R.Abraham
https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=showPoup&documentId={19EF7D88-8BE1-4200-A07C-74F01C4169A5}&documentTitle=20158-113193-03
REBUTTALS TO: Happer, Lindzen, Spencer, Bezdek
SURREBUTALS BY: Happer, Lindzen, Spencer, Bezdek
.
Detailed debunk, especially of research papers by Lindzen or Spencer that were rapidly refuted. (Happer has none.)
pp.45-68 CV
pp.69-89 "REVIEW OF THE CONSENSUS AND ASYMMETRIC QUALITY
OF RESEARCH ON HUMAN-INDUCED CLIMATE CHANGE"
p.73 "To explore this potential, we have identified two of the most prominent arguments made against the AGW consensus:
1) the climate is not warming and
2) the Earth is not very sensitive to climate change and there are strong natural processes which will moderate climate change emissions continue to rise (negative feedbacks)."
p.76 "Figure 1. Evolution of lower tropospheric temperature trends from satellite observations." UAH corrections

BEFORE THE MINNESOTA OFFICE OF ADMINISTRATIVE HEARINGS
600 North Robert Street
St. Paul, MN 55101

FOR THE MINNESOTA PUBLIC UTILITIES COMMISSION
121 Seventh Place East, Suite 350
St Paul, MN 55101-2147

In the Matter of the Further Investigation into Environmental and Socioeconomic Costs Under Minnesota Statute 216B.2422, Subd. 3

PUC Docket No. E-999/CI-14-643
OAH Docket No. 80-2500-31888

DIRECT TESTIMONY OF DR. JOHN ABRAHAM,
Professor of thermal sciences, University of St. Thomas School of Engineering

On Behalf of

Clean Energy Organizations

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I. EXPERT EXPERIENCE

Q. Please state your name, title, and business address.

A. Dr. John P. Abraham, Professor, thermal sciences, University of St. Thomas School of Engineering, 2115 Summit Ave., St. Paul, MN 55105-1079.

Q. On whose behalf are you testifying?

A. I am testifying on behalf of Minnesota Center for Environmental Advocacy, Fresh Energy, Sierra Club, and the Izaak Walton League of America – Midwest Office (collectively the "Clean Energy Organizations").

Q. Please describe your education, and professional and work experience.

A. I am a professor of thermal sciences. I specialize in the topics of heat transfer, fluid mechanics, climate change, and numerical modeling. I teach the above-referenced topics in formal courses and/or in lectures, and I carry out both basic and applied research in these areas. My research encompasses, but is not limited to, climate change, ocean warming, climate sensitivity, numerical modeling, paleoclimate research, and renewable energy. I have published multiple peer-reviewed papers and given multiple conference presentations on these topics. In total, I have produced approximately 120 journal papers, over 100 conference presentations or major public lectures, and more than 20 books, edited works, book chapters, and patents. I have published in journals such as Climate, Reviews of Geophysics, Science Bulletin, Ocean Engineering, Atmospheric and Oceanic Science Letters, Journal of Earth Science and Climate Change, Developments and Applications of Oceanic Engineering, Geothermics, International Journal of Heat and

Mass Transfer, Journal of Heat Transfer, Numerical Heat Transfer, Journal of Marine Biology and Oceanography, and many others. My Curriculum Vitae is attached as Schedule 2 to this testimony.

II. OVERVIEW OF TESTIMONY

Q. What is the purpose of your testimony?

A. I have been asked by the Clean Energy Organizations to respond to several opinions and assertions offered in the direct testimony submitted by Dr. Roger Bezdek, Dr. William Happer, Dr. Roy Spencer, and Dr. Richard Lindzen on behalf of Peabody Energy.

Q. Have you reviewed the Direct Testimony submitted by Dr. Roger Bezdek, Dr. William Happer, Dr. Roy Spencer, and Dr. Richard Lindzen in this proceeding?

A. Yes.

Q. Can you summarize your response to that testimony?

A. Yes. My summary of opinions is as follows:

- Human emissions of greenhouse gases have warmed the planet and will continue to warm the planet into the foreseeable future.
- The effects of global warming are evident throughout the Earth system.
- Claims by Drs. Spencer, Lindzen, Happer, and Bezdek that the warming has stopped, that models are not accurate, or that the effects of climate change will be beneficial are inaccurate and misleading.
- Claims by Drs. Spencer and Lindzen that the Earth is not very sensitive to greenhouse gas emissions are made using faulty information. They have relied upon studies which have been shown to be incorrect and have been corrected in

the peer-reviewed literature. Drs. Spencer and Lindzen have neglected the most recent and accurate publications in their direct testimony.

- The claim by Drs. Spencer, Lindzen, Happer, and Bezdek that models are not accurate is based on ignoring 99.8 percent of the Earth climate system and even then, is presented in a misleading manner. When their information is properly shown, it is seen that most satellite temperature results are in closer agreement with models than they have suggested.
- There is a strong consensus among the world's top climate scientists that human emissions are significantly affecting the Earth's climate. The very small minority of scientists who hold a contrarian view have, as a whole, published work which has been found to be faulty and has been corrected in the scientific literature.
- Drs. Spencer, Lindzen, Happer, and Bezdek rely upon non-scientific sources of information; many are from advocacy groups or political news organizations. Other statements are made without justification.

Q. How is climate sensitivity to increasing concentrations of carbon dioxide ("CO_2") related to whether the Federal Social Cost of Carbon is reasonable and the best available value to measure the damage to society caused by CO_2 emissions?

A. The models used to develop the Federal Social Cost of Carbon rely on assumptions regarding equilibrium climate sensitivity. The Interagency Working Group ("IWG") that developed the Federal Social Cost of Carbon used a probability distribution consistent with the equilibrium climate sensitivity assumptions of the Intergovernmental Panel on Climate Change ("IPCC").

Q. What is "equilibrium climate sensitivity"?

A. The equilibrium climate sensitivity is the temperature rise experienced by the Earth after some change to the amount of greenhouse gases in the atmosphere. Most commonly (and here), the change to greenhouse gases means a doubling of carbon dioxide. The equilibrium climate sensitivity is therefore the change in equilibrium temperature of the Earth after CO_2 has doubled.

Q. What is meant by the "probability distribution" of this sensitivity?

A. A probability distribution is a measure of the likelihood that the sensitivity is some value, or within some range. For instance, according to multiple lines of evidence (paleoclimate, climate models, the instrumental record, and others), it is deemed likely that the equilibrium sensitivity is between 1.5 and 4.5°C with high confidence, and it is deemed extremely unlikely that the sensitivity is less than 1°C, also known with high confidence.

Q. In your professional opinion was it reasonable for the IWG to rely on the probability distribution consistent with the equilibrium climate sensitivity assumptions of the IPCC?

A. Yes.

Q. Can you briefly summarize the prevailing view of human-caused climate change held by the scientific community?

A. Yes, see my Report, Summary of the Prevailing View of Human Caused Climate Change, attached to this testimony as Schedule 1. This Report discusses the fact that the climate is changing and that humans are a major reason. The changes are manifest across the globe by rising temperatures, loss of ice, rising seas, ocean acidification, and more extreme weather events. These trends will continue and get worse into the future. Fortunately, as a society, we can take meaningful action now to reduce the long-term threat of climate change. While we cannot reverse climate change, we can make the impacts smaller. Failure to reduce emissions will result in added costs to society into the foreseeable future.

Our understanding of climate change is strong and a very powerful consensus has emerged. The vast majority of the experts are in agreement that humans are a major cause of climate change. The very few scientific contrarians have not produced a viable alternative explanation to the observed events. It is important to rely upon the highest quality and most recent peer-reviewed science in order to make informed decisions about how to mitigate and adapt to this threat. It is also important not to rely upon non-reviewed information submitted by advocacy organizations.

III. SPECIFIC RESPONSES OR CORRECTIONS

Q: Are there specific statements in the direct testimony of Drs. Lindzen, Spencer, Happer, and Bezdek that you would like to address and/or correct?

A. Yes. In this document, I will address a number of claims made by Drs. Spencer, Lindzen, Happer, and Bezdek in which they misinterpret or misrepresent the science. These witnesses have selectively chosen evidence that minimizes the threats of climate change. In many cases their evidence is from advocacy organizations rather than from the peer-reviewed literature. In other cases, they have found a select number of studies, often authored by themselves, which support their claim. However, they have neglected to inform readers that many of these works have been found to be in error and have been corrected in the peer-reviewed literature. These witnesses have neglected to be forthcoming about these errors and their corrections. Furthermore, these witnesses have ignored the vast majority of research which is counter to their position. Finally, in a number of instances, these witnesses present opinions with no justification or background.

Q: On page 8 of Dr. Spencer's direct testimony and on page 5 in his Exhibit 2, Dr. Spencer claims that the Earth's sensitivity to carbon dioxide is low. Do you agree?

A. No. He is incorrect. Dr. Spencer relied upon his own research to claim that the Earth's sensitivity to greenhouse gases was far lower than a generally agreed-upon central estimate of approximately 3°C for a doubling of carbon dioxide (citing to Spencer and Braswell, 2014). Shortly after the appearance of Dr. Spencer's paper, errors were discovered and a correcting study was published (*see* Abraham et al., 2014a[1]). I was a co-author of this correcting study and we found that Dr. Spencer and his colleague made a series of serious mistakes which invalidated his conclusion. Some of the errors were with basic mathematics and others were because of a faulty understanding of climate change. Among the many errors we identified, we corrected a subset of them and found that Dr. Spencer had underestimated actual results. Our work was submitted for peer review and was published in the scientific literature. Dr. Spencer was aware of our correction of his

[1] A complete list of references cited in this testimony appears at the end.

results,[2] but to my best knowledge he has not refuted our work in the peer-reviewed literature nor has he published any corrections for the mistakes made in his work.

Q. Are you aware of whether the IWG has responded to similar criticisms?

A. Yes**.** The IWG published its response to comments in July 2015. With respect to comments related to climate sensitivity, the IWG stated:

> At the time the 2013 SCC update was released, the most authoritative statement about ECS [equilibrium climate sensitivity] appeared in the IPCC's AR4. Since that time, as several commenters noted, the IPCC issued a Fifth Assessment Report that updated its discussion of the likely range of climate sensitivity compared to AR4. The new assessment reduced the low end of the assessed likely range (high confidence) from 2°C to 1.5°C, but retained the high end of the range at 4.5°C. . . . The IWG will continue to follow and evaluate the latest science on the equilibrium climate sensitivity and seek external expert advice on the technical merits and challenges of potential approaches prior to updating the ECS distribution in future revisions to the SCC estimates, including (but not limited to) using the AR5 climate sensitivity distribution for the next update of the SCC.[3]

Q: Dr. Lindzen, Dr. Spencer, Dr. Bezdek, and Dr. Happer all assert that global warming stopped approximately 20 years ago. Do you agree?

A. No. They are incorrect.

The excess heat entering the Earth is manifested in many parts of the climate. Figure 1 shows the sizes of various thermal reservoirs of the Earth's climate system. In the figure, I have separately identified the lower part of the atmosphere and a region of the atmosphere which was particularly addressed by Drs. Spencer, Lindzen, Happer, and Bezdek (the

[2] Roy Spencer website, accessed June 22, 2015, http://www.drroyspencer.com/2014/10/our-initial-comments-on-the-abraham-et-al-critique-of-the-spencer-braswell-1d-model/.
[3] Response to Comments: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, July 2015, at 12. The complete response of the IWG related to issues of climate science can be found at pages 11-17.

Tropical Mid Troposphere). The atmosphere in general is a very small part of the climate and the part that these witnesses focus on in particular is even smaller still (it comprises approximately 1/500 of the Earth's system).

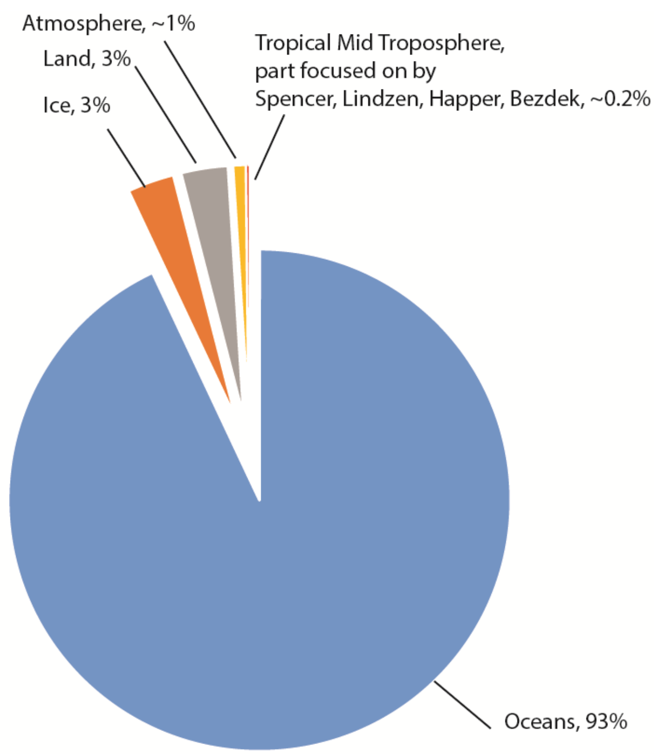

Figure 1. Various thermal components of the Earth system

To quantify climate change, a more accurate approach is to look at the largest thermal reservoirs. Figure 2, which shows ocean heating, is the clearest evidence that the Earth is warming. Any claims that this warming stopped approximately 20 years ago are unsupported from these measurements.

