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Working Group (WG) I's Contribution to the IPCC's Fourth Assessment Report (AR4): A Critique

Executive Summary

This report reviews and critiques the findings contained in the Summary for Policymakers (SPM) of Working Group (WG) I's contribution to the Intergovernmental Panel on Climate Change (IPCC)'s Fourth Assessment Report (AR4) that are likely to attract the most attention. It draws on material from the final draft of the underlying WG I report and scientific literature that was either not considered or not given sufficient weight by WG I.

The Marshall Institute is commenting on eight findings in the WG I SPM which are most likely to receive the most attention. These findings, presented in the order in which they appear in the SPM, and our evaluation of them are summarized in the table on the following page.

Overall, it is clear that many of WG I's findings are not supported by their underlying report and are unduly alarmist.

Introduction

The Summary for Policymakers (SPM) of Working Group I (Science)'s contribution to the IPCC's Fourth Assessment Report (AR4) was finalized on February 1 and available on the WG I's website[1] shortly thereafter. The full report, which presents a detailed discussion of the science, is not available until May, but copies of the final draft (circulated for review last fall, but no longer officially available) are widely available on the Internet.[2] Inputs to IPCC reports are frozen long before the report is actually published to allow for final review by governments. Inputs to this WG I report were limited to literature published no later than July 2006. As a result, the report cannot reflect the latest contributions to the scientific literature.

In an effort to assist the public's evaluation of the strong claims of the SPM and the subsequent use of those conclusions by the media and public policymakers, this review draws on the approved SPM and the final draft of the underlying report, as well as scientific literature published before and after the WG I froze inputs to its report.

This critique will focus on the eight WG I findings that the Marshall Institute believes will attract the most attention. These findings are presented in the order they appear in WG I's SPM and include:

1. warming of the climate system is unequivocal;
2. losses from the ice sheets of Greenland and Antarctica have *very likely* contributed to sea level rise over 1993 to 2003;
3. the intensity of tropical cyclones in the North Atlantic since about 1970 has increased, correlated with increases of tropical sea surface temperatures;
4. paleoclimate information supports the interpretation that the warmth of the last half century is unusual in at least the last 1300 years;

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Table 1 – Critique of WGI Findings

Finding	Critique
Warming of the climate system is unequivocal.	There is no dispute that global average surface temperatures have risen over the past century. However, there are significant questions about the accuracy of temperature measurements, what caused the warming, and projections of its impacts.
Losses from the ice sheets of Greenland and Antarctica have *very likely* contributed to sea level rise over 1993 to 2003.	This conclusion does not seem justified by the information in the final draft of the underlying report, which states that ice loss from Greenland and Antarctica cannot be accurately estimated. Antarctica may have gained ice during the 1993-2003 period.
The intensity of tropical cyclones in the North Atlantic since about 1970 has increased, correlated with increases of tropical sea surface temperatures.	This conclusion has already been challenged in the scientific literature. It is not supported by a historical comparison prepared by William Gray, widely recognized for having developed the best predictive model for hurricane formation in the North Atlantic.
Paleoclimate information supports the interpretation that the warmth of the last half century is unusual in at least the last 1300 years.	The studies used to support this conclusion are not independent and have been heavily criticized for not making use of statistical expertise.
Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations.	WG I bases its finding on a comparison of results from unvalidated climate models, using uncertain input data, with a global temperature record of dubious quality.
Best estimates and likely ranges for globally average surface air warming between 1980-1999 and 2090-2099 for the six SRES emissions marker scenarios are given; the best estimate for the low scenario (B1) is 1.8 °C (3.2 °F), (*likely* range is 1.1 °C to 2.9 oC (2.0 °F to 5.2 °F), and the best estimate for the high scenario (A1FI) is 4.0 °C (7.2 °F), (*likely* range is 2.4 °C to 6.4 °C (4.3 °F to 11.5 °F).	WG I documents significant shortcomings in the models used to make these estimates. The SRES scenarios used as input to these models are based on the unrealistic assumption that no overt action will be taken to reduce greenhouse gas emissions. In addition the SRES scenarios, particularly the higher emission scenarios, have been criticized as unrealistic by a variety of evaluators, including a Select Committee of the UK House of Lords.
Global average sea level rise for 2090-2099 relative to 1980-1999 is estimated at 0.18 to 0.59 meters (7 to 23 inches) for the six SRES marker scenarios.[3]	Projections of sea level rise are developed from models of ocean thermal expansion and glacier and ice cap melting using projections of temperature rise as input. As such, estimates of sea level rise can be no better than the estimates of temperature rise, and in reality are poorer because of the uncertainties added by the additional level of modeling.
More extreme weather events and other impacts of climate change are *likely* or *very likely.*	WG I lists eight categories of extreme events and impacts of climate change which it projects as *likely* or *very likely*. Three of these, e.g., sea ice melting, are direct consequences of the warming WG I projects. Three more, e.g., greater warming over high northern latitudes, are extrapolations of the climate pattern of the past few decades. One, more intense tropical cyclones, is an extrapolation of WG I's questionable finding that hurricane intensity has increased in the North Atlantic since the 1970s. The last impact, that the Atlantic meridional overturning circulation will slow down, but not shut down, during the 21st century, is questionable because it is based on the assumption that temperature and salinity differences drive this circulation, when scientific evidence indicates that it is driven by the slow movement of the Moon away from the Earth.

