise as the area in which the person is formally trained and continues to practice. In short, it is a characteristic of a person with the status of authority in a subject by reason of special training or knowledge. Just as one would consider medicine (or aspects of medical practices) to be the expertise of those trained as a physician, we consider the expertise of climate scientists to be their ability to address the issue of climate and climate change in accord with formal training and a special mode of discourse. This is of particular relevance for the extension of the dialogue past one's area of expertise, which, however, might be an unavoidable circumstance if one considers the potential for multiple levels of discourse, for there is a wider margin for interpretation. Typically, many natural scientists are accustomed to conveying results by the use of restrictive formalisms, for example, as statistics or mathematical expressions. However, the broader audience is not necessarily as well versed in this mode of discourse and consequently some of the specificity is lost and the issue is open for misinterpretation. Conversely, the climate scientist is not necessarily versed in the discourse of other sciences and therefore can offer no more than an educated lay perspective on issues extending beyond his or her expertise, political, social, or economic matters, for example, again pointing to the difficulties of knowledge dissemination in the case of complex issues.

Funtowicz and Ravetz (1990b) applied their concept of postnormal science to global warming (greenhouse) research, pointing in particular to the level of uncertainty regarding baseline and empirical data in regard to global warming and to the fact that climate science, at the same time, is at risk of distortion by political power plays, ideological conflicts, and differences both internal and external to the scientific community. They suggest that researchers with different academic credentials will also impose different views.[5] Overall, the claim is made that

> the phenomena of climate change are novel, complex and variable, and poorly understood. In such circumstances, science cannot always provide well-founded theories based on experiments for explanation and prediction; but can frequently achieve at best only mathematical models and computer simulations, which are essentially untestable. The trouble is that on the basis of uncertain inputs, decisions must be made, under conditions where science cannot proceed on the basis of factual predictions, but only on forecasts influenced by value and policy. Typically, in such issues, the facts are uncertain, values in dispute, stakes high and decisions urgent. In this way, it is "soft" scien-

[5]A disaggregated analysis according academic credentials is not yet available from the dataset incorporated in this paper.

> tific information which serves as input to "hard" policy decisions on many environmental issues (Funtowicz and Ravetz 1990b).

The following discussion presents the scientific assessment of development of the "normal science" of climate change, as well as addresses those aspects of the science determined to be characteristic of postnormal science.

Further features of this transition in the nature of science were noted by Dorothy Nelkin, as early as 1978:

> A striking feature of the new scientific activism is the public nature of its activities and the willingness of activists to engage in and, indeed, to abet political controversy. Disputes among scientists are normally resolved within the scientific community using well-established provisions of collegial review. However, recently, scientists appear willing to air grievances in a political forum—through mass media, litigation, or appeals to citizens' groups or political representatives. Citizen participation is sought today for a different reason—as a means to increase the political accountability of science. While activists in the 1940s fought against political control over research, their recent counterparts—by calling public attention to conflicts of interest within the scientific community—seek to increase political control. Such actions have polarized the scientific community, as less radical scientists seek to maintain intact the principles of autonomy and self-regulation that were fought for by activists nearly 30 years ago (Douglas and Wildavsky 1983, p. 64).

It is the recognition of the change of roles, from scientists to political and social commentators, and the apparent conditions of a postnormal science, that instigated this study. To provide a benchmark from which to comment on it was necessary to explore the range of perspectives that climate scientists might have regarding the skills of the climate science, particularly the modeling aspect. With this as a basis it became meaningful to inquire as to the perspectives regarding the interaction of climate, society, and politics and the inherent danger of the interference of nonscientific factors in the process of science.

The study began with a series of 50 in-depth interviews with climate scientists from Germany, the United States, and Canada (Bray and von Storch 1996). The qualitative data were used to develop a meaningful questionnaire to pose to a large international sample of climate scientists. Details of the sampling and survey procedure are presented in section 2. In section 3 we present the analysis of sections of the survey. Consistent with Fig. 1, all data are presented so as to distinguish groups according to national bases. We proceed first with the presentation of perspectives pertaining to "scientific" knowledge and follow with an analysis of the metamorphosis of such knowledge into the social and political commentary. Section 4, the conclusion, recapitulates the overall results, and some conclusions are drawn regarding the interfaces of science, society, and policy in light of the growing phenomenon of risk in society. An analysis of the survey, guided by the different intensity of contact with decision makers and media is offered by Bray and von Storch (1999). Subsequently, the survey has been extended to include samples of scientists in Italy and Denmark. Results of the survey conducted in Italy and Denmark are presently being analyzed and will be published elsewhere.

2. The survey

A survey of climate scientists' perspectives regarding global warming and the extension of the knowledge from the physical to the social world was distributed to climate scientists in Germany, Canada, and the United States in 1996. To assist in the design of pertinent questions, a series of in-depth interviews was conducted with scientists in major institutions in the United States, Canada, and Germany. The resulting questionnaire, consisting of 74 questions, was pretested in a German institution and after revisions, distributed to a total of 1000 scientists in North America and Germany. Most questions were designed on a 7-point rating scale. A set of statements was presented to which the respondent was asked to indicate his or her level of agreement or disagreement, for example, 1 = strongly agree, 7 = strongly disagree.[6] The value of 4 can be considered as an expression of ambivalence or impartiality or, depending on the nature of the question posed, for example, in a question posed as a subjective rating such as "how much do you think

[6]In those instances where the clarity of the question raised comments regarding the possibility for multiple interpretations, the frequency of such occurrences will be noted.

climate scientists are aware of the information that policy makers incorporate into their decision making process?", a value of 4 is no longer a measure of ambivalence, but rather a metric.

The anonymous, self-administered questionnaire was distributed by post with no follow-up letters of reminder. Sampling was less than ideal. Sample size was limited by resources. The sample for the North American component was drawn from the EarthQuest mailing list. Due to the fact that the mailing list is more extensive than the discipline of climate science, a true random sampling technique was not employed. Rather, subjects were selected according to institutional and disciplinary affiliations, all of which were related to the climate sciences. Nonetheless, the mailing list was adequate to provide the predetermined sample size of 500 North American scientists. This resulted in a final sample of 460 U.S. scientists and 40 Canadian scientists. The sampling of German scientists, due to reasons of confidentiality, was beyond full control. A random sample of German scientists was drawn from the mailing list of the Deutsche Meteorlogische Gesellschaft by its administration, resulting in the distribution of 450 survey questionnaires. A further 50 questionnaires were distributed to members of the Max Planck Institute for Meteorology, Hamburg, and members of the University of Hamburg. Returns of the German sample extended beyond Germany and included 13 respondents reporting to be other than German. However, since they were drawn from the German mailing list, they are included here in the German sample. The number of completed returns were as follows: United States 149, Canada 35, and Germany 228, a response rate of approximately 40%, a favorable response rate when compared to response rates of similar surveys.[7]

3. Results

This data are explored in the form of box-plots, allowing for the illustration of median, mean, spread, and data values. The presentation of the data in this format is to enable a visual assessment of the degree of consensus *within* and *between* the sample categories. Lowest and highest values are indicated by the "whisker" lines extended from the boxes. In the case of Fig. 1, a value of 1 indicates "very inadequate" and a value of 7 indicates "very adequate." The boxes contain the 50% of values falling between the 25th and 75th percentile; the lower boundary of the box is the 25th percentile and the upper boundary the 75th percentile. This means that 50% of the cases have values within the box, 25% have values larger than the upper boundary, and 25% have values less than the lower boundary. The length of the box indicates how much spread there is in the data values within the middle 50th percentile; consequently, if one box is much longer than another then the data values in the longer box have more variability. Outliers and extreme values are excluded from the figures.[8] The solid line across the box determines the median. The median (a measure of central tendency, that is, in 28, 29, 30, 31, 32, 30 is the median) is appropriate since the scale of measurement is ordinal (i.e., the numerical code provides an ordering rather than a quantity). The dotted line indicates the mean. Statistically significant differences at a level of 0.05 between the means are noted by "*" and "x." Note that the range of variability, as indicated by the lower and upper whiskers, increases with the sample size so that an intercomparison between, for instance, U.S. and Canadian ranges may be misleading. The boxes, given by the 25th and 75th percentiles, as well as the means, are unbiased estimates.

