Global Warming: Forecasts by Scientists versus Scientific Forecasts

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Abstract

In 2007, the Intergovernmental Panel on Climate Change's Working Group One, a panel of experts established by the World Meteorological Organization and the United Nations Environment Programme, issued its Fourth Assessment Report. The Report included predictions of dramatic increases in average world temperatures over the next 92 years and serious harm resulting from the predicted temperature increases. Using forecasting principles as our guide we asked: Are these forecasts a good basis for developing public policy? Our answer is "no". To provide forecasts of climate change that are useful for policy-making, one would need to forecast (1) global temperature, (2) the effects of any temperature changes, and (3) the effects of feasible alternative policies. Proper forecasts of all three are necessary for rational policy making. The IPCC WG1 Report was regarded as providing the most credible long-term forecasts of global average temperatures by 31 of the 51 scientists and others involved in forecasting climate change who responded to our survey. We found no references in the 1056-page Report to the primary sources of information on forecasting methods despite the fact these are conveniently available in books, articles, and websites. We audited the forecasting processes described in Chapter 8 of the IPCC's WG1 Report to assess the extent to which they complied with forecasting principles. We found enough information to make judgments on 89 out of a total of 140 forecasting principles. The forecasting procedures that were described violated 72 principles. Many of the violations were, by themselves, critical. The forecasts in the Report were not the outcome of scientific procedures. In effect, they were the opinions of scientists transformed by mathematics and obscured by complex writing. Research on forecasting has shown that experts' predictions are not useful in situations involving uncertainly and complexity. We have been unable to identify any scientific forecasts of global warming. Claims that the Earth will get warmer have no more credence than saying that it will get colder.

Comments

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GLOBAL WARMING: FORECASTS BY SCIENTISTS VERSUS SCIENTIFIC FORECASTS*

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ABSTRACT

In 2007, the Intergovernmental Panel on Climate Change's Working Group One, a panel of experts established by the World Meteorological Organization and the United Nations Environment Programme, issued its Fourth Assessment Report. The Report included predictions of dramatic increases in average world temperatures over the next 92 years and serious harm resulting from the predicted temperature increases. Using forecasting principles as our guide we asked: Are these forecasts a good basis for developing public policy? Our answer is "no".

To provide forecasts of climate change that are useful for policy-making, one would need to forecast (1) global temperature, (2) the effects of any temperature changes, and (3) the effects of feasible alternative policies. Proper forecasts of all three are necessary for rational policy making.

The IPCC WG1 Report was regarded as providing the most credible long-term forecasts of global average temperatures by 31 of the 51 scientists and others involved in forecasting climate change who responded to our survey. We found no references in the 1056-page Report to the primary sources of information on forecasting methods despite the fact these are conveniently available in books, articles, and websites. We audited the forecasting processes described in Chapter 8 of the IPCC's WG1 Report to assess the extent to which they complied with forecasting principles. We found enough information to make judgments on 89 out of a total of 140 forecasting principles. The forecasting procedures that were described violated 72 principles. Many of the violations were, by themselves, critical.

The forecasts in the Report were not the outcome of scientific procedures. In effect, they were the opinions of scientists transformed by mathematics and obscured by complex writing. Research on forecasting has shown that experts' predictions are not useful in situations involving uncertainly and complexity. We have been unable to identify any scientific forecasts of global warming. Claims that the Earth will get warmer have no more credence than saying that it will get colder.

Keywords: accuracy, audit, climate change, evaluation, expert judgment, mathematical models, public policy.

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†Information about J. Scott Armstrong can be found on Wikipedia.

"A trend is a trend,
But the question is, will it bend?
Will it alter its course
Through some unforeseen force
And come to a premature end?"
Alec Cairncross, 1969

Research on forecasting has been conducted since the 1930s. Empirical studies that compare methods in order to determine which ones provide the most accurate forecasts in specified situations are the most useful source of evidence. Findings, along with the evidence, were first summarized in Armstrong (1978, 1985). In the mid-1990s, the Forecasting Principles Project was established with the objective of summarizing all useful knowledge about forecasting. The knowledge was codified as evidence-based principles, or condition-action statements, in order to provide guidance on which methods to use when. The project led to the *Principles of Forecasting* handbook (Armstrong 2001): the work of 40 internationally-known experts on forecasting methods and 123 reviewers who were also leading experts on forecasting methods. The summarizing process alone required a four-year effort.

The forecasting principles are easy to find: They are freely available on forecastingprinciples.com, a site sponsored by the International Institute of Forecasters. The Forecasting Principles site has been at the top of the list of sites in Internet searches for "forecasting" for many years. A summary of the principles, currently numbering 140, is provided as a checklist in the Forecasting Audit software available on the site. The site is often updated in order to incorporate new evidence on forecasting as it comes to hand. A recent review of new evidence on some of the key principles was published in Armstrong (2006). There is no other source that provides evidence-based forecasting principles.

The strength of evidence is different for different principles, for example some principles are based on common sense or received wisdom. Such principles are included when there is no contrary evidence. Other principles have some empirical support, while 31 are strongly supported by empirical evidence.

Many of the principles go beyond common sense, and some are counter-intuitive. As a result, those who forecast in ignorance of the forecasting research literature are unlikely to produce useful predictions. Here are some well-established principles that apply to long-term forecasts for complex situations where the causal factors are subject to uncertainty (as with climate):

- *Unaided judgmental forecasts by experts have no value*. This applies whether the opinions are expressed in words, spreadsheets, or mathematical models. It applies regardless of how much scientific evidence is possessed by the experts. Among the reasons for this are:
    - a) Complexity: People cannot assess complex relationships through unaided observations.
    - b) Coincidence: People confuse correlation with causation.
    - c) Feedback: People making judgmental predictions typically do not

receive unambiguous feedback they can use to improve their forecasting.

d) Bias: People have difficulty in obtaining or using evidence that contradicts their initial beliefs. This problem is especially serious for people who view themselves as experts.

- *Agreement among experts is weakly related to accuracy*. This is especially true when the experts communicate with one another and when they work together to solve problems, as is the case with the IPCC process.
- *Complex models (those involving nonlinearities and interactions) harm accuracy because their errors multiply.* Ascher (1978), refers to the Club of Rome's 1972 forecasts where, unaware of the research on forecasting, the developers proudly proclaimed, "in our model about 100,000 relationships are stored in the computer." Complex models also tend to fit random variations in historical data well, with the consequence that they forecast poorly and lead to misleading conclusions about the uncertainty of the outcome. Finally, when complex models are developed there are many opportunities for errors and the complexity means the errors are difficult to find. Craig, Gadgil, and Koomey (2002) came to similar conclusions in their review of long-term energy forecasts for the US that were made between 1950 and 1980.
- *Given even modest uncertainty, prediction intervals are enormous*. Prediction intervals (ranges outside which outcomes are unlikely to fall) expand rapidly as time horizons increase, for example, so that one is faced with enormous intervals even when trying to forecast a straightforward thing such as automobile sales for General Motors over the next five years.
- *When there is uncertainty in forecasting, forecasts should be conservative*. Uncertainty arises when data contain measurement errors, when the series are unstable, when knowledge about the direction of relationships is uncertain, and when a forecast depends upon forecasts of related (causal) variables. For example, forecasts of no change were found to be more accurate than trend forecasts for annual sales when there was substantial uncertainty in the trend lines (Schnaars and Bavuso 1986). This principle also implies that forecasts should revert to long-term trends when such trends have been firmly established, do not waver, and there are no firm reasons to suggest that they will change. Finally, trends should be damped toward no-change as the forecast horizon increases.

