Climate Science and the Dynamics of Expert Consensus

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I. Introduction and scope of memorandum

How can a motivated layperson who is not an expert in a highly technical field understand the current state of knowledge and make decisions—whether as a citizen, policymaker, or consumer—based on it?

This type of question pervades decisions ranging from toxic clean up to tumor treatment. It is particularly salient now on the issue of climate change.

Given enough time and some guidance, a thoughtful layperson can understand the basic scientific issues underlying the recommendations of any given expert scientific community. But when there is disagreement among experts and when the disagreement involves technical details—of chemistry, physics, math, medicine, or statistics—a layperson is stuck. Indeed, even highly intelligent experts in related scientific fields often cannot sufficiently grasp and judge among the details of the scientific disagreement on their own.

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A publication of the Schneider Lab at Stanford University and the Center for Conservation Biology.
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We postulate that, when experts disagree on a technical issue that is beyond the grasp of key decision-makers and the public, laypersons committed to rational and researched decision-making have one reasonable way to get the information they need to make good decisions. They must use the state of the debate among experts as a proxy for the likelihood that different answers to a question are correct. Particularly when decisions must be made in a short timeframe, it is a better bet to go with a 75% majority of relevant unbiased experts rather than a 25% minority. (As we discuss below, the majority to minority ratio is considerably greater on the core questions of climate change.) This method is imperfect and, as discussed later in this memo, cannot be expected to always provide the right answer. There are many cases in history when a 75% majority was proven wrong. There are many more cases, however, when the 75% majority was right. Non-experts making decisions on everything from cancer treatment to climate change attribution have the best chance of making the best possible decision using this type of "weighing experts" framework.[1]

This memo provides a preliminary analysis of the state of expert consensus and dissensus on some of the fundamental questions in climate change science. It does not address the policy implications of various approaches to addressing climate change. Using a "weighing experts" framework, we conduct a rough assessment by counting of the number of credentialed scientists who hold mainstream beliefs and the number that hold alternative beliefs and weighing one side against the other.

Climate systems are extraordinarily complex, subject to immense uncertainties. Ideally, policymakers, businesses, and other actors could wait until there was a perfect consensus before making decisions. But with credible claims that waiting to decide could result in catastrophic damage to the earth and human societies, decision-makers have no choice but to assess the current state of the scientific debate and to make the best bets under the circumstances. This is essentially the kind of choice faced by someone diagnosed with prostate cancer. Doctors may differ about which, if any, treatment regime to follow, but ultimately the patient must make his best estimate of the potential benefits and costs both of treatment and of doing nothing, and make a decision in a timely fashion.

II. Assessing consensus in climate science

Defining criteria: Who should be counted as credible experts?

First, we should seek to identify all those and only those experts who have relevant credentials with respect to the particular issues on which they are opining. To be "relevant," credentials must be closely related to the particular scientific or mathematical question at hand.

Second, the strength of an expert's credentials matters. Indicators of "strong" credentials to include (1) publishing widely and recently in respected peer-reviewed journals and (2) holding a faculty or research scientist appointment in a recognized and relevant department and institution.[2]

1 Note that a consensus among laypersons, even policymakers, should have no bearing on a rational layperson's conclusions about a scientific issue, although consensus about policy options must include a broader field of experts. To the extent that the consensus or trend is based on laypersons' perceptions of the views of scientists, those perceptions are at best second-hand compared to the method proposed in this paper.

2 Reliance on peer review is inevitably somewhat circular. But the peer review processes is generally considered to have contributed greatly to the advancement of knowledge. Like independent replication and validation, peer review is a mechanism of quality-control in science not present in many other disciplines.

Third, experts' opinions should be considered in the light of any potential conflicts of interest and discounted to the extent their views may be significantly influenced by these conflicts of interest. While we do not explore this dimension here, we acknowledge this aspect of expert opinion and provide resources for further investigation where appropriate.

Although not fully enumerated here, expert trends toward a consensus or dissensus on the issue in question are also relevant. For instance, if an individual expert or group of experts has moved from one position to another, such movement provides evidence of independent thought and validation of the conclusion reached.

The scientific questions addressed

We seek to assess the scientific consensus on nine questions:

1. Have global average temperatures risen since the pre-industrial era?
2. Have atmospheric greenhouse gas concentrations risen since the pre-industrial era?
3. Have temperature increases been caused by increased greenhouse gas concentrations?
4. Have human activities caused increases in greenhouse gas concentrations?
5. Will greenhouse gas concentrations continue to rise in the future?
6. Will temperatures increase significantly ($\geq$ ~1.5˚C) in the near future (by about 2100)?
7. Has any abnormal rise in temperatures already impacted natural systems (for example, biodiversity, agricultural yields, and sea-levels)?
8. Will continued temperature increases cause further impacts in these systems?
9. Can future reductions in greenhouse gas emissions slow global warming?

Levels of Expert Agreement: For purposes of this memo, we define levels of expert agreement as follows:

- **Consensus:** more than 95% agreement among relevant experts
- **Supermajority:** between 66% and 95% agreement among relevant experts
- **Debate:** less than 66% agreement, with or without a majority

Expert Groups: The Intergovernmental Panel on Climate Change (IPCC) is charged by the United Nations with assessing the state of understanding, evidence, and consensus in climate change. We use its conclusions represent the "mainstream" view of the expert community. The IPCC's latest report was collectively composed by more than 3000 scientists representing 130 countries. The IPCC's process and structure is described in Section III. Additional detail is available in Appendix II.

The IPCC concludes, with nuanced levels of certainty and likelihood, that global warming is happening and will continue, that this warming is caused by human activity, and that it will significantly harm natural systems and human societies. We term viewpoints opposing this basic message to be "alternate" beliefs and term those who hold them—for lack of a better term—"climate change skeptics."[3]

The following matrix sets out our broad findings for each question, including the nuances of the mainstream view, the number and credibility of climate skeptics, and the "net" agreement

3 While we analyze the consensus of "mainstream" and "alternate" expert opinion, treated here as binary groups (and phrased as binary questions in the Expert Opinion Matrix) for clarity, we stress that both climate science and expert dynamics play out on a broad and continuous spectrum of views.

throughout the climate science expert community. Section III summarizes the procedures of the major mainstream scientific bodies that have addressed climate change. Section IV considers dissenting opinions and the credentials of the dissenting experts. Section V assesses the status of expert agreement and draws conclusions.

