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A Profile of U.S. Climate Scientists' Perspectives

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Climate Change: A Profile of U.S. Climate Scientists' Perspectives

Abstract

Climate scientists have played a significant role in investigating global climate change. In the U.S., a debate has swirled about whether a consensus on climate change exists among reputable scientists and this has entered the policy process. In order to better understand the views of U.S. climate scientists, we conducted an empirical survey of U.S. climate scientists (N=468) in 2005, and compared the results with the 2007 Intergovernmental Panel on Climate Change (IPCC) physical science report and policy summaries. Our results reveal that survey respondents generally agree about the nature, causes, and consequences of climate change, and are in agreement with IPCC findings. We also found that there is strong support for a variety of policy initiatives to reduce greenhouse gas emissions.

1 Introduction

Few issues have been more discussed, debated, or used to support policy positions and political action than the presumed beliefs of U.S. climate scientists on the existence, causes, and likely effects of global climate change. The competing assertions that there is or is not consensus among most scientists on the severity, causes, likely effects, and need for action regarding climate change have been at the center of a U.S. policy debate for the past several years. Those who see the problem as real, caused by human activity, and in need of decisive action argue that U.S. scientists are in agreement that the science is clear and overwhelmingly supportive of their position. Those who disagree that the problem is acute or in need of decisive action like to note points of disagreement among scientists to bolster their position that the science is unsure and not defined enough to use as a foundation for policy decisions. This latter position has had some success, as recent public opinion polls indicate that the public believes that scientists do, in fact, disagree about this topic and that this perceived disagreement increases public uncertainties (ABC News/Washington Post/Stanford Poll, 2007).

Where have the two sides of the debate obtained their information about the consensus, or lack thereof, among U.S. climate scientists? Those who argue that scientists are sure that climate change is real, caused by human activity, and in need of strong action point to comprehensive reviews of years of scientific research compiled, evaluated, and reported by respected scientific bodies like the Intergovernmental Panel on Climate Change (IPCC) (2007), the National Academy of Sciences (2006), the National Research Council (2007), and the Scientific Expert Group on Climate Change and Sustainable Development (2007). Opponents to these scientific reviews point to specific disagreements of selected scientists such as Richard Lindzen and Patrick Michaels (Lindzen, 2007a, b; Michaels, 2004; Michaels, 2005), to the reasoning of some politically motivated think tanks: the George C. Marshall Institute; the Competitive Enterprise Institute; the Heritage Foundation; and the Cato Institute (Michaels, 2004; Michaels, 2005, Schaefer and Lieberman, 2007; Lewis, 2007), and individual public officials, such as former NASA chief, Michael Griffin (2007).

However, neither side of the debate has direct, empirical information from U.S. climate scientists on how these scientists frame and understand the climate change problem and the science surrounding it. Our study seeks to clarify the debate by providing this information.[1]

2 Research Methods

We conducted a multi-modal survey of U.S. climate scientists between March and September 2005.[2] The sample frame used to identify climate scientists included the lead author and co-authors of all published research articles between 1995 and 2004 in 13 peer-reviewed scientific journals that highlight climate change research: Global Environmental Change; Journal of Climate; Journal of Atmospheric Sciences; Journal of Geophysical Research; Climatic Change; Journal of Applied Meteorology; Monthly Weather Review; Journal of Atmospheric and Oceanic Technology; Weather and Forecasting; Journal of Hydrometeorology; Earth Interactions; Bulletin of the American Meteorological Society; and Meteorological Monographs.[3]

The climate scientist survey had a response rate of 53% (N=468). The article selection process provided the names of 986 U.S. climate scientists, but 57 were not eligible or had no contact information and were dropped.[4] Respondents who self-identified themselves as social scientists (e.g. economists, political scientists, etc.) and those with missing academic training were also dropped. Social scientists

were dropped in order to clearly analyze the views of respondents in the biological and physical sciences.[5] The response rate was calculated using the remaining 883 contacts (468/883=53%).[6] Over half of the respondents work at universities and a third work for the U.S. government. Close to two-thirds conduct applied research and less than a quarter conduct theoretical research; 85% are male, and the mean age is 48 years (see Table 1).

3 Key Research Questions

We sought to examine the beliefs of these U.S. climate scientists on the major dimensions of the policy debate that rest on climate change research, including: the understanding of climate change; its certainty; the validity of climate models; the role of human causes; climate change's likely effects; relevant timelines; importance of mitigation and adaptation strategies; and preferred policy solutions. We examine each of these dimensions below.

3.1 Understanding of Climate Change

Due to the importance of understanding each climate scientist's assessment of the status of climate change research, we asked a variety of questions on this topic. First, we asked how well they thought climate scientists understood global climate change (GCC). Fifty-six percent believe that climate scientists understand GCC very well and 41% responded that scientists understand GCC moderately well. This finding supports other research (IPCC, 2007a, b) indicating that climate scientists believe they have a firm understanding of how and why GCC is occurring. As highlighted in Table 2, a majority of respondents think it is likely that global warming is already underway and that human activities are accelerating it.[7] In addition, most respondents did not think that scientific uncertainty about the rate and extent of GCC excludes the need for immediate policy decisions.[8]

These results also correlate with an open-ended survey question: "What are climate scientists clearly in agreement about with regard to GCC?" Although there were diverse responses, three distinct themes emerged: 1) GCC is occurring and it is accelerated by human activities; 2) world temperatures are warming; and 3) anthropogenic greenhouse gases (GHG) are raising temperature levels. These findings compare with IPCC reports that state: 1) warming of the climate system is unequivocal (IPCC, 2007a); 2) the increase in globally averaged temperatures is very likely (>90%) due to anthropogenic greenhouse gas concentrations (IPCC, 2007a); and 3) GHG emissions must start declining by the year 2015 to prevent Earth's temperature from rising more than 2 degrees Celsius over pre-industrialized temperatures (IPCC, 2007b).