5. most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations;
6. best estimates and likely ranges for globally average surface air warming between 1980-1999 and 2090-2099 for the six SRES emissions marker scenarios are given; the best estimate for the low scenario (B1) is 1.8 °C (*likely* range is 1.1 °C to 2.9 °C), and the best estimate for the high scenario (A1FI) is 4.0 °C (*likely* range is 2.4 °C to 6.4 °C);
7. global average sea level rise for 2090-2099 relative to 1980-1999 is estimated at 0.18 to 0.59 meters (7 to 23 inches) for the six SRES marker scenarios;
8. more extreme events are projected including:
   - more frequent hot events are *very likely;*
   - more intense hurricanes and typhoons are *likely*;
   - increased precipitation is *very likely* in high latitudes, decreases are *likely at low latitudes*, and
   - it is *very likely* that the meridional overturning circulations of the Atlantic Ocean will slow down during the 21st century, but *very unlikely* that it will shut down during that period.

The above findings contain a number of likelihood statements. These are one aspect of WG I's treatment of uncertainty, which is summarized below.

WG I's Treatment of Uncertainty

Where WG I has what it considers sufficient data to allow statistical analysis, e.g., the global average surface temperature increase of the last 100 years, it reported its results as an average value and a 5-95% confidence interval (average [lower bound to upper bound]). This is a 90% confidence interval, not the 95% confidence interval normally used in the scientific literature, and results in smaller uncertainty ranges than would typically be reported. As a result, WG I's results appear more robust than they actually are.

For projections of future climate change, and for observations where there is insufficient information to make a statistical analysis, WG I uses **expert judgment** and the following likelihood terms[4]:

Likelihood of the occurrence/outcome		
Virtually Certain	>99%	probability of occurrence
Extremely Likely	>95%	probability
Very Likely	>90%	probability
Likely	>66%	probability
As Likely as Not	>50%	probability
Medium Likelihood	33 – 66%	probability
Unlikely	<33%	probability
Very Unlikely	<10%	probability
Extremely Unlikely	<5%	probability
Exceptionally Unlikely	<1%	probability

WG I also uses the following confidence scale to characterize its findings[5]:

Degree of confidence in being correct	
Very high confidence	At least 9 out of 10 chance of being correct
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance

While WG I stresses that its report is the work of over a thousand authors and reviewers, it is important to remember that each individual assignment of likelihood is the result of the expert judgment of a handful of authors, reviewed by a relatively small number of reviewers. In the SPM and in this review, all likelihood and confidence terms are emphasized with *italics*.

Overview of WG I's Results

Compared with IPCC's Third Assessment Report (TAR), WG I came to relatively few new findings, but in almost all cases, AR4 provides more data or modeling studies in support of its findings and expresses a higher level of confidence in them. One of the objectives of this review is to examine whether those higher levels of confidence are justified.

Each of the most significant findings in WG I's report, which are presented in the order they appear in the SPM, is presented in **bold**, though not necessarily as a direct quote from the SPM. Some of the SPM language is convoluted, having resulted from a compromise between the WG I authors followed by a political compromise between the governments that participated in the WG I Plenary's word-by-word review of the SPM.

A comparison of the final draft SPM and the approved SPM indicates that while the government review did not change the basic meaning of, or level of likelihood assigned to any of WG I's findings, it did significantly change the wording, in some cases changing the emphasis. Two examples are shown in Table 2.

In the first example, the change emphasizes the role of human activities, in the second, a concern about sea level rise has been added.

The information supporting each conclusion is discussed and a judgment offered as to whether WG I was justified in its conclusion and the level of confidence it assigned to the conclusion. WG I did not provide a discussion of key uncertainties in its report, but a summary of key uncertainties and an assessment of whether they are likely to be reduced by further research, is presented at the end of this review.

Overall, it is clear that many of WG I's findings are not supported by their underlying report and are unduly alarmist.

Critique of Key Findings

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level.

Media coverage of this WG I finding made it appear that there were a host of skeptics who

Table 2 – Examples of Changes to the SPM that Changed Emphasis

Draft SPM	Approved SPM
Current atmospheric concentrations of carbon dioxide and methane far exceed pre-industrial values determined from ice cores spanning the last 650,000 years. The increases in these greenhouse gases since 1750 [see Figure SPM-1] are due primarily to emissions from fossil fuel use, agriculture, and land-use changes.	Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide *have increased markedly as a result of human activities since 1750* (emphasis added) and now far exceed pre-industrial values determined from ice cores spanning many thousands of years [See Figure SPM-1]. The increases in global carbon dioxide concentration are due primarily to fossil fuel use and land-use change, while those of methane and nitrous oxide are primarily due to agriculture.
Paleoclimate information supports the unusual nature of the recent warming and suggests that past warming has driven large-scale ice sheet retreat and sea level rise.	Paleoclimate information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1300 years. *The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 meters of sea level rise.* (emphasis added)

were questioning whether the warming had, in fact, occurred. This is a classic example of setting up a straw man, then knocking down, but it does not reflect the reality of the climate change debate.