Key questions about climate change science

	IPCC View	Experts with alternate views (if any)*	Credentials of experts with alternate views**	Status of expert agreement (hypothesis)
1. Have global average temperatures risen since the pre-industrial era?	Unequivocal	Trend skeptics	None relevant	Consensus
2. Have atmospheric greenhouse gas concentrations risen since the pre-industrial era?	Unequivocal	None	None	Consensus
3. Have temperature increases been caused by increased greenhouse gas concentrations?	"Very likely" [>90%] that "most" of 20th century increases due to GHG	Attribution skeptics	Some relevant, many not	Consensus
4. Have human activities caused increases in greenhouse gas concentrations?	CO2, N2O, halocarbons: unequivocal; CH4: "very likely" [>90%]	None	None	Consensus
5. Will greenhouse gas concentrations continue to rise in the future?	"high agreement" "much evidence" [qualitative]	None	None	Consensus
6. Will temperatures increase significantly (>1.5C) in the near future (by 2100)?	"Very likely" [>90%]	Attribution & trend skeptics	Few relevant	Consensus
7. Has any abnormal rise in temperatures already impacted natural systems? (e.g. biodiversity, agriculture, sea-level rise)	"Likely" [>66%]	Impacts skeptics	Very few relevant	Supermajority
8. Will continued temperature increases cause further impact in these systems?	"likely" reduction in resilience [>66%]; "likely" 20–30% of species at risk of extinction [>66%]; "medium confidence" in crop productivity changes (varies by latitude) [~5/10 chance]; "very high confidence" of sea level rise [>9/10 chance];	Impacts skeptics	Varies by impact—few credible regarding biodiversity, extinction, sea-level rise	Supermajority
9. Can future reductions in greenhouse gas emissions slow global warming?	Unequivocal, although 0.1 degrees C/decade increase is already built into the system. "High confidence" [~8/10 chance] that neither mitigation nor adaptation can avoid all impacts	Attribution skeptics	Some relevant, many not	Supermajority

III. Mainstream scientific institutions and climate change

How much weight should we give the mainstream view in column 2 of our matrix? Given the large number of scientists involved, we cannot identify every expert with relevant and strong credentials who agrees with the conclusions reached by the IPCC. We can, however, look at key scientific institutions as proxies for the opinions of the majority of scientists, especially if the positions of these institutions are transparently crafted with the input of many members, as is the case with national academies of science and discipline-specific scientific associations.

These scientific institutions set up procedures for scientists to collectively sift through a broad body of evidence. The peer-review processes conducted by (and embodied by) these scientific institutions are some of the most important determinants of good science, particularly for systems sciences like climate science.[4] They are the best available tools for both the scientific community and the public to judge among competing viewpoints.

Scientific bodies of international standing overwhelming support the conclusion that global warming is happening, that much of it is caused by humans, and that it is likely to cause serious harm to humankind. In this section, we consider 1) how the IPCC assesses the current understanding of climate science, thereby presenting the evidence and conclusions of the mainstream scientific community; and 2) how various national academies of science, particularly, the U.S. National Academy of Science and discipline-specific professional unions, particularly, the American Geophysical Union, provide external and independent validation of the IPCC's conclusions. We give brief background on each of these three focus institutions, present their specific positions of each on climate change science, and finally assess the credibility and impartiality of the scientists involved. Other relevant bodies are summarized in Appendix III.

Intergovernmental institutions

The Intergovernmental Panel on Climate Change (IPCC)[5] is the one and only intergovernmental institution designed specifically to assess scientific questions surrounding climate change. Its reports are widely-cited as the most authoritative syntheses of the science of climate change, with transparent processes and formal participation by thousands of scientists representing 130 countries.

Background: The IPCC was created in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). The Principles governing the IPCC state,

4 This analysis is particularly appropriate given the nature of climate science relative to other sciences. Because the climate system is immensely complicated, climate scientists can rarely use techniques like randomized controlled trials to test hypotheses. Instead, they use statistical analysis of parts of natural systems, such as carbon dioxide concentrations in the atmosphere. These pieces are then put together into a greater whole. Climate science is, thus, a team sport. This type of systems-level analysis cannot directly be proven "false" by any single piece of analysis. Rather, the scientific community must work together as a group to weigh and integrate multiple streams of data in order to consider the validity of a given theory, as is done by the IPCC.

5 In 2007 the Intergovernmental Panel on Climate Change (IPCC) published the Fourth Assessment Report about the known state of climate change science, causes, impacts, and mitigation options. Later that year, the IPCC was awarded a shared Nobel Peace Prize with former U.S. Vice President Al Gore for "their efforts to build up and disseminate greater knowledge about man-made climate change." However, by our definition of relevant, this prize cannot be considered as part of the analysis of the IPCC's scientific credibility.

"The role of the IPCC is to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. IPCC reports should be neutral with respect to policy, although they may need to deal objectively with scientific, technical and socio-economic factors relevant to the application of particular policies. Review is an essential part of the IPCC process. Since the IPCC is an intergovernmental body, review of IPCC documents should involve both peer review by experts and review by governments."

Scientific statements: Most relevant to our discussion are the Assessment Reports published by the IPCC. The Fourth Assessment Report (AR4) was published in 2007 and included contributions from scientists and reviewers from around the world. The conclusions of the AR4 are summarized in the expert opinion matrix above.