a. Assessment of knowledge of the physics: "Normal science"

The following section of this discussion addresses the physics and measurement of climate change, namely, the area of expected expertise of climate scientists. We address the scientific assessment of how

[7]Similar surveys include the following: Stewart et al. (1992), a SCIENCEnet electronic survey received 118 responses from "a computer-based network . . . which has over 4000 subscribers;" the National Defense University Study (1978) based its conclusions on the responses from 21 experts; the Slade Survey (1989) based conclusions on responses from 21 respondents; the Global Environmental Change Report Survey (1990) had a response rate of approximately 20% from a sample 1500; the Science and Environmental Policy project (Singer 1991) received a 32% response rate from a sample of 102, and later a 58% response rate from another sample of 24; the Greenpeace International Survey received 113 responses from a sample of 400; and Auer et al. (1996) report that "about 250 questionnaires were distributed (by method of personal contact at conferences) and 101 were sent back." Morgan and Keith (1995) employed the data drawn from a sample size of 16 U.S. climate scientists. This list is by no means exhaustive of such surveys but is included for further reference should the reader be so inclined as to assess other perspectives.

[8]Excluded values are those values that exceed 1.5 box lengths from the upper or lower edge of the box. Such values are considered outliers and their exclusion has no impact on the median.

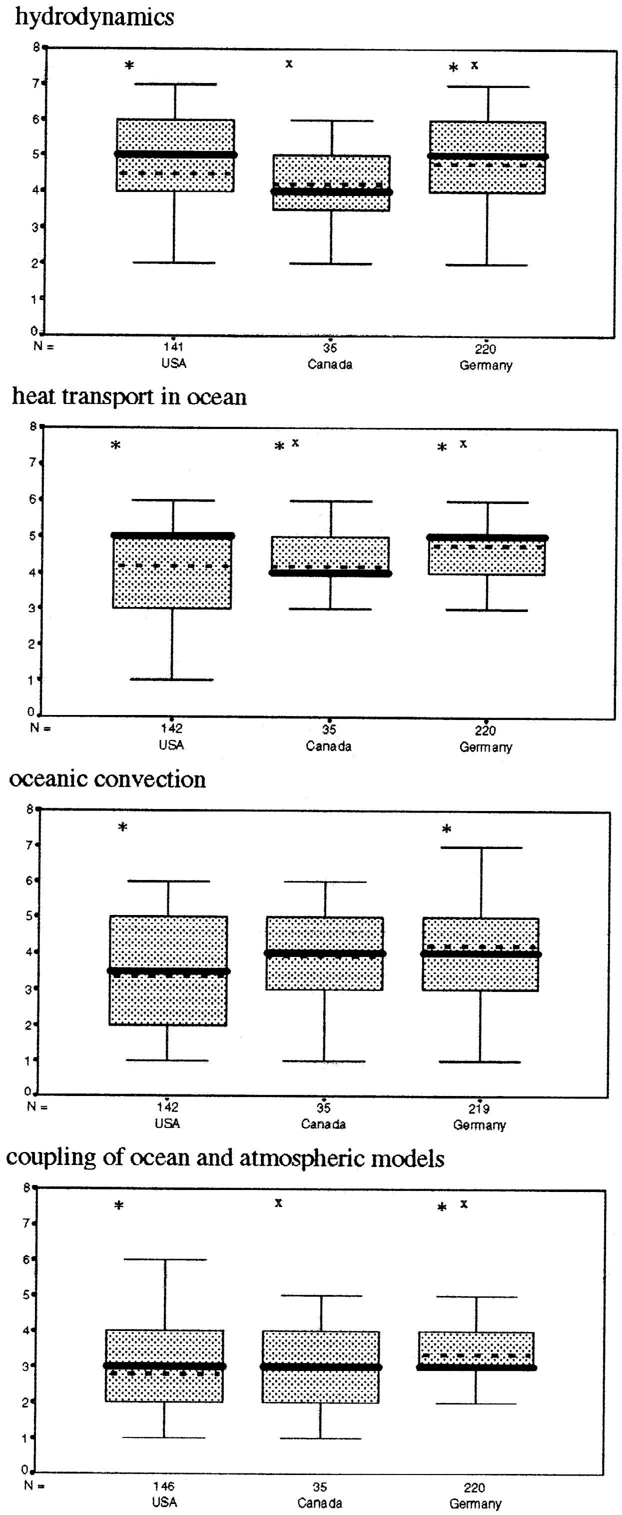


FIG.1. The perspective of the utility of the physics: ocean models (1 = very inadequate; 7 = very adequate). One respondent claimed the question, "To what extent do you think ocean models can deal with hydrodynamics?" was not clear.

the knowledge of individual physical elements of the climate system are incorporated into larger models. Dealing first with ocean models, the sample of scientists was asked to what extent ocean models could deal with the process of hydrodynamics, heat transport in the ocean, oceanic convection, and the coupling of atmospheric models and ocean models (Fig. 1).

When assessing the ability of ocean models to deal with the listed processes, the sample of German scientists tended to have a slightly more optimistic perspective. While there was optimism from all groups included in the sample regarding the ability of ocean models to deal with the process of hydrodynamics (overall mean 4.7), the response of the German sample was statistically significantly different from both the U.S. sample and the Canadian sample, expressing a greater belief in the ability of the models. This pattern of responses was repeated regarding the ability of the models to deal with heat transport in the ocean, and again when assessing the ability of coupling ocean and atmospheric models. Concerning the ability to deal with oceanic convection, a statistically significant difference was found only between Germany and the U.S. samples. The least confidence regarding ocean models, both overall and within each group, was in the ability to couple atmospheric and ocean models. In all cases the sample drawn from the German scientific community expressed more faith in the ability of ocean models.

As with the perspectives regarding ocean models, the same procedure was repeated concerning atmospheric models. These results are presented in Fig. 2. No statistically significant differences were found among the groups when asked about their perspectives pertaining to the ability of atmospheric models to deal with hydrodynamics or radiation. All groups tended to respond slightly toward an optimistic assessment that hydrodynamics and radiation are dealt with at an adequate level.

A statistically significant difference is evident between the U.S. sample and the German sample when assessing the adequacy of models to deal with atmospheric water vapor, with the German sample being slightly more optimistic of this possibility than the U.S. sample. The most optimistic assessment of the ability of atmospheric models to deal with clouds was expressed by the German sample. Here, however, the overall assessment of the ability of atmospheric models (in the sense of being able to deal with clouds) is much less than adequate with an overall mean of 2.9. The same pattern of significant differences was evident when asked to assess the ability to model precipitation, with this assessment only marginally higher than the ability to assess clouds. Again, statistically significant differences existed between the U.S. sample and the German sample. Overall, the German sample tended to be slightly more optimistic about the abilities of atmospheric models.

b. The utility of the science

At this point, after the assessment of the components of the physics, scientists were asked their perceptions pertaining to the broader utility of the knowledge. Bearing in mind the above discussion points to less than unanimous consensus as to the adequacy of the models to deal with some of the physical parameters of climate science, scientists were asked to assess the *predictive* capabilities of the models. This, of course, is still within the realm of the area of expertise of the respondents; however, it is a move toward the area in which normative judgments could begin to play a greater role in shaping expert opinion. This is of particular relevance in light of the fact that global warming, or at least the major impact of global warming, is for the most part, considered a thing of the future. To this extent, scientists were asked to what degree they felt that the current state of scientific knowledge is able to provide reasonable predictions of interannual variability, climate variability of timescales of 10 years, and climate variability of timescales of 100 years. The results are presented in Fig. 3.

