STATEMENT TO THE
COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
OF THE UNITED STATES HOUSE OF REPRESENTATIVES

Hearing on
Climate Science: Assumptions, Policy Implications and the Scientific Method

29 March 2017

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Major points:

- Scientific progress is driven by the creative tension spurred by disagreement, uncertainty and ignorance.
- Progress in understanding the climate system is being hampered by an institutionalized effort to stifle this creative tension, in the name of a 'consensus' that humans have caused recent climate change.
- Motivated by the mandate from the UN Framework Convention on Climate Change (UNFCCC), the climate community has prematurely elevated a scientific hypothesis on human-caused climate change to a ruling theory through claims of a consensus.
- Premature theories enforced by an explicit consensus building process harm scientific progress because of the questions that *don't* get asked and the investigations that *aren't* undertaken. As a result, we lack the kinds of information to more broadly understand climate variability and societal vulnerabilities.
- Challenges to climate research have been exacerbated by:
    - Unreasonable expectations from policy makers
    - Scientists who are playing power politics with their expertise and trying to silence scientific disagreement through denigrating scientist who do not agree with them
    - Professional societies that oversee peer review in professional journals are writing policy statements endorsing the consensus and advocating for specific policies
- Policymakers bear the responsibility of the mandate that they give to panels of scientific experts. The UNFCCC framed the climate change problem too narrowly and demanded of the IPCC too much precision – where complexity, chaos, disagreement and the level of current understanding resists such precision.
- A more disciplined logic is needed in the climate change assessment process that identifies the most important uncertainties and introduces a more objective assessment of confidence levels.
- Expert panels with diverse perspectives can handle controversies and uncertainties by assessing what we know, what we don't know, and where the major areas of disagreement and uncertainties lie.

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I thank the Chairman and the Committee for the opportunity to offer testimony today on 'Scientific Method as it Relates to Climate Change.' I am Professor Emeritus of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology. I have devoted four decades to conducting research on a variety of topics related to weather and climate. In recent years my focus has been on uncertainty and the interface between climate science and policy. As President of Climate Forecast Applications Network LLC, I have been working with decision makers to use weather and climate information to reduce vulnerability to extreme weather and climate events.

I am increasingly concerned that both the climate change problem and its solution have been vastly oversimplified. The result of this simplified framing of a complex, wicked problem is that we lack the kinds of information to more broadly understand climate variability and societal vulnerabilities.

Motivated by the mandate from the UN Framework Convention on Climate Change (UNFCCC) to address dangerous human-caused climate change, the climate community has worked for more than 20 years to establish a scientific consensus on human-caused climate change, which has prematurely elevated a scientific hypothesis to a ruling theory. Premature theories enforced by an explicit consensus building process harm scientific progress because of the questions that *don't* get asked and the investigations that *aren't* undertaken.

Challenges to climate research have been exacerbated by:

- Expectations from policy makers
- Scientists who are playing power politics with their expertise and trying to silence scientific disagreement through denigrating scientists who do not agree with them
- Professional societies (that oversee the peer review in professional journals) who are writing policy statements endorsing the consensus and advocating for specific policies

Motivated by these concerns, my testimony focuses on the following issues of central relevance to the issues of climate science and the scientific method:

- Scientific method for complex environmental systems
- How scientists fool themselves
- Disagreement and reasoning about climate uncertainty
- The interface between climate science and policy

Scientific method for complex environmental systems

My perspective on the scientific method is based on four decades as a scientist and extensive readings on the philosophy and sociology of science. Over the past seven years, I have been exploring these issues as they relate to climate science in a series of blog posts[1] and several publications.[2] My perspective is summarized below.

Science is a *process* for understanding how nature works. The scientific process can be summarized as: ask a question or pose a hypothesis, set up an objective test or experiment, and make a scientific argument – and then repeat. A scientific argument uses logic to combine assumptions and evidence. Science is often *mis*characterized as the assembly and organization of data and as a collection of facts on which scientists agree. Science is *correctly* characterized as a process in which we keep exploring new ideas and changing our understanding of the world, to find new representations of the world that better explain what is observed. Part of science is to do calculations and to make predictions, but another part of science is to ask deep questions about how nature works.

