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REBUTS: Happer, Lindzen, Spencer
SURREBUTALS BY: Happer, Lindzen, Spencer
p.4 Focus on ECS claims by the above.
p.5 "One of the guiding principles of science is to use *all* of the available data when testing hypotheses. Reliable science does not throw out the vast majority of the data that disagrees with a hypothesis, and then use the remaining tiny fraction to conclude that the sought-after result is correct. This type of "cherry picking" is how Drs. Spencer, Lindzen, and Happer reach the conclusions in their testimony. "
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p.8 "I do not view the satellite record as a robust data set, and I would not trust it to 10 guide climate policy."
(reviews history of errors and corrections), see also R.Abraham.
p.14 "Thus, I view the satellite record as a work in progress, and it is far from the "gold standard" that Drs. Spencer, Lindzen, and Happer present it as. And I do not judge the satellite record to be of sufficient quality to use it to (in)validate the climate models."
p.15 "It is also worth noting that skeptics frequently make claims about the surface record that, upon cursory examination, turn out to be wrong. ... Dr. Lindzen stood before the *House of Commons* and *accused a major NASA center of fraud* based on a plot that he clearly *knew nothing about*." *(He had gotten a plot from someone else and had not checked it.)*
p.22 "Thus, I find that Drs. Spencer, Lindzen, and Happer's claim that climate change has stopped, or paused, is incorrect. "
pp.34-42 CV

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

REBUTTAL TESTIMONY OF DR. ANDREW DESSLER,

Professor in the Department of Atmospheric Sciences
Texas A&M University

On Behalf of

Clean Energy Organizations

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I. EXPERT EXPERIENCE

Q. Please state your name and address for the record.

A. My name is Andrew Dessler. My address is 5110 Congressional Dr., College Station, Texas 77845.

Q. What is your educational background and profession?

A. I am currently a professor in the Department of Atmospheric Sciences at Texas A&M University. I have a Bachelor of Arts degree in physics from Rice University, a Doctor of Philosophy ("Ph.D.") in chemistry from Harvard University, and I spent two years doing postdoctoral research at NASA in Greenbelt, Maryland. Prior to taking my job at Texas A&M University in 2005, I was on the research faculty in the Department of Meteorology and the Earth System Science Interdisciplinary Center at the University of Maryland. My complete curriculum vitae is attached as Schedule 1 to this testimony.

Q. Please describe the work you have done related to global warming, if any.

A. My research for the past decade has focused on water vapor and clouds, both of which play an important role in regulating our climate. On the policy side, I spent a year as a Senior Policy Analyst in the White House Office of Science and Technology Policy, where I was the Office's staff atmospheric scientist. Based on my experience, I have co-authored two books on climate change: "The Science and Politics of Global Climate Change: A Guide to the Debate" (Cambridge

University Press, 2006, 2010); and "Introduction to Modern Climate Change" (Cambridge University Press, 2012, 2015).

Q. Does your current profession require you to keep informed of developments and to maintain your in-depth understanding of global warming issues?

A. Yes.

II. OVERVIEW OF TESTIMONY

Q. What is the purpose of your testimony?

A. I have been asked by the Minnesota Center for Environmental Advocacy, Fresh Energy, Sierra Club, and the Izaak Walton League of America – Midwest Office (collectively "Clean Energy Organizations") to respond to opinions and assertions offered in the direct testimony submitted on behalf of Peabody Energy by Dr. William Happer, Dr. Roy Spencer, and Dr. Richard Lindzen criticizing the equilibrium climate sensitivity assumption used by the Interagency Working Group ("IWG") to develop a Social Cost of Carbon.

Q. Please explain what "equilibrium climate sensitivity" is.

A. Equilibrium climate sensitivity (hereafter "ECS") is typically defined to be the warming in response to a doubling of atmospheric carbon dioxide from pre-industrial amounts (280 parts per million) to twice that (560 parts per million), after equilibrium is established. The Intergovernmental Panel on Climate Change ("IPCC") reviewed all of the evidence in the peer-reviewed literature and

concluded in their 2007 Fourth Assessment Report that the *likely* range for the ECS was 2-4.5°C. The IWG used this estimate, along with an economic model, to estimate the cost of the damage caused by a ton of carbon dioxide released to the atmosphere. In the IPCC's 2013 Fifth Assessment Report, the *likely* range was slightly expanded to 1.5-4.5°C.

Q. Have you reviewed the direct testimony submitted in this proceeding by Dr. Roy Spencer, Dr. Richard Lindzen, and Dr. William Happer?

A. Yes.

Q. What is your overall impression of their testimony?

A. I find that the conclusions offered in their testimony are unreliable because they have not employed unbiased and rigorous scientific methods. One of the guiding principles of science is to use *all* of the available data when testing hypotheses. Reliable science does not throw out the vast majority of the data that disagrees with a hypothesis, and then use the remaining tiny fraction to conclude that the sought-after result is correct. This type of "cherry picking" is how Drs. Spencer, Lindzen, and Happer reach the conclusions in their testimony. Looking at *all* of the data strongly supports the fundamental conclusions that the Earth is warming, humans are extremely likely responsible for the recent warming, and future warming carries with it the risk of significant harm—the exact opposite of what they concluded. In my testimony, I will point out many of the places where Drs.

Spencer, Lindzen, and Happer relied on cherry picking to support otherwise untenable scientific positions.

III. SPECIFIC RESPONSES OR CORRECTIONS

Q. Do you have responses or corrections to specific assertions in the testimony of Drs. Spencer, Lindzen, and Happer?

A. Yes. In this testimony I will first give my opinion regarding the general assertion by Drs. Spencer, Lindzen, and Happer that the ECS assumed by the IWG is too large. Next, I will discuss the primary bases for this general assertion, namely that the satellite temperature data show a "hiatus" in the warming trend of global average temperatures and that models significantly overestimate the warming that will occur in the coming decades. Lastly, I provide a response to the assertion that there has been no increase in extreme weather due to climate change.