The IPCC has a sophisticated process for assessing and reflecting uncertainty and disagreement both within the experts as a group and among the experts. These are handled in two ways:

1. When questions arise regarding individual experts' beliefs as to the truth or validity of various theories, observations, and models, a qualitative approach is taken to reflect the degree of agreement or disagreement among the experts. In these cases, statements are accompanied by terms ranging from "high agreement/much evidence" to "medium agreement/medium evidence."
2. When questions arise regarding the overall group of experts' understanding of the quantitative strength of data, models, and analyses, the experts collectively agree to a statement reflecting their collective assessment of the robustness of the underlying science. When these assessments are done using only expert judgment, statements are accompanied by terms ranging from "very high confidence," meaning at least 90% certainty, to "very low confidence," meaning less than 10% certainty. When these assessments are done using both expert judgment and statistical analysis of all of the available data, statements are accompanied by terms ranging from "virtually certain," or at least 99% certainty, to "exceptionally unlikely," or less than 1% certainty.

Credentials and impartiality: The IPCC goes to extraordinary lengths to ensure comprehensiveness, credibility, and transparency (see Appendix II). The chapters of the AR4, for example, were written by over 450 lead authors, 800 contributing authors, and reviewed by over 2,500 expert and government reviewers. Many of the IPCC's lead authors are quite clearly among the world's top experts in their respective fields. Independent analyses based on the hallmark standards of scientific expertise and credibility (number of publications and citations on those publications) indicate that IPCC lead authors have exceptional expertise in climate science (Anderegg et al., forthcoming). While we have not analyzed each of the scientists involved, we think there is strong evidence that, for the most part, the authors and expert reviewers involved in the IPCC meet our criteria for relevant and strong credentials and for unbiased analysis.

The review process for chapters of Assessment Reports has at times received criticism, but remains widely-regarded for its thoroughness and transparency. A "zero order" initial draft is internally reviewed by members of the IPCC Working Group Bureaux. After a "first order" a draft of a chapter is produced it goes out to external review by experts(selected by the IPCC Working Group Bureaux)

and governments. Hundreds to thousands of comments come back from expert reviewers. The lead authors of each chapter must address each comment individually, either by accounting for it in the chapter or by writing a response of why they did not address the comment. These changes and responses are then reviewed by an independent group of review editors to ensure that the authors adequately and fairly responded to all comments. After these revisions this process is repeated with reviewers from more than 130 national governments.

National academies of science

No mainstream scientific organizations challenge the IPCC's conclusions or credentials. However, independent and external reviews of the IPCC's process, conclusions, and the state of climate science provide strong validation tests of the state of expert consensus around climate change. National academies of science are among the most respected of scientific bodies and fulfill this role.

Every major nation (and many small ones) hosts an academy of sciences. These academies are learned societies that coordinate scientific research and work to advance science. In most cases, they are wholly or partly sponsored by their home government. All of the major national academies of science have issued statements regarding human-caused climate change and the conclusions of the IPCC. Several have conducted their own independent review of the scientific literature. However, as transparency and thoroughness of scientific investigation vary by country in the national academies outside of the U.S., we focus on the U.S. National Academy of Sciences in our analysis. We should note that, as a group, these academies and several multi-national academies carry a weight and validity of scientific analysis equivalent to tens of thousands of credible and impartial scientists. With the recent statement issued by the Russian Academy of Sciences in May 2009, no major national science academy now disagrees with the views on climate science put forth by the IPCC. The U.S. National Academy of Sciences, European Academy of Sciences and Arts, InterAcademy Panel on International Issues (consisting of over 90 national science academies), InterAcademy Council (a board of 15 national academy presidents), and over 32 national academies have issued statements endorsing the assessment by the IPCC of climate change and its man-made causes. A more extensive discussion of these groups can be found in Appendix III.

Here we review the process and conclusions of the U.S. National Academy of Sciences.

Background: The U.S. National Academy of Sciences (NAS) conducts about 200 scientific studies per year, each of which seeks to answer questions on the basis of hard scientific evidence. Studies are conducted by committees composed of individuals with significant recognized scientific experience and expertise in the relevant area of inquiry.

Scientific statements: Climate Change has been assessed through many NAS studies since the 1970s. In 2001, the George W. Bush administration asked the Academy for an analysis of the state of climate change science. In addition, the Bush administration requested an analysis of processes of the IPCC and to determine whether the IPCC's conclusions were sufficiently valid and robust, or whether the process was too inherently political to yield unbiased scientific conclusions. The resultant NAS study was led by sixteen climate scientists, including climate skeptic Richard Lindzen from MIT. This study agreed with the vast majority of the IPCC's findings and found that the IPCC had a valid process for coming to and reflecting a scientific consensus and recommended that its conclusions be taken seriously by the U.S. government. Thus, independent analyses by the U.S.

National Academy of Sciences provide external validation of the IPCC's conclusions and contribute to the weight of mainstream expert opinion.

Credibility and impartiality: Again, while a complete analysis is beyond the scope of this document, there is good reason to believe that the vast majority of individuals involved in NAS studies meet our criteria for relevant and strong credentials and for unbiased analysis. Individuals are elected to the NAS only after years of significant contributions to their scientific fields and the climate science assessments are undertaken by Academy identified experts.

Over time, the Academy has established an elaborate process to incorporate input from many angles about who should be on specific study committees. Initial recommendations are put forth by a standing Academy committee that oversees all studies in a particular scientific area, for instance, the climate change committee. Then, staff does the leg work, following up on long lists of names and assessing their credentials in publishing and the broader scientific community. Staff then puts forward recommendations that are vetted by the Standing Board of the Academy. Many of these individuals are members of the Academy itself but up to 75% can be nonmembers. They can be non-citizens and can come from any sector of the economy, except that they cannot be government officials involved in the relevant area of inquiry nor can they have personal conflicting interests. Ultimately, final decisions are made by the President of NAS, who is *ex officio* also the president of the National Research Council. All committee members serve voluntarily and are not paid by NAS. Each committee additionally has a standing board (also unpaid) and a full-time staff (paid).

Transparency and accountability are critical to NAS's credibility. Its staff goes to great lengths to allow civil society and government to be kept in the loop as to their processes all along the way. Committee members are listed on a public website long before reports come out and a comments section allows the public to vet and opine on the individuals selected. No closed door meetings are held with government officials; all information that the committee members collect throughout the study process is collected publicly and openly.

