# What NOT to Read: A Lesson in Reviewing and Critiquing Scientific Literature Using a Junk Science Article on Climate Change

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## Abstract:
A central challenge for college-level science and ecology students is understanding the significance of peer-reviewed scientific literature. Such literature is increasingly easy to access, but students have little appreciation for how it is generated and little insight into how it should be critiqued. We propose a simple exercise that demonstrates the importance of a critical reading of not only the text and data of a research article but a careful analysis of the reputation of the journal and the qualifications of the authors. We use a widely accessible article ("Environmental effects of increased atmospheric carbon dioxide," by A. B. Robinson, N. E. Robinson and W. Soon, available at: http://www.oism.org/pproject/GWReview_OISM600.pdf) that is frequently cited by critics of climate change science. The article superficially resembles a "real" scientific article, but the flaws and departures from acceptable norms in scientific publishing quickly become clear to students. This exercise functions well as an initial assignment in a research article-based course because it gives students motivation and tools to critically judge published research articles. It also introduces major concepts involving ecological effects of increased atmospheric carbon dioxide and exposes students to the political and scientific debates surrounding global warming. Thus, it works particularly well in a global change, earth system science, or ecosystem ecology course.

## Learning Objectives:

1. Students will learn about the nature of scientific literature in ecology, how it is produced, and how it can be critiqued.
2. Students will gain an appreciation for the importance of scientific peer review.
3. Students will realize the importance of accurate citing of references and proper interpretation of data.
4. Students will learn about the most current, scientific assessments and types of evidence pertaining to increased atmospheric $CO_2$ and its environmental consequences.

## Time frame:
We recommend assigning this exercise early in a course where students are going to be making heavy use of primary or secondary, peer-reviewed, scientific literature. The exercise can be assigned in one class period for review and discussion in a subsequent session. Total time required for students to complete the assignment is 2-6 hours. Since students work with one particular table or figure from the article, it is useful to have them compare notes in a group discussion at the conclusion of the exercise.

**List of Materials:** Internet-based access to scientific literature

## Procedure and General Instructions (for Instructor):

### What NOT to Read: A Lesson in Reviewing and Critiquing Scientific Literature Using a Junk Science Article on Climate Change

#### *Step 1: Discuss the nature and quality of scientific literature*

The assignment should be prefaced by some general comments from the instructor on the nature of scientific literature. These comments can be given under the guise of, "Since we are going to be making heavy use of primary articles and review articles from the scientific literature this semester, we are going to talk about what this body of knowledge entails and how it is produced." This is especially important to discuss in a course where students are going to be choosing their own articles to critique or making extensive use of primary research articles in a term paper. We find in these cases that students often choose articles that are inappropriate or of low quality, unless they have been given a clear lesson in judging the nature and quality of scientific literature.

Since we teach a course in ecosystem ecology, we also give a list of the major journals in ecosystem ecology and introduce the concept of journal quality, scope and audience. We talk about several indicators of journal quality, such as rejection rates and citation statistics. We also talk about the different audiences of various journals. One important concept to reinforce is that no single journal is really "best" (although one might note the global importance of *Nature* and *Science*) but that journals differ in their intended scope and audience. Some key indicators of quality are an editor or editorial board from reputable institutions, a rigorous peer-reviewing process and perhaps not-for-profit publication outlets such as scientific societies. To demonstrate the concepts on journal quality and structure, the instructor might present recent rankings of journals, citation statistics, example lists of editorial boards, and examples of statements from journals on their intended scope and audience. Some brief comments could also be made about the variety of ways that research is funded, ranging from reputable, unbiased sources such as NSF, NIH, USDA etc., to sources that may have some financial stake in the outcome.

The instructor could also discuss a typical scenario by which an original article is submitted for publication and how the article is reviewed, perhaps by using an example from her/his own work. This scenario will serve to show students the process of peer review and its intended outcome to improve a paper to ultimately represent the most accurate state of the knowledge.

#### *Step 2: Assign the article and go over the instructions*

With the preface on the nature of scientific literature, which might take anywhere from 15 minutes to 1.5 hours, the instructions for the assignment can be given. We recommend not commenting too much on the specifics of this particular article by Robinson *et al*. so as to not lead students to a particular conclusion. On the other hand, it might be wise to raise a few flags about the article so that students are motivated to do a careful analysis.

### *Information pertaining to the Robinson et al. article, for the instructor*

The Robinson *et al*. article superficially appears to be a conventional scientific "review article", with a layout and design that resembles that of common journals. The paper includes 132 citations to give the impression that the ideas are well supported. Further, the use of color and heavy annotation of figures seems to make this article more user-friendly than those in conventional journals. That said, there are significant problems with its content and background. In addition, the *Journal of American Physicians and Surgeons* is certainly not recognized as a credible source on climate issues and does not have a clear editorial board and peer review process.

Michael MacCracken provides a thorough summary of the background of the Robinson *et al*. article, as well as a detailed critique of the science (see: http://www.climatesciencewatch.org/file-uploads/Comment_on_Robinson_et_al-2007R.pdf). It is always possible that students will run across MacCracken's analysis, and take a short-cut on this assignment by using his work. Instructors may wish to head this off by making his analysis available to students or by simply asking students to not read it until they are done with the assignment. Even if students do take shortcuts, we hope that Step 4 described below will insure that their completed assignment has substance and depth.

MacCracken's extensive comments on the background and critique of Robison *et al.* is attached in Appendix 1.

Here is a list of MacCracken's main points on the background of the article:

- A shorter form of the Robinson *et al.* article was first circulated to the scientific community in 1998 with a cover letter from Dr. Frederick Seitz, past president of the U.S. National Academy of Sciences.
- Dr. Seitz's letter and the article were sent via direct mail to many scientists throughout the country. (See his cover letter at: http://www.petitionproject.org/seitz_letter.php). At the time, the article was formatted to match the style that is used by the Proceedings of the National Academy of Science. This fact, together with the letter from a past president of NAS, gave the false impression that the contents were endorsed by the NAS and led the NAS to disassociate itself from the article and its contents soon after the circulation in 1998.
- The packet circulated by Dr. Seitz also included a petition that could be signed that expressed opposition to the U.S. participation in the Kyoto protocol and possibly, although it was not clear, opposition to the science reported by IPCC and others that showed evidence of climate change. This petition was supposedly signed by about 17,000 qualified scientists in the ensuing months, although some signatures appeared to be bogus (e.g. the Spice Girls) and many of the names were not climate scientists. [Related, updated note by MAV: The petition project is still active on the web (see: http://www.petitionproject.org/) and purports to contain signatures of 31,487 scientists. The petition project is a well-known target on the web for fact-checking entities, who point out serious problems, such as the fact that most names are not

climate scientists and even the 31,000 figure is a small proportion (~0.3%) of working scientists.

- The latest version of the Robinson *et al*. article was published in 2007 apparently as a response to the IPCC report earlier in the year. This version is substantially longer than the 1998 article and is published in the *Journal of American Physicians and Surgeons*. The authors' institution is listed as the Oregon Institute of Science and Medicine. Both the journal and the institution are not recognized as leading climate change sources. MacCracken's critique concerns this 2007 version of the Robinson *et al*. article.

MacCracken presents a detailed commentary, evaluation and analysis on the content of the article. Instead of rehashing those here, refer to pp. 3-16 in his paper in Appendix 1.

### *Possible options for implementing the exercise*

Since the Robinson paper is quite lengthy and contains 27 figures, this assignment could be constrained to just one section of the paper (for example, the "summary", "atmospheric and surface temperatures", or "atmospheric carbon dioxide" section). In particular, the section labeled "summary" is the first three pages and contains 12 figures, so it would work well as a way to cut down the length of the assignment.

Another possibility to facilitate this exercise when time is short or class size is large is to assign certain sections or figures in the paper to a group of 3-4 students. The group could work together to evaluate the paper and a specific figure or set of figures. The following week, a "reporter" could summarize the results of each group's work and the floor could be opened for a general discussion.

Even when there are no time constraints and the class size is small, it might be advisable to assign the work to groups. This might increase the likelihood that even the "shyer" students get a chance to discuss their impressions of the paper.

Finally, one way to use this exercise with students who might have very little background in science or reading scientific articles is to completely omit step 4 (the more in-depth analysis of a figure or table). In this way, the exercise would simply focus on journal quality, funding sources, and peer review, all key criteria in judging scientific literature.