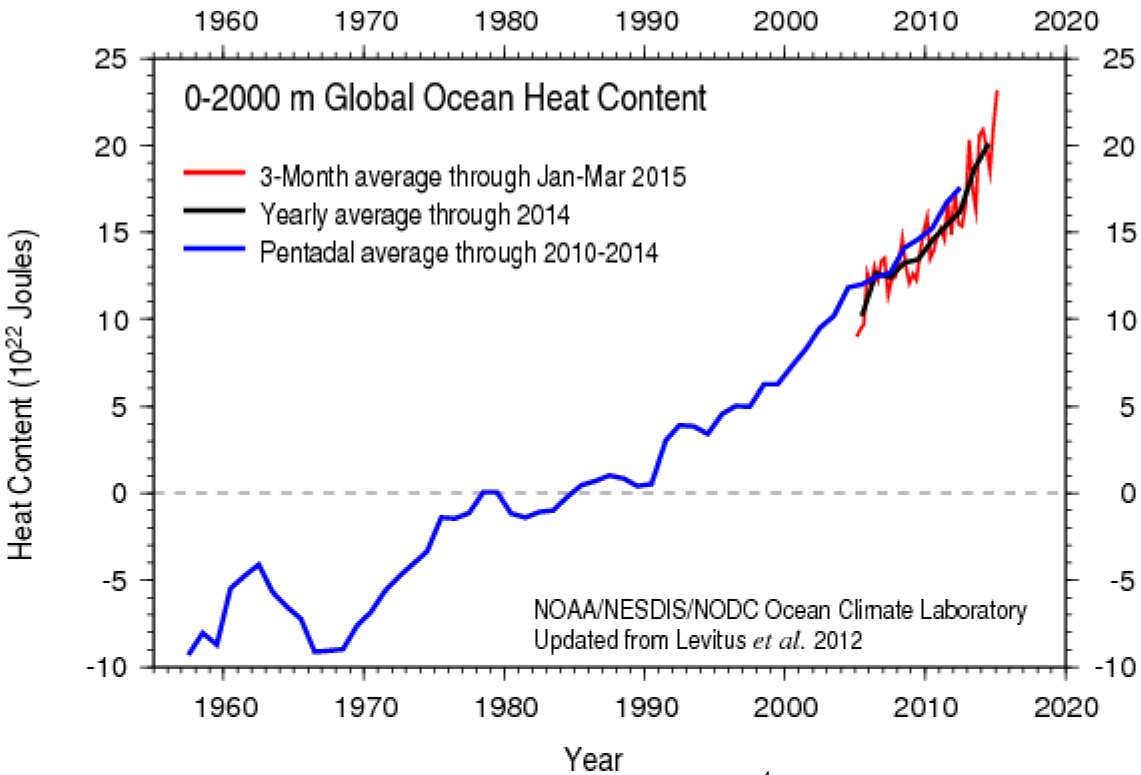

Figure 2. Ocean heat content anomalies, since the 1950s[4]

Q. Is there other evidence that the Earth has continued to warm over the last two decades?

A. Yes. We are also observing sea level rise which is expected to continue to rise to approximately three feet by 2100 (displacing approximately 150 million people worldwide). The reason sea level is important to this discussion is that a major reason the seas are rising is that they are warming (warmer water expands). Consequently, a rising sea is a way to measure global warming. Another thermal reservoir is the cryosphere (ice regions) and they too are decreasing in mass, this fact reinforces observations from the oceans. For example, glacier ice is being lost on the vast majority of glaciers, according to

[4] Graph available at http://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/ (last visited June 22, 2015).

the World Glacier Monitoring Service. In an article just published in the *Journal of Glaciology*, Zemp et al., 2015 conclude that "the rate of early 21st century mass loss are without precedent on a global scale… [which] implies that glaciers in many regions will very likely suffer further ice loss, even if the climate remains stable." Arctic sea ice (National Snow and Ice Data Center), Greenland ice (Arctic Report Card), and Antarctica ice is also being lost (Scambos and Abraham, in press and references therein).

Measurements of temperatures in the ground are also increasing (discussed in Gorman et al., 2014, and references contained therein), and surface temperatures over both oceans and land regions, shown in Figure 3 from NASA, clearly show an increase in temperatures over the past two decades.

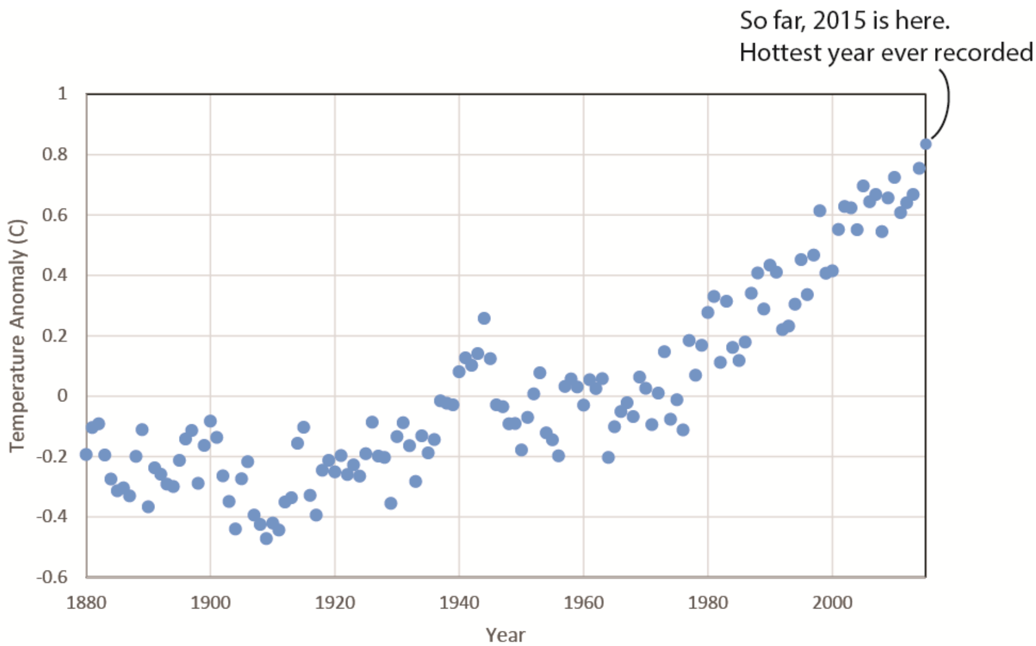

Figure 3. Changes to surface temperatures across ocean and land regions[5]

[5] From NASA GISTEMP with current year-to-date value for 2015 (data.giss.nasa.gov).

Q. Are your assessments of the continued warming over the last two decades supported by peer-reviewed academic literature?

A. Yes. Three recent papers are particularly relevant and none finds a significant decrease in the surface warming rate (Karl et al., 2015; Foster and Abraham 2015; Cahill et al., 2015). According to a summary by NOAA[6] of the Karl et al., 2015, study:

> A new study published online today in the journal *Science* finds that the rate of global warming during the last 15 years has been as fast or faster than that seen during the latter half of the 20th century. The study refutes the notion that there has been a slowdown or 'hiatus' in the rate of global warming in recent years.

Similarly, Foster and Abraham, 2015, used statistical tests to evaluate the claim of a slowdown and found none. Importantly, Foster and Abraham, 2015, performed the test to increase the likelihood that a slowdown would be found by halting their analysis at 2013. If the latest years (2014 which is the hottest year recorded and 2015 which is currently even hotter than 2014) were included in the analysis, their findings of no slowdown would be even stronger. Cahill et al.,2015, considered four different temperature records (NASA, NOAA, HadCRUT, and Cowtan and Way) and they concluded that the comments from the opposition experts are not supported by their statistical analysis. These three mutually supported scientific studies, along with other measurements of oceans and ice, show that global warming has not stopped.

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[6] Available at https://www.ncdc.noaa.gov/news/recent-global-surface-warming-hiatus.

Q: Have you read the claims by Drs. Lindzen, Happer, Bezdek, and Spencer that models overpredict global warming and do you have an opinion?

A: Yes, I have, and, in my opinion, Drs. Lindzen, Spencer, Bezdek, and Happer are incorrect. Computer models are ways of calculating the effect of various influences on the Earth's climate. Influences include changes to greenhouse gases, changes to solar variability, volcanic eruptions, and many others. Models are one of the tools scientists use to predict the future climate (other tools include paleoclimate studies, instrumental temperature changes, and measurements of current energy imbalance). Models have been found very helpful in the past and have been reinforced by real world measurements. Drs. Spencer, Lindzen, Happer, and Bezdek all claim that models overpredict climate change and consequently future warming will not be as large as most scientists predict. This claim is false on two accounts. First, models are not overpredicting climate change. Second, as stated earlier, the predictions from models agree with other methods (for instance measurements, energy balance calculations, and paleoclimate studies). These modes of investigation are mutually reinforcing.

Q. Why do you claim that models are not overpredicting climate change?

A. A recent study just published shows that models have slightly *underestimated* warming in the upper 700 meters of the oceans over the past few decades (Cheng et al., 2015). As noted earlier in my testimony, the world's oceans are by far the largest thermal reservoir. Figure 4 compares models with observations.

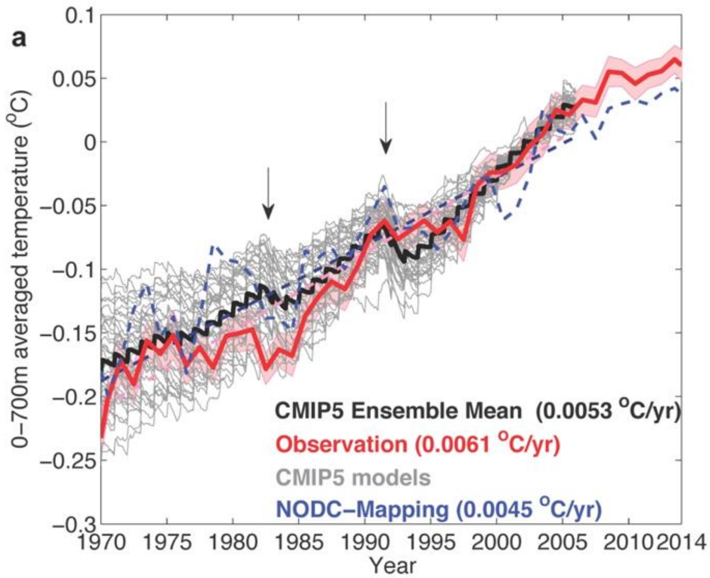

Figure 4. Comparison of measurements with model predictions[7]

Models have also underestimated ice loss significantly (Stroeve et al., 2007), as seen in Figure 5.

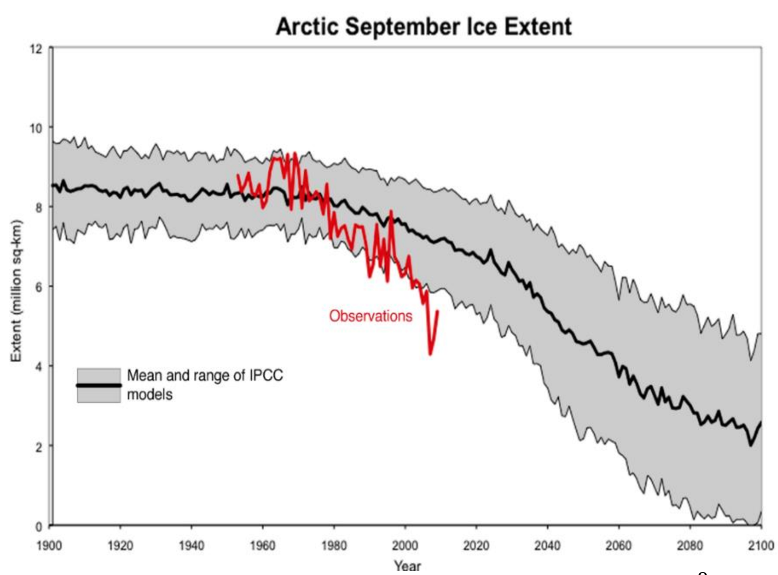

Figure 5. Comparison of predictions and observed Arctic ice loss[8]

[7] Cheng et al., 2015.
[8] Updated from Stroeve at el., 2007, available at http://nsidc.org/icelights/2011/02/23/is-dirty-air-adding-to-climate-change-2/.

Q. What about the models that focus on surface temperatures—do those models overpredict climate change?

A. No. Figure 6 compares surface-temperature models with observations. Annotations on the left of the image indicate which temperature dataset corresponds to a particular color. Figure 6 shows that the 2015 temperature is nearly identical with the predicted value. The comparison is the red star with the center dashed line within the grey region.

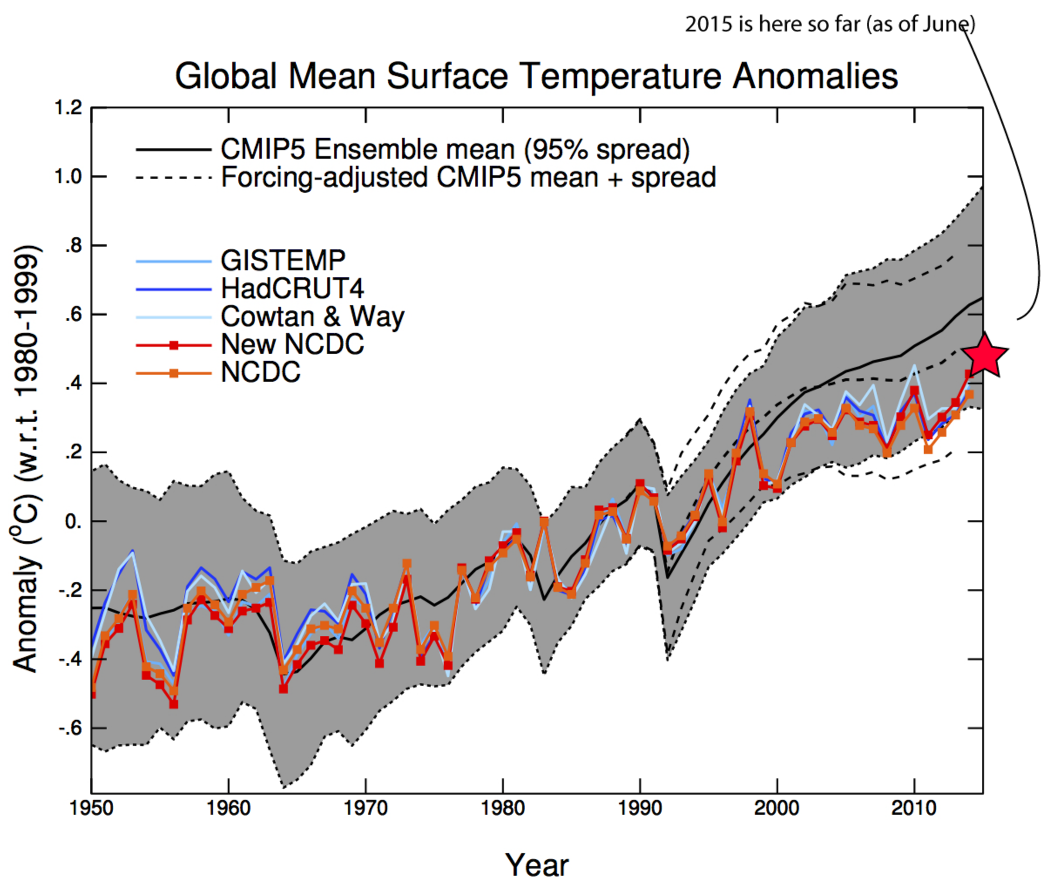

Figure 6. Comparison of computer models and observations of surface temperatures[9]

[9] Updated from Schmidt et al., 2014.

What is also important to note is that, with respect to Figure 6, models should actually be hotter than measurements. The reason for this is that measurements use temperatures of the ocean surface (temperature of the water) and models report temperatures of the lower air. This apples-to-oranges comparison means that the air temperatures in Figure 6 should be below the middle dashed line of the model. According to the results of the recently published Cowtan et al., 2015, when this difference is factored in, models are actually underpredicting surface warming.

The most important issue to determine is whether models get the big picture correct. When one considers the thermal reservoirs from Figure 1, the clear answer is that they do. Furthermore, any general statements that models systematically overpredict warming are demonstrably false.

Q. What is the basis for Drs. Spencer, Lindzen, Happer, and Bezdek's claims that models overpredict climate change?

A. Drs. Lindzen, Happer, and Bezdek, include a figure in their testimony,[10] reproduced below in Figure 7, which focuses on a portion of an upper layer of the troposphere. To my best knowledge, the image has not appeared in a scientific paper or as a result of a scientific study. Rather, it was prepared for a non-scientific congressional testimony. This figure appears to show that a portion of the Earth climate (approximately 0.2 percent) is warming much slower than the models predict.