Once information has been collected, committee members draft a report of usually 50–200 pages. That report is then sent out for anonymous peer review by other individual scientists judged to be relevant experts in the area of inquiry. They submit reviews, comments, and questions back to the committee of 50–100 pages. The committee is then required to respond to all comments and questions, though not necessarily to agree to them.

Finally, the re-drafted report and any other comments and responses from committee members are made public. Most reports are consensus-based documents, but there are also sometimes dissenting opinions.

Discipline-specific professional associations

Hundreds of discipline-specific professional associations have issued statements regarding climate change. Their assessment of the climate science relevant to their discipline provides another further independent test of expert opinion on climate science and validation of the IPCC conclusions. The vast majority of these statements confirm the conclusions of the IPCC and various national academies. We focus on one specific professional association, the American Geophysical Union, because it represents an immense body of scientists from a variety of fields in the Earth Sciences,

many of which (e.g. petroleum engineers) might seem initially skeptical about the mainstream scientific conclusions about climate change. For a more detailed list of associations who have made statements about climate science, we recommend a web resource for a broad overview[6].

See Appendix III for a detailed listing of discipline-specific professional associations.

Background: The American Geophysical Union (AGU) is the largest scientific society in the world and consists of approximately 50,000 researchers, teachers, and students from 137 countries. Members span many areas of the Earth and space sciences, including geologists, geophysicists, oceanographers, astrophysicists, and climatologists.

Scientific statements: The AGU drafted an official position statement on climate science and policy in 2003 and revised and reaffirmed it in 2007. The position statement was drafted by climate scientists Marvin Geller, Ellen Druffel, and prominent climate skeptic John Christy, and was approved by the AGU Council. The Council consists of five elected AGU officers, eleven presidents of sections (broad areas of geophysical science), and eleven section president-elects. The statement corroborates the IPCC assessment and reads:

> The Earth's climate is now clearly out of balance and is warming. Many components of the climate system—including the temperatures of the atmosphere, land and ocean, the extent of sea ice and mountain glaciers, the sea level, the distribution of precipitation, and the length of seasons—are now changing at rates and in patterns that are not natural and are best explained by the increased atmospheric abundances of greenhouse gases and aerosols generated by human activity during the 20th century...Evidence from most oceans and all continents except Antarctica shows warming attributable to human activities. Recent changes in many physical and biological systems are linked with this regional climate change. A sustained research effort, involving many AGU members and summarized in the 2007 assessments of the Intergovernmental Panel on Climate Change, continues to improve our scientific understanding of the climate.[7]

Credibility and impartiality: By our definition of credibility, many individuals in institutions such as the AGU have credentials that are considered relevant and strong by their respective disciplines. Other studies have explicitly quantified the level of scientific consensus about climate change within the AGU and this provides another tool for assessing credibility-weighted expert consensus (see Section V; Appendix I, Doran and Kendall-Zimmerman 2009).

IV. Climate change skeptics

As described above, the major scientific institutions with international standing support the mainstream conclusions about climate science. The conclusions of these institutions represent the findings of many thousands of credible and impartial scientists around the world.

6 "Scientific opinion on climate change." http://en.wikipedia.org/wiki/Scientific_opinion_on_climate_change#Statements_by_concurring_organizations.

7 See: http://www.sciencedaily.com/releases/2008/01/080125154628.htm.

Nonetheless, a minority of scientists contest some of the conclusions of the mainstream scientific community. We estimate that climate change skeptics constitute less than 5% of the overall community of climate scientists. Two independent studies, based off separate datasets, place the percentage of climate change skeptics at around 2.0–3.5% of relevant experts in climate science (Doran & Kendall-Zimmerman 2009, Anderegg et al., forthcoming).

The German climate scientist Stefan Rahmstorf usefully classifies climate skeptics into three broad categories based on the aspects of the mainstream climate science paradigm with which they disagree:

- *Trend Skeptics* hold that the global average temperature has not warmed detectably in recent decades.
- *Attribution Skeptics* agree that the planet has warmed appreciably in the last century but argue that this temperature change cannot be attributed to anthropogenic greenhouse gases.
- *Impacts Skeptics* agree that humans are responsible for at least some of recent warming but hold that either future temperature increases will be mostly beneficial or that the costs of mitigation far exceed any damages from projected impacts from temperature increases. The large majority of scientists in this category choose to base their analyses on relatively small projected temperature increases, such as in the case of Patrick Michaels and Bjorn Lomborg.

Research methods

Any analysis of the strength and relevance of individual scientists' credentials, their possible biases, and the aggregate numbers of credible and impartial climate skeptics must be approached with caution and thorough examination.

We conducted a search to identify the most influential and most cited climate skeptics and those most likely to have relevant expertise. We compiled a list of fifty-four names from two recent academic volumes (Singer & Avery 2007; ed. Michaels 2005) and a web resource[8]. We selected a list of twenty of the most prominent of these skeptics, based off a researcher's presence in both an academic volume and the web resource and supplemented with researchers from the web resource judged most likely to be credible climate experts, and then further assessed their scientific credibility.[9]

While we have not compiled a comprehensive list of climate skeptics and analyzed the credibility of the skeptical community, such analyses are forthcoming (Anderegg et al., forthcoming). Here, we focus primarily on the most influential and cited climate skeptics and those most likely to have expertise in the relevant areas.

Our analysis of the "leading" climate skeptics may overlook some skeptical scientists cited in the media or publishing in academic circles, but we argue it is the most useful method for two reasons. First, comprehensive lists of scientists who do and do not support various facets about climate

8 See: Wikipedia "List of scientists opposing the mainstream scientific assessment of global warming."

9 NOTE: "skeptic" is an imprecise term here, given the complex, multi-dimensional nature of this debate. That said, we use it as shorthand for those who publicly dispute the mainstream consensus.

change suffer immensely from problems of credibility and transparency[10]. Any blogger or unrelated PhD may claim to be an expert in climate science in such formats. Second, the leading and most qualified climate skeptics should be able to present the strongest case against the current scientific understanding. That is, the arguments and credibility of the group we analyze are likely stronger than the arguments and credibility of the larger community of skeptics. This group provides the strongest possible counterpoint to the prevailing consensus and the experts involved in the IPCC.