Even those most critical of the IPCC's findings and projections acknowledge that the climate warmed during the 20th century. There is no inconsistency in acknowledging this fact and questioning other WG I findings. Among the areas which the Marshall Institute questions are: the accuracy of temperature measurements and the quantitative estimates of warming derived from those measurements,[6] the certainty with which the warming can be attributed to human activities, and the projections of the effects of warming. These later two issues will be discussed in detail in response to the WG I findings on these topics.

New data since the TAR now show that losses from the ice sheets of Greenland and Antarctica have *very likely* contributed to sea level rise over 1993 to 2003. Flow speed has increased for some Greenland and Antarctic outlet glaciers, which drain ice from the interior of the ice sheets. The corresponding increased ice sheet mass loss has often followed thinning, reduction or loss of ice shelves or loss of floating glacier tongues. Such dynamical ice loss is sufficient to explain most of the Antarctic net mass loss and approximately half of the Greenland net mass loss. The remainder of the ice loss from Greenland has occurred because losses due to melting have exceeded accumulation due to snowfall.

The high level of confidence expressed in this conclusion does not seem to be justified by the text of the underlying report, which states:

> Until recently, (including in the TAR), it was assumed that the velocities of these outlet glaciers and ice streams cannot change rapidly, and impacts of climate change were estimated primarily as changes in snowfall and surface melting. Recent observations show that outlet-glacier and ice-stream speed can change rapidly, for reasons that are still under investigation. Consequently, this assessment will not adequately quantify such effects.[7]

The underlying report acknowledges that the ice sheet in central Greenland is thickening, but then claims that melting at the coast and increased ice-stream speed have more than offset this.[8] This claim is based on conjecture, since the underlying report also states:

> Data are not available to assess whether the effects of increased surface melting in Greenland have been transmitted to the bed and contributed to ice-flow acceleration.[9]

Elsewhere in the SPM, WG I acknowledges that there was a warm period in the Arctic from 1925 to 1945.[10] It extended longer in southern Greenland. However, neither the SPM or the underlying report comment on the effect that this warm period had on ice loss from Greenland, in all probability because the information is not available. Given the uncertainty about the current and past history of the Greenland ice sheet, it is reasonable to question whether there is a net loss of ice from Greenland, and if there is, whether that loss exceeds normal variability.

Similar questions can be raised about the contribution of Antarctica to sea level rise. The underlying report states:

> Assessment of the data and techniques suggests overall Antarctic ice-sheet balance ranging from growth by 50 Gt (Billion metric tonnes)/year to shrinkage by 200 Gt/year from 1993-2003. As in the case of Greenland, the small number of measurements, lack of agreement between techniques, and existence of systematic errors that cannot be estimated accurately preclude formal error analysis and confidence limits. There is

> no implication that the mid-point of the range provides the best estimate.[11]

This statement, which appears in WG I, Chapter 4, did not prevent WG I, Chapter 5 from converting **assumed** ice loss into sea level rise and calculating both a best estimate and a confidence interval, or the leadership of WG I from including these values in the SPM. One questions whether either the leadership of WG I or the authors of Chapter 5 bothered to read Chapter 4.

Overall there seems to be no justification for the finding "… losses from the ice sheets of Greenland and Antarctica have *very likely* contributed to sea level rise over 1993 to 2003."

There is observational evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical sea surface temperatures. There are also suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater. Multi-decadal variability and the quality of the tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity. There is no clear trend in the annual numbers of tropical cyclones.

As WG I's text indicates, it does not have a strong basis for its conclusion. WG I depends heavily on the work of Emanuel,[12] who found that the total power dissipation of hurricanes in the North Atlantic and typhoons in the North Pacific increased beginning in the mid-1970s. However, because the total power dissipation index depends on the cube of wind speed, it is very sensitive to data quality. In fact, after first publishing his results, Emanuel had to adjust them downward to reflect this problem. Emanuel's work has been challenged by other scientists, including Landsea[13] of NOAA, who resigned as an IPCC author because he felt that his views were not adequately reflected in early drafts of WG I's report. More recently, Kossin, *et al.*[14] published a paper in *Geophysical Research Letters* which found no upward trend in hurricane intensity in any ocean basin other than the North Atlantic. These authors note that the North Atlantic accounts for only 15% of global hurricane activity, calling into question the underlying assumption in Emmanuel's work that increasing sea surface temperature leads to more intense hurricanes.

William M. Gray, Professor Emeritus of Atmospheric Science at Colorado State University, is widely recognized for having developed the best predictive model for hurricane formation in the North Atlantic. Sea surface temperature is a factor in Gray's model, but not the controlling factor. Gray compares two fifty-year periods: 1900-1949 and 1956-2005. Global average surface temperature rose 0.4 °C (0.7 °F) between these two periods, an amount similar to the temperature rise since the 1970s, but there were fewer named storms, hurricanes, or intense hurricanes making landfall on the U.S. during the 1956-2005 period than during the earlier period. The explanation for this apparent contradiction lies in the complex way that heat is distributed in the North Atlantic Ocean. Based in his analysis of the climate system, Gray predicts that the warming of the last thirty years will come to an end in the next five to ten years and that global average surface temperatures will *lower* twenty years from now than they are today.[15]

There is also evidence of an approximately sixty-year cycle in the frequency of hurricanes in the North Atlantic, thirty years of above average storm frequency followed by thirty years of below average storm frequency. On average, the 1930s to 1960s had more hurricanes per year than the 1960s to early 1990s. Indications are that North Atlantic hurricane frequency increased starting in 1995.[16] If projections of the cycle are correct, we can expect another ten to fifteen years of higher than average numbers of hurricanes in the North Atlantic. This potential cycle raises further questions about WG I's conclusion, since what appears to be a change in hurricane intensity could simply be part of a naturally occurring cycle.