THE FORECASTING PROBLEM

In determining the best policies to deal with the climate of the future, a policy maker first has to select an appropriate statistic to use to represent the changing climate. By convention, the statistic is the averaged global temperature as measured with thermometers at ground stations throughout the world, though in practice this is a far from satisfactory metric (see, e.g., Essex et al., 2007).

It is then necessary to obtain forecasts and prediction intervals for each of the following:

1. *Mean global temperature in the long-term (say 10 years or longer).*
2. *Effects of temperature changes on humans and other living things.*
   If accurate forecasts of mean global temperature can be obtained *and* the changes are substantial, *then* it would be necessary to forecast the effects of the changes on the health of living things and on the health and wealth of humans. The concerns about changes in global mean temperature are based on the assumption that the earth is currently at the optimal temperature and that variations over years (unlike variations within days and years) are undesirable. For a proper assessment, costs and benefits must be comprehensive. (For example, policy responses to Rachel Carson's *Silent Spring* should have been based in part on forecasts of the number of people who might die from malaria if DDT use were reduced).
3. *Costs and benefits of feasible alternative policy proposals.*
   If valid forecasts of the effects of the temperature changes on the health of living things and on the health and wealth of humans can be obtained *and* the forecasts are for substantial harmful effects, *then* it would be necessary to forecast the costs and benefits of proposed alternative policies that could be successfully implemented.

A policy proposal should only be implemented *if* valid and reliable forecasts of the effects of implementing the policy can be obtained *and* the forecasts show net benefits. Failure to obtain a valid forecast in any of the three areas listed above would render forecasts for the other areas meaningless. We address primarily, but not exclusively, the first of the three forecasting problems: obtaining long-term forecasts of global temperature.

But is it necessary to use scientific forecasting methods? In other words, to use methods that have been shown by empirical validation to be relevant to the types of problems involved with climate forecasting? Or is it sufficient to have leading scientists examine the evidence and make forecasts? We address this issue before moving on to our audits.

ON THE VALUE OF FORECASTS BY EXPERTS

Many public policy decisions are based on forecasts by experts. Research on persuasion has shown that people have substantial faith in the value of such forecasts. Faith increases when experts agree with one another.

Our concern here is with what we refer to as unaided expert judgments. In such cases, experts may have access to empirical studies and other information, but they use their knowledge to make predictions without the aid of well-established forecasting principles. Thus, they could simply use the information to come up with judgmental forecasts. Alternatively, they could translate their beliefs into mathematical statements (or models) and use those to make forecasts.

Although they may seem convincing at the time, expert forecasts can make for humorous reading in retrospect. Cerf and Navasky's (1998) book contains 310 pages of examples, such as Fermi Award-winning scientist John von Neumann's 1956 prediction that "A few decades hence, energy may be free". Examples of expert climate forecasts that turned out to be completely wrong are easy to find, such as UC Davis ecologist Kenneth Watt's prediction in a speech at Swarthmore College on Earth Day, April 22, 1970:

> If present trends continue, the world will be about four degrees colder in 1990, but eleven degrees colder in the year 2000. This is about twice what it would take to put us into an ice age.

Are such examples merely a matter of selective perception? The second author's review of empirical research on this problem led him to develop the "Seer-sucker theory," which can be stated as "No matter how much evidence exists that seers do not exist, seers will find suckers" (Armstrong 1980). The amount of expertise does not matter beyond a basic minimum level. There are exceptions to the Seer-sucker Theory: When experts get substantial well-summarized feedback about the accuracy of their forecasts and about the reasons why their forecasts were or were not accurate, they can improve their forecasting. This situation applies for short-term (up to five day) weather forecasts, but we are not aware of any such regime for long-term global climate forecasting. Even if there were such a regime, the feedback would trickle in over many years before it became useful for improving forecasting.

Research since 1980 has provided much more evidence that expert forecasts are of no value. In particular, Tetlock (2005) recruited 284 people whose professions included, "commenting or offering advice on political and economic trends." He asked them to forecast the probability that various situations would or would not occur, picking areas (geographic and substantive) within and outside their areas of expertise. By 2003, he had accumulated over 82,000 forecasts. The experts barely if at all outperformed non-experts and neither group did well against simple rules.

Comparative empirical studies have routinely concluded that judgmental forecasting by experts is the least accurate of the methods available to make forecasts. For example, Ascher (1978, p. 200), in his analysis of long-term forecasts of electricity consumption found that was the case.

Experts' forecasts of climate changes have long been newsworthy and a cause of worry for people. Anderson and Gainor (2006) found the following headlines in their search of the *New York Times*:

Sept. 18, 1924	MacMillan Reports Signs of New Ice Age
March 27, 1933	America in Longest Warm Spell Since 1776
May 21, 1974	Scientists Ponder Why World's Climate is Changing: A Major Cooling Widely Considered to be Inevitable
Dec. 27, 2005	Past Hot Times Hold Few Reasons to Relax About New Warming

In each case, the forecasts behind the headlines were made with a high degree of confidence.

In the mid-1970s, there was a political debate raging about whether the global climate was changing. The United States' National Defense University (NDU) addressed this issue in their book, *Climate Change to the Year* 2000 (NDU 1978). This study involved nine man-years of effort by the Department of Defense and other agencies, aided by experts who received honoraria, and a contract of nearly $400,000 (in 2007 dollars). The heart of the study was a survey of experts. The experts were provided with a chart of "annual mean temperature, 0-80^0 N. latitude," that showed temperature rising from 1870 to early 1940 then dropping sharply until 1970. The conclusion, based primarily on 19 replies weighted by the study directors, was that while a slight increase in temperature might occur, uncertainty was so high that "the next twenty years will be similar to that of the past" and the effects of any change would be negligible. Clearly, this was a forecast by scientists, not a scientific forecast. However, it proved to be quite influential. The report was discussed in The Global 2000 Report to the President (Carter) and at the World Climate Conference in Geneva in 1979.

The methodology for climate forecasting used in the past few decades has shifted from surveys of experts' opinions to the use of computer models. Reid Bryson, the world's most cited climatologist, wrote in a 1993 article that a model is "*nothing more* than a formal statement of how the modeler believes that the part of the world of his concern actually works" (p. 798-790). Based on the explanations of climate models that we have seen, we concur. While advocates of complex climate models claim that they are based on "well established laws of physics", there is clearly much more to the models than the laws of physics otherwise they would all produce the same output, which patently they do not. And there would be no need for confidence estimates for model forecasts, which there most certainly are. Climate models are, in effect, mathematical ways for the experts to express their opinions.

To our knowledge, there is no empirical evidence to suggest that presenting opinions in mathematical terms rather than in words will contribute to forecast accuracy. For example, Keepin and Wynne (1984) wrote in the summary of their study of the International Institute for Applied Systems Analysis's "widely acclaimed" projections for global energy that "Despite the appearance of analytical rigor… [they] are highly unstable and based on informal guesswork." Things have changed little since the days of Malthus in the 1800s. Malthus forecast mass starvation. He expressed his opinions mathematically. His mathematical model predicted that the supply of food would increase arithmetically while the human population grew at a geometric rate and went hungry.

International surveys of climate scientists from 27 countries, obtained by Bray and von Storch in 1996 and 2003, were summarized by Bast and Taylor (2007). Many scientists were skeptical about the predictive validity of climate models. Of more than 1,060 respondents, 35% agreed with the statement, "Climate models can accurately predict future climates," and 47% percent disagreed. Members of the general public were also divided. An Ipsos Mori poll of 2,031 people aged 16 and over found that 40% agreed that "climate change was too complex and uncertain for scientists to make useful forecasts" while 38% disagreed (Eccleston 2007).