'Scientifically proven' is a contradiction in terms – science does not prove anything. Scientists have a vision of reality that is the best they have found so far, and there may be substantial disagreement among individual scientists. Science works just fine when there is more than one hypothesis to explain something – in fact, disagreement spurs scientific progress through creative tension and efforts to resolve the disagreement. Science is driven by uncertainty, disagreement and ignorance – the best scientists actively cultivate doubt. Scientists do not concentrate on what they know, but rather on what they don't know. Science is an ongoing process of revision that may be incremental, occur in fits and starts, or through an unexpected breakthrough. Scientists tackle ignorance in formulating their research approach through challenging assumptions and presuppositions, curiosity, imagination, identifying connections with other research, and revisiting apparently settled questions.

How do we evaluate scientific theories, which are collections of hypotheses? All theories are underdetermined by data. Theories are evaluated based on independent corroboration, effectiveness in explaining phenomena and making predictions. Aspects of science that are reasonably settled are reliably used as assumptions for other scientific investigations and often enter into the realm of engineering.

What is the status of climate science as it relates to the nature and causes of variations on timescales from decades to centuries?

The foundation of climate science rests on fundamental laws such as Newton's laws of motion, Planck's Law and the Stefan Boltzmann Law, the first and second laws of thermodynamics, ideal gas laws, gravitation, and conservation of mass and energy. There are numerous theories of complex processes (collections of hypotheses) that contribute to our understanding of climate science, including the theory of rotating fluids, the theory of boundary layers, the theory of gaseous infrared spectroscopy and radiative transfer. These theories are widely accepted.

The meta-theory of greenhouse warming of the climate system incorporates many hypotheses and theories about how components of the climate system work. It is an empirical fact that the Earth's climate has warmed overall for at least the past century. However, we do not know how much humans have contributed to this warming and there is disagreement among scientists as to whether human-caused emissions of greenhouse gases is the dominant cause of recent warming, relative to natural causes.

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[1] https://judithcurry.com/category/scientific-method/

[2] Curry, JA and Webster PJ 2011: Climate science and the uncertainty monster. *Bull Amer Meteorol. Soc.,* 92, 1667-1682.

Complexity

Scientific arguments in physics, chemistry and cell biology are typically based on controlled laboratory experiments, where explanation and prediction can be based on a few variables. There are elements of climate science that can be addressed using these methods, notably in atmospheric chemistry and the physics and chemistry of aerosol and cloud particles.

However, scientific investigations of the dynamics of the entire climate system have more in common with systems biology and economics than with laboratory physics and chemistry, owing to the complexity of the systems under investigation and the inability to conduct controlled experiments. Complexity of the climate system arises from chaotic behavior and the nonlinearity of the equations for motions in the atmosphere and ocean, high dimensionality of the system (many different variables, varying in three dimensions and with time), and the linking of multiple subsystems (e.g. atmosphere, oceans, land surface, glacier ice).

The aggregate properties and changes of complex systems cannot be determined from sum of the individual components, owing to interactions among the components and the different scales of organization within the system. Complex systems are studied using information theory and computer simulation models (e.g. global climate models.) While some of the equations in climate models are based on the laws of physics, many key processes in the model are only approximated and are not directly related to physical laws.

Global climate models are used by scientists to represent aspects of climate that are difficult to observe, experiment with theories in a new way by enabling hitherto infeasible calculations, understand a system of equations that would otherwise be impenetrable, and explore the system to identify unexpected outcomes. As such, global climate models are an important element of climate research. For models of a complex system, the notion of a correct or incorrect model is not well defined. The relevant issue is whether the model 'works' and is fit for its intended purpose.

Assessment of climate models

In a recent report 'Climate Models for Laymen,'[3] I described how climate models are useful tools for conducting scientific research to understand the climate system. However, I argued that current global climate models are not fit for the purpose of attributing the causes of recent warming or for predicting global or regional climate change on timescales of decades to centuries, with any high level of confidence. Concerns about the utility of climate models include:

- Predictions of the impact of increasing CO_2 on climate cannot be rigorously evaluated for order of a century.
- Failure of climate models to provide a consistent explanation of the early 20th century warming and the mid-century cooling.
- Inability of climate models to simulate the magnitude and phasing of large-scale ocean oscillations on decadal to century timescales
- Insufficient exploration of climate model uncertainties.
- Extremely large number of unconstrained choices in terms of selecting model parameters and parameterizations.
- Evaluation of climate models against the same observations used for model tuning.
- Concerns about a fundamental lack of predictability in a complex nonlinear system.