Here, we begin to assess the transition toward the characteristics of what has been labeled postnormal science. With a value of 1 indicating the highest level of belief that predictions are possible and a value of 7 expressing the least faith in the predictive capabilities of the current state of climate science knowledge, the mean of the entire sample of 4.6 for the ability to make reasonable predictions of interannual variability tends to indicate that scientists feel that reasonable prediction is not yet a possibility. As would be expected, there was an inverse relationship between the perception of the predictive capabilities of the science and the time span involved. The overall mean of 4.8 for reasonable predictions of 10 years indicates less faith in this ability than in the ability to predict interannual

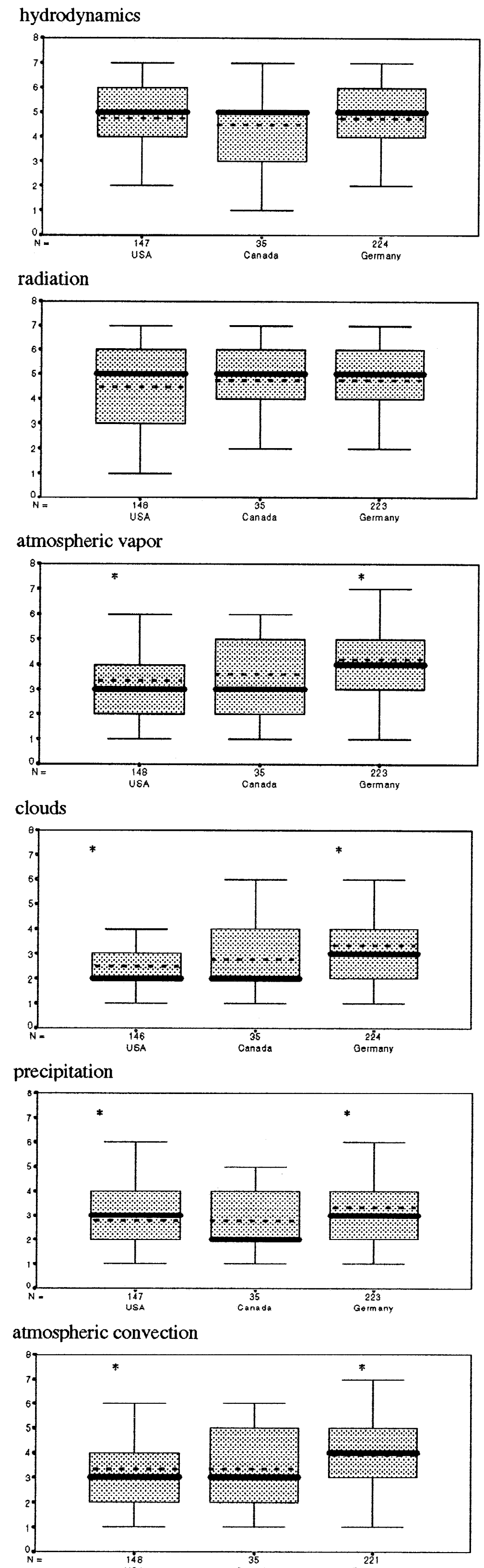


FIG. 2. The perspective of the utility of the physics: atmospheric models (1 = very inadequate; 7 = very adequate). One respondent for each of the questions claimed the question to be ambiguous.

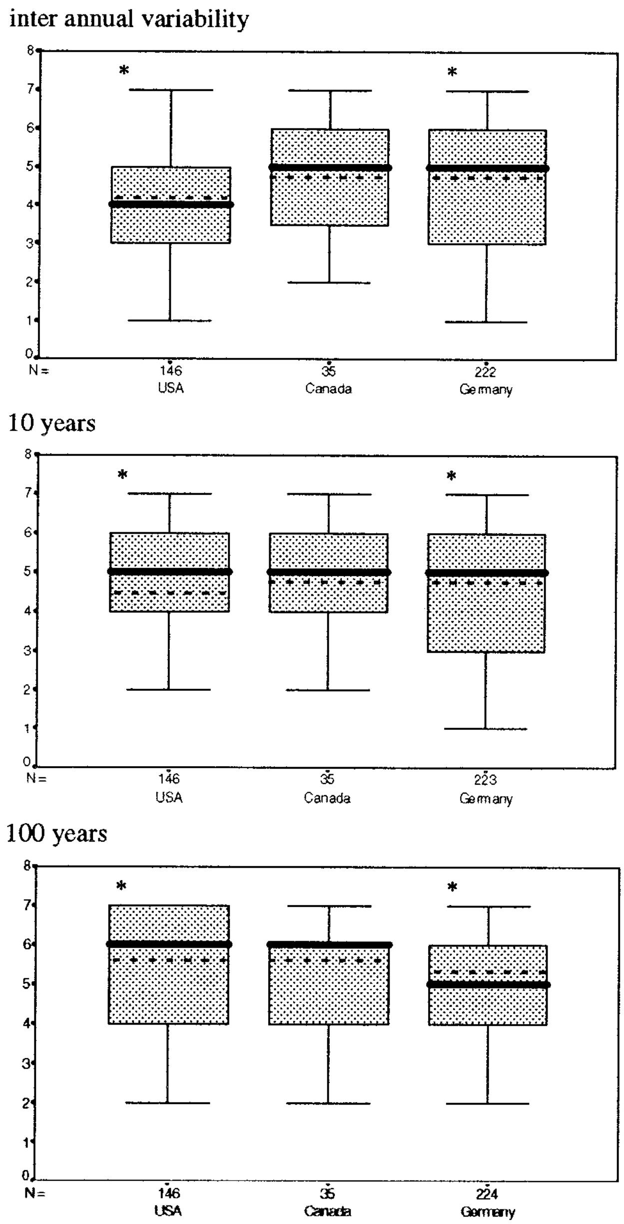


FIG. 3. Assessing the predictive ability of the current knowledge in climate science: "To what degree do you think the current state of scientific knowledge is able to provide reasonable predictions of . . . ?" (1 = a great degree; 7 = not at all). Two respondents reported the question, "To what degree do you think the current state of scientific knowledge is able to provide reasonable predictions of interannual variability to be 'vague' and 'unclear'?"

variability. A mean of 5.2 for periods of 100 years is consistent with this pattern. In terms of statistically significant differences among the groups with respect to interannual variability the United States sample, with a mean of 4.3, expressed a slightly more optimistic perspective than their German counterpart with a mean of 4.7. However, this slightly more positive attitude was not consistent. With regard to both the 10-yr period and the 100-yr period, in both instances the German sample expressed greater confidence in the ability to make reasonable predictions of climate variability, perhaps due to their higher estimation of the abilities of the science. However, in all cases optimism is noticeably absent.