### *Examples of critiques - Figure 2 and Table 1 from Robinson et al.*

Robinson *et al*. use Figure 2 to contend that glacial shortening continues at the same trend before and after substantial increase in hydrocarbon levels. The authors claim the graph shows that glacier shortening began twenty years before the substantial increase in hydrocarbons; this leads them to conclude increased levels of carbon dioxide in the atmosphere could not have contributed to the melting of glaciers. Furthermore, they believe the graph demonstrates the shortening is simply a naturally occurring event that is unaffected by increased use of hydrocarbons. This is another case of Robinson *et al*. using the flawed reasoning that "non-correlation proves non-causation." Further, they use a "sleight of hand" trick in only considering "hydrocarbon increase", meaning oil/gas but not coal. If coal is included, the confluence of glacier shortening and fossil fuel use is much closer than when only oil/gas are considered.

As Michael MacCracken points out in his response to this article, there are a myriad of problems with this figure and its interpretation. First, Robinson *et al*. impose a linear relationship that suggests a drastically oversimplified relationship between glacier length, hydrocarbon levels, and time. In Oerlemans' original article, "Extracting a Climate Signal from 169 Glacier Records," data on fossil fuel use were not included. Furthermore, Oerlemans clearly explains that most of the glacier length data were collected from the European Alps. To interpret a trend observed mainly in the European Alps as applicable to the entire globe is inappropriate. Further, to correlate glacier dynamics in this one region to the global-scale increase in fossil fuel use is a good example of the flawed reasoning in the Robinson *et al*. article.

A second example of the misrepresentation of scientific literature can be observed in Table 1 in the "Atmospheric and Surface Temperatures" section of the article. Robinson *et al.* claim these data suggest that the 20th century does not exhibit an abnormal temperature when compared with the Medieval Climate Optimum and the Little Ice Age. The authors portray these data as representative of a worldwide trend, as the information is a "comprehensive review" of world climate data taken throughout the three periods. The original article, " Reconstructing climatic and environmental changes of the past 1000 years: a reappraisal," recognizes that climate data traced back to the Medieval Warm Period are deficient for seven locations, at a minimum, including areas in Australia, India, Southeast Asia, Eastern Europe, the Middle East, and Africa. In acknowledging this significant absence of information, the original article claims instead the data is "provisional," and therefore cannot be conclusive of a worldwide trend.

Furthermore, the original article points out the large uncertainty of data taken from the 20th century. In particular, the original article has a relatively large number of Yes/No answers, or answers that could not be provided due to inconclusive data, for the 20th century. Where the 20th century had 14 Yes/No answers, the Medieval Climate Optimum had 7 and the Little Ice Age had only 2. This uncertainty does not support Robinson *et al.'s* claim that temperature change was not observed in the 20th century. The original article states this noticeable uncertainty "could be related to inaccurate calibration between proxy and instrumental data," a detail that Robinson *et al.* do not mention in their article. Instead, Robinson *et al*. use the table to contend that the majority of areas throughout the world experienced no noticeable increase in temperature throughout the twentieth century. A closer look at this table in its original context, however, reveals that this claim is not appropriately supported and imposes a worldwide, general trend that simply is not evidenced in the literature.

### *An example of a student response to the assignment*

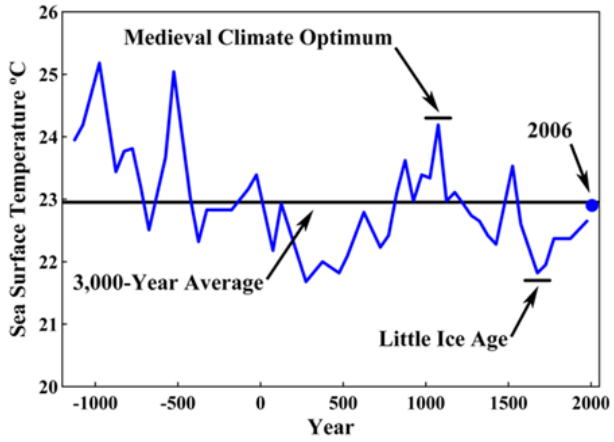
The assigned article was published *Journal of American Physicians and Surgeons* in the year 2007. This journal mission includes "a commitment to publishing scholarly articles in defense of the practice of private medicine and the pursuit of integrity in medical research". Included in the mission statement is the claim that, "Political correctness….and orthodoxy will be challenged by logical reasoning". Being so, it is no surprise that this journal has been known to publish articles ranging from skepticism on if HIV really causes AIDS to claims that the gay male lifestyle shortens life expectancy by twenty years.

In it is this journal that we find our article that claims that increases in carbon dioxide has no harmful effects to our atmosphere, temperature, and landscape. The journal has been subject to a wide range of

criticisms for the articles that it has published throughout its years. However, given the scrutiny and criticisms from mainstream medical sources, the articles that are published in the journal adhere to a double blind peer review process before being accepted.

The main author of this paper is Professor Arthur Robinson. Robinson is a professor of chemistry at the Oregon Institute of Science and Medicine, an institution that he founded. Robinson has been considered an expert in arguing for the null effect that humans have on global warming. His research has been used to contrast information that was presented by former Vice-President Al Gore in his worldwide documentary, *The Inconvenient Truth.* Some of what Robinson says has been heavily criticized by many in the science community; however it must be noted that much of what Robinson said has stood its ground in the scientific community and is still cited by other scientists as a credible source.

After reading this article I am slightly skeptical about the research that Robinson *et al.* reviewed for the journal. The very first figure in the text appears as I have shown below:




This figure shows the surface temperatures at the Sargasso Sea over a 3000 year span. Noted on the figure are the 3,000 year average temperature, the Medieval Climatic Optimum and the “little ice age.”

What strikes me as odd is that this very same figure is presented in other publications as well, but is often accompanied by the data set below.

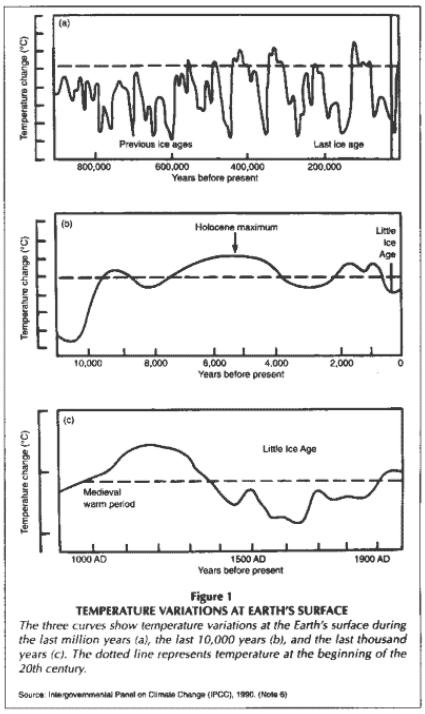



**Figure 1**
**TEMPERATURE VARIATIONS AT EARTH'S SURFACE**
*The three curves show temperature variations at the Earth's surface during the last million years (a), the last 10,000 years (b), and the last thousand years (c). The dotted line represents temperature at the beginning of the 20th century.*

Source: Intergovernmental Panel on Climate Change (IPCC), 1990. (Note 6)

The way that Robinson *et al.* use the initial figure is to show how the Earth's surface temperature varied over a 3,000 year period. In this context the use is correct. However, to only show this figure may be omitting some of the truth and highlighting certain research to make Robinson's research more believable. Showing the many fluctuations gives the impression that what Robinson is showing is that temperature varies often but not much. Although, if one takes a look at the original data set with the additional graphs the fluctuation all but disappears. Omission of this data strengthens Robinson's argument that the increase in C02 has no major effect on temperature change. However, if one observes all the data, an argument can be made that we are making changes to our earth's temperature. The omission of data by Robinson *et al.* could be taken as attempt to mislead the reader into believing Robinson's point of view

## *Step 3: Assign a follow-up activity to reinforce learning objectives 1-3 (on the nature and quality of scientific literatures) and to address learning objective 4 (the most current assessments on the effects of increased atmospheric CO2)*

After a thorough discussion of the assignment and the student responses, the instructor should ask students to practice their newly informed ability to critique and judge scientific literature. Specifically, they could be assigned to choose a current, scientific article on atmospheric $CO_2$ increase, bring the article to class next time, and present a summary and evaluation of this article, perhaps contrasting it with the Robinson *et al*. article. In this way, closure could be brought to this exercise, but emphasizing that many high quality articles exist on this topic and furthermore, the actual effects of enhanced $CO_2$ are the topic of much concerted, ongoing effort that is contributing a great deal to our understanding of the global climate.