[10] *See* Bezdek Ex. 2 at 62, Fig. III-6 (citing Spencer, 2013); Happer Ex. 2 at 6, Fig. 4; and Lindzen Ex. 2 at lines 290-309.

A more complete interpretation of the results shows that this image is highly misleading. The image shows an average of two satellite temperature datasets (RSS and UAH). However, it would be more instructive to separately show the individual datasets, which would show a large difference between the datasets that is lost in the image. In fact, a recently published paper looked into this topic (Po-Chedley et al., 2015). The authors state: “Large differences in tropical TMT trends between this work and the University of Alabama [Spencer’s team] are attributed to differences in the treatment of the NOAA-9 target factor and the diurnal cycle correction.”

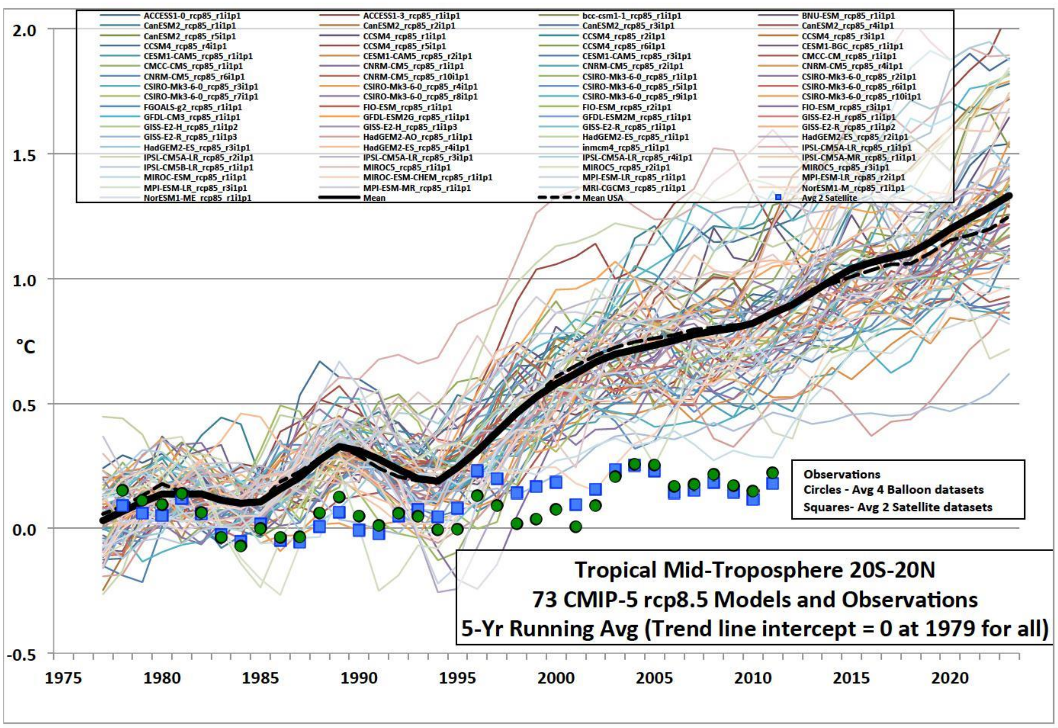

Figure 7. Image from Lindzen, Happer, and Bezdek direct testimony which misrepresents satellite temperature trends.

The authors of Po-Chedley et al., 2015, compared five different calculations of tropical mid-troposphere temperature trends (heating rate) over the same period as Figure 7. They present the results shown in Table 1, which shows that Dr. Spencer's data (UAH) is by far the coolest of the entire group. Dr. Spencer's data show temperatures increasing at approximately 25 percent of the other groups. A more honest presentation of the different results would be to show the individual results of each study, rather than simply an average of the two coldest results, as was done in Figure 7.

Table 1. Various warming rates of the mid-troposphere from different research groups[11]

Group	**Warming rate (°C/decade)**
UW method 1	0.114
UW method 2	0.124
NOAA	0.105
RSS	0.089
UAH	0.029

Finally, Figure 7 was created to magnify differences between models and satellite measurements. When comparing two sets of climatologic data, it is necessary to use a similar baseline period (typically a decade or longer). This was not done in Figure 7 as evident by the fact that the temperatures throughout the 1980s and 1990s differ significantly. It appears that the two sets of data may have been given initial values that were equal (which shows that the use of the graph confuses weather with climate). This misleading presentation is made to show larger differences between models and measurements that are, in reality, small.

[11] Po-Chedley et al. 2015.

When this information is considered as a whole, we see that the arguments that models overpredict warming are based on a very small portion of the Earth's climate system (approximately 0.2 percent) and Drs. Spencer, Lindzen, Happer, and Bezdek ignore the vast majority of available evidence. Furthermore, the presentation given is not an accurate representation of the actual data. Finally, Drs. Spencer, Lindzen, Happer, and Bezdek neglect to mention several recent studies which corrected faulty observations and brought them more in line with the models.

Q. Have you read Dr. Lindzen's claim that the trend of decreasing Arctic Sea ice has reversed, and do you have a response?

A: Yes. He is incorrect.

On page 7, line 2, of his testimony, Lindzen makes the claim that: "Even where trends exist, such as summer Arctic ice cover, the reduction has reversed in the last few years." He makes a similar claim on page 10, line 23. Figure 8 depicts the measured June sea ice since approximately 1980, according to the National Snow and Ice Data Center. This image shows a long term trend of decreasing ice. While there are year-to-year fluctuations, ice experts focus on the long term trend, indicated by the black line.

Dr. Lindzen's assertion that the reduction has reversed this trend is without merit. As can be seen in the image, such an assertion could have been made 13 prior times in the record, and it would have been wrong each time. Additionally, the ice maximum reached this year was the lowest ever recorded, providing further evidence that there is no reversal in the long term trend (National Snow and Ice Data Center).

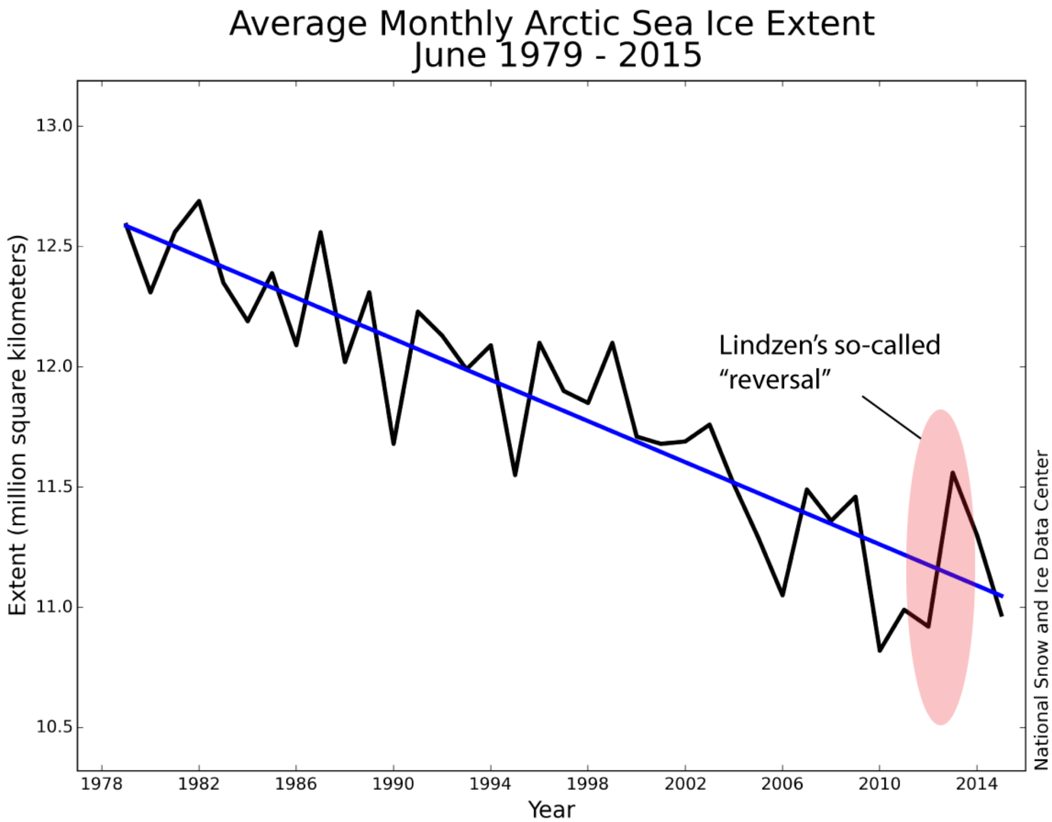

Figure 8. June Arctic sea ice extent, from National Snow and Ice Data Center.

Q. Have you read Drs. Lindzen and Happer's claims that there is no evidence of changes to extreme weather and do you have a response?

A. Yes. They are incorrect. Both Drs. Lindzen and Happer cite to non-peer-reviewed statements to support their assertions.[12] Lindzen instead cites to a popular press book (Pielke Jr., 2014). The views of Drs. Lindzen and Happer on this matter conflict with the scientific literature. A summary of the peer-reviewed science is provided in my report attached as Schedule 1, which demonstrates the evidence of increasing frequency and intensity of extreme weather events.

[12] *See* Happer Direct Testimony at 9 and Lindzen Direct Testimony Section 5, lines 544 *et seq*.

Q. Dr. Bezdek claims that there is no consensus in the scientific community regarding climate change. Do you agree?

A. No. I have co-authored a study addressing this issue, Abraham et al., 2014b, which is attached as Schedule 3 and summarized below.

Q. What is the mainstream view that is held by the climate-science community?

A. We often hear the claim that 97 percent of the world's climate scientists agree that humans are causing climate change. This phrase is used with good reason because it has been supported over a period of years with multiple studies that have assessed consensus in different ways. The mutual support of the studies provides compelling evidence that there is a very strong consensus among scientists. What is now also known, is that the contrarian views (such as those of Drs. Spencer and Lindzen in particular), have been found to be of low technical quality and have been corrected in the normal process of scientific exploration.

Q. Can you explain why you reached the conclusions in your report that (1) there is near unanimity of consensus on the basic tenets of Anthropogenic Global Warming ("AGW"), (2) the expertise of the scientists who agree with AGW is greater than of those that dissent, and (3) the results are robust to various means of measure?

A. Yes. The basis for these conclusions was drawn from mutual support of many independent studies (Oreskes, 2004; Zimmerman, 2008; Doran and Zimmerman, 2009; Anderegg et al., 2010; Farnsworth and Lichter, 2012; Cook et al., 2013). A major reason for the conclusions contained in this article was that the few contrarian scientific publications that exist were rebutted or corrected at a very high rate. Since the publication of Abraham et al., 2014b, even more contrarian papers have been found to be in error and numerous corrections have been published within the past year. This fact makes even stronger the conclusions of Abraham et al., 2014b.

Q. Do the studies cited by Dr. Bezdek support his claim that the scientific consensus surrounding climate change is a "manufactured myth?"

A. No. Studies that have polled both climate scientists and non-climate scientists found that a respondent's climate expertise is positively correlated with their view that humans were responsible for climate change, as discussed above. This means that the more people know about climate science, the more certain they are that humans are causing climate change. The studies cited by Dr. Bezdek must therefore be viewed through this lens.

Moreover, Bezdek's summary of a 2012 American Meteorological Society survey is demonstrably false. He claimed that "A survey by the American Meteorological Society found that only 25 percent of respondents agreed with the UN IPCC claims that humans are primarily responsible for recent warming." In fact, a large majority from that survey stated that humans were either a primary cause or a force approximately equal to that of natural influences (Maibach et al., 2012).

In summary, all of the scientific studies which have been carried out on the consensus of climate experts lead to two conclusions. First, there is a strong consensus. Second, the consensus gets stronger with expertise (the more expert a scientist is in climate research, the more likely they are to recognize human influences).

Q. Have you read the opinion of Dr. Spencer that satellite measurements have a high degree of accuracy and do you have a response?

A. Yes. I disagree.

As discussed in Abraham et al., 2014b,[13] despite claims of accuracy from Dr. Spencer and his team, other researchers began to question the results (Hansen and Wilson, 1993; Schneider 1994; Hurrell and Trenberth, 1997; Hurrell and Trenberth, 1998; Wentz and Schabel, 1998) and raise many questions regarding the purported accuracy of the satellite measurements. The specific errors uncovered throughout the years regarding Dr. Spencer's satellite measures are discussed in detail in Abraham et al., 2014b, and in the Rebuttal Testimony of Dr. Andrew Dessler submitted in this proceeding.

With this well-documented history of errors and inaccuracies, it is clear that over-reliance on satellite measurements of a tiny fraction of the Earth's climate system is inappropriate to use as a benchmark of climate change.

[13] The discussion in Abraham et al., 2014b, on the errors of past work of Drs. Spencer and Lindzen does not include the very recent and new corrections to their work (Po-Chedley et al., 2015; Sherwood and Nishant., 2015) which were not available at the time of publication.

Q. Have you read the opinion of Dr. Spencer (page 5, line 19) that surface temperatures measurements are biased because of land-use or urban heat islands effects and do you have a response?

A: Yes, this is not an issue.

While it is true that the urban heat island effect and land use changes can influence temperature measurements, this issue has been looked at in great detail by a number of teams. The strong conclusion is that they are a negligible influence. First, the urban heat island effect and land-use changes do not influence ocean temperatures which cover approximately 70 percent of the Earth's surface. Second, the major datasets remove the influence of urban locations. For instance, Hansen et al., 2010, uses satellite-observed night lighting to identify urban stations. Similarly, Hausfather et al., 2013, showed that adjustments used in the Global Historical Climatology Network dataset removed much of the urban/rural differences in the U.S. Interestingly, Roy Spencer's colleague John Christy and other climate-change skeptics published a work in 2011 (Fall et al., 2011) which found that poorly sited sensors lead to an "underestimate of maximum temperature trends."

Recently, an entirely new global temperature dataset was created in part to look at this issue (Berkeley Earth, http://berkeleyearth.org/about/). The creators of this dataset report that:

> From 2010-2012, Berkeley Earth systematically addressed the five major concerns that global warming skeptics had identified, and did so in a systematic and objective manner. The first four were potential biases from data selection, data adjustment, poor station quality, and the urban heat island effect. Our analysis showed that these issues did not unduly bias the record.

Therefore, I agree with the conclusion expressed in the Fifth IPCC Assessment Report that "it is unlikely that any uncorrected urban heat-island effects and land use change effects have raised the estimated centennial globally averaged land surface air temperature by more than 10 percent of the reported trend."

Q. Have you read the opinion of Dr. Lindzen that the Earth's climate has a naturally occurring thermostat for limiting temperature increases (the Iris Effect) and do you have a response?

A. Yes. I disagree.

One attempt to suggest an actual mechanism was published in 2001 (Lindzen et al., 2001). While this concept gained much media attention, it was quickly and thoroughly rebutted within the scientific literature. Within approximately one year of publication of Lindzen et al., 2001, four refuting papers appeared (Fu et al., 2001; Hartmann and Michelsen, 2002; Lin et al., 2002; del Genio and Kovari, 2002). These papers included numerous criticisms of the Lindzen et al., 2001, and invalidated the findings.

