Decision making under uncertainty

Including the issues of public perception and engagement

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Almost all important problems..

…involve considerable uncertainty.

At a personal level:

- Where to go to college
- Who to marry
- When and whether to have kids

In a company or other organization:

- Who to hire
- What products to develop

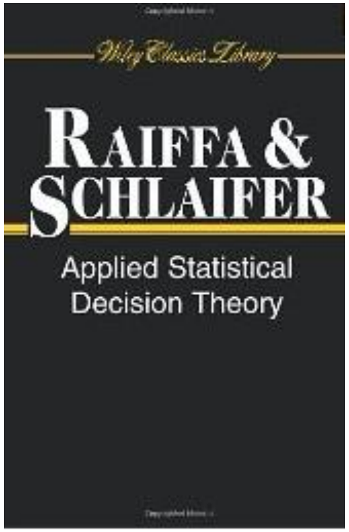
In a nation:

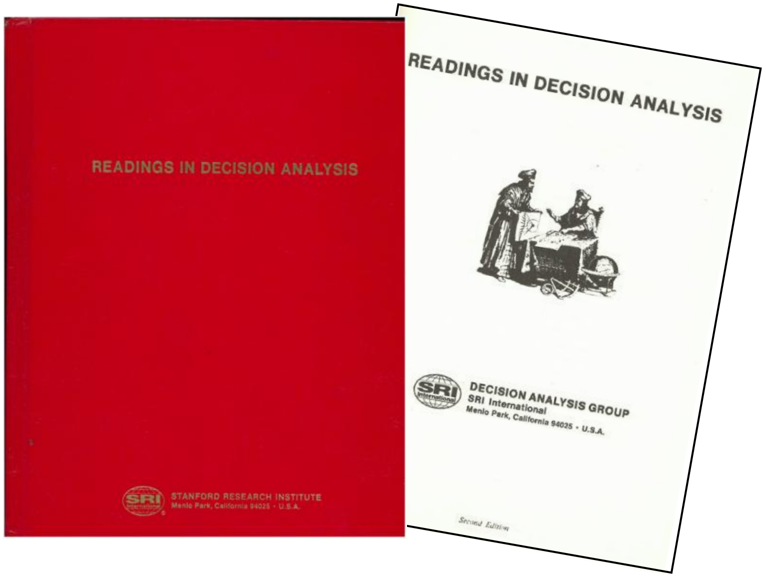
- How best to structure taxes
- How best to deal with social services & health care
- When to go to war
- When to sue for peace

The fact that there is uncertainty…

…should not by itself be grounds for inaction. Indeed, the consequences of doing nothing often carry comparable or larger uncertainty.

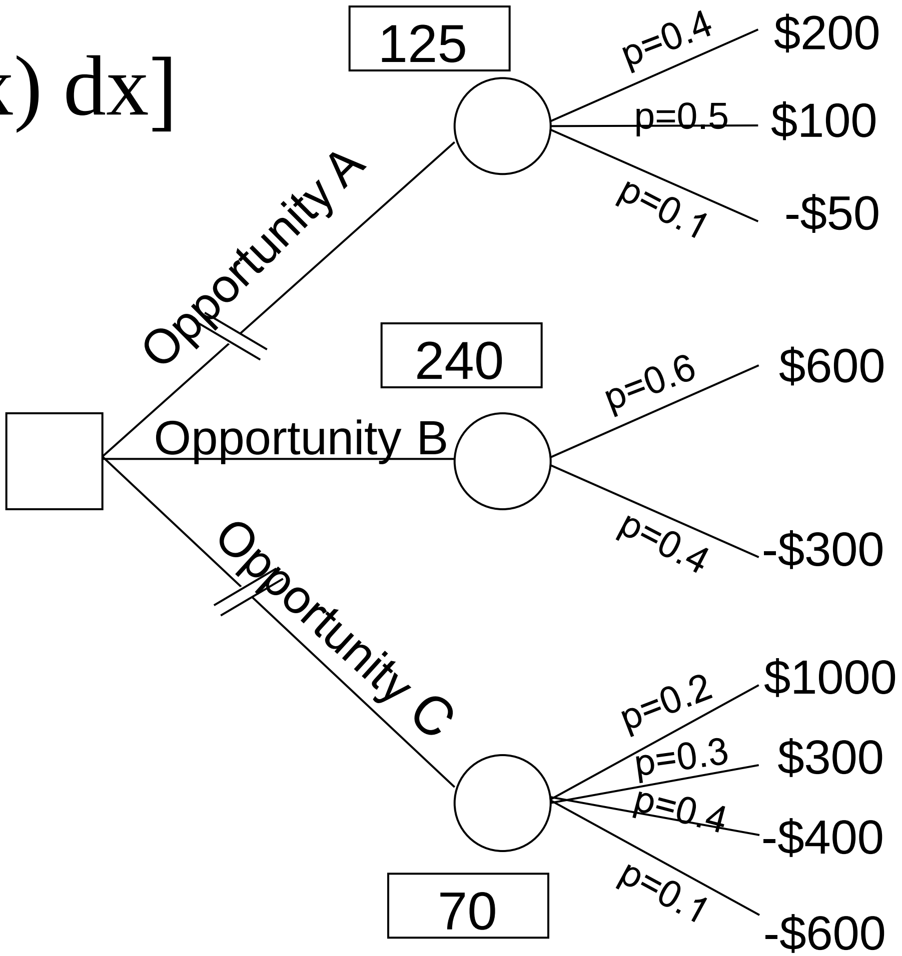
There is a large literature on analytical strategies for framing and making decisions in the face of uncertainty.





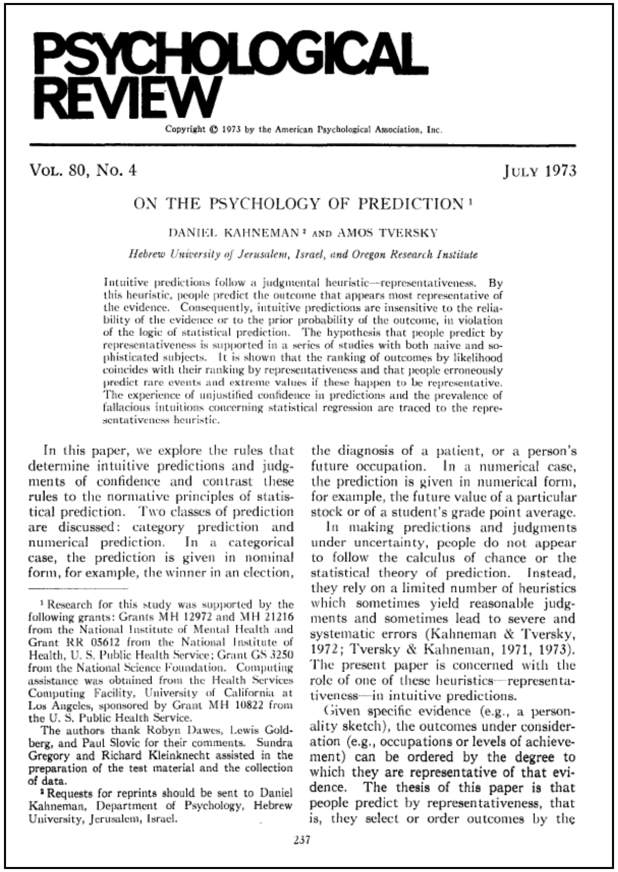
The resulting methods are now termed Decision Analysis

$$\text{Max}\left[\int p(x|c)\, U(x)\, dx\right]$$



There is also a large literature…

…based on empirical studies, that describes how people make decisions in the face of uncertainty.



PSYCHOLOGICAL REVIEW

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VOL. 80, No. 4 JULY 1973

ON THE PSYCHOLOGY OF PREDICTION[1]

DANIEL KAHNEMAN[2] AND AMOS TVERSKY

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Intuitive predictions follow a judgmental heuristic—representativeness. By this heuristic, people predict the outcome that appears most representative of the evidence. Consequently, intuitive predictions are insensitive to the reliability of the evidence or to the prior probability of the outcome, in violation of the logic of statistical prediction. The hypothesis that people predict by representativeness is supported in a series of studies with both naive and sophisticated subjects. It is shown that the ranking of outcomes by likelihood coincides with their ranking by representativeness and that people erroneously predict rare events and extreme values if these happen to be representative. The experience of unjustified confidence in predictions and the prevalence of fallacious intuitions concerning statistical regression are traced to the representativeness heuristic.

In this paper, we explore the rules that determine intuitive predictions and judgments of confidence and contrast these rules to the normative principles of statistical prediction. Two classes of prediction are discussed: category prediction and numerical prediction. In a categorical case, the prediction is given in nominal form, for example, the winner in an election, the diagnosis of a patient, or a person's future occupation. In a numerical case, the prediction is given in numerical form, for example, the future value of a particular stock or of a student's grade point average.

In making predictions and judgments under uncertainty, people do not appear to follow the calculus of chance or the statistical theory of prediction. Instead, they rely on a limited number of heuristics which sometimes yield reasonable judgments and sometimes lead to severe and systematic errors (Kahneman & Tversky, 1972; Tversky & Kahneman, 1971, 1973). The present paper is concerned with the role of one of these heuristics—representativeness—in intuitive predictions.

Given specific evidence (e.g., a personality sketch), the outcomes under consideration (e.g., occupations or levels of achievement) can be ordered by the degree to which they are representative of that evidence. The thesis of this paper is that people predict by representativeness, that is, they select or order outcomes by the

[1] Research for this study was supported by the following grants: Grants MH 12972 and MH 21216 from the National Institute of Mental Health and Grant RR 05612 from the National Institute of Health, U. S. Public Health Service; Grant GS 3250 from the National Science Foundation. Computing assistance was obtained from the Health Services Computing Facility, University of California at Los Angeles, sponsored by Grant MH 10822 from the U. S. Public Health Service.

The authors thank Robyn Dawes, Lewis Goldberg, and Paul Slovic for their comments. Sundra Gregory and Richard Kleinknecht assisted in the preparation of the test material and the collection of data.

[2] Requests for reprints should be sent to Daniel Kahneman, Department of Psychology, Hebrew University, Jerusalem, Israel.

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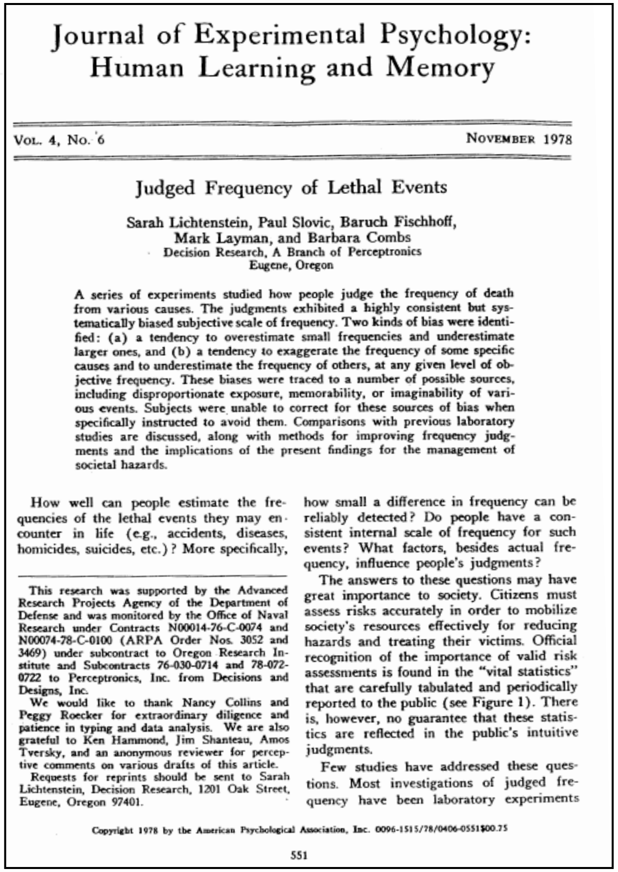

Journal of Experimental Psychology: Human Learning and Memory

VOL. 4, No. 6 NOVEMBER 1978

Judged Frequency of Lethal Events

Sarah Lichtenstein, Paul Slovic, Baruch Fischhoff, Mark Layman, and Barbara Combs

Decision Research, A Branch of Perceptronics

Eugene, Oregon

A series of experiments studied how people judge the frequency of death from various causes. The judgments exhibited a highly consistent but systematically biased subjective scale of frequency. Two kinds of bias were identified: (a) a tendency to overestimate small frequencies and underestimate larger ones, and (b) a tendency to exaggerate the frequency of some specific causes and to underestimate the frequency of others, at any given level of objective frequency. These biases were traced to a number of possible sources, including disproportionate exposure, memorability, or imaginability of various events. Subjects were unable to correct for these sources of bias when specifically instructed to avoid them. Comparisons with previous laboratory studies are discussed, along with methods for improving frequency judgments and the implications of the present findings for the management of societal hazards.