A. Equilibrium Climate Sensitivity

Q. Drs. Spencer, Lindzen, and Happer all claim that the ECS is below the IPCC's canonical range of 1.5-4.5°C for doubled carbon dioxide. Do you agree?

A. No. Specifically, it is incorrect to say that:

- ECS is "extremely unlikely to exceed 2°C." (Dr. Lindzen)
- "The temperature increase for doubling CO_2 levels appears to be close to the feedback-free doubling sensitivity of S = 1 K." (Dr. Happer)

In fact, none of the credible peer-reviewed literature cited supports either of those claims.

It is true that several recent estimates have uncertainty ranges that extend to low values. Thus, Dr. Spencer's testimony is most accurate when he says that ECS is "possibly as low as 1°C or less." What he neglects to say, however, is that these same analyses also allow much higher values of ECS—well within the IPCC's ECS range. Thus, while these measurements allow a low ECS value, they also allow higher values in the upper end of the IPCC's range.

In addition, Drs. Spencer, Lindzen, and Happer only discuss estimates of ECS based on the 20th century record. This is another example of cherry picking—other analyses of ECS, such as those from paleoclimate data and from model simulations, suggest ECS values nearer to the top of the IPCC range.

Thus, while there is *some* evidence that ECS is near the bottom of the IPCC range, there is other evidence that it is nearer to the top. That is why the IPCC range is as wide as it is.

Q. Drs. Spencer, Lindzen, and Happer all suggest that a small amount of warming due to increased carbon dioxide emissions might be beneficial for the Earth. Is warming of a few degrees significant?

A. A few degrees may not seem like much warming to some. After all, summer days can be 50°C warmer than the winter days and daytime can be 25°C warmer than the following night. And one day can be several tens of degrees Celsius warmer

or cooler than the next. If you consider these ranges of temperature variations, changes in the global average of a few degrees Celsius may sound insignificant.

In this case, however, this common intuition is wrong. Although the temperature in any single place can vary considerably by season, by day, and even by hour, the variations tend to cancel when averaged over the entire globe. When you are experiencing the warmth of daytime, someone on the other side of the globe is experiencing the coolness of night. When it is summer where you live, it is winter in the other hemisphere. Heat waves in one location are generally canceled by a cold spell somewhere else. In other words, the large temperature variations you experience are nearly completely canceled by opposite variations somewhere else on the Earth.

Because of this cancellation, the global average temperature of the Earth is very stable, with year-to-year temperature variations of just a few tenths of a degree. Moreover, seemingly small changes in global average temperature are associated with significant shifts in the Earth's climate. For example, the global annual average temperature during the last ice age was about 10°F colder than that of our present climate. At that time, the Earth was basically a different planet: glaciers covered much of North America and Europe, leading to a very different distribution of ecosystems, and because so much water was tied up in glaciers, sea level was approximately 400 feet lower than it is today.

During the summer of 2003, a heat wave struck Europe in which the average temperature in Europe was about 3°C above average. Despite this seemingly small amount of warming, this heat wave caused the deaths of several tens of thousands of people. And temperatures a few hundred years ago were about 1°C cooler than today—a large enough difference that we refer to that period as the Little Ice Age.

Furthermore, it is not just the magnitude of the warming but also the rate of warming that is of concern. It took more than 10,000 years for the planet to warm 5°C and emerge from the last ice age—an average rate of 0.05°C per century. The rate of warming predicted for the twenty-first century is a few degrees per century—about 100 times faster. Rate matters because the faster the warming occurs, the less time people and natural ecosystems have to adapt to the changes. If the sea level rises one meter in 1,000 years, we could likely adapt to that change without too much trouble. But a one-meter increase in sea level in a century would be much more expensive to adjust to. And a one-meter increase in a decade would be a disaster, displacing millions of people and destroying trillions of dollars of infrastructure.

B. Temperature Data

Q. Much of Drs. Spencer, Lindzen, and Happer's testimony claiming that the ECS assumed by the IWG is too high is based on measurements of the Earth's temperature. What temperature records are available?

A. There are several widely used records, including the surface thermometer and satellite records. Weather balloon records are also discussed, but are much less frequently used by the scientific community for reasons discussed below.

Q. Drs. Spencer, Lindzen, and Happer all emphasize the satellite record, particularly Dr. Spencer. What is your opinion of that data set?

A. I do not view the satellite record as a robust data set, and I would not trust it to guide climate policy. A review of its history provides justification for my views. Dr. Spencer and his colleague John Christy first published this data set in 1990. Surprisingly, Spencer and Christy's data showed a cooling trend (Christy et al., 1995[1]) in the mid-1990s. This result was surprising given that all of the other data at that time showed the climate system was warming.

In 1998, Wentz and Schabel discovered that Spencer and Christy had neglected the decay of the satellites' orbit in their trend calculation. Spencer and Christy acknowledged this problem and updated their algorithm to incorporate this effect (Christy et al., 2000). Despite their correction, there was no significant change to the cooling trend they saw. This was at least partially because, when correcting

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

for their last error, they introduced a new error into their algorithm—an incorrect diurnal cycle.[2]

In 2004, Fu et al. discovered that the tropospheric temperature trend in the satellite record was contaminated by stratospheric cooling. That is, the trend measured by the satellite was a combination of warming of the troposphere and cooling of the stratosphere. They offset each other to some extent, causing the resulting trend to be lower than the actual tropospheric trend. This was not, strictly speaking, an error. However, it underlines the complexity of the satellite temperature measurement and the fact that, even 15 years after the data set was first published, the scientific community was still learning what the measurements actually meant.