Table 1. Respondent Characteristics

Training		Employment		Primary Expertise		Research		Gender		Age		Views	
Atmos*		University		Modeling		Applied		Male		≤ 45		Liberal	
201	43.0%	223	53.6%	188	40.4%	300	64.8%	354	85.1%	170	41.4%	270	67.5%
Ecology		Federal		Data Analysis		Theoretic		Female		≥ 46		Middle	
52	11.1%	77	18.5%	109	23.4%	106	22.9%	62	14.9%	241	58.6%	78	19.5%
Ocean*		Gov. Lab		Field Observations		Other#		—		—		Conservative	
42	9.0%	61	14.7%	49	10.5%	57	12.3%					52	13.0%
Physics		Private		Satellite Observations		—		—		—		—	
36	7.7%	13	3.1%	43	9.3%								
Engineering		State		Other†		—		—		—		—	
26	5.6%	5	1.2%	76	16.3%								
Interdisciplinary		Other±		—		—		—		—		—	
22	4.7%	37	8.9%										
Mathematics		—		—		—		—		—		—	
20	4.3%												
Chemistry		—		—		—		—		—		—	
9	1.9%												
Geography		—		—		—		—		—		—	
7	1.5%												
Glaciology		—		—		—		—		—		—	
6	1.3%												
Other**		—		—		—		—		—		—	
47	10.0%												
N=468		N=416		N=465		N=463		N=416		N=411		N=400	

Percentages are taken as the fraction of respondents who answered the question.
*Atmos = Atmospheric Sciences; Ocean = Oceanography
**"Other Training category" includes biology, forestry, and hydrology, and other physical sciences
±"Other Employment" includes appointments to multiple arenas
†"Other Expertise" includes instrument development, laboratory experimentation, impact assessment, and multiple areas of expertise.
#"Other Research" includes combinations of applied and theoretical research
Some respondents did not answer all survey questions. This is common for web based surveys where respondents can choose not to answer every question. Consequently, N varies by question.

Table 2. Certainty about Global Climate Change

Survey Question	Strongly Agree	Agree	Disagree	Strongly Disagree	Total
Scientists can say with great certainty that global warming is a process that is already underway	61.64%	32.42%	4.79%	1.14%	100.00%
	270	142	21	5	438
Scientists can say with great certainty that human activities are accelerating global warming	49.19%	39.26%	9.47%	2.08%	100.00%
	213	170	41	9	433
There is enough scientific uncertainty about the rate and extent of global warming and climate change that there is no need for immediate policy decisions	1.84%	6.91%	35.48%	55.76%	100.00%
	8	30	154	242	434

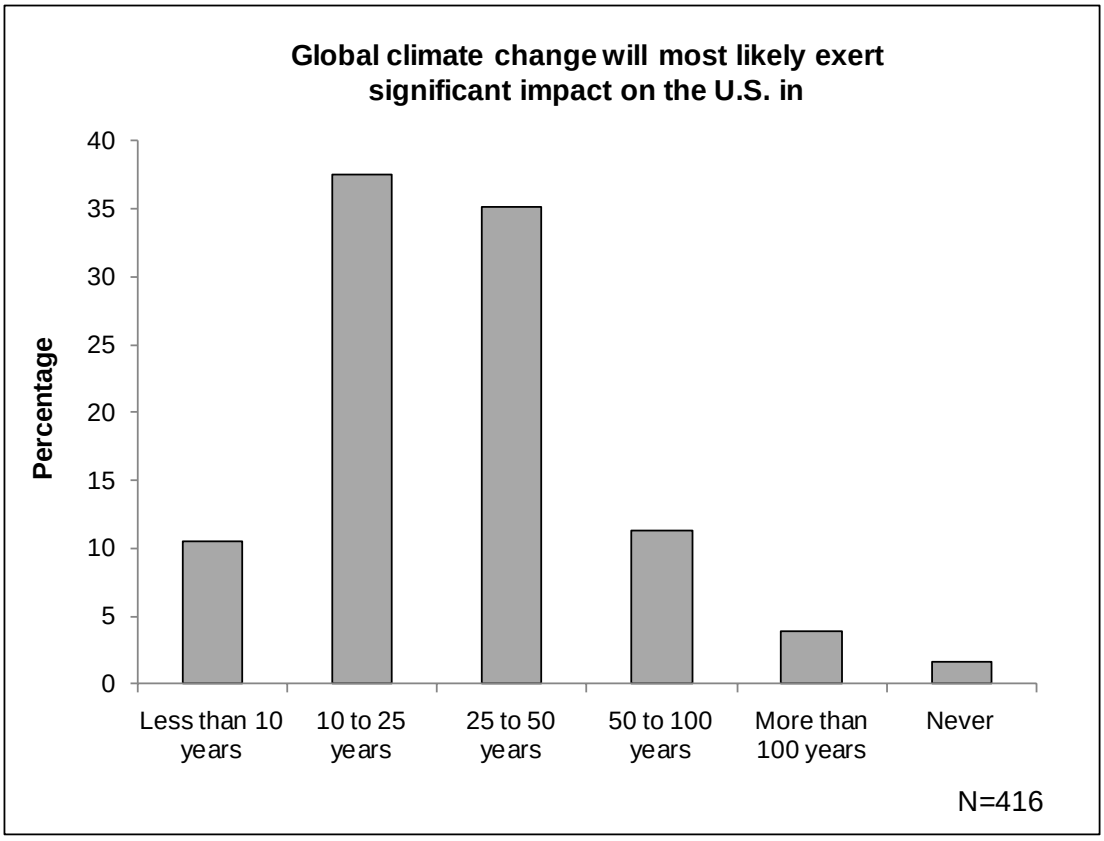
Percentages are taken as the fraction of respondents who answered the question.
Some respondents did not answer all survey questions. This is common for web based surveys where respondents can choose not to answer every question. Consequently, N varies by question.

