

RESEARCH REPORT

Scientists' Agreement and Disagreement about Global Climate Change: Evidence from Surveys

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April 1992

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Abstract

The first part of this paper describes results of a survey of 118 scientists, indicating at least three different points of view about human-induced global climate change. One point of view generally conforms to the conclusions of the report of the Intergovernmental Panel on Climate Change. A second perspective discounts the seriousness of the threat of global warming. A third point of view emphasizes the uncertainties in current predictions.

The second part of the paper reviews the major conclusions of several related surveys and describes an analysis of the combined results of the present survey and four other recent ones, revealing a pattern of agreement and disagreement among scientists. They tend to agree most about fundamental scientific principles and observations and general policy directions. They disagree most about scientific issues related to predicting the precise magnitude and rate of climate change. Possible reasons for disagreement among scientists about global climate change and the role of surveys of scientists in the policy process are discussed.

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1. Introduction

Although "scientific consensus" is often cited in support of opposing views on global climate change, there has been little systematic study of prevailing opinion within the scientific community. Scientists are well aware that scientific consensus can be wrong, but, nonetheless, it is invoked frequently by scientists and non-scientists alike in debates with enormous policy implications. Informed choice among policy options requires an accurate assessment of critical scientific uncertainties. The degree of consensus among scientists is, at best, an imperfect indicator of scientific uncertainty. Until the major reasons for agreement or disagreement among scientists are understood, it is not possible to assess accurately the underlying scientific uncertainty.

This paper describes an initial exploration of the nature and extent of agreement and disagreement among scientists about human-induced greenhouse warming. The first part of the paper describes a survey of scientists' opinions about global climate change that was designed to address certain broad issues that are contested in the policy debate and to assess the nature of scientific uncertainty and disagreement about global climate change. The second part of the paper reviews several other related surveys and describes an analysis of areas of agreement and disagreement among scientists based on the combined results of the present survey and four other recent ones.

2. Survey method

Participants were recruited via SCIENCEnet, a computer-based network operated by OMNETtm, which has over 4000 subscribers, primarily ocean or atmospheric scientists, in 45 countries. In early November 1991, messages describing the survey and the questionnaire itself were posted on an electronic bulletin board that was accessible to all subscribers. Most respondents obtained the questionnaire by downloading it from SCIENCEnet, but some requested copies by telefax or mail. A "day message" which appeared automatically whenever any user logged onto the system was also posted for one week to alert users to the survey.

The initial bulletin board message invited scientists who "are involved in research that is related to global climate change, or have an interest in the issue and follow the literature" to complete the questionnaire. It also asked subscribers to distribute the messages and the questionnaire to their colleagues who were not SCIENCEnet users. By the end of January 1992, 118 questionnaires had been returned.¹

The major advantage of this method of distributing the questionnaire was that it provided rapid access to a large international pool of scientists actively engaged in climate-related research. A recent study of SCIENCEnet oceanographers (Hesse et al., in press) concluded that they are "active and productive scientists." They also found that more active users of the system were also more productive than less active ones.

The major disadvantage of the method was that it did not necessarily produce a sample that was representative of the community of scientists involved in global climate change research. Two obvious selection biases were operating. First, only scientists who use SCIENCEnet, or have a colleagues who do, were contacted. Second, scientists who chose to complete the survey were a self-selected subsample of those contacted. Of course, these biases (due to sampling frame and self-selection) are present, to a greater or lesser degree, in any survey.

In order to learn something about reasons for non-response, a follow-up survey was conducted in January 1992. A random sample of 110 SCIENCEnet addresses was drawn. Four turned out to be invalid addresses, leaving an effective sample size of 106. Four of those (3.8%) had responded to the survey. A brief message was sent to the remaining 102 asking them why they did not respond. An automatic receipt was received from 96 of them, indicating that the message was received. 71 responded to the message. Of those who responded,

- 43 (60.6%) did not see the questionnaire or read it,
- 1 (1.4%) experienced technical problems,
- 17 (23.9%) have research interests that have nothing to do with climate change,
- 17 (23.9%) didn't have the time, and
- 7 (9.9%) cited other reasons, usually having to do with the nature of their jobs or their expertise.

(The percents do not sum to 100 because some people gave more than one answer.)

The results of the follow-up survey indicate that less than half of SCIENCEnet users read the messages about the survey posted on the bulletin board and that less than 10% of the users who did read the message chose to respond. The primary reasons for lack of response were either lack of time or research interests that were not related to global climate change.

Since the sample cannot be considered representative of all scientists who work on issues related to global climate change, population estimates should not be made from this sample. The results of the survey are of value, however, because responses were obtained from a highly qualified, diverse, international group of scientists, and because an interesting and coherent pattern of responses emerged. Comparison of our results with those of other similar surveys also suggests that our sample was not atypical.

3. Characteristics of the sample of respondents

The 118 scientists who responded were largely North American. 91% were from the U.S. (98 respondents) or Canada (9 respondents). Other countries represented were Australia (4), Italy (1), Sweden (1), Japan (1), U.K. (2), Germany (1), and Russia (1).

104 of the respondents had received doctorates, 12 had received master's degrees and two had received bachelor's degrees. Respondents' major fields of study were classified into five categories: 1) meteorology and atmospheric science (31); 2) ocean sciences, oceanography and marine science (35); 3) physics (25); 4) biology/ecology (13); and 5) other (14).

Respondents were generally actively involved in research related to global climate change. All but seven of the respondents indicated that they participated in at least one listed activity related to global climate change, and 99 reported two or more activities, as is summarized in Table 1.

About 85% of the respondents considered themselves very familiar or somewhat familiar with the research in their field related to global climate change. Specifically, 60 respondents (51.7%) indicated that they were very familiar, 39 (33.6%) indicated that

they were somewhat familiar, and 17 (14.7%) indicated that they were very unfamiliar (two did not respond to this question).

Table 1. Activities related to global climate change research

Number of respondents	Activity
19 (16.1%)	I work with GCM's (General Circulation Models)
54 (45.8%)	I study the historical climate record
81 (68.6%)	Much of my research is devoted to topics directly related to global climate change
97 (82.2%)	I regularly keep up on current developments in climate change research
89 (75.4%)	I attend meetings and meeting sessions regularly where climate change issues are discussed

4. Description of responses

Three groups of questions addressed scientists' beliefs and opinions about global climate change. Responses to each group will be described below.

4.1. Question 1: Uncertainty about global temperature change

As a reference point for judging global temperature change, a key finding of the report of the Intergovernmental Panel on Climate Change (IPCC, 1990) was presented:

1. The Intergovernmental Panel on Climate Change predicts, under Business-as-Usual (Scenario A) emissions of greenhouse gases, a rate of increase of global mean temperature during the next century of about 0.3 degrees C. per decade (with an uncertainty range of 0.2 to 0.5 degrees C.)