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[3] Curry, J. 2017: Climate Models for the Layman http://www.thegwpf.org/content/uploads/2017/02/Curry-2017.pdf

How scientists fool themselves

Prior to 2010, I accepted and supported the consensus conclusions from the Assessment Reports published by the Intergovernmental Panel on Climate Change (IPCC) – I felt that this was the responsible thing to do. However, following the revelations of ClimateGate,[4] I realized that I had fallen victim to 'groupthink' – a pattern of thought characterized by conformity to group values and the manufacture of consensus that results in self-deception. I undertook an investigation into the ways that scientists can fool themselves, by examining deceptions from other fields of science and reading analyses from the perspectives of psychology and the philosophy and sociology of science. Below are my reflections on how climate scientists can fool themselves, and what they can do about it.

Cognitive biases

Because of the complexity of the climate problem, scientists use different mental models for evaluating the interconnected evidence. Biases can abound when reasoning and making judgments about such a complex problem. Bias can occur by excessive reliance on a particular piece of evidence, the presence of cognitive biases in reasoning shortcuts, failure to account for indeterminacy and ignorance, and logical fallacies and errors including circular reasoning.

Cognitive biases relate to self-deception. Cognitive biases of particular relevance to the science of climate change include:

- *Confirmation bias*: the tendency to search for or interpret information in a way that confirms one's preconceptions
- *Self-serving bias*: a tendency for people to evaluate information in a way that is beneficial to their interests
- *Belief bias*: evaluating the logical strength of an argument based on belief in the truth or falsity of the conclusion
- *Framing*: using a narrow approach that pre-ordains the conclusion
- *Overconfidence*: unjustified, excessive belief
- *Illusory correlations*: false identification of relationships with rare or novel occurrences

A recent article by statistician Regina Nuzzo in *Nature* summarizes the problem:

> *This is the big problem in science that no one is talking about: even an honest person is a master of self-deception. In today's environment, our talent for jumping to conclusions makes it all too easy to find false patterns in randomness, to ignore alternative explanations for a result or to accept 'reasonable' outcomes without question — that is, to ceaselessly lead ourselves astray without realizing it.* [5]

Simply, scientists are human and subject to biases. Further, they have personal and professional stakes in the outcomes of research – their professional reputation and funding is on the line. Assuming that individual scientists have a diversity of perspectives and different biases, then the checks and balances in the scientific process including peer review will eventually see through the biases of individual scientists. However, when biases become entrenched in the institutions that support science – the professional societies, scientific journals, universities and funding agencies – then that subfield of science may be led astray for decades and make little progress.

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[4] Mosher and Fuller (2010) ClimateGate: The CRUTape letters https://www.amazon.com/dp/B003552M76/ref=dp-kindle-redirect?_encoding=UTF8&btkr=1

[5] http://www.nature.com/news/how-scientists-fool-themselves-and-how-they-can-stop-1.18517

Premature theories and manufactured consensus

A scientific argument can evolve prematurely into a ruling theory if cultural forces are sufficiently strong and aligned in the same direction. Science policy expert Daniel Sarewitz describes the process:

> *"Like a magnetic field that pulls iron filings into alignment, a powerful cultural belief is aligning multiple sources of scientific bias in the same direction. The belief is that progress in science means the continual production of positive findings. All involved benefit from positive results, and from the appearance of progress. Scientists are rewarded both intellectually and professionally, science administrators are empowered and the public desire for a better world is answered."* [6]

I have argued that cognitive biases in the context of the IPCC's consensus building process surrounding human-caused climate change have resulted in the consensus becoming increasingly confirmed in a self-reinforcing way, to the detriment of the scientific process.[7]

Princeton philosopher Thomas Kelly provides some general insights into the sources of confirmation bias and belief polarization[8] that are relevant to the climate change consensus. Kelly argues that belief held at earlier times can skew the total evidence that is available at later times, via characteristic biasing mechanisms, in a direction that is favorable to the initial belief. All else being equal, individuals tend to be significantly better at detecting fallacies in an argument for a conclusion that they disbelieve, than when the same fallacy occurs in an argument for a conclusion that they believe. Of particular relevance to the IPCC's consensus on human-caused climate change:

> *"As more and more peers weigh in on a given issue, the proportion of the total evidence which consists of higher order psychological evidence [of what other people believe] increases, and the proportion of the total evidence which consists of first order evidence decreases . . . At some point, when the number of peers grows large enough, the higher order psychological evidence will swamp the first order evidence into virtual insignificance."* [9]

So what are the implications of Kelly's arguments for the IPCC's consensus on human-caused climate change? Cognitive biases in the context of an institutionalized consensus building process have arguably resulted in the consensus becoming increasingly confirmed in a self-reinforcing way. An extended group of scientists derive their confidence in the consensus in a second-hand manner from the institutional authority of the IPCC and the emphatic nature in which the consensus is portrayed. This 'invisible hand' marginalizes skeptical perspectives and is operating to the substantial detriment of climate science, as well as biasing policies that are informed by climate science.