AN EXAMINATION OF CLIMATE FORECASTING METHODS

We assessed the extent to which those who have made climate forecasts used evidence-based forecasting procedures. We did this by conducting Google searches. We then conducted a "forecasting audit" of the forecasting process behind the IPCC forecasts. The key tasks of a forecasting audit are to:

- examine all elements of the forecasting process,
- use principles that are supported by evidence (or are self-evidently true and unchallenged by evidence) against which to judge the forecasting process,
- rate the forecasting process against each principle, preferably using more than one independent rater,
- disclose the audit.

To our knowledge, no one has ever published a paper that is based on a forecasting audit, as defined here. We suggest that for forecasts involving important public policies, such audits should be expected and perhaps even-required. In addition, they should be fully disclosed with respect to who did the audit, what biases might be involved, and what were the detailed findings from the audit.

REVIEWS OF CLIMATE FORECASTS

We could not find any *comprehensive* reviews of climate forecasting efforts. With the exception of Stewart and Glantz (1985), the reviews did not refer to evidence-based findings. None of the reviews provided explicit ratings of the processes and, again with the exception of Stewart and Glantz, little attention was given to full disclosure of the reviewing process. Finally, some reviews ignored the forecasting methods and focused on the accuracy of the forecasts.

Stewart and Glantz (1985) conducted an audit of the National Defense University (NDU 1978) forecasting process that we described above. They were critical of the report because it lacked an awareness of proper forecasting methodology. Their audit was hampered because the organizers of the study said that the raw data had been destroyed and a request to the Institute for the Future about the sensitivity of the forecasts to the weights went unanswered. Judging from a Google Scholar search, climate forecasters have paid little attention to this paper.

In a wide-ranging article on the broad topic of science and the environment, Bryson (1993) was critical of the use of models for forecasting climate. He wrote:

> …it has never been demonstrated that the GCMs [General Circulation Models] are capable of prediction with any level of accuracy. When a modeler says that his model shows that doubling the carbon dioxide in the atmosphere will raise the global average temperature two to three degrees Centigrade, he really means that a simulation of the present global temperature with current carbon dioxide levels yields a mean value two to three degrees Centigrade lower than his model simulation with doubled carbon dioxide. This implies, though it rarely appears in the news media, that the error in simulating the present will be unchanged in simulating the future case with doubled carbon dioxide. That has never been demonstrated—it is faith rather than science.” (pp. 790-791)

Balling (2005), Christy (2005), Frauenfeld (2005), and Posmentier and Soon (2005) each assess different aspects of the use of climate models for forecasting and each comes to broadly the same conclusion: The models do not represent the real world sufficiently well to be relied upon for forecasting.

Carter, et al. (2006) examined the *Stern Review* (Stern 2007). They concluded that the authors of the *Review* made predictions without reference to scientific validation and without proper peer review.

Pilkey and Pilkey-Jarvis (2007) examined long-term climate forecasts and concluded that they were based only on the opinions of the scientists. The scientists' opinions were expressed in complex mathematical terms without evidence on the validity of chosen approach. The authors provided the following quotation on their page 45 to summarize their assessment: "Today's scientists have substituted mathematics for experiments, and they wander off through equation after equation and eventually build a structure which has no relation to reality (Nikola Telsa, inventor and electrical engineer, 1934)." While it is sensible to be explicit about beliefs and to formulate these in a model, forecasters must also demonstrate that the relationships are valid.

Carter (2007) examined evidence on the predictive validity of the general circulation models (GCMs) used by the IPCC scientists. He found that while the models included some basic principles of physics, scientists had to make "educated guesses" about the values of many parameters because knowledge about the physical processes of the earth's climate is incomplete. In practice, the GCMs failed to predict recent global average temperatures as accurately as simple curve-fitting approaches (Carter 2007, pp. 64 – 65). They also forecast greater warming at higher altitudes in the tropics when the opposite has been the case (p. 64). Further, individual GCMs produce widely different forecasts from the same initial conditions and minor changes in parameters can result in forecasts of global cooling (Essex and McKitrick, 2002). Interestingly, when models predict global cooling, the forecasts are often rejected as "outliers" or "obviously wrong" (e.g., Stainforth et al., 2005).

Roger Pielke Sr. (Colorado State Climatologist, until 2006) gave an assessment of climate models in a 2007 interview (available via http://tinyurl.com/2wpk29):

> You can always reconstruct after the fact what happened if you run enough model simulations. The challenge is to run it on an independent dataset, say for the next five years. But then they will say "the model is not good for five years because there is too much noise in the system". That's avoiding the issue then. They say you have to wait 50 years, but then you can't validate the model, so what good is it?
>
> …Weather is very difficult to predict; climate involves weather plus all these other components of the climate system, ice, oceans, vegetation, soil etc. Why should we think we can do better with climate prediction than with weather prediction? To me it's obvious, we can't!
>
> I often hear scientists say "weather is unpredictable, but climate you can predict because it is the average weather". How can they prove such a statement?

In his assessment of climate models, physicist Freeman Dyson (2007) wrote:

> I have studied the climate models and I know what they can do. The models solve

> the equations of fluid dynamics, and they do a very good job of describing the fluid motions of the atmosphere and the oceans. They do a very poor job of describing the clouds, the dust, the chemistry and the biology of fields and farms and forests. They do not begin to describe the real world that we live in.

Bellamy and Barrett (2007) found serious deficiencies in the general circulation models described in the IPCC's *Third Assessment Report*. In particular, the models (1) produced very different distributions of clouds and none was close the actual distribution of clouds, (2) parameters for incoming radiation absorbed by the atmosphere and for that absorbed by the Earth's surface varied considerably, (3) did not accurately represent what is known about the effects of CO_2 and could not represent the possible positive and negative feedbacks about which there is great uncertainty. The authors concluded:

> The climate system is a highly complex system and, to date, no computer models are sufficiently accurate for their predictions of future climate to be relied upon. (p. 72)

Trenberth (2007), a lead author of Chapter 3 in the IPCC WG1 report wrote in a *Nature.com* blog "… the science is not done because we do not have reliable or regional predictions of climate."

Taylor (2007) compared seasonal forecasts by New Zealand's National Institute of Water and Atmospheric Research (NIWA) with outcomes for the period May 2002 to April 2007. He found NIWA's forecasts of average regional temperatures for the season ahead were 48% correct, which was no more accurate than chance. That this is a general result was confirmed by New Zealand climatologist Jim Renwick, who observed that NIWA's low success rate was comparable to that of other forecasting groups worldwide. He added that "Climate prediction is hard, half of the variability in the climate system is not predictable, and so we don't expect to do terrifically well." Renwick is a co-author with Working Group I of the IPCC 4th Assessment Report, and also serves on the World Meteorological Organization Commission for Climatology Expert Team on Seasonal Forecasting. His expert view is that current GCM climate models are unable to predict future climate any better than chance (New Zealand Climate Science Coalition 2007).

Similarly, Vizard, Anderson, and Buckley (2005) found seasonal rainfall forecasts for Australian townships were insufficiently accurate to be useful to intended consumers such as farmers planning for feed requirements. The forecasts were released only 15 days ahead of each three month period.