3.2 Timelines

Our survey findings reveal that 75% of respondents believe it "most likely" that GCC will occur with a combination of gradual changes in all areas of the world and possible abrupt changes in some areas.[9] Only 12% responded that there will be gradual changes in some areas of the world, 6% that there will be gradual changes in all areas of the world, and 4% that there will be abrupt changes in some areas of the world. These results reflect an overall acceptance of the new climate change paradigm (National Research Council, 2002). They also highlight that most respondents believe that impacts of GCC will not occur uniformly throughout the world and some regions will experience lesser or greater impacts. This finding supports the IPCC 2007 assertions in its policy summary table SPM.2. For example, Africa and Asia are projected to likely experience extreme water stress and Africa will be especially vulnerable to reductions in freshwater availability because of a low adaptive capacity (IPCC, 2007a).

At this time, determining GCC impacts is too complex to allow wide agreement on timelines for significant impacts in specific regions. Instead IPCC uses estimates for 20-year time periods (e.g. 2011-2030; 2046-2065; 2080-2099) based on multi-model means because averages across different models tend to cancel out individual model biases (IPCC, 2007a). In 2000, IPCC published a new Special Report on Emissions Scenarios (SRES) used in their Third and Fourth Assessment Reports. The SRES team developed (with broad research and stakeholder input), four storylines (Nakićenović and Swart, 2000). Within these, 40 model scenarios were created to cover the full range of GHGs and SO_2 emissions estimates and represent different demographic, social, economic, technological, and environmental developments. Climate scientists use these various scenarios in their models to project changes and impacts for the 20-year time periods (IPCC, 2007a). In our survey, respondents were asked when GCC will most likely exert significant impact on the U.S., and 73% stated that this will occur in 10 to 50 years (see Figure 1).[10] While these findings are lower than the U.S. Global Change Research Program's (USGCRP) estimates of 100 years (National Assessment Synthesis Team, 2001), they are similar to IPCC's estimates. IPCC (2007a) states with *high confidence* that natural systems are already affected on all continents and that moderate changes will occur in North America in the early decades of this century.[11]

Figure 1. Timeline of Significant GCC Impacts on the U.S.



3.3 Validity of Climate Models

The accuracy of climate change models has long been an issue of controversy in the climate change debate.[12] Many uncertainties regarding magnitude and timing, cloud responses, and regional details of predicted change still exist (IPCC, 2007a; Stocker and Marchal, 2000; Schneider, 2004). We asked climate scientists about their views on the accuracy of climate model predications of future climate conditions. Seventy-seven percent believe that climate model predictions are moderately accurate and 22% believe they are inaccurate. This is similar to other research on perceived accuracy of climate change modeling (Stocker, 2004).

Historically, determining local impacts of GCC was difficult in General Circulation Models because of regional variability and because approximations of many important small-scale processes overwhelmed available computing power (Bell et al., 2004). However, with increases in computing power and detailed data on local physical processes, regional climate models have become more successful at representing smaller-scale features (IPCC, 2007a). Survey respondents were asked about the degree to which it was now possible to determine local impacts of GCC. Although 16% believed that it was very likely, 65% of the respondents believed that it was only fairly likely, and 19% responded that there was a limited likelihood.[13] Survey respondents' views echo IPCC assertions that there is now "higher confidence" regarding the reliability of local predictions (IPCC, 2007a). In addition, there are an increasing number of scientific publications on local impacts of GCC (Snyder et al., 2002; Patz et al., 2005; Marengo and Ambrizzi, 2006).

3.4 Likely Effects

The severity of climate change effects depends on several variables associated with "key vulnerabilities."[14] These include magnitude, timing, persistence/reversibility, potential for adaptation, distributional aspects, likelihood and "importance" of impacts (IPCC, 2007a). In addition to biophysical impacts from climate change, there are social, economic, and public health effects that can profoundly influence daily lives of citizens (IPCC, 2007a; National Assessment Synthesis Team, 2001). Our

respondents were asked to rate GCC as a problem affecting social, economic, and public health in the U.S. Sixty percent rated GCC as a *significant* to *very significant* problem (see Figure 2).[15] This correlates with recent IPCC findings that GCC events such as drought, cyclones, sea level rise, heat waves, and heavy precipitation will likely (>66%) to very likely (>90%) have significant social, economic, and public health effects (IPCC, 2007a).