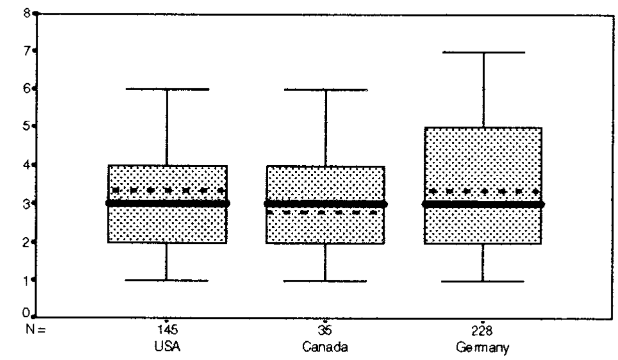
One final aspect of this part of the discussion, concerning the scientific interpretation of scientific "facts," concerns the *detection* of climate *change.* Scientists were asked first, to what degree he or she felt that we can say for certain that global warming was a process already underway, and second, to what degree he or she felt certain that, without change in human behavior, global warming will definitely occur sometime in the future. Basically this is the distinction between agreement with detection and theoretical possibility. In both cases a value of "1" represents the strongest expression of agreement, that is, a response of a value of 1 indicates a strong level of agreement with the statement of certainty that global warming is already underway or will occur without modification to human behavior. Dealing first with the claims of detection of global warming, the mean response for the entire sample was 3.3 indicating a slight tendency toward the position that global warming has indeed been detected and is underway. (Six respondents reported the statement "we can say for certain that global warming is a process already underway" to be poorly formulated.) Regarding global warming as being a possible future event, there is a higher expression of confidence as indicated by the mean of 2.6. (Four respondents reported the statement "we can say for certain that, without change in human behavior, global warming will definitely occur in the future" to be ambiguous.)

Figure 4, pertaining to the future of global warming, indicates a high expression of agreement that this is indeed a prospect to be considered. Overall, however, we could conclude that within the samples of scientists included in this survey, there is some agreement that global warming is a process already underway but that there is a greater tendency to agree that it is a prospect for the future.

c. The extension of scientific knowledge to the political realm: Postnormal science

Within the climate debates most often those with *political* interests are consumers, not producers, of scientific knowledge. This is not to say scientists have no concern for the *internal* politics of science, or for

Detection
(1 = strong agreement that global warming is underway 7= strong disagreement)



Theory *(1= strong agreement that global warming will occur in future 7= strong disagreement)*

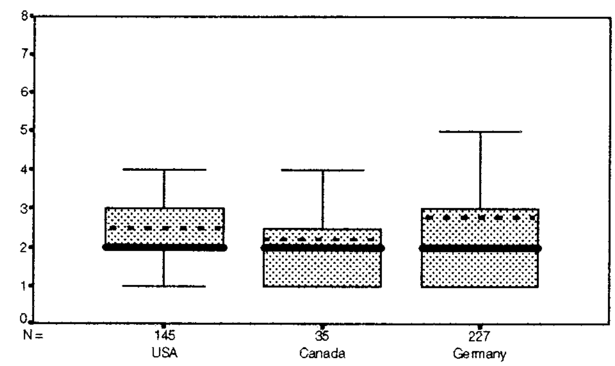


FIG. 4. Assessing detection vs theory.

broader political decisions, but simply that the broader political institutions that implement political policy are separate from science. As the ultimate implementation of policy and action arise not from the scientific community but from the translation of scientific evidence into, and by, the political realm, this section of the discussion addresses the scientific perspective of this process, namely scientists' perceptions of the relationship between science and policy. As to the level of involvement of scientists with the policy makers, there is a statistically significant difference between the German sample and the remaining groups of scientists, with the German scientists claiming the least amount of involvement. Here some major differences of the process of science–policy interaction become evident. In the sample from the United States, on the other hand, participation seems to be somewhat more level. The "less-than-arm's length" relationship between policy making institutes and many of the research institutes in Canada may account for the responses of the Canadian sample, which expressed the highest level of contact with policy makers. This contact, however, may be in the form of the negotiation of the process of knowledge transfer as indicated in the following excerpt of an interview with a Canadian scientist. Although the interview series with Canadian scientists was not extensive, the above possibility is suggested in at least one of the responses:

> The Canadian government does not want, for political reasons, the scientists that it employs to go and talk to the press at will. Although, this has happened. I think the reason for the caution lies in the fact that the government wants to fully understand the policy before it attempts to implement it. If you are a government employed scientist in disagreement with government policy the option is to take it upon yourself, should you choose to do so, to make your point of view known. However, it should be made clear that your point of view does not represent the views of your employer. If one chooses to go public, obviously there is a risk of consequences, perhaps loss of employment. In the role of the government scientist in Canada, and I believe in other places where there is a close relationship between scientists and government, the relationship might be somewhat less than at arms length. Certainly university scientists and others without government affiliation make a noise in Canada. But I think the role of the government scientist is to try and ensure that public policy reflects the best efforts of science.
>
> If it doesn't and if the scientist is convinced that it doesn't, then the scientist might consider going public. Of course, there is again, the risk of consequences. I think one might be able to go through some of the twentieth century history and find a few cases of government scientists who left because they did not agree with what was being done in their particular departments.
>
> But I think, at least in my experience as a government scientist, the government has been reasonably responsive [to its scientists] if for no other reason than you can go and talk to your friends at the universities and have them express your opinion. There is a network. We are all scientists. In the government we all have collaboration with people in the universities. When there is something desperately wrong with policy it is possible to simply ask your university colleagues to raise the issue. It would get raised regardless, mainly because we are so

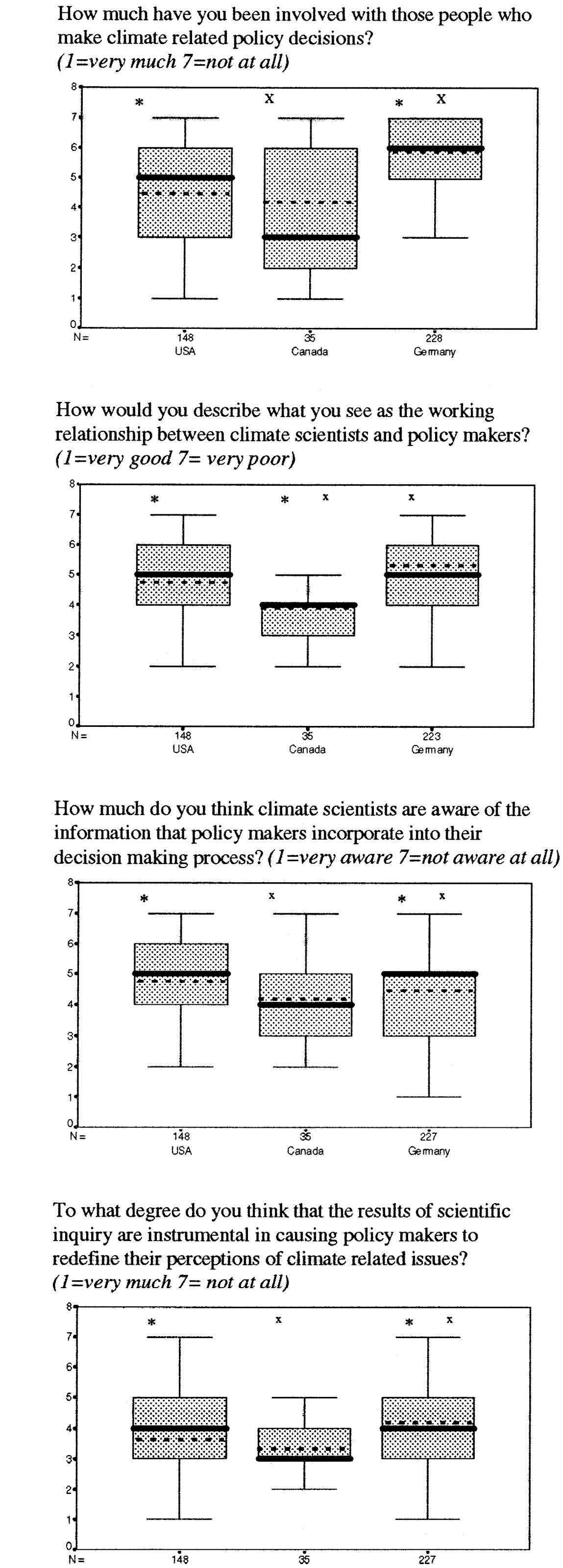


FIG. 5. Science–policy interface. Two respondents found the question "To what degree do you think that the results of scientific inquiry are instrumental in causing policy makers to redefine their perceptions of climate related issues?" to be ambiguous.