How well can people estimate the frequencies of the lethal events they may encounter in life (e.g., accidents, diseases, homicides, suicides, etc.)? More specifically, how small a difference in frequency can be reliably detected? Do people have a consistent internal scale of frequency for such events? What factors, besides actual frequency, influence people's judgments?

The answers to these questions may have great importance to society. Citizens must assess risks accurately in order to mobilize society's resources effectively for reducing hazards and treating their victims. Official recognition of the importance of valid risk assessments is found in the "vital statistics" that are carefully tabulated and periodically reported to the public (see Figure 1). There is, however, no guarantee that these statistics are reflected in the public's intuitive judgments.

Few studies have addressed these questions. Most investigations of judged frequency have been laboratory experiments

This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by the Office of Naval Research under Contracts N00014-76-C-0074 and N00074-78-C-0100 (ARPA Order Nos. 3052 and 3469) under subcontract to Oregon Research Institute and Subcontracts 76-030-0714 and 78-072-0722 to Perceptronics, Inc. from Decisions and Designs, Inc.

We would like to thank Nancy Collins and Peggy Roecker for extraordinary diligence and patience in typing and data analysis. We are also grateful to Ken Hammond, Jim Shanteau, Amos Tversky, and an anonymous reviewer for perceptive comments on various drafts of this article.

Requests for reprints should be sent to Sarah Lichtenstein, Decision Research, 1201 Oak Street, Eugene, Oregon 97401.

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Judgment under Uncertainty: Heuristics and Biases

Biases in judgments reveal some heuristics of thinking under uncertainty.

Amos Tversky and Daniel Kahneman

Many decisions are based on beliefs concerning the likelihood of uncertain events such as the outcome of an election, the guilt of a defendant, or the future value of the dollar. These beliefs are usually expressed in statements such as "I think that . . . ," "chances are . . . ," "it is unlikely that . . . ," and so forth. Occasionally, beliefs concerning uncertain events are expressed in numerical form as odds or subjective probabilities. What determines such beliefs? How do people assess the probability of an uncertain event or the value of an uncertain quantity? This article shows that people rely on a limited number of heuristic principles which reduce the complex tasks of assessing probabilities and predicting values to simpler judgmental operations. In general, these heuristics are quite useful, but sometimes they lead to severe and systematic errors.

The subjective assessment of probability resembles the subjective assessment of physical quantities such as distance or size. These judgments are all based on data of limited validity, which are processed according to heuristic rules. For example, the apparent distance of an object is determined in part by its clarity. The more sharply the object is seen, the closer it appears to be. This rule has some validity, because in any given scene the more distant objects are seen less sharply than nearer objects. However, the reliance on this rule leads to systematic errors in the estimation of distance. Specifically, distances are often overestimated when visibility is poor because the contours of objects are blurred. On the other hand, distances are often underestimated when visibility is good because the objects are seen sharply. Thus, the reliance on clarity as an indication of distance leads to common biases. Such biases are also found in the intuitive judgment of probability. This article describes three heuristics that are employed to assess probabilities and to predict values. Biases to which these heuristics lead are enumerated, and the applied and theoretical implications of these observations are discussed.

Representativeness

Many of the probabilistic questions with which people are concerned belong to one of the following types: What is the probability that object A belongs to class B? What is the probability that event A originates from process B? What is the probability that process B will generate event A? In answering such questions, people typically rely on the representativeness heuristic, in which probabilities are evaluated by the degree to which A is representative of B, that is, by the degree to which A resembles B. For example, when A is highly representative of B, the probability that A originates from B is judged to be high. On the other hand, if A is not similar to B, the probability that A originates from B is judged to be low.

For an illustration of judgment by representativeness, consider an individual who has been described by a former neighbor as follows: "Steve is very shy and withdrawn, invariably helpful, but with little interest in people, or in the world of reality. A meek and tidy soul, he has a need for order and structure, and a passion for detail." How do people assess the probability that Steve is engaged in a particular occupation from a list of possibilities (for example, farmer, salesman, airline pilot, librarian, or physician)? How do people order these occupations from most to least likely? In the representativeness heuristic, the probability that Steve is a librarian, for example, is assessed by the degree to which he is representative of, or similar to, the stereotype of a librarian. Indeed, research with problems of this type has shown that people order the occupations by probability and by similarity in exactly the same way (*1*). This approach to the judgment of probability leads to serious errors, because similarity, or representativeness, is not influenced by several factors that should affect judgments of probability.

Insensitivity to prior probability of outcomes. One of the factors that have no effect on representativeness but should have a major effect on probability is the prior probability, or base-rate frequency, of the outcomes. In the case of Steve, for example, the fact that there are many more farmers than librarians in the population should enter into any reasonable estimate of the probability that Steve is a librarian rather than a farmer. Considerations of base-rate frequency, however, do not affect the similarity of Steve to the stereotypes of librarians and farmers. If people evaluate probability by representativeness, therefore, prior probabilities will be neglected. This hypothesis was tested in an experiment where prior probabilities were manipulated (*1*). Subjects were shown brief personality descriptions of several individuals, allegedly sampled at random from a group of 100 professionals—engineers and lawyers. The subjects were asked to assess, for each description, the probability that it belonged to an engineer rather than to a lawyer. In one experimental condition, subjects were told that the group from which the descriptions had been drawn consisted of 70 engineers and 30 lawyers. In another condition, subjects were told that the group consisted of 30 engineers and 70 lawyers. The odds that any particular description belongs to an engineer rather than to a lawyer should be higher in the first condition, where there is a majority of engineers, than in the second condition, where there is a majority of lawyers. Specifically, it can be shown by applying Bayes' rule that the ratio of these odds should be $(.7/.3)^2$, or 5.44, for each description. In a sharp violation of Bayes' rule, the subjects in the two conditions produced essen-

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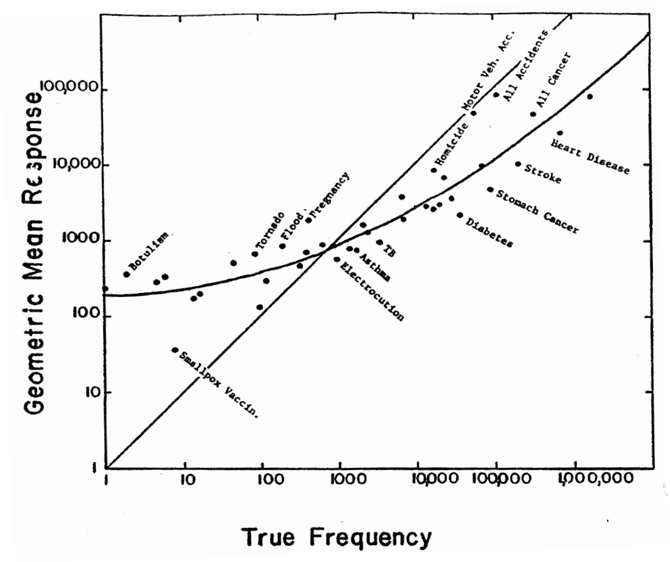
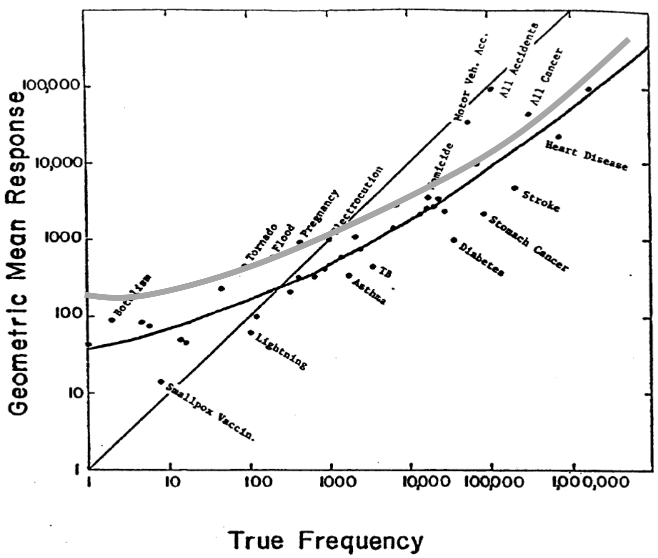
Examples of cognitive heuristics

Availability: probability judgment is driven by ease with which people can think of previous occurrences of the event or can imagine such occurrences.

Anchoring and adjustment: probability judgment is frequently driven by the starting point which becomes an "anchor."

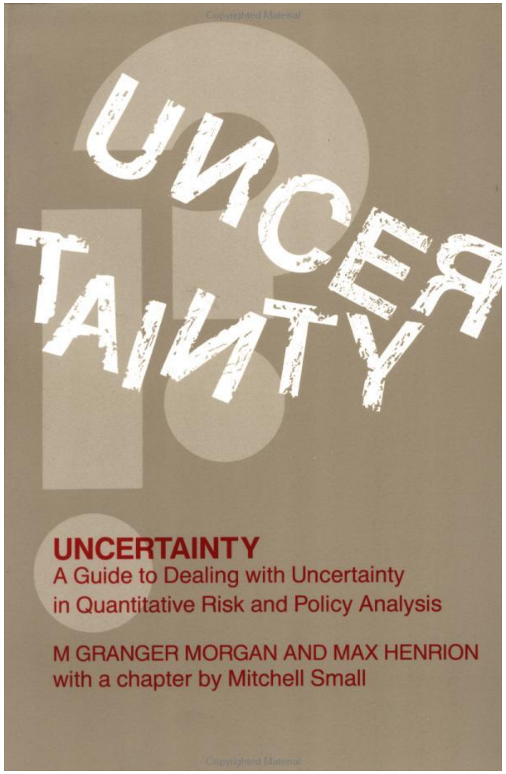


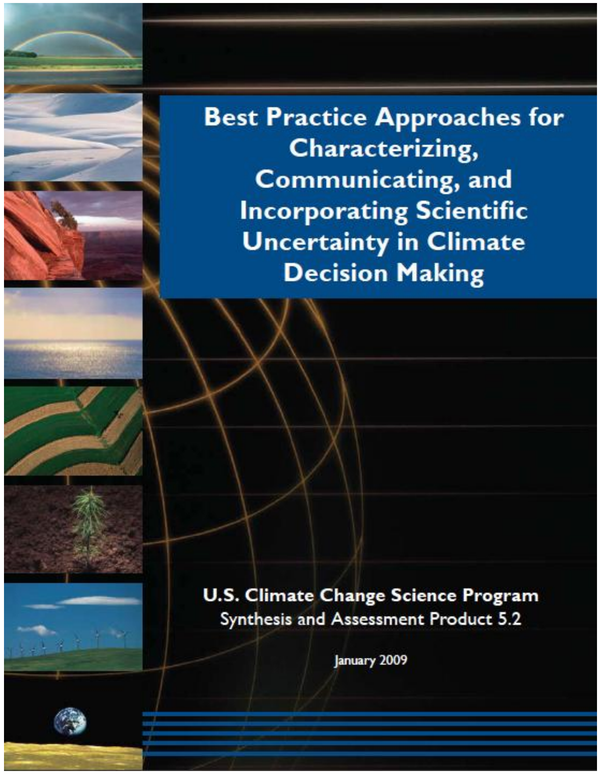


from Lichtenstein et al., 1978.

Finally there is a literature…

…on how to incorporate many of these ideas into policy analysis. For example:





M. Granger Morgan, Baruch Fischhoff, Ann Bostrom and Cynthia Atman, *Risk Communication: A mental models approach*, 351pp., Cambridge University Press, New York, 2002; CCSP, 2009: *Best Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Decision-making*. [M. Granger Morgan (Lead Author), Hadi Dowlatabadi, Max Henrion, David Keith, Robert Lempert, Sandra McBride, Mitchell Small, and Thomas Wilbanks (Contributing Authors)]. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research. National Oceanic and Atmospheric Administration, Washington, DC, 96pp., 2009.

In 10 to 15 minutes…

…there is no way to do justice to any of these literatures, or to the many other topics to which they are linked.

I will touch briefly on four topics:

1. The use of formal quantitative expert elicitation.
2. Limitations in the use of scenarios and integrated assessment models that focus on optimizing.
3. Studies of public perceptions.
4. Studies of public engagement.

While the issues involved are all general, I will draw my examples from the domains of energy and climate change.

Why be quantitative?

Some ask:

Why be quantitative about uncertainty?

Aren’t words such as “likely” and “unlikely” perfectly adequate?

The problem is that such words can mean very different things in different circumstances and different things to different people in the same circumstance.

Words are not enough

An example from the EPA-SAB

The minimum probability associated with the word "likely" spanned four orders of magnitude.