In 2005, Mears and Wentz discovered the diurnal cycle problem that Spencer and Christy introduced when they corrected for the orbit decay problem. To understand how the diurnal cycle affects the trend, imagine that a satellite flies over a location at 2 PM each day and takes a measurement of that location's temperature. Over time, the satellite's orbit drifts so that it flies over that location later and later each day. After a few years, the satellite is flying over that location at 3 PM. Because temperatures rise throughout the day, it is generally warmer at that location at 3 PM than it is at 2 PM. Thus, the drift in the satellite's orbit

[2] The diurnal cycle refers to the daily cycle of temperatures: warming during the day and cooling at night.

would by itself introduce a warming trend, even if the climate were not actually changing. This artifact must also be identified and adjusted for.

Here's what Mears and Wentz said in a letter to *Science* in response to a letter from Spencer and Christy in 2005:

> Once we realized that the diurnal correction being used by Christy and Spencer for the lower troposphere had the opposite sign from their correction for the middle troposphere sign, we knew that something was amiss. Clearly, the lower troposphere does not warm at night and cool in the middle of the day. We question why Christy and Spencer adopted an obviously wrong diurnal correction in the first place. They first implemented it in 1998 in response to Wentz and Schabel [1998], which found a previous error in their methodology: neglecting the effects of orbit decay.

In the years since, new problems with the satellite temperature record keep being identified. Po-Chedley and Fu, 2012, pointed out issues with how Spencer and Christy constructed their satellite time series. This problem arises because the record is stitched together from data gathered by about a dozen satellites, each of which lasts just a few years before it fails and is replaced by the next. This makes the temperature trend highly sensitive to how the records from successive satellites are intercalibrated. To understand this, suppose you are trying to watch your weight, but your scale breaks and a month passes before you buy a new one. If the new scale says you are two pounds heavier than your last reading on the old one, does this mean you have gained two pounds? Or does the new scale just read two pounds heavier than the old one? You could tell which of these was the case if you bought a new scale before the old one broke, and measured yourself on

both scales for a while to estimate the difference between them—if you had the foresight, patience, and money to do this.

The U.S. Government has tried to do this by launching each new satellite while the previous one is still operating. That way, overlapping measurements can be collected long enough to calibrate the new instrument. But since it is impossible to predict exactly when an instrument is going to fail, they have not been entirely successful in obtaining records that overlap for a sufficient period of time. As a result, the temperature trend estimated from the satellite data is quite sensitive to how one connects data between these satellites. After analyzing the methodology, Po-Chedley and Fu, 2012, concluded that the way Spencer and Christy stitched the satellites together artificially reduced the global mid-tropospheric trend by 0.042°C per decade for 1979–2009.

Most recently, Po-Chedley et al., 2015, have revisited the issue of diurnal cycle corrections and found that problems still remain in the trend calculations from these satellites.

Q. What are your conclusions about using satellite temperature data based on this history?

A. From this history, I extract three important points. First, every few years, significant new issues are discovered in the satellite temperature record, some of which are still being resolved. Second, the errors Spencer and Christy make always tend to *reduce* the trend—i.e., they work to lessen the magnitude of

climate change. Third, Spencer and Christy never discover these issues themselves.

Thus, I view the satellite record as a work in progress, and it is far from the "gold standard" that Drs. Spencer, Lindzen, and Happer present it as. And I do not judge the satellite record to be of sufficient quality to use it to (in)validate the climate models.

Q. Are balloon radiosonde data more reliable?

A. No. In my opinion, the radiosonde, or weather balloon, record is another unreliable data set. Issues with data homogenization (e.g., shifts in the trend due to changes in instrumentation) are even bigger problems than they are for the satellite record.

Also, as with the satellite record, scientists are continually uncovering issues with the data set. Sherwood et al., 2005, for example, found an uncorrected bias in the trend caused by daytime solar heating of the balloon instrument. And the methodology used to calculate the trends can have a huge impact on the answer one gets. In a recent paper, Sherwood and Nishant, 2015, used a novel homogenization technique to calculate an atmospheric warming in good agreement with the climate models.

One might view the supposed agreement between the satellite and balloon records as validations of both data sets. However, such comparisons have not identified the many problems in the satellite data, described above. Thus, the satellite-

balloon temperature comparisons appear to be a very loose check on either data set. Overall, like the satellite data, I do not judge the balloon record to be of sufficient quality to use it to (in)validate the climate models.

Q. Drs. Spencer, Lindzen, and Happer claim that the surface record has biases in it. What's your opinion of that claim?

A. In the mid-2000s, criticisms about the poor quality of the surface thermometer network surfaced. Some thermometers were admittedly placed in locations (e.g., a parking lot) that could cause reasonable people to wonder whether there was contamination in the long-term surface thermometer temperature record.

But the scientists who produce and maintain these records have been aware of this issue for decades and account for changes in station location, as well as many other factors, when calculating the temperature trends. After claims were made about poor siting, this issue was reexamined by independent groups (e.g., Hausfather et al., 2013; Wickham et al., 2013). In all cases, the surface temperature record has emerged unscathed.

It is also worth noting that skeptics frequently make claims about the surface record that, upon cursory examination, turn out to be wrong. For example, in 2012, during testimony to the UK House of Commons, Lindzen claimed to have found evidence that NASA Goddard Institute for Space Studies ("GISS") was

nefariously manipulating data[3] to inflate the warming trend. It turned out that his "evidence" was actually a simple mistake on his part, and no evidence of data tampering exists.[4]

When the error was pointed out, Lindzen issued a correction[5] that acknowledged that he took the plot from someone else and that he had done no work to verify the contents of the plot. This episode is deeply revealing about climate skeptics in general and Dr. Lindzen in particular. Dr. Lindzen stood before the *House of Commons* and *accused a major NASA center of fraud* based on a plot that he clearly *knew nothing about*. The fact that Dr. Lindzen throws accusations of fraud around so freely, without even a cursory checking of the facts, speaks volumes about the quality of his skepticism. I can assure you that his testimony in this case shows the same level of scholarship and due diligence as his claim of tampering in the NASA GISS data.