The critiques of Dr. Lindzen continued throughout the years (Chambers et al., 2002; Lin et al., 2004; Rapp et al., 2005; Wong et al., 2006; and Trenberth and Fasullo, 2009). The large volume of responses show that the scientific community took seriously the initial hypothesis but, despite years of investigation, found little evidence to support the conclusions of the proponents, and much evidence contradicting these conclusions.

I again refer to Abraham et al., 2014b, which discusses this in detail.

Q. Have you read the opinion of Drs. Lindzen and Spencer that the Earth's climate has low climate sensitivity or other negative feedback which will limit warming and do you have a response?

A. Yes. I disagree.

Papers with the theme of low sensitivity/negative feedbacks from Drs. Spencer and Lindzen have continued to appear in the literature. Among the most prominent was that of Spencer and Braswell, 2008. Shortly after its appearance in the literature, this manuscript was heavily criticized in a study that identified three significant errors (Murphy and Forster, 2010). When these errors were corrected, the effect that was originally reported in Spencer and Braswell, 2008, nearly disappeared.

A similar near-contemporary to the Spencer and Braswell study was published in 2009 (Lindzen and Choi, 2009). This paper was quickly responded to in the literature (Murphy, 2010; Trenberth et al.,2010; Chung et al., 2010; Dessler, 2010; Dessler, 2013). A follow-on paper (Lindzen and Choi, 2011) was similarly rebutted by Dessler, 2011, on methodological grounds. The large number of errors in these papers and the very quick

http://www.nytimes.com/2012/05/01/science/earth/clouds-effect-on-climate-change-is-last-bastion-for-dissenters.html?pagewanted=3&_r=3 "Dr. Lindzen acknowledged that the 2009 paper contained "some stupid mistakes" in his handling of the satellite data. "It was just embarrassing," he said in an interview. "The technical details of satellite measurements are really sort of grotesque.""

correction of the identified errors within the scientific literature is highly unusual. I know of no other paper in any field of science ever published that was rebutted four times by four science teams in the year following the faulty paper's publication.

One final example along this theme was published in 2011 (Spencer and Braswell, 2011). This paper was quickly criticized by scientists in the media for its unsupported claims. The Editor-in-Chief of the publishing journal acknowledged and agreed with those criticisms; he resigned shortly after the paper was published (BBC, 2011) stating that the journal failed "to identify fundamental methodological errors or false claims" and that the "paper should therefore not have been published" (Kerr, 2011). A rebuttal in the literature appeared promptly (Trenberth et al., 2011), demonstrating a number of errors in the original paper. As a result, the major conclusions of Spencer and Braswell, 2011, were shown to be arbitrary and depend on subjective assumptions. The resignation of an editor because of the poor quality of a paper published in a journal is also a highly unusual event.

It can therefore be seen that the opinions of Drs. Lindzen and Spencer rely heavily upon their own research which has been found to be faulty by their peers and in the peer-reviewed literature.

Among the other pieces of evidence reported by the opposition experts are reports or articles from advocacy groups such as the Cato Institute, Wall Street Journal, the climateaudit.org website, as well as a recent paper (Monckton et al., 2015) which has already be found to be in error (Richardson et al., 2015).

Q. Do you have any conclusions on the quality of source information Peabody Energy's witnesses rely upon to form their opinions?

A. Yes. The information these witnesses rely upon is substandard for scientific discussion.

The gold standard for quality information in the sciences is peer-review. Subjecting research to peer review is essential (but not sufficient) to guarantee its quality. Using non-reviewed advocate-based information is inappropriate for a scientist or researcher, particularly in an area outside their expertise.

In the Direct Testimony of Dr. Bezdek for instance, great liberty was taken with non-scientific documents. References 7, 10, 12, 13, 14, 22, 23, 29, 31, 36, 37, and 50 are from advocacy organizations such as the Heartland Institute, the George Marshall Institute, Cato Institute, and the Global Warming Petition Project. His references 17, 18, 29, 47, 48, and 54 are from online or print news sources many of which are self-acknowledged as politically biased.

Many of his claims, such as "Similar rates of growth cannot be sustained by other fuel sources, such as renewables, because they are unreliable, intermittent, expensive, and are not scalable" have no supporting documentation or analysis. In fact, we have seen rapid growth here in Minnesota of clean, renewable energy in the past decade and it continues into the foreseeable future. On page 17, Dr. Bezdek forecasts a $10 trillion benefit from CO_2 fertilization without any supporting documentation or inclusion of the scientific literature on this topic. Finally, on page 33, he states that there is no indication of increased extreme weather events. This statement is contrary to the peer-reviewed science which I have already discussed and is discussed in Schedule 1 to this testimony.

IV. CONCLUSION

Q. Based on your understanding of the equilibrium climate sensitivity used by the IWG to develop the Federal Social Cost of Carbon values, do you have any concerns about the reasonableness of the Federal Social Cost of Carbon value?

A. No. In my opinion the climate science underlying the IWG's development of the Social Cost of Carbon is sound and consistent with the consensus position of scientists and professionals with expertise in climate science.

Q. Does this conclude your testimony?

A. Yes.

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SUMMARY OF PREVAILING VIEW OF HUMAN-CAUSED CLIMATE CHANGE

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August 2015

Human emissions of greenhouse gases such as carbon dioxide are exerting a major influence on the Earth's climate.

The warming is manifest in many ways throughout the climate. It is found in the increasing ocean temperatures, rising sea levels, melting land ice (glacier ice and loss of ice sheet mass atop Greenland and Antarctica), rising atmospheric temperatures, and increases to land temperatures, among others. The evidence paints a compelling picture.

There are many external influences that affect the Earth climate, including greenhouse gases, changes to solar output, variations of the Earth's orbit around the sun, changes to land surface (deforestation for instance), and changes to the number of particulates which reflect sunlight in the atmosphere. Among the human influences on the Earth, the release of greenhouse gases dominates any natural effects.

Scientific understanding of greenhouse gases was developed in the 1800s; the first predictions of global warming were made more than 100 years ago. Subsequently, our understanding of the climate has become more advanced; however, the general understanding that there is a strong link between greenhouse gases and temperature has remained.

The climate sensitivity of the Earth is estimated to be 1.5-4.5°C (approximately 3-8°F) to a doubling of carbon dioxide. Earth's climate sensitivity is estimated in a number of ways including past climate variations (paleoclimate), modern computer simulations, and the observational record. Since approximately 1900, we have seen increases in Earth temperatures and in the amount of greenhouse gases in the atmosphere. Figure A1 shows the change in atmospheric carbon dioxide since the late 1950s.

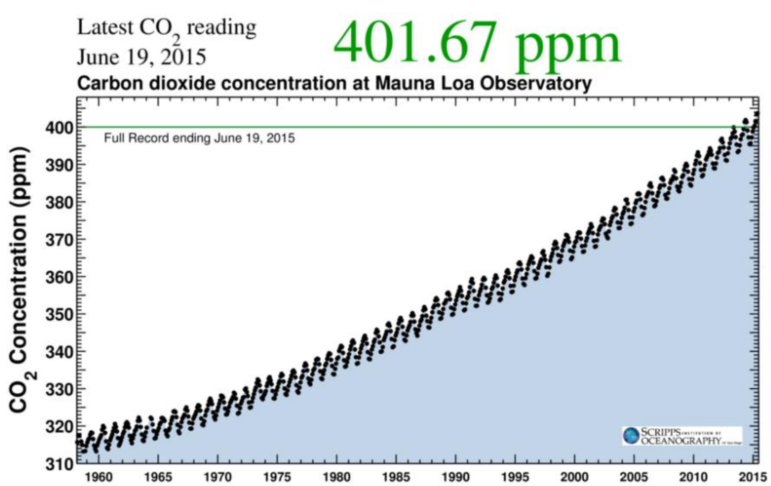

Figure A1 – Increase in atmospheric carbon dioxide (Keeling Curve)

The warming that we have observed, and the corollary observations, will continue into the future. There are already some extreme weather phenomena which are made more frequent or more intense with climate change. A sample of recent studies have clearly connected heat waves and droughts to human-induced climate change. For instance, in Hansen et al., 2012, the authors conclude that:

> This distribution of seasonal mean temperatures has shifted toward higher temperatures and the range of anomalies has increased. An important change is the emergence of a category of summertime extremely hot outliers…. This hot extreme which covered much less than 1% of the Earth's surface during the base period, now typically covers about 10% of the land area. It follows that we can state, with a high degree of certainty that extreme anomalies, such as those in Texas and Oklahoma in 2011 and Moscow in 2010 were a consequence of global warming[.]

Other studies have evaluated the influence of greenhouse gases and global warming on the thermodynamic state of the atmosphere. They too have found that events are made more severe by human emitted greenhouse gases (Trenberth et al., 2015). Many other studies show similar outcomes, for instance Abraham et al., in press, and the references contained therein deal with increases to intense precipitation events, Diffenbaugh et al., 2014, and others related to severe thunderstorms, as well as changes to atmospheric patterns shown in Francis and Vavrus, 2012, and Horton et al., 2015. These studies are intended to be representative, not exhaustive. They connect global warming to current severe weather and make predictions of future changes.

Further, Dai, 2011, a study which connected drought to sea surface temperatures, reported: "The warming in the Indian Ocean is likely related to recent global warming, which is largely attributed to human-induced greenhouse gas increases." And later:

> Besides the El Nino-related drying, the above results show that the recent surface warming has enhanced evaporative demand over land and contributed to the drying since the 1980s. Because a large part of the recent surface warming is attributed to human-induced greenhouse gas increases, we conclude that anthropogenic greenhouse gas increases have contributed to the recent drying over land. Furthermore, the increased GHGs likely have contributed to the warming in the Indian Ocean and the tropical Pacific, which in turn have contributed to the drying in Africa and East Asia, respectively. Therefore, we can conclude that human activities have contributed significantly to the recent drying over land.

Similarly, Wang et al., 2014, studied the 2013-2014 California drought and found that, "there is a traceable anthropogenic warming footprint in the enormous intensity of the anomalous ridge during winter 2013-14, the associated drought and its intensity."

Many other studies can be cited (Trenberth et al., 2014; Adam et al., 2009; Ault et al., 2014) for more information and projections of drought risk into the future. For some perspective, Figures A2 and A3 are provided which show, respectively, the extent of drought in the United States in 2012 and 2015. These droughts are unusual and present financial and social costs.

With respect to how unusual some of these events are, Griffin and Anchukaitis , 2014, investigated the recent drought in California and found that "the current event is the most severe in the last 1200 years." Clearly the evidence shows that the current events are unusual.

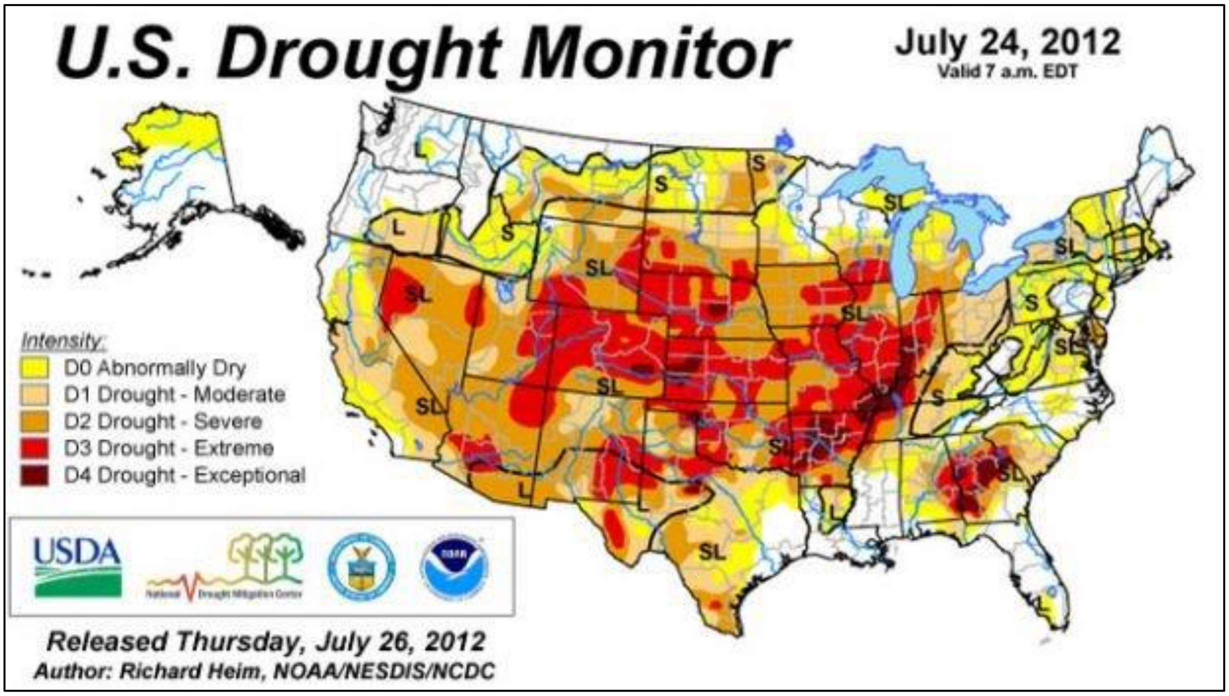

Figure A2 – US Drought monitor, data from July, 2012

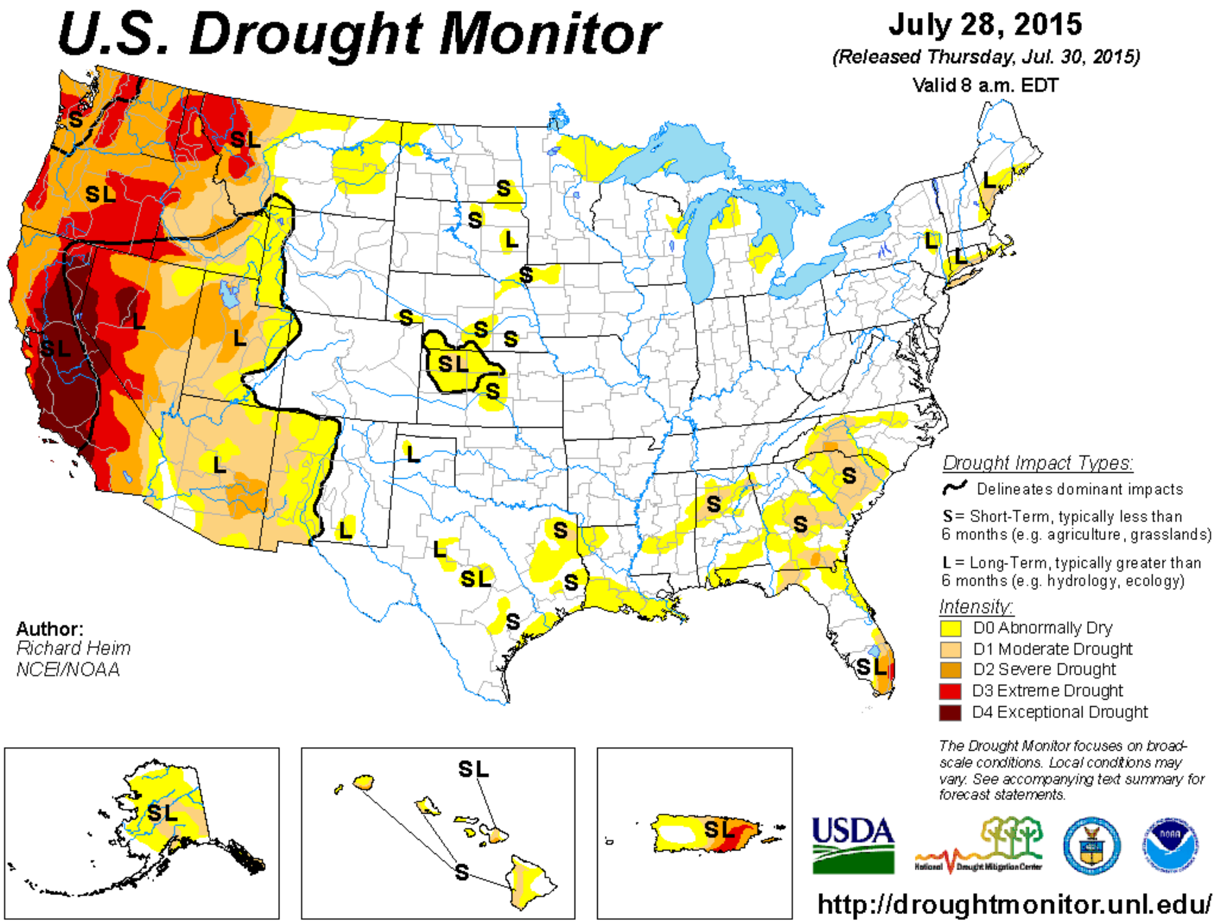

Figure A3 – US Drought monitor, data from July, 2015

As already stated, extreme weather has financial consequences. Insurance companies such as Munich Re have already reported insurance loss increases and have made strong statements about climate change. Insurance companies are expert at risk assessment within the private industry; their expertise should be considered.