A SURVEY TO IDENTIFY THE MOST CREDIBLE LONG-TERM FORECASTS OF GLOBAL TEMPERATURE

We surveyed scientists involved in long-term climate forecasting and policy makers. Our primary concern was to identify the most important forecasts and how those forecasts were made. In particular, we wished to know if the most widely accepted forecasts of global average temperature were based on the opinions of experts or were derived using scientific forecasting methods. Given the findings of our review of reviews of climate forecasting and the conclusion from our Google search that many scientists are unaware of evidence-based findings related to forecasting methods, we expected that the forecasts would be based on the opinions of scientists.

We sent a questionnaire to experts who had expressed diverse opinions on global warming. We generated lists of experts by identifying key people and asking them to identify others. (The lists are provided in Appendix A.) Most (70%) of the 240 experts on our lists were IPCC reviewers and authors.

Our questionnaire asked the experts to provide references for what they regarded as the most credible source of long-term forecasts of mean global temperatures. We strove for simplicity to minimize resistance to our request. Even busy people should have time to send a few references, especially if they believe that it is important to evaluate the quality of the forecasts that may influence major decisions. We asked:

> "We want to know which forecasts people regard as the most credible and how those forecasts were derived…
>
> In your opinion, which scientific article is the source of the most credible forecasts of global average temperatures over the rest of this century?"

We received useful responses from 51 of the 240 experts, 42 of whom provided references to what they regarded as credible sources of long-term forecasts of mean global temperatures. Interestingly, eight respondents provided references in support of their claims that no credible forecasts exist. Of the 42 expert respondents who were associated with global warming views, 30 referred us to the IPCC's report. A list of the papers that were suggested by respondents is provided at publicpolicyforecasting.com in the "Global Warming" section.

Based on the replies to our survey, it was clear that the IPCC's Working Group 1 Report contained the forecasts that are viewed as most credible by the bulk of the climate forecasting community. These forecasts are contained in Chapter 10 of the Report and the models that are used to forecast climate are assessed in Chapter 8, "Climate Models and Their Evaluation" (Randall et al. 2007). Chapter 8 provided the most useful information on the forecasting process used by the IPCC to derive forecasts of mean global temperatures, so we audited that chapter.

We also posted calls on email lists and on the forecastingprinciples.com site asking for help from those who might have any knowledge about scientific climate forecasts. This yielded few responses, only one of which provided relevant references.

Does the IPCC report provide climate forecasts?

Trenberth (2007) and others have claimed that the IPCC does not provide forecasts but rather presents "scenarios" or "projections." As best as we can tell, these terms are used by the IPCC authors to indicate that they provide "conditional forecasts." Presumably the IPCC authors hope that readers, especially policy makers, will find at least one of their conditional forecast series plausible and will act as if it will come true if no action is taken. As it happens, the word "forecast" and its derivatives occurred 37 times, and "predict" and its derivatives occurred 90 times in the body of

Chapter 8. Recall also that most of our respondents (29 of whom were IPCC authors or reviewers) nominated the IPCC report as the most credible source of forecasts (not "scenarios" or "projections") of global average temperature. We conclude that the IPCC does provide forecasts.

A FORECASTING AUDIT FOR GLOBAL WARMING

In order to audit the forecasting processes described in Chapter 8 of the IPCC's report, we each read it prior to any discussion. The chapter was, in our judgment, poorly written. The writing showed little concern for the target readership. It provided extensive detail on items that are of little interest in judging the merits of the forecasting process, provided references without describing what readers might find, and imposed an incredible burden on readers by providing 788 references. In addition, the Chapter reads in places like a sales brochure. In the three-page executive summary, the terms, "new" and "improved" and related derivatives appeared 17 times. Most significantly, the chapter omitted key details on the assumptions and the forecasting process that were used. If the authors used a formal structured procedure to assess the forecasting processes, this was not evident.

We each made a formal, independent audit of IPCC Chapter 8 in May 2007. To do so, we used the Forecasting Audit Software on the forecastingprinciples.com site, which is based on material originally published in Armstrong (2001). To our knowledge, it is the only evidence-based tool for evaluating forecasting procedures.

While Chapter 8 required many hours to read, it took us each about one hour, working independently, to rate the forecasting approach described in the Chapter using the Audit software. We have each been involved with developing the Forecasting Audit program, so other users would likely require much more time.

Ratings are on a 5-point scale from -2 to +2. A rating of +2 indicates the forecasting procedures were consistent with a principle, and a rating of -2 indicates failure to comply with a principle. Sometimes some aspects of a procedure are consistent with a principle but others are not. In such cases, the rater must judge where the balance lays. The Audit software also has options to indicate that there is insufficient information to rate the procedures or that the principle is not relevant to a particular forecasting problem.

Reliability is an issue with rating tasks. For that reason, it is desirable to use two or more raters. We sent out general calls for experts to use the Forecasting Audit Software to conduct their own audits and we also asked a few individuals to do so. At the time of writing, none have done so.

Our initial overall average ratings were similar at -1.37 and -1.35. We compared our ratings for each principle and discussed inconsistencies. In some cases we averaged the ratings, truncating toward zero. In other cases we decided that there was insufficient information or that the information was too ambiguous to rate with confidence. Our final ratings are fully disclosed in the Special Interest Group section of the forecastingprinciples.com site that is devoted to Public Policy (publicpolicyforecasting.com) under Global Warming.

Of the 140 principles in the Forecasting Audit, we judged that 127 were relevant for auditing the forecasting procedures described in Chapter 8. The Chapter provided insufficient information to rate the forecasting procedures that were used against 38 of

Table 1. Clear Violations

Setting Objectives
- Describe decisions that might be affected by the forecast.
- Prior to forecasting, agree on actions to take assuming different possible forecasts.
- Make sure forecasts are independent of politics.
- Consider whether the events or series can be forecasted.

Identifying Data Points
- Avoid biased data sources.

Collecting Data
- Use unbiased and systematic procedures to collect data.
- Ensure that information is reliable and that measurement error is low.
- Ensure that the information is valid.

Selecting Methods
- List all important selection criteria before selecting methods.
- Ask unbiased experts to rate potential methods.
- Select simple methods unless empirical evidence calls for a more complex approach.
- Compare track records of various forecasting methods.
- Assess acceptability and understandability of methods to users
- Examine the value of alternative forecasting methods.

Implementing Methods: General
- Keep forecasting methods simple.
- Be conservative in situations of high uncertainty or instability.

Implementing Quantitative Methods
- Tailor the forecasting model to the horizon.
- Do not use "fit" to develop the model.

Implementing Methods: Quantitative Models with Explanatory Variables
- Apply the same principles to forecasts of explanatory variables.
- Shrink the forecasts of change if there is high uncertainty for predictions of the explanatory variables.

Integrating Judgmental and Quantitative Methods
- Use structured procedures to integrate judgmental and quantitative methods.
- Use structured judgments as inputs of quantitative models.
- Use prespecified domain knowledge in selecting, weighing, and modifying quantitative models.

Combining Forecasts
- Combine forecasts from approaches that differ.
- Use trimmed means, medians, or modes.
- Use track records to vary the weights on component forecasts.