Q. So what do you view as the most reliable data set?

A. My view is that the surface thermometer record is the most reliable data set. To reach this conclusion, one need only compare the history of the surface thermometer record with that of the satellite record. As discussed above, every few years another major problem in the satellite record is discovered, and there is

[3] http://i.telegraph.co.uk/multimedia/archive/02148/RSL-HouseOfCommons_2148505a.pdf, slide 12.
[4] http://www.realclimate.org/index.php/archives/2012/03/misrepresentation-from-lindzen/.
[5] https://web.archive.org/web/20140720170731/http://repealtheact.org.uk/blog/apology-from-prof-lindzen-for-howard-haydens-nasa-giss-data-interpretation-error.

abundant evidence of on-going issues in the data set (e.g., the diurnal cycle correction). The surface thermometer record, on the other hand, because of its central role in the climate debate, has undergone incredible scrutiny over the last decade and has emerged unscathed. In the end, there is absolutely no legitimate scientific reason to reject the surface record in favor of the satellite record, and there are many good reasons to consider the surface record superior to the satellite record.

C. No Evidence of a Warming "Hiatus"

Q. Has the climate stopped changing over the past two decades?

A. No, the climate is still changing. Figure 1 shows the trend in surface air temperature between the date on the x-axis and March 2015 (the most recent available month). The trend is positive for every month, except January 2005, thereby demonstrating that the climate has been (nearly) continuously warming since the late 1970s.

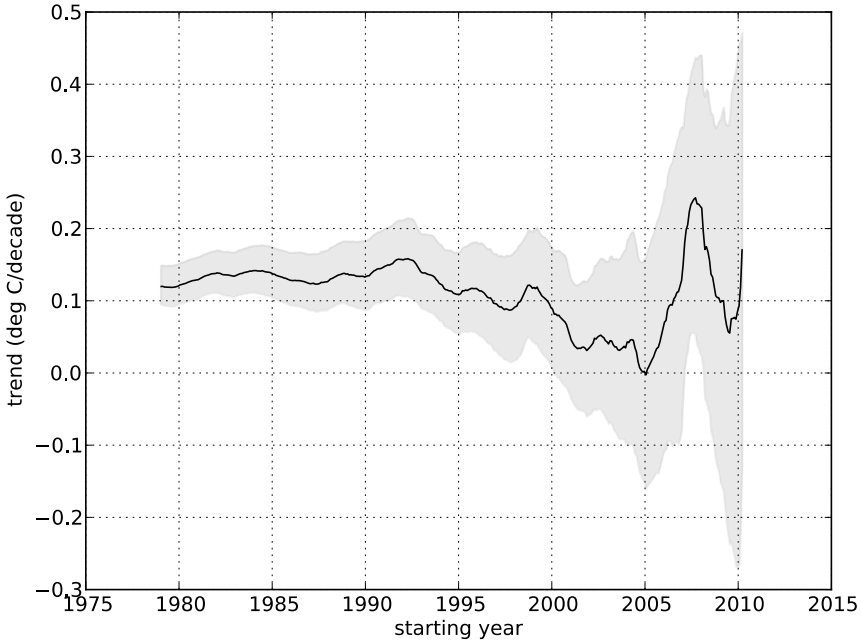

Figure 1. Trend in monthly and global average European Center for Medium Range Weather Forecast interim reanalysis 2-m air temperature (Dee et al., 2011) over time. The value for a particular time is the trend between that point and March 2015, and is calculated by linear least-squares fit. The shaded area is the 95% uncertainty, which is adjusted for autocorrelation following Santer et al., 2000.

It is important to point out that, in most cases, Drs. Spencer, Lindzen, and Happer qualify their claim that there has been no warming over the last few decades by saying things like "no discernible warming" (Dr. Lindzen) or "virtually no warming" (Dr. Happer). *Discernible* and *virtually* sound impressive but have no scientific meaning. Their use of these qualifiers shows that even they know the climate is indeed changing.

Dr. Spencer says in his testimony that there is "no statistically significant warming" in the recent record. In this case, *statistically significant* does have a

specific scientific meaning. It means that the error bars on the trend extend below zero—so you cannot *exclude* a trend of zero. This is quite different from saying that there *is* no trend, and Dr. Spencer is capitalizing on the fact that most people do not understand the nuances of the language of statistics.

Figure 1 shows that Dr. Spencer is correct: beginning around 2000, the uncertainty in the trend expands and begins to encompass zero. Thus, it is correct to say that there has been no *statistically significant* warming since 2000. But this does not mean the trend is zero, close to zero, or even small. It means that the trend is smaller than the uncertainty. It seems quite clear to me that Drs. Spencer, Lindzen, and Happer recognize this, which is why they have to qualify their claims.

In addition, Drs. Spencer, Lindzen, and Happer only investigate a single metric for climate change: global average temperature. This is not necessarily an unreasonable choice, but there are many other metrics one should look at before claiming that climate change had stopped. This is yet another example of cherry picking in their testimony.

If one looks at the spatial distribution of temperature change rather than global average temperature for example, quite a different picture of trends over the last two decades emerges. Figure 2 shows that most of the globe has warmed considerably since the 1980s and 1990s, except for the Eastern Pacific, which has actually cooled. The cooling in the Eastern Pacific largely offsets the warming in the rest of the planet, leading to the reduced global average trends apparent since the early 2000s, shown in Figure 1. Thus, our climate is changing, even though the global average temperature may not be changing much.