4.1.1. Question 1a: Probability that IPCC range is correct

1a. What do you think is the probability that the rate of increase in global mean temperature will actually fall within this range during the next century? (Give your answer as a percent from 0-100.)

The judged probability that the IPCC range is correct (Figure 1) ranged from 0 to 100% with a mean of 59.2%. The modal response was 50% with a second mode at 90%.

The 90% mode probably reflects the selection of that point as a cutoff for requiring respondents to make their own estimates (see Question 1b below). Responses to this question indicate a wide range of opinion regarding the accuracy of the IPCC prediction.

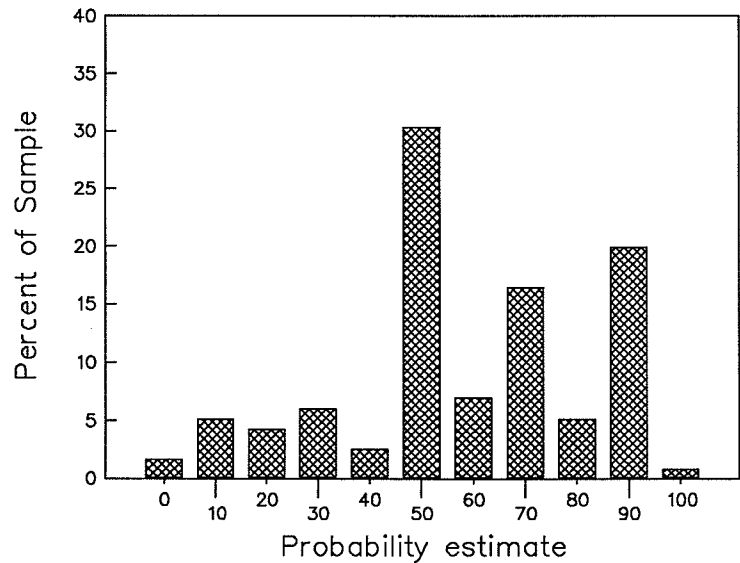


Figure 1. Responses to Question 1a: Probability that IPCC range will turn out to be correct (n = 115)

4.1.2. Question 1b: Estimates of rate of change per decade

1b. If your answer to part a is less than 90%, what prediction of rate of increase per decade and what uncertainty range do you think has a 90% chance of being correct?

"Best guess" prediction of rate of increase: _____ degrees C. per decade

uncertainty range: _____ degrees C. to _____ degrees C.

If, in response to Question 1a, a respondent gave a probability of 90% or higher, the IPCC estimates were entered as responses to Question 1b.

The best estimates of rate of change per decade (Figure 2) ranged from 0.0 to 0.8. Only two respondents, however, gave estimates higher than 0.5, and 92% gave estimates of 0.3 or below.² Only eight (8%) made estimates higher than the IPCC while 50 (52%) made lower estimates.

The lower bounds of the estimate of change per decade (Figure 2) ranged from -1.5 to 0.5; 88 (88%) of the responses were between -.2 and 0.2. Only five scientists estimated a lower bound greater than the IPCC lower bound of 0.2 while 65 (65%) made lower estimates.

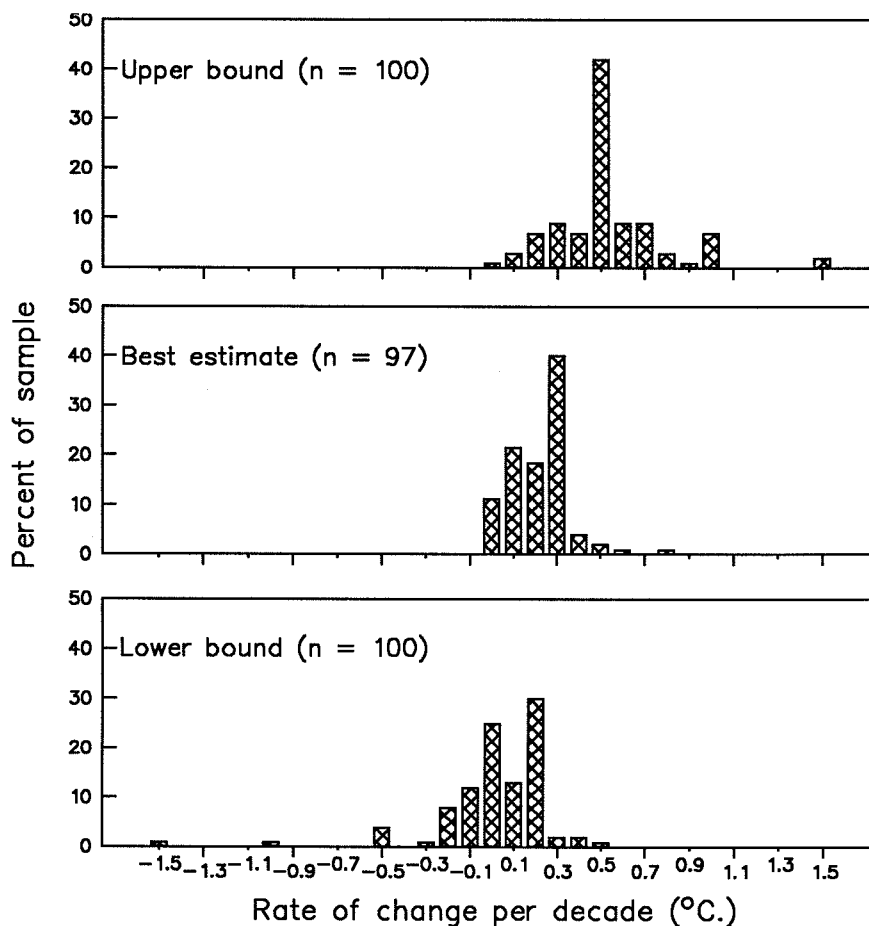


Figure 2. Responses to Question 1b: Range of estimates of rate of global temperature change per decade

The upper bounds of the estimate of change per decade (Figure 2) ranged from 0.05 to 1.5; 94 (94%) of the responses were between 0.2 and 1.0. The upper bound estimates were roughly centered on the IPCC estimate of 0.5; 31 scientists estimated an upper bound greater than the IPCC upper bound and 27 (27%) made lower estimates.

4.2. Question 2: Names of people whose opinion would be respected

2. Whose opinion would you most respect about the previous question?
 (Please list at least 3 people, not necessarily OMNET subscribers)

The respondents listed names of a total of 119 different individuals whose opinions they would most respect about question 1. Only 13 of those names were listed more than three times (Table 2). Even those most frequently mentioned were cited by only 15 (13%) of the respondents. Influence on this group of scientists is widely dispersed.