The maximum probability associated with the word "not likely" spanned more than five orders of magnitude.

There was an overlap of the probability associated with the word "likely" and that associated with the word "unlikely"!

Figure from: M. Granger Morgan, "Uncertainty Analysis in Risk Assessment," *Human and Ecological Risk Assessment*, *4*(1), 25-39, February 1998.

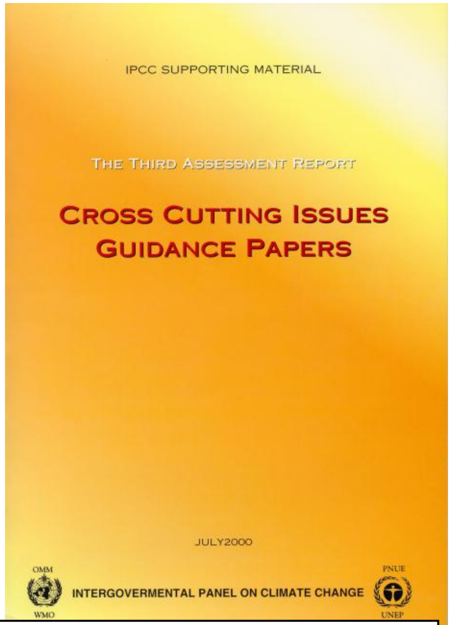
Words are not enough…(Cont.)

Without some quantification, qualitative descriptions of uncertainty convey little, if any, useful information.

The climate assessment community is gradually learning this lesson.

Steve Schneider and Richard Moss worked hard to promote a better treatment of uncertainty by the IPCC.

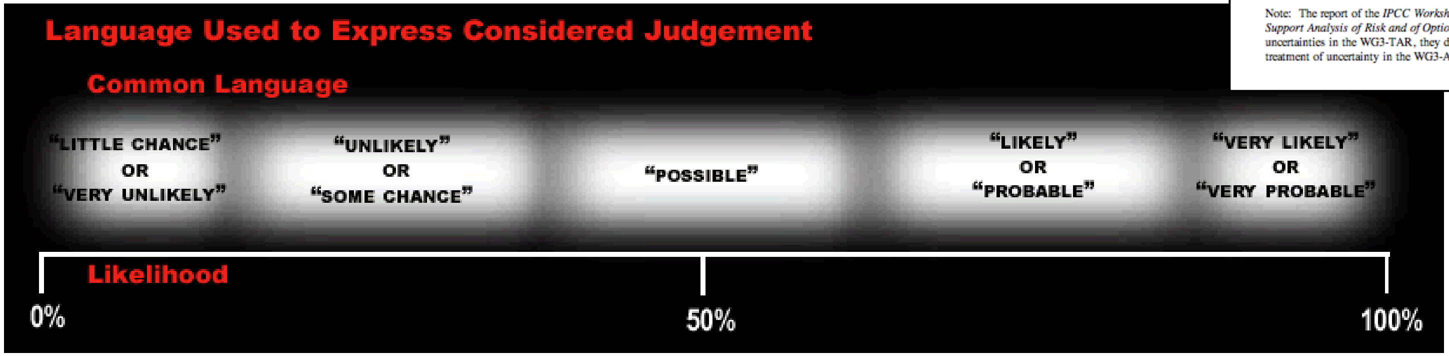
At my insistence, the first U.S. National Assessment Synthesis Team gave quantitative definitions to five probability words:



Mapping of probability words into quantitative subjective probability judgments, used by WG I and II of the IPCC Third Assessment (2001) based on recommendations developed by Moss and Schneider (2000).

word	probability range
Virtually certain	> 0.99
Very likely	0.9-0.99
Likely	0.66-0.9
Medium likelihood	0.33-0.66
Unlikely	0.1-0.33
Very unlikely	0.01-0.1
Exceptionally unlikely	< 0.01

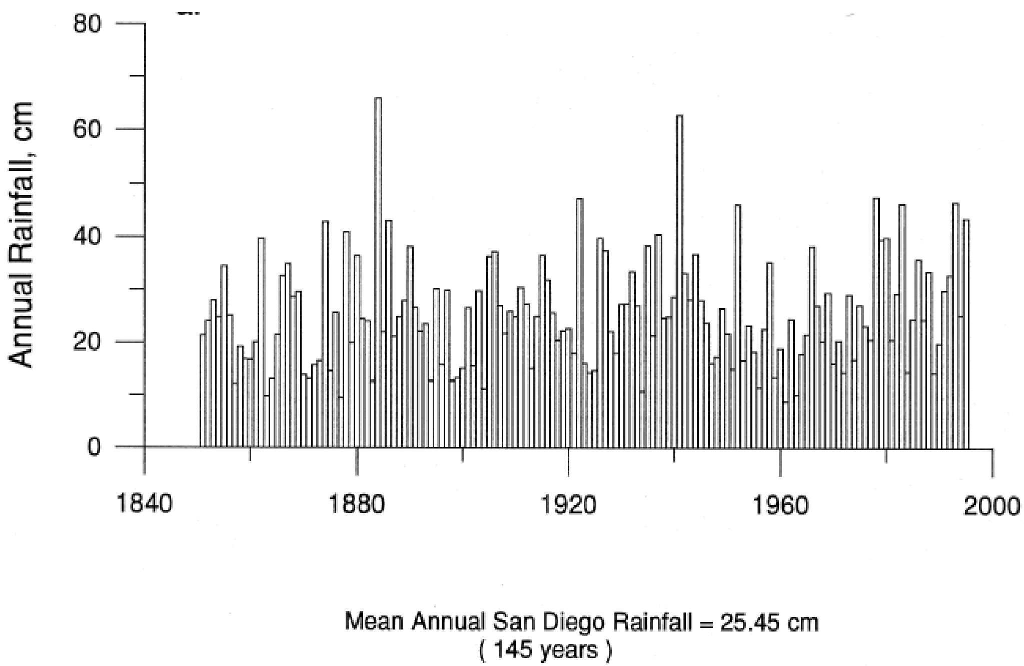
Note: The report of the *IPCC Workshop on Describing Scientific Uncertainties in Climate Change to Support Analysis of Risk and of Options* (2004) observed: "Although WGIII TAR authors addressed uncertainties in the WG3-TAR, they did not adopt the Moss and Schneider uncertainty guidelines. The treatment of uncertainty in the WG3-AR4 can be improved over what was done in the TAR."



Many other communities have not yet got the message

If I have good data...

...in the form of many observations of a random process, then I can construct a probability distribution that describes that process. For example, suppose I have the 145 years of rainfall data for San Diego, and I am prepared to assume that over that period San Diego's climate has been "stationary" (that is the basic underlying processes that create the year-to-year variability have not changed)…

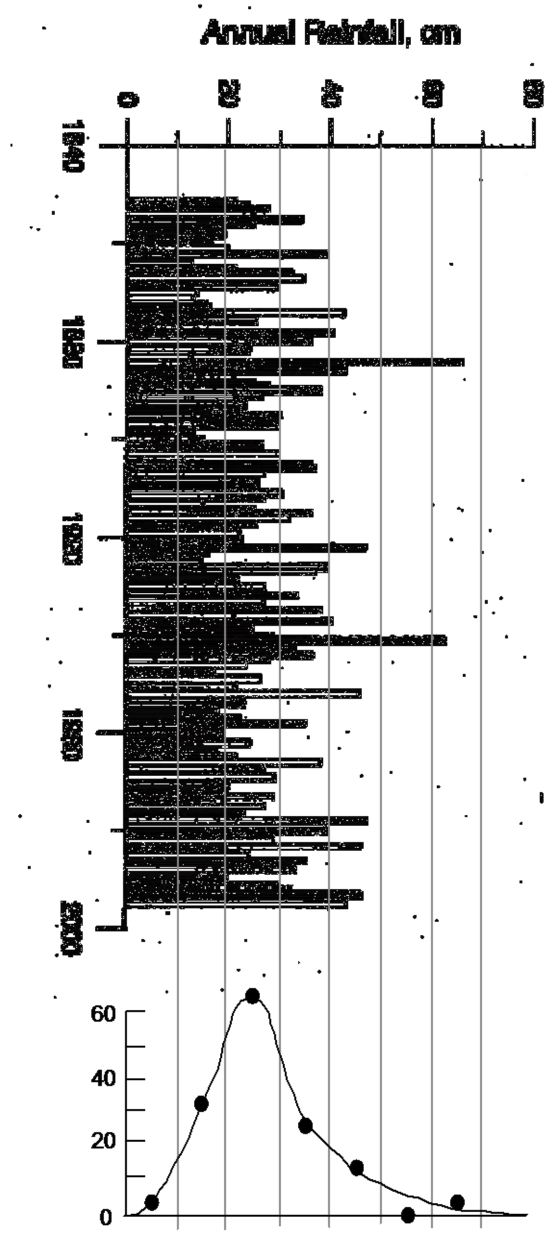


Source: Inman et al., Scripps, 1998.

Then if I want…

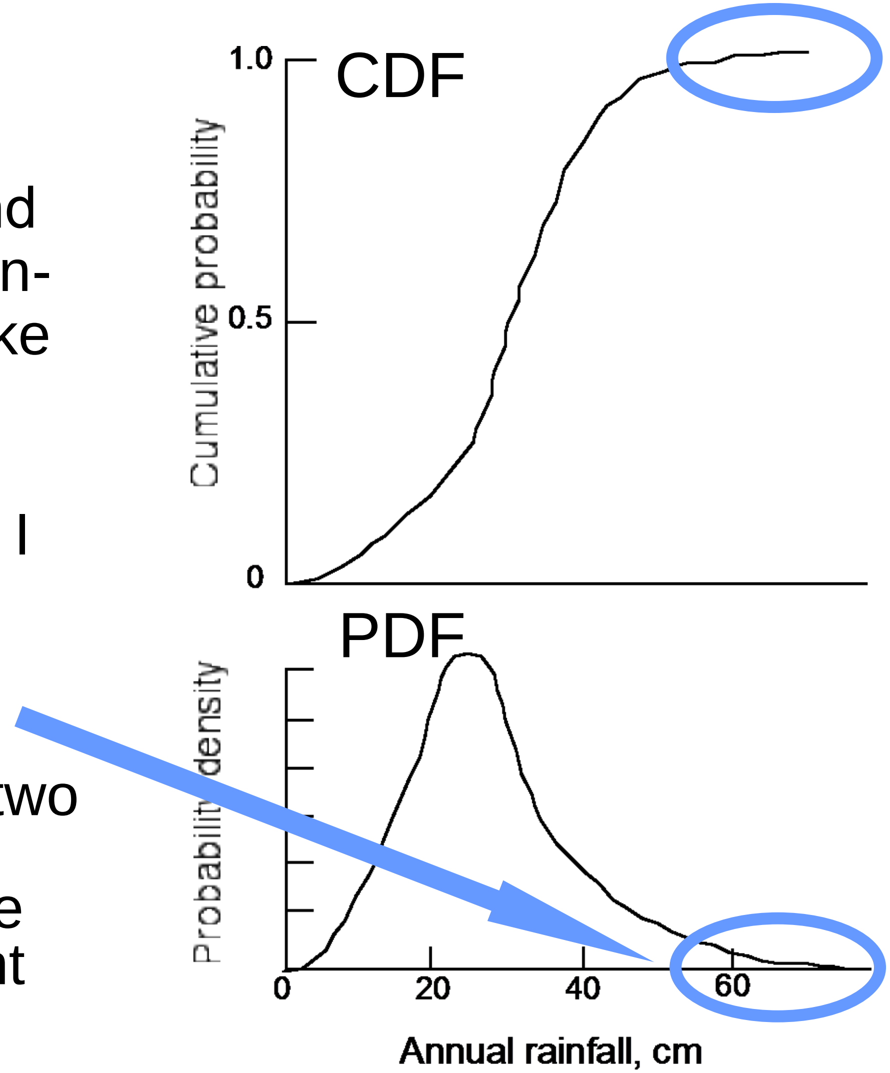
…a PDF for future San Diego annual rainfall, the simplest approach would be to construct a histogram from the data, as illustrated to the right.

If I want to make a prediction for some *specific* future year, I might go on to look for time patterns in the data. Even better, I might try to relate those time patterns to known slow patterns of variation in the regional climate, and modify my PDF accordingly.



In that way…

…I could construct a PDF and CDF for future San Diego rain-fall that would look roughly like this.



However, suppose that what I really care about is the probability that very large rainfall events will occur.

Since there have only been two years in the past 145 years when rainfall has been above 60 cm/yr, I'll need to augment my data with some model, physical theory and expert judgment.