We then asked:

1. *Academic affiliations.* Have they excelled sufficiently to become current researchers or tenured professors at a university or research institution? Is their professor position relevant to the area of climate in which they claim expertise? Are they retired or still actively pursuing research?
2. *Publication records in peer-reviewed journals.* Extensive peer-reviewed publications indicate a deep and thorough engagement with current research and scientific understanding of climate science. Have the researchers published more than twenty peer-reviewed papers directly applicable to their appropriate field[11]? We assessed this by counting a researcher's peer-reviewed publications under the topic "climate" in the ISI Web of Knowledge academic database.
3. *Potential conflict of interest.* Have they or their research been directly funded by organizations or corporations that may have a strong stake in the findings of the research in the last ten years? We do not fully explore these connections here, but direct readers to several excellent sources.

See Appendix IV for full results of the twenty selected climate change skeptics.

Overview of climate change skeptics

Two main points emerge from the examination of leading climate change skeptics. First, nearly half cannot be considered credible experts in their relevant areas of climate science. Second, only a third of the climate change skeptics analyzed here have a substantial lifetime publication record concerning climate.

Nine of the twenty climate change skeptics (45%) do not hold directly relevant degrees, experience, or professor positions in environmental science, climatology, or atmospheric science. The nine researchers have backgrounds that are partially relevant (e.g. meteorologist, solid-state physicist), to some of the broader set of climate science questions, or are unrelated to climate science (e.g. hydrologist, agricultural analyst). Only one of these researchers shows a strong publication record (>20 lifetime publications) in climate. Thus, nearly half of the climate change skeptics do not hold related degrees to climate science and have published few to no peer-reviewed articles in climate science in their lifetimes (see Appendix IV for full table).

10 For example, the "Oregon Petition". See: http://en.wikipedia.org/wiki/Oregon_petition.

11 While at twenty-publication cutoff may be difficult young researchers, we suggest that an extensive publication record is among the best indicator for expertise in a given field. Furthermore, twenty publications can be viewed as a strongly conservative cutoff relative to the climate science community. While measured with a different citation index, forthcoming research suggests the median of IPCC author climate publications is around 85 publications (Anderegg et al. forthcoming).

Three of the twenty skeptics (15%) hold relevant degrees to climate science but do not show a strong lifetime publication record. This could be a function of a researcher's age (in accumulating enough publications to meet our definition of >20 climate publications) or that the researcher is broadly familiar with climate but does not publish in climate science nor have extensive climate expertise.

Eight of the twenty skeptics (40%) have relevant credentials and strong climate publication records in peer-reviewed journals. A more extensive study of publication records has demonstrated that even these researchers' expertise and credibility is far below that of mainstream (IPCC) climate researchers (Anderegg et al., forthcoming).

It is worth noting that the vast majority of the examined climate skeptics have connections to industry organizations that could be seen as potential conflicts of interest. Beyond direct financial connections, many are affiliated with and have received funding from organizations that are funded by fossil fuel interests, such as the Competitive Enterprise Institute or George Marshall Institute.[12,13]

Analysis of climate skeptics' arguments

Below is a brief examination of the general scientific arguments of these climate skeptics, regardless of credentials or conflict of interest.

Trend Skeptics: Trend skeptics often point to large spatial biases and uncertainty in instruments, especially surface thermometers, to suggest that global mean temperatures have not increased in the 20th century. They often point to satellite measurements of global surface temperature, which used to indicate no substantial warming since the 1970s.

Time and improved science has all but proved these skeptics incorrect. As the planet has continued to warm and previously contested satellite temperature records (see Spencer & Christy 1998, Fu et al. 2004) come to corroborate the warming signal, the number of trend skeptics has decreased substantially. Very few of the leading climate skeptics continue to hold this point.

None of the examined climate skeptics holding this belief can be considered credible in this area.

Attribution Skeptics: The argument that increasing global temperatures are not due to human-emitted greenhouse gases defines the largest, yet shrinking group of climate skeptics. One group holds that recent temperature changes are entirely or largely naturally caused, primarily by changes in solar radiation, while others point to the urban heat-island effect (that, as cities have grown, so has the heat trapped by buildings, warming the surface), while others posit no alternate theory and argue that anthropogenic greenhouse gas forcing is not large enough to have caused observed warming.

While nearly 30% of examined skeptics do not have relevant expertise or publishing records in this area, the credentials and arguments of the remainder merit examination. Relatively few of

12 The Union for Concerned Scientists published an extensive and well-documented report titled *Smoke, Mirrors, and Hot Air* that tracks ExxonMobil's donations of around $15 million dollars between 1998–2005 to manufacture scientific uncertainty and doubt regarding human-caused climate change. This report follows the funding from ExxonMobil to think-tank organizations and from these institutions to many of the most prominent climate change skeptics.

13 See also: Hoggan, J. *Climate Cover-Up.* Greystone Books. Vancouver, BC, Canada. 2009.

the examined skeptics actually worked directly with the model or data, and thus the credentials of many of these researchers are tenuous. Several (e.g. Christy, Douglass) do work tangentially with primary data and modeling. However, the skeptics in this group can be broadly characterized as experienced in the field, but not deeply immersed in cutting-edge research.

These skeptics often base their arguments on supposed discrepancies between climate models and observed temperature patterns and the supposed lack of attribution "fingerprints"—predictions from climate system theory expected with greenhouse gas induced warming. Many of these debates have been either fully resolved or largely addressed by the mainstream scientific community.