Premature theories enforced by an explicit consensus building process harm scientific progress because of the questions that *don't* get asked and the investigations that *aren't* undertaken. Overconfident assertions take away the motivation for scientists to challenge the consensus, particularly when they can expect to be called a 'denier' for their efforts and see their chances diminish for professional recognition and research funding. As a result of the enforced consensus, there is little independent thought that seeks to advance fundamental understanding or develop an independent aggregate understanding of how the climate system works.

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6 Foreword to Science on the Verge http://www.andreasaltelli.eu/file/repository/Foreword_Dan_Sarewitz.pdf
7 Curry JA, 2013: Climate change: No consensus on consensus. *CAB Reviews*, 8, 001.
8 Kelly T (2005) ''The epistemic significance of disagreement.' Epistemology, 19, 179–209
9 Kelly T (2008) 'Disagreement, dogmatism and belief polarization'. J Philosophy 611–633

When a field of science becomes entangled with politics and public policy debates – such as climate science – the stakes for diverging from the consensus point of view become much higher. Rather than encouraging scientific debate, there are attempts by scientists, the media and politicians to end debate by insisting that a large majority of scientists support a consensus, referring to those that disagree as 'deniers'. Sound theory does not need to demonize its opponents; rather these are the tactics of elevating a premature theory to dogma and enforcing it for political purposes.

Overcoming bias

A scientist's job is to continually challenge his/her own biases and ask 'How could I be wrong?' Playing 'devil's advocate' helps a scientist examine how their conclusions might be misguided and how they might be wrong. Overcoming one's own biases is difficult; an external devil's advocate can play a useful role in questioning and criticizing the logic of the argument.

T.C. Chamberlain's method of 'multiple working hypotheses'[10] is a strategy that brings into view every rational explanation of the phenomena. The value of multiple working hypotheses lies largely in its suggestiveness of lines of inquiry that might otherwise be overlooked. More formal methods include 'Red Team' and 'Team B' approaches that provide competitive analyses to challenge the dominant ones. I have participated in two interesting experiments along these lines for climate science, which are described below.

In 2014, the American Physical Society (APS) held a Workshop to consider its statement on climate change. A committee of eminent physicists, each with no particular expertise in climate science or an apparent dog in the public debate, selected six climate scientists with diverse perspectives (Isaac Held, Ben Santer, William Collins, Judith Curry, Richard Lindzen, John Christy) to address specific questions prepared by the committee that were related to the IPCC 5th Assessment Report. The APS produced a complete transcript of the Workshop.[11] This transcript is a remarkable document — it provides, in my opinion, the most accurate portrayal of the scientific debates surrounding climate change.

Organized under the auspices of the Dutch Ministry of Infrastructure and the Environment, Climate Dialogue[12] offered a blog platform for discussions between scientists on important climate topics that are of interest to both fellow scientists and the general public. The goal was to explore the full range of views that scientists have on the selected issue. Each discussion was initiated by a short introduction written by the editorial staff, followed by guest essays by two or more invited scientists. The scientists reacted to each other's essays and to questions posed by the editorial staff. The public (including other climate scientists) could comment on a separate thread. After the online discussion, Climate Dialogue editors wrote a summary, describing the areas of agreement and disagreement between the discussants. I participated in the inaugural dialogue on Arctic sea ice, and there were a total of six dialogues before the effort was terminated. Each of these dialogues is a testament to the importance of this kind of scientific dialogue and debate in terms illuminating and clarifying the scientific issues and uncertainties.

Beyond overcoming bias, the dialectical nature of science can play an important role in solving problems of societal relevance. When scientific input is sought on a socially relevant issue, we need to acknowledge that there are competing hypotheses and theories that are of practical consequence. Societal problem solving would benefit greatly from forums that bring together the proponents of these competing inquiries for debate and joint problem solving.

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[10] http://www.auburn.edu/~tds0009/Articles/Chamberlain%201965.pdf
[11] http://www.aps.org/policy/statements/upload/climate-seminar-transcript.pdf
[12] http://www.climatedialogue.org/

Disagreement and reasoning about climate uncertainty

During my investigation of arguments and evidence being used to support the IPCC statement on the causes of recent climate change, it became apparent to me that there were rational reasons for disagreement about many aspects of these arguments. I concluded that reasoning about a complex system with many uncertainties is not at all straightforward. My investigations on this topic included reading about argumentation and disagreement from the perspectives of philosophy and law, as well as logical inference and network theory. I published two articles on these topics.[13,14] My reflections on disagreement, uncertainty and reasoning about the complex climate problem are summarized below.