Table 2. Question 2: Names given by more than three respondents

Name	Number of times listed
1. Manabe, S.	15
2. Schneider, S.	15
3. Hansen, J.	14
4. Dickenson, R.	9
5. Lindzen, R.	9
6. Broecker, W.	8
7. Karl, T.	8
8. Ramanathan, V.	7
9. MacCracken, M.	6
10. Bretherton, F.	4
11. Ellsaesser, H.	4
12. Washington, W.	4
13. Wigley, T.	4

4.3. Questions 3-6: Agreement with statements about global climate change

Following are quotes from well-known scientists³ about potential global climate change. Indicate your agreement or disagreement with each statement as follows:

- 1-Strongly disagree
- 2-Disagree
- 3-Neutral
- 4-Agree
- 5-Strongly agree

NOTE: These statements may involve value judgments that go beyond what can be established through research. We are simply interested in your opinion as a particularly well informed citizen.

3. "... most of the scientific community would agree that the effects are going to be substantial."
Disagree-agree (1-5): _____

4. "As is becoming evident, consensus [among scientists] is increasingly restricted to relatively trivial points, such as the existence of a greenhouse effect."
Disagree-agree (1-5): _____

5. "... the current uncertainties are such that a delay in taking action is the proper policy."
Disagree-agree (1-5): _____

6. "There is little doubt among scientists that global mean temperature will increase."
Disagree-agree (1-5): _____

Questions 3-6 cannot be answered on the basis of scientific evidence alone. They may involve, in addition to an appraisal of the scientific case for global climate change, judgments and opinions about the consensus views of the scientific community (questions 3, 4, and 6), about the magnitude of the effects of global climate change (questions 3 and 5) and about benefits and costs of alternative policies (question 5). Responses to all the questions could be influenced by values as well as facts, but question 5 is particularly value-laden.

The responses to these questions (Table 3) suggest a wide range of opinion. On three of the questions at least 30% agreed while another 30% disagreed. Only on question 5, where 74.6% disagreed and 17.8% agreed, was there anything resembling a consensus.

Table 3. Responses to Questions 3-6

Response category	Number of responses			
	Question 3	Question 4	Question 5	Question 6
1. Strongly Disagree	11 (9.6%)	25 (21.7%)	50 (42.4%)	9 (7.6%)
2. Disagree	25 (21.7%)	42 (36.5%)	38 (32.2%)	27 (22.9%)
3. Neutral	21 (18.3%)	10 (8.7%)	9 (7.6%)	9 (7.6%)
4. Agree	41 (35.7%)	28 (24.3%)	10 (8.5%)	48 (40.7%)
5. Strongly Agree	17 (14.8%)	10 (8.7%)	11 (9.3%)	25 (21.2%)
Total	115 (100.0%)	115 (100.0%)	118 (100.0%)	118 (100.0%)
Mean response	3.24	2.62	2.10	3.45

5. Patterns of responses: Results of a cluster analysis

Responses were cluster analyzed to determine whether they could be grouped according to consistent patterns or "points of view." Three variables, based on responses to question 1, were selected for clustering: 1) the probability that IPCC range is correct, 2) the best estimate of rate of change per decade, and 3) the range (upper bound minus lower bound) of possible rates of change. The clustering method used was the K-means algorithm (Hartigan, 1975). Because 26 respondents gave incomplete answers to question 1, only 92 were clustered. The means and standard deviations for the four clusters identified are reported in Table 4.

Cluster 4 isolated three people who gave a range of estimates far greater than any other respondents. In fact, their range estimates were so great that it is possible they misunderstood the question and judged amount of temperature change rather than change per decade. Because of the small number of respondents in this cluster, it will not be discussed further. The following results are based on 89 respondents in clusters 1-3.

Table 4. Means and standard deviations (in parentheses) for clusters

Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Probability (%)	21.9 (17.4)	54.9 (11.9)	85.1 (12.0)	48.3 (17.6)
Best estimate (°C.)	.058 (.005)	.188 (.088)	.332 (.103)	.267 (.252)
Range (°C.)	.304 (.113)	.572 (.252)	.384 (.128)	2.167 (.764)
Number in cluster	13	39	37	3

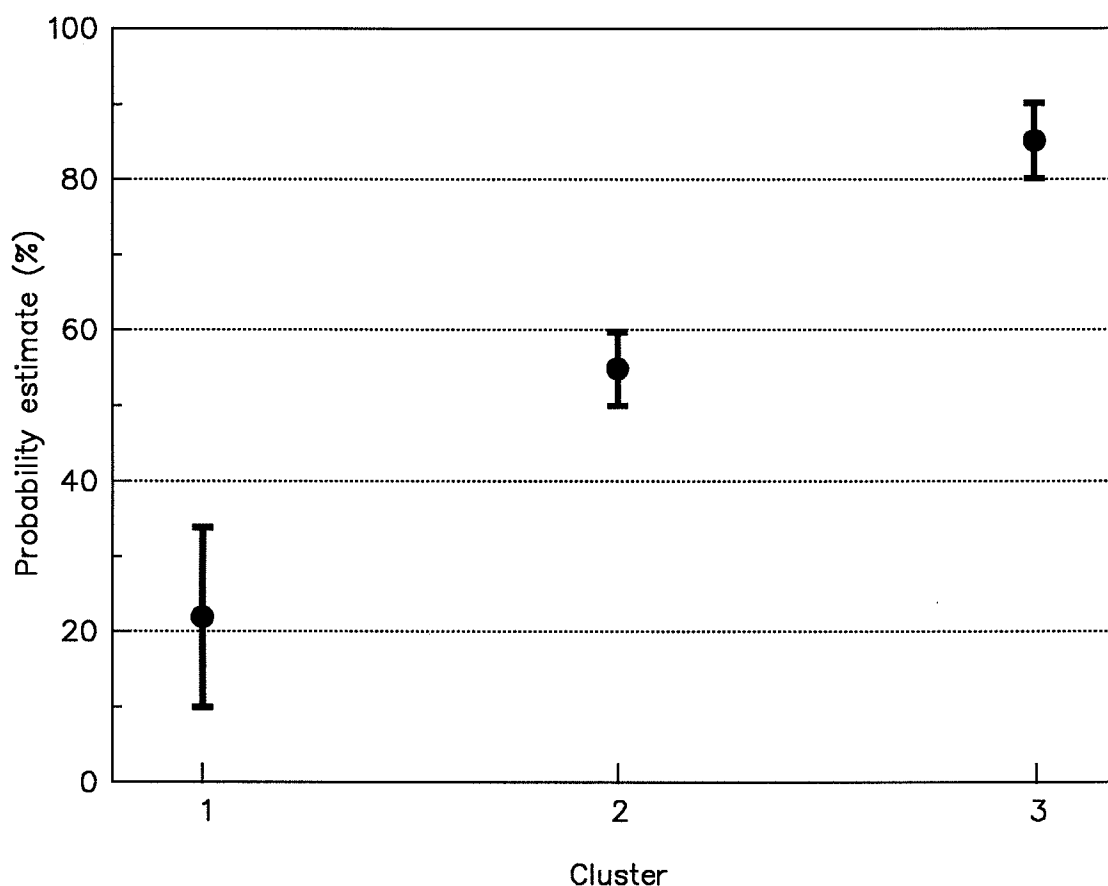


Figure 3. Means and 99% confidence intervals for probability estimates by cluster