3.5 Role of Mitigation and Adaptation

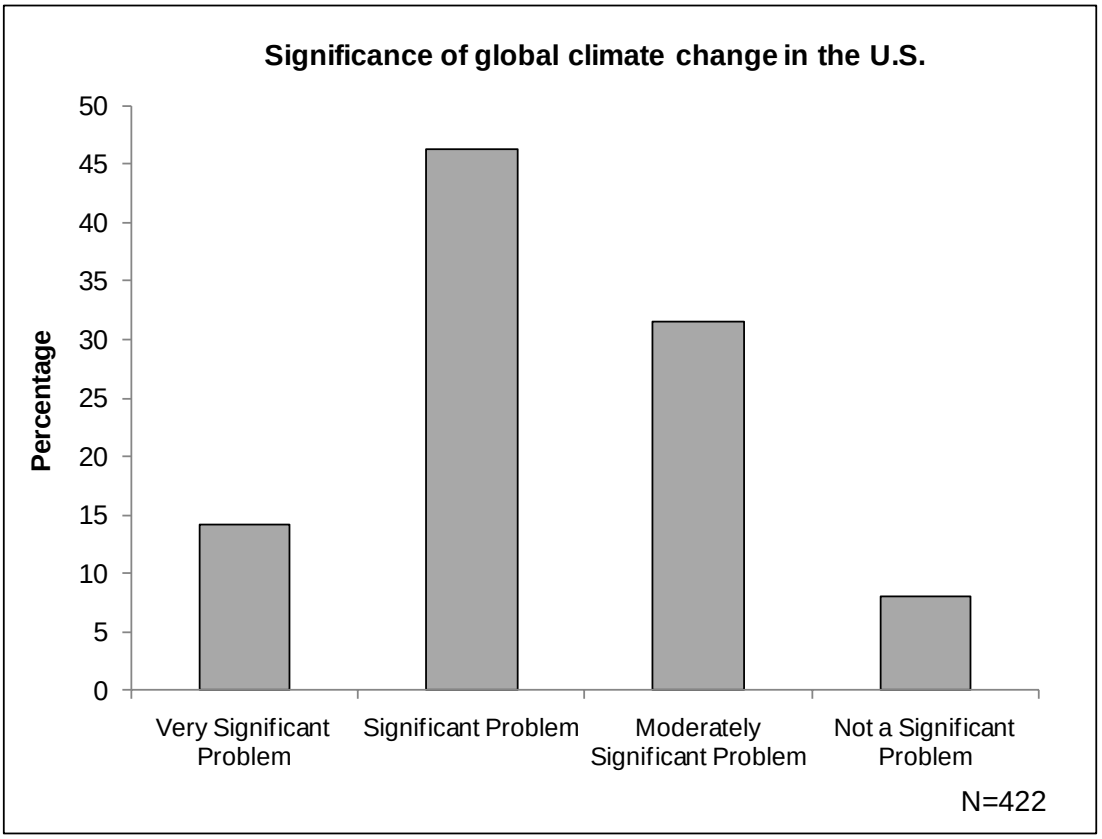
Mitigation is a critical issue in the discussion of GCC. Respondents were asked about the degree to which mitigation, defined as human intervention to reduce the sources of GHGs,[16] is an option in the U.S. Sixty-five percent of respondents answered that mitigation was a *likely* or *very likely* option, 24% considered it a *fairly likely* option, and 11% believed it was an option of limited value.[17] Mitigation is a complex concept global in its reach and prescriptive tenets. Citizens and decision makers in community or nation X may act to reduce their contribution to GHG's, at a significant cost to them, but the benefits are shared by all while the costs are born by the few. This creates a collective action, free-rider problem. Consequently, most climate scientists believe that mitigation is a *likely* option to deal with climate change and this puts them in agreement with recent IPCC findings stating there is "high agreement" and "much evidence" for mitigation (IPCC, 2007a).[18]

Adaptation has also been discussed as a method to deal with the effects of GCC (Yohe and Tol, 2002; Agrawala, 2004). The United Nations Framework Convention on Climate Change (UNFCCC) established a framework for both addressing international adaptation needs and facilitating national adaptation programs (UNFCC, 2004; UNDP, 2004). According to the IPCC (2007a) numerous adaptive responses to climate change are available: technological (e.g. levees, warning systems), behavioral (e.g. different choices in food, housing, and recreation), managerial (e.g. business and agricultural practices), and policy (e.g. regulations).[19] Unlike mitigation efforts, adaptation strategies can be more location specific and, therefore, more selective to those who make the investments. Survey respondents were asked to rate the likelihood that the U.S. will be able to successfully adapt to the effects of GCC. Adaptation was defined as adjustments in natural or human systems in response to climate change conditions or effects. Results show that 44% of respondents believe there is a strong likelihood that the U.S. will adapt successfully, 36% felt it was fairly likely, and 20% believe that it is limited.[20] Their mixed response reflects IPCC's and USGCRP's contention that it is difficult to understand barriers, costs, or limitations of successful adaptation because measures depend on regional risk factors as well as financial, political, and institutional constraints (IPCC, 2007a; National Assessment Synthesis Team, 2001). However, both IPCC and the U.S. Climate Change Science Program (USCCSP) stress the need for research on adaptation measures (IPCC, 2007b; USCCSP, 2007).[21]

4 Areas Where U.S. Climate Scientists Disagree

Although there is consensus among climate scientists that GCC is occurring and is accelerated by human activities, there is disagreement about specific aspects of GCC. We asked survey respondents about areas of disagreement among climate scientists in regard to GCC in an open-ended question and the responses included a diversity of answers. However, we discerned three major themes. First, there is disagreement about the extent and magnitude of GCC. Other research has also shown this difference among climate scientists (IPCC, 2007a; National Assessment Synthesis Team, 2001). Second, there is disagreement about specific rates of change and timelines. Again, reports from IPCC (IPCC, 2007a) and USGCRP (National Assessment Synthesis Team, 2001) concur. Third, many comments focused on GCC outcomes, such as local and regional impacts. This demonstrates that determining precise outcomes is difficult, although refinements in modeling and computing power are improving predictions. Scientists' comments included, "How much is the magnitude of the change?", "How quickly will climate change proceed?" and "What will the regional impacts of climate change be, particularly for variables other than temperature (precipitation, floods, droughts, etc)?" To a lesser extent, respondents also expressed some disagreement on models, human effects, and the role of clouds and aerosols. These results are similar to other findings (Gaffney and Marley, 1998; Karl and Trenberth, 2003; Williams et al., 2003) and comments by the IPCC (2007a) and USCCSP (2007).