Expert elicitation takes time and care

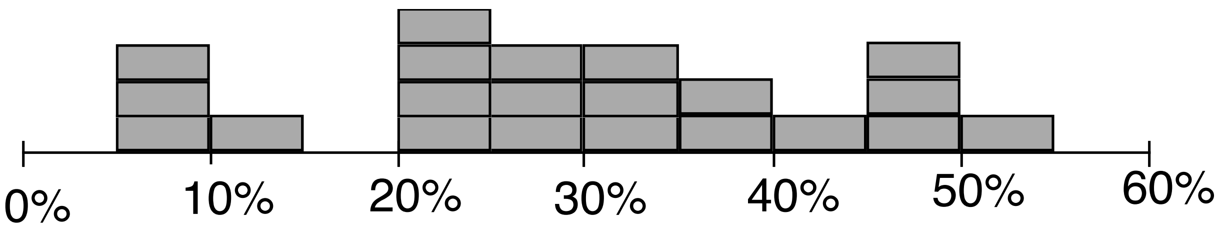
Eliciting probabilistic judgments from experts requires careful preparation and execution.

Developing and testing an appropriate interview protocol typically takes several months. Each interview is likely to require several hours.

When addressing complex, scientifically subtle questions of the sorts involved with most problems in climate change, there are no satisfactory short cuts. Attempts to simplify and speed up the process almost always lead to shoddy results.

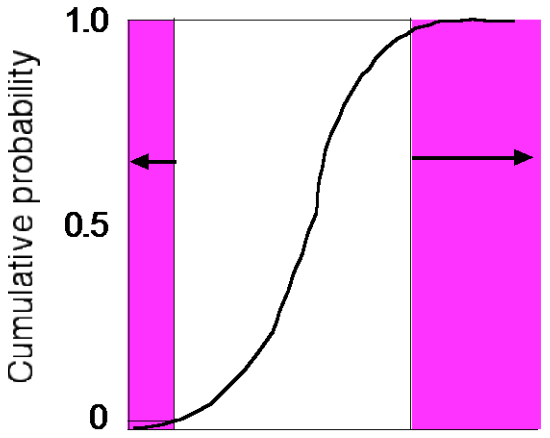
While I don't have time to elaborate, there is compelling evidence that most of us are systematically overconfident…

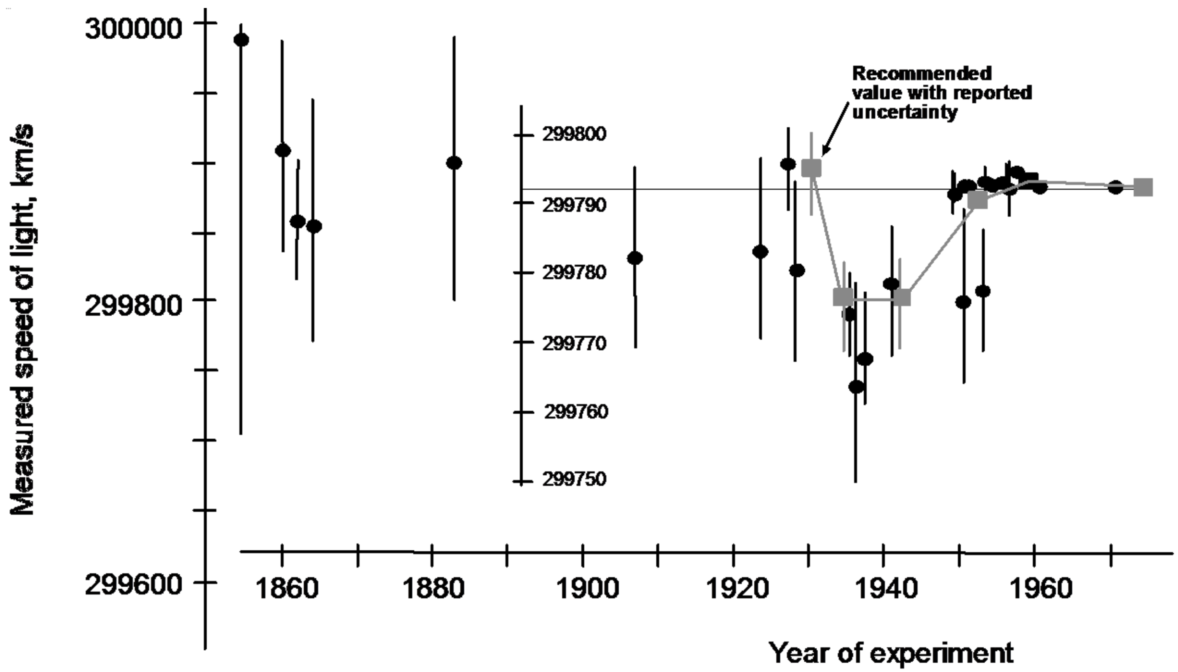
Over Confidence



Percentage of estimates in which the true value lay outside of the respondent's assessed 98% confidence interval.

2% probability that true value lies below the 1% lower bound or above the 99% upper bound.

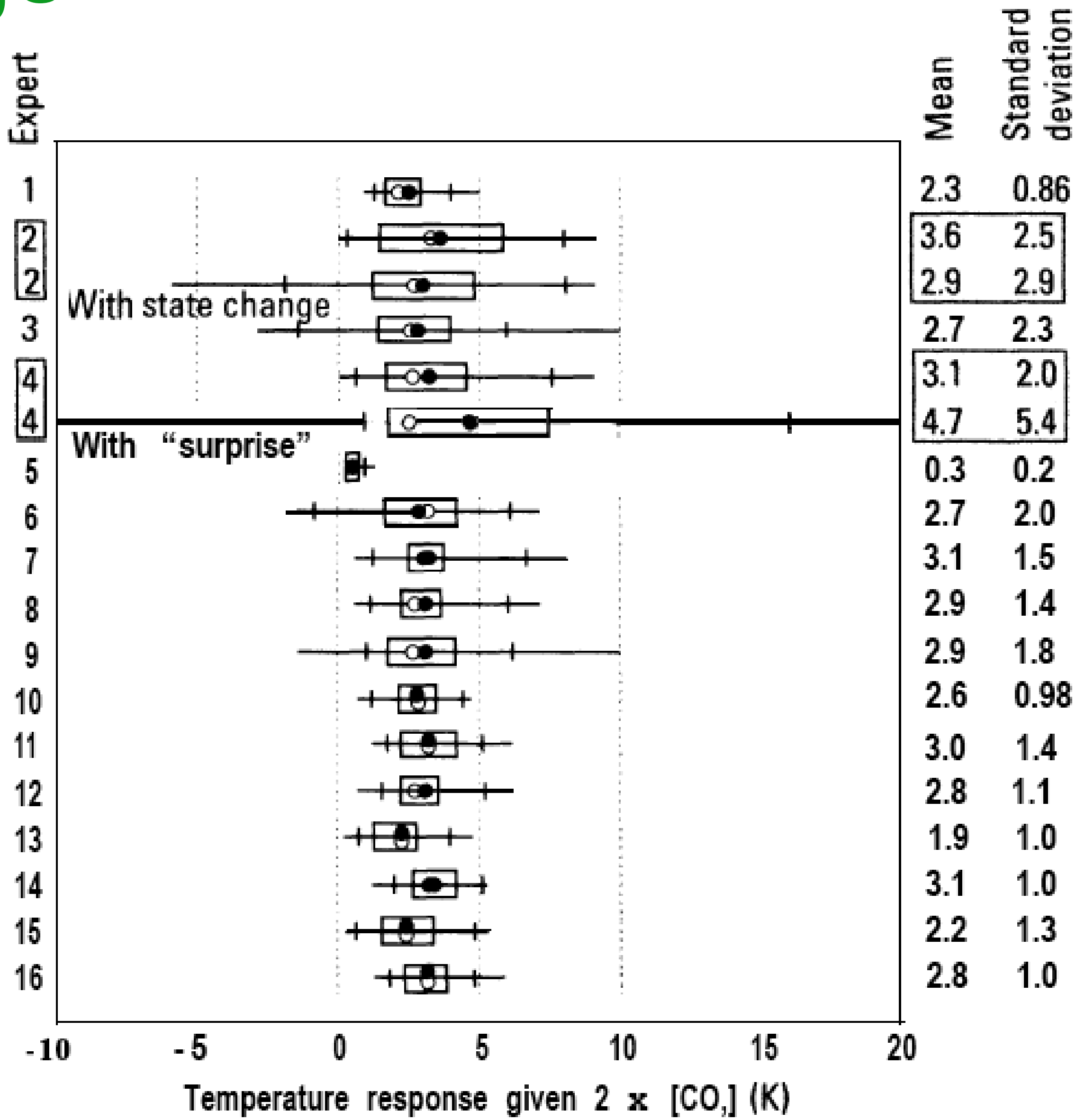




For details see: Henrion and Fischhoff, "Assessing Uncertainty in Physical Constants," *American Journal of Physics*, 54, pp791-798, 1986.

Equilibrium change in global average temperature

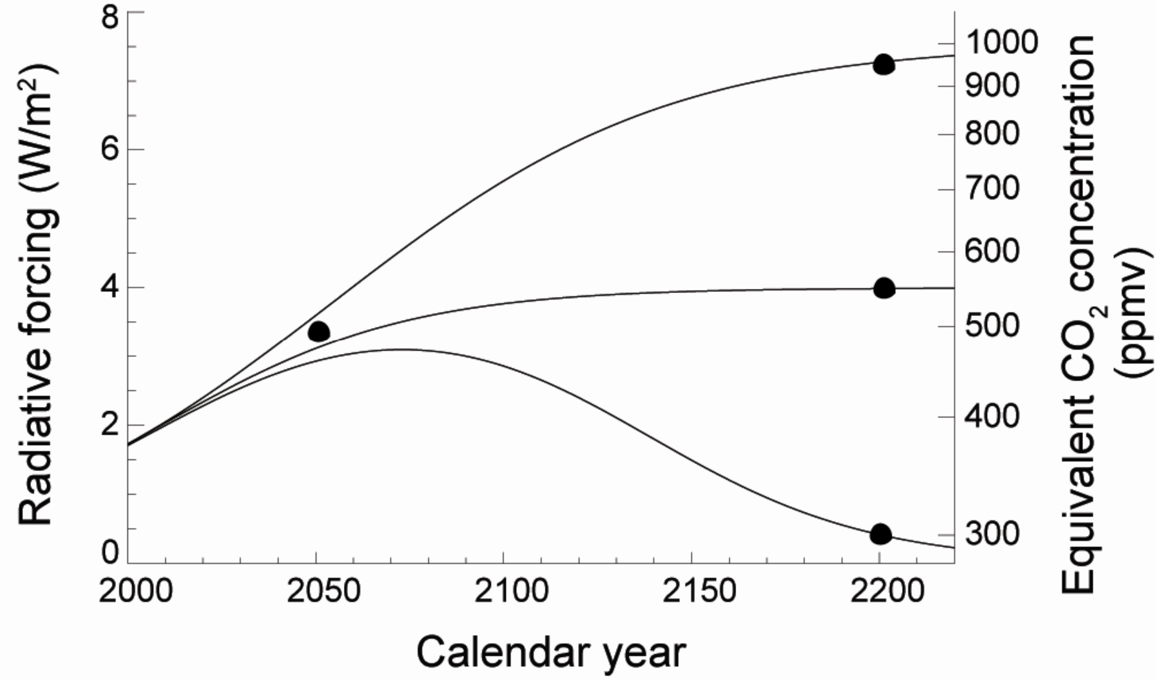
200 years after a $2xCO_2$ change



M. Granger Morgan and David Keith, "Subjective Judgments by Climate Experts," *Environmental Science & Technology*, *29*(10), 468A-476A, October 1995.