Given the questions that have been raised about Emmanuel's work, the IPCC's conclusion on hurricanes appears to be unjustified.

Paleoclimate information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1300 years.

The so-called "hockey stick," which purported to show from tree ring data that the temperatures of the late 20th century were unprecedented in the last 1000 years, was one of the most controversial findings in the TAR. Subsequent to 2001, several analyses[17] showed serious flaws in the work of Mann, *et al.,*[18] on which the hockey stick was largely based. (The TAR included two other reconstructions of the temperature of the last 1000 years, but the Mann, *et al*. "hockey stick" was the figure shown the WG I's TAR SPM and in IPCC publicity about the TAR.) In AR4, WG I acknowledges the criticisms of Mann, *et al.*, but strongly defends the work.[19]

WG I's finding is based on the three studies from the TAR and nine new ones. All use proxy data (tree rings, coral reefs, etc.), since there are no direct measurements of the temperature of 1000 years ago, and all show a similar temperature profile. Only one shows a fifty-year period in the last 1000 years that was warmer than current temperatures. While this would seem like strong support for the WG I finding, serious questions have been raised about the independence of these studies and the statistical methods they use.

In 2006, an *ad hoc* committee chaired by Edward Wegman, Professor of Information Technology and Applied Statistics at George Mason University, prepared a report for the House Committee on Energy and Commerce evaluating the methodology used in developing the "hockey stick" and similar temperature reconstructions.[20] The committee found:

> It is clear that many of the proxies are re-used in most of the papers. It is not surprising that the papers would obtain similar results and so cannot be claimed to be independent verifications.

WG I does not discuss the degree to which the twelve studies it cites use the same proxy data. However, given the scarcity of this type of information, there must be considerable re-use of the available proxies.

The committee also found:

> As statisticians, we are struck by the isolation of communities such as the paleoclimate community that rely on statistical methods, yet do not seem to be interacting with the mainstream statistical community. The public policy implications of this debate are financially staggering and yet apparently no independent statistical expertise was sought or used.

This criticism is important, since it supports the evaluation of McIntyre and McKitrick,[21] two of the most vocal critics of the hockey stick, who found that Mann, *et al*. improperly used standard statistical techniques.

WG I's comparison of current temperatures to past temperatures is based on limited information, a mix of measured and paleoclimatic data. This is a difficult statistical problem, but no statisticians were actively involved in the assessment. Involving statisticians would have helped avoid errors such as those made by Mann, *et al*., and would have provided a more solid basis for conclusions reached.

Finally, the committee found: "… the work (of Mann, *et al*.) has become sufficiently politicized that this community can hardly reassess their public positions without losing credibility." While this explains WG I's strong defense of Mann, *et al*. in the face of the legitimate criticism of this study, it casts doubt on the scientific objectivity of WG I's assessment.

Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations. This is an advance since the TAR's conclusion that "most of the observed warming over the last fifty years is *likely* to have been due to the increase in greenhouse gas concentrations." Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns.

AR4's greater confidence in the conclusion that human activities are responsible for most of the warming since the mid-20th century is based on the larger number of modeling studies supporting this conclusion. The TAR conclusion was based mostly on a Hadley Centre modeling study. AR4's conclusion draws on studies with more than a dozen climate models. While this is an impressive array of results, it does not overcome the basic problem with the approach: the fact that with proper tuning, a model's output can match a single set of data (such as the global average temperature of the last 150 years) without accurately representing the underlying physical processes. In such cases, the model cannot be depended upon to accurately predict future conditions.

The modeling studies WG I is relying on simulate the global climate of the past 150 years using both natural and human drivers of climate change. The results of these simulations are analyzed to determine the relative importance of natural and human drivers. For this technique to work, both the climate models and the input data on drivers of climate change must be reliable. Also, the comparison has to be made against a reliable record of global climate for the past 150 years. Unfortunately, none of these conditions are met. The models have systematic flaws, the input data is unreliable prior to 1970 at the earliest, and the historical record of climate is incomplete and flawed.

None of the climate models used by WG I has been independently validated. In fact, WG I does not discuss model validation, but uses a less demanding term: evaluation.[22] And that evaluation shows that major problems exist in the design of climate models. Among the problems WG I lists[23] are:

- systematic biases in simulation of the Southern Ocean, which is important for the transfer of heat between the atmosphere and oceans;
- on-going problems in simulating the El Niño – Southern Oscillation (ENSO) cycle, which is a major factor in the Earth's climates;
- poor simulations of precipitation events: "In general, models tend to produce too many days with weak precipitation (< 10 millimeters/day, <0.4 inches/day) and too little precipitation overall in intense events (>10 millimeters/day, >0.4 inches/day)"; and
- substantial uncertainty in the simulation of feedbacks from sea-ice, which are coupled with polar cloud formation and transport of heat through the polar oceans.