The National Oceanic and Atmospheric Administration archives weather and climate disasters. These events have been increasing, as shown in Figure A4. The data there is subdivided by event type and has been adjusted for inflation.

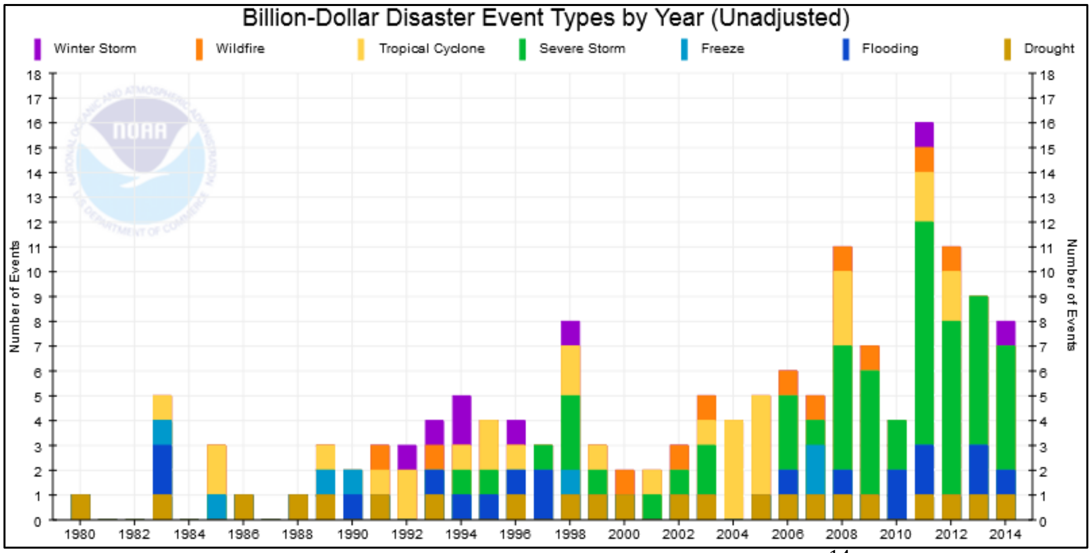

Figure A4 – Billion dollar disaster events, adjusted for inflation[14]

[14] Available at https://www.ncdc.noaa.gov/billions/time-series.

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APPOINTMENTS

Professor, *University of St. Thomas, St Paul, MN* **2013-Present**
Associate Professor, *University of St. Thomas, St Paul, MN* **2008-2013**
Assistant Professor, *University of St. Thomas, St Paul, MN* **2002-2008**

EDUCATION

University of Minnesota - Twin Cities, Minneapolis, MN
Ph.D., **Mechanical Engineering, Advisor: Dr. Ephraim Sparrow** **August, 2002**
Thesis Title: ***A Comprehensive Experimental, Analytical, and Numerical Investigation of the Modes of Heat Transfer in an Electrically Heated Oven***
M.S., Mechanical Engineering, overall GPA 3.96/4.00 **Fall 1999**
B.S., Mechanical Engineering, overall GPA 4.00/4.00, **Minor**: Mathematics **Spring 1997**

HONORS/AWARDS/PROFESSIONAL ACTIVITIES

- Climate Generation: A Will Steger Legacy Advisory Board.
- Science Advisor, Citizens Engagement Lab, Climate Disaster Response Fund.
- USA Green Deal of the Year business excellence award, 2013.
- IPCC AR5 Expert Reviewer (2011-2013)
- Composites Sustainability Award, American Composites Manufacturers Association Award for Composite Excellence, 2013.
- Nominated, George Mason University, Center for Climate Change Communication, Climate Change Communicator of the Year (2011)
- University of St. Thomas John Ireland Award (2009)
- NSF Review Panel Member, Chemical, Bioengineering, Environmental and Transport Systems (2009)
- University of St. Thomas Distinguished Educator Award (2008)
- NSF Review Panel Member, Division of Civil, Mechanical, and Manufacturing Innovation (2008)
- Associate Fellow of the Supercomputing Institute for Digital Simulation and Advanced Computation (2005)
- University of St. Thomas Engineering Professor of the Year (2005)
- Graduate Teaching Fellowship (2001/2002)
- Institute of Technology Teaching Assistant of the Year, awarded by Institute of Technology Student Board, University of Minnesota (1999/2000)
- Institute of Technology Teaching Assistant of the Year, awarded by Institute of Technology Student Board, University of Minnesota (2000/2001)
- Institute of Technology Teaching Assistant of the Year, awarded by Institute of Technology Student Board, University of Minnesota (2001/2002)

- Mechanical Engineering Teaching Assistant of the Year, Mechanical Engineering Department, University of Minnesota (1998/1999)
- Minnesota Professional Engineers Foundation Orion Buan Memorial Scholarship (1996)
- Walter and Margaret Pierce Endowment Fund Scholarship (1996)
- National Space Grant Consortium Scholarship (1996)
- Frank Louk Scholarship (1996)
- Citizens' Scholarship (1992-1995)
- Alfred O. Neir Scholarship (1994)
- Dean's List (1993-1997)

PUBLICATIONS

Editing Activities

1. Editor, Advances in Heat Transfer, Vol. 47, Elsevier, 2015.
2. Editor, Advances in Heat Transfer, Vol. 46, Elsevier, 2014.
3. Editor, Advances in Numerical Heat Transfer Vol. 5: Numerical Models of Heat Exchangers, Taylor and Francis, New York, (to appear).
4. Editor, Small-Scale Wind Power – Design, Analysis, and Economic Impacts, Momentum Press, 2014.
5. Editor, Advances in Heat Transfer, Vol. 45, Elsevier, 2013.
6. Editor, Advances in Heat Transfer, Vol. 44, Elsevier, 2012.
7. Editor, Advances in Numerical Heat Transfer Vol. 4: Nanoscale Heat Transfer and Fluid Flow, Taylor and Francis, New York, 2012.
8. Guest Editor, Advances in Numerical Heat Transfer Vol. 3: Numerical Implementation of Biological Models and Equations, Taylor and Francis, New York, 2009.
9. Guest Editor, Special Edition of the International Journal of Heat and Mass Transfer: Bioheat and Biofluid Flow, Elsevier, Vol. 51, 23-24, November, 2008.
10. Assistant Editor, Handbook of Numerical Heat Transfer, 2nd Ed. Editors: Sparrow, Minkowycz, and Murthy, John-Wiley & Sons, Inc., New York, 2006.

Books

1. Abraham, J.P., Plourde, B.D., Small-Scale Wind Power – Design, Analysis, and Environmental Impacts, Momentum Press, 2014.

2. Abraham, J. P., Ellis, P. S., MacCracken, M. C., & Woodwell, G. M., Climate controversy 2013. New York, NY: AuthorHouse, 2013.

3. All Fluid-Flow-Regimes Simulation Model for Internal Flows, Nova Science Publishers, Inc., Hauppauge, NY, 2011.

Book Chapters

1. B.D. Plourde, E.D. Taylor, P.O. Okaka, and J.P. Abraham, Financial and Implementation Considerations for Small-Scale Wind Power, in Small-Scale Wind Power – Design, Analysis, and Economic Impacts, Momentum Press, 2014.

2. B.D. Plourde, E.D. Taylor, W.J. Minkowycz, and J.P. Abraham, Introduction to Small-Scale Wind Power, in Small-Scale Wind Power – Design, Analysis, and Economic Impacts, Momentum Press, 2014.

3. Modeling Internal Flows by an Extended Menter Transition Model, Turbulent: Theory, Types, and Simulation, Nova Publishers, New York, 2011.

4. A Mathematical Model to Predict Tissue Temperatures and Necrosis During Microwave Thermal Ablation of the Prostate, Advances in Numerical Heat Transfer Vol. 3: Numerical Implementation of Bioheat Models and Equations, Taylor and Francis, New York, 2009.

5. Heat-Transfer and Temperature Results for a Moving Sheet Situated in a Moving Fluid, a chapter from Heat-Transfer Calculations, 2nd ed., editor, Myer Kutz, McGraw-Hill, 2005.

Journal Articles

1. J.P. Abraham, B.D Plourde, L.J. Vallez, J.R. Stark, K. R. Diller, Estimating the time and temperature relationship for causation of deep-partial thickness skin burns, *Burns* (in press).

2. G. Foster and J.P. Abraham, Lack of Evidence for a Slowdown in Global Temperature, US Climate Variability and Predictability Program (CLIVAR) Summer 2015, Vol. 13, pp. 6-9, 2015.

3. L. Cheng, J. Zhu, and J.P. Abraham, Global Upper Ocean Heat Content Estimation: Recent Progresses and the Remaining Challenges, *Atmospheric and Oceanic Science Letters*, (in press).

4. L.J. Vallez, B.D. Plourde, J.P. Abraham, A New Computational Thermal Model fo the Whole Human Body: Applications to Patient Warming Blankets, *Numerical Heat Transfer*, (in press).

5. J. P. Abraham and B.D. Plourde, Validation of numerically simulated tissue temperatures during transcutaneous recharge of neurostimulation systems, *Journal of Neuromodulation*, (accepted).

6. M. Richardson, Z. Hausfather, D.A. Nuccitelli, K.Rice, and J.P. Abraham, Misdiagnosis of Earth Climate Sensitivity Based on Energy Balance Model Results, *Science Bulletin*, (accepted).

7. B.D. Plourde, J.P. Abraham, W.J. Minkowycz, Continuous Flow Solar Thermal Pasteurization of Drinking Water: Methods, Devices, Microbiology, and Analysis, *Renewable Energy*, Vol. 81, pp. 795-803, 2015.

8. J.M. Gorman, M. Carideo, E.M. Sparrow, J.P. Abraham, Heat Transfer and Pressure Drop Comparison of Louver- and Plain-finned Heat Exchangers Where One Fluid Passes Through Flattened Tubes, *Case Studies in Thermal Engineering*, Vol. 5, pp. 122-126, 2015.

9. J.C.K. Tong, J.P. Abraham, J.M.Y.Tse, and E.M. Sparrow, Impact of Chamfer Contours to Reduce Column Drag, *Engineering and Computational Mechanics*, Vol. 168, pp. 79-88, 2015.

10. L. Cheng, J.P. Abraha, G. Gon, T. Boyer, S. Wijffels, R. Cowley, V. Gouretski, F. Reseghetti, S. Kizu, S. Dong, F. Bringas, M. Goes, L. Houpert, J. Zhu, Fourth XBT Science Workshop Progress Report: Making Consensus and Establishing Best Practices to Reduce XBT Biases, *Bulletin of the American Meteorological Society*, (accepted).

11. D. Egbe, T Mayah, E. Ebota, P. Egbe, J. Abraham, Performance Evaluation and Improvement on a Melon Seed Shelling Machine, *World Journal of Agricultural Sciences and Engineering*, Vol. 1, pp. 1-10, 2015.

12. A. Lundardelli, J.E. Wentz, J.P. Abraham, and B.D. Plourde, Shielding Nozzle Design and Analysis for Atomization-Based Cutting Fluid Systems in Micromachining, *ASME Journal of Micro- and Nano-Manufacturing*, Vol. 3, paper no. 024501, 2015.

13. N. Langat, T. Thoruwa, J. Wanyoko, J. Kiplagat, B.D Plourde, J.P. Abraham, Models and Experiments for Energy Consumption and Quality of Green Tea Drying, *Energy Science and Engineering*, Vol. 3, 43-50, 2015.

14. E. Burr, G. Laden, and J.P. Abraham, The USO Hypothesis in Human Evolution, *Reports of the National Center for Science Communication*, (*submitted).*

15. T. Scambos and J.P. Abraham, Antarctic Ice Sheet mass loss and future sea level rise, *Forensic Engineering*, (in press)

16. J.P. Abraham, J.R. Stark, W.J. Minkowycz, Extreme weather: Observations of precipitation changes in the USA, *Forensic Engineering*, (in press).

17. N. Dib, D.B. Schwalbach, B.D. Plourde, R.E. Kohler, D. Dana, and J.P. Abraham, Single lumen balloon angioplasty catheter reduces cell viability when compared to multi lumen infusion catheter, *Cardiovascular Translation Research*, Vol. 7, pp. 781-787, 2014.

18. J.P. Abraham, J.T. Fasullo, G. Laden, Continued global warming in the midst of natural climate fluctuations, *Reports of the National Center for Science Communication*, Vol. 34(6), 2014.

19. N. Dib, J.P. Abraham, B.D. Plourde, D.B. Schwalbach, D. Dana, L. Myers, K. Hunkler, S.R. D'Silva, T.R. Flower, and R.E. Kohler, TCT-155 A a Novel Multi Lumen Compliant Balloon Catheter (ND Infusion Catheter) Preserves Stem Cell Viability and Improves Dispersion When Compared to a Standard Single Lumen Balloon Angioplasty Catheter, *Journal American College of Cardiology*, Vol. 64, 11, 2014.

20. J.P. Abraham, B.D. Plourde, J.R. Stark, Cryosurgical Treatment of Cancer: The Importance of Modeling, *Journal of Cancer Science and Therapy*, Vol. 6, 2014 (abstract).

21. J.P. Abraham, S. Kumar, B.R. Bickmore, J.T.Fasullo, Issues Related to the Use of One-Dimensional Ocean Diffusion Models for Determining Climate Sensitivity, *Journal of Earth Science and Climate Change*, Vol. 5, paper 1000220, 2014.