Figure 2. Climate Change and Social, Economic, & Public Health Effects in the U.S.



Respondents rated GCC as a problem that affects the social, economic, and public health aspects of the U.S. on a 1-11 scale (1=not a problem at all, 11=very significant problem) and this was transformed into 4 categories: very significant (11), significant (8-10), moderately significant problem (4-7), and not a problem (1-3).

5 Views on Science-Policy Interface

The science-policy interface is an important element in any discussion of GCC. Scientific knowledge about climate change has played a significant role in transforming this topic into a highly visible global issue (Jasanoff and Wynne, 1998). Scientists' views on the nature and severity of the problem, and on specific policy solutions, are very important. The fact is that climate scientists are key participants in the climate change public policy debate. They are central to problem identification and acceptance, and resulting policy actions. The IPCC reports themselves are not just scientific compilations, but they are crucial policy documents.

In addition to respondent views about climate change research and the effects of GCC, we asked a number of policy related survey questions. Table 3 highlights 10 policy initiatives to reduce greenhouse gases that survey respondents support.[22] Over 90% support: 1) market incentives to encourage industries to reduce emissions; 2) educating the public on human causes of climate change and variability; 3) requiring more efficient appliances and industrial systems; 4) developing renewable energy sources; and 5) requiring automobile companies to build more fuel-efficient vehicles. Over 80% support: 1) a tax on industry to discourage practices that contribute to global warming; 2) higher prices for energy and other consumer goods that are not "environmentally friendly;" 3) ratification of the Kyoto Protocol; and 4) higher prices of fossil fuels to encourage conservation and the development of energy efficient devices. Meanwhile, 71% support a tax on individuals to discourage them from practices that contribute to global warming.

Climate scientists were asked about the level of relevancy their work had for policy makers in different fields.[23] Table 4 highlights these findings. Overall, they believe their work is more relevant for policy makers in agriculture and land use than public health and economic development.[24]

Table 3. Support for Policy Initiatives to Reduce Greenhouse Gases

Survey Question	Strongly Support	Support	Oppose	Strongly Oppose	Total
Use market incentives to encourage industries to reduce emissions	50.61%	45.04%	3.15%	1.21%	100.00%
	209	186	13	5	413
Impose a tax on industry to discourage industry practices that contribute to global warming	41.95%	43.41%	12.20%	2.44%	100.00%
	172	178	50	10	410
Impose a tax on individuals that discourages them from practices that contribute to global warming	29.31%	41.87%	24.38%	4.43%	100.00%
	119	170	99	18	406
Educate the public on the human causes of climate change and variability	74.40%	24.64%	0.97%	0.00%	100.00%
	308	102	4	0	414
Set higher prices for types of energy and other consumer goods that are not environmentally friendly	50.86%	38.33%	8.60%	2.21%	100.00%
	207	156	35	9	407
Ratify the Kyoto Protocol, committing the U.S. to reducing carbon dioxide emissions	41.65%	42.14%	10.72%	5.49%	100.00%
	167	169	43	22	401
Legally require more efficient appliances and industrial systems	51.59%	42.79%	5.62%	0.00%	100.00%
	211	175	23	0	409
Develop renewable energy sources, like hydro and solar power, that emit no carbon dioxide	76.39%	22.65%	0.48%	0.48%	100.00%
	317	94	2	2	415
Require automobile companies to build more fuel-efficient vehicles	71.84%	23.54%	4.37%	0.24%	100.00%
	296	97	18	1	412
Increase the price of fossil fuels to encourage conservation and the development of energy efficient devices	49.39%	31.70%	16.95%	1.97%	100.00%
	201	129	69	8	407

Percentages are taken as the fraction of respondents who answered the question.
Some respondents did not answer all survey questions. This is common for web based surveys where respondents can choose not to answer every question. Consequently, N varies by question.

Respondents were also asked about the role they thought scientists played in transforming the climate issue from a scientific issue to a public policy issue. Fifty-one percent believed that scientists played a very important or important role, 36% felt they played a fairly important role, and only 13% thought they played a limited role.[25]

Table 4. Relevance of Work for Policy Makers in Different Fields

Relevance	Public Health	Economic Development	Land Use	Agriculture
Relevant to very relevant	26.19%	36.90%	43.81%	48.33%
	110	155	184	203
Moderately relevant	24.52%	30.24%	30.71%	29.29%
	103	127	129	123
Limited relevance or not relevant at all	49.29%	32.86%	25.48%	22.38%
	207	138	107	94
TOTAL	100.00%	100.00%	100.00%	100.00%
	420	420	420	420

Percentages are taken as the fraction of respondents who answered the question.
Respondents rated the relevance of work from policy makers on a 1-11 scale (1=no relevance, 11= very relevant), and this was categorized into 3 groups: relevant to very relevant (8-11), moderately relevant (5-7), and limited relevance to no relevance (1-4).
Some respondents did not answer all survey questions. This is common for web based surveys where respondents can choose not to answer every question. Consequently, N varies by question.