Evaluating Methods
- Compare reasonable methods.
- Tailor the analysis to the decision.
- Describe the potential biases of the forecasters.
- Assess the reliability and validity of the data.
- Provide easy access to the data.
- Provide full disclosure of methods.
- Test assumptions for validity.
- Test the client's understanding of the methods.
- Use direct replications of evaluations to identify mistakes.
- Replicate forecast evaluations to assess their reliability.
- Compare forecasts generated by different methods.
- Examine all important criteria.
- Specify criteria for evaluating methods prior to analyzing data.
- Assess face validity.
- Use error measures that adjust for scale in the data.
- Ensure error measures are valid.
- Use error measures that are not sensitive to the degree of difficulty in forecasting.
- Avoid error measures that are highly sensitive to outliers.
- Use out of sample (ex-ante) error measures.
- (Revised) Tests of statistical significance should not be used.
- Do not use root mean square error (RMSE) to make comparisons among forecasting methods.
- Base comparisons of methods on large samples of forecasts.
- Conduct explicit cost-benefit analysis.

Assessing Uncertainty
- Use objective procedures to estimate explicit prediction.
- Develop prediction intervals by using empirical estimates based on realistic representations of forecasting situations.
- When assessing PIs, list possible outcomes and assess their likelihoods.
- Obtain good feedback about forecast accuracy and the reasons why errors occurred.
- Combine prediction intervals from alternative forecast methods.
- Use safety factors to adjust for overconfidence in PIs.

Presenting Forecasts
- Present forecasts and supporting data in a simple and understandable form.
- Provide complete, simple, and clear explanations of methods.
- Present prediction intervals.

Learning That Will Improve Forecasting Procedures
- Establish a formal review process for forecasting methods.
- Establish a formal review process to ensure that forecasts are used properly.

these 127 principles. For example, we did not rate the Chapter against Principle 10.2: "Use all important variables." At least in part, our difficulty in auditing the Chapter was due to the fact that it was abstruse. It was sometimes difficult to know whether the information we sought was present or not.

Of the 89 forecasting principles that we were able to rate, the Chapter violated 72. Of these, we agreed that there were clear violations of 60 principles. Principle 1.3 "Make sure forecasts are independent of politics" is an example of a principle that is clearly violated by the IPCC process. This principle refers to keeping the forecasting process separate from the planning process. The term "politics" is used in the broad sense of the exercise of power. David Henderson, a former Head of Economics and Statistics at the OECD, gave a detailed account of how the IPCC process is directed by non-scientists who have policy objectives and who believe that anthropogenic global warming is real and dangerous (Henderson 2007). The clear violations we identified are listed in Table 1.

We also found 12 "apparent violations". These principles, listed in Table 2, are ones for which one or both of us had some concerns over the coding or where we did not agree that the procedures clearly violated the principle.

Table 2. Apparent Violations

Setting Objectives
- Obtain decision makers' agreement on methods.

Structuring the Problem
- Identify possible outcomes prior to making forecast.
- Decompose time series by level and trend.

Identifying Data Sources
- Ensure the data match the forecasting situation.
- Obtain information from similar (analogous) series or cases. Such information may help to estimate trends.

Implementing Judgmental Methods
- Obtain forecasts from heterogeneous experts.

Evaluating Methods
- Design test situations to match the forecasting problem.
- Describe conditions associated with the forecasting problem.
- Use multiple measures of accuracy.

Assessing Uncertainty
- Do not assess uncertainty in a traditional (unstructured) group meeting.
- Incorporate the uncertainty associated with the prediction of the explanatory variables in the prediction intervals.

Presenting Forecasts
- Describe your assumptions.

Finally, we lacked sufficient information to make ratings on many of the relevant principles. These are listed in Table 3.

Table 3. Lack of Information

Structuring the Problem
- Tailor the level of data aggregation (or segmentation) to the decisions.
- Decompose the problem into parts.
- Decompose time series by causal forces.
- Structure problems to deal with important interactions among causal variables.
- Structure problems that involve causal chains.

Identifying Data Sources
- Use theory to guide the search for information on explanatory variables.

Collecting Data
- Obtain all the important data.
- Avoid collection of irrelevant data.

Preparing Data
- Clean the data.
- Use transformations as required by expectations.
- Adjust intermittent series.
- Adjust for unsystematic past events.
- Adjust for systematic events.
- Use graphical displays for data.

Implementing Methods: General
- Adjust for events expected in the future.
- Pool similar types of data.
- Ensure consistency with forecasts of related series and related time periods.

Implementing Judgmental Methods
- Ask experts to justify their forecasts in writing.
- Obtain forecasts from enough respondents.
- Obtain multiple forecasts of an event from each expert.

Implementing Quantitative Methods
- Match the model to the underlying phenomena.
- Weigh the most relevant data more heavily.
- Update models frequently.

Implementing Methods: Quantitative Models with Explanatory Variables
- Use all important variables.
- Rely on theory and domain expertise when specifying directions of relationships.
- Use theory and domain expertise to estimate or limit the magnitude of relationships.
- Use different types of data to measure a relationship.
- Forecast for alternative interventions.

Integrating Judgmental and Quantitative Methods
- Limit subjective adjustments of quantitative forecasts.

Combining Forecasts
- Use formal procedures to combine forecasts.
- Start with equal weights.
- Use domain knowledge to vary weights on component forecasts.

Table 3. ***continued***

Evaluating Methods
- Use objective tests of assumptions.
- Avoid biased error measures.
- Do not use R-square (either standard or adjusted) to compare forecasting models.

Assessing Uncertainty
- Ensure consistency of the forecast horizon.
- Ask for a judgmental likelihood that a forecast will fall within a pre-defined minimum-maximum interval.

Learning That Will Improve Forecasting Procedures
- Seek feedback about forecasts.

Some of these principles might be surprising to those who have not seen the evidence—"Do not use R-square (either standard or adjusted) to compare forecasting models." Others are principles that any scientific paper should be expected to address—"Use objective tests of assumptions." Many of these principles are important for climate forecasting, such as "Limit subjective adjustments of quantitative forecasts."

Some principles are so important that any forecasting process that does not adhere to them cannot produce valid forecasts. We address four such principles, all of which are based on strong empirical evidence. All four of these key principles were violated by the forecasting procedures described in IPCC Chapter 8.

Consider whether the events or series can be forecasted (Principle 1.4)

This principle refers to whether a forecasting method can be used that would do better than a naïve method. A common naïve method is to assume that things will not change.

Interestingly, naïve methods are often strong competitors with more sophisticated alternatives. This is especially so when there is much uncertainty. To the extent that uncertainty is high, forecasters should emphasize the naïve method. (This is illustrated by regression model coefficients: when uncertainty increases, the coefficients tend towards zero.) Departures from the naïve model tend to increase forecast error when uncertainty is high.

In our judgment, the uncertainty about global mean temperature is extremely high. We are not alone. Dyson (2007), for example, wrote in reference to attempts to model climate that "The real world is muddy and messy and full of things that we do not yet understand." There is even controversy among climate scientists over something as basic as the current trend. One researcher, Carter (2007, p. 67) wrote:

> …the slope and magnitude of temperature trends inferred from time-series data depend upon the choice of data end points. Drawing trend lines through highly variable, cyclic temperature data or proxy data is therefore a dubious exercise. Accurate direct measurements of tropospheric global average temperature have only been available since 1979, and they show no evidence for greenhouse warming. Surface thermometer data, though flawed, also show temperature stasis since 1998.

Global climate is complex and scientific evidence on key relationships is weak or absent. For example, does increased CO_2 in the atmosphere cause high temperatures or do high temperatures increase CO_2? In opposition to the major causal role assumed for CO_2 by the IPCC authors (Le Treut et al. 2007), Soon (2007) presents evidence that the latter is the case and that CO_2 variation plays at most a minor role in climate change.