> visible. The government can't hide things very easily. Well, it can, but scientists are not inclined to hide their work. Government scientists publish in the regular literature. Nothing that we do is secret. All of our reports and publications are open to public access. We do not put things in our reports that are misinformation. I have witnessed situations where early publication of an unverified result have met with reprimand to some extent. But that is reasonable. I think that is just being cautious.[9]

In fact, a trend consistent with the Canadian example is expressed throughout the entire line of questioning (Fig. 5). When asked "How would you describe what you see as the working relationship between scientists and policy makers?" (1 = very good, 7 = very poor), the Canadian sample, although indicating much room for improvement, evaluated this relationship in the most positive light. When asked "How much do you think climate scientists are aware of the information that policy makers incorporate into their decision making process?" (1 = very aware, 7 = not aware at all), again the responses from the Canadian sample produced a result that is statistically significantly different from the U.S. and German samples. Finally, Canadian scientists felt themselves to be most effective in their ability to influence policy. When asked "To what degree do you think that the results of scientific inquiry are instrumental in causing policy makers to redefine their perceptions of a climate related issue?" (1 = very much, 7 = not at all), again the results identify the Canadian groups as being statistically significantly different from both the U.S. and German samples, emphasizing the greatest ability to influence policy. As Fig. 5 readily displays, in general, the Canadian sample expresses the highest degree of satisfaction with the science–policy interface. The sample of German climate scientists, claiming the least involvement with the policy realm also claimed the relationship between policy and science to be the poorest, claimed the least level of understanding of what policy makers need in terms of climate science knowl-

[9]The above excerpt, and all following excerpts unless otherwise noted, were drawn from a series of in-depth interviews conducted by Bray and von Storch with climate scientists in the United States, Canada, and Germany. For reasons of assured anonymity, no scientist is identified by name. Longer accounts of scientific perspectives arising from the analysis of the interviews can be found in Bray and von Storch (1996).

edge, and perceived themselves to be the least effective of the samples of scientists in shaping policy matters.

d. The science–public interface: Postnormal science

At this point we shift our discussion of the extension of the knowledge of climate change toward the *social* implications of climate change, that is, to a realm again beyond the area of expertise of those trained in the physical sciences. We begin by addressing the process of the *transfer* of knowledge to the *social* realm, rather than the *interpretation* of such knowledge. To this end, scientists were first asked how much he or she had contact with the media (Fig. 6). This was simply posed to the respondent as "How often are you contacted by the media?", with a value of 1 indicating a response of very often and a value of 7 indicating a response of not at all. Here, although the question could have been posed to generate a metric, for example, "How many times have you been contacted by the media?" it is likely that scientists do not necessarily keep a score card and the perception of the amount of contact is perhaps relative to the society in question. (The question received criticism from one respondent as being unclear.) For example, government scientists' reports are public documents and might result in the media accessing reports more than scientists. To this end, the question was posed to capture the scientist's *perception* of this pattern of interaction. The analysis of the responses indicate statistically significant differences among all groups, with the German sample reporting the least contact with the media (mean 5.3) and the U.S. sample reporting the highest level of contact with the media (mean 4.5). Next, they were asked to what degree they felt that scientists have played a role in transforming the climate issue from being a scientific issue into a social and public issue, with the response of the value of 1 indicating that the scientists felt that the scientists have been very instrumental in this regard and a value of 7 indicating the perspective that scientists have not been overly instrumental in this transition of knowledge. Statistically significant differences are evident between the U.S. sample (mean 3.3) and the German sample (mean 2.3) with the German sample being more inclined to perceive the scientific voice to be instrumental in this transition of knowledge to

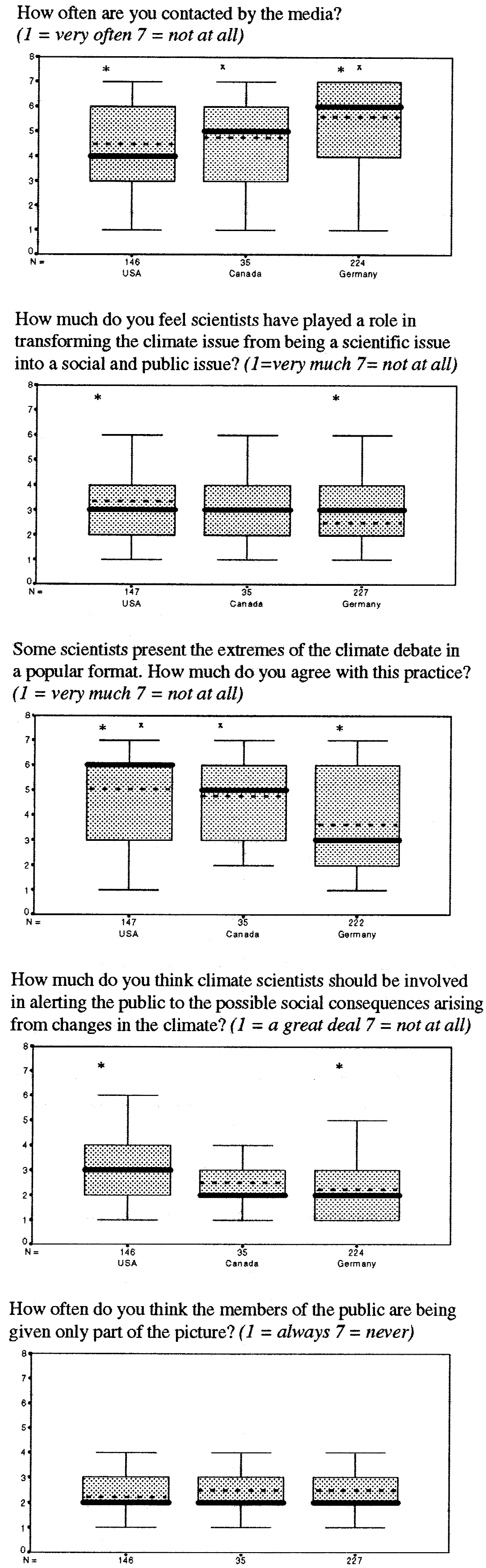


Fig. 6. Science–public interface.

the public arena. Consequently, we can draw the conclusion that while the German sample claims the lowest rate of participation in the transformation process of scientific knowledge into public knowledge, they claim the highest level of success perhaps pointing to the achievements of a few energetic spokespersons or cultural characteristics of the science–public relationship. On the other hand, this may be indicative of a more environmentally concerned industrial sector or a lesser degree of coalitions designed to block climate policy. However, this is beyond the scope of this discussion.

In regard to the *method of the presentation* of this knowledge, scientists were asked his or her level of acceptance of the practice of presenting the extremes of the climate debate in a popular format so as to alert the public. (The question "Some scientists present the extremes of the climate debate in a popular format with the claim that it is their task to alert the public. How much do you agree with this practice?" was assessed by two respondents as being ambiguous and poorly constructed.) Here again, statistically significant differences were found among all three groups, with the German sample having the highest level of acceptance of this practice (mean 3.5) and the American sample having the least tolerance for such a practice (mean 5.0). A similar pattern of responses is apparent in responses to the question of how much should climate scientists be involved in alerting the general public to the possible social consequences arising from change in the climate. Again, statistically significant differences were evident between the U.S. sample (mean 3.0) and the German sample (mean 2.5) with the German sample more ready to accept this responsibility.