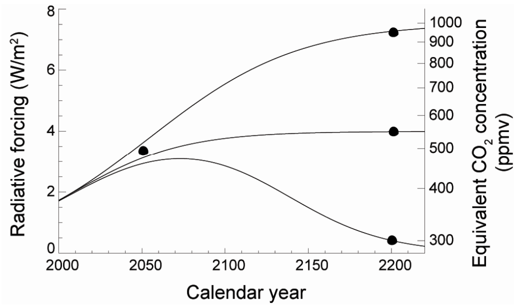
A similar study 15 years later…

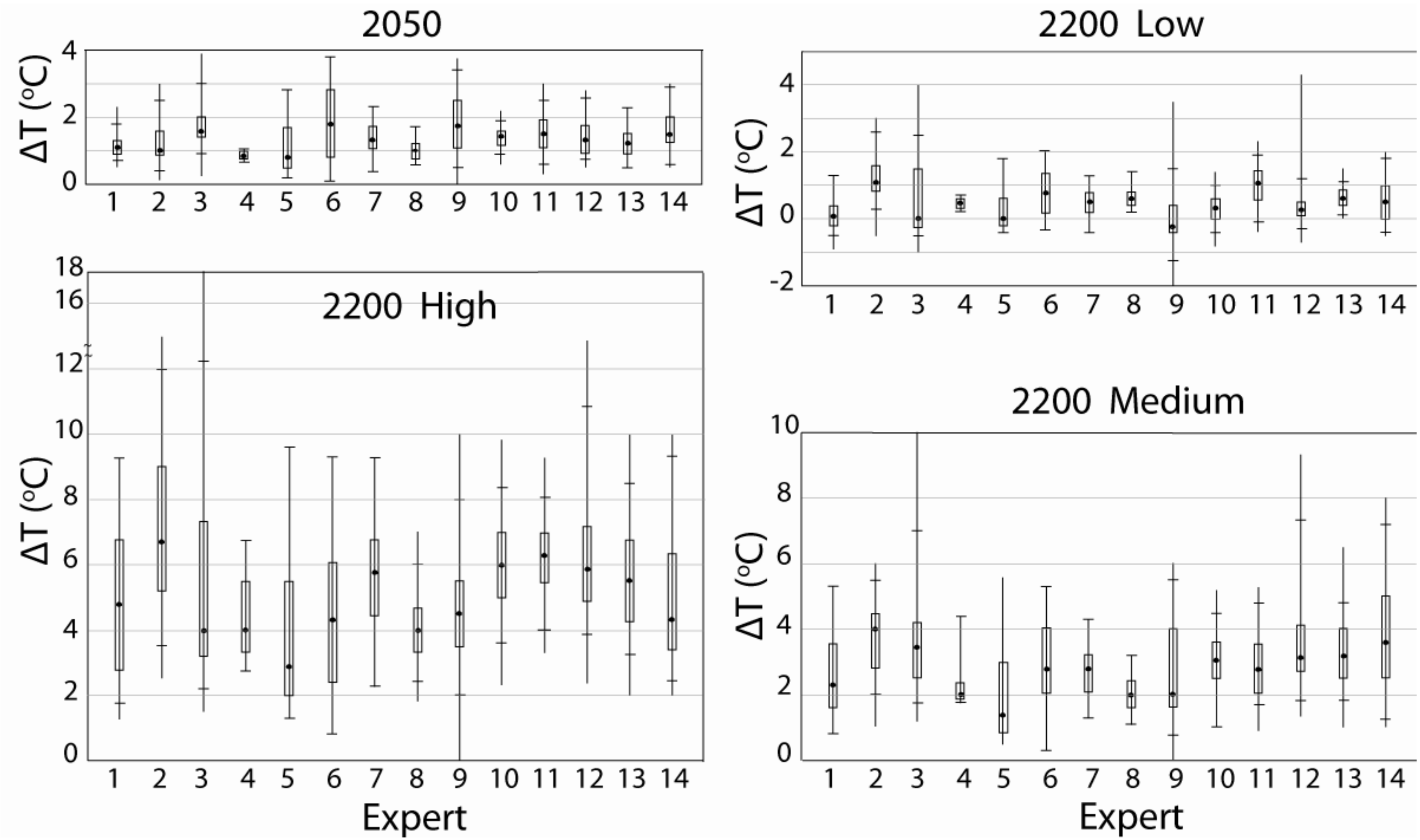
…considered three scenarios of future forcing:



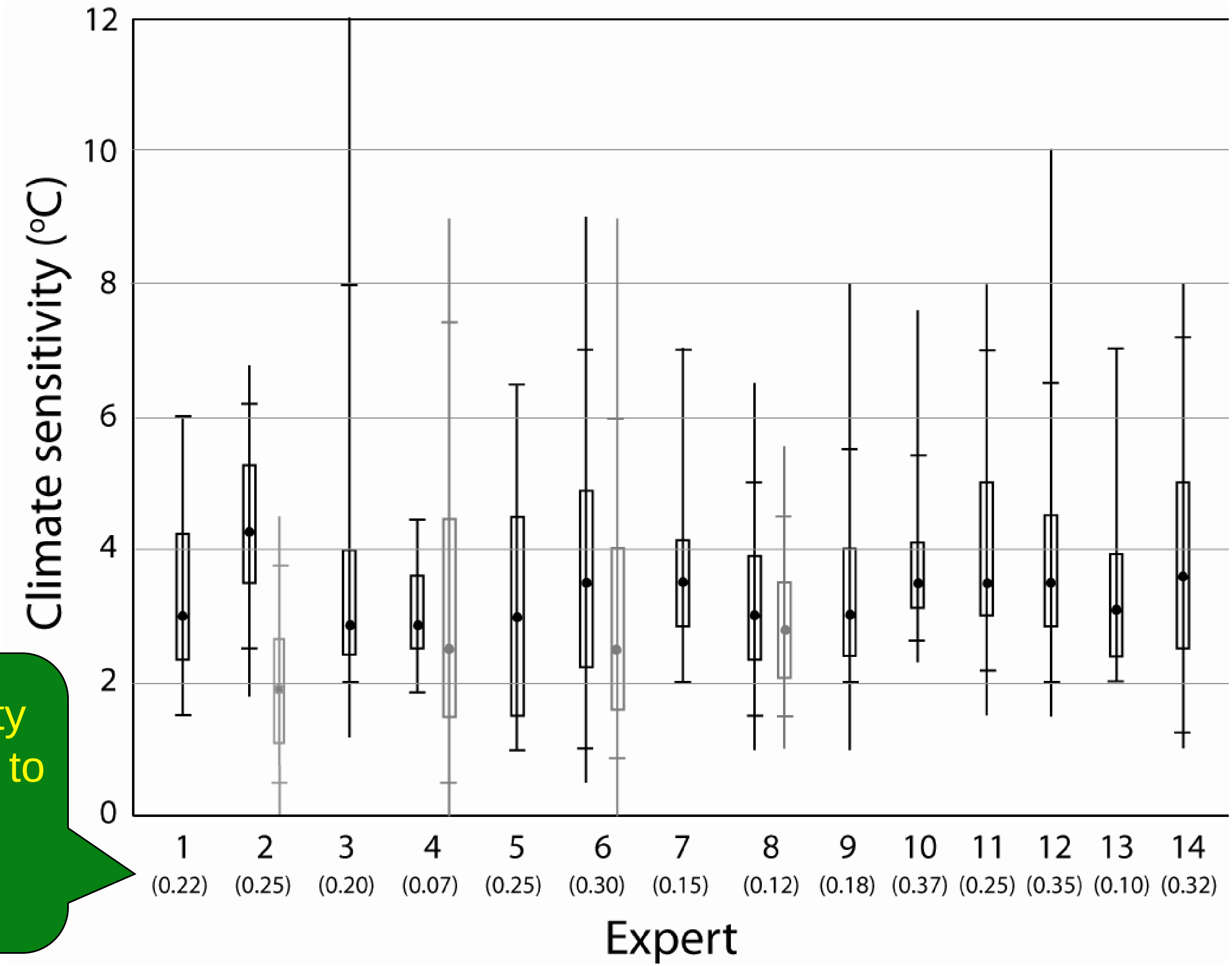
Kirsten Zickfeld, M. Granger Morgan, David Frame and David W. Keith, "Expert Judgments About Transient Climate Response to Alternative Future Trajectories of Radiative Forcing," *Proceedings of the National Academy of Sciences*, *107*, 12451-12456, July 13, 2010.