Other authors provide more detailed assessments of the shortcomings of climate models.[24]

Looking next at the input data, WG I assumes that climate change is driven by both natural and human factors. The key natural factors are variations in solar insulation, the intensity of solar radiation reaching the Earth's surface, and volcanic eruptions. The key human factors are greenhouse gas and aerosol emissions. Values for each of these factors are uncertain for any time prior to the 1970s.

- Solar variability is uncertain. Satellites have been making direct measurements of solar radiation since the late 1970s, but for periods before that proxy data must be used. Between the TAR and AR4, WG I cut the estimated radiative forcing due to changes in solar intensity from 0.30 to 0.12 Watts per square meter.[25] WG I continues to assign a low level of scientific understanding (LOSU) to this value.[26]

- While the occurrence of volcanic eruptions since 1850 is well documented, their effects are not. Only volcanic eruptions, such as Mt. Pinatubo in 1992, that emit significant amounts of sulfate into the stratosphere, affect climate. Direct measurement of the amount of sulfate emitted by volcanic eruptions has been possible only since the early 1980s when satellites equipped to make such measurements were launched.[27] In the TAR, WG I made an estimate of the radiative forcing due to volcanic eruptions. In the notes to Figure SPM-2 which is WG I's summary of radiative forcing, WG I states: "Volcanic eruptions contribute an additional natural forcing but are not included in this figure due to their episodic nature."[28]

- Human emissions of GHGs and sulfate aerosols are reasonably well documented for the last few decades, but emissions of other aerosols, which have a significant effect on climate, are not well understood, even today. WG I assigns a high LOSU to the effects of long-lived greenhouse gases, but only a medium to low LOSU to the ability of aerosols to either reflect or absorb solar radiation, and a low LOSU to the indirect, but highly important, effects that aerosols have on cloud formation.[29]

We also need to consider the quality of the temperature record against which climate model outputs are being evaluated. While considerable effort has gone into constructing a global temperature record, it is of dubious quality. Even today, there is inadequate weather monitoring for large parts of Africa, South America, and the oceans,[30] and as well documented in the Implementation Plan for the Global Observing System for Climate in Support of the UN Framework Convention on Climate Change, weather monitoring facilities in many parts of the developing world are deteriorating.[31] The historical record is even less certain. Dr. Robert Balling, Director of the Office of Climatology at Arizona State University, estimates that the error in estimates of global average temperature could be 0.2-0.3 °C, a third to a half of the estimated temperature rise during the 20th century.

Thus WG I bases its finding on a comparison of results from unvalidated climate models, using uncertain input data, with a global temperature record of dubious quality.

The Marshall Institute does not question that global temperature has risen over the last century, or that human emissions have played a role in that temperature rise. However, we strongly question WG I's finding that most of the warming of the last fifty years is due to the observed increase in anthropogenic greenhouse gas concentrations, and the high level of likelihood that WG I assigns to this finding.

It is also useful to step back from the complexities of climate models, and look at the raw data on temperature. Dr. S-I Akasofu, Founding Director of the International Arctic Research Center at the University of Alaska, Fairbanks, has done this using a variety of data from the Arctic. Ice core data from the Russian Arctic shows a roughly linear increase in temperature dating back to at least 1800. Estimates of winter temperature in the Baltic, based on ice break-up date at the port of Tallinn, Estonia show a rising trend dating back to at least 1600. Summer temperature data from Tallinn indicate a rising trend since 1750. The retreat of ice in the Norwegian Sea shows a linear trend back to 1800. Akasofu asks whether the WG I approach of measuring temperature rise from an assumed linear baseline is correct, or whether the baseline should be a linearly rising trend.[32] Even against the rising baseline, global average temperatures have been higher than would be expected for the past two decades, but the deviation from expected is much smaller. This analysis does not preclude a role for human activities in recent warming, but it does question the WG I conclusion that most of the warming can be attributed to human activities.

The second part of the conclusion, that human activities are responsible for changes in other aspects of climate, is based on the same modeling studies as the primary conclusion about the role of human activities on global average temperature. It is well recognized that climate models become less certain as the scale is reduced from global to continental, ocean basin, or regional. WG I's SPM states that global average warming is "unequivocal," but warming over each of the continents except Antarctica is only considered *likely*.[33] WG I's choice of "discernible" is indicative of this lower level of uncertainty. Discernible implies that model results indicate an outcome, but with such a high level of uncertainty that the outcome cannot be quantified.

Best estimates and likely ranges for globally average surface air warming for six SRES emissions marker scenarios are given in this assessment. For example, the best estimate for the low scenario (B1) is 1.8 °C (*likely* range is 1.1 °C to 2.9 °C), and the best estimate for the high scenario (A1FI) is 4.0 °C (*likely* range is 2.4 °C to 6.4 °C). Although these projections are broadly consistent with the span quoted in the TAR (1.4 to 5.8 °C), they are not directly comparable. The AR4 is more advanced as it provides best estimates and an assessed likelihood range for each of the marker scenarios. The new assessment of the likely ranges now relies on a larger number of climate models of increasing complexity and realism, as well as new information regarding the nature of feedbacks from the carbon cycle and constraints on climate response from observations.