Furthermore, at least one subsequent lecture (and perhaps several more, depending on the scope/level of the course) should be devoted to the current consensus among scientists on

enhanced $CO_2$ effects on global climate, using a mainstream source like the latest IPCC report or a current ecology textbook.

### *Our observations of how students typically respond to this assignment*

Students tend to enjoy this assignment because they are able to act as "sleuths" to reveal the inadequacies of this pseudo-scientific article. They very quickly pick up on the fact that the journal (*Journal of American Physicians and Surgeons*), its editorial board, and its peer review are all problematic. Many of our students are pre-med and intend to be physicians; this exercise provides a good opportunity for them to think about the appropriate role of medical knowledge and whether it would normally lead to a great deal of expertise in, for example, climate science.

Most students are able to detect that the tone of the article is very biased and subjective, unlike a real scientific article. We find that students start the exercise by thinking the Robinson *et al*. article appears to be quite impressive and authoritative because, for example, the figures are in color with detailed annotations and many sources are listed. The process of debunking this impression is engaging and enjoyable for students, especially as they take get to take the lead in doing so.

## Procedure and General Instructions (for Students):

### What NOT to Read: A Lesson in Reviewing and Critiquing Scientific Literature Using a Junk Science Article on Climate Change

You must write a one page summary and critique of the assigned article. We will discuss your critiques during the next class period. Your instructor may ask you to divide up into groups to compete the assignment. Follow the steps below.

**Step 1: Retrieve the following paper. If you have trouble with the link, see me for a copy of the paper. Read the paper.**

http://www.oism.org/pproject/GWReview_OISM600.pdf

It can also be downloaded from the journal web page:
http://www.jpands.org/jpands1203.htm

**Step 2: Do a general summary and evaluation of the journal quality and author credibility.**

You should use the internet to access the homepages of the journal and the authors. Keep in mind the factors we talked about. Examples of issues you can examine to help judge the nature and quality of the journal and the qualifications of the authors are:

- Who is the publisher of this journal?
- What is the scope of papers that are published by this journal?
- Who is the intended audience for articles in this journal?
- Are the papers peer-reviewed by experts in the field?
- Can you find any details that support the existence of a rigorous editorial or peer-reviewing process?
- Can you find any information on acceptance or citation rates?
- Are the authors from credible institutions or organizations (for example academic or government-sponsored)? What sources of funding were used for the research and do these sources have any stake in the outcome of the research?

**Step 3: Do a general evaluation of the format, theme, and tone of the article.**

Examples of issues to consider include:

- Does the paper resemble a scientific paper with a well organized narrative in text form, supplemented by data presented in well-constructed figures and tables?
- Does the paper contain references to the peer-reviewed scientific literature? If so, how many sources are listed?

- Are assertions and statements in the paper well supported by data and references?
- Is the general tone objective and scientific?

### Step 4: Do a more in-depth evaluation of a portion of this article by picking one figure.

Robinson *et al*. is an example of a "review article" in which, instead of presenting data collected by the authors themselves, the authors present data collected and published by others. Such a format is widely accepted in science and can be a very useful summary of an area, as well as a way to generate new insights. However, one must be careful to summarize data accurately, and you should judge the extent to which Robinson *et al*. do so.

In order to do this, pick one figure from the Robinson *et al.* paper and do a thorough analysis of it. Many of the figures use data from other sources. In cases where it is possible to locate the original source, compare how that figure is used by Robinson *et al.* with how it was originally used in the paper in which the figure originates.

Here are some questions to consider:

- How does Robinson *et al.* use the figure in their paper?
- How did the original authors use the figure?
- What is your interpretation of the original figure? What is your interpretation of the Robinson *et al*. version?
- Was any part of the original data set modified or omitted? Does this affect the interpretation?
- Was the figure used correctly in Robinson *et al.* paper? Why or why not?

### Step 5: Next class period – use the knowledge gained in the first discussion period to select a recent, scientific article on some aspect of increased $CO_2$ effects on global climate.

Read your paper and be prepared to summarize it for an in-class discussion. Furthermore, compare and contrast this article to the Robinson *et al.* one in terms of its tone, style, journal, audience, scope, and use of data.

**APPENDIX 1**

# Analysis by Michael MacCracken of the paper:

## "Environmental Effects of Increased Atmospheric Carbon Dioxide" by Arthur B. Robinson, Noah E. Robinson, and Willie Soon

(published in *Journal of American Physician and Surgeons* (2007) 12, 79-90)

### Summary

Expanding on a paper first presented ten years ago, the authors present a summary of climate change science that finds fault with nearly all of the internationally peer-reviewed findings contained in the comprehensive scientific assessments of the Intergovernmental Panel on Climate Change (IPCC). In particular, the authors find fault with IPCC's conclusions relating to human activities being the primary cause of recent global warming, claiming, contrary to significant evidence that they tend to ignore, that the comparatively small influences of natural changes in solar radiation are dominating the influences of the much larger effects of changes in the atmospheric greenhouse gas concentrations on the global energy balance. After many scientific misstatements and much criticism of IPCC science, the authors conclude with a section on the environment and energy that argues for construction of 500 additional nuclear reactors to provide the inexpensive energy needed for the US to prosper and to end importation of hydrocarbon fuels (particularly petroleum). Taking this step, along with the beneficial effects of the rising $CO_2$ concentration, will, they argue in complete contrast to the prevailing scientific views, create a "lush environment of plants and animals" that our children can enjoy.

### Background

In early 1998, following the negotiation of the Kyoto Protocol in late 1997, the late Dr. Frederick Seitz, past president of the U.S. National Academy of Sciences and president emeritus of Rockefeller University, widely distributed a letter presenting for consideration an article entitled "Environmental Effects of Increased Atmospheric Carbon Dioxide." The authors of this article were Arthur B. Robinson of the Oregon Institute of Science and Medicine (OISM), Willie Soon and Sallie L. Baliunas, both of the Harvard-Smithsonian Center for Astrophysics, and Zachary Robinson, also of OISM. The article was composed and formatted to appear as if it had been published in the *Proceedings of the National Academy of Sciences* (PNAS), even though, at the time it had not yet been published by any journal, much less by PNAS. The impression that the article was endorsed by the National Academy of Sciences (NAS) was so strong, however, that it led the NAS to take the exceptional action of disassociating itself from the article and the science that the article contained (NAS, 1998).

Basically, the article, which was later published in non-mainline journals as Robinson et al. (1998) and Soon et al. (1998), took strong exception to the findings and international consensus on science presented in the assessments of the Intergovernmental Panel on Climate Change (IPCC), which relied on literature that had been published in peer-reviewed journals. As documented in an analysis that I prepared in early 1998 (see appendix), the arguments and findings presented seemed to be strongly contradicted by the scientific findings summarized by the IPCC.

Using the supposed article as partial justification, Seitz's letter also circulated a relatively brief petition that, for scientific, economic, and other reasons, expressed opposition to US concurrence with the Kyoto Protocol. Although there was really no basis for drawing the conclusion, the packaging of the letter, the article and the petition created the impression, quite possibly intentionally, that signing the petition also indicated agreement with the findings in the attached article, suggesting, in turn, that there were many qualified people that fundamentally disagreed with the IPCC's scientific assessments. Although it is not clear what role the article played in gaining agreement with the petition (one could agree with the petition while still agreeing with the IPCC's findings), roughly 17,000 names of supposedly qualified scientists and other experts were listed as having signed the petition over the ensuing few months. Among those listed were a few well-known scientists, but also a few who were clearly not experts on the subject matter (e.g., the names of the Spice Girls were listed); many others whose names were listed were not recognized as having published in the climate change peer-reviewed literature.

More detailed reviews of this and related efforts to discredit the IPCC science and create doubt about global warming are presented at http://en.wikipedia.org/wiki/Oregon_Petition#cite_noteseitz-7 and http://www.realclimate.org/index.php/archives/2007/10/oregon-institute-of-scienceand-malarkey/, among others.