Summary of PDFs in ΔT



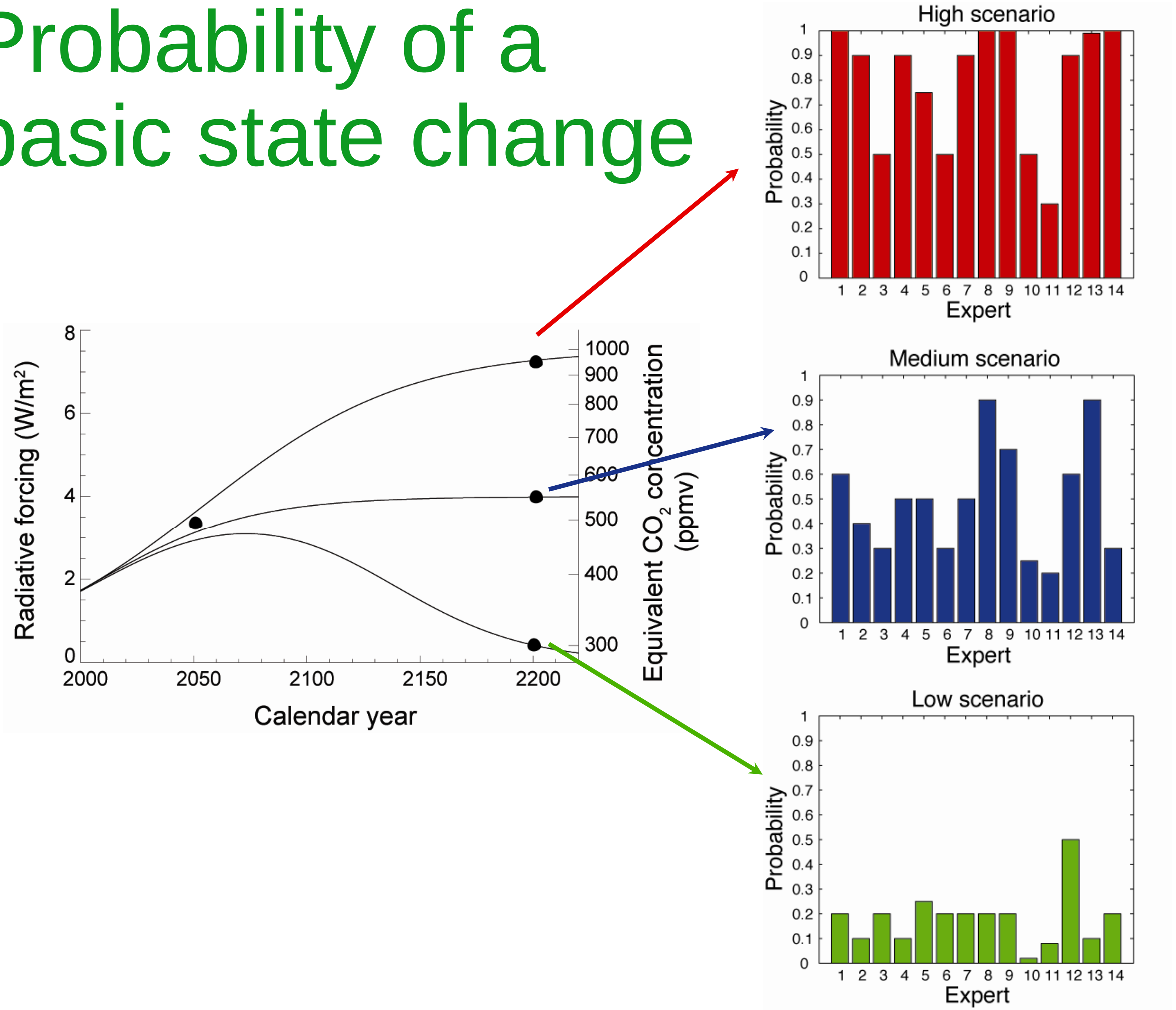


Climate sensitivity



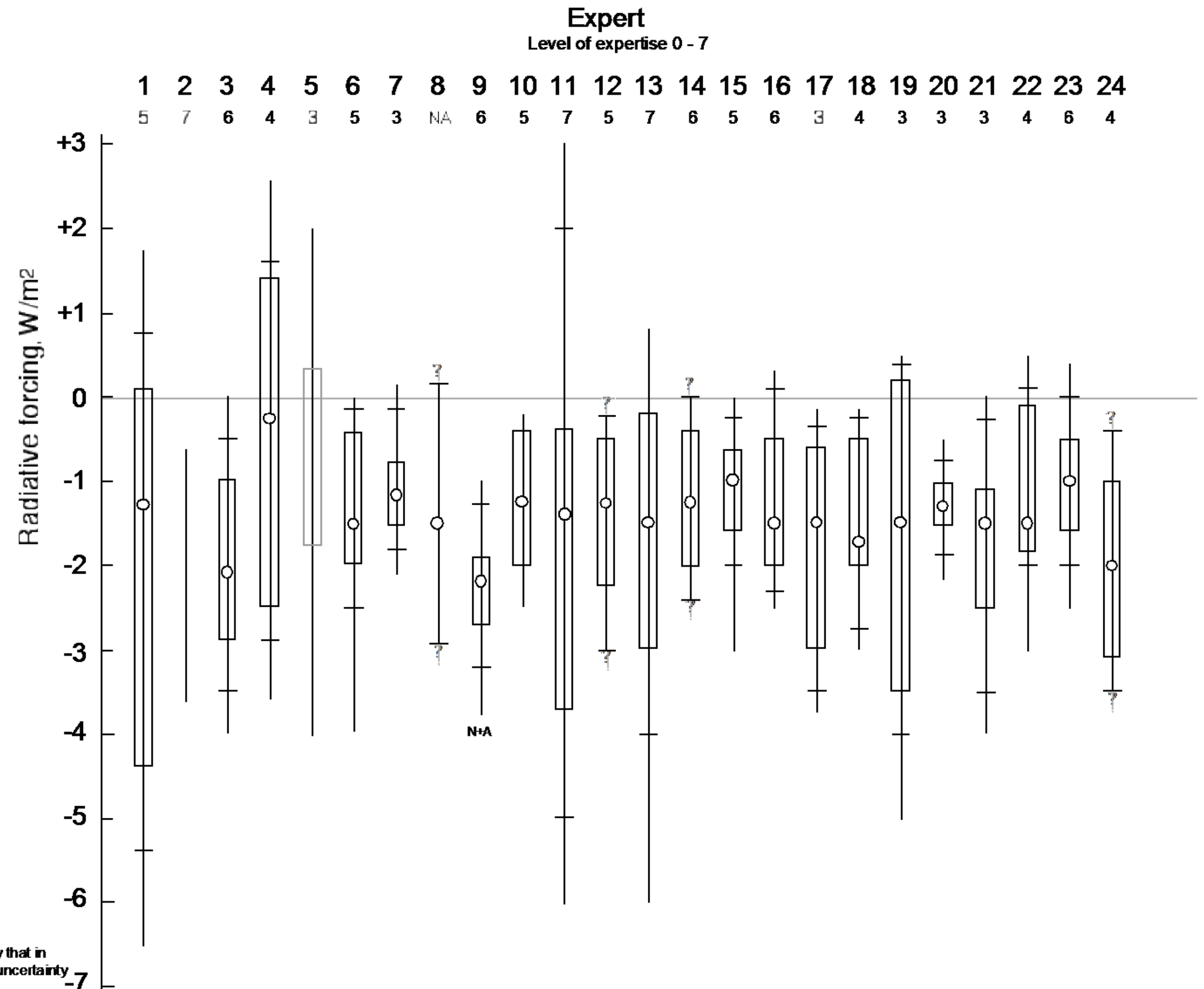
Probability allocated to values above 4.5° C

Probability of a basic state change



Total aerosol forcing

(at the top of the atmosphere)



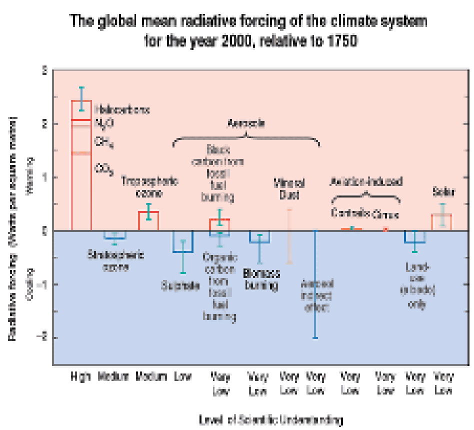
Probability that in 20 years uncertainty will have:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Grown	0.1	N A	0.1	0.3	N A	0.1	0.1	0.1	N A	N A	0.1	0.2	0.3	0.02	0.2	0.2	0.1	0.1	0.1	0.3	0	0.1	0.2	0.3
Shrunk by 0-50%	0.35		0.8	0.2		0.7	0.5	0.7			0.8	0.5	0.5	0.49	0.5	0.4	0.5	0.6	0.65	0.3	0.5	0.7	0.6	0.5
Shrunk by 50-80%	0.35		0.1	0.2		0.2	0.3	0.15			0.1	0.2	0.15	0.49	0.2	0.3	0.3	0.2	0.2	0.2	0.3	0.1	0.18	0.1
Shrunk by >80%	0.2		~0	0.3		0.1	0.1	0.05			0	0.1	0.05	0	0.1	0.1	0.1	0.1	0.05	0.2	0.2	0.1	0.02	0.1

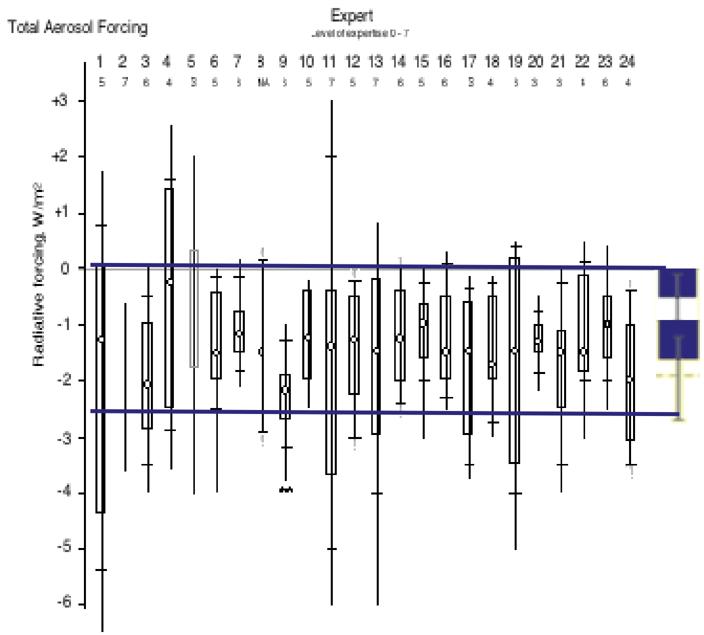
M. Granger Morgan, Peter Adams, and David W. Keith, "Elicitation of Expert Judgments of Aerosol Forcing," *Climatic Change*, *75*, 195-214, 2006.

Comparison with IPCC 4th assessment consensus results

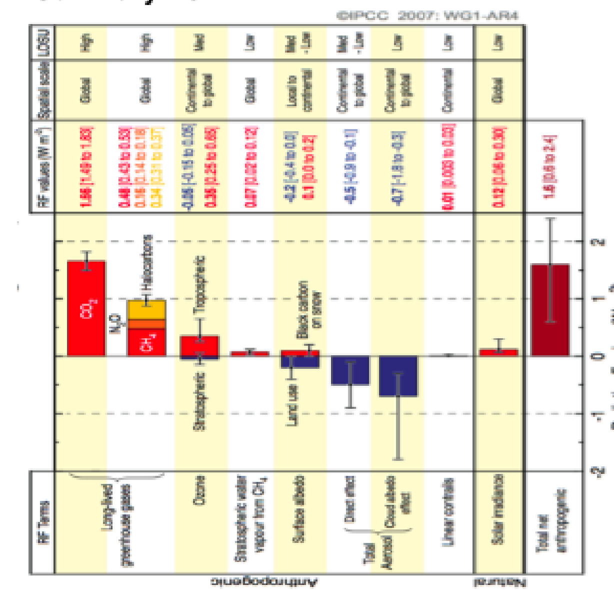
Summary from TAR



Total aerosol forcing from
Morgan, Adams and Keith



Summary from FR4



IPCC reports area available at www.IPCC.ch

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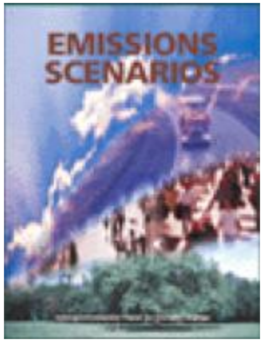
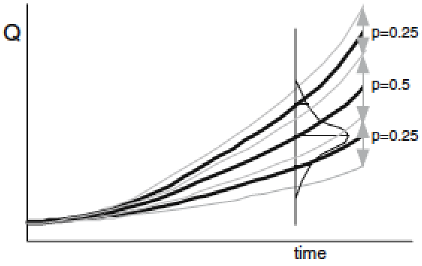
Scenarios are widely used



For example, the last IPCC assessment made use of the very detailed SRES scenarios in making its projections.

While in principle there are ways to create scenarios that span ranges across the space of plausible futures, this is very rarely done.



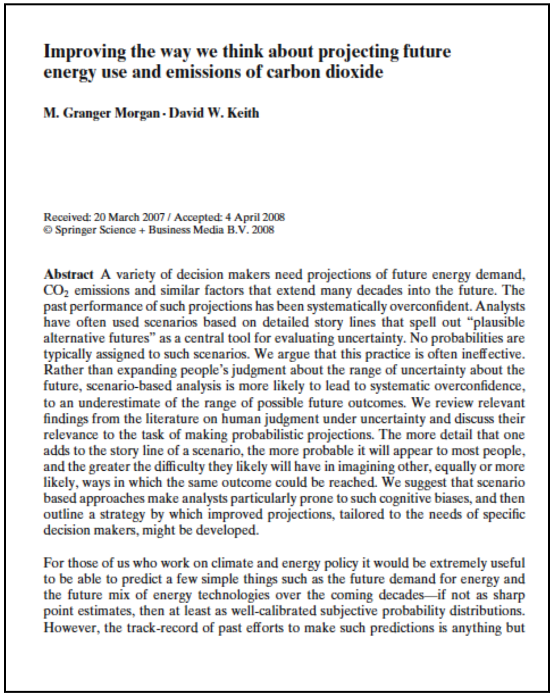
Folks who construct scenarios often argue that they should not be viewed as "predictions" but rather as a strategy to help people think about how things might unfold in the future.

But, there is a problem with this argument…

SRES is at: www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0

The more detail…

…that gets added to the "story line" of a scenario, the harder people find it to remember that there are typically many other ways that one could reach the same outcome, as well as many other possible outcomes that could result - this because of the heuristic of "availability."



Improving the way we think about projecting future energy use and emissions of carbon dioxide

M. Granger Morgan · David W. Keith

Received: 20 March 2007 / Accepted: 4 April 2008

Abstract A variety of decision makers need projections of future energy demand, CO_2 emissions and similar factors that extend many decades into the future. The past performance of such projections has been systematically overconfident. Analysts have often used scenarios based on detailed story lines that spell out "plausible alternative futures" as a central tool for evaluating uncertainty. No probabilities are typically assigned to such scenarios. We argue that this practice is often ineffective. Rather than expanding people's judgment about the range of uncertainty about the future, scenario-based analysis is more likely to lead to systematic overconfidence, to an underestimate of the range of possible future outcomes. We review relevant findings from the literature on human judgment under uncertainty and discuss their relevance to the task of making probabilistic projections. The more detail that one adds to the story line of a scenario, the more probable it will appear to most people, and the greater the difficulty they likely will have in imagining other, equally or more likely, ways in which the same outcome could be reached. We suggest that scenario based approaches make analysts particularly prone to such cognitive biases, and then outline a strategy by which improved projections, tailored to the needs of specific decision makers, might be developed.

For those of us who work on climate and energy policy it would be extremely useful to be able to predict a few simple things such as the future demand for energy and the future mix of energy technologies over the coming decades—if not as sharp point estimates, then at least as well-calibrated subjective probability distributions. However, the track-record of past efforts to make such predictions is anything but

For additional elaboration of this and related arguments, and some suggestions for how to improve on past practice, see:

M. Granger Morgan and David Keith, "Improving the Way We Think About Projecting Future Energy Use and Emissions of Carbon Dioxide," *Climatic Change*, *90*(3), 189-215, October 2008.

My colleagues and I…

…have been strong proponents for the use of integrated assessment, for example using these methods to explore the issue of acid rain (Rubin et al.). We thought that similar methods could be useful for addressing climate change.

EDWARD S. RUBIN
LESTER B. LAVE
M. GRANGER MORGAN

Keeping Climate Research Relevant

The federal government must avoid repeating the mistakes it made in studying acid rain.

Recent post-mortems of the National Acid Precipitation Assessment Program (NAPAP) confirmed what Congress and other key parties to the acid rain debate already knew: that the 10-year, half-billion-dollar interagency program to guide U.S. policy on acid rain control proved largely irrelevant to the effort to forge the new Clean Air Act last fall. Although NAPAP won praise for its scientific accomplishments, the program failed in its primary mission—to provide policy-relevant information in a timely manner. Now, government attempts to deal with the more difficult and far-reaching environmental issues associated with global warming appear to be headed down the same ill-fated path.

Global climate change has become the most important environmental issue on the world agenda. The potentially enormous human and ecological implications of global warming—rising sea levels, altered precipitation patterns, and damage to natural ecosystems—have generated concern. But the equally large uncertainties about the timing and magnitude of possible effects, coupled with questions about the costs and impacts of possible abatement measures, have thus far kept policymakers from agreeing on what to do.

European nations, especially the Scandinavian countries, have called for immediate, large-scale reductions in emissions of carbon dioxide and other "greenhouse" gases. The Bush administration has rejected such initiatives as hasty and wasteful of resources needed for more pressing matters. Until the global climate problem is better understood, the administration contends, the United States should not be stampeded into taking actions that could have ruinous consequences for the economy. The administration does, however, subscribe to the need for more research, boasting a billion-dollar annual federal research program.