When asked, however, if the public are only given part of the scientific picture, there were limited differences among the samples, all tending toward agreement that most of the time the public receive only part of the picture (mean 2.4, with a value of 1 indicating that the public always receive only part of the picture and a value of 7 indicating the perception that the public never received only part of the picture; one respondent found the question ambiguous).

In the evaluation of the transition of the scientific knowledge into the public realm, scientists from the German sample felt overall that it was the responsibility of the scientific community to alert the public of the possibilities of global warming, even if this meant representing the information in the form of extremes. The German sample assessed its influence stronger than the other two samples, while they perceived their contact to the media as less than the Canadian and U.S. samples. This may be the effect of the perceived ability of others; that is, the German climate science community may perceive their lower number of spokespeople to be very effective in this regard.

The fact that the samples from all three scientific communities agree that the public are seldom given the full picture could be interpreted in two ways: one, the scientists themselves, in an effort to get the picture across, do not fully inform the media, or two, the media are selective in the presentation of scientific accounts.

It seems that scientific–public discourse is perceived by some to be a "duty." As one German scientist noted "I think scientists should always face the obligation that he should try and inform the media as well as possible and to give a fair picture of what is happening." The same scientists continued, however, that what eventually finds its way into the popular media format does not necessarily coincide with initial scientific statements: "very often the media just go ahead and give a completely sordid view just because the more dramatic, the better it sells."

There are, of course, opposing views within all of the groups participating in the study. As one U.S. scientist stated:

> Sometimes there is a problem. Scientists discuss scientific problems not in science journals, but in newspapers and on TV, or whatever, and this is really a problem. I think as long as we are not certain about several things we should discuss those things in scientific journals and not in public. As long as we do that I think we are on the safe side.

The difficulty in conveying scientific information to the public format is well noted by a German scientist, claiming that when talking to the media, climate scientists

> should certainly present the impact on the physical system because that is what they can do. In principle [a climate scientist] should stay away from the discussion of the biological impacts, for example, but it is hard to escape from that. I know it myself because the media don't want to talk to say, 20 people. They want to talk to one, and so they ask you everything and so it is up to you give them an answer or not and it's hard for instance on a TV show to say 'no I don't answer these questions.'

In brief, regarding the science–public interface (similar to the science–policy interface) at least in the case of climate scientists that took part in this particular study, there is an indication of a polarization within the climate science community, between those adhering to the older principles of autonomy and self regulation and those opting toward the characteristics of postnormal science. The claim of course could be made, that by definition, that of a high uncertainty and a high degree of risk, all climate scientists work within postnormal science. However, postnormal science has as much to do with content as it does with practice and it is here that distinctions can be made.

e. Beyond expertise: The content of a postnormal climate science

According to the comments made in an interview with U.S. scientists, information that constitutes subjective assessments well beyond areas of expertise (of course, one cannot deny the role of normative judgments even in areas of expertise) is precisely the information that politicians hope to gain. The reply to the question "Do politicians ask for advice on how to make a decision?" resulted in the following response:

> Yes, in fact there is this phrase that congressman use, I would love to have a one-handed scientist, because a scientist will testify and say "on one hand," such and such and then "on the other hand," such and such and that doesn't give any policy guidance.
>
> I think they do often (ask for more general advice which is beyond the qualification of the scientist). In fact the way that they normally do it, you all sit down at the table, with the pros and cons on some issue and then each one of them has your few minutes and they then ask questions and so forth, and then anybody in the congress who is sitting on that committee can ask questions depending on how much time there is, and then at the end usually they will say, we certainly know that all of you aren't experts in this general area, or that you have such and such specialties, but we would be interested in your general views. How do you feel about say, global warming, and you can speak on that in the more general sense, than just the technical sense.

And again, this was apparent in comments made by a German scientist:

> When the issue of global warming started the discussion between high-ranked politicians and scientists got a totally different ground. I am able at present to sit together with our Minister. . . . All we need is two hours and then we go through a lot of topics in climate science *and in politics*, . . . they even ask me, *politicians*, (politicians ask me, the scientist) "what would you expect as a scientist to be the right decisions, and what is your expectation, what is politically achievable."

The results of the quantitative analysis are presented in Fig. 7. Regarding the *content* of what might get conveyed, each scientist was asked his or her level of agreement (1 = strongly agree, 7 = strongly disagree) with the statement that, assuming climate change will occur, it will occur so suddenly that a lack of preparation could result in devastation of some areas of the world. There were no statistically significant differences in the responses made by the groups, and the overall mean of 4.4 is an indication that this is not a commonly presented risk from among the sample of scientists. However, this is contrary to much of the media presentation claimed to be based on scientific evidence.

Scientists were then asked if they thought that it was possible yet to explicitly state the detrimental effects that climate change will have on some societies. The use of "some" as a qualifier was intended to represent those areas of the world often stated as being at high risk. An overall mean of 4.5 (1 = a great degree, 7 = none at all) would indicate that the sample from the scientific community tends toward the position that we cannot yet explicitly state the detrimental effects that climate change may bring. There were no statistically significant differences among the sample groups in this regard. Only when questioned about the society in which the scientist resides do statistically significant differences become apparent, perhaps adding the role of cultural interpretation to scientific facts.

When asked "To what degree do you think climate change will have a detrimental effect for the society in which you live?" (1 = a great degree, 7 = none at all; one respondent claimed the question to be poorly worded) the overall mean response of 4.1 is not insightful. When looking at the individual means however, we find that in both Germany and the United States the sample of scientists tended toward expressing that the impacts of global warming would be negative while in Canada, with a mean of 4.3, the tendency