**The 2007 Version of the Article**

In late 2007, apparently following the publication of the Fourth Assessment Report of the IPCC earlier in the year (IPCC, 2007a, 2007b, 2007c, 2007d), Arthur Robinson, Noah Robinson (another son of Arthur Robinson), and Willie Soon published an article with the same title and in the same format as the 1998 article, although this updated version of the article is now 50% longer. The article (Robinson et al., 2007) was published in the *Journal of American Physicians and Surgeons*, a journal not known for being a publication that would impose the type of independent and high quality peer-review required of the major journals and that is conducted as part of the IPCC review process. The affiliation for all the authors was listed as OISM, an institution not generally recognized as a leading climate change research center, as described in a number of sites on the Web.

In October 2007, with one day's warning, I was invited to come to the 11th annual Telecosm meeting organized by Steve Forbes and George Gilder and to respond to a presentation of the updated Robinson et al. paper by Arthur Robinson and his son Noah. Believing that the mainline scientific views should be presented to the attendees of such a prestigious meeting, I accepted, venturing, as Steve Forbes later put it, 'into the lion's den.' While it remains surprising to me that so much attention and confidence could be put into the claims of these authors versus the authoritativeness of the IPCC findings, I did agree to participate. This note describes the many problems with the science that I identified while preparing for that presentation and in listening to the presentations of the Robinsons at the conference. I am devoting time to preparing this compilation of scientific criticisms because this has apparently

not been systematically done,[1] presumably because the views seem so out of the mainstream that no attention will be paid to them. I only wish that were the case, for those attending the Telecosm conference seemed to give them significant credence.

**General Comments on the 2007 Paper**

Before offering a section by section analysis, a few observations about the general style and tone of the article (and their oral presentation):

1. The Robinson et al. (2007) paper covers a lot of ground. There are quite a number of points where their presentation of the science is correct, and I will not comment on these points. The article also contains a number of mainly political statements, which I will also let pass, focusing instead on critiquing the science and not personal preferences.

2. It is generally inappropriate in scientific, or other, papers to be inferring, ascribing, and then criticizing the motives and political views to others. To the extent that this is done, it suggests the author is pushing an individual agenda rather than simply explaining the science. Again, I will try to stick to the scientific issues.

3. Scientific papers are supposed to be based on inferences drawn from the historical record, experiments, theoretical analyses based on fundamental physical laws (and this includes modeling), relevant analogues, consistency across different systems (e.g., across different planetary atmospheres), etc. Arguments need to be soundly based, not relying on belief, but on rational and internally consistent explanations. Alternative explanations that are introduced need to be considered across the same breadth of evidence as the mainline explanations (e.g., taking exception to the greenhouse effect needs to be explained in the context of not just the Earth's atmosphere, but those of Venus and Mars, in results from Earth's paleoclimatic history, in laboratory experiments, etc.). Because science has been building a solid and interlocked explanation and not a house of cards, the suggestion that one aspect of the explanation is less certain than indicated does not, even if the criticism is true, cause the whole explanation to collapse. In general, analyses and findings presented in the Robinson et al. (2007) paper, as in the earlier paper, fail to expose their explanations to the full range of evidence and to come up with an alternative, self-consistent explanation.

4. Scientific papers typically explain the extent of and reasons for uncertainty in the arguments being made by the author(s), and not just in the views of other scientists. This paper makes quite a few assertions and offers considerable speculation supporting the authors' views without indicating providing the supporting evidence and indicating the uncertainties concerning often controversial lines of evidence. Assertion, and especially bold assertion and repetition, do not make a statement true. The authors of the Robinson et al. (2007) paper generally fail to apply the same level of scrutiny to their own arguments as they apply to the arguments of others.

5. In science, correlations are interesting, but they do not prove causality. The authors indicate a recognition of this, although they frequently fail to adhere to this principle, and in addition, they also assert that a lack of correlation disproves a point. This last assertion is just not the case, especially when there are multiple factors involved in, for example, affecting the

[1] For example, a compilation of comments sent in by some of those following realclimate.org is available at http://www.realclimate.org/index.php?title=OISM.

radiation balance and the time algs in the system. Indeed, science seeks to find explanations that are physically consisten and do not volate fundamental principles (e.g., asserting that small forcings can cause large consequences while large forcings will have no effect at all).

6. Certainly, uncertainties exist in the explanations of the causes and extent of past and future changes in climate—indeed, uncertainty is inevitable and can never be completely removed. However, the presence of uncertainty does not make a finding wrong—indeed, even the most plausible explanations have uncertainties.

7. It is important to keep in mind that uncertainties work both ways. Scientific tradition and analysis techniques—and especially the IPCC process--lead to defining uncertainties broadly enough to cover all possibilities that cannot be definitively ruled out. As a consequence, there is typically a range in the uncertainties around a best estimate or most plausible estimate, recognizing that the actual value or answer (if there is indeed a narrow one—and this is not always the case for a chaotic system) could be more than or less than the specified value, so possibly making the change larger or smaller than the most plausible estimate.

8. The IPCC is a process for the international scientific community to come to a consensus; it does not have an agenda other than the task assigned to it by the international Conference of the Parties of the UN Framework Convention on Climate Change. In the IPCC process, the lead authors are chosen to be experts that are knowledgeable in their field and capable of fairly representing the range of recognized expert understanding. The chapters that are prepared are charged with fairly representing the full range of the up-todate, peer-reviewed literature—narrowing the range of expert understanding only when there is good reason to suggest that this is justified by the sweep of current literature.

9. There are many ideas and findings in the literature that have been overtaken by newer research, so just because there was an article in the peer-reviewed literature some time ago or an out-dated argument is re-raised does not, without additional information and analysis, make the argument worth considering or worthy of inclusion in the latest assessments. The Robinson et al. (2007) article seems to frequently cite literature that is no longer considered to represent the level of understanding that has developed with the benefit of newer research.

10. The IPCC, being a process that involves developing consensus across a wide number of participants and reviewers, tends to be cautious in coming to conclusions and in ruling out of alternative explanations—thus, charging that the IPCC has too narrow a viewpoint really requires presenting arguments and alternative explanations with considerable care. What has been most apparent in considering the series of IPCC assessments is that the newest research findings are consistently leading to IPCC concluding that climate change is occurring more rapidly and intensely than indicated by the cautious findings in its previous assessment, so generally indicating that the situation is worsening.

11. IPCC's assessments are considered the most authoritative scientific summaries available. If one is going to pick and choose among their findings, as the Robinson et al. (2007) article does, then it is important to be especially rigorous in explaining the basis for taking exception--just saying one disagrees, whatever the level of one's expertise, needs to be explained thoroughly for the exception to be taken seriously. The Robinson et al. (2007) article does poorly in this regard.

12. Research on the climate change issue goes back many decades, and many smart people have been asking tough questions about it over this period—the questions this paper raises are not new, but have been asked and investigated many times. Through this effort, the underlying hypothesis that human-induced changes in atmospheric composition can cause significant changes in the climate has proven to be very solid. Asserting that some new criticism can overturn all that has been done fails to understand the depth and intensity of the testing and questioning. The notion of such human dominance has only prevailed recently, there being no other viable explanation for what is occurring.

13. Scientific papers tend to use cautious language without making value judgments or using value-laden words. This paper describes the hypothesis of human influence as "catastrophic," whereas the scientific question is whether it is valid or not. While it is fair to argue that higher confidence in the scientific findings about socially beneficial activities should be required before taking significant policy action, what the effect of a policy action might have on society is not relevant to evaluating the scientific likelihood of a particular outcome. The Robinson et al. (2007) paper, like the earlier one, tends to try to bias the scientific evaluation by intermixing fearful scenarios about what the consequences of particular policy actions could mean, when those are not nearly the only policy actions that could be taken.

14. Scientific review papers, such as this strives to be, try to be comprehensive in the references they use (or at least build upon those that IPCC uses, as their reviews are very comprehensive). Making narrow choices in the set of selected references, as is done here, rather than considering the findings of the full range in the literature, is not a characteristic of an authoritative scientific review.

15. Occam's Razor is a long-followed principle used in analysis of systems, particularly complex phenomena and systems. Basically it states that the explanation should be as simple and straightforward as possible, making the fewest assumptions. Physically based explanations are preferred over explanations based on undefined, imprecise, or immeasurable relationships. This principle also argues for preferring well-developed explanations over ones characterized by contradictions and assertions. That the Robinson et al. (2007) paper evidences so many of these problems tends to obscure the technical aspects of many of its arguments. The specific comments in the next section provide an alternative, and even more critical, critique.