22. T. Shepard, J.P. Abraham, D.S. Schwalbach, S. Kane, D. Sigling, and T. Harrington, Velocity and Density Effect on Impact Force During Water Entry of Spheres, *Journal of Geophysics and Remote Sensing*, Vol. 3, paper no. 1000129, 2014.

23. D. S. Schalbach, T. Shepard, S. Kane, D. Siglin, T. Harrington, J.P. Abraham, Effect of Impact Velocity and Mass Ratio During Vertical Sphere Water Entry, *Developments and Applications of Oceanic Engineering*, Vol. 3, 55-62, 2014.
24. J.P. Abraham, B.D. Plourde, J.R. Stark, and W.J. Minkowycz, Improvements to the Quality and Quantity of Ocean Heat Content Measurements, *Journal of Earth Science and Climate Change*, Vol. 5, pp. 100, 2014 (abstract).

25. J.P. Abraham, B.D. Plourde, and K.E. Trenberth, Closing Earth's Energy Balance, *Journal of Earth Science and Climate Change*, Vol. 5, pp. 69, 2014 (abstract).

26. J.M. Gorman, E.M. Sparrow, and J.P. Abraham, Temperature Determination by Means of Optoacoustic Measurements, *Studies in Engineering and Technology*, Vol. 1, 15-20, 2014.

27. J.M. Gorman, E.M. Sparrow, and J.P. Abraham, Slot Jet Impingement Heat Transfer in the Presence of Jet Axis Switching, *International Journal of Heat and Mass Transfer,* Vol. 78, 50-57, 2014.

28. J.P. Abraham, A review of the HANDY Study, *Cosmopolis,* Vol. 2014-1, pp. 8-87, 2014.

29. J.P. Abraham Climate Change in the Midwest: Impacts, Risks, Vulnerabilities, and Adaptation. A Review of New Biological Books, *The Quarterly Review of Biology*, Vol. 89, pp. 171-172, 2014.

30. B.D. Plourde, D.B. Schwalbach, J.P. Abraham, and R.E. Kohler, Intracoronary Injection of Medication from multi-lumen injection Catheters, *Journal of Medical Devices,* Vol. 8, paper number 020901, 2014.

31. J.P. Abraham, J. Cook, J. T. Fasullo, P. H. Jacobs, S. A. Mandia, and D. A Nuccitelli, Review of the Consensus and Asymmetric Quality of Research on Human-Induced Climate Change, *Cosmopolis*, Vol. 2014-1, pp. 3-18, 2014.

32. B. L. Viglianti, M.W. Dewhirst, J.M. Gorman, and J.P. Abraham, E.M. Sparrow, Rationalization of Thermal Injury Quantification Methods: Application to Skin Burns, *Burns*, Vol. 40, pp. 896-902, 2014.

33. N.M. Naughton, B.D. Plourde, J.R. Stark, S. Hodis, and J. P. Abraham, Impacts of Waveforms on the Fluid Flow, Wall Shear Stress, and Flow Distribution in Cerebral Aneurysms and the Development of a Universal Reduced Pressure, *J. Biomedical Science and Engineering*, Vol. 7, 7-14, 2014.

34. J. M. Gorman, J.P. Abraham, D. B. Schwalbach, T. S. Shepard, J.R. Stark, and F. Reseghetti, Experimental Verification of Drag Forces on Spherical Objects Entering Water, *Journal of Marine Biology and Oceanography*, Vol. 3, paper no. 1000126, 2014.

35. S. Beacher, E.M. Sparrow, J.M. Gorman, and J.P. Abraham, Theory and Numerical Simulation in Thermochemical Ablation, *Numerical Heat Transfer Part A*, Vol. 66, pp. 131-143, 2014.

36. J.P. Abraham, J.M. Gorman, F. Reseghetti, E.M. Sparrow, J.R. Stark, T.G. Shepard, Modeling and Numerical Simulation of the Forces Action on a Sphere During Early-Water Entry, *Ocean Engineering,* Vol. 76, 1-9, 2014.

37. J.M. Gorman, J.P. Abraham, E.M. Sparrow, A Novel, Comprehensive Numerical Simulation for Predicting Temperatures Within Boreholes and the Adjoining Rock Bed, *Geothermics*, Vol. 50, pp. 213-219, 2014.

38. D.B. Schwalbach, B.D. Plourde, J.P. Abraham, and R.E. Kohler, Drug Dispersion for Single- and Multi-Lumen Catheters, *J. Biomedical Science and Engineering*, Vol. 6, pp. 1021-1028, 2013.

39. N. Dib, R.E. Kohler, J.P. Abraham, B.D. Plourde, D.B. Schwalbach, D. Dana, B.J. Baird, T.R. Flower, L. Myers, and K. Hunkler, TCT-811 Stem Cell Viabilitiy Significantly Reduced After Passing Through a Standard Single Lumen Over-the-Wire 0.014 Balloon Angioplasty Cather, *Journal of the American College of Cardiology*, Vol. 62, B246, 2013.

40. N. Dib, R.E. Kohler, J.P. Abraham, B. Plourde, D. Schwalbach, D. Dana, L. Myers, B.J. Baird, and T.R. Flower, Stem Cell Viability Significantly Reduced After Passing Through a Standard Single Lumen Over-the-Wire 0.014 Inch Balloon Angioplasty Catheter, *Journal of the American College of Cardiology*, Vol. 62, pp. B246, 2013.

41. D.A. Nuccitelli, J.P. Abraham, R.E. Benestad, S.A. Mandia, Comment on: Akasofu, S.-I. On The Present Halting of Global Warming, *Climate*, Vol. 1, pp. 76-83, 2013.

42. J.M. Gorman, E. M. Sparrow, J.P. Abraham, Differences Between Measured Pipe Wall Surface Temperatures and Internal Fludi Temperatures, *Case Studies in Thermal Engineering*, 1, 13-16, 2013.

43. J. R. Stark, J. M. Gorman, E. M. Sparrow, J. P. Abraham, R. E. Kohler, Controlling the Rate of Penetration of a Therapeutic Drug Into the Wall of an Artery by Means of a Pressurized Balloon, *J. Biomedical Science and Engineering*, Vol. 6, pp. 527-532, 2013.

44. J.P. Abraham, M. Baringer, N.L. Bindoff, T. Boyer, L.J. Cheng, J.A. Church, J.L. Conroy, C.M. Domingues, J.T. Fasullo, J. Gilson, G. Goni, S.A. Good, J. M. Gorman, V. Gouretski, M. Ishii, G.C. Johnson, S. Kizu, J.M. Lyman, A. M. Macdonald, W.J. Minkowycz, S.E. Moffitt, M.D. Palmer, A.R. Piola, F. Reseghetti, K. Schuckmann,K.E. Trenberth, I. Velicogna, J.K. Willis, A Review of Global Ocean Temperature Observations: Implications for Ocean Heat Content Estimates and Climate Change, *Reviews of Geophysics*, Vol. 51, pp 450-483, 2013.

45. R. Rend, E. Sparrow, J. R. Stark, J.P. Abraham, Experimental Pressure Losses in Diffusers Compared to Numerical Simulations, *Journal Fluids Engineering*, (submitted).

46. J. Abraham, J. Stark, J. Gorman, E. Sparrow, R. Kohler, A Model of Drug Deposition Within Artery Walls, *J. Medical Devices*, Vol. 7, paper no. 020902, 2013.

47. E.M. Sparrow, N.T. Littlejohn, J.M. Gorman, and J.P. Abraham, Mass Transfer and Particle Separation by Swirl-Chamber and Swirl-Tube Devices, *Numerical Heat Transfer A*, Vol. 64, 611-620, 2013.

48. E.M. Sparrow, J. M. Gorman, and J.P. Abraham, Quantitative Assessment of the Overall Heat Transfer Coefficient U, *J. Heat Transfer*, Vol. 135, paper no. 061102, 2013.

49. J. P. Abraham, E.M. Sparrow, J.M. Gorman, J.R. Stark, R. E. Kohler, A Mass Transfer Model of Temporal Drug Deposition in Artery Walls, *International Journal of Heat and Mass Transfer*, Vol. 58, pp. 632-638, 2013.

50. R.R. Rend, E. M. Sparrow, D. W. Bettenhausen, J. P. Abraham, Parasitic Pressure Losses in Diffusers and in Their Downstream Piping Systems for Fluid Flow and Heat Transfer, *International Journal of Heat and Mass Transfer*, Vol. 61, pp. 56-61, 2013.

51. E.M. Sparrow, J.M. Gorman, K.S. Friend, and J.P. Abraham, Flow Regime Determination for Finned Heat Exchanger Surfaces with Dimples/Protrusions, *Numerical Heat Transfer*, Vol. 63, pp. 245-256, 2012.

52. B.D. Plourde, J.P. Abraham, G.S. Mowry, and W.J. Minkowycz, Simulations of Three-Dimensional Vertical-Axis Turbines for Communications Applications, *Wind Engineering*, Vol. 36, pp. 443-454, 2012.

53. J. P. Abraham, B.D. Plourde, G.S. Mowry, W.J. Minkowycz, Summary of Savonius Wind Turbine Development and Future Applications for Small-Scale Power Generation, *Journal of Renewable and Sustainable Energy*, Vol. 4, paper no. 042703, 2012.

54. J.M. Gorman, EM. Sparrow, J.P. Abraham, and G.S. Mowry, Operating Characteristics and Fabrication of a Uniquely Compact Helical Heat Exchanger, *Applied Thermal Engineering*, Vol. 5, pp. 1070-1075, 2012.

55. E. M. Sparrow, J.M. Gorman, A. Trawick, and J. P. Abraham, Novel Techniques for Measurements of Thermal Conductivity of Both Highly and Lowly Conducting Media, *International Journal of Heat and Mass Transfer*, Vol. 55, pp. 4037-4042, 2012.

56. J. P. Abraham, J.M. Gorman, F. Reseghetti, E.M. Sparrow, and W.J. Minkowycz, Drag Coefficients for Rotating Expendable Bathythermographs and the Impact of Launch Parameters on Depth Predictions, *Numerical Heat Transfer A*, Vol. 62, pp. 25-43, 2012.

57. M. Nelson and J.P. Abraham, Hemodynamics of AV Grafts for Hemodialysis Access, *Journal of Medical Devices*, Vol. 6, artcile no. 017553, 2012.

58. J. Abraham and J. Jeske, Cryosurgical Simulations for Ablation of Kidney Tumors, *Journal of Medical Devices*, Vol. 6, article no 017504, 2012.

59. J. Abraham, J. Gorman, F. Reseghetti, W. Minkowycz, and E. M. Sparrow, Turbulent and Transitional Modeling of Drag on Oceanographic Measurement Devices, *Computational Fluid Dynamics and its Applications* 2012, article ID 567864, doi:10.1155/2012/567864.

60. J. Abraham, J. Gorman, F. Reseghetti, K. Trenberth, and W. Minkowycz, A New Method of Calculating Ocean Temperatures Using Expendable Bathythermographs, *Energy and Environment Research*, Vol. 1, pp. 2-11, 2011.

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62. B. D. Plourde, J. P. Abraham, G.S. Mowry, W.J. Minkowycz, Use of Small-Scale Wind Energy to Power Cellular Communication Equipment, *Sensors and Transducers*, Vol. 13, pp. 53-61, 2011.

63. J. Gorman, E. Sparrow, G. Mowry, J. Abraham, Simulation of Helically Wrapped, Compact Heat Exchangers, *J. Renewable and Sustainable Energy*, Vol. 3, article no. 043120, 2011.

64. R. D. Lovik, J.P. Abraham, and E. M. Sparrow, Surrogate Human Tissue Temperatures Resulting from Misalignment of Antenna and Implant During Recharging of a Neuromodulation Device, *J. Neuromodulation*, Vol. 14, pp. 501-511, 2011.

65. K.E. Trenberth, J.T Fasullo, and J.P. Abraham, Issues in Establishing Climate Senstivity in Recent Studies, *Remote Sensing*, Vol. 3, pp. 2051-2055, 2011.

66. R. D. Lovik, E. M. Sparrow, J. P. Abraham, C. Zelmer, S. Oh, K. Friend, and D. K. Smith, Effect of Component Misalignment on Human Tissue Temperatures Associated with Recharged Nueromodulation Devices, *J. Medical Devices*, Vol. 5, 0207516, 2011.

67. T. Gebreegziabher, E.M. Sparrow, J.P. Abraham, E. Ayorinde, and T. Singh, High-Frequency Pulsatile Pipe Flows Encompassing All Flow Regimes, *Numerical Heat Transfer A*, Vol. 60, pp. 811-826, 2011.

68. J.P. Abraham, M.P. Hennessey, and W.J. Minkowycz A Simple Algebraic Model to Predict Burn Depth and Injury, *Int. Comm. Heat Mass Transfer*, Vol. 38, pp. 1169-1171, 2011.

69. J. P. Abraham, B.D. Plourde, G.S. Mowry, E. M. Sparrow, W.J. Minkowycz, Numerical Simulation of Fluid Flow Around a Vertical-Axis Turbine, *Journal of Renewable and Sustainable Energy*, Vol. 3, article no. 033109, 2011 (doi:10.1063/1.3588037).

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71. B. D. Plourde, J. P. Abraham, G. S. Mowry, and W. J. Minkowycz, An Experimental Investigation of a Large, Vertical-Axis Wind Turbine: Effects of Venting and Capping, *Wind Engineering*, Vol. 35, pp. 213-220, 2011.

72. N.N. Johnson, J.P. Abraham, Z.I. Helgeson, W.J. Minkowycz, and E. M. Sparrow, An Archive of Skin-Layer Thicknesses and Properties and Calculations of Scald Burns with Comparisons to Experimental Observations, *Journal of Thermal Science and Engineering Applications*, Vol. 3, paper no. 011003, 2011.

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Conference Presentations and Public Lectures

1. G. Foster and J.P. Abraham, Lack of Evidence for a Slowdown in Global Temperature, US Climate Variabilty and Predictability Program (CLIVAR) Summit, Tuscon, AZ, August 4-6, 2015.

2. J.P. Abraham, Small-scale wind turbines: design, analysis and applications, *Hong Kong University*, January 28, 2015 (invited).

3. J.P. Abraham, The Science of Climate Change, What do we really know, *Hong Kong University of Science and Technolog*y, January 26, 2015 (invited).

4. J.P. Abraham et al., A Novel Multi Lumen Compliant Balloon Catheter (ND® Infusion Catheter) Preserves Stem Cell Viability and Improves Dispersion When Compared to a Standard Single Lumen Balloon Angioplasty Catheter, *European Society of Cardiology*, 2015, (submitted).

5. J.P. Abraham, T.M. Shepard, W.J. Minkowycz, J.R. Stark, J. M. Gorman, Quantification of Near-Surface Impact Forces on XBTs, The 4th XBT Workshop: XBT Science and the Way Forward, Beijing, China, November 11-13, 2014.

6. J.P. Abraham, B.D. Plourde, S.A. Mandia, and K.E. Trenberth, Closing the Earth Energy Imbalance, *3rd International Conference on Earth Science and Climate Change*, San Francisco, CA, July 28-30, 2014.