Measurements of key variables such as local temperatures and a representative global temperature are contentious and subject to revision in the case of modern measurements because of inter alia the distribution of weather stations and possible artifacts such as the urban heat island effect, and are often speculative in the case of ancient ones, such as those climate proxies derived from tree ring and ice-core data (Carter 2007).

Finally, it is difficult to forecast the causal variables. Stott and Kettleborough (2002, p. 723) summarize:

> Even with perfect knowledge of emissions, uncertainties in the representation of atmospheric and oceanic processes by climate models limit the accuracy of any estimate of the climate response. Natural variability, generated both internally and from external forcings such as changes in solar output and explosive volcanic eruptions, also contributes to the uncertainty in climate forecasts.

The already high level of uncertainty rises rapidly as the forecast horizon increases.

While the authors of Chapter 8 claim that the forecasts of global mean temperature are well-founded, their language is imprecise and relies heavily on such words as "generally," "reasonable well," "widely," and "relatively" [to what?]. The Chapter makes many explicit references to uncertainty. For example, the phrases ". . . it is not yet possible to determine which estimates of the climate change cloud feedbacks are the most reliable" and "Despite advances since the TAR, substantial uncertainty remains in the magnitude of cryospheric feedbacks within AOGCMs" appear on p. 593. In discussing the modeling of temperature, the authors wrote, "The extent to which these systematic model errors affect a model's response to external perturbations is unknown, but may be significant" (p. 608), and, "The diurnal temperature range… is generally too small in the models, in many regions by as much as 50%" (p. 609), and "It is not yet known why models generally underestimate the diurnal temperature range." The following words and phrases appear at least once in the Chapter: unknown, uncertain, unclear, not clear, disagreement, not fully understood, appears, not well observed, variability, variety, unresolved, not resolved, and poorly understood.

Given the high uncertainty regarding climate, the appropriate naïve method for this situation would be the "no-change" model. Prior evidence on forecasting methods suggests that attempts to improve upon the naïve model might increase forecast error. To reverse this conclusion, one would have to produce validated evidence in favor of alternative methods. Such evidence is not provided in Chapter 8 of the IPCC report.

We are not suggesting that we know for sure that long-term forecasting of climate is impossible, only that this has yet to be demonstrated. Methods consistent with forecasting principles such as the naïve model with drift, rule-based forecasting, well-specified simple causal models, and combined forecasts might prove useful. The methods are discussed in Armstrong (2001). To our knowledge, their application to long-term climate forecasting has not been examined to date.

Keep forecasting methods simple (Principle 7.1)

We gained the impression from the IPPC chapters and from related papers that climate forecasters generally believe that complex models are necessary for forecasting climate and that forecast accuracy will increase with model complexity. Complex methods involve such things as the use of a large number of variables in forecasting models, complex interactions, and relationships that employ nonlinear parameters. Complex forecasting methods are only accurate when there is little uncertainty about relationships now and in the future, where the data are subject to little error, and where the causal variables can be accurately forecast. These conditions do not apply to climate forecasting. Thus, simple methods are recommended.

The use of complex models when uncertainty is high is at odds with the evidence from forecasting research (e.g., Allen and Fildes 2001, Armstrong 1985, Duncan, Gorr and Szczypula 2001, Wittink and Bergestuen 2001). Models for forecasting variations in climate are not an exception to this rule. Halide and Ridd (2007) compared predictions of El Niño-Southern Oscillation events from a simple univariate model with those from other researchers' complex models. Some of the complex models were dynamic causal models incorporating laws of physics. In other words, they were similar to those upon which the IPCC authors depended. Halide and Ridd's simple model was better than all eleven of the complex models in making predictions about the next three months. All models performed poorly when forecasting further ahead.

The use of complex methods makes criticism difficult and prevents forecast users from understanding how forecasts were derived. One effect of this exclusion of others from the forecasting process is to reduce the chances of detecting errors.

Do not use fit to develop the model (Principle 9.3)

It was not clear to us to what extent the models described in Chapter 8 (or in Chapter 9 by Hegerl et al. 2007) are either based on, or have been tested against, sound empirical data. However, some statements were made about the ability of the models to fit historical data, after tweaking their parameters. Extensive research has shown that the ability of models to fit historical data has little relationship to forecast accuracy (See "Evaluating forecasting methods" in Armstrong 2001.) It is well known that fit can be improved by making a model more complex. The typical consequence of increasing complexity to improve fit, however, is to decrease the accuracy of forecasts.

Use out-of-sample (ex ante) error measures (Principle 13.26)

Chapter 8 did not provide evidence on the relative accuracy of *ex ante* long-term forecasts from the models used to generate the IPCC's forecasts of climate change. It would have been feasible to assess the accuracy of alternative forecasting methods for medium- to long-term forecasts by using "successive updating." This involves withholding data on a number of years, then providing forecasts for one-year ahead, then two-years ahead, and so on up to, say, 20 years. The actual years could be disguised during these validation procedures. Furthermore, the years could be reversed (without telling the forecasters) to assess back-casting accuracy. If, as is suggested by forecasting principles, the models were unable to improve on the accuracy of forecasts from the naïve method in such tests, there would be no reason to suppose that accuracy would improve for longer forecasts. "Evaluating forecasting methods" in Armstrong 2001 provides evidence on this principle.

SUMMARY OF AUDIT FINDINGS

Our ratings of the processes used to generate the forecasts presented in the IPCC report are provided on the Public Policy Forecasting Special Interest Group Page at forecastingprinciples.com. These ratings have been posted since the time that our paper was presented at the International Symposium on Forecasting in New York in late June 2007.

Prior to the publication of this paper, we invited other researchers, using messages to email lists and web sites, to replicate our audit by providing their own ratings. In addition, we asked for information about any relevant principles that have not been included in the Forecasting Audit. At the time of writing, we have received neither alternative ratings nor evidence for additional relevant principles.

The many violations provide further evidence that the IPCC authors were unaware of evidence-based principles for forecasting. If they were aware of them, it would have been incumbent on them to present evidence to justify their departures from the principles. They did not do so. We conclude that because the forecasting processes examined in Chapter 8 overlook scientific evidence on forecasting, the IPCC forecasts of climate change are not scientific.

We invite others to provide evidence-based audits of what they believe to be scientific forecasts relevant to climate change. These can be posted on web sites to ensure that readers have access to the audits. As with peer review, we will require all relevant information on the people who conduct the audits prior to posting the audits on publicpolicyforecasting.com.

Climate change forecasters and their clients should use the Forecasting Audit early and often. Doing so would help to ensure that they are using appropriate forecasting procedures. Outside evaluators should also be encouraged to conduct audits. The audit reports should be made available to both the sponsors of the study and the public by posting on an open web site such as publicpolicyforecasting.com.

CLIMATE FORECASTERS' USE OF THE SCIENTIFIC LITERATURE ON FORECASTING METHODS

Bryson (1993) wrote that while it is obvious that when a statement is made about what climate will result from a doubling CO_2 it is a forecast, "I have not yet heard, at any of the many environmental congresses and symposia that I have attended, a discussion of forecasting methodology applicable to the environment" (p. 791).

We looked for evidence that climate modelers relied on scientific studies on the proper use of forecasting methods. In one approach, in April and June 2007, we used the Advanced Search function of Google Scholar to get a general sense of the extent to which climate forecasters refer to scientific studies on forecasting. When we searched for "global warming" and "forecasting principles," we found no relevant sites. Nor did we find any relevant citations of "forecastingprinciples.com" and "global warming." Nor were there any relevant citations of the relevant-sounding paper, "Forecasting for Environmental Decision-Making" (Armstrong 1999) published in a book with a relevant title: *Tools to Aid Environmental Decision Making*. A search for "global warming" and the best selling textbook on forecasting methods (Makridakis et al. 1998) revealed two citations, neither related to the prediction of global mean temperatures. Finally, there were no citations of research on causal models (e.g., Allen and Fildes 2001).