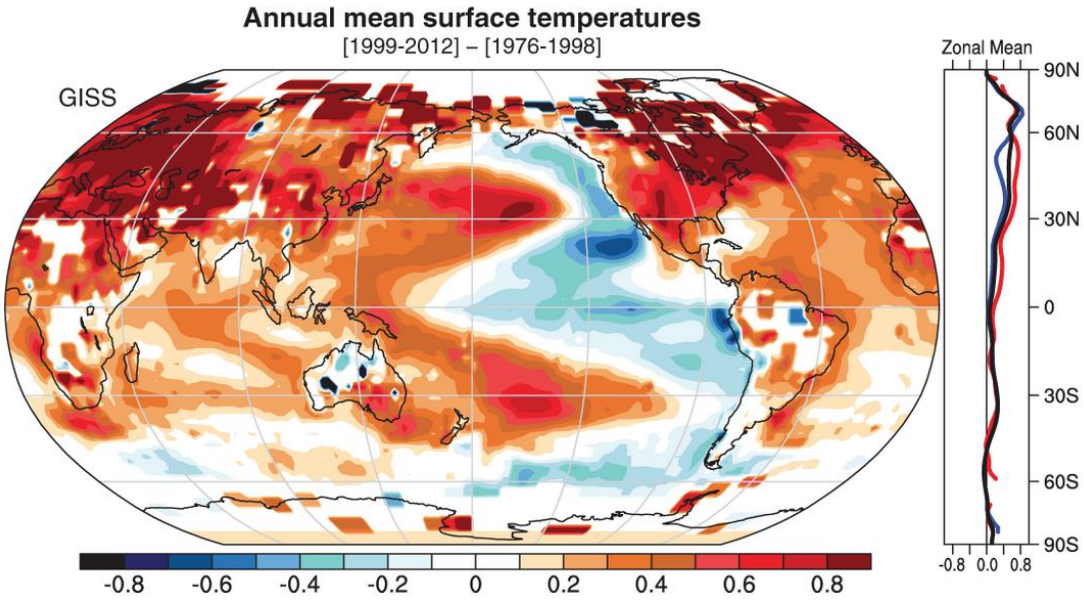

Figure 2. Mean annual surface temperature differences from NASA GISS Surface Temperature Analysis for 1999–2012 and 1976–1998 in °C, with zonal means at right for ocean (blue), land (red), and zonal mean (black). From Trenberth and Fasullo, 2013.

Other measures of climate change may very well be better predictors of the impact that increased concentrations of greenhouse gases will have on our planet. Indeed, as discussed by Dr. John Abraham in his Rebuttal Testimony, most of the energy trapped by greenhouse gases goes into the ocean, so that changes in ocean heat content ("OHC") are an important indicator of climate change. Figure 3 shows OHC has increased rapidly since 1998, even as the rate of warming of the surface temperature has slowed.

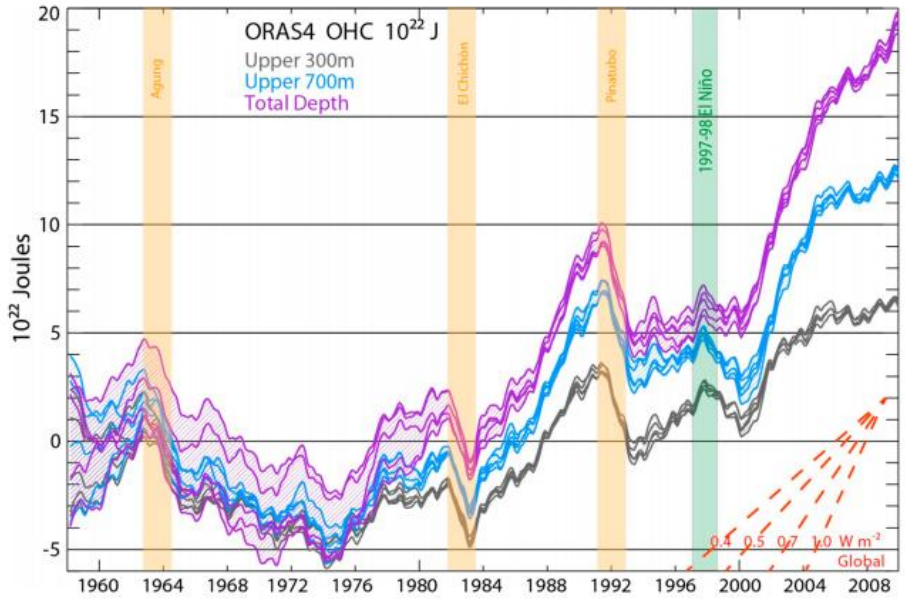

Figure 3. Ocean heat content ("OHC") integrated from 0 to 300 m (grey), 700 m (blue), and total depth (violet) from a reanalysis system, as represented by its 5 ensemble members. The time series show monthly anomalies smoothed with a 12 month running mean, with respect to the 1958-1965 base period. Hatching extends over the range of the ensemble members and hence the spread gives a measure of the uncertainty. The vertical colored bars indicate a 2 year interval following volcanic eruptions with a 6 month lead (owing to the 12 month running mean), and the 1997-1998 El Nino event again with 6 months on either side. On lower right, the linear slope for a set of global heating rates (W/m2) is given. After Fig. 1 of Balmaseda et al., 2013.

Finally, Figure 4 shows a time series of the 95th percentile temperatures over land; this figure demonstrates that the warmest 5 percent of observed temperatures have risen rapidly over the period that Drs. Spencer, Lindzen, and Happer claim that climate change has stopped. In other words, extreme temperatures over land are becoming more extreme. This result is consistent with Figure 2, which shows that land areas have continued warming over the past decade.