The distinguishing features of each cluster are readily apparent from Figures 3 and 4. Figure 3 shows 99% confidence intervals for the mean probability estimate for each cluster. There was a clear difference among clusters about the judged probability that the IPCC uncertainty estimate will turn out to be correct. Figure 4 shows the 99% confidence intervals for mean rate of change estimates for each cluster. Based on these results, we can describe the clusters as follows:

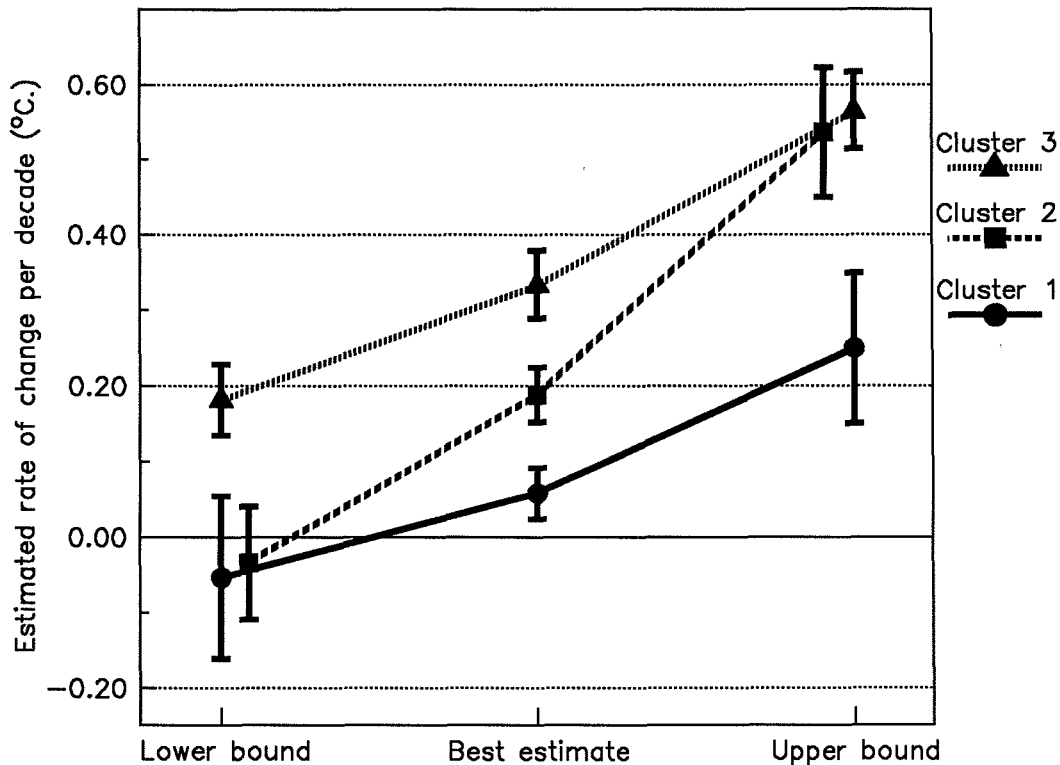


Figure 4. Means and 99% confidence intervals for rate of change per decade by cluster

Cluster 1 (n = 13). Scientists in this group registered skepticism about the IPCC uncertainty range. They assigned a low probability to the IPCC estimate and their own best estimate of rate of change per decade was lower than the IPCC estimate.

Cluster 2 (n = 39). Scientists in this group tended to fall between the other two clusters on probability estimate and best estimate. They attached a wider range of uncertainty to their estimates than did members of the other clusters. It is interesting that their estimated lower bound agreed closely with Cluster 1 and their upper bound agrees closely with Cluster 3. Members of this cluster seemed to emphasize the uncertainty in current estimates.

Cluster 3 (n = 37). Scientists in this group assigned a high probability to the correctness of the IPCC estimate and their own estimate corresponded closely to the IPCC's. Views of this group closely matched the IPCC estimate.

The three points of view resemble the distinction, made by Glantz (1988), between "doves," "owls," and "hawks" within the scientific community. He describes doves as those who "feel that the greenhouse warming scenario is yet another doomsday scenario that will most likely fail to materialize" and also those who believe in "societal ingenuity." They might fall in our Cluster 1. The owls (similar to our Cluster 2) "have yet to make up their minds on the issue." Hawks "believe that the evidence of a CO₂/trace-

gases warming is very convincing and that the warming is already underway." They might fall in our Cluster 3.

Since the sample was not representative, no conclusions should be drawn from the size of these groups in our sample. However, the results do provide evidence that these points of view exist in the scientific community. The following paragraphs describe relations between the clusters and other variables.

Only one statistically significant relation between field of study and cluster membership was found. Atmospheric scientists were more likely to fall into Cluster 2 than other scientists. 16 out of 22 (72.7%) atmospheric scientists were in Cluster 2 versus 23 out of 67 other scientists (34.3%). The relation between being an atmospheric scientist and cluster was statistically significant (Chi-square (2) = 11.08, p = .004).

Table 5. Names of people whose opinion you would most respect, by cluster

Name	Number of times listed by scientists in		
	Cluster 1	Cluster 2	Cluster 3
1. Manabe, S.	0	7	7
2. Schneider, S.	0	4	10
3. Hansen, J.	1	3	7
4. Dickenson, R.	0	4	5
5. Lindzen, R.	4	2	1
6. Broecker, W.	1	3	3
7. Karl, T.	2	3	1
8. Ramanathan, V.	1	2	2
9. MacCracken, M.	1	3	2
10. Bretherton, F.	1	2	0
11. Ellsaesser, H.	1	1	0
12. Washington, W.	0	3	1
13. Wigley, T.	0	3	1

Table 5 shows the number of times each of the scientists listed in Table 2 was mentioned by respondents in each cluster as one of the people whose opinions they would most respect. Different scientists are influential in different clusters. Schneider and Hansen are mentioned more often by members of Cluster 3 than the others. Lindzen is mentioned most often by members of Cluster 1. Washington and Wigley are mentioned most often by members of Cluster 2. Other scientists (e.g., Manabe) are mentioned by members of two or more clusters with similar frequency.

The relation between cluster membership and self-rated familiarity with research on global climate change was not statistically significant (Chi-square (4) = 5.972; p = .205). People who indicated that much of their research was related to climate change, however, were more likely to fall in Cluster 1 than those who did not so indicate (13 of 60, 21.7%, vs. 0 of 27). This relation was statistically significant (Chi-square (2) = 6.891; p = .032). No other activity (Table 1) was significantly related to cluster membership.

The mean responses for questions 3-6 for each cluster are presented in Table 6. Members of Cluster 1, like Glantz's "doves," questioned the importance of greenhouse warming and its effects. Members of Cluster 3 express the greatest concern about the effects of greenhouse warming. Views of members of Cluster 2 fall between the other two, nearer the point of neutrality.