Using the titles of the papers, we independently examined the references in Chapter 8 of the IPCC Report. The Chapter contained 788 references. Of these, none had any apparent relationship to forecasting methodology. Our examination was not difficult as most papers had titles such as, "Using stable water isotopes to evaluate basin-scale simulations of surface water budgets," and, "Oceanic isopycnal mixing by coordinate rotation."

Finally, we examined the 23 papers that we were referred to by our survey respondents. These included Chapter 10 of the IPCC Report (Meehl et al. 2007). One respondent provided references to eight papers all by the same author (Abdussamatov). We obtained copies of three of those papers and abstracts of three others and found no evidence that the author had referred to forecasting research. Nor did any of the remaining 15 papers include any references to research on forecasting.

We also examined the 535 references in Chapter 9. Of these, 17 had titles that suggested the article might be concerned at least in part with forecasting methods. When we inspected the 17 articles, we found that none of them referred to the scientific literature on forecasting methods.

It is difficult to understand how scientific forecasting could be conducted without reference to the research literature on how to make forecasts. One would expect to see empirical justification for the forecasting methods that were used. We concluded that climate forecasts are informed by the modelers' experience and by their models—but that they are unaided by the application of forecasting principles.

CONCLUSIONS

To provide forecasts of climate change that are useful for policy-making, one would need to prepare forecasts of (1) temperature changes, (2) the effects of any temperature changes, and (3) the effects of feasible proposed policy changes. To justify policy changes based on climate change, policy makers need scientific forecasts for all three forecasting problems. If governments implement policy changes without such justification, they are likely to cause harm.

We have shown that failure occurs with the first forecasting problem: predicting temperature over the long term. Specifically, we have been unable to find a scientific forecast to support the currently widespread belief in "global warming." Climate is complex and there is much uncertainty about causal relationships and data. Prior research on forecasting suggests that in such situations a naïve (no change) forecast would be superior to current predictions. Note that recommending the naïve forecast does not mean that we believe that climate will not change. It means that we are not convinced that current knowledge about climate is sufficient to make useful long-term forecasts about climate. Policy proposals should be assessed on that basis.

Based on our literature searches, those forecasting long-term climate change have no apparent knowledge of evidence-based forecasting methods, so we expect that similar conclusions would apply to the other two necessary parts of the forecasting problem.

Many policies have been proposed in association with claims of global warming. It is not our purpose in this paper to comment on specific policy proposals, but it should be noted that policies may be valid regardless of future climate changes. To assess this, it would be necessary to directly forecast costs and benefits assuming that climate does not change or, even better, to forecasts costs and benefits under a range of possible future climates.

Public policy makers owe it to the people who would be affected by their policies to base them on scientific forecasts. Advocates of policy changes have a similar obligation. We hope that in the future, climate scientists with diverse views will embrace forecasting principles and will collaborate with forecasting experts in order to provide policy makers with scientific forecasts of climate.

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REFERENCES

Allen, P.G. and Fildes, R. (2001). Econometric Forecasting in Armstrong, J.S. ed. *Principles of Forecasting: A Handbook for Researchers and Practitioners*. Norwell, MA: Kluwer.

Anderson, R.W. and Gainor, D. (2006). Fire and Ice: Journalists have warned of climate change for 100 years, but can't decide weather we face an ice age or warming. Business and Media Institute, May 17. Available at http://www.businessandmedia.org/specialreports/2006/fireandice/FireandIce.pdf

Armstrong, J.S. (1980). The Seer-Sucker theory: The value of experts in forecasting. *Technology Review,* 83 (June-July), 16-24.

Armstrong, J.S. (1978; 1985). *Long-Range Forecasting: From Crystal Ball to Computer.* New York: Wiley-Interscience.

Armstrong, J.S. (1999). Forecasting for environmental decision-making, in Dale, V.H. and English, M.E. eds., *Tools to Aid Environmental Decision Making*. New York: Springer-Verlag, 192-225.

Armstrong, J.S. (2001). *Principles of Forecasting: A Handbook for Researchers and Practitioners*. Kluwer Academic Publishers.

Armstrong, J.S. (2006). Findings from evidence-based forecasting: Methods for reducing forecast error. *International Journal of Forecasting*, 22, 583-598.

Ascher W. (1978). *Forecasting: An Appraisal for Policy Makers and Planners*. Baltimore:

Johns Hopkins University Press.

Balling, R. C. (2005). Observational surface temperature records versus model predictions, In Michaels, P. J. ed. *Shattered Consensus: The True State of Global Warming*. Lanham, MD: Rowman & Littlefield, 50-71.

Bast, J. and Taylor, J.M. (2007). *Scientific consensus on global warming*. The Heartland Institute: Chicago, Illinois. Available at http://downloads.heartland.org/20861.pdf. [The responses to all questions in the 1996 and 2003 surveys by Bray and von Storch are included as an appendix.]

Bellamy, D. and Barrett, J. (2007). Climate stability: an inconvenient proof. *Proceedings of the Institution of Civil Engineers – Civil Engineering, 160*, 66-72.

Bryson, R.A. (1993). Environment, environmentalists, and global change: A skeptic's evaluation, *New Literary History*, 24, 783-795.

Carter, R.M. (2007). The myth of dangerous human-caused climate change. The Aus/MM New Leaders Conference, Brisbane May 3, 2007. Available at http://members.iinet.net.au/~glrmc/new_page_1.htm

Carter, R.M., de Freitas, C.R., Goklany, I.M., Holland, D. and Linzen, R.S. (2006). The Stern review: A dual critique: Part 1. *World Economics*, *7*, 167-198.

Cerf, C. and Navasky, V. (1998). *The Experts Speak*. New York: Pantheon. Baltimore, MD: Johns Hopkins University Press.

Christy, J. (2005). Temperature Changes in the Bulk Atmosphere: Beyond the IPCC, In Michaels, P. J. ed. *Shattered Consensus: The True State of Global Warming*. Lanham, MD: Rowman & Littlefield, 72-105.

Craig, P.P., Gadgil, A., and Koomey, J.G. (2002). What can history teach us? A retrospective examination of long-term energy forecasts for the United States. *Annual Review of Energy and the Environment, 27*, 83-118.

Dyson, F. (2007). Heretical thoughts about science and society. *Edge: The Third Culture*, 08/08/07. Available at http://www.edge.org/3rd_culture/dysonf07/dysonf07_index.html

Duncan, G. T., Gorr W. L. and Szczypula, J. (2001). Forecasting Analogous Time Series, in Armstrong, J. S. ed. *Principles of Forecasting: A Handbook for Researchers and Practitioners*. Norwell, MA: Kluwer.

Eccleston, P. (2007). Public 'in denial' about climate change. *telegraph.co.uk*, 12:01 BST 03/07/2007. Available at http://www.telegraph.co.uk/core/Content/displayPrintable.jhtml;jse...MGSFFOAVCBQWIV0?xml=/earth/2007/07/03/eawarm103.xml&site=30&page=0

Essex, C., McKitrick, R. and Andresen, B. (2007). Does a global temperature exist? *Journal of Non-Equilibrium Thermodynamics*, *32*, 1-27. Working paper available at http://www.uoguelph.ca/~rmckitri/research/globaltemp/globaltemp.html

Essex, C. and McKitrick, R. (2002). *Taken by Storm. The Troubled Science, Policy & Politics of Global Warming*, Toronto: Key Porter Books.