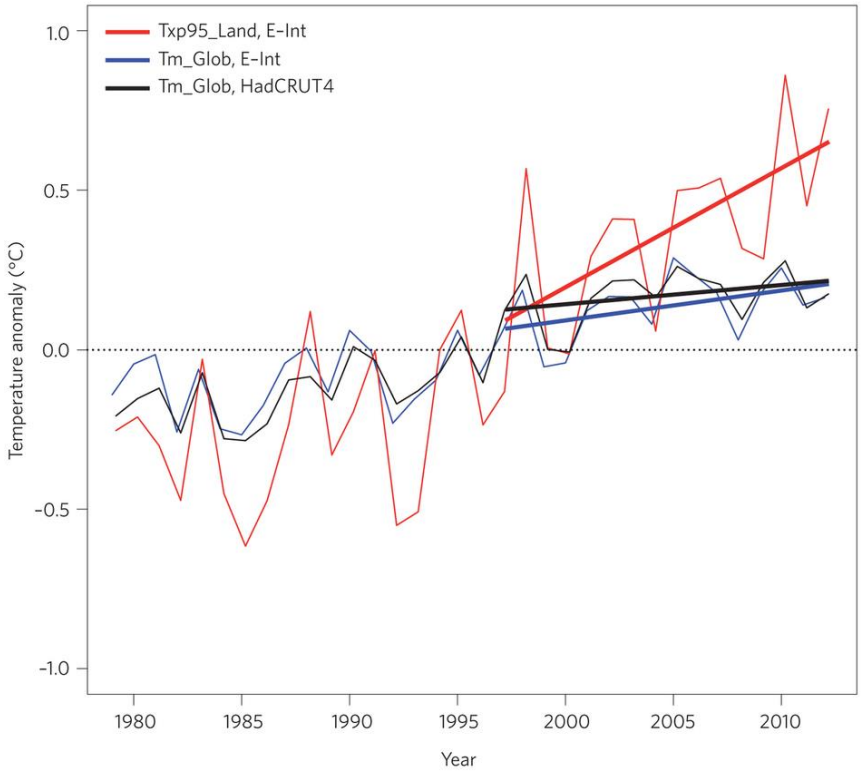

Figure 4. The time series are the ERA-Interim 95th percentile of the maximum temperature over land (Txp95_Land, red) and the global (ocean + land) mean temperature (Tm_Glob) in ERA-Interim (blue) and HadCRUT4 (black). The anomalies are computed with respect to the 1979-2010 time period. From Fig. 2 of Seneviratne et al., 2014.

Thus, I find that Drs. Spencer, Lindzen, and Happer's claim that climate change has stopped, or paused, is incorrect. A more complete and less biased examination

of the data yields the exact opposite conclusion to the one advanced by Drs. Spencer, Lindzen, and Happer—that, indeed, climate change continues unabated.

Q. Has the rate of warming slowed down over the last decade or so?

A. Yes. Figure 1 shows that the warming since the beginning of the 21st century has been smaller than that since the 1990s (although the differences are not statistically significant).

Q. Does a smaller trend over a decade or so tell you anything about the long-term trajectory of the climate?

A. No. The trend over short periods (e.g., a decade) can deviate significantly from the long-term trend. As an example, Figure 5 shows a time series of monthly and global average surface temperature from the surface thermometer record. Also shown as short black segments are trends based on endpoints that were carefully selected to produce cooling trends. As you can see, it is possible to generate a continuous set of short-term cooling trends, even as the climate is experiencing a long-term warming. All you have to do is start the trend calculation during a particularly hot year (e.g., an El Niño year) and then end it in a cool year (e.g., a La Niña or volcanic year).

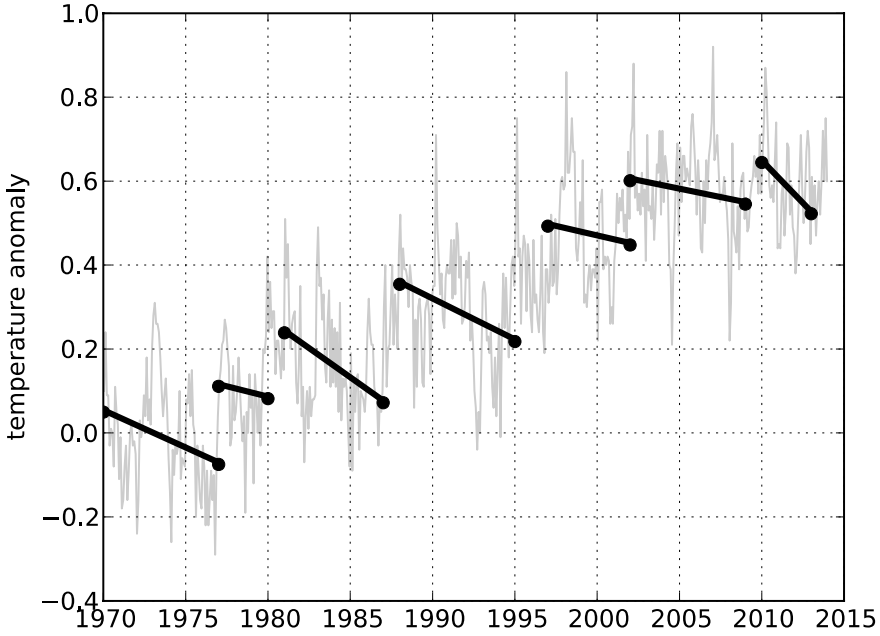

Figure 5. A plot of monthly and global average surface temperature from the surface thermometer record (gray line) along with short-term trend lines (black lines). Data are from the NASA GISS Surface Temperature Analysis (Hansen et al., 2010), downloaded from data.giss.nasa.gov/gistemp/. This was taken from Fig. 2.5 of Dessler, Introduction to Modern Climate Change, 2nd edition, to be published in Sept. 2015 by Cambridge Univ. Press.

