Happer v. Karoly

A Summary by Andy May

February 15, 2016 was the beginning of an in-depth debate on man-made climate change between two well-known experts in the field, Dr. William Happer and Dr. David Karoly, hosted by TheBestSchools.org. Both have been heavily involved in atmospheric research since the 1980s, but they have landed on opposite sides of the debate.

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The Great Climate Debate

Happer v. Karoly

Dr. Happer is a physicist who has specialized in the interactions of radiation with matter, a key issue in greenhouse warming and optics. Happer, Princeton physics professor emeritus, invented the sodium laser guide star used by astronomers and the military to reduce atmospheric distortion of light and was a co-author of an early book on global warming, *The Long-Term Impacts of Increasing Atmospheric Carbon Dioxide Levels* (MacDonald 1981). Dr. Karoly, University of Melbourne (Australia) professor, is a climate scientist who has been heavily involved in several IPCC reports and first described the famous "atmospheric fingerprint" (cooling in the stratosphere and warming in the troposphere) that shows rising greenhouse gas concentrations have an impact on recent surface warming. Although the fingerprint does not allow the magnitude of human climate impacts to be computed, it does allow us to infer that human CO_2 emissions have some finite impact on climate.

We are very fortunate to have this detailed record of a debate between two such prominent atmospheric physicists. Brief biographies of each and the man-made climate change positions they argue can be read in full here:

https://thebestschools.org/special/karoly-happer-dialogue-global-warming/

Unfortunately, Dr. Karoly backed out in the middle of the debate, so the responses to Dr. Happer's statement and interview were written by Glenn Tamblyn, a blogger for the website skepticalscience.com.

The debate is fascinating, but the material provided by TheBestSchools is very long, often repetitive, and poorly organized. Here we summarize the debate by asking six key questions. For each question we will present the arguments for both Happer and Karoly, using their words whenever possible.

Special notes

Dr. William Happer, the Cyrus Fogg Bracket Professor of physics, Emeritus, at Princeton University

David Karoly is the Leader of the Earth Systems and Climate Change Hub in the Australian Government's National Environmental Science Program, based in CSIRO.

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The questions are:

1. **Is recent global warming unusual?**
2. **How do we know the excess CO_2, and other greenhouse gases, are from human activities?**
3. **How do we know that the increase in CO_2 and other greenhouse gases in the atmosphere have caused most of the recent global warming?**
4. **Climate models have been used to compute the amount of warming caused by human activities, how accurate are they?**
5. **How do we know global warming and more CO_2 will have substantial adverse impacts on humans and the planet?**
6. **Should anything be done to combat global warming?**

The six questions we will use to organize the remarks by Happer and Karoly

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The views of both scientists are given for all questions. Many readers will find little new but may enjoy reading the arguments from two such prominent scientists. Both are very familiar with the data but draw quite different conclusions from it, we try and show why. Debates on climate change between prominent scientists are rare, as discussed by Anthony Watts here. So, enjoy this one. Following are the overarching theses argued by each scientist in their own words:

> ***Dr. Karoly: "Science has established that it is virtually certain that increases of atmospheric CO2 due to burning of fossil fuels will cause climate change that will have substantial adverse impacts on humanity and on natural systems. Therefore, immediate, stringent measures to suppress the burning of fossil fuels are both justified and necessary."***

> ***Dr. Happer: "There is no scientific basis for the claim that increases of atmospheric CO_2 due to burning of fossil fuels will cause climate change that will have substantial adverse impacts on humanity and on natural systems. If fossil fuels are burnt responsibly to limit real pollutants like fly ash, oxides of nitrogen or sulfur, heavy metals, etc., the CO_2 released will be a benefit to the world. Any resulting climate change will be moderate, and there will be very major benefits to agriculture and other plant life."***

Karoly and Happer agree that climate changes, that the world has become warmer over the past 120 years, and that adding CO_2 to the atmosphere will cause some warming. They also fully agree that the CO_2 concentration in our atmosphere is increasing about 2 ppm/year, which is about half of human emissions. The other half is absorbed by the ocean and biosphere. These facts are not in dispute. They differ on the projected impacts of the warming and additional CO_2. Happer thinks the impacts will be net beneficial and Karoly thinks they will be detrimental to humans and nature. We will unpack this disagreement into the six key questions listed above, then provide the arguments from each scientist. The first three parts have no "discussion and comments" section, my views on the debate will be in a final post, Part D. This is all about Happer and Karoly, with a little supporting material added from IPCC AR5 (IPCC 2013), other references needed for clarity, and Glenn Tamblyn's replies to Happer.

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1. Is recent global warming unusual?

Karoly compares the relatively accurate, high-resolution modern global average temperature rise of 0.9°C over the past 100 years, to the sparse, very low resolution and poorly-dated temperature proxy records of the past 1,000 years and asserts that no 100-year temperature rise in the past millennium is as large as we have recently seen. To quote him:

> "There are a number of estimates of the hemispheric average temperature using different methods and different proxy data, not just the one shown [below, Figure 1] by Michael Mann and his collaborators. They all show that the period around 1000 AD was relatively warm and that the period around 1600 to 1800 was relatively cool, just as the Hockey Stick does. However, they all show that the increase in Northern Hemisphere average temperature over the twentieth century was larger than in any other century over the last millennium and that the last 30 years was likely warmer than any other 30-year period over the last 1000 years averaged over the whole Northern Hemisphere." From the Karoly Interview.

The "Hockey Stick" graph he refers to is from (Mann, Bradley and Hughes 1998). This paper is often abbreviated as MBH98. The hockey stick shown in Figure 1 is the same data, but from the third IPCC report, called "TAR."

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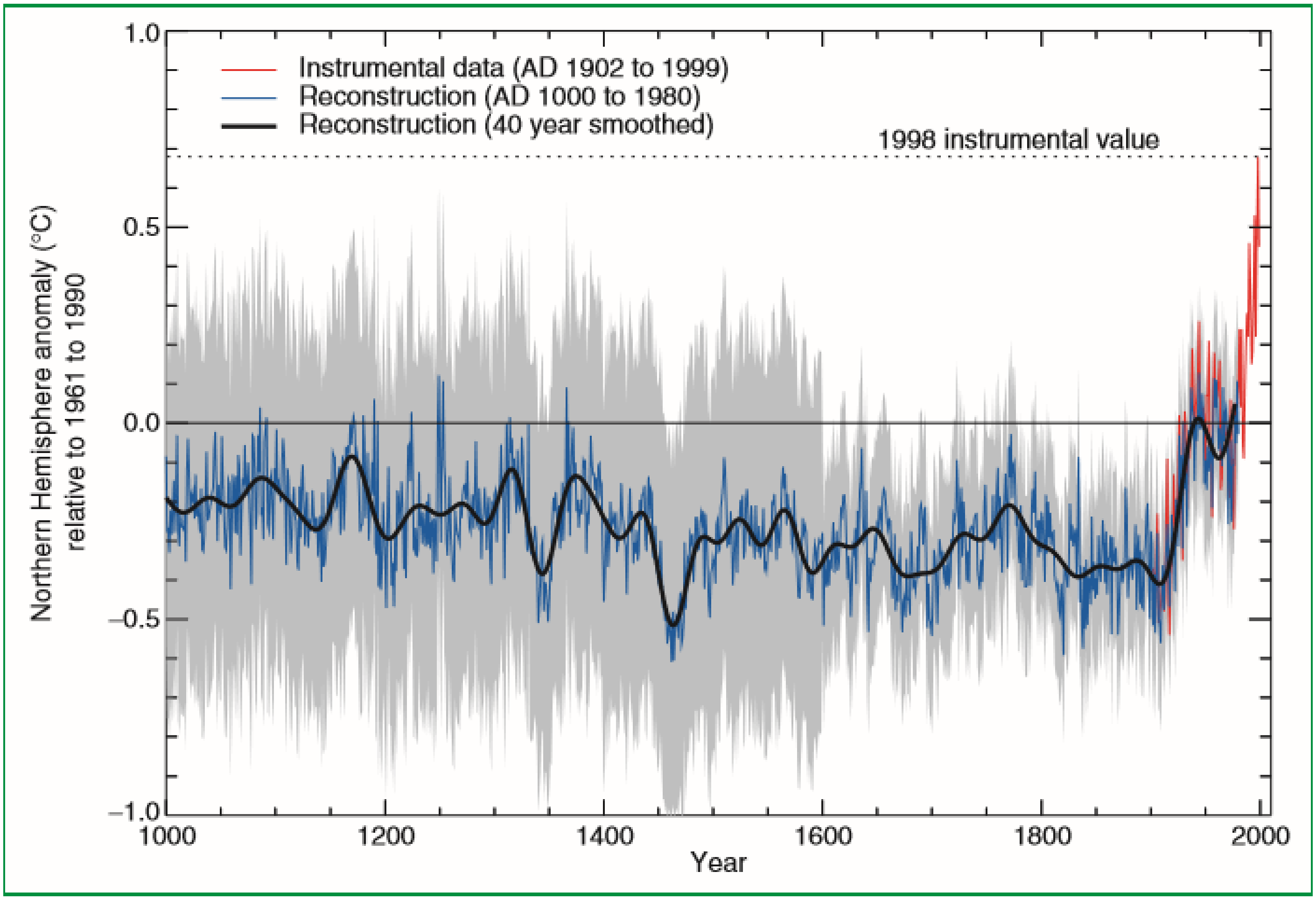

Figure 1. Mann's "Hockey Stick" Northern Hemisphere temperature reconstruction. Source: IPCC TAR Technical summary 2001, page 29.