Impacts Skeptics: The IPCC states that the extent and severity of future climate impacts on natural systems will depend largely on the degree of warming. Working Group II of the IPCC reviews the observed impacts of recent anthropogenic climate change and concludes that changes are already visible in many natural systems, for example, species range and phenology (study of plant and animal life cycles) and agricultural yields, and that future increases in temperature will be largely negative, especially with higher temperature increases. Impacts skeptics, however, argue two interconnected points—that changes in global surface temperature are likely to be small (<1.0 C) and that these will be mostly beneficial to society.

In these areas, especially regarding natural systems, where impacts are assessed with natural science tools, not economic or social science methods, the examined climate skeptics have little relevant credibility. Both Michaels and Idso have relevant training but have published little in the area in recent years. Idso has published about possible mechanisms through which CO2 could have positive effects, namely the "CO2 fertilization effect," which remains hotly debated. It is worth noting that this is one of the few "positive" impacts projected for natural systems and that the large majority of other expected effects, including bleaching of coral reefs, species extinctions, and wildfire intensity, to name a few, are likely to be immensely negative. These are often ignored by the impacts skeptics. The dearth of experts suggests that impacts skeptics have limited expertise in assessing future impacts in natural systems.

V. Analysis and conclusion

It is difficult—but possible—to assess expert opinion on a multifaceted and complex topic like climate science. In this memo, we assessed the relative strength and depth of credibility of the IPCC and other scientific organizations. In turn, we have weighed the scale and credibility of researchers that contest the viewpoints of these scientific organizations.

The IPCC process already incorporates significant numbers of review comments from experts in relevant fields and any skepticism or controversy should be incorporated into the state of climate science in these reports. A few notable climate change skeptics have been lead authors or reviewers on these reports. Both national academies of science and discipline-specific professional organizations provide independent validation of IPCC conclusions, each with their own process of incorporating in review comments and dissenting opinions. We use a very conservative estimate that climate change skeptics comprise 10% of the relevant scientific community (2.5–5% is more likely, as discussed above) to evaluate expert agreement on our core questions of climate science. We conduct this expert-weighted assessment of scientific agreement by constructing a hypothetical

expert senate. To generate the numbers of expert senators on each side (mainstream and alternate) for each question, we multiply the IPCC's level of likelihood or confidence by the 90% of the expert community it represents and the proportion of the climate change skeptics by the 10% of the community they represent. Thus, if the IPCC expresses 50% confidence on a question and twenty out of twenty climate skeptics have credible and dissenting positions, the senate would consist of 45 mainstream members, 10 skeptical members, and reach a supermajority position of around 82%. This method is necessarily coarse, but provides an assessment of scientific agreement consistent with both the number and the credibility of researchers presented above.

Based on our external assessment and relative weighing of expert opinion, we conclude that for five questions, the scientific community has reached a *de facto* consensus (more than 95% agreement) aligned with the view of the IPCC:

Consensus "yes" for six questions:

1. Have global average temperatures risen since the pre-industrial era?
2. Have atmospheric greenhouse gas concentrations risen since the pre-industrial era?
3. Have temperature increases been caused by increased greenhouse gas concentrations?
4. Have human activities caused increases in greenhouse gas concentrations?
5. Will greenhouse gas concentrations continue to rise in the future?
6. Will temperatures increase significantly (>1.5C) in the near future (by 2100)?

Questions 2, 4, and 5 are not disputed by any of the prominent skeptics analyzed here and thus the community has reached a consensus. Our results of a consensus on questions 1 and 3 agree closely with a recent study that demonstrated via direct polling of AGU members that 96–97% of expert climate scientists agree that global average temperatures have risen since pre-industrial area and that anthropogenic greenhouse gases are a significant contributing factor in these temperature increases (Doran & Kendall-Zimmerman 2009).

For the other three questions, we conclude that the scientific community has reached agreement with the view of the IPCC characterized by a supermajority (at least 66% but less than 95% agreement):

Supermajority "yes" for three questions:

7. Has any abnormal rise in temperatures already impacted natural systems? (e.g. biodiversity, agriculture, glacial extent, wildfire severity, sea-level rise)
8. Will continued temperature increases cause further harm to these systems?
9. Can future reductions in greenhouse gas emissions slow global warming?

Ronald Bailey, who wrote *Global Warming and Other Eco-Myths,* published by the conservative think-tank Competitive Enterprise Institute in 2002, summarizes the state of the debate nicely. He wrote in 2005 "Anyone still holding onto the idea that there is no global warming ought to hang it up." By 2007, with the publication of the IPCC's Fourth Assessment Report he wrote, "Details like sea level rise will continue to be debated by researchers, but if the debate over whether or not humanity is contributing to global warming wasn't over before, it is now..." (Quotes from *Reason Magazine*: August 11, 2005 and February 2, 2007)

It is important to note that, for these three questions, the IPCC itself presents a nuanced view. It does not unequivocally answer yes to any, but rather gives estimates of probabilities and certainty. Thus, the less than 95% agreement in the scientific community does not represent a large minority disagreeing with the IPCC, but rather ongoing analysis within the community about certainties and likelihoods and ranges.

Many important questions about climate change are still being explored by the scientific community. How large will temperature increases be in the next century with a given amount of greenhouse gas emissions? How extensive and vast will the impacts and damages of anthropogenic climate change be? How can society best mitigate and adapt to avoid the impacts of climate change at the lowest cost? Are there irreversible and threshold tipping points, beyond which dangerous and unexpected climatic disasters could occur?

Our analysis has indicated that the IPCC will continue to provide the most transparent and thorough "one-stop-shop" for assessments of the state of the literature regarding these questions. Finally, we note that "scientific consensus" is a difficult topic to address, define, and achieve. We would welcome and encourage others to add to our own analysis here.

APPENDICES

Appendix I: Complementary analytic approaches

This analysis in this paper could be complemented with other approaches. For example:

1. What proportion of published, peer-reviewed climatology papers are aligned with the mainstream consensus?
2. What proportion of active, credentialed climatologists ascribe to the mainstream consensus?
3. What are the broad publication and citation credentials of mainstream climate scientists versus those of the climate change skeptics?