Disagreement

Science proceeds just fine with indefinite conclusions, disagreement and multiple hypotheses. In fact, science works best under the creative tension of competing hypotheses. Disagreement among scientists and support for rival hypotheses can arise from:

- Insufficient and inadequate observational evidence
- Disagreement about the value of different classes of evidence (e.g. paleoclimate reconstructions, global climate models)
- Disagreement about the appropriate logical framework for linking and assessing the evidence
- Overconfidence and differing assessments of areas of ambiguity and ignorance
- Belief polarization as a result of cultural pressures and the politicization of the science

In the context of disagreement, it is important to distinguish between disbelief – believing an argument is false – and nonbelief – believing that the argument is not true. Disbelief is actually a case of belief, whereas nonbelief is a state of suspended judgment of neither believing the argument true nor believing it false. A failure to make this distinction was the recent media coverage of statements made by EPA Administrator Scott Pruitt:

> *"I think that measuring with precision human activity on the climate is something very challenging to do and there's tremendous disagreement about the degree of impact, so no, I would not agree that it's a primary contributor to the global warming that we see. But we don't know that yet. We need to continue the debate and continue the review and the analysis."* [15]

The media characterized this statement as "*EPA Head Scott Pruitt Denies That Carbon Dioxide Causes Global Warming*."[16] Pruitt's statement was incorrectly characterized as a statement of disbelief, when it was clearly a statement of non-belief.

Reasoning about climate uncertainty

Reasoning about a complex system with many uncertainties is not at all straightforward. The general reasoning underlying the IPCC's arguments for human-caused climate change is described by Oreskes[17] as a 'consilience of evidence' argument, which consists of independent lines of evidence that are explained by the same theoretical account. Oreskes draws an analogy for the consilience of evidence approach with what happens in a legal case. Continuing with the legal analogy, legal scholar James

[13] Curry, JA 2011: Reasoning about climate uncertainty. *Climatic Change,* 108, 723-732
[14] Curry, JA 2011: Nullifying the climate null hypothesis. *WIRES Climate Change*, 2, DOI: 10.1002/wcc.141
[15] http://www.cnbc.com/2017/03/09/epa-chief-scott-pruitt.html
[16] https://www.theguardian.com/environment/2017/mar/09/epa-scott-pruitt-carbon-dioxide-global-warming-climate-change?CMP=share_btn_tw
[17] Oreskes, N. (2007) The scientific consensus: how do we know we're not wrong? Climatic Change http://www.cpp.edu/~aebresnock/aebres/ec435/oreskespaper.pdf

Johnston[18] characterized the IPCC's arguments as a legal brief, designed to persuade, in contrast to a legal memo that is intended to objectively assess both sides. Along the lines of a legal memo, the consilience of evidence argument is not convincing unless it includes parallel evidence-based analyses for competing hypotheses. Any evidence-based argument that is more inclined to admit one type of evidence or argument rather than another tends to be biased. Multiple lines of evidence that produce a high confidence level for each of two opposing arguments is referred to as the 'ambiguity of competing certainties.' If uncertainty and ignorance are acknowledged adequately, then the competing certainties disappear. Disagreement and clarification of uncertainties then becomes the basis for focusing research in a certain area, and so moves the science forward.

The complexity of the climate system makes the concept of 'consilience failure' rather challenging. If one of the lines of evidence turns out to be flawed, then how does this influence the overall argument? The 'doesn't matter' versus 'death knell' interpretations can be explained by the use of two different logics represented by the 'jigsaw puzzle analogy'[19] and the 'house of cards analogy.'[20] Consider a partially completed jigsaw puzzle, with many pieces in place, some pieces tentatively in place, and some missing pieces. Default reasoning allows you to infer the whole picture from an incomplete puzzle if there is not another picture that is consistent with the puzzle in its current state. Under a monotonic logic, adding new pieces and locking existing pieces into place increases what is known about the picture. For a climate scientist having a complex mental model of interconnected evidence and processes represented by the jigsaw puzzle, the evidence in the North Report[21] critical of the paleo-temperature reconstructions (so-called 'hockeystick') merely jiggled loose a few puzzle pieces but didn't change the overall picture. Skeptics, lacking the same puzzle frame but focused on the specific conclusions of the North Report, viewed the evidence as collapsing the house of cards and justifying major belief revision on the subject. Which frame is 'correct'? Well, both are overly simplistic heuristics used in the absence of formal logical arguments.