The advance WG I claims involved generating output from a sufficient number of climate models using the same emissions scenario as input to allow a statistical analysis of the results. While this mimics the procedure used with data from observations, model results should not be confused with experimental data. The models used do not give independent results since they have been derived from the same set of assumptions. There is no way to judge whether their outputs represent a reasonable projection of future climate, since none of the models has been independently verified. They could all suffer the same set of systematic biases.

While newer climate models are more complex and include more variables, it is far from clear that this is an advance. As Dr. Syukuro Manabe, the developer of one of the first three dimensional climate models that link atmospheric and ocean climate processes, pointed out: Models that incorporate everything from dust to vegetation may look like the real world, but the error range associated with the addition of each new variable could result in nearly total uncertainty. This would certainly represent a paradox: The more complex the models, the less we know![34]

Dr. Manabe was referring to a basic fundamental of uncertainty statistics: if the confidence in each of two parameters is 90%, the confidence in an outcome that depends on both parameters is only 81%, the product of the two confidence levels. Climate modes use literally dozens of parameters, some of which are known with far less than 90% confidence. WG I does not present evidence that the additional variables incorporated in newer models results in reduced uncertainty. The opposite is probably true, since WG I identifies the added variables and processes, e.g., the sea ice feedback, as among the least well understood. Statistical analysis indicates that the confidence level for climate model outputs approaches zero.

It is difficult to see how reliance on the current state of knowledge of carbon-cycle modeling can be considered an improvement in modeling techniques. In its underlying report, WG I concludes:

> There is as yet no statistically significant trend in CO_2 growth-rate as a fraction of fossil fuel plus cement emission since routine atmospheric CO_2 emission began in 1958. The 'airborne fraction' has shown little variation over this period.[35]

During that period, atmospheric CO_2 concentration has increased from 315 to 380 ppm, and global average temperature has increased by at least 0.4°C. Given the size of these increases and the huge mass of data available on atmospheric concentrations of CO_2, it would seem that if there were a significant climate-carbon cycle feedback, it should be detectible.

WG I reports on the results of a comparison of eleven climate models with carbon cycle feedback that used the SRES A2 scenario as input. The feedback multiplied atmospheric carbon content from a factor of 1.04 (an increase of 24 ppm CO_2) to 1.44 (an increase of 224 ppm CO_2), a factor of 9 or 10 difference depending on which measure is used.[36] It is difficult to believe that the feedback is being correctly modeled with such a varied output

WG I also claims that constraints from observations have improved climate model predictions. However, this claim is only weakly supported by the underlying report, which states:

> Models have been extensively used to simulate observed climate change during the 20th century. Since forcing changes are not perfectly known over that period, such tests do not fully constrain future response to forcing changes. Knutti, *et al*. (2002) show that … a range of climate sensitivities are consistent with the observed surface air temperature and ocean heat content records, if aerosol forcing is allowed to vary within its range of uncertainty. Despite this fundamental limitation, testing of 20th century simulations against historical observations does place some constraints on future climate response.[37]

Finally, WG I's estimates of temperature rise to 2100 are based on the SRES scenarios.[38] These are baseline scenarios, i.e., they assume that no overt action is taken to control greenhouse gas emissions. This is an unrealistic assumption, since a variety of actions are currently being taken to control greenhouse gas emissions, some voluntary, some mandatory, and more are planned for the future. Other criticisms of these scenarios include:

- the scenarios with high CO_2 emission rates, which lead to high levels of temperature rise, are unrealistic,[39] and

- the scenarios are based on market exchange rates rather than purchasing power parity, which would provide a more realistic comparison of the economies of different nations.[40]

These and other criticisms of the SRES scenarios led the Select Committee on Economics of the UK House of Lord to conclude: "There are significant doubts about some aspects of the IPCC's emission scenario exercise, in particular, the high emission scenarios."[41]

WG I does not discuss the criticisms of the SRES scenarios.

Global average sea level rise for 2090-2099 relative to 1980-1999 is estimated at 0.18 to 0.59 meters (7 to 23 inches) for the six SRES marker scenarios.

The estimate of global average sea level rise in the TAR was 0.09 to 0.88 meters from 1990 to 2100. The best estimate of sea level rise for the 20th century is 0.17 meters (6.7 inches). The time frame used for the AR4 estimates is different, and somewhat longer, so the reduction in both the range of uncertainty and the upper estimate of sea level rise is significant. WG I has been criticized for not including the potential impact of accelerated ice flow from

Greenland and Antarctica in its estimate of future sea level rise. However, given the uncertainty about this phenomenon, WG I's approach is the only acceptable one.

Projections of sea level rise are developed from models of ocean thermal expansion and glacier and ice cap melting using projections of temperature rise as input. As such, the estimate of sea level rise can be no better than the estimates of temperature rise, and in reality are poorer because of the uncertainties added by the additional level of modeling.