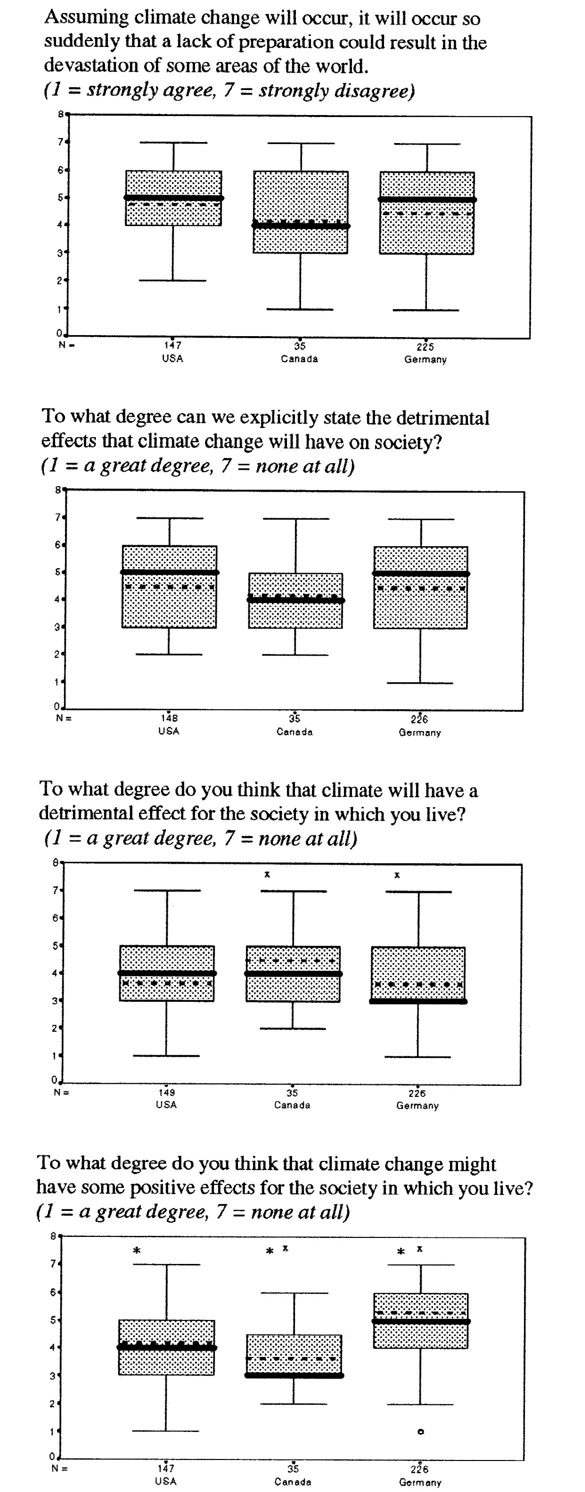


FIG. 7. Extending the boundaries beyond *scientific* discourse I.

was in the other direction, with a statistically significant difference between Canada and Germany.

This tendency was reinforced when scientists were asked "To what degree do you think that climate change might have some positive effects for the society in which you live?" (1 = a great deal, 7 = not at all; one critical comment about the question). Here there are statistically significant differences among all groups, with the sample of Canadian scientists (mean 3.8) the most inclined to suggest the possibility of positive effects of global warming and the German sample of scientists (mean 5.2) the least inclined to believe in the possibility of positive effects.

In summary, the German climate scientists tend to perceive the greater understanding of the interaction between climate and society while at the same time have the lowest level of involvement, in terms of numbers of scientists, with public and political discourse. German climate scientists responding to the survey were also those survey participants who most readily agreed that climate is a natural resource, the most likely to agree that there is a need for immediate policy decisions, the most likely to perceive that the impact of climate change will be detrimental for the scientist's host society, and the most likely to agree that societies will require substantial changes.

The scientists' perceptions of the importance of climate to humanity is, in one way, suggested in the level of agreement that "Climate should be considered a natural resource" (1 = strongly agree, 7 = strongly disagree; two claims of ambiguity; Fig. 8). The overall mean response of 2.0 indicates that indeed, climate scientists tend to perceive the topic of their discipline to extend well beyond the expression of weather and its statistics, and here there were *no* statistically significant differences between groups. Considering climate to be a natural resource implies the need for its governance similar to other natural resources, and implies a relationship with the economic well being of societies.

Bearing in mind the uncertainties expressed in the evaluation of the components of the science and the less than unanimous faith given to the predictive abilities, climate scientists were asked if they felt "There is enough uncertainty about the phenomenon of global warming that there is *no* need for immediate policy decisions" (1 = strongly agree, 7 = strongly disagree; one claim of ambiguity). Here there is undisputed support for immediate policy to be implemented with the overall mean response of 5.6 and *no* statistically significant differences among groups.

When asked "To what degree do you think it would be possible for most societies to adapt to climate change without having to make substantial changes to current social practices?" (1 = there is a need for many changes 7 = no substantial change is necessary), the majority of scientists tended to agree to some extent

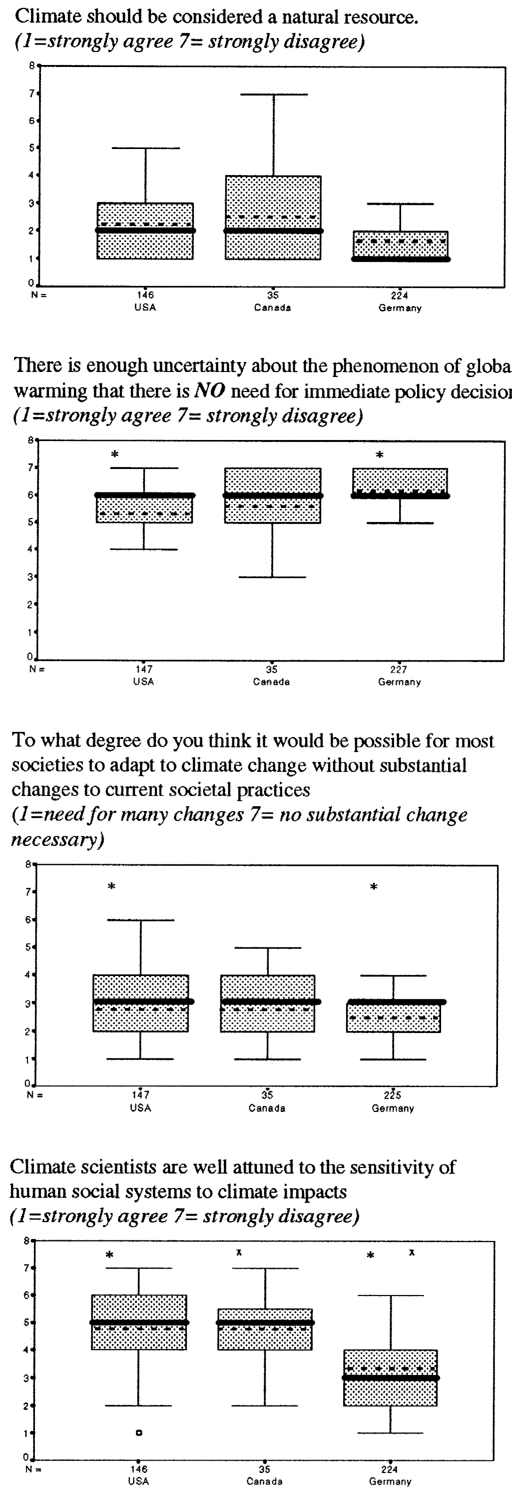


FIG. 8. Extending the boundaries beyond *scientific* discourse II.

that there is a need for many changes. This again is implicit in the translation of knowledge of the physical world into social affairs.

One should note here that the *estimation* of the risk is most definitely a legitimate natural science activity. However, the *acceptability* of the risk should remain a political activity [see Handler, president of the U.S. National Academy of Science; "Some Comments on Risk Assessment" (Douglas and Wildavsky 1983)]. While the estimation of risk should remain the undertaking of the natural sciences, the acceptability levels of such risk requires the incorporation of the social sciences (and not merely economic analyses). From the above figures it appears that some natural scientists perceive themselves well adept to also assess the levels of acceptability of risk.

4. Conclusions

As the above has demonstrated, when assessing the physics of the science, the area of expertise of the scientists, a number of statistically significant different appraisals, however minor, exist among the three groups included in the survey. This may be a result of the national focus and scope of the research program. In discussing the physics of the science, discrepancies are evident, but again, minor. It appears that scientists agree within their own area of expertise. Concerning the predictive utility of the science, the diversity of agreement increases both within groups and between groups. Concerning the science–public interface there are statistically significant differences among groups concerning the responsibilities of science and the means by which the process should occur.[10]

Under conditions of great uncertainty the issue of global warming has become a well-politicized risk, no doubt the process aided by media coverage, political, and other vested interests. According to Lewis (1990), one widely held view in this regard is that the public should be excluded from the policy process associated with risks since the public are generally too ill informed to make rational choices. Yet we can see from the above discussion that scientific credentials, whether relevant or not to the topic at hand, are often deemed sufficient to make comment well beyond the area of scientific expertise. In fact, it seems this is expected. However, to make such comment would depend upon the scientist's interpretation of the science.