The ways of combining evidence and the associated uncertainties and logics becomes critical in determining how one would even go about falsifying the theory or inferring anything about the theory from comparison of model predictions and observations. I have found that most disagreement on topics related to climate change is associated with different mental models for assessing and combining evidence to make inferences. A more disciplined logic is needed to assess the relative merits of the different arguments through identifying the most important uncertainties and introducing a more objective assessment of confidence levels.

In 'Reasoning About Climate Uncertainty,'[22] I argued that a useful approach would be the development of hierarchical logical hypothesis models that provides a structure for assembling the evidence and arguments in support of the main hypotheses or propositions. A logical hypothesis hierarchy (or tree) links the root hypothesis to lower level evidence and hypotheses. While developing a logical hypothesis tree is somewhat subjective and involves expert judgments, the evidential judgments are made at a lower level in the logical hierarchy. Essential judgments and opinions relating to the evidence and the arguments linking the evidence are thus made explicit, lending structure and transparency to the assessment. To the extent that the logical hypothesis hierarchy decomposes arguments and evidence to the most elementary propositions, the sources of disagreement are easily illuminated and potentially minimized.

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[18] Johnson, J (2010) Global warming advocacy science: a cross examination. http://scholarship.law.upenn.edu/faculty_scholarship/315/
[19] http://sciencepoliticsclimatechange.blogspot.com/2006/10/puzzle-analogy.html
[20] http://sciencepoliticsclimatechange.blogspot.com/2006/10/house-of-cards-analogy.html
[21] Surface Temperature Reconstructions for the last 2000 years. (2006) National Academy Reports https://www.nap.edu/read/11676/chapter/1
[22] .Curry, JA 2011: Reasoning about climate uncertainty. *Climatic Change,* 108, 723-732 http://link.springer.com/article/10.1007/s10584-011-0180-z

An issue of central importance for the use of scientific research in policy making is uncertainty management and elucidation of the elements of uncertainty. My paper 'Reasoning about Climate Uncertainty'[23] describes several such approaches that comprehensively describe the pedigree and quality of the relevant data sets and methods, and characterize uncertainty in a manner that covers the range from complete numerical formalization of probabilities to ignorance, and includes the possibility of unspecified but surprising events.

The interface between climate science and policy

I first became caught up in the political debate about climate change following publication of our paper in 2005 relating hurricane intensity with global warming.[24] The uncanny timing of publication of this paper was three weeks after Hurricane Katrina devastated New Orleans. While global warming was mentioned only obliquely in the paper, the press focused on the global warming angle and a media and political furor followed. My reflections on this were published in a paper 'Mixing Politics and Science in Testing the Hypothesis that Greenhouse Warming is Causing a Global Increase in Hurricane Intensity.'[25] In recent years, I have continued to investigate the interface between climate science and policy, and have become increasingly concerned about its dysfunction.

In the 1990's, the world's nations embarked on a path to prevent dangerous anthropogenic climate change by stabilization of the concentrations of atmospheric greenhouse gases, which was codified by the 1992 UN Framework Convention on Climate Change (UNFCCC) treaty.[26] This objective has led to a focus on identifying human influences on climate, dangerous environmental and socio-economic impacts of climate change, and stabilization of CO_2 concentrations in the atmosphere. The IPCC has become conflicted by its makeup and its mandate from the UN – to focus on a change of climate that is attributed to human activity. If the IPCC found that climate change was *not* being affected by human alteration of the atmosphere or that it is not 'dangerous,' the UNFCCC would not need it to exist. Findings of 'dangerous human-caused climate change' seem inevitable with this framing of the climate change problem and the mandate from policy makers.

In the early 1990's there was belief in the feasibility of reducing uncertainties in climate science and climate models, and a consensus seeking approach was formalized by the IPCC. Global climate models were elevated to a central role through investigations of climate change impacts and applications. Very substantial investments have been made in further developing climate models, with the expectation that these models will provide actionable information for policy makers.

The hope, and the potential, of climate models for providing actionable information for policy makers have not been realized. With the failure of climate models to reduce uncertainty about the sensitivity of the climate system to CO_2 and the failure to accurately simulate decadal and regional climate variability,[27] we have arguably reached the point of diminishing returns from this particular path of climate modeling – not just for decision support but also for scientific understanding of the climate system. The climate modeling community, the funding agencies and policy makers have locked themselves into a single climate modeling framework that has been very expensive in terms of funding and personnel.

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23 Curry, J. Reasoning About Climate Uncertainty, op. cit.