There is now higher confidence in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation, and some aspects of extremes and of ice. Specifics include:

1. Warming greatest over land and at high northern latitudes, least of over the Southern Ocean and parts of the North Atlantic.
2. Snow cover to contract, and permafrost to melt.
3. Sea ice to shrink, with the possibility of the Arctic Ocean being ice free in late summer under high emission scenarios.
4. More frequent hot events *very likely*.
5. More intense tropical cyclones (hurricanes and typhoons) *likely*. Less confidence in projections of increased numbers of storms.
6. Extra-tropical storm tracks are projected to move poleward.
7. Increased precipitation *very likely* in high-latitudes; decreases *likely* at low latitudes.
8. *Very likely* that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century, but *very unlikely* that it will shut down during that period. Longer-term changes in the MOC cannot be assessed with confidence.

All of these projections are based on analysis of climate model outputs or use those outputs to drive impact models. As such, they are subject to all of the uncertainties discussed for climate model projections of temperature, plus the additional uncertainties in the impact models. By making this long list of statements, WG I creates the appearance of a comprehensive understanding of future climate, when in reality, the more detailed the projection, the less certain it is.

Some of the items on this list, snow cover to contract, sea ice to melt and more frequent hot events, are to be expected if the projected warming occurs. Others, i.e., more warming over land and northern high latitudes, increased precipitation at high-latitudes, decreased precipitation at low latitudes, and extra-tropical storm tracks moving poleward, are merely extensions of the climate patterns observed over the past few decades. The projection of more intense tropical cyclones is an extrapolation from the claim that hurricane intensity has increased in the North Atlantic since the 1970s. As discussed above, observations do not support this claim, which makes projections of intensification in the future highly speculative.

The last projection, that it is *very likely* that meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century, but *very unlikely* that it will shut down, requires a more extensive discussion. The MOC used to be referred as thermohaline circulation (THC). The driving force for this circulation was claimed to be the difference between the temperature and salinity of ocean water in the sub-topical North Atlantic and the temperature and salinity of that water when transported to higher latitudes by ocean currents. However, as early at 2000, Carl Wunsch, an oceanographer at MIT, argued that it was tidal forces, driven by the slow movement of the Moon away from the Earth, that were responsible for this circulation.[42] Wunsch's claim was supported by satellite measurements showing that the Moon was indeed slowly moving away from the Earth, and that this generated the gravitational energy needed to drive the MOC.[43] If the slow movement of the Moon away from the Earth is the driver of the MOC, then climate change will have no effect on this circulation. It will not slow down or shutdown in the 21st century, or anytime thereafter.

The projected shutdown of the MOC has been the basis for some of the more lurid depictions of abrupt climate change, e.g., the rapid onset of an ice age in the film *The Day After Tomorrow.* Whatever the artistic merits of this film, it is important to realize that it has absolutely no basis in scientific fact.

Key Uncertainties

While WG I claims greater confidence in its results than at the time of the TAR, the list of key uncertainties has not changed significantly in the intervening six years.

Future climate will depend on the response of the climate system to anthropogenic and natural drivers. The major anthropogenic drivers are greenhouse gas and aerosol emissions and land-use changes. These are affected by future population, economic growth, technological development, and regulation, all of which are unknowable to a greater or lesser degree. Natural drivers are solar variability, volcanic eruptions, and the Earth's orbital mechanics. Solar variability is currently poorly understood, but in concept, it should be knowable. Volcanic eruptions are random events, and therefore unknowable other than as statistical averages. The Earth's orbital mechanics are well understood, but are a significant factor only when projections are being made for very long periods of time.

The key areas of uncertainty in climate processes involve water vapor, aerosols, and their interactions to produce clouds. WG I's SPM identifies cloud feedbacks as the largest area of uncertainty. These topics have been studied for more than a decade, and while some progress has been made, it appears likely that parts of the system will remain unknowable.

One of the more interesting recent findings about the role of clouds in the climate systems is that they tend to act as climate regulators, balancing the effect of warming. Lindzen, *et al*.[44] analyzed satellite data for cloud cover over the Western Pacific Ocean and found that high cirrus clouds decreased 22%/°C (12%/°F) of surface temperature. This reduction of cloudiness with increasing temperature allows the Earth to radiate more energy to space, providing a cooling effect. Lindzen, *et al*. referred to this phenomenon as an "adaptive iris," likening it to the opening and closing of the eye's iris in response to light intensity. More recently, Spencer, *et al*.[45] analyzed satellite data for the whole tropical oceans for the 2000-2005 period and also found that cloud cover decreased as surface temperature increased at a rate that was qualitatively consistent with the Lindzen, *et al*.'s findings. If tropical clouds do, in fact, act to regulate the Earth's climate, then WG I's projections of high rates of warming over the 21st century are incorrect.

As mentioned above, WG I characterizes its understanding of some of the key variables in the climate system in terms of level of scientific understanding (LOSU). WG I's LOSU ratings[46] are reproduced below:

Variable	LOSU
Long-lived greenhouse gases	High
Ozone	Medium
Surface albedo (reflectivity)	Medium – Low
Direct effects of aerosols	Medium – Low
Indirect effects of aerosols	Low
Solar variability	Low
Stratospheric water vapor from CH_4	Low
Aircraft contrails	Low

Some of the parameters for which there is a low LOSU have large impacts on the climate system. For example, the total impact of aerosols could be as large as the total impact of long-lived greenhouse gases.

Additional areas of uncertainty include:

1. The effect of climate change on the carbon cycle, which WG I calls the climate-carbon cycle feedback: This is a relatively new topic and one which should be knowable with sufficient research.