Happer says the following about the Hockey Stick:

> "The hockey-stick temperature record was conspicuously absent from the latest IPCC report, which speaks volumes. My guess is that the hockey stick started out as an honest but mistaken paper, but one welcomed by the global-warming establishment. They had been embarrassed for years by the Medieval Warm Period, when Vikings farmed Greenland, and when emissions from fossil fuels were negligible. A.W. Montford's book, The Hockey Stick Illusion (Anglosphere Books, 2015), is a pretty good summary of what happened."

Another rebuttal to the Hockey Stick can be found in (McIntyre and McKitrick 2005) and as discussed by (McKitrick 2018) the National Academy of Sciences validated their criticisms. The events unfolded as follows, according to McKitrick:

> "After publishing their 2003 E&E article and reviewing Mann's unpublished responses to it, McIntyre and McKitrick [M&M] submitted an extended critique of the errors and misrepresentations in MBH98 to Nature magazine, which had published the first of the hockey

> stick papers. Nature solicited a response from Mann et al., and after examining it they ordered Mann et al. to publish a detailed correction and restatement of their methodology, which appeared in June 2006. M&M also extended their critique of Mann's statistical methodology and submitted it to GRL, which had published the 2nd hockey stick paper, and after peer review GRL published their study. Mann et al. never submitted a response. A panel led by Professor Wegman later conducted an independent review of the mathematical and statistical issues and upheld the M&M critique. A panel of the National Academy of Sciences also conducted an examination of the whole issue of paleoclimate reconstructions and upheld all the technical criticisms M&M made of Mann's work, going so far as to publish their own replication (North et al., 2006, pp. 90-91) of the spurious hockey stick effect M&M identified." (McKitrick 2018)

A precise global temperature record, that can accurately show a one-degree change in 100 years, of the past millennium will probably never be created, the temperature proxies available are simply not that accurate. While the MBH98 "Hockey Stick" is not used by the IPCC anymore, there are a variety of other reconstructions they do use to show the range of possible temperatures over the past millennium, some are shown in Figure 2, from the most recent IPCC report, called "AR5" (IPCC 2013).

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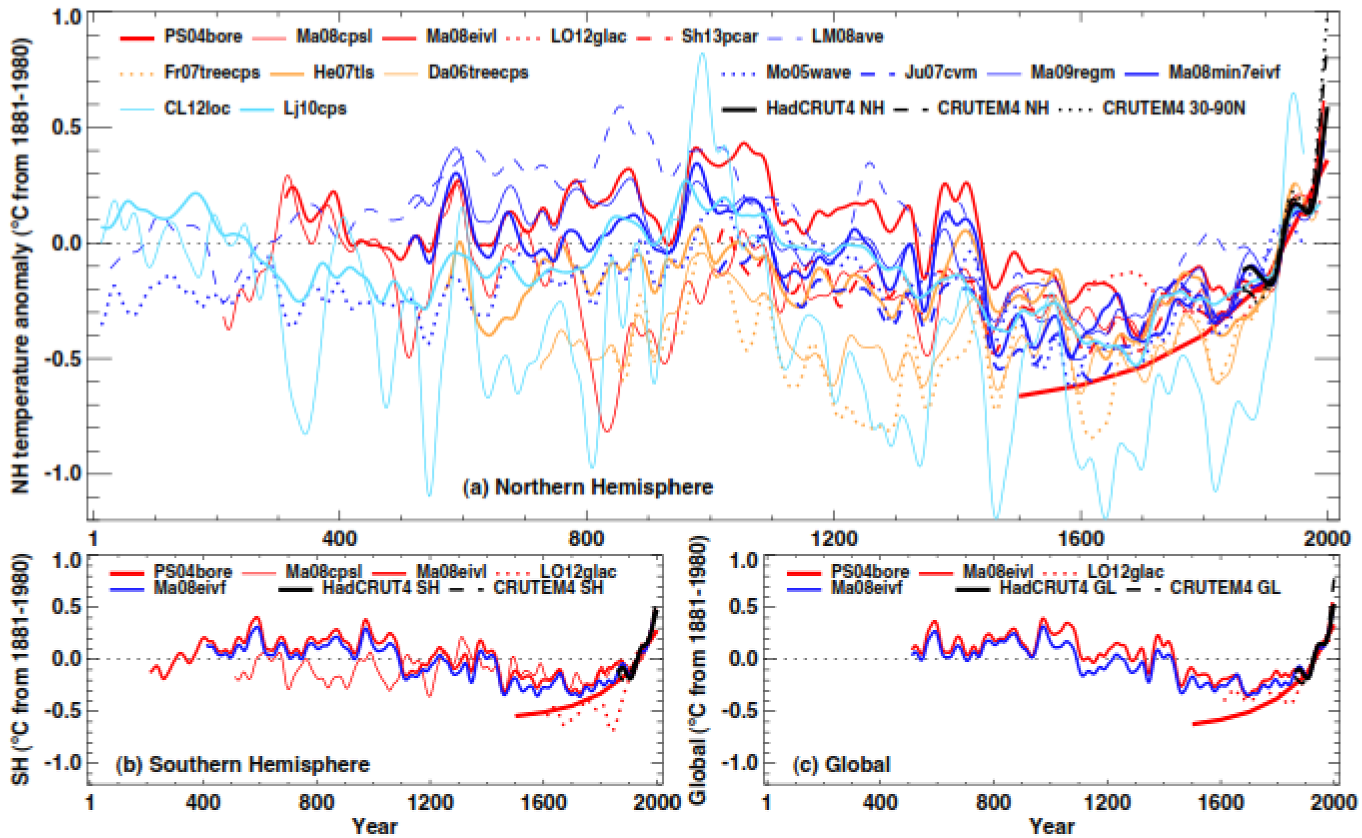

Figure 5.7 | Reconstructed (a) Northern Hemisphere and (b) Southern Hemisphere, and (c) global annual temperatures during the last 2000 years. Individual reconstructions (see Appendix 5.A.1 for further information about each one) are shown as indicated in the legends, grouped by colour according to their spatial representation (red: land-only all latitudes; orange: land-only extratropical latitudes; light blue: land and sea extra-tropical latitudes; dark blue: land and sea all latitudes) and instrumental temperatures shown in black (Hadley Centre/ Climatic Research Unit (CRU) gridded surface temperature-4 data set (HadCRUT4) land and sea, and CRU Gridded Dataset of Global Historical Near-Surface Air TEMperature Anomalies Over Land version 4 (CRUTEM4) land-only; Morice et al., 2012). All series represent anomalies (°C) from the 1881–1980 mean (horizontal dashed line) and have been smoothed with a filter that reduces variations on time scales less than about 50 years.

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Figure 2. Various temperature reconstructions for the Northern and Southern Hemispheres and the globe. Source IPCC AR5, page 409 (IPCC 2013).

Rather than just showing the MBH98 graph of Northern Hemisphere temperature (Figure 1), Figure 2 shows 15 temperature reconstructions of the Northern Hemisphere to illustrate the variability. Several of the reconstructions show one degree or larger changes in less than 100 years, further the range of temperature estimates in many 100-year periods is larger than one degree. One extreme example is from 1400 to 1500 AD. The graph also shows three modern high-resolution instrumental global temperature anomalies from the 19th century to 2000. The display portrays the uncertainty in the proxy reconstructions and clearly demonstrates that one cannot definitively say the recent 0.9 degree rise in global average temperature is unusual. It may be unusual, but the data are not accurate enough to establish the fact. The various reconstructions clearly show the Medieval Warm Period (roughly 900 to 1150 AD), which is a matter of historical record. As discussed in the IPCC caption, the red lines are land-only reconstructions,

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orange are land only extra-tropical, the light blue are land and sea extra-tropical reconstructions, dark blue are land and sea all latitudes.

Karoly disagrees with researchers that think the Medieval Warm Period (MWP) (~900-1200 AD) was warmer than today. However, the spread of values and the amplitude of the proxy temperature swings in Figure 2 shows we don't know this. While historical records suggest Europe, Greenland and many other areas were warmer then, we do not have enough data to show the whole world was warmer. Estimates of temperature anomalies in the MWP, in Figure 2, range from -0.2° to +0.8°C. The records are ambiguous, Karoly could be correct, but the global average temperature during the MWP is unknown. Tamblyn also suggests that the speed of recent warming is unprecedented, but since the variability of the temperature changes in Figure 2 is larger than the recent warming and it is invalid to compare proxy temperatures to instrumental temperatures in any case, the assertion remains unproven. Further, the rate of warming from 1910-1945, before man-made CO_2 was a factor, is nearly the same as the rate of warming from 1975 to 2005, which is a problem for Tamblyn.

2. How do we know the excess CO_2, and other greenhouse gases, are from human activities?

Karoly explains that the recent increase in atmospheric CO_2 is associated with a decline in the ratio of the carbon isotopes ^{13}C to ^{12}C, which is expected if some of the CO_2 is from burning fossil fuels since plants prefer ^{12}C. Fossil fuels have less of the long-lived ^{13}C isotope of carbon, since they are mostly made from decaying plant material. In addition, there is a slight decrease of atmospheric oxygen as one would expect from burning fossil fuels.

> "The increase in atmospheric carbon dioxide over the past 40 years agrees very well with the increase expected from emissions associated with burning fossil fuels, land clearing, and industrial activity, less the additional uptake of carbon dioxide into the oceans and the land ecosystems due to the higher concentrations." *Karoly's major statement*

Karoly also points out that during the last 800,000 years of the Pleistocene Ice Age, Antarctic ice cores suggest that CO_2 levels have never been above 300 ppm. Thus, the current level of 400 ppm is very unlikely to have a natural cause, such as volcanic eruptions or CO_2 out-gassing from the warmer oceans.