**Specific Comments on the 2007 Paper by Robinson et al.**

***Abstract and throughout the article:***

This review is not put in the context of the many other reviews by highly respected organizations that have come to quite different conclusions. The statements here are in many cases assertions with no qualifications indicated, and, based on assessments by many other highly qualified experts across many fields, are not backed up by the findings in this paper and cited in the abstract.

***Summary Section:***

First paragraph: The conclusions drawn by the leaders in Kyoto, Japan in December 1997 (and by such leaders at the 1992 Earth Summit in Rio de Janeiro and at many later meetings) have been based on the evidence and findings presented in the assessments of scientific understanding prepard by IPCC and other authoritative bodies – not on fear.

Third paragraph and Figure 1: The text and the caption to Figure 1 focus on a record from the Sargasso Sea. The record shows no indication of uncertainties, and there is no reason to believe this record is typical for the world. Indeed, the very peaked nature of the record suggests that the location may be affected by shifts in currents or other problems—there is simply no way that the temperature of the whole world could just randomly shift by 2.5ºC over a couple of hundred years, as is suggested occurred at about 500 BC. Estimates for the past 1000 years and more developed by other scientists using various indicators from multiple proxy indicators suggest a different and much smoother record. Whether the "Medieval Climate Optimum" and the "Little Ice Age" were an Atlantic Basin phenomenon or a simultaneous global occurrence is scientifically controversial. It is an unsupported assertion that the Earth would naturally have recovered from the Little Ice Age (we do not nearly adequately understand its cause to assert this) and it is an unsupported assertion that the recovery would still be continuing. The comparison to the record of what happened at Valley Forge, which is just another point and for which no uncertainties in the results are indicated, suggests a significant problem in the analysis. Valley Forge is on land and so it would be expected that it would have larger variations, especially over one winter, than would typically occur for an ocean point because the ocean's heat capacity buffers temperature changes. Yet, the fluctuation at Valley Forge was "only about 1º Centigrade" whereas the ocean temperature changes over century long periods was as much as 2ºC. Very odd.

Fourth paragraph and Figure 2: The curve for changes in glaciers appears to be mainly for Europe, which essentially has to be the case for that is where data are available. It is not at all clear that this record represents the average for the globe. More significantly, showing a correlation with hydrocarbon use, shows no recognition of the roles of other factors (e.g., other gases, sulfate aerosols, changes in solar radiation and volcanic eruptions, etc.) in affecting the climate, or of how emissions from the use of coal, oil, and gas accumulate in the atmosphere and exert their influence on the climate. The analysis also fails to recognize that in very cold areas, some warming leads to more snow (e.g., lake effects snows around the Great Lakes) and glaciers can expand (e.g., in much of Antarctica, and Scandinavia)— interpretations are not nearly so simple and linear.

Fifth paragraph and Figure 3: Were the atmospheric temperature regulated only by the Sun, it would be frightfully cold at night; even in the polar night, temperatures do not fall to absolute zero. Conditions result from the interactions of many factors—and the Earth's greenhouse effect, which depends on the atmospheric composition of water vapor and other gases, is absolutely essential to determining the present climate. As one measure of the importance, the infrared radiation emitted from the atmosphere back to the surface, integrated over the world and day-night cycle, is more than twice as much as the solar radiation absorbed at the surface. Regarding the plot of solar radiation, the solar activity that is shown is inferred from changes in sunspot numbers, and recent satellite observations indicate that the inversion overestimates the variations in the amount of solar radiation reaching the surface. Again, considering a correlation with use of hydrocarbons makes no sense for it leaves out the roles of other factors.

Sixth paragraph: The assertion that "Figure 1 is illustrative of most geographical locations" is

simply not the case, and the references given here are very selective, especially in their geographical coverage. Results from other than the Atlantic basin are far too sparse to justify the assertion that the "current *Earth* temperature is approximately 1ºC lower than during the Medieval Climate Optimum 1,000 years ago [emphasis added]." Indeed, the "Medieval Climate Optimum" is a term characterizing the climate of northern Europe.

Seventh paragraph, Figures 4-6: In that it is widely recognized that variability decreases as one averages over larger and larger areas, one would think the search for a correlation with solar radiation would involve searching for correlations with the global average temperature rather than using the record over a comparatively small region such as the US. While it is encouraging that the authors are arguing that changes in various factors can cause changes in the climate, asserting that variations in solar radiation (and, as noted above, the particular reconstruction is not consistent with recent satellite observations) are the dominant explanation for multidecadal temperature trends (and presumably for the so-called recovery from the Little Ice Age) allows no room for other factors to play a role (other factors would include volcanic eruptions, greenhouse gases, sulfate aerosols, land cover change, etc.). The comparisons shown in Figure 6 are really of quite different things: the bar for "Earth Day-Night & Seasonal" is apparently the range between the maximum and minimum temperature anywhere on Earth at a given time or over the course of a season, irrespective of the characteristic of the location or of the role of other forcings (like the Sun going up and down and shifting over the seasons)—certainly the whole Earth does not change by this much. Similarly for the "Oregon Day-Night and Seasonal Temperature Range," comparing a range created by changes in the Sun's daily and seasonal cycle at a given point to changes in the average US temperature change over a century makes no sense at all.

Eighth paragraph: In that the loss of heat from the planet is proportional to the fourth power of the temperature (the Stefan-Boltzmann relationship), it makes no sense to equate a 0.5ºC temperature increase to a 0.21% change in absolute temperature; what matters is the energy flux, not the temperature. Drawing from Figure 5, a change in solar irradiance at the top of the atmosphere (that is, the flux coming at the Earth if looking directly at the Sun) of about 2 $W/m^2$ out of 1370 $W/m^2$ (so about 0.15%), leads to an increase in U.S. surface temperature of about 1ºC. But, this radiation (and the change in radiation) must be spread over the Earth (given that the Earth is a sphere), so divide by 4. In addition, about one-third of the incoming radiation is reflected by clouds, so, on a per square meter basis, Robinson et al. are suggesting that a change in absorbed solar radiation of 0.35 $W/m^2$ (and recent reconstructions of this change are smaller) is causing a change in temperature of 1ºC, giving a climate sensitivity of about 3ºC warming for an increase of 1 $W/m^2$. Atmospheric radiation models, which have been tested against laboratory experiments and performing in accord with observations for the atmospheres of Earth, Venus, and Mars, indicate that the increase in the $CO_2$ concentration alone that has been observed is contributing to an increase in the net downward flux at the tropopause (so at the top of the atmosphere-surface system) of about 1.6 $W/m^2$—so four to five times as much as the change in energy that the change in solar radiation is causing. Assuming, reasonably, that the response is proportional to the change in energy available (and it should not matter if the energy comes from a change in solar radiation or from a change in the downward radiation by greenhouse gases), the greenhouse gas induced change in radiation should have caused a current warming of about 5ºC —but the recent warming has been only about 0.8ºC. This inconsistency can only be resolved if: (a) the climate sensitivity is reduced

from 3ºC per W/m$^2$ to about 0.8ºC per W/m$^2$ (IPCC actually considers a range from 0.55 to 1.25), so roughly by a factor of 4 from that given by Robinson et al.; (b) the warming influences of all greenhouse gases and the warming and cooling influences of aerosols are considered; and (c) a lag in warming is created by the oceans and their quite large heat capacity. When this is done, results presented in IPCC's Fourth Assessment Report (AR4) indicate that, since the mid-19$^{th}$ century, there is very good consistency between the effects of the various climate-changing factors and the observed temperature changes, both at the global scale and over each continent.

Ninth paragraph and Figure 5: While the correlation may look impressive, it does not work out quantitatively, as explained in the discussion about the eighth paragraph—correlation is not necessarily causation, and, given that the two data sets are both flawed choices, the conclusion is simply not justified. In addition, because the temperature fluctuations are being caused by multiple factors, it makes no sense to simply compare them to the time history of fossil-fuel emissions.