Table 6. Mean responses to questions 3-6 by cluster

	Question 3	Question 4	Question 5	Question 6
Cluster 1	1.92	3.92	2.77	2.15
Cluster 2	3.03	2.68	2.31	3.28
Cluster 3	3.89	2.17	1.59	4.22

Note: 1 = Strongly disagree, 3 = Neutral, 5 = Strongly agree

Statements for each question:

3. "... most of the scientific community would agree that the effects are going to be substantial."
4. "As is becoming evident, consensus [among scientists] is increasingly restricted to relatively trivial points, such as the existence of a greenhouse effect."
5. "... the current uncertainties are such that a delay in taking action is the proper policy."
6. "There is little doubt among scientists that global mean temperature will increase."

Note that statements 3, 4, and 6 are statements about consensus or agreement among scientists. It would be possible, for example, for a scientist to agree with statement 3 if his or her personal beliefs were a) that the effects were *not* going to be substantial, and b) that most scientists thought otherwise. The pattern of differences among clusters suggests, however, that scientists' beliefs about the nature of scientific consensus are related to their own personal beliefs.

In summary, there was substantial disagreement in our sample about predictions of the rate of global warming over the next century and the cluster analysis showed that the disagreement could be characterized in terms of three clusters, each representing a different point of view. Membership in clusters was related to

- a) being an atmospheric scientist (atmospheric scientists were most likely to fall in Cluster 2, the one expressing the most uncertainty about climate change);
- b) which scientists' views about climate change are most respected;
- c) whether the respondent indicated that most of his or her research was related to global climate change (a weak tendency for those indicating that most of their research was related to global climate change to fall in Cluster 1--the group most skeptical of the IPCC estimate); and
- d) agreement or disagreement with general statements about the scientific consensus, effects of climate change, and policy.

6. Results of previous surveys

This section briefly reviews six previous surveys of scientists' opinions about global climate change, compares their results with those of our survey, and presents the results of a combined analysis of the results of five surveys.

6.1. NDU: National Defense University study (1978)

In the mid 1970's, as part of a study of the potential effects of climate change on agriculture, the National Defense University (1978) selected a panel of climatologists representing diverse views about climate change. Based on questionnaire responses from 21 experts, they concluded that "the salient finding is that the likelihood of catastrophic climatic change by the year 2000 is assessed as being small" (p. xvii).

Several of the NDU panelists predicted a global cooling trend, a point of view that is rare today. In our survey, the range of uncertainty for 28 (out of 100 who responded to the question) scientists allowed for the possibility of a cooling trend, but no scientist's best estimate suggested cooling. In the GEGR survey, described below, 1.9% predicted that a cooling will occur during the next 100 years.

This study showed substantial disagreement among climatologists' predictions of global temperature change. In their critique of this study, Stewart and Glantz (1985) pointed out that the conclusion of the study was based on averaging the views of scientists who predicted global cooling with the views of those who predicted global warming. An average of such conflicting views clearly does not represent consensus.

6.2. Slade survey (1989)

Slade (1989) surveyed 21 scientists "conversant with or actively involved in studying global greenhouse climate change." The method for choosing scientists and the number who refused to respond was not reported. Of the 16 questions asked, two were relevant to beliefs about the magnitude of climate change. 17 scientists indicated a strong belief in "the reality of a significant climate change." Also, 13 indicated that a prediction of global average change of 3 - 5°C. (no time period was specified in the questionnaire) was "about right," three indicated that prediction was too high and two indicated it was too low.

The Slade survey contained several questions about uncertainty. Heading the list of "major uncertainties" mentioned were clouds, oceans, and general circulation model (GCM) error propagation and parameterizations. Most respondents indicated a moderate to high probability that these uncertainties would "dramatically change current GCM-simulated, global climatic predictions."

Slade concluded that the "survey generally endorsed the widespread beliefs that a climate change is likely and that the global climate model simulations describe the gross characteristics of the future climate state."

6.3. GECR: *Global Environmental Change Report Survey (1990)*

In March 1990, the editors and staff of *Global Environmental Change Report* (GECR), a newsletter published by Cutter Information Corporation, sent a questionnaire to 1500 scientists randomly sampled from a database of 5000 researchers that was compiled from conference attendance rosters and lists provided by other climate change research bodies. Based on 331 completed surveys from 41 countries, it was concluded that there was "strong agreement on action, less so on warming" (Global Environmental Change Report, 1990).

This survey indicated substantial agreement among the scientists surveyed with respect to:

- a) established scientific principles or measurements, e.g., the greenhouse principle, that global temperatures have increased during last 100 years;
- b) policy directions, stated abstractly, that reflect value judgments and may be considered good by many whether or not global warming occurs, e.g., countries should take steps to halt deforestation, countries should reduce carbon dioxide emissions; and
- c) conditional statements about the direction, but not magnitude, of effects of global warming, assuming that it occurs, e.g., global warming would cause sea levels to rise.

There was less agreement about quantitative estimates of the magnitude of global warming. For example, when asked "What do you think is the probability of a greenhouse warming of at least 2°C. during the next 100 years?" responses ranged from "Greater than 90%" (19.3%) to "Less than 10% (8.7%)". Almost 40% said the probability was 75% or greater while about 30% said it was less than 50%. This level of disagreement is similar to that found in our survey.

6.4. SEPP: *Science and Environmental Policy Project Survey (1991)*

Singer and Winston (1991) mailed questionnaires to 102 reviewers and contributors to the June 1990 IPCC report; 32% were returned. They also mailed the same questionnaire to 24 members of the "Phoenix group" who had met in Phoenix in October 1990 to discuss alternatives to the popular vision of the greenhouse effect; 58% were returned.

The IPCC reviewers and contributors tended to agree that "the individual sections of the IPCC report reflect my views." The Phoenix group tended to disagree with the same statement. When asked for their "best personal estimate of global average warming, corresponding to a doubling of greenhouse gases in the next century," the reviewers and contributors responses ranged from 0.5 to 5°C. with a modal response of 2°C. The Phoenix group's responses ranged from 0 to 1.5°C.

When asked "What fraction of the approximately 0.5 degree C. warming of the past century do you attribute to greenhouse warming, reviewers' and contributors' responses ranged from 0 to 100%, while the Phoenix group's responses ranged from 0 to 50%.

Reviewers and contributors to the IPCC report and the Phoenix group both tended to agree (although the Phoenix group agreed more strongly) with the following statement from the IPCC report: "It is not possible to attribute all, or even a large part, of the observed global-mean warming to the enhanced greenhouse effect on the basis of observational data currently available." Both groups tended to disagree (although the Phoenix group disagreed more strongly) with the statement "Current global circulation models have been adequately validated by the climate record of the past 100 years."