6 Are Climate Scientists a Homogeneous Set of Actors?

In addition to the overall views of respondents, we wanted to investigate whether assessments of the status of climate change science and policy approaches to it vary systematically by the political and demographic characteristics of climate scientists. Sociopolitical factors, such as gender and employment, have been found to affect the risk perception of scientists, and research has demonstrated that attitudinal differences exist between scientists working in industry and those in academic settings (Slovic et al., 1997; Slovic, 1999). Key variables for this study included whether climate scientists working for federal agencies had a different perspective than those in a university setting and whether academic training, research orientation, age, or political views affected their views about policy initiatives to reduce GHGs. Therefore, we conducted a number of bivariate analyses to determine whether background characteristics or attitudinal dispositions of our sample of climate scientists were related to systematic differences in their approaches to climate change. The analytic categories we used to assess this possibility were employment (federal agency vs. university), research orientation (applied vs. theoretical), academic training (atmospheric sciences, ecology, or oceanography), primary expertise (data modeling, analysis, field observations and satellite observations), age (≤45 yr or ≥46 yr),[26] and political views (liberal, moderate, or conservative). Overall, the respondents were a fairly homogeneous group (see Appendix A, Tables A1 and A2) and only political views had a substantial number of statistically significant findings. For example, if you look at responses for increasing fossil fuel prices to encourage conservation, this action is supported by: 81% of federal scientists and 82% of university scientists; 80% of applied scientists, and 83% of theoretical scientists; 80% of atmospheric scientists, 84% of oceanographers, and 91% of ecologists; 85% of data modeling scientists, 74% of analytical scientists, 80% of scientists whose primary expertise are field observations and 82% of scientists whose expertise are satellite observations; and 81% of scientists 45 years of age and younger, and 80% of those 46 and older. Meanwhile, Fisher's Exact tests on political views found 7 of 10 policy questions to be statistically significant (see Table 5).[27] The homogeneity of climate scientists in our survey is an important finding and highlights the amount of cohesiveness among our respondents. Political orientation provided the only significant fault line and focused primarily on policy choices, not on the basic science foundations.

7 Conclusions

In this study we looked directly at the climate change science and policy beliefs of U.S. climate scientists. The survey results reveal that a majority of respondents believe: 1) climate scientists have a strong understanding of GCC; 2) global warming is already underway and human activities are accelerating it; 3) GCC will occur with a combination of gradual changes in all areas of the world and the possibility of abrupt changes in some areas; 4) GCC will most likely exert significant impact on the U.S. in 10 to 50 years; 5) GCC is a significant problem that affects the social, economic, and public health aspects of the U.S.; 6) mitigation is a likely or very likely option in the U.S.; and 7) the U.S. is likely or fairly likely to adapt successfully to the effects of GCC. Our results also show that survey respondents' views on climate change are in alignment with recent IPCC findings (IPCC, 2007a, 2007b), and previous content analysis of GCC scientific publications (Oreskes, 2004).[28]

We also find significant agreement among scientists on nearly all elements of the climate change debate, except for a minority of ideologically conservative scientists who are less supportive of some policy choices, such as imposing taxes to discourage certain practices. Climate scientists in our survey strongly support a variety of policy initiatives to reduce greenhouse gases, believe that climate scientists played an important role in transforming this issue into a public policy issue, and think it is time to implement strategies to reduce GHGs. Our findings provide insights into the perspectives of U.S. climate scientists and clarify their views on the climate change science and policy debate.

Table 5. Political Views and Support for Initiatives to Reduce Greenhouse Gases

Survey Question	Liberal	Moderate	Conservative	Total
Use market incentives to encourage industries to reduce emissions	95.51% 255	96.05% 73	96.08% 49	95.69% 377
Impose a tax on industry to discourage industry practices that contribute to global warming***	91.73% 244	82.67% 62	60.78% 31	85.97% 337
Impose a tax on individuals that discourages them from practices that contribute to global warming***	79.23% 206	71.05% 54	40.00% 20	72.54% 280
Educate the public on the human causes of climate change and variability	99.25% 264	98.72% 77	98.04% 50	98.99% 391
Set higher prices for types of energy and other consumer goods that are not environmentally friendly***	95.09% 252	87.50% 63	64.71% 33	89.69% 348
Ratify the Kyoto Protocol, committing the U.S. to reducing carbon dioxide emissions***	92.40% 243	74.32% 55	53.19% 25	84.11% 323
Legally require more efficient appliances and industrial systems**	97.39% 261	92.00% 69	88.00% 44	95.17% 374
Develop renewable energy sources, like hydro and solar power, that emit no carbon dioxide†	100.00% 269	100.00% 76	92.00% 46	98.99% 391
Require automobile companies to build more fuel-efficient vehicles**	98.13% 262	92.21% 71	88.24% 45	95.70% 378
Increase the price of fossil fuels to encourage conservation and the development of energy efficient devices***	91.32% 242	76.00% 57	41.18% 21	81.84% 320

A Fisher's Exact test was performed for each 2 x 3 table formed by the respondent's positive/negative answer to the survey question and the political ideology they adhere to.

Statistically significant results indicate that the response to the survey question and political ideology of the respondent are related.

*statistically significant at ≤ 0.05 **statistically significant at ≤ 0.01 ***statistically significant at ≤ 0.001

†This Fisher's Exact test does not meet standard statistical criteria. There is a zero-count cell in the analyzed table

Percentages are taken as the fraction of Political Ideology X that agree with Survey Question Y

Some respondents did not answer all survey questions. This is common for web based surveys where respondents can choose not to answer every question. Consequently, N varies by question.