This gives rise to the need for further research to determine if, in fact, the public believe the scientific statements in the manner in which they get reported

[10]Advice on how to conduct such a role is offered by Stephen Schneider (1996).

or if the process has acted to discredit both the science and journalism in the view of the public. This is particularly relevant for the scientific enterprise for as Franklin (1998) points out "As scientific information becomes increasingly ambiguous, there is a strong impulse to turn to what we see as more certain forms of knowledge and understanding as external reference points which offer more security. Religion, morality, and the politics of authority offer one way back . . . ." Kane (1998) presents the argument that the resurgence of interest in alternative medicines, in mysticism, astrology, and magic, all might be related to "the failing hope that our problems can be solved by an appeal to something beyond rational argument and accepted scientific method."

Concerning the science–policy interface, the scientific perception is far from that of a perfect relationship. It would seem that the perception of the working relationship with the political realm has a direct relationship to the level of contact. The Canadian sample whose membership claimed the highest level of contact with policy makers also ranked the relationship between policy and science as being the best. Conversely, in Germany with the sample claiming the lowest level of contact with policy makers, the rating of the relationship between science and policy was rated the worst of the three sample groups, and the influence of science on policy determination was rated as being the least. Yet one could arguably conclude that the German political realm has the highest degree of commitment toward global warming concerns from among the three groups considered in this study, suggesting perhaps the embeddedness of vested political interests in the perspective of large, problem-specific bureaucracies.

When it comes to extending the commentary beyond areas of scientific expertise, the sample of the German climate science community rated themselves as having a greater understanding of the interaction between climate and society, in spite of having a lesser opportunity to participate in the dissemination of this knowledge in terms of numbers of scientists involved with public and political discourse. German climate scientists are also those who most readily agree that climate is a natural resource, the most likely to agree that there is a need for immediate policy decision, the most likely to perceive that the impact of climate change will be detrimental for the scientist's host society, the most likely to agree that societies will require substantial changes, more likely than the United States to claim the need for a restructuring of the global economy, and most likely, as the above results would lead one to think, to claim a higher level of understanding of the sensitivity of societies to climate impacts.

In short, as scientists move from their specific areas of expertise, as would be expected, the diversity of opinion widens. Unfortunately, however, it is these opinions that, according to at least the one excerpt of the interviews presented, as well as others not presented, are the most sought after in the policy realm, and it is these opinions that the climate scientists can only present at the level of the lay perspective since they are not formally trained (at least in most cases) to assess social or economic matters in a formal manner. This is not to say, however, that social scientists or economists are devoid of normative judgments, only that they are perhaps better equipped to assess the social and/or economic options. Just as a sociologist or economist could not provide a very enlightening diatribe on atmospheric physics, so too should a climate scientist be cautious of making social and economic commentary. Perhaps it is time to begin to question the utility of traditional disciplinary boundaries and disciplinary content in light of the recognition of truly global problems, or at least begin, as some institutes have, to introduce cross disciplinary appointments spanning both the natural and social sciences.

Acknowledgments. The project was generously funded by the Thyssen Stiftung in Germany. We are indebted to Rick Anthes for the provision of the North American mailing list and Gerd Tetzlaff of the Deutsche Meteorologische Gesellschaft for arranging the distribution of the survey to the German sample, the GKSS Research Center, the Max-Planck Institut für Meteorologie for their support, and the many scientists making themselves available for interviews and for spending their time to deal with our survey. The statistics of the responses to all questions has been made public on the Internet: http://w3g.gkss.de/G/Mitarbeiter/storch/thyssen/surveyintro.htm.

References

Auer, I., R. Böhm, and R. Steinacker. 1996: An opinion poll among climatologists about climate change topics. *Meteor. Z.*, **5**, 145–155.

Bray, D., and H. von Storch, 1996: Inside science: A preliminary investigation of the case of global warming. Max-Planck Institut für Meteorologie Rep. 195, 58 pp. [Available from Max-Planck Institut für Meteorologie, Bundesstrasse 55, 20146 Hamburg, Germany.]

——, and ——, 1999: Some characteristics of the interaction among science, politics and public: The case of the climate sciences. *Anthropogenic Climate Change,* H. von Storch and G. Flöser, Eds., Springer Verlag, 295–344.

Collingridge, D., and C. Reeves, 1986: *Science Speaks to Power: The Role of Experts on Policy.* St. Martin's Press.
Douglas, M., and A. Wildavsky, 1983: *Risk and Culture.* University of California Press.
Elzinga, A., 1997: From Arrhenius to Megascience: Interplay between science and public decision making. *Ambio,* **26,** 72–80.
Franklin, J., Ed., 1998: *The Politics of Risk Society.* Polity Press, 137 pp.
Funtowicz, S., and J. Ravetz, 1985: Three types of risk assessment: A methodological analysis. *Risk Analysis in the Private Sector,* C. Whipple and V. Covello, Eds., Plenum.
——, and ——, 1990a: *Uncertainty And Quality in Science for Policy.* Kluwer, 229 pp.
——, and ——, 1990b: Post-normal science: A new science for new times. *Sci. European*.
——, and ——, 1992: Three types of risk assessment and the emergence of post normal science. *Social Theories of Risk,* S. Krimsky and D. Golding, Eds., Praeger.
Global Environmental Change Report, 1990: GECR climate survey shows strong agreement on action, less so on warming. Global Environmental Change Rep. 2, **9,** 1–3.
Jasanoff, S., 1991: Science, politics, and the renegotiation of expertise at EPA. *Osiris,* **7**, 195–217.
——, and B. Wynne, 1998: Science and decisionmaking. *Human Choice and Climate Change,* S. Rayner and E. Malone, Eds., Battelle Press, 1–87.
Kane, P., 1998: There's method in the magic. *The Politics of Risk Society,* J. Franklin, Ed., Polity Press, 76–82.
Krimsky, S., and D. Golding, Eds., 1992: *Social Theories of Risk.* Praeger, 412 pp.
Kuhn, T., 1962: *The Structure of Scientific Revolutions.* University of Chicago Press, 210 pp.
Lewis, H. W., 1990: *Technological Risk.* Norton, 353 pp.
Matthews, W. H., W. W. Kellog, and G. D. Robinson, Eds., 1971: *Man's Impact on the Climate.* MIT Press, 594 pp.
Morgan, M. G., and D. W. Keith, 1995: Subjective judgements by climate experts. *Environ. Sci. Technol.,* **29,** 468A–476A.
National Defense University (NDU), 1978: *Climate Change To The Year 2000: A Survey of Expert Opinion.* National Defense University, 109 pp.
Rayner, S., and E. L. Malone, Eds., 1998: *Human Choice And Climate Change.* Vol. 1. Battelle Press, 419 pp.
Ross, A., 1990: *Strange Weather Culture, Science and Technology in the Age of Limits.* Verso, 277 pp.
Schneider, S. H., 1996: Is the scientists/advocate an oxymoron. *Elements of Change,* S. J. Hassol and J. Katzenberger, Eds., Aspen Global Change Institute, 220–223.
Singer, S. F., and J. S. Winston, 1991: *IPCC Report: Survey, Science and Environmental Policy Project.* IPCC.
Slade, D. H., 1989: *A Survey of Informed Opinion Regarding the Nature and Reality of a Global "Greenhouse" Warming.* David H. Slade Environmental Sciences.
Stewart, T. R., J. L. Mumpower, and P. R. Cirincione, 1992: Scientists' agreement and disagreement about global climate change: Evidence from surveys. Research Rep., Nelson A. Rockefeller College of Public Affairs and Policy.
Wynne, B., 1980: Technology, risk, and participation: The social treatment of uncertainty. *Society, Technology and Risk,* J. Conrad, Ed., Academic Press, 303 pp.