The results of this survey indicate substantial disagreement among those surveyed about the magnitude of global climate change. Among the IPCC reviewers and contributors are both scientists who seem to accept the IPCC report and those with more skeptical views, resembling the Phoenix group.

6.5. Greenpeace survey (1992)

Greenpeace International (1992) surveyed 400 scientists during December 1991 and January 1992. All scientists who were involved in the IPCC report and others who published relevant papers in *Science* or *Nature* during 1991 were included; 113 responded. The key question was:

"Do you think there will be a point-of-no-return, at some time in the future, at which continued business-as-usual policies run a serious risk of instigating a runaway greenhouse effect?" The responses were:

Probably:	15	(13%)
Possibly:	36	(32%)
Probably not:	53	(47%)
Other:	4	(3%)
No answer	5	(4%)

Based on these responses, it was concluded that "...almost half of surveyed world climate scientists believe that a runaway greenhouse effect is possible if action is not taken to cut greenhouse gas emissions."

As with the NDU study, the interpretation of the results by the sponsoring organization was misleading. Greenpeace's Dr. Jeremy Leggett stated that "This result reveals an as-yet poorly expressed fear among a growing number of climate scientists that global warming could not lead just to severe problems but complete ecological collapse." This statement may or may not be valid, but it is clearly not supported by the survey results. The question wording includes nothing about scientists' "fears" or about "complete ecological collapse." Furthermore, a single survey cannot establish whether the number of scientists holding any belief is growing or shrinking.

6.6. CSTM: Center for Science, Technology, and Media Survey (1992)

In October 1991, the Center for Science, Technology, and Media commissioned the Gallup Organization to conduct a survey of 400 experts. Eighteen questions were asked in telephone interviews of members of the American Meteorological Society and/or the American Geophysical Union. The Center for Media and Public Affairs was also commissioned to catalog nearly 400 news reports about global warming.

The response rate for this survey was not reported, but telephone surveys generally result in higher rates of participation than mail surveys. Students and broadcast meteorologists were screened out at the beginning of the interview.

The principal finding was that discrepancies exist between the opinions of scientists and the way global warming is reported in the media. "The uncertainty revealed in the Gallup survey contrasts with the content of nearly 400 major media reports in which most sources assert that the theory is valid" (Center for Science, Technology, and Media, 1992).

As with the other surveys, substantial disagreement was found about estimates of the magnitude of global temperature change. When asked to estimate the probability of human-induced global warming of 2°C. or more during the next 50 to 100 years, responses ranged from 0 to 100%, with 16% answering "Don't know." 22% estimated probabilities of 70% or greater while 26% estimated probabilities less than 30%. The range of disagreement is similar to that found for a similar question in the GEGR survey.

7. Analysis of combined survey results

Taken together, the results of these surveys indicate that scientists disagree when they are asked to predict the rate or magnitude of global temperature change. In addition to predictions of temperature change, the surveys contain information about scientists' agreement and disagreement about a number of other issues. This section describes an analysis of areas of agreement and disagreement among scientists (other than about predictions of temperature change) based on the combined results of five surveys.

Five of the most recent surveys were included: Slade (SLADE), Global Environmental Change Report (GEGR), Science and Environmental Policy Project (SEPP), Center for Science, Technology, and Media (CSTM), and our survey (CPR). The Greenpeace survey was not included in the analysis because the questions asked were not comparable to any of the other surveys. The results from the Phoenix group in the SEPP survey were also excluded because that group was chosen to represent a particular point of view and was therefore expected to be much more homogeneous than the general scientific community.

A simple index of agreement was constructed for each question. For questions with two or three possible answers, the index was simply the percent of the sample choosing the most popular response. For questions with five possible responses, the responses on either side of the neutral point were combined, thus reducing the responses to three categories. The agreement index was the number choosing the most popular of the resulting categories. Bias in the index due to the number of original response categories was removed by an adjustment that equated the mean agreement index for questions with two, three, or five categories. Questions with more than five categories, which were always about probabilities or magnitudes of change, were excluded because any single index of agreement for these questions would be highly subjective.

A total of 43 items from the five surveys were classified into seven topical groups. The mean agreement index was computed for the items in each group (after weighting the agreement index for each item by the number of respondents). The topics are listed below in order of agreement:

- 1) Questions about policies that countries should adopt (5 items, mean agreement = 78.7%)
- 2) Questions about scientific principles or observations of past climatic trends (3 items, mean agreement = 72.2%)
- 3) Questions about confidence in the scientific understanding of greenhouse-related issues and the validity of GCM's (15 items, mean agreement = 72.0%)
- 4) Questions about factors that influence warming (3 items, mean agreement 67.4%)
- 5) Questions about whether human-induced greenhouse warming is now occurring, or will occur, and whether warming is within range of natural fluctuation (6 items, mean agreement = 63.7%)
- 6) Questions about the impacts of warming (7 items, mean agreement 62.1%)
- 7) Questions about whether current evidence substantiates that human-induced greenhouse warming is occurring (4 items, mean agreement 58.0%)

If there was a consensus among scientists who responded to these surveys, it was about policies. In our survey, that consensus was exemplified by the disagreement expressed by 74.6% of the respondents with the statement that "...the current uncertainties are such that a delay in taking action is the proper policy." It was also indicated in the GEGR survey by general agreement that countries should adopt policies to reduce emissions of CO₂ and other greenhouse gases, halt deforestation, and preserve rain forests. Since these issues cannot be decided on scientific evidence alone (and, in any event, scientists disagree more about the scientific evidence than they do about policy options), this agreement may reflect a shared value orientation. Perhaps it reflects the belief of many scientists that "the things we would do to mitigate the greenhouse effect are things we should be doing anyway."

The importance of this apparent high level of agreement among scientists about the policy implications of greenhouse warming must be tempered by two considerations. First, scientists are generally not experts in policy decisions. They may be no more aware than other well-educated citizens of the complexities, costs, and benefits of international policy programs designed to reduce emissions of greenhouse gases or preserve rain forests. Second, the questions are stated only in general terms. Statements such as "should countries take steps now to reduce carbon dioxide emissions" (GEGR, question 17) can only elicit responses based on general attitudes because they do not specify *which* steps and *at what cost*. More specific questions about policy options might well elicit more disagreement among scientists. In other words, the agreement found on these question may be "empty agreement" that disappears when the details are disclosed.

Not surprisingly, scientists also agree about scientific principles and observations of past climatic trends. The highest level of agreement on any item was obtained in response to the question "Do you think that the greenhouse principle is valid, i.e., that increasing the concentration of water vapor and trace gases such as carbon dioxide, methane, CFC's and nitrous oxides would increase the atmosphere's heat-trapping capacity and warm the climate?" (GEGR, question 3); 95.8% answered "yes." Two other questions in this category had the following wording: "Do you think that global average

temperature has increased during the past 100 years?" (GECR, question 1 and CSTM, question 3). In the GECR survey, only yes or no responses were allowed and 81.4% answered "yes." In the CSTM survey, a "Don't know" category was included and 60% answered "yes;" 25% answered "Don't know." (Such dramatic shifts, due to subtle differences in question wording or sample selection are a well-known hazard of survey research.)