2. Mechanisms of tropical cyclone formation and intensification: The debate on whether tropical cyclone intensity has increased since the mid-1970s points up the lack of knowledge of the details of formation and growth of these storms as well as a lack of good historical data. Better mechanistic understanding would resolve many of the issues should be knowable with additional research.

3. Solar radiation feedbacks: Svensmark and Friis-Christiansen[47] hypothesized that cloud formation rates were a function of the number of cosmic rays reaching the Earth's lower atmosphere, and that the number of cosmic rays reaching the Earth's lower atmosphere was affected by the intensity of solar radiation. This would create a feedback mechanism in which small changes in the intensity of solar radiation would be magnified by their effect on cloudiness. Since clouds reflect solar radiation, changes in average cloudiness affect global climate. Correlations indicate that these relationships existed during the 1984-1995 eleven-year solar cycle. Further evidence for the feedback mechanism was provided by a recent laboratory experiment.[48] When Svensmark and his co-workers exposed a mixture of gases matching atmosphere composition to simulated cosmic radiation, they observed the formation of the type of particles that lead to cloud formation. Further research will be needed to ensure that the mechanism is actually operating in the atmosphere, but it should be possible to remove this uncertainty if the additional research is carried out.

4. While not strictly part of the climate system, ice sheet dynamics are a topic of growing importance since it will have a significant effect on sea level rise. Again, this is a topic which should be knowable with sufficient research.

The term "natural variability" is often used to characterize what we do not know about the climate system as well as well-understood cyclical phenomena. As such it covers all of the natural unknowns, some of which are knowable, other of which are not. It is reasonable to assume that the magnitude of uncertainty will decrease as our knowledge of the climate system increases, but that it will not be eliminated. Also, different aspects of the climate system have different "natural variabilities." The natural variability of precipitation is currently larger than the natural variability of temperature, because we understand less about precipitation. Whether we can reduce uncertainty about precipitation to the same level as that of temperature is also unknown.

Notes

1. ***http://ipcc-wg1.ucar.edu/wg1/docs/WG1AR4_SPM_Approved_05Feb.pdf***
2. See, for example, ***www.junkscience.com/draft_AR4***.
3. The projection of sea level rise does not include the effects of land rise or subsidence of either the ocean floor or seashore.
4. WG I Final Draft, 2007: Technical Summary, Box TS 1.1, Pg TS-3-TS-5.
5. *Ibid.*
6. For a full discussion of the uncertainties in estimates of global average temperature, see: Balling, R, 2003: The increase in global temperature: What it does and does not tell us. ***www.marshall.org/article.php?id=170***.
7. WG I Final Draft, 2007: Chapter 4: Observations: Changes in Snow, Ice and Frozen Ground, Section 4.6.1, Pg. 21.
8. *Ibid.*, Section 4.6.2.2.1, Pg. 23.
9. *Ibid.*, Section 4.6.3.3, Pg. 28.

10. WG I SPM, Pg. 8. ***http://ipcc-wg1.ucar.edu/wg1/docs/WG1AR4_SPM_Approved_05Feb.pdf***

11. WG I Final Draft, 2007: Chapter 4: Observations: Changes in Snow, Ice and Frozen Ground, Section 4.6.2.2.2, Pg. 25.

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20. Wegman, E.J., D.W. Scott and Y. H. Said, 2006: Ad Hoc Committee Report on the 'Hockey Stick" Global Climate Reconstruction. ***www.uoguelph.ca/~rmckitri/WegmanReport.pdf***.

21. McIntyre, S. and R. McKitrick, 2003: Corrections to the Mann et al.(1998) Proxy Data Base and Northern Hemisphere Average Temperature Series. *Energy and Environment*, 14, 751-771.

22. WG I Final Draft, 2007: Chapter 8, Climate Models and their Evaluation.

23. *Ibid.*, Executive Summary, Pg. 3-6.

24. See, for example, Green, K., T. Ball and S. Schroeder, 2004: The Science Isn't Settled: The limitations of global climate models, ***www.fraserinstitute.ca/admin/books/fules/ScienceIsntSetteled.pdf***, or Pilkey, O.H. and L. Pilkey-Jarvis, 2007: *Useless Arithmetic: Why Environmental Scientists Can't Predict the Future.* New York: Columbia University Press, 230 pp.

25. WG I Final Draft, 2007: Chapter 2, Changes in Atmospheric Constituents and in Radiative Forcing, Section 2.7.1, Pg. 51.

26. WG I SPM, Figure SPM-2.

27. WG I Final Draft, 2007: Chapter 2, Changes in Atmospheric Constituents and in Radiative Forcing, Section 2.7.2, Pg. 56.

28. WG I SPM, Figure SPM-2.

29. *Ibid.*

30. Green, K., T. Ball and S. Schroeder, 2004: The Science Isn't Settled: The limitations of global climate models, ***www.fraserinstitute.ca/admin/books/fules/ScienceIsntSetteled.pdf***

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35. WG I Final Draft, 2007: Chapter 7, Coupling Between Changes in the Climate System and Biogeochemistry, Executive Summary

36. *Ibid.*, Section 7.3.5.2.

37. WG I Final Draft, 2007: Chapter 8, Climate Models and their Evaluation., Section 8.1.2.3, Pg. 9.

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