Although the government's decision to commit resources to research on global climate change is laudable, the structure of the program and the research

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Issues in Science and Technology, *VIII(2)*, 47-55, Winter 1991-92.

Uncertainties of climate change

SIR — To resolve the uncertainties enveloping global climate change, the United States and, to a lesser extent, Europe have embarked on an extensive research effort. We believe that these research programmes will do little to provide a solid scientific foundation for policy decisions in the next decade.

Marginal improvements in current models, or additional runs of the global circulation models, will not resolve the fundamental uncertainties paralysing international negotiations. Research is at present focused on predicting the extent of climate change, a question that is unlikely to be resolved for at least another decade. More likely to be resolved and of greater importance in determining policy are the cost of abatement and the effects of climate change. In our view, scientific research is destined to remain largely irrelevant to political decisions about global climate change as it is not designed to produce answers when needed by policy makers.

These problems were the downfall of the decade long, half-billion-dollar National Acid Precipitation Assessment Project (NAPAP). Its important scientific findings had virtually no effect on policy and legislation. Research on the greenhouse effect is following the same path. If science is to be relevant to social decisions about global climate change, the programme's management and focus must be changed. The focus should be on informing policy decisions over the next decade or two, not on abstract research. Fundamental research is needed, but the agenda must be structured to answer crucial policy questions, not simply to advance knowledge.

The United States is spending $1,200 million on climate change research this year, but only 25 per cent of these resources are focused on the core issues. Even these programmes were generally designed to answer other questions. If scientific research is to inform political decisions, administrators need to exercise tough control. An integrated assessment is needed to identify the priority research and coordinate individual projects.

In our judgement, several independent assessments should be undertaken in parallel. Integrated assessments can spot the critical gaps in the current research agenda, discover research that isn't on target or is wasteful, and detect the mismatches between the inputs that each group is expecting and the outputs that will be produced by other researchers. Global climate change is too important to repeat the same mistakes that crippled the $500-million NAPAP programme.

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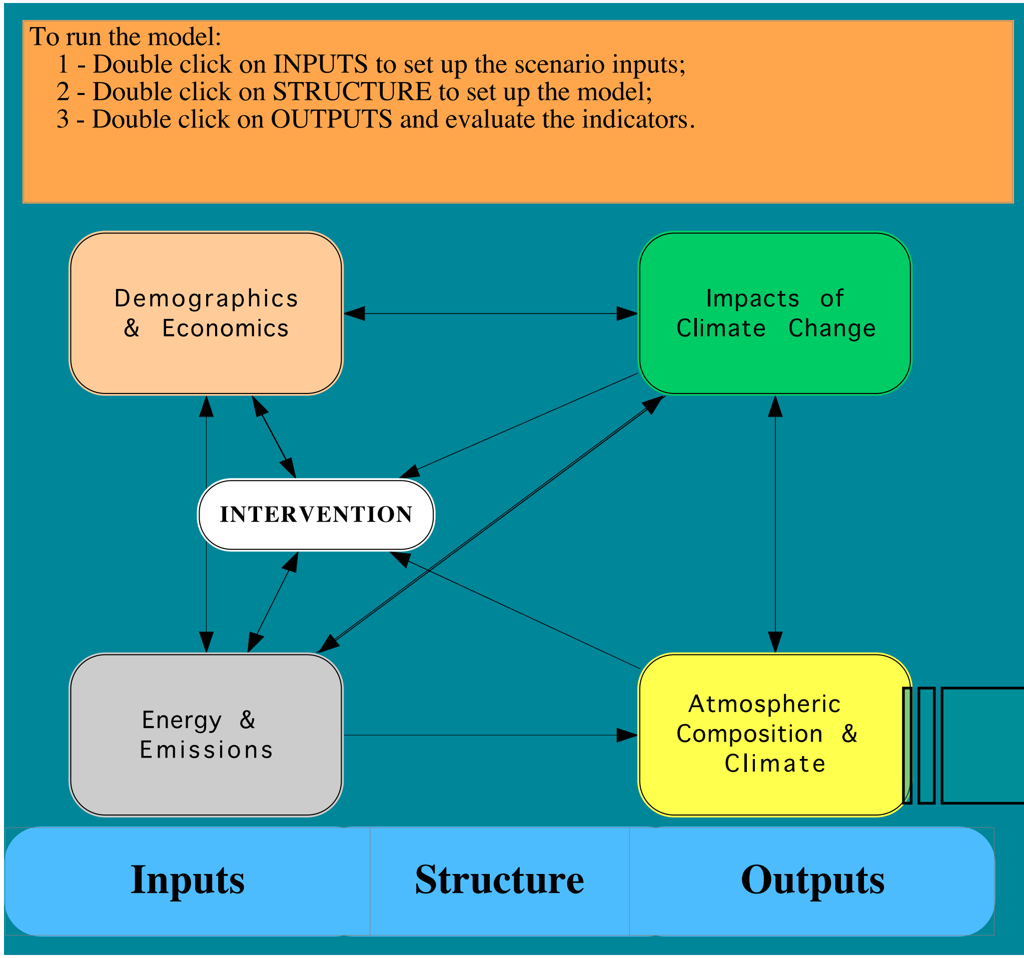
Nature, 355, 1992 January 16.

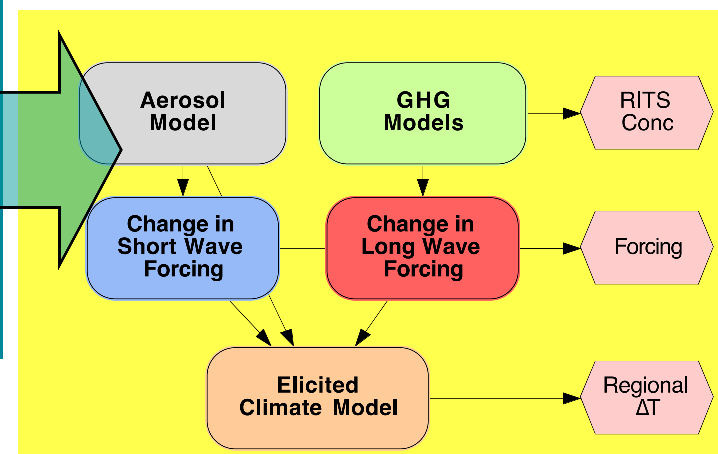
With NSF support we built ICAM



ICAM

Integrated Climate Assessment Model

A very large hierarchically organized stochastic simulation model built in Analytica®.



See for example:
Hadi Dowlatabadi and M. Granger Morgan, "A Model Framework for Integrated Studies of the Climate Problem," *Energy Policy*, *21*(3), 209-221, March 1993.
and
M. Granger Morgan and Hadi Dowlatabadi, "Learning from Integrated Assessment of Climate Change," *Climatic Change*, *34*, 337-368, 1996.

ICAM is focused on…

…doing a good job of dealing with uncertainty.

It treats all important coefficients as full probability distributions and produces results that are PDFs.

It contains switches that allow the user to use a variety of different functional forms.

We found that:

- One could get a large variety of answers depending on how you structured the model.
- In light of this, we concluded that global IA models that do optimization, using just one assumed structure, make absolutely no sense.

Accordingly…

…while others continue to build new IA models for the climate problem, or elaborate old ones, we have stopped doing global-scale IA for climate.

We are now focusing our attention on decisions that may actually contribute to reducing the adverse impacts of climate change, and on decision makers whose choices may actually do that. That is why our latest NSF center is the center for

Climate and Energy Decision Making

At its root, the climate problem is the problem of de-carbonizing the energy system.

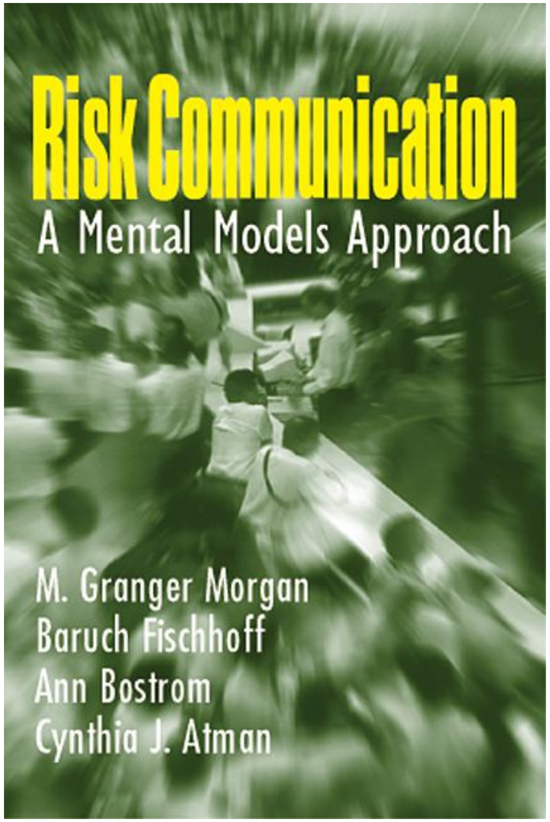
Details at http://cedm.epp.cmu.edu

I will touch briefly on four topics:

1. The use of formal quantitative expert elicitation.
2. Limitations in the use of scenarios and integrated assessment models that focus on optimizing.
3. Studies of public perceptions.
4. Studies of public engagement.

Mental models methods

One problem with just asking people what they think about a topic like climate change, or "sustainability" is that you have to put information into your questions…and pretty soon you can't tell if what people are saying is what they thought before you asked the question, or their inference based on the information in your question.



This multi-step process begins with a simple open-ended interview question.

Example of opening response in interview

Interviewer: "I'd like you to tell me all about the issue of climate change."

Subject: "Climate change. Do you mean global warming?"

Interviewer: "Climate change."

Subject: "OK. Let's see. What do I know. The earth is getting warmer because there are holes in the atmosphere and this is global warming and the greenhouse effect. Um... I really don't know very much about it, but it does seem to be true. The temperatures do seem to be kind of warm in the winters. They do seem to be warmer than in the past.. and.. hmm.. That's all I know about global warming.

Another example…

Interviewer: "Tell me all about the issue of climate change."

Subject: "Climate change? Like, what about it? Like, as far as the ozone layer and ice caps melting, water level raising, rainforest going down, oxygen going down because of that? All of that kind of stuff?"

Interviewer: "Anything else?"

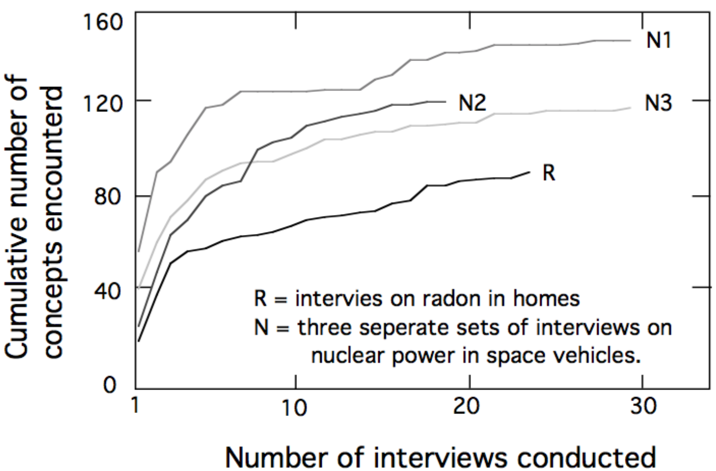
Subject: "Well, erosion all over the place. Um, topsoils going down into everywhere. Fertilizer poisoning. "Interviewer: "Anything else that comes to mind related to climate change? Subject: "Climate change. Winter's ain't like they used to be. Nothing's as severe. Not as much snow. Nothing like that."

Another example…

Interviewer: "Tell me all about the issue of climate change."

Subject: "I'm pretty interested in it... The ice caps are melting -- the hole in the ozone layer. They think pollution from cars and aerosol cans are the cause of all that. I think the space shuttle might have something to do with it too, because they always send that up through the earth, to get out in outer space. So I think that would have something to do with it, too."

The identification of new concepts typically reaches an asymptote after 15-20 interviews



The results…

…can then be used to develop a closed-form survey to get statistical power with large N.