Happer agrees that the observed increase in CO_2 concentration in the atmosphere is due to human activity: burning fossil fuels and other industrial activity.

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3. How do we know that the increase in CO_2 and other greenhouse gases in the atmosphere have caused most of the recent global warming?

Karoly's first argument is an appeal to the "consensus."

> "Nevertheless, an overwhelming consensus of climate scientists agree that human-caused climate change is happening, and that global warming will continue throughout the current century, with many adverse impacts on human and natural systems." *From the Karoly major statement.*

Happer's detailed response contains his view of "consensus science."

> "Truth has never been determined by "an overwhelming consensus," and in fact, consensuses have often been completely wrong." From *Happer's detailed response.*

In Karoly's statement, he goes straight into a discussion of how we know much of the increase in CO_2 concentration in the atmosphere is from humans (see the previous question, note Happer agrees the increase in CO_2 is due to human activities) but provides no more evidence that CO_2 and other greenhouse gases have caused *most* of the recent warming. For the calculation of the greenhouse gas contribution, he turns to climate models.

How computer models are used to separate natural warming from human-caused warming:

> "… climate model simulations have been used to assess the relative importance of different forcing factors on the climate system and how well they explain the observed global warming. The simulations are driven by natural forcing factors, such as changes in solar radiation and volcanic aerosols, as well as human-caused changes in greenhouse gases and human activity-related climate forcing factors, including industrial aerosols and land use change." *From the Karoly statement.*

Karoly refers to a whisker plot from the IPCC AR5 report (Figure 3) which shows the impact of human and natural "climate forcings" as computed by the climate models from 1951-2010.

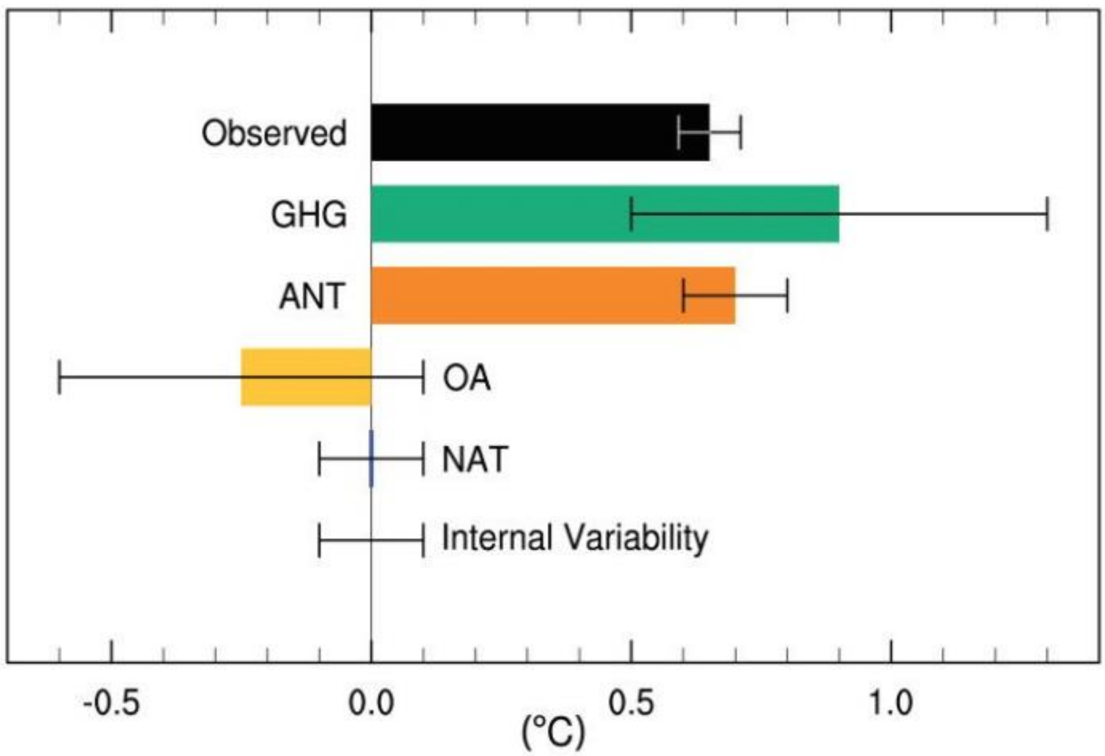

Figure 3. The assumed temperature changes due to GHG (greenhouse gases), ANT (anthropogenic), OA (other anthropogenic), NAT (natural forces), and INT (internal climate variability) from 1951 to 2010. Source Figure 10.5 from (IPCC 2013) page 884.

Karoly also provides the following illustration of the reasons we "know" humans are causing global warming (Figure 4).

Figure 4. Reasons that we know humans are causing [some] global warming. Source SkepticalScience.com.

Most of the reasons given are related to human CO_2 emissions, which both Happer and Karoly agree are the main cause of the rising CO_2 concentration in the atmosphere and oceans. The principal disagreement between them is how much warming is caused by CO_2. The tropopause rises as the surface warms, this is not controversial. Karoly believes that since winter is warming more than summer and nights more than days, this excludes solar variability as a cause of the warming, perhaps this is so. But, none of the reasons given exclude internal variability (mainly ocean cycles).

The cooling upper atmosphere (stratosphere) could be due to more CO_2, since CO_2 radiates a lot of infrared radiation (IR) to space from the stratosphere. It could also be due to increased shielding of thermal radiation from below due to additional IR absorption in the troposphere. But, regardless of the cause, there is a noticeable correlation between the observed tropospheric warming and the stratospheric cooling in the atmosphere. For a discussion of the significance of the correlation, displays of the data and additional references see Munshi, 2018 (Munshi 2018). Thus, the essence of the debate is not if CO_2 warms the lower

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atmosphere, the argument is about how much warming is due to CO_2 and other greenhouse gases. More detail on Figure 4 and references can be seen at this link by John Cook.

Happer points out at the beginning of his statement that CO_2 levels today are much lower than during almost any time in the history of life on Earth. Figure 5 shows the history of CO_2 levels for the past 550 million years.

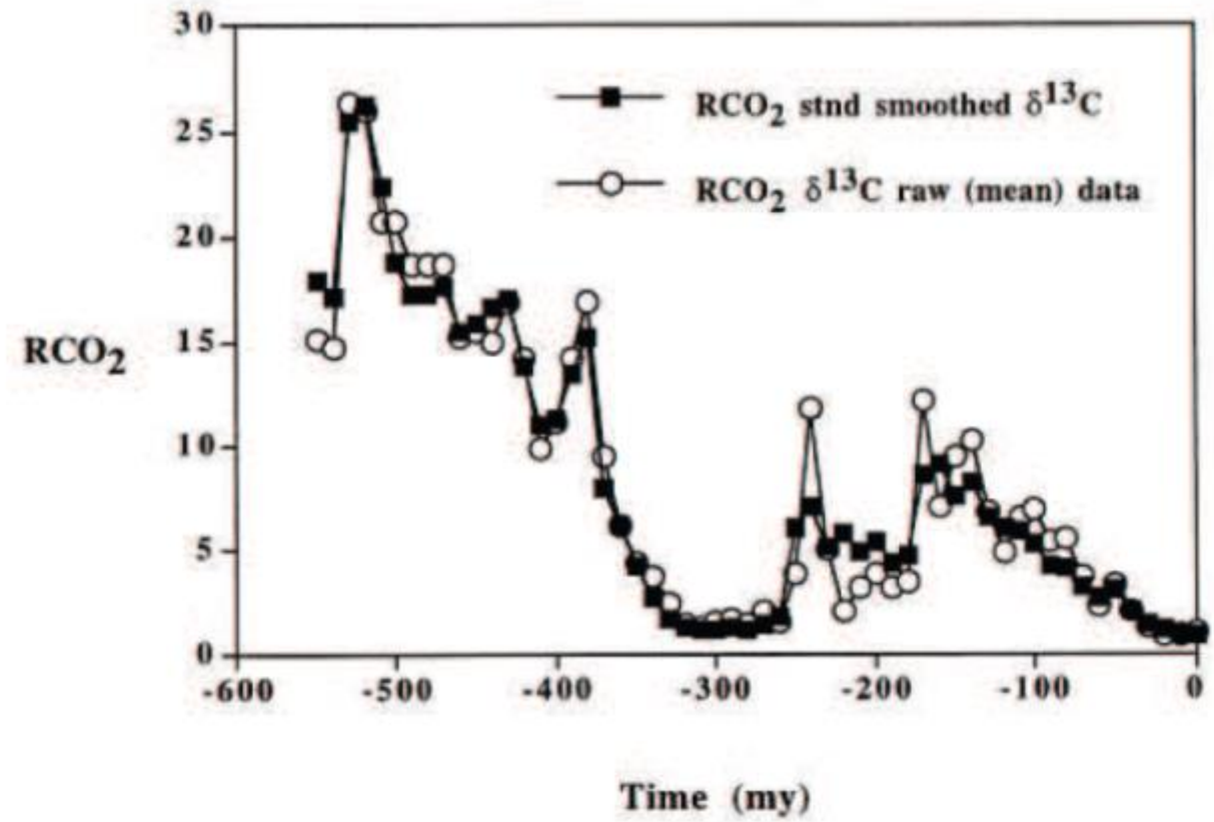

Figure 5. History of CO_2 levels for the past 550 million years. Source: (Berner and Kothavala 2001).