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8. J.P. Abraham, B.D. Plourde, J.R. Stark, W.J. Minkowycz, Cryosurgical Treatment of Cancer: The Importance of Modeling, *4th World Congress on Cancer Science and Therapy*, Chicago, October 20-22, 2014.

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REVIEW OF THE CONSENSUS AND ASYMMETRIC QUALITY OF RESEARCH ON HUMAN-INDUCED CLIMATE CHANGE

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Abstract

Climate science is a massively interdisciplinary field with different areas understood to varying degrees. One area that has been well understood for decades is the fundamental fact that humans are causing global warming. The greenhouse effect has been understood since the 1800s, and subsequent research has refined our understanding of the impact of increased concentrations of greenhouse gases on the planet. Also increasing has been the consensus among the world's climate scientists that the basic principles of anthropogenic global warming (AGW) are correct. This has been demonstrated by multiple reinforcing studies that the consensus of scientists on the basic tenets of AGW is nearly unanimous. Nevertheless, the general public in many countries remains unconvinced not only of the existence of AGW, but also of the degree of scientific consensus. Additionally, there remain a few high-profile scientists who have continued to put forth alternative explanations for observed climatic changes across the globe. Here, we summarize research on the degree of agreement amongst scientists and we assess the quality of scholarship from the contrarian scientists. Many major contrarian arguments against mainstream thinking have been strongly challenged and criticized in the scientific literature; significant flaws have often been found. The same fate has not befallen the prominent consensus studies.

Measurements of scientific consensus on AGW

The evolution of scientific understanding is often characterized by novel studies that propose new and alternative explanations to the existing behaviors of the natural world. These explanations may or may not be initially accepted by their colleagues; however, further investigations are pursued to test the concepts.

This evolution has occurred in climate science in general and on the human impact on climate in particular. The first significant studies of the impact of increasing greenhouse gases on the Earth's climate were published more than 100 years ago (Fourier, 1824; Tyndall 1861; Arrhenius, 1896). In the following decades, the details of AGW were refined but the basic principles were already established.

Despite this solidification of the scientific community around the basic tenets of AGW, the general public has remained unconvinced with sizable populations either dismissive of AGW in general or dismissive of scientific consensus (Zimmerman, 2008; Doran and Zimmerman, 2009; Leiserowitz et al., 2011; Leiserowitz et al., 2012; Pew, 2012;).

In order to establish the extent of the current scientific consensus, a number of different approaches have been pursued. Naomi Oreskes performed a seminal study on the scientific consensus (Oreskes, 2004) that involved the evaluation of 928 peer-reviewed journal articles published between 1993 and 2003 that were found using a literature search of "global climate change". The study used six different classifications for the abstracts: 1) endorsement of AGW, 2) evaluation of impacts, 3) mitigation proposals, 4) methods, 5) paleoclimate reconstructions, and 6) rejection of AGW. The author found 75% of the reviewed papers were in the first three categories as either explicit or implicit endorsements, while the remaining papers dealt were in categories 4 and 5. No papers fell into category 6.

A second study used a different methodology assessing the consensus of the basic tenets of climate change (Zimmerman, 2008; Doran and Zimmerman, 2009). There, the authors accessed a large dataset of Earth scientists (10,257 total) and requested the completion of an electronic survey. The survey was carried out through a professional survey site that limited answers to one for each invitation. Of the 3,146 respondents, more than 90% had a PhD and approximately 97% had advanced degrees. 267 respondents were actively publishing climate scientists with more than 50% of their publications in this area.

The respondents were asked a series of questions associated with their expertise, their perception of the causes of climate change, and their perception of the view of their colleagues. Perhaps the most critical question was number two in the survey, "Do you think human activity is a significant contributing factor in changing mean global temperatures?"

Based on the responses, the authors categorized the level of agreement with basic AGW tenets and expertise. They found that in general, as expertise level increased, so too did the consensus. For the most active climate scientists, approximately 97% agreed by answering "yes" to question number two. Despite this overwhelming agreement, the authors noted that only 47% of the general US population believes there is a scientific consensus.

The third significant work on scientific consensus was completed in 2010 (Anderegg et al., 2010). The approach taken in this study was to collect a listing of prominent climate researchers by utilizing authorship of significant climate-related documents. The list encompassed 1,372 researchers who were segregated into two groups (unconvinced by the evidence [UE], and convinced by the evidence [CE]). The authors were ranked by their expertise and prominence. Expertise was based on the number of climate-relevant publications authored by the scientist whereas prominence was measured by the impact of the published papers (number of citations of a researcher's four most cited papers). Among the conclusions of Anderegg et al., (2010) was that only 2% of the top 50 scientists fell into the UE category. They also found that on average, the UE authors as a group possessed a lower expertise and a lower prominence than the CE researchers. For instance, the average number of publications of the UE group was only half that of the CE population.

A subsequent survey of scientists affiliated with the American Meteorological Society (AMS) and the American Geophysical Union (AGU), with 489 participants, found that 97% agreed that global temperatures had increased in the past 100 years (Farnsworth and Lichter, 2012). 84% agreed that human-induced warming was occurring while 5% disagreed. Multivariate analysis found that whether scientists worked for government or industry had no influence on their climate opinions. However, scientists in academia were more pessimistic about future climate change. This analysis suggests that scientists' climate opinions are not based on workplace pressures or desires to further their own careers.

Recently, a study was published (Cook et al., 2013) which, similar to Oreskes (2004), surveyed the climate science literature. The authors examined over 12,000 abstracts from 1991-2011 dealing with "global climate change" or "global warming". They found that 66% of the abstracts expressed no position on AGW, 33% endorsed AGW, and 1% were either dismissive or uncertain. Among those abstracts that expressed a position on AGW, 97% supported the basic tenets. Cook et al. further invited the authors to self-rate their own manuscripts and similarly, among the 774 respondents whose research expressed a position on the basic tenets of AGW, 97% were affirmative.

Taken together, these studies are mutually reinforcing in their findings about the view amongst climate scientists about the human impacts on climate change. Those findings are: 1) there is near unanimity of consensus on the basic tenets of AGW, 2) the expertise of the scientists who agree with AGW is greater than of those that dissent, 3) the results are robust to various means of measure, and 4) the general public is not aware of the strong consensus.

It must be mentioned that these above statements should not be interpreted to mean there is no active research in climate change or areas of disagreement. In fact, after consensus on basic tenets is reached, science typically moves to new questions which help solidify the community's basic understanding (Shwed and Bearman, 2010). For instance, there are real questions about the role of natural variability in temporarily masking human-induced warming, the impact of human and volcanic aerosols and changes to extreme weather, among others (Francis and Vavrus, 2012; Greene et al., 2013; Tang et al., 2013; Fyfe et al., 2013; Schmidt et al., 2014; Visbeck, 2014;

Santer et al., 2014; Trenberth and Fasullo, 2014; Wallace et al., 2014). These active areas of research are not focused on the basic and well-understood principles that human-emitted greenhouse gases are increasing, the Earth is being observed to warm, the Earth will continue to warm in the future, and that equilibrium warming for a doubling of carbon dioxide will be in the 1.5-4.5°C range (IPCC, 2001; IPCC 2007; Knutti and Hegerl, 2008; IPCC, 2013).

The strength of this conclusion on consensus is made stronger when official statements of authoritative bodies are considered. The leading expert body on assessing climate change is the Intergovernmental Panel on Climate Change (IPCC). As such, the IPCC has issued a series of increasingly definitive statements on the attribution of recent global warming that represent the evolving consensus position. The IPCC Second Assessment Report stated, "The balance of evidence suggests that there is a discernible human influence on the global climate" (IPCC, 1995). This position was strengthened in the Third Assessment Report in 2001, which concluded, "most of the warming observed over the last 50 years is attributable to human activities" (IPCC, 2001). A stronger IPCC statement on attribution came in the subsequent Fourth Assessment Report, concluding that "most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations" with "very likely" defined as greater than 90% probability (IPCC, 2007). Most recently, the 2013 IPCC Fifth Assessment Report stated that evidence has strengthened further so that it is "extremely likely" (greater than 95% probability) that human influence has been the dominant cause of the observed warming since the mid-20th century (IPCC, 2013).

In addition to the IPCC, the national academies of at least 80 countries have implicitly or explicitly endorsed the consensus position (e.g. G8 + 5 Academies, 2009; NASAC, 2007; Joint Academies' statement, 2005; US National Academy and Royal Society joint statement, 2014). Concurring statements have also been issued by relevant professional organizations including the American Association for the Advancement of Science, American Geophysical Union, American Meteorological Society, European Geosciences Union, Geological Society of America, Geological Society of London, and Royal Meteorological Society. An open letter to the United States Senate urging steps to avoid severe impacts from climate change and affirming the consensus has been signed by an additional 15 professional societies. Governmental agencies tasked with studying the climate system, such as the National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, United States Geological Survey, Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation have taken similar positions in endorsing the consensus.

The aforementioned consensus studies and community statements reflect nearly complete unanimity of the scientific community on the basic tenets of AGW.

The psychological significance of the "consensus gap"

Public perception of scientific consensus is important on several fronts. When forming views on complex scientific topics, the public relies on convenient heuristics such as the opinion of trusted sources of information. Public perception of scientific consensus also correlates with a number of important beliefs and attitudes, such as concern about the seriousness of climate change and support for mitigation policies (Ding et al., 2011; McCright et al., 2013). Malka et al. (2009)

found perception of consensus mediates the relationship between climate knowledge and climate concern. That is, learning more about climate change yields perceptions of higher consensus, which causes increased concern. These findings reinforce others that communicating the scientific consensus increases people's understanding that climate change is happening (Lewandowsky et al., 2012; Bolsen et al., 2013).

However, arguably the most crucial element of consensus is the fact that public perception of scientific consensus is associated with support for mitigation policies (Ding et al., 2011; McCright et al., 2013). When the public think scientists disagree about AGW, they are less likely to support climate action. Consequently, the "consensus gap" representing the discrepancy between public perception and the overwhelming consensus among scientists has significant societal consequences.

Difficulties in conveying consensus to broad public

Over the past few decades, there have been active efforts to minimize public awareness of the expert climate consensus. Efforts by opponents of tobacco regulations, which first were employed to manufacture doubt about the scientific consensus linking smoking to cancer, have transitioned to climate science (Oreskes and Conway, 2010).

One technique has been through circulation and publication of petitions of persons who dismiss the science or by amplifying the voices of vanishingly few scientists who downplay the potential impacts of climate change. Often, these contrarian "experts" are presented as representing a sizable fraction of the climate science population, when in fact they are a very small minority.

One argument often presented is that consensus does not guarantee truth, and we agree. A scientific consensus is only robust when multiple lines of study confirm it. With respect to the basic tenets of AGW, it is reinforced by a wide diversity of observations, theoretical studies, and numerical simulation. Among these are temperature measurements in the oceans, land surface areas, and atmosphere clearly showing increases of thermal energy; satellite measurements showing changes to the net flow of heat at the top of the Earth's atmosphere; measurements of sea level rise; land and polar ice loss; paleoclimate variations driven partly by past greenhouse gas levels; and fingerprint signatures in the spatial patterns of climate change that point to human emissions as the principle force, just to list a few.

Despite the mutually reinforcing lines of observational evidence, there exists a persistent, small minority of contrarian climate scientists. It is possible that a small minority of talented individuals is more able to assess science than a larger body of experts. One way to investigate this potential is to retrospectively view the success or failure of major contrarian arguments in the past few decades to see how they were responded to in the scientific literature. Have the prominent contrarian views been widely accepted and adopted or has their importance been minimized by critiques and rebuttals that have been leveled in the literature?

To explore this potential, we have identified two of the most prominent arguments made against the AGW consensus: 1) the climate is not warming and 2) the Earth is not very sensitive to climate change and there are strong natural processes which will moderate climate change as emissions continue to rise (negative feedbacks). These two contrary views have been presented numerous times over the past two decades, and in hindsight it is possible to evaluate their intellectual merit.

Past scientific arguments contradictory to the AGW consensus

The Earth is not warming

Perhaps the most common argument to appear which counters the consensus AGW viewpoint is that the Earth is not warming. While recently this viewpoint has been associated with incorrect notion that the Earth surface has not, for example, warmed in the past 15 years (Bloomberg, 2013; New York Times, 2013), it often is conflated with the concept that global warming has stopped. This, too, is false, as evident by measurements reported in numerous articles, such as Nuccitelli et al. (2012), Abraham et al. (2013), and Trenberth and Fasullo (2014). The foundation for many of the claims that the Earth has ceased or even slowed its warming is based on a selective assessment of small portions of the Earth system rather than the Earth as a whole.

However, the notion that parts of the Earth system which should warm with AGW are not warming perhaps had a genesis in the early 1990s when satellite temperature measurements became commonplace. Traditionally, Earth temperatures are measured by land-based temperature sensors; balloon sensors (radiosondes); temperature sensors on ships, buoys, or other ocean-going craft; and other instruments. Each of the different temperature-measuring methodologies suffers from limitations of geographical coverage and measurement accuracy. With the advancement of satellite measuring methodologies, it became possible to achieve near global coverage using microwave radiometers. The radiometers relate emission of atmospheric oxygen to temperatures throughout the atmosphere. With continuous and long-term records, it was possible to make longitudinal studies of the rate of temperature change in the troposphere and the stratosphere. A number of papers appeared in the early 1990s describing the methodology, accuracy, and findings (e.g. Spencer and Christy, 1990; Spencer and Christy 1993; Christy and Goodridge, 1995; Christy, et al., 1995; Christy and Spencer, 1995; Spencer, et al., 1996). Among the early findings was the surprising conclusion that the lower atmosphere of the Earth was cooling, in direct contradiction to the consensus AGW view.

Despite claims of accuracy from the authors, other researchers began to question the results (Hansen and Wilson, 1993; Schneider 1994; Hurrell and Trenberth, 1997; Hurrell and Trenberth, 1998; Wentz and Schabel, 1998) with many questions raised regarding the purported accuracy of the satellite measurements. Among the issues of concern were errors associated with merging satellite records, orbital decay of satellites as their altitude decreased over time, errors of on-board temperature calibration measurement systems, and drift in the time of observation and thus aliasing of the diurnal cycle.

The original authors defended the work in the scientific literature (Christy et al., 1997) and often pointed to comparisons of their measurements with weather balloon data (radiosondes) (e.g., Spencer and Christy, 1993; Christy and Spencer, 1995; Christy et al., 1998; Christy et al., 2000) as validation of the satellites. Meanwhile, as corrections were made to the methodology and new data were obtained, the original conclusions of a cooling troposphere were modified to show warming.

In the ensuing years, the critiques of the satellite records continued (Mears, et al., 2003; Mears and Wentz, 2005), which most notably identified an error in the diurnal correction of satellite drift (changes to the satellite orbit), an error acknowledged by the originators (Christy and Spencer, 2005).

The argument that comparisons with radiosonde data validated the satellite measurements was questioned when it was found that solar heating of the instruments or changes to instrumentation introduced errors in the measured temperatures (Sherwood et al., 2005; Randel and Wu, 2006). The accuracy of radiosonde temperature measurements and their utility in calibrating satellite data is still being dealt with in the literature (e.g., Thorne et al., 2005; Lanzante and Free, 2008; Allen and Sherwood, 2008; Santer et al., 2008; Titchner et al., 2009; Thorne et al., 2011;).