Tenth paragraph: While people in a room might not notice a 0.5ºC change, there are many studies indicating that plant and animal species are responding to a temperature increase of this size. Indeed, referring back to Figure 1, Robinson et al. are suggesting that a 2ºC change is the difference between the warmth of the Medieval Climate Optimum and the depth of the Little Ice Age. In addition, paleotemperature data going back much further suggest that the temperature change from the present to a full ice age is only about 5-6ºC globally. While there are a number of problems with Figure 1, it does seem that the authors are indicating that, as other results show, a widespread and persistent temperature change of as little as 0.5ºC does indeed make a difference—and cannot simply be dismissed.

Eleventh paragraph, Figures 7-10: As noted earlier, there is no clear indication that the warming since the mid-19th century is a recovery from the Little Ice Age—the solar flux change alone seems unable to explain it if one uses the generally agreed climate sensitivity. Regarding Figure 7, not only is rainfall over the US increasing, but its average intensity is increasing. Regarding tornadoes, the database on tornados is controversial, generally being said to be showing an overall increase in number (whether due to more complete observation or changes in climate is undetermined), but there is no decrease in tornados occurring. Note that Figure 8 is for only the months March to August; in 2008, there were tornadoes in Wisconsin in January, so the full season needs to be considered. Regarding hurricanes and Figures 9 and 10, there is some indication that hurricanes are, on average, increasing in peak intensity and in destructive power over their lifetimes; changes in hurricane number are indeed uncertain.

Twelfth paragraph and Figures 11-12: The database on glacier shortening is quite limited until recent decades. Regarding sea level rise, contrary to the caption to Figure 11, the satellite record finds that sea level is currently rising at about *twice* the rate recorded by the coastal tide gauge network for the 20$^{th}$ century. As to the rise beginning before the increase in fossil-fuel use, it is important to remember that there are multiple factors that can contribute to sea level rise, including changes in land cover, damming of rivers, pumping of groundwater, etc., the time histories of each of which need to be considered. There are also multiple factors that can cause changes which would contribute to sea level rise, including the cooling influence of volcanoes and sulfate aerosols, that need to be considered before suggesting there is a contradiction with the finding that use of fossil fuels will lead to sea level rise.

Thirteenth paragraph: Supposed problems with simple correlations that are ignoring the influence of the many factors affecting the climate cannot be used to justify the assertion that "human use of hydrocarbons has not caused the observed increase in temperature." The IPCC chapter on detection and attribution indicates clearly how the roles of the many factors can be fit together in a coherent, internally consistent manner.

Fourteenth paragraph: The assertion that the "extent and diversity of plant and animal life have both increased substantially during the past half-century" is very imprecise. There is no indication that there has been any increase at the global level—evolution does not work that fast. At the local level, there are regions with both increases and decreases. However, as climate change is shifting the boundaries of preferred ranges, increases in many locations are resulting from the unintended introduction of non-native and invasive species, often due to global transport of people and goods.

Fifteenth paragraph: Paleoclimatic data such as the ice cores from Greenland do make clear that the Earth's climate can change quite rapidly, including experiencing dramatic shifts over a few years. This has most often occurred when the Earth was colder than at present. The National Academy of Sciences carried out a very interesting study on the potential for abrupt changes (NAS, 2002). In addition, drilling of ice cores in Greenland indicates that it was only about 50% covered by ice during the last interglacial about 125,000 years ago when the global average temperature was roughly 1ºC higher than at present. Remnants of beaches on low-latitude islands from that time suggest that sea level peaked at 4-6 meters above its present level during that interglacial. Such a rise would be catastrophic for many coastal cities, especially if the change took place over a few centuries or faster.

Sixteenth paragraph: While further improvements in climate models are certainly needed, the se models have become quite sophisticated tools for studying the Earth system and climate change. In that the notion of modeling the atmosphere goes back to before the first computer, presumably computer technologies should also be said to be in their "infancy," so that is a rather inapt criticism. That human activities are responsible for all of the $CO_2$ increase since preindustrial times has been determined from a number of studies of changes in carbon isotope concentrations over time—there is no indication that the change in the $CO_2$ concentration is due to natural causes. As to the effects being "benign," the changes have only just begun and there is no indication that increases in temperature, precipitation intensity, occurrence of drought and wildfire, melting of sea ice and glaciers, and sea level rise will continue to be benign.

Seventeenth through nineteenth paragraphs: It is certainly true that the combustion of fossil fuels provides many vital services to the world's population. Actions proposed to reduce global warming do not envision reducing these energy services—indeed, the scenarios for the future envision a significant increase in the energy services provided. What would change is the source of the energy for providing them and the efficiency with which they are provided. Quite a number of estimates of the economic cost of making the transition suggest that the cost would build over a few decades to be less than 1-2% of global GDP, which would be pretty much in the noise when spread over several decades (being equivalent to foregoing perhaps 4-6 months of global growth out of 50 years).

Twentieth paragraph: It is true that the climate has changed over recent centuries and longer, but by nowhere near as much as is projected for the 21$^{st}$ century if reliance on fossil fuels

continues unabated. Over the past few centuries, society has become more and more attuned to the existing climate (e.g., buildings are designed for the current weather, coastal city locations are based on current sea level). The change in temperature projected for the 21st century is roughly half as much as occurred going from a glacial maximum to the present— the coming changes will be very significant.

Twenty-first paragraph: Every indication is that most of the major changes in climate over Earth's history were caused by some physical change—whether changes in the distribution and timing of solar radiation caused by cycling of the Earth's orbital parameters, volcanic eruptions, variations in solar output, freshwater outbreaks through ice dams, etc. The degree of background fluctuations is apparently quite small, with most changes in global climate being forced by identifiable changes in forcing factors. With human activities sharply changing atmospheric composition, large changes in climate seem inevitable based on the Earth's paleoclimatic history.

***Section entitled "Atmospheric and Surface Temperatures"***

First and second paragraphs: As indicated earlier, the interpretation of the climate of the last 1,000 years is controversial, and the Sargasso Sea temperature record does not reflect the variable global pattern of conditions. The suggestion of the temperature recovering from the Little Ice Age does not explain how it got perturbed and why it should recover. Third paragraph: The claim that the "historical record does not contain any report of 'global warming' catastrophes" is simply not true. The Sahara desert and Mesopotamia were quite lush several thousand years ago as civilization dawned—the climate changed and they became quite arid. The Anasazi tribes of the southwestern US were doing quite well until the climate became much more arid, and they were scattered to the winds. Fourth paragraph: Great care has been taken in putting together the hemispheric and global records. In any case, averaging over larger areas gives much more representative results than recording the conditions for a single point. The logic used by the authors is upside down. Fifth and sixth paragraphs and Table 1: The locations covered by the cited analysis were mostly from the North Atlantic basin. The metaanalysis done in the reference cited did not require the changes to be simultaneous—just occurrence of even a short warm period during a several century interval. Given the natural spatial fluctuations of the climate, there is really little indication that the global climate played out as the authors suggest (NRC, 2006). Seventh to tenth paragraphs: The coastal locations and elevations of Phoenician salt flats and Roman baths suggest that sea level was near constant for the few millennia preceding the mid-19th century, at which time sea level rise began. Contrary to the text, satellite data indicate that the rate of rise since 1993 has been about twice the rate in the century before that time (IPCC, 2007a), and newer data suggest an even higher rate of rise. Regarding the correlation to fossil fuel use, it fails to consider: (a) that other factors can affect sea level (including groundwater pumping, land clearing, reservoirs, etc.); and (b) the response of sea level to greenhouse gases is delayed by the time it takes to warm and then melt glaciers, and for heat to get absorbed in the ocean and be moved downward to cause thermal expansion. As to the correlations mentioned regarding Figure 12, there is no data shown for the temperature change over this period, despite the claim of a lag in the caption. Eleventh to thirteenth paragraphs: Comments on much of this has been made earlier. Regarding Figure 15, it is also the case that irrigation in rural areas (and on golf courses) tends to reduce the temperature response. Indeed, one must be careful, and account for potential biases, and this has been done in compiling the global data sets (in addition, the oceans are warming, and no

one lives there, so that is not an urban effect). The argument at the end of these paragraphs that the best correlation is with solar radiation and not with fossil fuel use fails to consider either the quantitative issue of climate sensitivity discussed above or the roles of each of the various factors. For example, fossil fuel use also led to emission of $SO_2$ that was chemically transformed to sulfate aerosol and exerted a strong cooling influence on the climate during the mid-20$^{th}$ century when the observed cooling was taking place.