There was substantial agreement that confidence in scientific understanding of greenhouse-related issues is not high. For example, 90% of the respondents to the CSTM survey characterized the study of global climate change as an "emerging science" rather than a "fairly mature science." There was somewhat less agreement about GCM's. The 33 respondents to the SEPP survey were evenly split on whether current global circulation models accurately portray the atmosphere-ocean system, but only three agreed that "Current Global Circulation Models have been adequately validated by the climate record of the past 100 years."

The lowest agreement was on the items that addressed scientific issues, i.e., factors that influence warming, the likelihood of human-induced greenhouse warming, the impacts of warming, and whether current evidence substantiates that human-induced greenhouse warming is occurring. These are issues which can, in principle, at least, be settled on scientific grounds, and where the scientists' training and expertise are most relevant. The substantial lack of consensus on these issues validates the scientists' own judgment that the study of global climate change is an "emerging science."

8. Possible reasons for agreement and disagreement

The surveys indicate that scientists agree about data and fundamental principles, but disagree about the more complex scientific aspects of human-induced global warming, as reflected in the wide range of predictions of the rate and magnitude of change. The same surveys also show that scientists tend to agree that governments should adopt policies in response to the greenhouse issue, at least when those policies are stated abstractly. Cluster analysis of our survey suggests that at least three different perspectives on human-induced global warming are represented in the scientific community.

Surveys can provide a "snapshot" of the extent of disagreement among scientists at a given time. The results of surveys leave considerable doubt, however, about the underlying reasons for disagreement. Does disagreement accurately reflect scientific uncertainty, or is it a result of other cultural, social, or psychological factors? Resolving this question requires more detailed study than is possible with surveys. In this section, some possible explanations for disagreement are briefly discussed.

One possible explanation is that the disagreement is not real but rather an artifact of the survey methods used. In the surveys conducted to date, the population of scientists with relevant expertise has not been clearly specified and the samples have been self-selected. As a result, the samples may not be representative of the "scientific community," and certain points of view may be over- or under- represented. Furthermore, the survey questions are often vaguely worded and subject to differing interpretations. Questionnaires encourage scientists to make judgments they would not otherwise make, e.g., the probability of a 2°C warming, and to make those judgments casually. In their critique of the NDU study, Stewart and Glantz (1985) explain how the wording of questions, response modes, and data analysis can influence results.

The practical problems associated with survey design, sampling, and implementation make it unlikely that the shortcomings of previous surveys will be fully rectified in the near future, if ever. The emergence of consistent patterns of disagreement across several surveys that have used different methods with different samples and different wording of questions suggests, however, that the disagreement is not entirely artifactual.

Perhaps the most popular explanation for non-artifactual disagreement among scientists is the political one. As described by Stewart (1991):

The political stakes in the greenhouse debate are obvious. Strong policies designed to reduce CO₂ emissions would also result in energy conservation and reduced emissions of other pollutants, thus contributing to goals long sought by environmentalists. Those same policies could also impose an economic burden on industry and individuals. This somewhat oversimplified view is compelling to the layperson, and it leads to a simple explanation for disagreement among scientists: Scientists form opinions based on their political views and their perceived self-interest and then merely select evidence that supports their opinions. (p. 568)

As intuitively appealing as it might be, survey results do not support the political explanation. Scientists agree more on the most political items than they do on the items that are restricted to scientific issues. In our study, for example, the three clusters differed least on the most political question. Political differences clearly do not provide a complete explanation for the disagreements observed among scientists' responses to the survey, although they may contribute to them. To determine the relative importance of the political factor, further study will be needed. In particular, methods need to be used that will avoid the problem of "empty agreement," mentioned above. Perhaps the level of agreement among scientists concerning the need for governmental action will change when questions are asked about specific potential policy actions.

The search for reasons for disagreements among experts should be expanded beyond the sphere of methodological artifacts and political orientation. For instance, as a result of their training and experience, scientists might think about the problem in different ways. They might formulate or structure the problem differently, e.g., by using different analogies. They might have access to different information or attach different levels of importance to the same information. They might have different ways of organizing information to make judgments. They might also be influenced by different people. For a discussion of various potential reasons that scientists might disagree, see Mumpower and Stewart (1992).

In general, an explanation for disagreement that is often overlooked is the nature of the judgment process (Stewart, 1991). As Hammond et al. (1984) have pointed out, when scientists go beyond the available data to make inferences and predictions, they are using the same judgment processes that lay people use, and they are subject to the same problems, e.g., irrelevant factors influence judgment while more relevant factors are ignored; the capacity to process information is limited, and as a result, only selected, perhaps biased, information is attended to; and the judgment process is inconsistent and not fully controlled.

Our survey indicates that training and experience may be related to differences in global temperature change predictions and that those differences are related to scientists' opinions about other aspects of the greenhouse issue. It does not explain, however, why some scientists with similar backgrounds and access to the same body of

theory and data arrive at different conclusions. More in depth study, using a variety of methods, will be required to address that question. Future studies of scientists' opinions and judgments about global climate change should attempt to determine the generality of different points of view, their relative strengths, and the reasons that different scientists subscribe to these different points of view.

9. Conclusion

The work reported in this paper is related to our broader interest in one of the most critical issues for effective public policy formation: How can a democratic society make informed decisions about issues that involve uncertainty and scientific and technical complexity? Inevitably, part of the answer to that question involves reliance on the opinions of experts. But when the experts disagree, policy makers are unsure about how to proceed. In the absence of consensus, which experts should they believe? Policy decisions that are based on either over- or under-estimates of scientific uncertainty may have disastrous consequences. How, then, does one obtain an accurate estimate of scientific uncertainty?

Surveys of scientists can provide important information by documenting disagreement and agreement among scientists, but it is less clear that they necessarily improve the use of scientific information in policy making. This is so because survey results may be misleading to the extent that they:

- a) encourage scientists to make judgments that they would not otherwise make without the requisite thought and preparation;
- b) provide the appearance of consensus by aggregating disparate views;
- c) enhance the appearance of disagreement through the use of vague questions that are subject to differing interpretations;
- d) encourage scientists to make value judgments that are beyond their expertise and confuse value judgments with scientific opinion; and
- e) are misinterpreted by their sponsors for use as political ammunition.

Results from surveys should be interpreted with caution; this applies to the results of our own survey as well as those of others. Future efforts need to move beyond merely documenting disagreements among scientists to improving understanding of the reasons for such disagreement. If we understand better why scientists disagree, we will be able to make better assessments of the scientific uncertainties about critical technical issues, and, ultimately, perhaps, better policy choices.

10. Notes

¹40 responses were received on SCIENCEnet, three on BITNET, 19 by telefax, and 56 by regular mail.