The existence of these short-term negative trends allows people like Drs. Spencer, Lindzen, and Happer to claim during almost any year covered by Figure 5 that global warming had stopped or even that the Earth had entered a cooling period. But in reality, the short-term cooling trends provide zero information about the long-term trajectory and it is not accurate for Drs. Spencer, Lindzen, and Happer to imply otherwise.

D. Accuracy of Models

Q. Drs. Spencer, Lindzen, and Happer all claim that climate models have overpredicted temperature increases when compared to observations. In your opinion, have models been able to simulate the 20th century historical record?

A. Yes. Figure 6 shows a comparison between climate models and observations, and the overall agreement between models and observations is excellent. In particular, I see no evidence supporting Dr. Spencer's claim that climate models have warmed two to three times faster than the observations over the last thrity-five to fifty-five years.

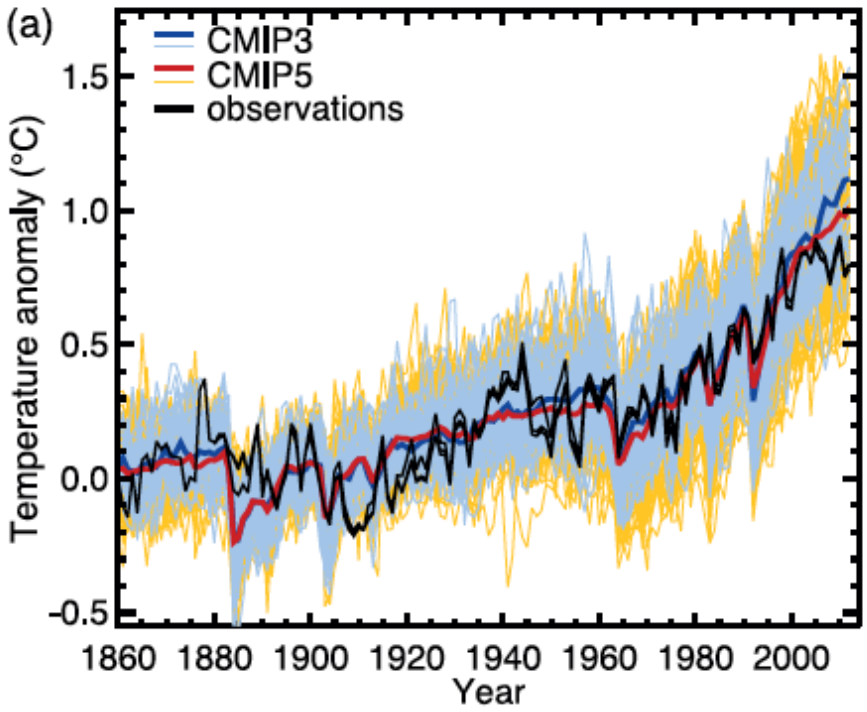

Figure 6. Three observational estimates of global mean surface temperature (black lines) from the Hadley Centre/Climatic Research Unit gridded surface temperature data set (HadCRUT4), Goddard Institute for Space Studies Surface Temperature Analysis (GISTEMP), and Merged Land-Ocean Surface Temperature Analysis (MLOST), compared to model simulations (CMIP3 models – thin blue lines and CMIP5 models – thin yellow lines) with anthropogenic and natural forcings. After Figure TS.9 of the Technical Summary of the 2013 IPCC Working Group I report.

Q. Have models been able to simulate temperature changes during the last one to two decades?

A. For long-term comparisons, such as that in Figure 6, short-term fluctuations (e.g., El Nino cycles and volcanic eruptions) have little effect on the comparison. But when comparing periods of a decade or two, they can have a huge effect. As demonstrated in Figure 5, sometimes these short-term variations can produce a short-term negative trend during a period long-term warming.

So the key to comparing short-term trends in models and observations is to account for these short-term variations in the comparison. This means that comparing the observed temperature time series to an average of an ensemble of models, as done in the testimony of Drs. Spencer, Lindzen, and Happer (see, e.g., Figures 1 and 3 of Dr. Spencer's Exhibit 2), will not produce accurate results. In an ensemble of models, the highs and lows caused by the short-term variability do not occur at the same time. When many model runs are averaged together, the short-term ups and downs cancel out and you get a smooth increase in temperature. When such an ensemble average is compared to a single time series, full of ups and downs, the agreement may look terrible. This is certainly a major problem with Drs. Spencer, Lindzen, and Happer's comparisons.

To do this comparison correctly, the models must incorproate the same the exact phasing of short-term variability as is in the observations. Recent publications have actually done this and it substantially improves the comparison between the models and observations (Dai et al., 2015; Huber and Knutti, 2014).

Another issue with the model-data comparison is that the models assumed incorrect "forcing"[6] over the last decade. In particular, the models assumed a brighter sun than we actually had, which causes the models to run "hot." And the models do not include the effects of several small volcanic eruptions that occurred

[6] "Forcing" is an imposed energy imbalance imposed on the planetary system. Addition of CO_2 causes a forcing, as do changes in the intensity of the Sun, addition of aerosols, etc. In response to a forcing, the planet's temperature adjusts until it reestablishes energy balance.

in the last decade. This also tends to make the models run "hot." Accounting for these errors in the forcings of the models improves agreement between the models and observations (Huber and Knutti, 2014).