Happer writes this about Figure 5:

> "The important message of Fig. [5] is that CO2 concentrations have been much higher than present values over most of the history of life. Even though CO2 concentrations were measured in thousands of parts per million by volume (ppm) over most of the Phanerozoic, not the few hundred ppm of today, life flourished in the oceans and on the land. Average pH values in the ocean surface were as low as pH = 7.7, a bit lower than the pH = 8.1 today. But this was still far from acidic, pH < 7, because of the enormous natural alkalinity of seawater. The mean global temperature was sometimes higher and sometimes lower than today's. But the temperature did not correlate very well with CO2 levels. For example, there were ice ages in the Ordovician, some 450 million years ago, when the CO2 levels were several thousand

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> ppm.” (Berner and Kothavala 2001) and (Quinton and MacLeod 2014) From Happer’s statement.

Tamblyn writes the following about the same graph and a separate, but similar one in his detailed response:

> “Lest we wonder how the Ordovician ice age could have occurred … GEOCARB III (which Professor Happer also references) is a geochemical model, which estimates past CO2 levels from the chemistry of rocks. Its calculations are run over steps of 10 million years and averaged over 50 million years. It is not sensitive enough to detect shorter-term changes. Direct geological evidence shows that CO2 levels fell sharply during that period, in 1 to 2 million years or less — too small for GEOCARB III to capture. A higher-resolution geochemical model applied just to this period suggests a decline of CO2 levels from ~5000 to 3000 ppm. With differences in solar output, 3000 ppm then is equal to 500 ppm today. Climate models applied to late Ordovician conditions predict icehouse conditions at CO2 levels below about 2240 to 3920 ppm.
>
> The explanation is that changes in the greenhouse effect over time, due to changes primarily in CO2 and methane levels, explain much of the observed climate history. They aren’t the only factors. Orbital cycles influence how much sunlight the Earth receives. The extent of snow and ice changes how reflective the Earth is. The position of the continents matters (land reflects more sunlight than the oceans), and continents shape the flow of ocean currents, influencing heat transport. For around 30 million years, Antarctica has been isolated and surrounded by a huge current, the Antarctic Circumpolar Current, promoting cooling. For many, hundreds of millions of years before, this wasn’t so.” Tamblyn detailed response.

So, 3000 ppm in the Ordovician ice age is equal to 500 ppm today, yet we are currently at 400 ppm? I should mention that Tamblyn’s unreferenced assertion about 3000 ppm in the Ordovician being equal to 500 ppm today is controversial, the Sun in the Ordovician was probably weaker than the Sun today, true, but only 5% weaker (Feulner 2012). This is not enough of a reduction in solar power to cause 3000 ppm to be equivalent to 500 ppm today.

Tamblyn’s point about resolution is valid but does not prove his case and his numbers are inconsistent with basic physics and his thesis. He lists many valid influences on climate but fails to make the case that CO_2 is the dominant influence. The quoted passage appears to weaken Tamblyn’s case and strengthen Happer’s.

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4. Climate models have been used to compute the amount of warming caused by human activities, how accurate are they?

Karoly explains that natural forces are separated from human influences on climate with more than 30 computer models that compare well to observations since 1860 and writes:

> "The observed significant cooling for one to two years after major volcanic eruptions —Santa Maria (1903), Agung (1963), El Chicon (1982), and Pinatubo (1991) —is simulated very well. The observed global mean temperature variations throughout the whole period lie within the range of all the model simulations with combined forcings, indicating the models simulate well the chaotic interannual variability of global mean temperature. There is very good agreement between the observed long-term global warming since the late nineteenth century and the average global warming across all the model simulations for combined natural and anthropogenic forcing." *From the Karoly statement.*

He shows the following illustrations (Figure 6) from IPCC AR5 (IPCC 2013):

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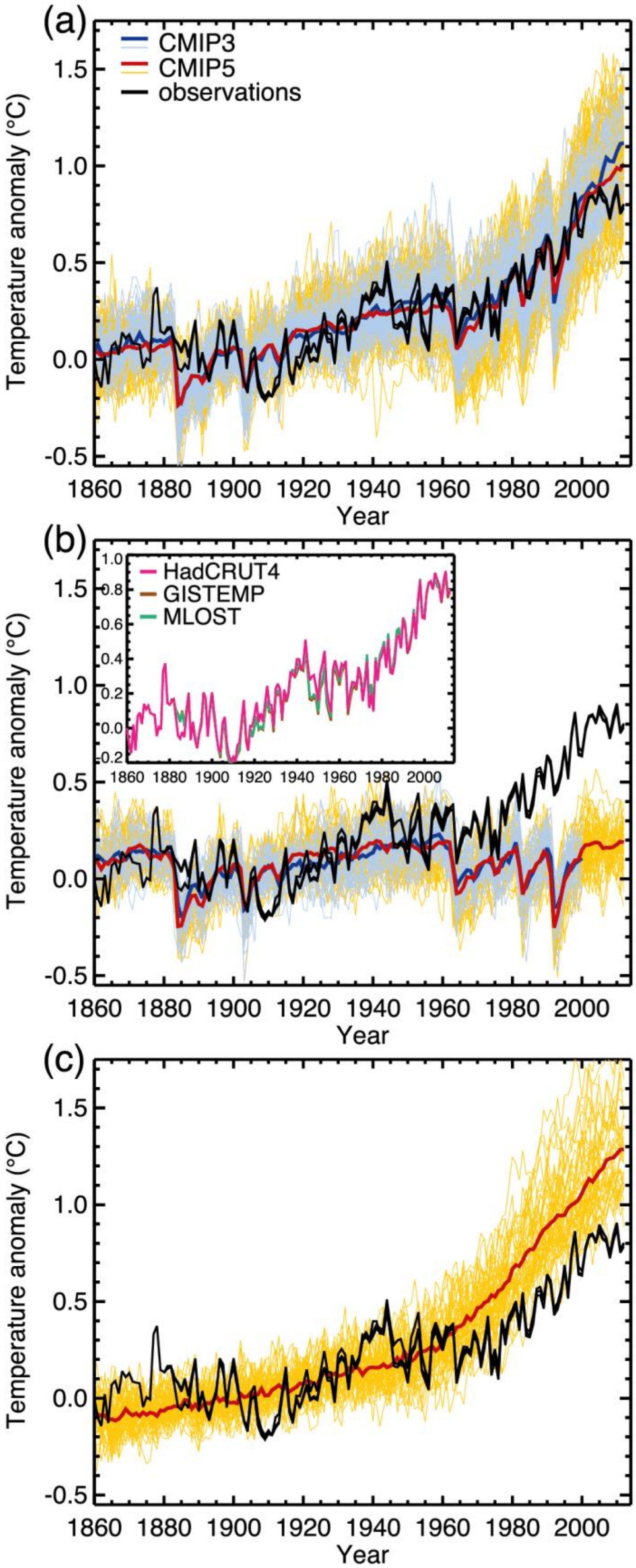

FIGURE 6

(a) The ensemble mean of numerous CMIP3 and CMIP5 climate models are shown in blue and red and compared to observations shown in black. The range of modeled results is shown with yellow and gray shading. The minimum warming in (a) from the models can be almost a degree C lower than the maximum model value for any given date and the error increases with time. This display models both human-caused and natural warming. (b) Same as (a) but only natural warming is simulated. (c) Same as (a) but only greenhouse gas warming is simulated. (c) suggests that net forcing (except for greenhouse gases) is negative, since natural forcings are assumed to be zero by the IPCC, they claim the negative forcings are "other anthropogenic." The temperature anomalies are computed relative to the mean from 1880-1919. Source IPCC AR5, figure 10.1 (IPCC 2013) page 879.

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Thus, the evidence for the magnitude of the human impact on climate is entirely model-based and direct measurements of the impact have not been made. Critics also point out that the warming from 1910 to 1945 and 2000 to 2012 are poorly matched by the models. Karoly responds:

> "Of course, a small number of scientists say that the climate models are tuned to simulate the recent observed warming but are unreliable for projecting future warming trends. Others say that they show too much global warming, because the observed warming from 1998 to 2010 was very small, while the simulated warming continued, if you consider the average across all the climate model simulations. As shown already when considering the observed global mean temperature variations, there is large natural variability in global mean temperature in the observations and the models. The observed departure in 2010 from the multi-model mean is no larger than in 1910 or in 1940 and is well within the envelope of all the model simulations." *From the Karoly statement.*

Thus, the poor reproduction of 1910-1945 and 2000-2012 is acknowledged, but in Karoly's opinion the mismatch is acceptable. The error from 1910 to 1945 ranges from -0.2° to +0.4°C, approximately equal to the warming from 1975 to 2010, but human emissions of CO_2 were not considered (or modeled) to be significant before 1951. How interesting that both sides use the poor model match from 1910-1945 in their arguments, but with opposite intent.

Happer has the following to say about using climate models to "prove" global warming since 1951 is primarily due to human activity:

> "I disagree. This statement is based on excessive faith in computer models. The wide availability of computers and powerful software to make color displays has been a serious problem, since it has blurred the lines between reality and virtual reality. These are not the same. In my Statement and Interview I tried to stick to real satellite pictures of visible and thermal radiation from the Earth, real measurements of ocean pH, real records of tornados, hurricanes, floods, droughts, etc. Essentially all of Dr. Karoly's claims of warming from greenhouse gases come from computer models, with lurid, threatening reds to represent the supposedly harmful effects of the demon gas, CO_2." *Happer's detailed response.*

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5. How do we know global warming and more CO_2 will have substantial adverse impacts on humans and the planet?