Notes

1. Although Bray and von Storch conducted a survey of climate scientists in 1996, our different approaches to the topic do not allow comparison (Bray & Krück, 2001).
2. We opted for a multi-modal (web-based survey, phone survey and mail/fax survey) survey strategy for two reasons. First, we wanted to provide climate scientists with many options to accommodate busy schedules – professional communities are notoriously difficult to survey representatively (Gore-Felton et al. 2002). Second, survey methodology literature indicates that multi-modal surveys produce similarly valid and reliable results across modal type (Smith et. al 2007; Burkey and Harris 2006). In addition, we screened data to test for statistically significant differences on survey responses by modal type. We compared probability distributions of survey items by response modes (web-based versus other) using the Mann-Whitney U test (for ordinal measured variables). With only one exception – the question pertaining to the extent to which climate scientists understand global climate change, where web-based survey takers had significantly lower scores ($z= -2.83$, $p= .000$) than other takers – distributions of survey items exhibited no significant differences between response modes with regard to central tendency or dispersion. Results suggest that no significant differences exist between the data collected by either modality, and that respondents are drawn from the same population.
3. These journals were selected based on discussions with climate scientists, reported impact factors, meteorology association publications, and other relevant data.
4. Of the 57 authors dropped, 39 had no contact information, 1 retired, 3 were deceased, 11 were not climate scientists, and 3 were international scientists discovered later in the process.
5. Among the total N=514 who responded to the survey, 8 with missing academic training were dropped, leaving N=506. Then 38 social scientists were dropped from the sample so that the final N=468.
6. The total contacts were 986. After 57 non-eligible authors, 8 missing academic training authors, and 38 social scientists were dropped the final contact number is 883.
7. The survey question used the terms: strongly agree; agree; disagree; and strongly disagree. The IPCC 2007 report used the following likelihood ranges to express probabilities: virtually certain >99%; extremely likely >95%; very likely >90%; likely >66%; more likely than not > 50%; about as likely as not 33% to 66%; unlikely <33%; very unlikely <10%; extremely unlikely <5%; exceptionally unlikely <1%. In order to make appropriate comparisons with language used in the IPCC report "strongly agree" will be held synonymous with "extremely likely;" "agree" with "likely;" "disagree" with "unlikely;" and "strongly disagree" with "extremely unlikely." Questions were introduced using the terms "global warming" and "climate change" and no definition of these terms was given to respondents.
8. It is important to note that our survey occurred in 2005 long before the 2007 IPCC reports were published.
9. "Most likely" correlates with IPCC's "extremely likely."
10. This is comparable to IPCC's "extremely likely." As is common in survey research, the term "significant impact" was not defined in the survey. Therefore, each respondent personally interpreted this term and what it meant in regard to future climate change and this may have affected their specific response.
11. IPCC 2007 uses the following scale to assess the chance of a finding being correct: *very high confidence* at least 9 out of 10; *high confidence* about 8 out of 10; *medium confidence* about 5 out of 10; *low confidence* about 2 out of 10; and *very low confidence* less than 1 out of 10. Survey respondents rated the degree they thought it is now possible to determine local impacts of GCC on a 1-11 scale (1=not at all, 11=to a great degree) and this was transformed into 3 categories: very likely (8-11), fairly likely (4-7), and limited likelihood (1-3).
12. The word "accuracy" in the survey question relates to a subjective "value" judgment on the part of the climate scientist and not the actual accuracy of the model predications.
13. Respondents rated the degree they thought it is now possible to determine local impacts of GCC on a 1-11 scale (1= not at all, 11= to a great degree) and this was transformed into three categories: very likely (8-11), fairly likely (4-7), and limited likelihood (1-3).

14. Vulnerability is defined as a society's degree of exposure to climate change risk and its capacity to adapt.
15. "Significant" to "very significant" correlates to IPCC's language "likely" to "very likely."
16. IPCC definition for mitigation and adaptation.
17. Respondents rated the degree that mitigation is an option in the U.S. on a 1-10 scale (1= not at all an option, 10= very much an option), and this was transformed into four categories: very much an option (10), likely option (7-9), fairly likely option (4-6), and limited option (1-3).
18. Where uncertainly is expressed qualitatively, IPCC 2007 uses the following categories to assess the degree of agreement: *high agreement, much evidence; high agreement, medium evidence; medium agreement, medium evidence*; etc.
19. See IPCC WGIII AR4 2007 for a table of adaptation options.
20. Respondents rated the likelihood that the U.S. will be able to successfully adapt to effects of climate change on a 0-10 scale (0= not at all likely, 10= very likely), and this was transformed into three categories: successful adaptation is likely (7-10), fairly likely (4-6), and limited (0-3). "Strong likelihood" correlates with IPCC's "extremely likely."
21. The U.S. Global Climate Research Program (USGCRP) was created by the 1990 Global Change Research Act to coordinate climate research conducted by various U.S. agencies. In 2002, the Bush Administration directed USGCRP to integrate the research efforts of 13 federal agencies and reorganized it as the U.S. Climate Change Research Program (USCCSP).
22. The survey included only 10 questions about policy initiatives and respondents supported all of them.
23. Respondents were asked, "How relevant do you consider your work to be for policy makers in public health?" A respondent may have interpreted this in regard to their own work or the work of climate scientists in general.
24. It is possible that these results may be influenced by our respondents and the journals used to select our respondents. Climate scientists involved in public health issues may publish in journals specific to public health and may not have been included in our list of potential participants. The results may also recognize that additional funding for climate change and human health is necessary.
25. Respondents rated the role scientists played in transforming the climate issue into a public policy issue on a 1-11 scale (1= no role, 11= very important role), and this was categorized into 4 groups: very important role (11), important role (8-10), fairly important role (5-7), and limited role (1-4).
26. Forty-five was selected as the dividing point due to the distinctiveness of 1988 in the climate change arena. In 1988, IPCC was established, ice core studies highlighted important new findings, the Toronto conference was held, and the news media began to increase its coverage of climate change. We approximated that a new Ph.D. in this field in 1988 was 28 (7 year average from undergraduate degree to Ph.D.) and our survey was conducted in 2005.
27. All data analyses were performed using Stata version 10.1.
28. We also recognize that there may even be greater consensus among climate scientists today due to the publication of the 2007 IPCC reports, compared to when we conducted the survey in 2005.