Risk Analysis, Vol. 30, No. 10, 2010

DOI: 10.1111/j.1539-6924.2010.01448.x

Now What Do People Know About Global Climate Change? Survey Studies of Educated Laypeople

Travis William Reynolds,[1,*] Ann Bostrom,[1] Daniel Read,[2] and M. Granger Morgan[3]

In 1992, a mental-models-based survey in Pittsburgh, Pennsylvania, revealed that educated laypeople often conflated global climate change and stratospheric ozone depletion, and appeared relatively unaware of the role of anthropogenic carbon dioxide emissions in global warming. This study compares those survey results with 2009 data from a sample of similarly well-educated laypeople responding to the same survey instrument. Not surprisingly, following a decade of explosive attention to climate change in politics and in the mainstream media, survey respondents in 2009 showed higher awareness and comprehension of some climate change causes. Most notably, unlike those in 1992, 2009 respondents rarely mentioned ozone depletion as a cause of global warming. They were also far more likely to correctly volunteer energy use as a major cause of climate change; many in 2009 also cited natural processes and historical climatic cycles as key causes. When asked how to address the problem of climate change, while respondents in 1992 were unable to differentiate between general "good environmental practices" and actions specific to addressing climate change, respondents in 2009 have begun to appreciate the differences. Despite this, many individuals in 2009 still had incorrect beliefs about climate change, and still did not appear to fully appreciate key facts such as that global warming is primarily due to increased concentrations of carbon dioxide in the atmosphere, and the single most important source of this carbon dioxide is the combustion of fossil fuels.

In 1992, a mental-models-based survey in Pittsburgh, Pennsylvania, revealed that educated laypeople often conflated global climate change and stratospheric ozone depletion, and appeared relatively unaware of the role of anthropogenic carbon dioxide emissions in global warming. This study compares those survey results with 2009 data from a sample of similarly well-educated laypeople responding to the same survey instrument. Not surprisingly, following a decade of explosive attention to climate change in politics and in the mainstream media, survey respondents in 2009 showed higher awareness and comprehension of some climate change causes. Most notably, unlike those in 1992, 2009 respondents rarely mentioned ozone depletion as a cause of global warming. They were also far more likely to correctly volunteer energy use as a major cause of climate change; many in 2009 also cited natural processes and historical climatic cycles as key causes. When asked how to address the problem of climate change, while respondents in 1992 were unable to differentiate between general "good environmental practices" and actions specific to addressing climate change, respondents in 2009 have begun to appreciate the differences. Despite this, many individuals in 2009 still had incorrect beliefs about climate change, and still did not appear to fully appreciate key facts such as that global warming is primarily due to increased concentrations of carbon dioxide in the atmosphere, and the single most important source of this carbon dioxide is the combustion of fossil fuels.

KEY WORDS: Climate change; global warming; laypeople; mental models; risk communication; United States

TION

conducted a survey of beliefs and United States concerning global cli- Since that time both the public dis- a coverage of the issue have changed ecognition. By 2008 climate change

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was at the forefront of popular media. Al Gore had starred in an Academy Award winning movie on climate change; rock stars like David Gilmour and U2 offered "carbon neutral" CDs; and marketers, auto manufacturers, and even airlines were beginning to promote their products based on their reduced effects on climate change.[4] Whereas in 1992 there was little official acknowledgment of global warming, in 2008 both U.S. presidential candidates proposed explicit policies designed to reduce or slow climate change.

[4] For an example, see http://www.easyjet.com/en/Environment/index.html. Accessed April 15, 2010.

Ann Bostrom, M. Granger Morgan, Baruch Fischhoff and Daniel Read, "What Do People Know About Global Climate Change? Part 1: Mental models," *Risk Analysis*, *14*(6), 959-970, 1994; Daniel Read, Ann Bostrom, M. Granger Morgan, Baruch Fischhoff and Tom Smuts, "What Do People Know About Global Climate Change? Part 2: Survey studies of educated laypeople," *Risk Analysis*, *14*(6), 971-982,1994; Travis Reynolds, Ann Bostrom, Daniel Read and M. Granger Morgan, "Now What Do People Know About Climate Change?," *Risk Analysis*, *30*(10), 1520-1538, 2010.

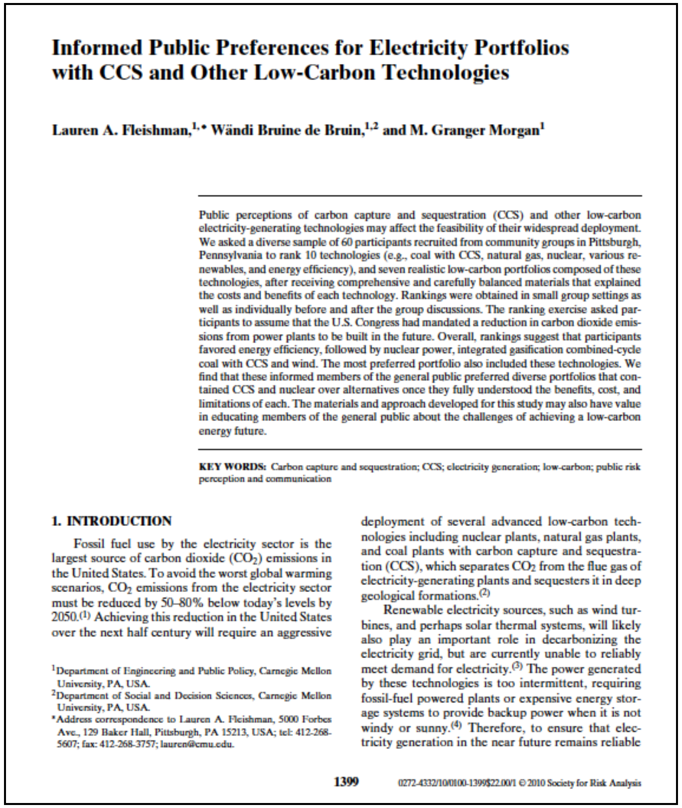
I will touch briefly on four topics:

1. The use of formal quantitative expert elicitation.
2. Limitations in the use of scenarios and integrated assessment models that focus on optimizing.
3. Studies of public perceptions.
4. Studies of public engagement.

There has been…

…lots of work on strategies to support stakeholder involvement. Ortwin Renn is developing web-based guidance for IRGC.

www.resolv.org/



Informed Public Preferences for Electricity Portfolios with CCS and Other Low-Carbon Technologies

Lauren A. Fleishman,[1,*] Wändi Bruine de Bruin,[1,2] and M. Granger Morgan[1]

Public perceptions of carbon capture and sequestration (CCS) and other low-carbon electricity-generating technologies may affect the feasibility of their widespread deployment. We asked a diverse sample of 60 participants recruited from community groups in Pittsburgh, Pennsylvania to rank 10 technologies (e.g., coal with CCS, natural gas, nuclear, various renewables, and energy efficiency), and seven realistic low-carbon portfolios composed of these technologies, after receiving comprehensive and carefully balanced materials that explained the costs and benefits of each technology. Rankings were obtained in small group settings as well as individually before and after the group discussions. The ranking exercise asked participants to assume that the U.S. Congress had mandated a reduction in carbon dioxide emissions from power plants to be built in the future. Overall, rankings suggest that participants favored energy efficiency, followed by nuclear power, integrated gasification combined-cycle coal with CCS and wind. The most preferred portfolio also included these technologies. We find that these informed members of the general public preferred diverse portfolios that contained CCS and nuclear over alternatives once they fully understood the benefits, cost, and limitations of each. The materials and approach developed for this study may also have value in educating members of the general public about the challenges of achieving a low-carbon energy future.

KEY WORDS: Carbon capture and sequestration; CCS; electricity generation; low-carbon; public risk perception and communication

1. INTRODUCTION

Fossil fuel use by the electricity sector is the largest source of carbon dioxide (CO_2) emissions in the United States. To avoid the worst global warming scenarios, CO_2 emissions from the electricity sector must be reduced by 50–80% below today's levels by 2050.(1) Achieving this reduction in the United States over the next half century will require an aggressive deployment of several advanced low-carbon technologies including nuclear plants, natural gas plants, and coal plants with carbon capture and sequestration (CCS), which separates CO_2 from the flue gas of electricity-generating plants and sequesters it in deep geological formations.(2)

Renewable electricity sources, such as wind turbines, and perhaps solar thermal systems, will likely also play an important role in decarbonizing the electricity grid, but are currently unable to reliably meet demand for electricity.(3) The power generated by these technologies is too intermittent, requiring fossil-fuel powered plants or expensive energy storage systems to provide backup power when it is not windy or sunny.(4) Therefore, to ensure that electricity generation in the near future remains reliable

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1399 0272-4332/10/0100-1399$22.00/1 © 2010 Society for Risk Analysis

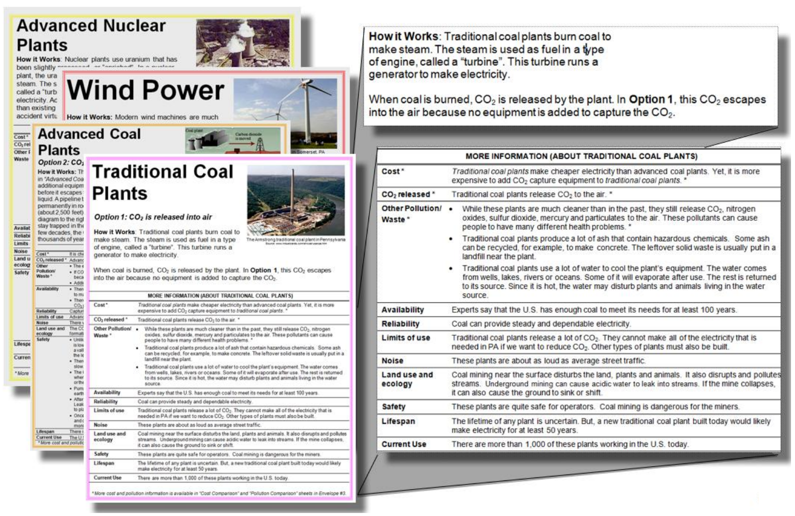
My colleagues and I have developed a variety of strategies to support lay groups to make informed decisions about topics such as risk ranking, transmission line siting, and the development of portfolios of low carbon electricity generation technologies.

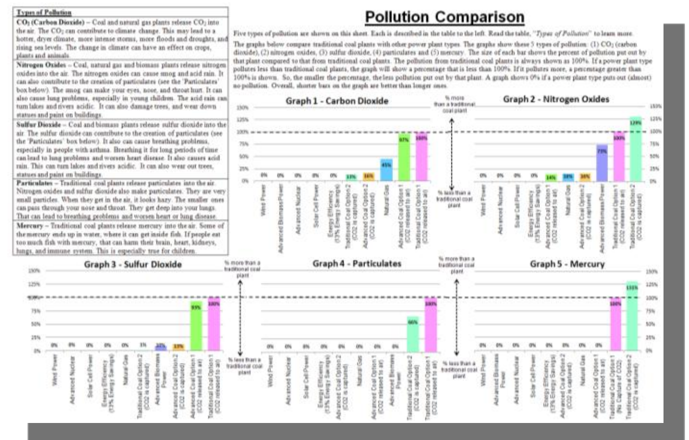
Lauren A. Fleishman, Wändi Bruine de Bruin and M. Granger Morgan, "Informed Public Preferences for Electricity Portfolios with CCS and Other Low-Carbon Technologies," *Risk Analysis*, *30*, 1399-1410, 2010.

Example materials…

…from the work of Lauren Fleishman et al.

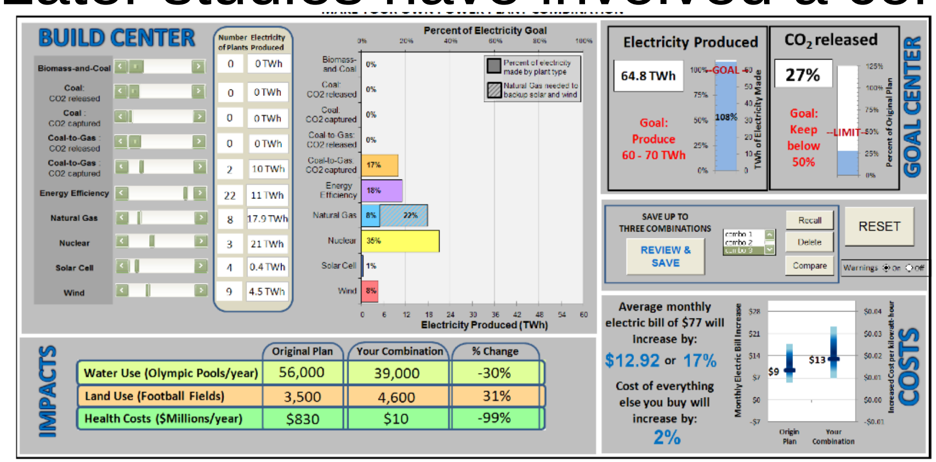
First study used paper materials:





Worked with experts at CMU and EPRI to review and refine the material.

Later studies have involved a computer tool:



The tool is available at:
http://cedm.epp.cmu.edu/tool-public-lowcarbon.php

Acknowledgments

Most of the specific examples I have presented are drawn from work that has been supported by NSF.

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