One other source of error has long been identified but still not fully quantified. It is the bias associated with the measurement instruments themselves on board the satellites. In particular, a warm calibration target is needed to relate the microwave emissions to atmospheric temperatures. When corrected, the trend in the middle part of the troposphere is found to be significantly greater than previously disclosed (Po-Chedley and Fu, 2012). This latest correction represents the still unsettled yet strongly rebutted satellite temperature trends and early claims of atmospheric cooling.

The result of this two-decade investigation is that the previously reported cooling of the atmosphere was based on faulty technique and equipment. In the ensuing years, various improvements have been made, and currently there is better agreement between different research teams measuring temperature trends in the lower and upper layers of the atmosphere. All data now shows that the lower atmosphere is heating (as expected) while the upper atmosphere is undergoing a long-term cooling trend (also as expected) because of increased emissions of greenhouse gases. This spatial behavior is a strong indicator that the temperature increases of the Earth’s surface over the past 40 years is caused by greenhouse gas emissions (rather than by other causes such as increased solar activity). The evolution in estimated lower tropospheric temperature trends are shown in Figure 1.

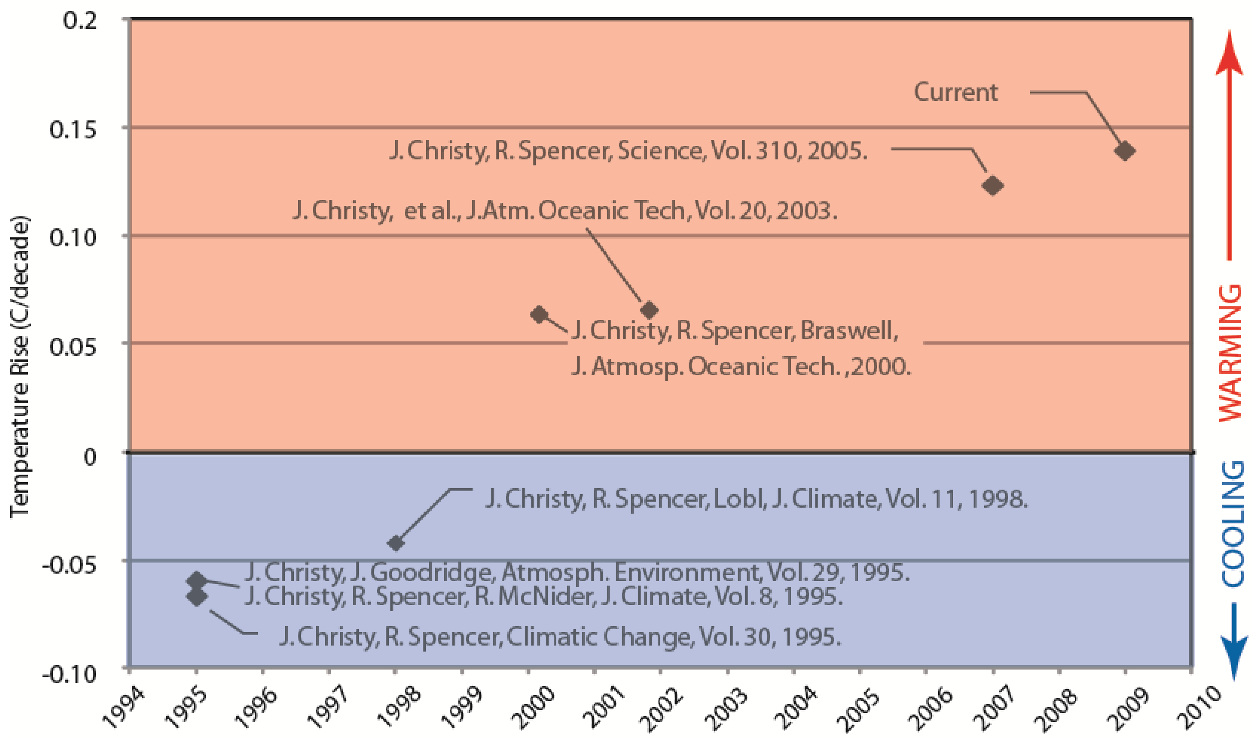

Figure 1. Evolution of lower tropospheric temperature trends from satellite observations.

The Earth has a natural climatic response that will offset greenhouse gas warming

There have been many arguments that suggest some natural phenomenon(a) will offset greenhouse gas warming (aside from the Planck response). The most commonly employed mechanism is some change to clouds that will cause a negative feedback (reduced warming) as greenhouse gases increase.

Among this group are studies reporting a specific cooling mechanism and studies that merely try to show by correlation that some undetermined mechanism exists. One attempt to suggest an actual mechanism was published in 2001 (Lindzen et al., 2001). The premise behind this work was that as the climate warms, the area covered by high cirrus clouds will contract to allow more heat to escape into outer space (similar to the iris in a human eye contracting to allow less light to pass through the pupil in a brightly lit environment). The so-called ‘iris effect’ would hypothetically increase the amount of outgoing infrared energy from the Earth, which would offset the added thermal energy to the Earth system and thereby counteract global warming.

While this concept gained much media attention, it was quickly and thoroughly rebutted within the scientific literature. Within approximately one year of publication of Lindzen et al., (2001), four refuting papers appeared (Fu et al., 2001; Hartmann and Michelsen, 2002; Lin et al., 2002; Del Genio and Kovari, 2002). These papers included numerous criticisms of the Lindzen et al., (2001) approach including the large geographical separation between deep convective clouds and those which experience variations in cloud-weighted sea surface temperatures (Hartmann and Michelsen, 2002). Another criticism was that clouds have a much higher reflectivity and larger infrared heat flows than the original study assumed (Lin et al., 2002). Also, the water vapor feedback from Lindzen et al., (2001) was overestimated by approximately 60% (Fu et al., 2001). Cloud observations from the Tropical Rainfall Measuring Mission did not support the hypothesis that tropical cirrus clouds contract with rising temperatures (Del Genio and Kovari, 2002). Finally, Lindzen et al., (2001) incorrectly estimated the impact of low tropical clouds (Lin et al., 2002).

The critiques of Lindzen continued throughout the years (Chambers et al., 2002; Lin et al., 2004; Rapp et al., 2005; Wong et al., 2006; and Trenberth and Fasullo, 2009), as did responses from proponents of the iris effect (Chou and Lindzen, 2005). The large volume of responses show that the scientific community took seriously the initial hypothesis but, despite years of investigation, found little evidence to support the conclusions of the proponents, and much evidence contradicting these conclusions.

Papers with the theme of low sensitivity/negative feedbacks have continued to appear in the literature. Among the most prominent was that of Spencer and Braswell (2008). It purported to examine how certain heat flows can contaminate the calculations of climate sensitivity from satellite observations. Shortly after its appearance in the literature, this manuscript was heavily criticized in a study that identified three significant errors (Murphy and Forster, 2010). Those errors were: 1) an unrealistic ocean mixed layer depth, 2) incorrect standard deviations of outgoing radiation, and 3) incorrect duration of calculations of model temperature variability. When these errors were corrected, the effect that was originally reported in Spencer and Braswell (2008) nearly disappeared.

A near contemporary to this study was published in 2009 (Lindzen and Choi, 2009). As with the lead author's earlier study on the so-called iris effect, this paper concluded that climate models overestimate the Earth's sensitivity to increases in greenhouse gases. They also claimed that the climate feedbacks observed from satellite sensors differed in character from the feedbacks predicted by computer models.

This paper was quickly responded to in the literature. Within approximately one year, four refutations appeared. For instance, Murphy (2010) showed that the Lindzen and Choi (2009) paper only focused on the tropics, yet applied their findings to the entire globe. Thereby, they neglected heat transport between different regions of the planet. They also made poor choices in their statistical methodology, which contributed to their low sensitivity estimate. Trenberth et al., (2010). Identified an even more substantial set of errors in the study. Those authors noted that Lindzen and Choi's choice for start and endpoints of their study were entirely subjective and that small modifications of the start and endpoints led to significant changes in conclusions. They also showed that Lindzen and Choi did not properly account for forcing in their statistical processing. Finally, Lindzen and Choi made a mathematical error in their computation of climate sensitivity. Other rebuttals (Chung et al., 2010; Dessler, 2010; Dessler, 2013) concurred with the prior analyses that the Lindzen and Choi low sensitivity results were unsupported by the

Lindzen and Choi(2009)
http://www.nytimes.com/2012/05/01/science/earth/clouds-effect-on-climate-change-is-last-bastion-for-dissenters.html?pagewanted=3&_r=3 "Dr. Lindzen acknowledged that the 2009 paper contained "some stupid mistakes" in his handling of the satellite data. "It was just embarrassing," he said in an interview. "The technical details of satellite measurements are really sort of grotesque.""

evidence. A follow-on paper (Lindzen and Choi, 2011) was similarly rebutted by Dessler (2011) on methodological grounds.

One final example along this theme was published in 2011 (Spencer and Braswell, 2011), which purported to show that energy flows internal to the Earth system can corrupt analyses of the climate sensitivity. The authors suggested that when these internal effects are accounted for, the actual sensitivity of the Earth to greenhouse gases is lower than previously thought. This paper was quickly criticized by scientists in the media for its unsupported claims. The Editor-in-Chief of the publishing journal acknowledged and agreed with those criticisms; he resigned shortly after the paper was published (BBC, 2011). A rebuttal in the literature appeared promptly (Trenberth, et al., 2011), demonstrating a number of errors in the original paper. The identified errors included, 1) incorrect durations of model simulations, 2) unnecessary de-trending of results, 3) incorrect interpretation of modeling results, and 4) incorrectly implying causation of correlating phenomena (Dessler, 2011). As a result, the major conclusions of Spencer and Braswell (2011) were shown to be arbitrary and depend on subjective assumptions.

The examples highlighted in the preceding paragraphs show samples of high-profile publications on the topics of climate sensitivity and processes within the Earth's climate that purported to minimize future temperature variations. In these cases, there was quick reaction in the peer-reviewed literature, which cast strong doubt on the validity of the studies.

Commentary on scientific credibility

The case supporting the basic tenets of AGW is broad-based. It comes from observational evidence using many variables. It comes from understanding and theory that relates variables to one another in a consistent manner, based on established physical laws of nature and strong empirical relationships that have stood up to close scrutiny. It also comes from improved climate models and simulations of past climate for decades to millennia. Basic scientific methods encourage formulation of new hypotheses perhaps based on ideas, empirical relationships, or new observations, but they must be tested with independent data and analyses. In this way, a gradual coalescence has formed amongst the world's top climate scientists that humans are causing significant climate change. Of course, there are still areas of active debate, particularly associated with the role of climate change on extreme weather, on methodologies to improve climate measurements, and on the rate of evolution of the Earth's climate as the atmosphere changes (to name just a few). However, none of these areas of debate are significant challenges to the central tenets of AGW.

The above discussion has highlighted a few of the main scientific arguments proposed in contradiction with the consensus AGW viewpoint – ones that have not stood the test of time. The selected arguments were based on their impact in the public discussion of climate change and the rich literature available to assess their quality. These proponents are scientists and they have developed credentials in other parts of climate science, and hence they were taken seriously.

Consequently, the main contrarian arguments have invoked a series of investigations by expert research teams to verify their conclusions. In every case, it has been found that after a thorough review, the contrarian arguments did not survive scientific scrutiny unmarred. In fact, a surprisingly large number of the contrarian studies were directly refuted in the literature. This process reflects the normal scientific method in which claims made by a group of researchers are tested by independent groups.

In fact, there have been critical responses in the literature to many other contrarian articles which minimize the human impact on the climate or find fault with the mainstream AGW consensus or methodology: (Mclean et al., 2009; Foster et al., 2010), (Douglass et al., 2008; Santer et al., 2008; Thorne et al., 2011), (Soon and Baliunas, 2003; Mann et al., 2003), and (Armstrong et al., 2008; Amstrup, et al., 2009) as separate examples on different topics. Another main contrarian argument has to do with the potential impact of solar variations and cosmic rays on climate. These too have been shown to be minor and, in many cases, the original works proposing such an impact were based on faulty data and/or analysis (Ammann et al., 2007; Bard and Frank, 2006; Benestad and Schmidt, 2009; Calogovic et al., 2010; Cubasch et al., 1997; Damon and Laut, 2004; Duffy, et al., 2009; Erlykin, Sloan and Wolfendale, 2009a; Erlykin, Sloan and Wolfendale, 2009b; Foukal, et al., 2004; Foukal et al., 2006; Kulmala et al., 2010; Laut, 2003; Legras et al., 2010; Lockwood and Frohlich, 2007; Sloan and Wolfendale, 2008; Solanki and Krivov, 2003; Trenberth and Fasullo, 2009). These topics have also been extensively reviewed in IPCC reports.

We do not intend this list to be exhaustive; there are many other examples that could be listed. Rather, these are representative of a seemingly frequent critical response following publication of contrarian AGW papers.

A few noteworthy comments are essential. First, in many of these examples, and in other examples not listed here, there were significant deficiencies in the analyses, which in many cases were conceded by the authors. It must be seen that these back and forth exchanges are the hallmark of the evolution of scientific development. In fact, the process of publishing rebuttals or critiques of contrarian views makes the field of science stronger.

With these comments as background, we conclude then that the quality of work of contrarian-view scientists, as showcased here by representative case studies, is notably lower than that of scientists who hold the consensus view. To our best knowledge, there are no comparable examples of major consensus viewpoints on the basic tenets of human-induced climate change that have been criticized to these extents in the literature or have been found to be fundamentally incorrect.

The observations showcased here were taken from the familiarity of the authors with the literature. These form the basis of a future systematic comparison of the rebuttal rate of contrarian view publications with those upholding the mainstream consensus. Such a systematic review would allow verification of the observations shown here.

Concluding remarks

It has been clearly shown by independent and complementary studies that the vast majority of climate scientists know that humans are causing significant changes to the Earth's climate. Regardless of the methodology, as a scientist's expertise and prominence increase, she or he is more likely to hold the consensus view. At the same time, there remain some issues in climate change science that have yet to be resolved. While these are important details, they do not undermine the view that there are basic observational and theoretical facts that are at the core of AGW.

In order to assess the quality of science representing the contrarian view, we have identified some of the most prominent themes of contrarian view (the Earth is not warming and the climate is not very sensitive to greenhouse gases because of an internal temperature-regulation mechanism). The selection of these two themes was a judgment by the present authors based on their significant roles in shaping public opinion, the frequency these themes are invoked in public discourse, and the rich history associated with their development.

We find that the scientific literature includes a series of strong responses from the mainstream scientific community including criticisms, corrections, and in some cases, resignation of editors. The contrarian views were often found to be unsubstantiated by the data and are no longer seriously considered by many climate scientists.

Insofar as these contrarian themes are representative of other contrarian viewpoints, our findings reinforce those of Anderegg et al., (2010) who found lower expertise and prominence among the contrarian scientists and those of Doran and Zimmermann (2009) who found that as scientific expertise increased, so did certainty in the main premises of AGW. Here we find case study evidence that the science representing major contrarian views is less robust than the counterparts that reflect the AGW consensus.

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