Frauenfeld, O.W. (2005). Predictive Skill of the El Nino-Southern Oscillation and Related

Atmospheric Teleconnections, In Michaels, P.J. ed. *Shattered Consensus: The True State of Global Warming*. Lanham, MD: Rowman & Littlefield, 149-182.

Henderson, D. (2007). Governments and climate change issues: The case for rethinking. *World Economics*, 8, 183-228.

Halide, H. and Ridd, P. (2007). Complicated ENSO models do not significantly outperform very simple ENSO models. *International Journal of Climatology*, in press.

Hegerl, G.C., Zwiers, F.W., Braconnot, P., Gillett, N.P., Luo, Y., Marengo Orsini, J.A., Nicholls, N., Penner, J.E. and Stott, P.A. (2007). Understanding and Attributing Climate Change, in Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (eds.), *Climate Change 2007: The Physical Science Basis*. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Keepin, B. and Wynne, B. (1984). Technical analysis of IIASA energy scenarios. *Nature*, 312, 691-695.

Le Treut, H., Somerville, R., Cubasch, U., Ding, Y., Mauritzen, C., Mokssit, A., Peterson, T. and Prather, M. (2007). Historical Overview of Climate Change, in Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (eds.), *Climate Change 2007: The Physical Science Basis*. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Makridakis, S., Wheelwright, S.C., and Hyndman, R.J. (1998). *Forecasting: Methods and Applications* (3rd ed.), Hoboken, NJ: John Wiley.

NDU (1978). *Climate Change to the Year 2000*. Washington, D.C.: National Defense University.

New Zealand Climate Science Coalition (2007). World climate predictors right only half the time. Media release 7 June. Available at http://www.scoop.co.nz/stories/SC0706/S00026.htm

Pilkey, O.H. and Pilkey-Jarvis, L. (2007). *Useless Arithmetic Why Environmental Scientists Can't predict the Future*. New York: Columbia University Press.

Posmentier, E. S. and Soon, W. (2005). Limitations of Computer Predictions of the Effects of Carbon Dioxide on Global Temperature, In Michaels, P. J. ed. *Shattered Consensus: The True State of Global Warming*. Lanham, MD: Rowman & Littlefield, 241-281.

Randall, D.A., Wood, R.A., Bony, S., Colman, R., Fichefet, T., Fyfe, J., Kattsov, V., Pitman, A., Shukla, J., Srinivasan, J., Stouffer, R. J., Sumi, A. and Taylor, K.E. (2007). Climate Models and Their Evaluation, in Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. eds., *Climate Change 2007: The Physical Science Basis*. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York, NY, USA: Cambridge University Press.

Schnaars, S.P. and Bavuso, R.J. (1986). Extrapolation models on very short-term forecasts. *Journal of Business Research*, 14, 27-36.

Soon, W. (2007). Implications of the secondary role of carbon dioxide and methane forcing in climate change: Past, present and future. *Physical Geography*, in press.

Stainforth, D.A., Aina, T., Christensen, C., Collins, M., Faull, N., Frame, D.J., Kettleborough, J.A., Knight, S., Martin, A., Murphy, J.M., Piani, C., Sexton, D., Smith, L.A., Spicer, R.A., Thorpe, A.J. and Allen, M.R. (2005). Uncertainty in predictions of the climate response to rising levels of greenhouse gases, *Nature*, *433*, 403-406.

Stern, N. (2007). *The Economics of Climate Change: The Stern Review*. New York: Cambridge University Press. Available from http://www.hmtreasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm

Stewart, T.R. and Glantz, M.H. (1985). Expert judgment and climate forecasting: A methodological critique of '*Climate Change to the Year 2000*'. *Climate Change*, 7, 159-183.

Stott, P.A. and Kettleborough, J.A. (2002). Origins and estimates of uncertainty in predictions of twenty-first century temperature rise, *Nature, 416*, 723-726.

Taylor, M. (2007). An evaluation of NIWA's climate predictions for May 2002 to April 2007. Climate Science Coalition. Available at http://www.climatescience.org.nz/assets/2007691051580.ClimateUpdateEvaluationText.pdf Data available at http://www.climatescience.org.nz/assets/2007691059100.ClimateUpdateEvaluationCalc.xls.pdf

Tetlock, P.E. (2005). *Expert Political Judgment: How Good Is It? How Can We Know?* Princeton, NJ: Princeton University Press.

Trenberth, K.E. (2007). Predictions of climate. *Climate Feedback: The Climate Change Blog, Nature.com*, June 4. Available at http://blogs.nature.com/climatefeedback/2007/06/predictions_of_climate.html

Vizard, A.L., Anderson, G.A., and Buckley, D.J. (2005). Verification and value of the Australian Bureau of Meteorology township seasonal rainfall forecasts in Australia, 1997-2005. *Meteorological Applications*, *12*, 343-355.

Wittink D., and Bergestuen T. (2001). Forecasting with Conjoint Analysis, in Armstrong, J.S. ed. *Principles of Forecasting: A Handbook for Researchers and Practitioners*. Norwell, MA: Kluwer.

APPENDIX A: PEOPLE TO WHOM WE SENT OUR QUESTIONNAIRE
(* indicates a relevant response)

IPCC Working Group 1

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Union of Concerned Scientists

Brenda Ekwurzel, Peter Frumhoff, Amy Lynd Luers

Channel 4 "The Great Global Warming Swindle" documentary (2007)
Bert Bolin, Piers Corbyn*, Eigil Friis-Christensen, James Shitwaki, Frederick Singer, Carl Wunsch*

Wikipedia's list of global warming "skeptics"
Khabibullo Ismailovich Abdusamatov*, Syun-Ichi Akasofu*, Sallie Baliunas, Tim Ball, Robert Balling*, Fred Barnes, Joe Barton, Joe Bastardi, David Bellamy, Tom Bethell, Robert Bidinotto, Roy Blunt, Sonja Boehmer, Andrew Bolt, John Brignell*, Nigel Calder, Ian Castles*, George Chilingarian, John Christy*, Ian Clark, Philip Cooney, Robert Davis, David Deming*, David Douglass, Lester Hogan, Craig Idso, Keith Idso, Sherwood Idso, Zbigniew Jaworowski, Wibjorn Karlen, William Kininmonth, Nigel Lawson, Douglas Leahey, David Legates, Richard Lindzen*, Ross Mckitrick*, Patrick Michaels, Lubos Motl*, Kary Mullis, Tad Murty, Tim Patterson, Benny Peiser*, Ian Plimer, Arthur Robinson, Frederick Seitz, Nir Shaviv, Fred Smith, Willie Soon, Thomas Sowell, Roy Spencer, Philip Stott, Hendrik Tennekes, Jan Veizer, Peter Walsh, Edward Wegman

Other sources
Daniel Abbasi, Augie Auer, Bert Bolin, Jonathan Boston, Daniel Botkin*, Reid Bryson, Robert Carter*, Ralph Chapman, Al Gore, Kirtland C. Griffin*, David Henderson, Christopher Landsea*, Bjorn Lomborg, Tim Osborn, Roger Pielke*, Henrik Saxe, Thomas Schelling*, Matthew Sobel, Nicholas Stern*, Brian Valentine*, Carl Wunsch*, Antonio Zichichi.