Fourteenth to sixteenth paragraphs and Figure 14: Recent studies have provided a lot more insight into the issue of tropospheric versus surface temperature changes (e.g., Karl et al., 2006). Of major importance has been recognition of shortcomings in the observations, which have had to be corrected for several factors, including changes in the height and timing of the satellite orbits (the satellites measure radiance that is inverted, using a radiation model, to estimate temperature—satellites do not measure temperatures directly). Basically, the results here are out-of-date, being based on what have been found to be biases in the observations.

Seventeenth to nineteenth paragraphs: This is all argued based on correlations—not a causal factor explanation. The dismissal of the role of fossil fuel emissions by simple correlation neglects the roles of the many factors contributing to climate change and the complicated processes and time lags that are involved. In addition, satellite measurements have shown that the solar reconstruction is not correct (IPCC, 2007).

Twentieth and twenty-first paragraphs: Asserting that "non-correlation proves non-causality" is just non-sense. Multiple factors are involved in affecting the climate and relative magnitudes and timing and mechanisms matter—not simply correlations. Accepting the assertion that human hydrocarbon use is not affecting the climate violates Occam's Razor, for there is no explanation of how quite small solar variations can cause large climatic responses whereas comparatively large greenhouse gas-induced changes in heating have no effect. More than that, one has to explain how a reduction in solar radiation over recent decades is consistent with strong global warming. The assertion of self-consistency of the authors' explanation simply does not hold up, not only against the Earth's climate, but also in how planetary climates and Earth system history work.

**Section entitled "Atmospheric Carbon Dioxide"**

First paragraph: Listing the human contribution to $CO_2$ emissions here is rather misleading. The fossil fuel sources transfer carbon from being sequestered underground (where it has resided for many tens of millions of years) into the atmosphere-upper ocean-biosphere system, whereas the $CO_2$ that humans exhale is from carbon taken up by the land biosphere, so already in the atmosphere-upper ocean-biosphere system. Thus, the former increases the amount of carbon cycling in the active reservoirs, while the latter simply is part of the active exchanges taking place. Not differentiating is like failing to note the difference between new money coming into a mutual fund and the amount that is there being cycled through purchases and sales of stock. Third paragraph: The recent rise in the $CO_2$ concentration has been definitively related to human activities by isotopic and other studies; this sentence is only acceptable because determining all the fluxes and terms "with certainty" (i.e., without any uncertainty) is not scientifically possible. With respect to past concentrations, over at least the last 750,000 years, ice core records indicate that the range has been from about 200 ppm during the coldest parts of glacial cycles to about 300 ppm during the warmest parts. Going back further,

concentrations may have been 1500-2000 ppm during the much warmer Cretaceous, which ended about 65,000,000 years ago with the impact of a large asteroid that apparently ended the period of dinosaurs. Going back further in time makes little sense.

Fourth to sixth paragraphs: It is true that the increase in $CO_2$ lags the increase in temperature in the ice core records covering about the last 750,000 years. This is to be expected, and occurs because, for the natural climate system, warming caused by changes in the shape and characteristics of the Earth's orbit around the Sun cause a shift of carbon from the ocean to the atmosphere as the world warms (just as $CO_2$ comes out of a cold soda as it warms). Because of its greenhouse effect, the resulting release of $CO_2$ causes more warming and more out-gassing, thus creating a positive natural feedback mechanism. Combusting fossil fuels provides an alternative mechanism for the rise in the $CO_2$ concentration, but once there, the added CO2 will cause additional warming just as happened during the glacial cycling.

Seventh through ninth paragraphs: This ratioing approach to estimating responses to the $CO_2$ concentration fails to recognize the roles of other factors (like changes in the Earth's orbital elements), the interplay of various processes, and the time it takes for the start of forcing to cause changes (e.g., for the oceans to warm). To keep track of all of these interactions requires quantitative models and the rigorous quantitative consistency they demand. When models are used, the outcomes the authors get can be explained as basically ill conceived; indeed, the climate system behaves as the IPCC has been suggesting and the physics explaining the ice-core record and human-induced warming are self-consistent.

Tenth and eleventh paragraphs: The authors are mixing up the lifetime of a particular $CO_2$ molecule in the atmosphere, which has been observed to be a few years based on bomb carbon-14 measurements, and the persistence time of the excess $CO_2$ added to the atmosphere-upper ocean-biosphere system that determines the atmospheric $CO_2$ concentration. Because this persistence time is determined by the slow rate that the additional carbon is transferred from the upper to the deep ocean, the half-life of the atmospheric persistence time is of order a century or more (it depends on the various gradients in concentration that are created, which means it depends to some extent on the rate of emission). Because the deep ocean is saturated, it cannot really accommodate all the $CO_2$, so once mixing through deep ocean waters occurs, the persistence time of the elevated $CO_2$ concentration is determined by the rate of removal of the excess $CO_2$ to the ocean sediments, and this is a very slow process, meaning that a fraction of the elevated concentration will persist not just for centuries, but for many millennia.

Twelfth paragraph: This comparison of human production of $CO_2$ to the amount in the total ocean was a criticism of the original Arrhenius hypothesis of 1896. It took until the observational studies of Revelle and Seuss in the 1950s to come to understand that the ocean is not well mixed, the deep ocean having a circulation time to the surface of about 1000 years. So, even if full uptake of the human contribution could occur (and the comparison should not be with the annual rate of emission, but with total emissions over time, which is now several hundred gigatons of carbon), the mixing the authors suggest would take millennia, and during the interval, the atmospheric concentration would be sharply elevated (just as is occurring). The authors mention that a "transient increase" will occur, and, indeed, that is what we are seeing, but the duration of the transient is very long.

Thirteenth paragraph: For scientists, how things happens matters. Understanding the "sources and amounts" is critical to getting beyond the unjustified correlations that this paper relies on.

***Section entitled "Climate Change"***

First paragraph: I am glad to see that the authors agree that a small change in temperature can cause important impacts (we apparently mainly disagree on the cause of the warming). Second paragraph: Arctic sea ice has been decreasing very sharply. Antarctic sea ice is not decreasing (likely due to processes relating to ocean circulation in the Southern Ocean), but the ice sheet on Antarctica is losing mass, based on recent satellite evidence. In that it is ice in ice sheets that determines changes in sea level, that the Antarctic ice mass is decreasing is contributing to sea level rise. Third paragraph: Indeed, diversity and plant mass are increasing in high elevations (and also in the Arctic), but as this happens, the species that were there are being pushed to extinction. So, locally, the variety of species goes up, but globally it goes down. And while new, hotter than ever environments are created, it is unlikely new species will evolve to fill in as fast as existing species are pushed to extinction. The net effect is projected to be a very large global loss of species, even as some regions have a greater variety of species than they did before. Fourth through seventh paragraphs: Comments on these points have been made earlier. The claim that "[a]ll of the observed climate changes are gradual, moderate, and entirely within the bounds of ordinary natural changes" is belied by what is happening in the Arctic, where the remarkable changes are unprecedented for the peoples who have lived there for millennia. That the Greenland and Antarctic ice sheets are both starting to lose mass is an early indication of very large sea level rise in the coming decades and centuries.

***Section entitled "Global Warming Hypothesis"***

Second paragraph and Figure 18: With respect to the radiative influence of $CO_2$, it can seem minor when looked at from the surface and treating the troposphere as a single layer—from this perspective, water vapor looks dominant. However, the water vapor concentration drops off sharply with altitude, so that in the upper troposphere and stratosphere, $CO_2$ plays a very large role and water vapor's role is greatly reduced. The problem with Hypothesis 2 is that if this were the answer, there would be no way to explain the very large changes in climate that occurred over Earth history (much less the natural greenhouse effect and the climates of Mars and Venus). The models cited by IPCC do not predetermine the response—they are based on fundamental physical relationships and some parameterizations that have a strong empirical basis. Based on these equations, the models generate the response—it is not something that is assumed, but emerges out of the physics. With respect to the processes described in the papers that are cited as leading to Hypothesis 2, all have a number of important shortcomings and no quantitative representation of them has succeeded in being able to explain the present seasonal cycle of climate over the Earth, much less climate change. Third paragraph and Figure 19: Models do have uncertainties—like democracy, however, they are better than any of the alternative ways for understanding and projecting climate change, and they are much better and more rigorous than the correlation-based speculation relied on in this article. Models are quantitative and objective, are based on fundamental physical relationships, and represent the integral of scientific understanding of the climate system. They are constantly being tested and evaluated, and they show substantial agreement with observations. Figure 18 is seriously out of date and has grossly over-estimated the problems with models.