Karoly writes that we are already seeing adverse impacts from global warming and that these will continue in the future.

> "Global warming has led to increases in hot extremes and heatwaves, affecting human health and leading to crop and animal losses, as well as increases in the occurrence and intensity of wild fires in some regions.
>
> Increases in global temperature have led to global sea level rise, flooding coastal areas and causing coastal erosion and pollution of coastal freshwater systems with seawater. The impacts of storm surges, combined with global and regional sea level rise, were clearly demonstrated by the storm surge impacts of Hurricane Sandy on New York City and the east coast of the United States. Expected sea level rise by the end of this century for even the smallest projected global warming will lead to the annual flooding of many hundreds of millions of people and the complete loss of some low-lying island countries.
>
> One of the other major impacts of climate change due to increasing carbon dioxide concentrations is the increase in carbon dioxide dissolved in the oceans. As shown below, the dissolved carbon dioxide in the upper waters of the ocean has increased in parallel with the increase in atmospheric concentration. As the oceans absorb more carbon dioxide, they become less basic (or more acidic), with a higher concentration of carbonic acid. This can be seen in the decrease in pH of ocean water by about 0.1 units over the last 30 years." *Karoly's major statement.*

Karoly acknowledges that there are some possible benefits from higher CO_2 and warming, but these benefits are only for "moderate levels of global warming." Thus, the magnitude of expected warming is important.

> "The increase in carbon dioxide concentrations in the atmosphere has some potential benefits for plants because carbon dioxide is essential for photosynthesis. Plants grown in an atmosphere with higher carbon dioxide have faster growth rates and lower water use, assuming there are no other limits on growth." *From Karoly's statement.*

Happer writes in his statement:

> "If increasing CO_2 causes very large warming, harm can indeed be done. But most studies suggest that warmings of up to 2 K will be good for the planet [(Tol 2009)] extending growing seasons, cutting winter heating bills, etc." *From Happer's statement.*

He adds:

> "More CO_2 in the atmosphere will be good for life on planet Earth. Few realize that the world has been in a CO_2 famine for millions of years — a long time for us, but a passing moment in

geological history. Over the past 550 million years since the Cambrian, when abundant fossils first appeared in the sedimentary record, CO_2 levels have averaged many thousands of parts per million (ppm), not today's few hundred ppm, which is not that far above the minimum level, around 150 ppm, when many plants die of CO_2 starvation [(Dippery, et al. 1995)]. An example of how plants respond to low and high levels of CO_2 is shown in Fig. [7] from the review by Gerhart and Ward." (Gerhart and Ward 2010) *From Happer's statement.*

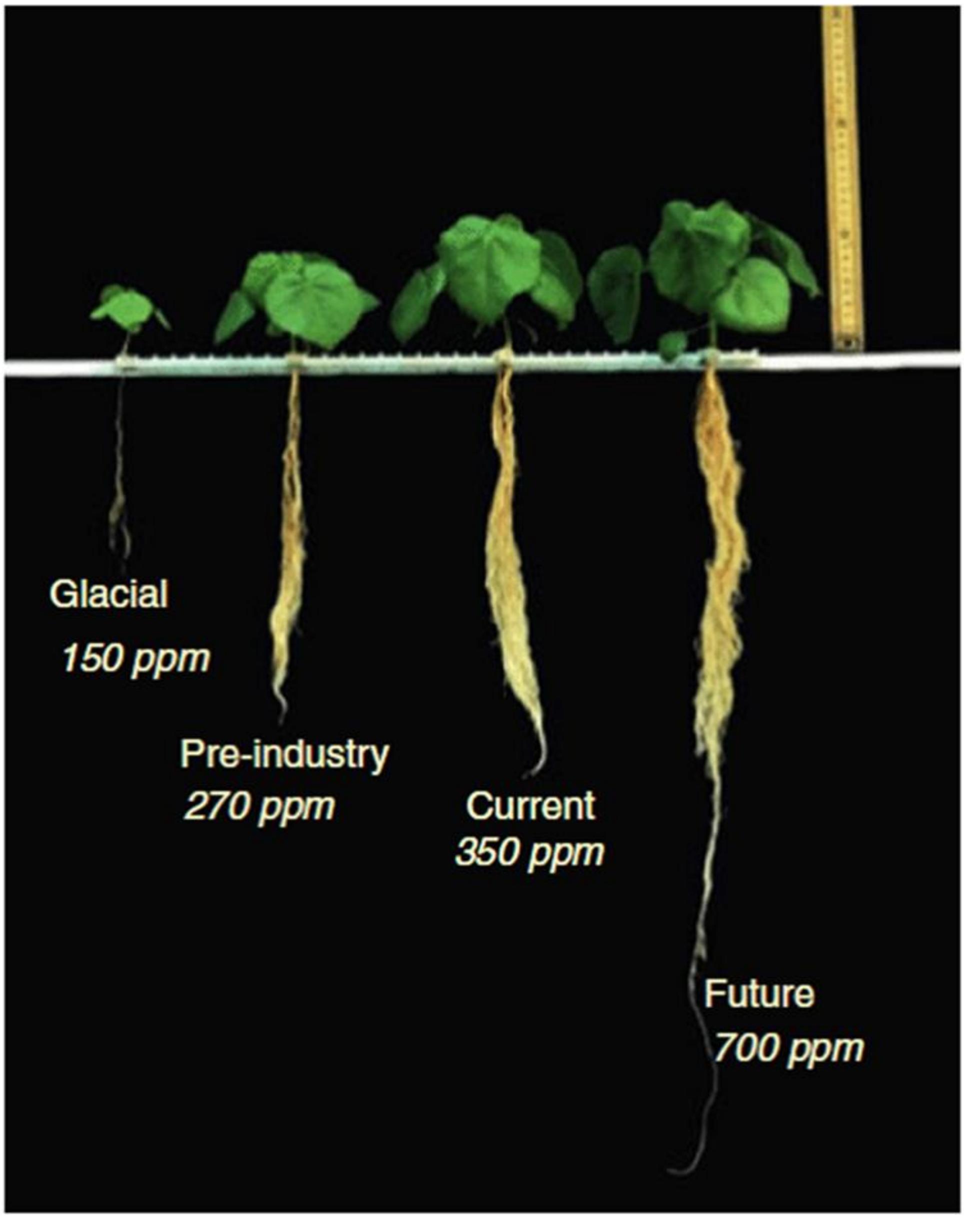

Figure 7. The response of velvetleaf seedlings to various CO_2 levels. Source (Gerhart and Ward 2010)

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From Tamblyn's detailed reply:

> "Temperature — specifically leaf temperature — is a critical factor in photosynthesis and crop yields. Photosynthesis is temperature-dependent: the productivity of photosynthesis is poor at low temperatures, rising to a peak around 30° C for C3 photosynthesizers, slightly higher for C4 plants. Beyond this peak, photosynthesis efficiency declines markedly, dropping to very low by around 40° C."

This is true and well known, but Happer was careful to say that warming of up to two degrees will be beneficial and Karoly agrees (assuming "moderate" means about 2°). The average temperature of the Earth's surface today is about 15°, well below the optimum temperature of 30°. Tamblyn also speculates that the nutritional value of plants may be less, but this is controversial. Tamblyn's comment is irrelevant to this discussion and a red herring, the debate is not about what happens at 40°, but what has happened and will happen at moderate temperature increases.

From Happer's interview:

> "I believe that more CO_2 is good for the world, that the world has been in a CO_2 famine for many tens of millions of years and that one or two thousand ppm would be ideal for the biosphere. I am baffled at hysterical attempts to drive CO_2 levels below 350 ppm, or some other value, apparently chosen by Kabbalah numerology, not science." *Happer's interview.*

From Happer's final reply:

> "Over most of the geological history of the Earth, CO_2 levels have been much higher than now. There were no tipping points: ocean acidification was not a problem; corals flourished, leaving extensive fossil reefs for us to study today; and evolution continued its steady course on land and in the oceans, punctuated by real catastrophes, including giant meteor strikes, massive volcanic eruptions leading to vast areas of flood basalts, etc. These events probably released CO_2, CH_4, SO_2, and other gases that significantly affected the oceans and atmosphere, but the catastrophes were not directly caused by greenhouse gases.
>
> The only undisputed effect of more atmospheric CO_2 over the past century has been a pronounced greening of the earth …" *Happer's final reply.*

Happer provides an excellent discussion of the benefits of more CO_2 in both his interview and his statement, they are well worth reading.

Happer disagrees with Karoly and Tamblyn's assertions that extreme weather events, excessive sea level rise, and ocean acidification will increase and cause problems.

> "One of the bogeymen is that more CO_2 will lead to, and already has led to, more extreme weather, including tornadoes, hurricanes, droughts, floods, blizzards, or snowless winters. But … the world has continued to produce extreme events at the same rate it always has, both long before and after there was much increase of CO_2 in the atmosphere. In short, extreme weather is not increasing. [Original reference (Pielke Jr. 2017)]

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> We also hear that more CO_2 will cause rising sea levels to flood coastal cities, large parts of Florida, tropical island paradises, etc. The facts, from the IPCC's Fifth Annual Report (2013), are shown in Fig. 19 [not reproduced here]. A representative sea level rise of about 2 mm/year would give about 20 cm or 8 in of sea level rise over a century. For comparison, at Coney Island, Brooklyn, NY, the sea level at high tide is typically 4 feet higher than that at low tide…
>
> In biologically productive areas, photosynthesizing organisms remove so much CO_2 during the day that the pH can increase by 0.2 to 0.3 units, with similar decreases at night when respiring organisms return CO_2 to the water." *Happer's major statement.*

Thus, Happer does not believe the estimated *average* decrease in pH of 0.1 unit cited by Karoly is significant. After all, if the daily local range of pH is over 0.2, how can this be a problem?