Recent related research has provided preliminary results on all three of these questions:

1. One researcher analyzed 928 abstracts of papers from refereed scientific journals between 1993 and 2003 that had the keywords "global climate change". Of the 75% of those papers which did not deal with paleoclimate (that is, dealt with the modern climate), zero explicitly disputed the mainstream consensus on anthropogenic climate change.[14]
2. One recent survey found that "96.2% of climatologists who are active in climate research believe that mean global temperatures have risen compared to pre-1800s levels, and 97.4% believe that human activity is a significant factor in changing mean global temperatures."[15]
3. Forthcoming research on an extensive dataset of the publication records and citation rates of ~1,400 researchers suggests that mainstream climate scientists have in general much greater expertise and much higher scientific credibility than do the climate change skeptics.[16]

Appendix II: Credibility, transparency, and processes in the IPCC[17]

Structure and governance

The IPCC was founded as an initiative of the World Meteorological Organization and the United Nations Environment Program and has a secretariat located in Geneva, Switzerland. Generally, its members include all sovereign states with general international recognition.

14 Oreskes, Naomi. "Beyond the Ivory Tower: The Scientific Consensus on Climate Change". (December 3, 2004 (Erratum January 21, 2005). *Science* 306 (5702): 1686.

15 Doran, Peter T.; Maggie Kendall Zimmerman "Examining the Scientific Consensus on Climate Change." *EOS* 90 (3): 22–23.

16 Anderegg et al. Expert Credibility in Climate Change. Submitted.

17 "Principles Governing IPCC Work" (Approved 1998, Vienna; Amended 2003, Vienna and 2006, Mauritius). Note: Most of the content comes from Appendix A "Procedures for the Preparation, Review, Adoption, Approval, and Publication of IPCC Reports"; Appendix B "Financial Procedures for the Intergovernmental Panel on Climate Change (IPCC)"; Appendix C "Rules of Procedures for the Election of the IPCC Bureau and Any Task Force Bureau".

Ultimate power rests in the members of the IPCC, which are individual member countries of WMO and UNEP. There are a total of 193 members.

- Southwest Pacific: 22 members
- Europe: 51 members
- Asia: 32 members
- South America: 12 members
- North America, Central America, and the Caribbean: 23 members
- Africa: 53 members

Members vote for IPCC Bureau, which serves as the executive body and makes most of the key decisions. Votes are by secret ballot and simple majority, with subsequent ballots if necessary. Candidates are nominated by member governments and must present curriculum vitae before elections. Candidates "shall have relevant scientific, technical, or socio-economic expertise". The membership is instructed to strive for geographic balance among the regions.

The IPCC Bureau is 30 individuals:

- Chair
- 3 Vice-Chairs
- 2 Co-chairs of the Task Force Bureau on National Greenhouse Gas Inventories
- 3 Working Group Bureaux, each with:
    - 2 Working Group Co-chairs
    - 6 Working Group Vice-chairs

The bulk of the actual analysis and writing is done by four working groups:

- Working Group I: The Scientific Basis
- Working Group II: Impacts, Vulnerability, Adaptation
- Working Group III: Mitigation
- Task Force Bureau on National Greenhouse Gas Inventories

Process

In general, the IPCC is instructed to attempt to reach consensus. Where that is not possible, differing views are to be represented in the appropriate document. The documents are subject to peer-review by both experts and governments. See the "Decision Making" section below for more detail.

Most of the synthesis happens in the Working Groups. The Working Group Co-chairs and Vice-chairs choose the members of the working groups. Work is done by chapter, with each chapter guided by the Lead Authors and a Coordinating Lead Author (with the latter responsible for coordinating the process of writing).

Generally, the process has six steps:

- Nomination of participants (Coordinating Lead Authors, Lead Authors, Expert Reviewers, Contributing Authors, Review Editors, and Government Focal Points)[18]
- Choice of Coordinating Lead Authors and Lead Authors by Working Group Bureaux
    - Additional authors may be added as needed by Lead Authors and Coordinating Lead Authors
- Preparation of draft report
- Review of report
    - First review: expert reviewers
    - Modifications for second draft report
    - Second review: government reviewers
- Preparation of final report
- Acceptance of report

Decision-making

Additionally, the certainty statements within documents produced by the IPCC are subject to different levels of scrutiny and ultimately reflect different levels of agreement by the group of experts and governments:

- For the majority of text in reports members agree that the report as a whole reflects "a comprehensive, balanced, and objective view of the subject matter" and then "accept" the language.
- For the "Synthesis Reports," the approximately 50 page summaries released in 1992, 1995, 2001, and 2007, members analyze each section and then "adopt" the language.
- For the "Summary for Policymakers," the approximately 20-page executive summary released in the same years, members analyze the language line by line and then "approve" it.

These IPCC processes help produce reports with not only a general consensus view from the scientific community, but also a nuanced analysis of exactly what we do and don't know and how well we know it. Each statement in the IPCC reports should be assessed based on the certainty qualifiers accompanying it and with an eye to the specific adoption processes it underwent.

Analysis

The IPCC process appears to be democratic and transparent. But it is, like all democratic processes, subject to political forces. We suggest two types:

- "Micro" forces: the personalities and interests of individual scientists.
    - Democratic processes are designed to address micro-forces. They don't go away, but are certainly attenuated by transparency and the balance inherent in democratic mechanisms.

18 See Annex 1 of Appendix A of "Principles Governing IPCC Work" for definitions of the different roles.

- "Macro" forces: the political/economic interests of member governments
  - If the macro forces are relevant, it seems very likely that they would operate to dampen, not enhance, the IPCC's findings as to the anthropogenic nature and severity of climate change.
  - A number of national governments have short- and medium-term economic interest to avoid regulation of carbon emissions: oil exporters (Saudi Arabia, Russia, UAE, Venezuela, etc), coal exporters (Australia, etc), exporters of forest products (Indonesia, Brazil), and countries with high per-capita emissions (USA, Canada, EU members).
  - Relatively few countries have selfish, direct short- or medium-term interests to reduce emissions—most notably low-lying island nations, which generally lack outsized political power. (Note: this not to say that most nations don't have *long-term* selfish interests to reduce climate change.)