In the end, the models do a reasonable job of simulating the last decade, just as they do a reasonable job of simulating the last century. I therefore find no evidence that climate models have been programmed to be too sensitive, as suggested by these witnesses.

E. Extreme Weather

Q. Drs. Spencer, Lindzen, and Happer also claim that there is no evidence that extreme weather events are increasing in frequency or intensity due to climate change. Do you agree?

A. No. These statements are false. For example, Dr. Happer writes:

> There is not the slightest evidence for any increase in extreme weather events, as summarized by the Senate Testimony of 1 August, 2012 by John Christy, which I reference in my prepared report.

But Figure 4 clearly shows an increase in extreme heat events. And by relying on the testimony of John Christy, Dr. Happer is also relying on a source that is several years old, not published in the peer-reviewed literature, and widely disputed by the scientific community.

In fact, a wide array of peer-reviewed analyses have indicated that humans are playing an increasingly important role in extreme temperature and precipitation

events (Christidis et al., 2011; Fischer and Knutti, 2015; Min et al., 2011; Min et al., 2013; Morak et al., 2013). And rising sea level is making extreme sea level events more damaging, even when the weather event driving the sea level is not more extreme. For example, the increase in sea level over the 20th century made the storm surge from Hurricane Sandy more damaging and more costly than it would otherwise have been.[7] And given the strong connection between temperature and sea level, we can expect sea level to continue to rise due to human activities—and bring with it more intense extreme sea level events.

Finally, while not exactly an "extreme event," the ongoing acidification of the ocean due to the release of carbon dioxide could have dire consequences (Orr et al., 2005). Two billion people on the planet rely on protein from the ocean, and changes in ocean ecosystems due to changing ocean chemistry could severely stress those food supplies.

[7] https://www.climate.gov/news-features/features/superstorm-sandy-and-sea-level-rise.

IV. CONCLUSION

Q. What are the most important aspects of climate change you would like the Public Utilities Commission to know?

A.

1. The climate has changed over the last century, and the climate has continued to change over the last decade or so.
2. There is no evidence that our predictions of several degrees Celsius of warming over the next 100 years are wrong.
3. A few degrees Celsius in global average warming is a huge amount of warming for human society and ecosystems.

Q. Does this conclude your testimony?

A. Yes.

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Education:

1994 - Ph.D. - Chemistry, Harvard University
1990 - A.M. - Chemistry, Harvard University
1986 - B.A. - Physics, Rice University

Employment

2007-present	Professor, Dept. of Atmospheric Sciences, Texas A&M University
2005-2007	Associate Professor, Dept. of Atmospheric Sciences, Texas A&M University
2000	Senior Policy Analyst, White House Office of Science and Technology Policy, Environment Division, Washington, DC
1998-2005	Associate Research Scientist, Earth System Science Interdisciplinary Center (ESSIC), Univ. of Maryland, College Park, MD
1996-1998	Assistant Research Scientist, ESSIC and the Dept. of Meteorology
1994-1996	National Research Council Research Associateship in the Atmospheric Chemistry and Dynamics Branch of NASA Goddard Space Flight Center, Greenbelt, MD.

Awards

2014	AMS Louis J. Battan Author's Award for *Introduction to Modern Climate Change*
2014	Texas A&M Association of Former Students Teaching Award (College of Geosciences)
2012	AGU Atmospheric Sciences Ascent Award
2011	Google Science Communication Fellow
2011	Texas A&M College of Geosciences Distinguished Achievement Award for Faculty Research

2011	Texas A&M Sigma Xi Outstanding Communicator Award
2006	Aldo Leopold Leadership Program Fellowship
1999	NASA Goddard Laboratory for Atmospheres Best Senior Author Publication Award for "A reexamination of the 'stratospheric fountain' hypothesis" [*Geophys. Res. Lett.*, 1998].
1999	NASA New Investigator Award recipient
1994-1996	National Research Council Research Associateship
1993	AGU Atmospheric Sciences Section Outstanding Student Paper Award
1991-1994	NASA Graduate Student Fellowship in Global Change Research

Notable recent invited presentations

2012	Woods Hole, H. Burr Steinbech at-large scholar
2012	NCAR ASP Thompson Lecturer
2012	Truman Distinguished Lecturer Series, Sandia National Laboratories

Leadership positions and notable committees

2012-2015	Chair of AAAS Section W (atmospheric and hydrospheric sciences)
2013-2016	Member, AMS Climate and Radiation Committee
2014-2017	Member, NASA Earth Science Subcommittee
2011, 2015	NASA Earth Science Senior Review for Mission Extension

Teaching:

- GEOS 444: *The science and politics of global climate change: A guide to the debate.* Developed this course, which is taught as part of the Enviromental Sciences curriculum.
- GEOS 210: *Climate change.* Developed this course, which is taught as part of the Enviromental Sciences curriculum.
- ATMO 602: *Atmospheric physics* (Fall 13 and 14)
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- ATMO 201, *Atmospheric Science* (Fall 07)

Graduate students:

Hyun Cheol Kim – Ph.D. (Univ. of Maryland), 2005

Joonsuk Lee – Ph.D, 2007, co-chair (with P. Yang)
Allison Cardona – M.A. 2008
Jeremy Solbrig – M.A. 2009
Sean Casey — Ph.D. 2009
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Tao Wang — M.A. 2011
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Books

A. E. Dessler, *The chemistry and physics of stratospheric ozone*, Academic Press, San Diego, 2000.

A. E. Dessler and E. A. Parson, *The science and politics of global climate change: A guide to the debate*, Cambridge Univ. Press, first edition 2006, second edition 2010, third edition expected 2016.

A. E. Dessler, *Introduction to modern climate change*, Cambridge Univ. Press, first edition 2011, second edition sent to publisher, publication expected 2015.

Refereed Publications

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