Tamblyn takes issue with a graph, from Rutgers University that Happer used to show Northern Hemisphere snowfall is increasing, which it is. He shows more data that shows the yearly variation in snow fall and snow cover is increasing, although it isn't clear what this means in terms of climate and his attempt to make it meaningful is not convincing, at least to this author. Tamblyn also claims the rate of sea level rise is going up in recent decades but acknowledges the current rate he quotes is 3.4 mm/year or just over a foot in 100 years. We should also point out that the last few years, since 2010, the rise in sea level has slowed considerably to about 1.6 mm/year according to CSIRO. The starting and ending points matter a great deal, the record is short, measurements inaccurate and difficult, and the accuracy desired, millimeters, very small.

Tamblyn acknowledges that a small decrease in pH will have little impact, if any, on the biosphere. But, he speculates that in the future there may be some adverse impacts based on studies of areas where conditions are very unusual, such as the Southern Ocean.

The debate over extreme weather events and how man-made climate change affects them will not be settled here or by Tamblyn, Happer and Karoly. The interested reader can read the various arguments in the original documents and Dr. Roger Pielke Jr.'s congressional testimony (R. Pielke Jr. 2017) and book (R. Pielke Jr. 2010) or this summary of the discussion of extreme weather and climate change. The only rational conclusion one can come to is that we do not know if the strength or frequency of extreme weather events are affected by climate change. A similar argument can be made for sea-level rise, as discussed in detail here.

Economic losses from extreme weather events have increased, but this is largely due to inflation and increases in wealth and the number of people living in areas exposed to extreme weather events, the connection to climate change is very weak, as stated by the IPCC in AR5:

> "Economic losses due to extreme weather events have increased globally, mostly due to increase in wealth and exposure, with a possible influence of climate change (low confidence in attribution to climate change)." *IPCC AR5, Technical Summary, page 49.*

In his final reply, Tamblyn includes a laundry list of potential dangers of climate change, but these are all speculative and based on models that use an assumed climate sensitivity to CO_2 that is probably too high and depend upon large potential temperature increases that may or may not happen. They are largely

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irrelevant to the discussion because Karoly and Happer, and presumably Tamblyn, all believe that a geologically rapid temperature increase of two-degrees C or less is benign and may be beneficial. The key argument here is will we reach two degrees or more anytime soon? Or the equivalent question, is the climate sensitivity to CO_2 around one or three or more? Listing hypothetical dangers to a temperature we may not reach is a waste of our time. The issue is how fast and how much.

6. Should anything be done to combat global warming?

Karoly thinks that "limiting global warming to any level requires stabilizing greenhouse gas concentrations in the atmosphere." Due to the unmeasured but computed "CS" (climate sensitivity to doubling the CO_2 concentration in the atmosphere) Karoly believes "rapid, substantial and sustained reductions in greenhouse gas emissions from human activity" are required. He continues:

> "The net emissions (sources minus sinks) of greenhouse gases into the atmosphere from human activity need to fall from present levels to near zero as quickly as possible." *Karoly's major statement.*

Karoly provides our Figure 8 below as an illustration of the impact of human CO_2 emissions on climate.

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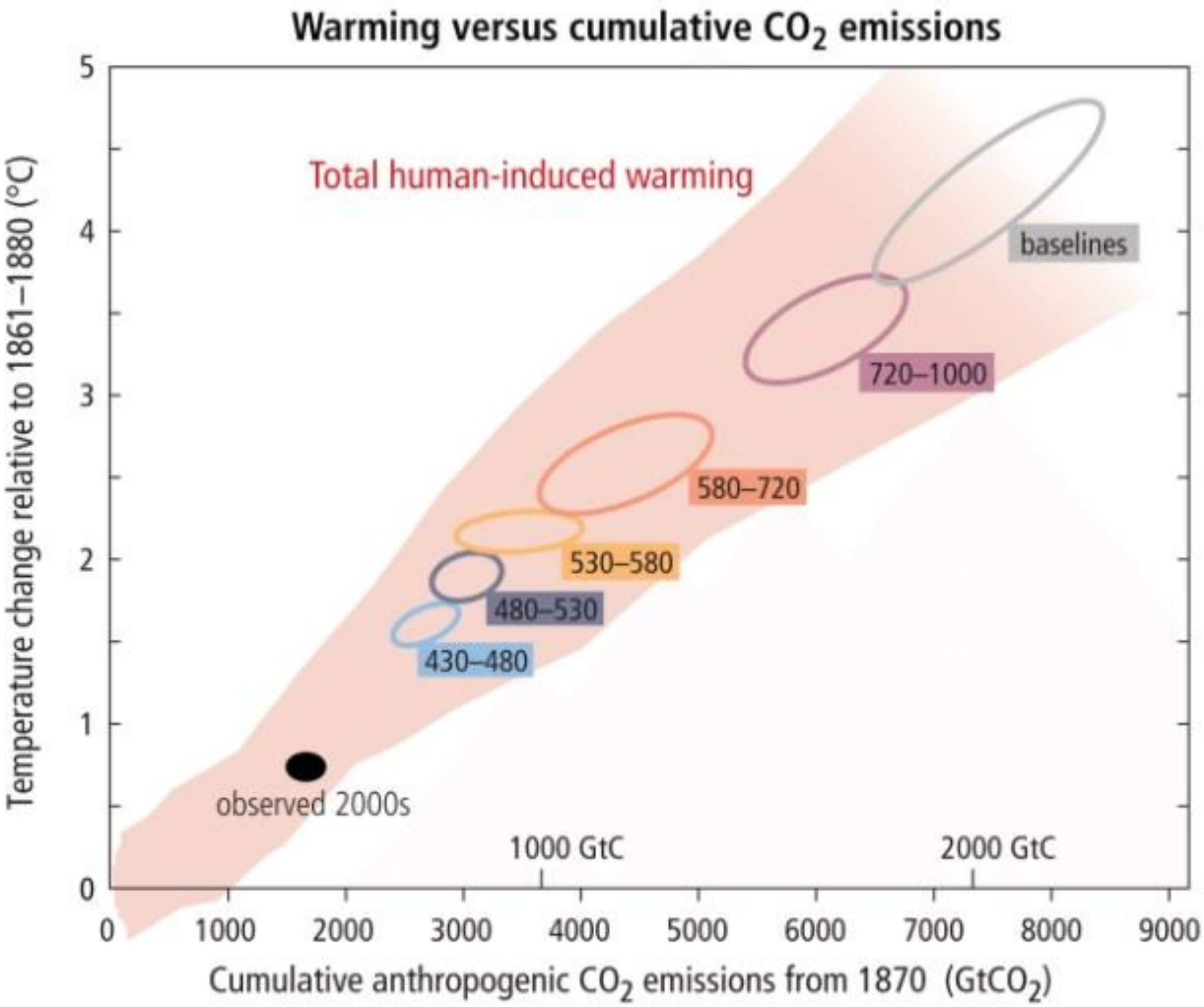

Figure 8. The IPCC estimated impact of human CO_2 emissions on global average temperature. From IPCC AR5, Synthesis Report page 9 (IPCC core writing team 2014). The ellipses show the temperature change location of various IPCC emission scenarios, the numeric labels are ranges of CO_2 concentration in 2100 in ppm. The position of the ellipses suggests an approximate assumed CS (climate sensitivity to CO_2) of just under 3.0°C/2xCO_2.

The plot in Figure 8 is model-based and assumes a range of CO_2 emissions scenarios that cover the shaded region. The warming shown is the warming at 2100. An unstated assumption, used to make the graph, is the expected CS, or climate sensitivity to a doubling of CO_2 abbreviated "°C/2xCO_2." The 2100 CO_2 concentrations on the plot imply a CS of approximately 3.0°C/2xCO_2. If the CS is lower than assumed by the IPCC or Karoly, the slope of the ellipses and the shaded region will be lower than illustrated and the resulting temperatures in 2100 will be lower at each level of CO_2 emissions.

The ECS or Equilibrium Climate Sensitivity is the temperature-rise reached after the oceans have equilibrated with a new surface temperature. It is unknown, but the IPCC estimates the true ECS to be between 1.5° and 4.5°C/2xCO_2, which is the same range given in the Charney report in 1979. Quoting the AR5 report:

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> "Equilibrium climate sensitivity is likely in the range 1.5°C to 4.5°C (high confidence), extremely unlikely less than 1°C (high confidence), and very unlikely greater than 6°C (medium confidence)."

The above quote, on page 14 of the "Summary for Policymakers" has a footnote that reads as follows:

> "No best estimate for equilibrium climate sensitivity can now be given because of a lack of agreement on values across assessed lines of evidence and studies."

What they mean by the footnote is that the model results and observation-based estimates of ECS do not agree with one another, the model results are higher by a factor of 2-3 times. To reach the ECS temperature, the Earth must equilibrate to the total additional heat energy uptake, mainly in the oceans (Lewis and Curry 2015), the length of time required is not known, but probably many hundreds of years or more. We, as humans, are more interested in the climate sensitivity, a smaller number, the rapid (70 years or so) temperature response of the surface to a change in CO_2. Happer calls this the climate sensitivity or "CS" or "S." Generally, it is assumed that CS (or TCR as it is also sometimes called) is about 70-80% of ECS (Lewis and Curry 2015), but it varies depending upon the assumed ocean response to surface warming.