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Appendix A. Bivariate Tables

Table A1. Employment, Research, Age and Expertise

Survey question	Employment		Research		Age		Primary Expertise			
	Federal Agency*	University Setting	Applied	Theoretical	≤45 yr	≥46 yr	Data Modeling	Analysis	Observation	
									Field	Satellite
Use market incentives to encourage industries to reduce emissions	97.01%	95.02%	95.38%	95.83%	97.02%	95.36%	97.50%	94.90%	91.49%	94.74%
	130	210	248	92	163	226	156	93	43	36
Impose a tax on industry to discourage industry practices that contribute to global warming	82.44%	88.74%	84.05%	90.82%	91.02%	81.36%	88.68%	80.81%	93.62%	83.78%
	108	197	216	89	152	192	141	80	44	31
Impose a tax on individuals that discourages them from practices that contribute to global warming	70.00%	74.77%	71.98%	70.53%	71.95%	70.51%	71.07%	72.16%	72.34%	70.27%
	91	163	185	67	118	165	113	70	34	26
Educate the public on the human causes of climate change and variability	99.25%	99.10%	99.23%	98.97%	100.00%	98.31%	98.76%	98.99%	97.87%	100.00%
	133	219	258	96	168	233	159	98	46	37
Set higher prices for types of energy and other consumer goods that are not environmentally friendly	84.33%	91.24%	87.50%	93.75%	92.07%	86.86%	93.71%	84.54%	91.30%	81.58%
	113	198	224	90	151	205	149	82	42	31

Ratify the Kyoto Protocol, committing the U.S. to reducing carbon dioxide emissions	79.69%	87.50%	81.82%	93.68%	86.59%	81.82%	90.26%	76.04%	93.48%	76.32%
	102	189	207	89	142	189	139	73	43	29
Legally require more efficient appliances and industrial systems	93.23%	95.91%	94.19%	94.79%	95.78%	93.25%	96.84%	91.84%	95.65%	84.62%
	124	211	243	91	159	221	153	90	44	33
Develop renewable energy sources, like hydro and solar power, that emit no carbon dioxide	98.54%	99.09%	98.47%	100.00%	98.82%	99.16%	99.38%	100.00%	100.00%	94.87%
	135	218	258	96	167	236	159	98	47	37
Require automobile companies to build more fuel-efficient vehicles	94.74%	95.95%	94.96%	95.88%	95.18%	95.38%	97.50%	91.84%	100.00%	89.74%
	126	213	245	93	158	227	156	90	47	35
Increase the price of fossil fuels to encourage conservation and the development of energy efficient devices	81.06%	82.11%	80.24%	82.65%	81.10%	80.43%	85.35%	74.23	80.43%	82.05%
	107	179	203	81	133	189	134	72	37	32

Percentages are taken as the fraction of category X that agree with policy Y

* Employment by Federal Government or in a Government Lab

**Atmos Sci = Atmospheric Sciences; ***Ocean = Oceanography

A Fisher's Exact test was performed for each table formed by the respondent's positive/negative answer to the survey question and their category

Zero Cell counts in the table make Fisher's Exact test fail.

Statistically significant at ≤ .1

Statistically significant at ≤ .05

Statistically significant at ≤ .01

Statistically significant results indicate that the response to the survey question and category are related.

Some respondents did not answer all survey questions. This is common for web based surveys where respondents can choose not to answer every question. Consequently, N varies by question.

Table A2. Training

Survey Question	Training		
	Atmospheric Science	Ecology	Oceanography
Use market incentives to encourage industries to reduce emissions	92.77% 154	97.78% 44	100.00% 37
Impose a tax on industry to discourage industry practices that contribute to global warming	87.12% 142	91.30% 42	86.49% 32
Impose a tax on individuals that discourages them from practices that contribute to global warming	72.39% 118	67.39% 31	78.38% 29
Educate the public on the human causes of climate change and variability	98.80% 165	100.00% 46	97.30% 36
Set higher prices for types of energy and other consumer goods that are not environmentally friendly	86.23% 144	91.30% 42	94.44% 34
Ratify the Kyoto Protocol, committing the U.S. to reducing carbon dioxide emissions	83.23% 134	90.91% 40	91.67% 33
Legally require more efficient appliances and industrial systems	92.12% 152	100.00% 45	97.22% 35
Develop renewable energy sources, like hydro and solar power, that emit no carbon dioxide	98.81% 166	97.83% 45	100.00% 37
Require automobile companies to build more fuel-efficient vehicles	94.64% 159	97.83% 45	94.59% 35
Increase the price of fossil fuels to encourage conservation and the development of energy efficient devices	80.12% 133	91.11% 41	83.78% 31

Percentages are taken as the fraction of category X that agree with policy Y

A Fisher's Exact test was performed for each table formed by the respondent's positive/negative answer to the survey question and their category

Zero Cell counts in the table make Fisher's Exact test fail.

Statistically significant results indicate that the response to the survey question and category are related.

Some respondents did not answer all survey questions. This is common for web based surveys where respondents can choose not to answer every question. Consequently, N varies by question.