The comparison to the flux change for $CO_2$ doubling is inappropriate—the other bars (all apparently based on peak values at any single location on Earth) refer to what are generally

called systematic errors (or offsets) that would be present in both a control and a perturbed model simulation, whereas the change in $CO_2$ would be present in only the perturbed simulation. There is no indication that the systematic errors have a significant effect on the calculation of the overall response of the climate to a perturbation (just as different mutual funds based on the same investment priorities tend to have the same response to a change in the market). Recognizing the importance of the uncertainties, scientific results are generally provided as bands of possibilities—a much more rigorous approach than the casual correlations relied on in the authors' analyses. With so much discussion of the complexities of the climate system, one would think the authors would be much more cautious in the assertion of their degree of understanding of it.

Fourth to sixth paragraphs: The authors keep focusing on simple correlations, showing no recognition of the competing effects of various factors or of the time scales involved in going from emission to response. Even if increasing solar radiance contributed to the warming up to the mid-20$^{th}$ century, since then solar radiation has been stable or decreasing, and yet the amount and rate of warming has increased. The looseness of their analysis seems to just ignore such inconsistencies.

Seventh paragraph: Of course, the change in climate is not based on the $CO_2$ influence alone—that is not how the Earth system works. When $CO_2$ is added to the atmosphere, it changes the radiation balance and this initiates changes in everything else—and this is why it takes models to keep track of the various interactions; simple correlations make no sense at all.

Eighth paragraph: The Sargasso Sea figure is for a single point; there is no basis for using this record alone as a global record of changes. Some of the changes likely result from small shifts in ocean currents that have little global effect—and these cannot be differentiated from the changes that indicate a global change. The conclusion is just totally unsupported. Even if the record here is correct, no evidence is presented for what is going on elsewhere (like the Anasazi civilization breaking apart due to drought in the southwestern United States).

Ninth paragraph: There is no basis here for differentiating the $CO_2$ and methane effects—the assertion of methane having no effect is simply not justified. In addition, the methane concentration has again started to rise, which is could contribute to an acceleration in the rate of warming.

Tenth paragraph: Climate models represent the integration of our understanding. Indeed, they are theoretical, but they have done quite well in explaining a range of situations (e.g., diurnal, seasonal, interannual, centennial, and glacial/interglacial variations). It is true that the situation we are facing with rapidly changing atmospheric composition is unprecedented, so we cannot be sure the models are correct—but there is virtually no justification for believing they are far off.

Eleventh paragraph: The climate models do not try to calculate the impacts—only the types of changes in climate that occur—the projected impacts are inferences about the future. Some of the impacts are very soundly based. For example, as the $CO_2$ concentration increases, more is dissolved in the ocean, and this changes the chemistry of the ocean, causing "ocean acidification;" observations indicate a change in the depth at which the calcium carbonate dissolves, and this change is consistent with the changing ocean acidity. Heat-caused deaths are not due to the slow rise in average temperature, but to the higher peak changes and longer duration of heat waves—and the associated failure to design cities so that people do not get

overheated. The final assertion is simply not scientifically justified—climate change cannot be dismissed by unsupported assertions such as made in this article.

***Section entitled "World Temperature Control"***

First paragraph: Global temperatures are controlled by the conditions of the climate system that influence the global energy balance, and human activities are affecting this, so the temperature is not controlled by natural processes alone. Second paragraph: The present distribution of temperature is optimum largely because we have adapted to it over the past several centuries. Had the conditions been different, we would likely have tried to adapt to them and called that temperature optimal for society. The statement that "we can cool the Earth with relative ease" is totally unsubstantiated—actually, we have much more experience with adding greenhouse gases that can warm (and are warming) the Earth. Third through fifth paragraphs: As volcanic eruptions make clear, increasing the loading of stratospheric aerosols does lead to a number of quite possibly important side effects. In addition to the cost estimates being mostly guesses, there has been virtually no study of the patterns of climate response if this is done. Further, and relevant to this article's point of view, all of the studies on this have been done with the very computer models that the authors find inadequate. Interestingly, the model results, at least to some extent, seem contrary to our understanding of how ice age cycling works (that is, it seems reasonable to expect that changes in solar radiation and changes in the $CO_2$ concentration might cause different patterns of climate change, but this is, somewhat surprisingly, apparently not the case). With respect to the claim that "[w]orld energy rationing, on the other hand, would not work," the issue is not about energy used, but about how it is derived. Studies indicate that a significant part of the transition to non-fossil energy could be done for about 1-2% of GDP or less—this would hardly spell the end of civilization.

***Section entitled "Fertilization by Plants"***

First paragraph: The problem is that being at "ultimate equilibrium" takes many, many millennia, and in the interim we will have a very substantial non-equilibrium increase. Second paragraph: While individual plants would absorb more, the degree of warming, drying, and increase in occurrence of fire may well limit the overall increase, which is what matters. In addition, the oceans are expected to be absorbing less $CO_2$ as warming increases their stability and reduces the upwelling of nutrient rich waters that supply the marine biological pump. As a result, the rise in the land biomass uptake is unlikely to be sufficient to moderate climate change. Further, at 600 ppm, ocean chemistry will be dramatically modified, basically starting to dissolve most coral formations. Third paragraph: While the $CO_2$ concentration has risen, much of the rise has been recent so that the climate has yet to have the decades needed to fully adjust—we are seeing only part of the response. In addition, sulfate aerosols are offsetting some of the warming influence, but this effect would diminish if $CO_2$ emissions were diminished sufficiently to keep its concentration level. Fourth paragraph: The claim that $CO_2$ enhances plant growth enough to substantially increase carbon storage assumes adequate water and nutrients. Also, the resulting biomass may well be less nutritious to animals, and weeds and pests tend to respond much more than the desirable plants. In addition, fire incidence seems likely to go up.

Sixth through ninth paragraphs and Figures 23-24: The problem with the figure for calculating impacts is that it fails to make clear that the actual amount of biomass that is produced varies dramatically between the two cases—while the "not resource limited" case shows a smaller percentage growth, its actual increase in growth dominates the actual increase for the

"resource limited" case—so, dryland farmers might well get a higher percentage increase, but their actual increase will be less than for farmers with rich soils and irrigation or precipitation, so the competitive disadvantage of dryland farmers will grow, not shrink.

Last sentence: Despite the essential role of $CO_2$ for life, under the Clean Air Act, human-created emissions of $CO_2$ are, by interpretation of the US Supreme Court, to be treated as are other air pollutants.

***Section entitled "Environment and Energy"***

Third paragraph: Reducing use of fossil fuels by 90% will clearly take time—it took time (and lots of subsidies, many still remaining) to build up to this level, and it will take time to change (and subsidies to renewables have been trivial in comparison). Economic studies by many groups suggest the cost of changing might grow over a few decades to no more than 12% of GDP (more argue less than more), not something that makes the goal unachievable if innovation and flexibility are encouraged. Fifth paragraph: The assertion that there "are no climatological impediments to increased use of hydrocarbons" is true only if one captures the $CO_2$ that is created and sequesters it underground. Rest of discussion: There is general agreement about the value of establishing a level playing field, but this requires not only removing subsidies, but also internalizing the environmental and social costs of each technology. For fossil fuels, this would include the costs of climate change, ecosystem impacts, etc. as well as the health and air pollution costs. Once that is done (and the proposed carbon tax or permit fee is one way of doing this), then the various technologies should be expected to compete. Right now, improvements in efficiency are generally viewed to be by far the least expensive option in the US—this is not giving up energy services, but getting them much more cost effectively. Beyond that, the US and other countries would likely most benefit from having a mix of technologies, each appropriate to fulfilling its special role in its region—there is no one answer for everywhere in the world.

***Conclusions section***

First through sixth paragraphs: The authors conclusion is in opposition to the carefully and thoroughly reviewed scientific assessments of the international community and the findings of all the major national academies of science of the world—that should give the authors some pause in their unqualified assertions.

***References***

Generally the references provided are from a quite small and carefully selected representation of scientists rather from the full international community—suggesting an unwillingness to be open to the full range of findings of the scientific community. The IPCC considers a much broader and more complete set, and has included consideration of the points raised in the references used to justify the points given in this paper and found them seriously wanting.

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