Happer estimates a feedback-free, pre-equilibrium climate sensitivity (CS) of about one-degree C/2xCO_2 in his statement and explains his calculation in some detail. The final calculation, for Princeton, New Jersey is given in his equation 19. How feedbacks affect the climate sensitivity is unknown, the IPCC believes the net feedback is positive, thus Figure 6 shows the result of a CS near 3°C/2xCO_2. As Happer notes, observations suggest the total CS, including all feedbacks, is closer to his theoretical value of one. Recent work by Nic Lewis and Judith Curry, using historical temperature and CO_2 data (Lewis and Curry 2018), suggest the maximum overall ECS is likely 1.6°C/2xCO_2, with CS around 1.3°C/2xCO_2. Richard Lindzen, using satellite data, has computed an ECS of 0.7°C/2xCO_2 and believes the net feedbacks on CO_2-based warming are negative (Lindzen and Choi 2011).

Tamblyn claims that as atmospheric temperature rises, the total water vapor in the atmosphere will rise. Water vapor is a powerful greenhouse gas, so if CO_2 causes temperature to rise and temperature causes water vapor to rise, the temperature increase will accelerate – positive feedback. He supports this claim with a reference to (Soden, et al. 2002). Soden et al. base their conclusion on data from 1991-1996 and data from IPCC AR5 from 1988-2012 over the oceans. Other data on the relationship between atmospheric temperature and total water vapor content is more ambiguous and various datasets do not agree with one another very well (Benestad 2016) (Miskolczi 2010). See this review for a discussion of the ambiguity in this data. Not considered in this assumption is the unknown relationship between increased water vapor and clouds or the unknown relationship between clouds and CS. Too many unknowns to take this speculation about water vapor seriously.

With the various proposed values of CS in mind, Happer provides us with an interesting graph, shown in Figure 7. The IPCC, and most climate scientists, believe that warming of two degrees is unlikely to cause problems. In Figure 9, Dr. Happer has noted how many years it will take to reach this milestone at CS values (called S in the graph) of 0.5° to 4°C/2xCO_2, the true value of CS is generally thought to lie between

these two extremes. A CS of 2°/2xCO_2 takes 200 years and an CS of one-degree takes 600 years. In Happer's opinion, the truth probably lies between these two values, with values less than one possible. The value of CS, inclusive of feedbacks, is probably the most important unknown in the whole climate debate, yet we know little more about it today than we did when the Charney Report was published in 1979 (Charney, et al. 1979) (Curry 2017).

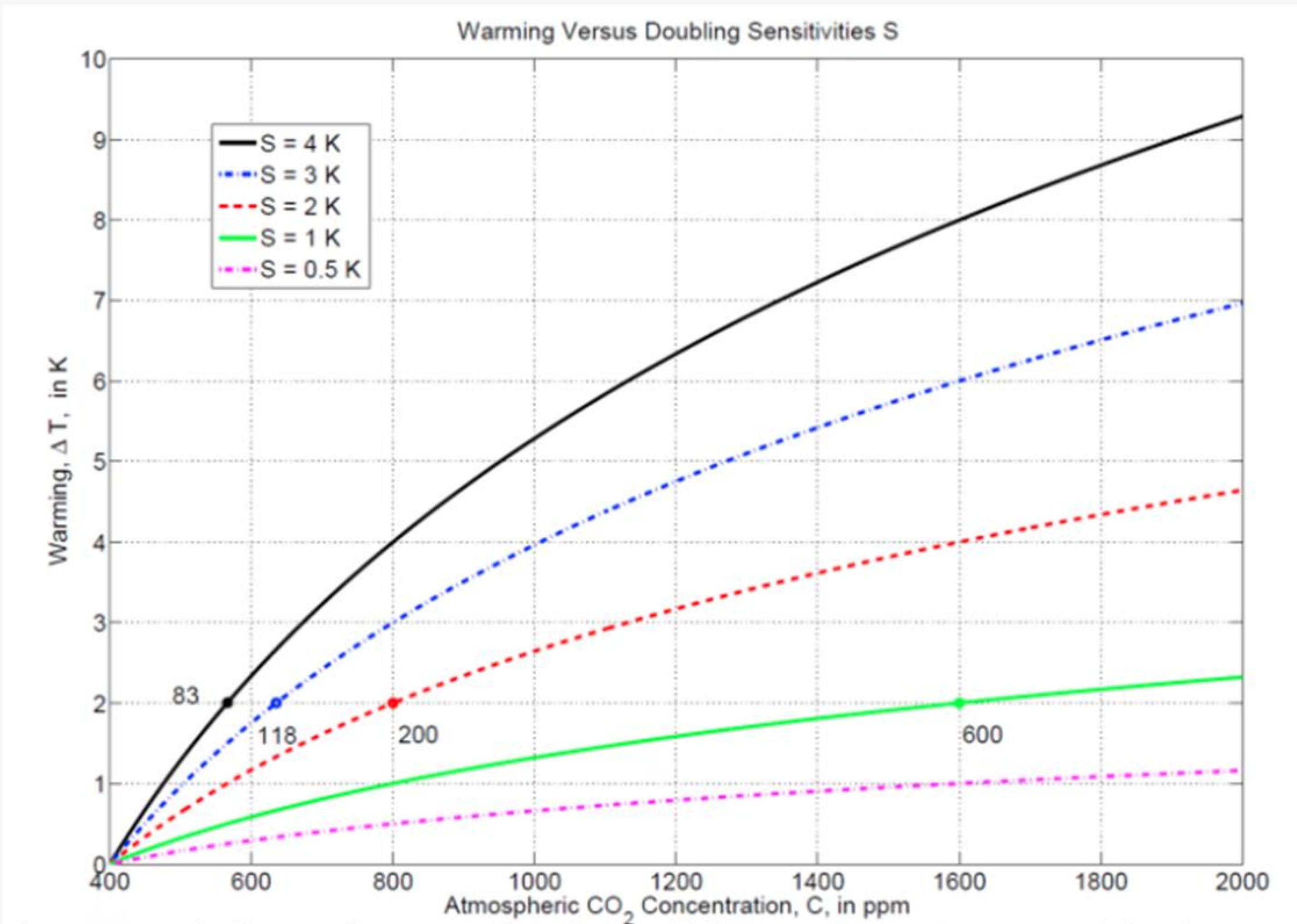

***Figure 12**. Warming from CO_2 from Eq. (24) for various sensitivities, S. We have used Eq. (27) to calculate the corresponding time, Δt (in years), needed to increase the temperature by 2 K. Observations indicate that the doubling sensitivity is close to the feedback-free value of S = 1 K, for which 600 years would be needed at the present growth rate, R = 2 ppm/year.*

Figure 9. A plot of warming (ΔT) versus CO_2 concentration in ppm, each line is a different CS ("S" or sensitivity). The feedback-free sensitivity computed by Happer is the green line and it takes 600 years to increase the Earth's temperature two-degrees. Source Happer's major statement.

The recent mismatch between observed temperatures and climate model predicted temperatures is easily seen in Figure 6a, as well as in Dr. John Christy's plot of the model average and observations in Figure 10 from Happer's major statement.

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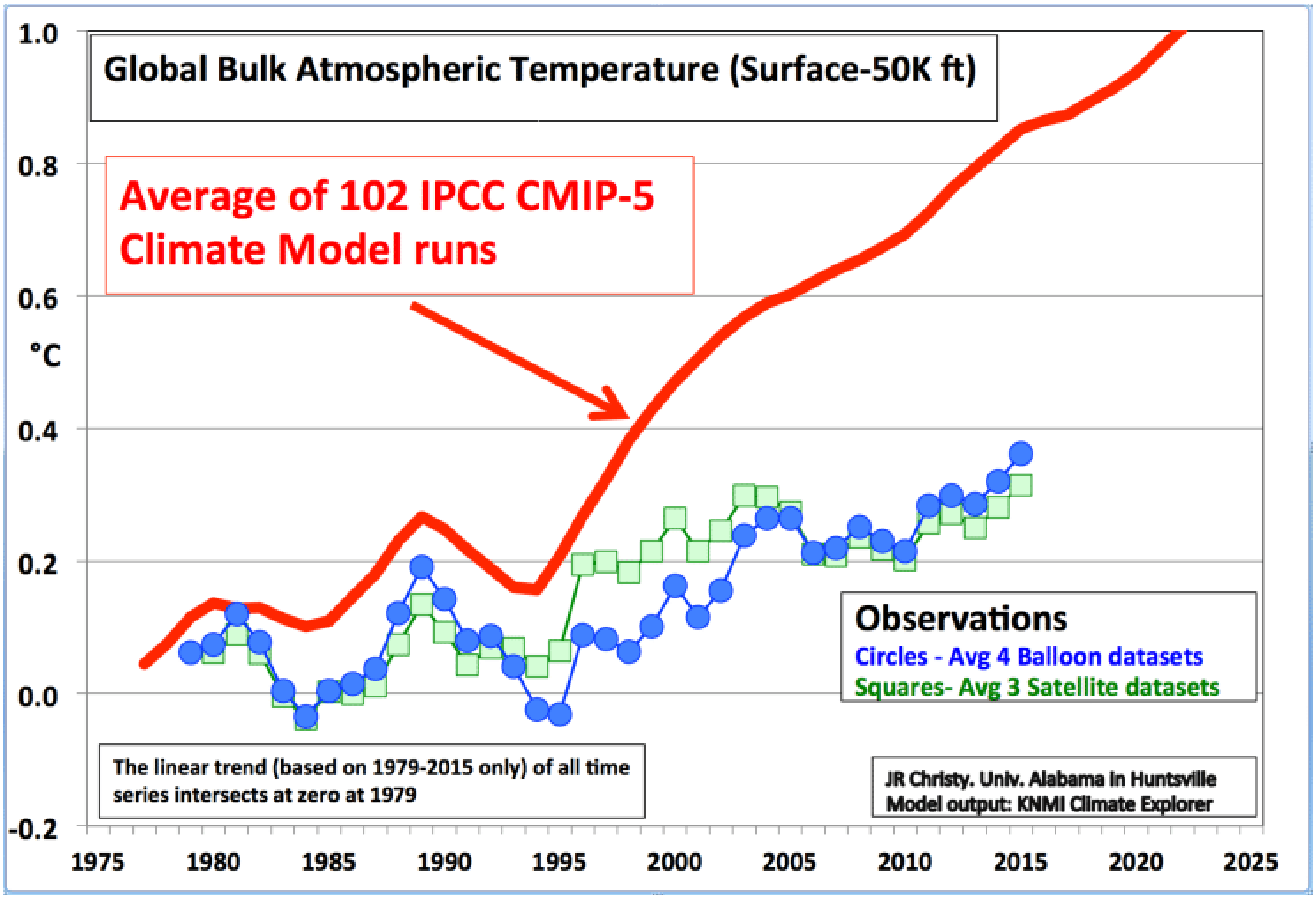