²Some respondents' estimates of rate of change per decade were so different from the other responses, that we strongly suspected that they had misinterpreted the question and estimated the magnitude of temperature change rather than the rate of change per decade. In order to eliminate these outliers from the analysis, we ignored all estimates if the lower bound was less than -1.5 or the upper bound was greater than 1.5. This resulted in deletion of four sets of estimates. The other responses given by these four individuals were included in the analysis.

³Following are the sources for each quote. These sources were not included in the questionnaire:

3. James Hansen, quoted in *USA Today*, "Some experts cool global warming talk," December 26, 1989, p. 11A.

4. Richard S. Lindzen, Letter to *Science*, 7 September 1990, vol 249.

5. William A Nierenberg, Letter to *Science*, 7 September 1990, vol 249.

6. Frank Press, What I would advise a head of state about global change, *Earthquest*, 1989, Vol.3, No. 2, 1-3.

11. Acknowledgements

This research was supported by the National Science Foundation (Division of Social and Economic Science) under Grant SES90-11868. We are grateful to the 118 scientists who took time to respond to our survey. We also want to thank OMNET staff and, particularly, Susan Kubany for their help and advice on conducting a survey on a computer-network.

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Appendix: Questionnaire and tabulated responses

GLOBAL CLIMATE CHANGE QUESTIONNAIRE

Center for Policy Research
University at Albany, State University of New York

Country:

Australia (4)	Italy (1)	Sweden (1)
Canada (9)	Japan (1)	U.K. (2)
Germany (1)	Russia (1)	U.S. (98)

1. The Intergovernmental Panel on Climate Change predicts, under Business-as-Usual (Scenario A) emissions of greenhouse gases, a rate of increase of global mean temperature during the next century of about 0.3 degrees C. per decade (with an uncertainty range of 0.2 to 0.5 degrees C.)

a. What do you think is the probability that the rate of increase in global mean temperature will actually fall within this range during the next century? (Give your answer as a percent from 0-100.)

_____ percent

Interval	Count	Percent
Missing	3	
0-20	11	9.6
21-40	12	10.4
41-60	40	34.8
61-80	28	24.3
81-100	24	20.9
Total	115	100.0

b. If your answer to part a is less than 90%, what prediction of rate of increase per decade and what uncertainty range do you think has a 90% chance of being correct?

"Best guess" prediction of rate of increase: _____ degrees C. per decade

Interval	Count	Percent
Missing	21	
0	10	10.3
.01-.10	17	17.5
.11-.20	20	20.6
.21-.30	42	43.3
.31-.40	4	4.1
.41-.50	2	2.1
.51-.60	1	1.0
.61-.70	0	0.0
.71-.80	1	1.0
Total	97	100.0

Uncertainty range: _____ degrees C. to _____ degrees C.

Interval	Count	Percent
Missing	18	
-1.50- -1.00	2	2.0
-0.99- -0.50	4	4.0
-0.49- -0.20	9	9.0
-0.19- -0.10	11	11.0
-0.09- 0.00	21	21.0
0.01- 0.10	18	18.0
0.11- 0.20	30	30.0
0.21- 0.50	5	5.0
Total	100	100.0

Interval	Count	Percent
Missing	18	
0.00- 0.25	11	11.0
0.26- 0.50	58	58.0
0.51- 0.75	18	18.0
0.76- 1.00	11	11.0
1.01- 1.25	0	0.0
1.26- 1.50	2	2.0
Total	100	100.0

2. Whose opinion would you most respect about the previous question? (Please list at least 3 people, not necessarily OMNET subscribers)

Name Number of times listed*

1. Manabe, S.	15
2. Schneider, S.	15
3. Hansen, J.	14
4. Dickenson, R.	9
5. Lindzen, R.	9
6. Broecker, W.	8
7. Karl, T.	8
8. Ramanathan, V.	7
9. MacCracken, M.	6
10. Bretherton, F.	4
11. Ellsaesser, H.	4
12. Washington, W.	4
13. Wigley, T.	4
14. Cess, R.	3
15. Michaels, P.	3
16. Mitchell, J.	3
17. Revelle, R.	3
18. Watson, R.	3

* Only names listed more than twice are included.
119 different names were listed.

Following are quotes from well-known scientists about potential global climate change. Indicate your agreement or disagreement with each statement as follows:

1-Strongly disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly agree

NOTE: These statements may involve value judgments that go beyond what can be established through research. We are simply interested in your opinion as a particularly well informed citizen.

3. "... most of the scientific community would agree that the effects are going to be substantial."

Disagree-agree (1-5): _____

	Count	Percent
Missing	3	
Strongly Disagree	11	9.6
Disagree	25	21.7
Neutral	21	18.3
Agree	41	35.7
Strongly Agree	17	14.8
Total	115	100.0

4. "As is becoming evident, consensus [among scientists] is increasingly restricted to relatively trivial points, such as the existence of a greenhouse effect."

Disagree-agree (1-5): _____

	Count	Percent
Missing	3	
Strongly Disagree	25	21.7
Disagree	42	36.5
Neutral	10	8.7
Agree	28	24.3
Strongly Agree	10	8.7
Total	115	100.0

5. "... the current uncertainties are such that a delay in taking action is the proper policy."

Disagree-agree (1-5): _____

	Count	Percent
Strongly Disagree	50	42.4
Disagree	38	32.2
Neutral	9	7.6
Agree	10	8.5
Strongly Agree	11	9.3
Total	118	100.0

6. "There is little doubt among scientists that global mean temperature will increase."

Disagree-agree (1-5): _____

	Count	Percent
Strongly Disagree	9	7.6
Disagree	27	22.9
Neutral	9	7.6
Agree	48	40.7
Strongly Agree	25	21.2
Total	118	100.0

PROFESSIONAL INFORMATION

7. Highest degree:

	Count	Percent
Bachelors	2	1.7
Masters	12	10.2
Doctorate	104	88.1
Total	118	100.0

8. In what field were you trained?

	Count	Percent
Meteorology and atmospheric science	31	26.3
Oceanography and marine science	35	29.7
Physics	25	21.2
Biology/ecology	13	11.0
Other	14	11.9
Total	118	100.0

9. What are your primary research interests? (No results available for this question)

10. How familiar are you with the research in your field that is related to global climate change?

	Count	Percent
Missing	2	
Very unfamiliar	17	14.7
Somewhat familiar	39	33.6
Very familiar	60	51.7
Total	116	100.0

11. Do any of the following describe you (check off all that apply)?

- 19 (16.1%) a. I work with GCM's (General Circulation Models)
- 54 (45.8%) b. I study the historical climate record
- 81 (68.6%) c. Much of my research is devoted to topics directly related to global climate change
- 97 (82.2%) d. I regularly keep up on current developments in climate change research
- 89 (75.4%) e. I attend meetings and meeting sessions regularly where climate change issues are discussed