24 Webster, P, G. Holland, J Curry and HR Chang 2005: Changes in tropical cyclone number, duration and intensity. Science. http://science.sciencemag.org/content/309/5742/1844.full

25 Curry, J.A., et al, 2006: Mixing Politics and Science in Testing the Hypothesis that Greenhouse Warming is Causing an Increase in Hurricane Intensity. *Bull. Amer. Meteorol. Soc.,* http://journals.ametsoc.org/doi/abs/10.1175/BAMS-87-8-1025.

26 UNFCC Treaty (1992) https://unfccc.int/resource/docs/convkp/conveng.pdf

27 Curry, J. 2017: Climate Models for the Layman http://www.thegwpf.org/content/uploads/2017/02/Curry-2017.pdf

An unintended consequence of this strategy is that there have been very few resources left over for true climate model innovations and fundamental research into climate dynamics and theory. Such research would not only support improved climate modeling systems, but would also lay the foundations for disruptive advances in our understanding of the climate system and our ability to predict emergent phenomena such as abrupt climate change. With climate science focusing on climate model outputs rather than on climate dynamics and theory, we've lost a generation of climate dynamicists. As a result, we are lacking the intellectual resources to understand important and challenging issues such as: the effects of the sun on climate, the network of natural internal variability on multiple time scales, the mathematics of extreme events, and predictability of a complex system characterized by spatio-temporal chaos.

Decision makers needing regionally-specific climate change information are being provided with either nothing or potentially misleading predictions from climate models that are not fit for this purpose. Hoping and expecting to rely on information from climate models about projected regional climate change to guide adaptation responses has diverted attention from using observational, historical and paleoclimate data from the region to develop the basis for future scenarios. Further, increased scientific focus on subseasonal (weeks) and seasonal (months) weather/climate forecasts[28] could produce the basis for tactical adaptation practices with substantial societal benefits.

How and why did we land between a rock and a hard place on the issue of climate science? There are probably many contributing reasons, but the most fundamental and profound reason is arguably that both the problem and solution were vastly oversimplified back in the early 1990's by the UNFCCC, who framed both the problem and the solution as irreducibly global in terms of human-caused global warming. This framing was locked in by a self-reinforcing consensus-seeking approach to the science and a 'speaking consensus to power' approach for decision making that pointed to a single course of policy action – radical emissions reductions.

The climate community has worked for more than two decades to establish a scientific consensus on human-caused climate change, prematurely elevating a hypothesis to a ruling theory. The IPCC's consensus-seeking process and its links to the UNFCCC emissions reduction policies have had the unintended consequence of hyper-politicizing the science and introducing bias into both the science and related decision making processes. The result of this simplified framing of a wicked problem is that we lack the kinds of information to more broadly understand climate variability and societal vulnerabilities.

The politicization of climate science has contaminated academic climate research and the institutions that support climate research, so that individual scientists and institutions have become activists and advocates for emissions reductions policies. Scientists with a perspective that is not consistent with the consensus are at best marginalized (difficult to obtain funding and get papers published by 'gatekeeping' journal editors) or at worst ostracized by labels of 'denier' or 'heretic.'

Policymakers bear the responsibility of the mandate that they give to panels of scientific experts. In the case of climate change, the UNFCCC demanded of the IPCC too much precision where complexity, chaos, disagreement and the level current understanding resists such precision. Asking scientists to provide simple policy-ready answers for complex matters results in an impossible situation for scientists and misleading outcomes for policy makers. Unless policy makers want experts to confirm their preconceived bias, then expert panels should handle controversies and uncertainties by assessing what we know, what we don't know, and where the major uncertainties lie.

[28] https://www.nap.edu/catalog/21873/next-generation-earth-system-prediction-strategies-for-subseasonal-to-seasonal

Imagine if, circa 1990, the UN had framed the climate change problem in the following way: 'There are a number of causes of climate change, including manmade causes. Climate science should work to understand all causes of climate variability change that are relevant on decadal to century timescales, and the impact of climate variability and change on societies and ecosystems.' Such a framing would have arguably led to better understanding of the climate system and a much more rational approach in developing policies related to reducing our vulnerabilities to extreme weather and climate variations.

A better social problem-solving framework is needed for managing risk under conditions of deep uncertainty, that employs a broader systems analysis and explicitly incorporates uncertainty to identify paths to a flexible, robust and economical outcome. Social science research is needed to analyze ways of incorporating scientific understanding with all of its uncertainties into decision making related to complex, wicked problems.