Figure 10. The model predicted temperatures are averaged and shown with the red line, the observed temperatures from weather balloons and satellite measurements are shown in blue and green respectively. The points plotted are all five-year averages to remove some of the year-to-year variability.

Happer points out that climate researchers have proposed more than 50 mechanisms for the poor model performance illustrated in Figure 10. However, in his opinion, the simplest reason for the discrepancy is that the doubling sensitivity (CS) assumed by the models (~3°C/2xCO_2) is much too large. He closes the discussion of sensitivity to CO_2 with this:

> "The simplest interpretation of the discrepancy of [Figure 10] is that the net feedback is small and possibly even negative. Recent work by Harde indicates a doubling sensitivity of S = 0.6 K." (Harde 2014)

So, Happer's contention is that the "doom and gloom" predictions of the IPCC community are the result of overestimating the sensitivity of climate to CO_2 concentration (CS). If they correct their sensitivity, they will

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find that no government intervention is needed. This is the answer to Tamblyn's laundry list of potential man-made climate hazards. Happer writes:

> "Is concerted governmental action at the global level desirable? No. More CO_2 will be good for the world, not bad. Concerted government action may take place anyway, as has so often happened in the sad history of human folly. *The Happer Interview.*

Tamblyn does not believe that the period of time shown in Figure 10 (and in other figures shown in Happer's statement) is long enough to draw any conclusions. Tamblyn also presents more estimates of ECS and they range from less than one to over five. He acknowledges that no one knows what ECS is but suggests that the estimates "cluster around 3." Not very precise when so much hangs in the balance. Far too many conclusions in climate science seem to have their roots in "guesstimates" like this one.

From Happer's final reply:

> "It is immoral to deprive most of mankind of the benefits of affordable, reliable energy from fossil fuels on the basis of computer models that do not work." *Happer's final reply.*

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Summary and final thoughts

Karoly summarizes as follows:

> "Science has established that it is virtually certain that increases of atmospheric CO_2 due to burning of fossil fuels will cause climate change that will have substantial adverse impacts on humanity and on natural systems. Therefore, immediate stringent measures to suppress the burning of fossil fuels are both justified and necessary."

Happer's key point is:

> "Climate models don't work. They have predicted several times more warming from greenhouse gas increases than has been observed."

In a nut shell, both agree the world is warming, and CO_2 and other greenhouse gases have contributed to the warming. Karoly and Tamblyn think the recent warming is unusual, but Happer and the historical record suggest it isn't, or if it is, there is certainly no evidence it is unusual. Rapid rises of more than one-degree are common in ice core records, three geologically recent examples that occur at about the same time in Greenland and Antarctica are shown in Table 1.

Vinther, 2009 - Renland-Agassiz, Greenland				**Pettit, 1999, Vostok, Antarctica**		
Rapid temperature change examples				Rapid temperature change examples		
From	To	Change		From	To	Change
Year BP	Year BP	°C		Year BP	Year BP	°C
450	370	1.26		495	397	2.41
850	830	1.228		848	788	0.68
1980	1880	1.307		2009	1853	0.51

Table 1. Examples of one degree increases in temperature in 100 years or less, in these examples increases occurred in both Greenland and Antarctic ice cores at about the same time. Source: (May 2018). Year BP means years before 1950.

Tamblyn, Karoly and Happer agree that the contribution of human emissions to modern warming cannot be measured and must be computed with climate models. Tablyn and Karoly think the models are accurate and use the model results to predict dangers to mankind and the planet. Happer disagrees and provides evidence the models are not accurate and compute too much warming. He also provides us with an elegant and novel calculation of the direct impact of CO_2 on temperature of about one-degree C per doubling of CO_2 (the "CS"), which if correct, predicts that it will take 600 years for temperatures to rise two-degrees.

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His calculation is net of any feedbacks, but as he points out we really don't know if the net feedback is positive or negative.

The debate clarifies a key point. The dangers due to man-made climate change hinge on CS, is it about three as Tamblyn and Karoly believe or is it about one as Happer believes? Is warming of two degrees a hazard or will we be fine up to higher temperatures? Even the assertion that 2° is a dangerous temperature rise is speculative and controversial. The current global average temperature is about 15 degrees, but over the last 500 million years the overall average surface temperature has been estimated by Christopher Scotese to be about 20 degrees, five degrees higher than today (Scotese 2015).

Karoly and Happer have significant and substantive disagreements on CS and on the temperature-rise that is dangerous. All the speculative hazards to mankind and the planet hinge on the value of CS used to predict future warming and on the temperature increase considered to be dangerous. Currently, as Happer and others have pointed out, warming and the additional CO_2 in the atmosphere are beneficial and they will continue to be beneficial for many more years. The dangers hinge entirely on model predictions based on assumed and unvalidated values of CS that are probably too high, according to Happer. They also rely on an assumed "tipping point" of 2°C above either today's average temperature or the 19th century temperature, depending upon who is speaking.

Thus, it appears that Karoly's initial statement that human-caused climate change is "virtually certain" to be dangerous and we must use "immediate, stringent measures" to deal with it is unproven.

Happer's initial statement was, in part:

> "There is no scientific basis for the claim that increases in atmospheric CO_2 due to burning of fossil fuels will cause climate change that will have substantial adverse impacts on humanity and natural systems."

This can be considered true. Because all the proposed hazards of CO_2 hinge on a poorly estimated value, the climate sensitivity (CS) to CO_2. Low values of CS are no problem. High values may be a problem, but no one knows what the correct value is.

The last part of Happer's initial statement is:

> "Any resulting climate change will be moderate, and there will be very major benefits to agriculture and other plant life."

Because the CS is so poorly understood, the first part of this statement is stated too firmly. Given what we read in the debate materials and the references, I think we can safely say any human-caused climate change will *probably* be moderate. The last part of the statement is fine, we can be certain that there will be major benefits to agriculture and other plant life, that is already happening.

Generally, the debate was very informative and interesting. The organization of the documents is poor, and they are quite long and repetitive. I've tried to fix these problems here. The material will not be new to many readers, but Karoly and Happer are well-known, credible experts and that gives weight to their

remarks and opinions. Tamblyn's arguments are weaker than those of the other two and are mostly conjecture, using unstated and unrealistic assumed temperature increases with little foundation. Happer describes them well in his final reply:

> "Mr. Tamblyn has produced not so much a response to my Statement, as a primer on global-warming alarmism, a whole list of scary talking points and computer-generated graphs, with occasional asides to deplore how obtuse I am for not understanding the gravity of this supposedly existential threat to the planet or how ignorant I am of basic physics."

That last bit had me chuckling, Professor Happer is probably the most accomplished and brilliant physicist alive today. Tamblyn did not pick up where Karoly left off and chose to begin a new debate by listing a lot of very speculative claims of the dangers of warming. Most of these "dangers" involved warming rates and amounts that are completely unrealistic. Unfortunately for us, what he adds is mostly irrelevant to the original discussion between Happer and Karoly. Thus, Happer had to defend his views in two separate debates, but he soldiered on and did quite well in both. It is a shame that Karoly backed out in the middle of the debate, had he stayed, the result would have been better. As it is we gained something, we found out it is all about how much and how fast it is warming. In my opinion, Happer won the debate, both of them.

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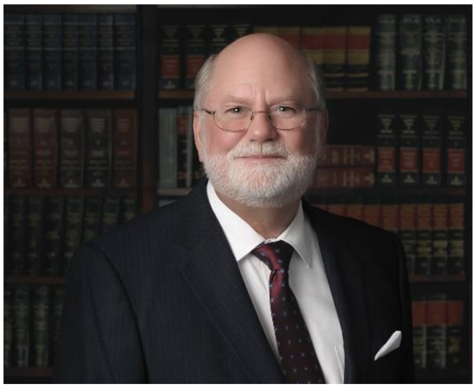
ABOUT THE AUTHOR



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Late in his career, he worked on unconventional shale oil and gas petrophysics and developed many unique techniques for evaluating these difficult reservoirs. In cooperation with Professor Mike Lovell (University of Leicester in the U.K.) he developed a one-week course in shale reservoir petrophysics. Andy has a B.S. in Geology from the University of Kansas.