Appendix III: Statements from scientific institutions[19]

Statements in support of general IPCC conclusions:

Academies of Science

- European Academy of Sciences and Arts (2007)
- InterAcademy Council (representative of the world's scientific and engineering academies) (2007)
- International Council of Academies of Engineering and Technological Sciences (2007)
- Joint science academies' statements (2001, 2005, 2007, 2008, 2009)
  - Signatories of these statements have been the national science academies of:

Australia	Belgium	Brazil	Cameroon
Canada	The Caribbean	China	France
Ghana	Germany	Indonesia	Ireland
Italy	India	Japan	Kenya
Madagascar	Malaysia	Mexico	Nigeria
New Zealand	Russia	Senegal	South Africa
Sudan	Sweden	Tanzania	Uganda
United Kingdom	United States	Zambia	Zimbabwe

- The national science academies of the G8+5 nations (2007, 2008, 2009)
- Network of African Science Academies (the science academies of Cameroon, Ghana, Kenya, Madagascar, Nigeria, Senegal, South Africa, Sudan, Tanzania, Uganda, Zambia, Zimbabwe, as well as the African Academy of Sciences) (2007)

19 Source for Appendix III: http://en.wikipedia.org/wiki/Scientific_opinion_on_climate_change#Statements_by_concurring_organizations. Where possible, dates of relevant statements are included. This list is not comprehensive.

General science

- American Association for the Advancement of Science (2006)
- European Science Foundation (2007)
- National Research Council (US) (2001)

Biology and life sciences

- American Association of Wildlife Veterinarians
- American Society for Microbiology (2003)
- Australian Coral Reef Society (2006)
- Institute of Biology (UK)
- Society of American Foresters (2008)
- The Wildlife Society (international)

Earth sciences

- American Geophysical Union (2003, 2007)
- European Federation of Geologists (2008)
- European Geosciences Union (2005, 2008)
- Geological Society of America (2006)
- International Union of Geodesy and Geophysics (2007)
- Stratigraphy Commission of the Geological Society of London

Human health

- American Academy of Pediatrics (2007)
- American College of Preventive Medicine (2006)
- American Medical Association (2008)
- American Public Health Association (2007)
- Australian Medical Association (2004, 2008)
- European Centre for Disease Prevention and Control (2009)
- World Federation of Public Health Associations (2001)
- World Health Organization (2008)

Meteorology/oceanography

- American Meteorological Society (2003)
- Australian Meteorological and Oceanographic Society
- Canadian Foundation for Climate and Atmospheric Sciences (2005)
- Canadian Meteorological and Oceanographic Society
- Royal Meteorological Society (UK) (2007)
- World Meteorological Organization (2006)
- American Quaternary Association
- International Union for Quaternary Research

Miscellaneous

- American Astronomical Society
- American Chemical Society (2008)
- American Institute of Physics
- American Physical Society (2007)
- American Statistical Association (2007)
- Engineers Australia (The Institution of Engineers Australia)

Noncommittal, expired, or mixed statements

- American Association of State Climatologists (no current statement)
- American Association of Petroleum Geologists (revising statement)
- American Geological Institute (last statement in 1999)
- American Institute of Professional Geologists (noncommittal)
- Canadian Federation of Earth Sciences (focused on geoengineering)

Appendix IV: Climate change skeptic credentials

Group	Skeptic	Credentials	Lifetime Pub's	Synthesis
Trend Skeptics	Timothy Ball	"Geographer, retired professor from University of Winnipeg"	12	**UC**
	Robert Carter	"Geologist, adjuct research professor, James Cook University, Queensland"	9	**UC**
Attribution Skeptics	Dennis Avery	"Agricultural analyst, Hudson Institute"	0	**UC**
	Sallie Baliunas	"Astronomer, Harvard-Smithsonian Center for Astrophysics"	15	**"C, P-"**
	Robert Balling	"Geographer, Professor at Arizona State University"	100	**"C, P+"**
	John Christy	"Atmospheric scientist, professor at University of Alabama, Huntsville"	39	**"C, P+"**
	Ian Clark	"Hydrologist, geochemist, professor at University of Ottowa"	16	**UC**
	David Douglass	"Solid-state physicist, professor at University of Rochester"	26	**"UC, P+"**

(Continued)

	William Gray	"Retired meteorologist, hurricane researcher"	6	**UC**
	William Happer	"Physicist, professor at Princeton University"	1	**UC**
	William Kininmonth	Retired meteorologist	2	**UC**
	George Kukla	Retired climatology professor from Columbia University	44	**"C, P+"**
	David Legates	"Geographer, climatologist, associate professor at University of Delaware"	24	**"C, P+"**
	Richard Lindzen	"Atmospheric physicist, Professor at MIT"	43	**"C, P+"**
	Fred Singer	Professor emeritus of Environmental Sciences at University of Virginia	14	**"C, P-"**
	Willie Soon	"Astrophysicist, Harvard-Smithsonian Center for Astrophysics"	14	**"C, P-"**
	Roy Spencer	"Atmospheric scientist, research scientist at University of Alabama, Huntsville"	48	**"C, P+"**
Impacts Skeptics	Sherwood Idso	Retired physicist from Arizona State University and USDA	102	**"C, P+"**
	Bjorn Lomborg	"Economist, adjust professor at Copenhagen Business School"	0	**UC**
NOTE: Most of the Attribution Skeptics also forward Impacts Skeptics beliefs	Patrick Michaels	Retired professor; ecology and climate science at the University of Virginia	46	**"C, P+"**

Table Legend: We present the twenty prominent climate change skeptics analyzed in this document. We provide a researcher's credentials (profession, expertise, academic affiliation), lifetime peer-reviewed publications under the topic "climate", and our synthesis of whether a researcher is uncredentialed (UC: field not directly related to climate AND no strong lifetime publication record), credentialed but no strong publication record (C, P-), or credentialed and strong publication record (C, P+).

Appendix V: Sources

NOTE: This source list is not comprehensive

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