The war on science

I read Chris Mooney's book 'The Republican War on Science'[29] shortly after it was published in 2005. It really resonated with me at the time, when I was in the midst of the 'hurricanes and global warming war'. Although the book has 'Republican' in the title, much of the content was really about a bipartisan war on science. The 'war on science' is being fought on two fronts: politicians ignoring science; and using bad science to justify a political agenda. The notion of 'war of science' is also about the naivete of scientists regarding the role of science and evidence in policy making.[30]

With the advent of the Trump administration, concerns about 'war on science' have become elevated, with a planned March for Science on 22 April 2017.[31] Why are scientists marching?[32] The scientists' big concern is 'silencing of facts'. This concern apparently derives from their desire to have their negotiated 'facts' – such as the IPCC consensus on climate change – dictate public policy. These scientists also fear funding cuts and challenges to the academic scientific community and the elite institutions that support it.

The 'war on science' that I am most concerned about is the war from *within* science – scientists and the organizations that support science who are playing power politics with their expertise and passing off their naïve notions of risk and political opinions as science. When the IPCC consensus is challenged or the authority of climate science in determining energy policy is questioned, these activist scientists and organizations call the questioners 'deniers' and claim 'war on science.' These activist scientists seem less concerned with the integrity of the scientific process than they are about their privileged position and influence in the public debate about climate and energy policy. They do not argue or debate the science – rather, they denigrate scientists who disagree with them. These activist scientists and organizations are perverting the political process and attempting to inoculate climate science from scrutiny – this is the *real* war on science.

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[29] Mooney, C. (2005) The Republican War on Science http://www.waronscience.com/home.php
[30] https://www.amazon.com/Politics-Evidence-Based-Policy-Making/dp/1137517808
[31] http://www.marchforscience.com
[32] https://www.theguardian.com/us-news/2017/feb/19/epa-trump-boston-science-protest

Conclusion

In the midst of disagreement among policy makers about the response to climate change, climate science has been caught in the crossfire. Challenges to climate research have been exacerbated by unreasonable expectations from policy makers, as well as by the behavior of climate scientists and professional societies who are using their professional expertise and preferred political outcomes as the basis for attempting to pervert the political process and inoculate climate science from scrutiny and debate.

My concern is that the integrity and objectivity of climate research is being compromised. As a result, we have oversimplified by the climate change problem and its solutions. This oversimplification has:

1. Biased scientific research through politicization and funding priorities.
2. Undercut the political process and dialog necessary for real solutions in a highly complex world.

We need to rethink the social contract between scientists and government, and develop a new model for policy-relevant science. This is needed to insure the integrity of science and to improve the basis for science to inform the policy process. Here are some recommendations:

1. Embrace science as an iterative process, not a collection of 'facts.' Scientists that engage the public across the political spectrum and invite them to engage in the process of science can help build public support for science.
2. New incentive structures for scientists working in fields that are policy relevant can focus on careful management of bias and uncertainty, public engagement, responsible interactions with the media, and participation in the policy process as an honest broker.
3. Scientists interested in engaging with the policy process need a much better understanding of the policy process, the role that science plays, and how complexity, pluralism and uncertainty in science is accommodated in the policy process.
4. Scientists need better guidelines on the ethical implications of using their expertise for political purposes and a code of conduct for communicating uncertainty and responsibilities for making public statements related to their expertise.
5. Bias and advocacy by institutions such as professional societies is a major concern for the integrity of science.
6. For policy-relevant science and regulatory science, more formal methods of uncertainty characterization and management should be used in scientific research and assessments.
7. For policy-relevant and/or regulatory science where there is substantial uncertainty or disagreement about key conclusions, a Red Team or Team B approach for assessments can clarify the strength of the arguments and key areas of disagreement. Avoid consensus-seeking approaches.
8. Narrow framing of research priorities on topics where there are widespread uncertainties and debate can bias the research. Funding for Red Team or Team B approaches would help overcome such systematic biases.
9. Funding priorities in climate research that support observing systems (surface and satellite-based), fundamental climate dynamics research and research to improve short-term climate predictions (sub-seasonal to interannual) would support improved climate models and lay the foundations for disruptive advances in our understanding of the climate system and our ability to predict emergent phenomena such as abrupt climate change.
10. A better social problem-solving framework that employs a broader systems analysis and explicitly incorporates uncertainty can provide paths to flexible, robust and economical outcomes.

I'm hoping that these recommendations and this Hearing will open up a dialogue on how the federal government can better support research into the complex climate system that in turn supports improved policy outcomes in reducing our vulnerability to climate variability.