A Guide to Understanding Global Temperature Data

by Roy W. Spencer, Ph.D.

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About the Author

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Spencer received a B.S. in atmospheric sciences from the University of Michigan in 1978 and his M.S. and Ph.D. in meteorology from the University of Wisconsin–Madison in 1980 and 1982. He then worked for two years as a research scientist in the Space Science and Engineering Center at the University of Wisconsin–Madison, and later joined NASA's Marshall Space Flight Center as a visiting scientist in 1984. After leaving NASA in 2001, Spencer attained his current position at UAH and continued his work for NASA's Aqua satellite, a position he has held since 1994.

Spencer has been a member of several science teams: the Tropical Rainfall Measuring Mission (TRMM) Space Station Accommodations Analysis Study Team, Science Steering Group for TRMM, TOVS Pathfinder Working Group, NASA Headquarters Earth Science and Applications Advisory Subcommittee, and two National Research Council (NRC) study panels.

He is also on the board of advisors of the Cornwall Alliance for the Stewardship of Creation. Spencer's research work is funded by NASA, NOAA, DOE and the DOT.

Introduction

When we measure temperature in our backyard, we really aren't that concerned if the thermometer we use is off by a degree or two. Since most people live where the temperature fluctuates by many degrees every day, and the seasonal swing in temperatures can be 80 F or more, a couple of degrees doesn't matter too much.

But in the case of global warming, one or two degrees is the entire change scientists are trying to measure over a period of 50 to 100 years. Since none of our temperature monitoring systems was designed to measure such a small change over such a long period of time, there is much disagreement over exactly how much warming has or will occur.

Whether we use thermometers, weather balloons, or Earth-orbiting satellites, the measurements must be adjusted for known sources of error. This is difficult if not impossible to do accurately. As a result, different scientists come up with different global warming trends—or no warming trend at all.

So, it should come as no surprise that the science of global warming is not quite as certain as the media and politicians make it out to be.

Increasingly, the "science" of global warming is being based upon theories of what might happen, not on what is being observed to happen. And the observations are increasingly at odds with the theory. The United Nations Intergovernmental Panel on Climate Change (IPCC) relies upon theoretical climate models which predict about 2 C (3.8 F) of warming by the end of this century, due primarily to carbon dioxide emissions resulting from our burning of fossil fuels. The IPCC claims that this rate of warming could be catastrophic for some forms of life.

But is the Earth really warming as rapidly as the IPCC says? And, is that warming entirely the fault of humans?

In this paper I will answer some basic questions about global temperature data in particular, climate change in general, and what it all means for the debate over energy policy. The following questions are some of the more frequently ones asked of me over the last 20 years I have been performing climate change research under U.S. government funding.

These questions include:

1) Does an increasing CO_2 level mean there will be higher global temperatures?

2) Can global temperatures go up naturally, even without rising CO_2 levels?

3) How are temperature data adjusted?

4) Are global temperatures really going up? If so, by how much?

5) Is warming enough to be concerned about? Is warming necessarily a bad thing?

6) Could the warming be both natural and human-caused?

7) Why would the climate models produce too much warming?

8) What is climate sensitivity?

9) Don't 97 percent of climate researchers agree that global warming is a serious man-made problem?

10) Haven't ocean temperatures been going up, too?

11) What does it mean when we hear "the highest temperature on record"?

12) Is there a difference between weather and climate?

13) Why would climate science be biased? Isn't global warming research immune from politics?

From the answers to these questions that follow it should be clear that the science of global warming is far from settled.

Uncertainties in the adjustments to our global temperature datasets, the small amount of warming those datasets have measured compared to what climate models expect, and uncertainties over the possible role of Mother Nature in recent warming, all combine to make climate change beliefs as much faith-based as science-based.

Until climate science is funded independent of desired energy policy outcomes, we can continue to expect climate research results to be heavily biased in the direction of catastrophic outcomes.

1) Does an increasing CO_2 level mean there will be higher global temperatures?

Probably, yes. As we burn fossil fuels (primarily petroleum, coal, and natural gas) to meet most of humanity's energy needs, carbon dioxide (CO_2) is unavoidably released. Its concentration has risen from about 270 parts per million (ppm) before the industrial revolution to about 400 ppm in 2015. It has been monitored accurately since 1959 at Mauna Loa, Hawaii, and at several other locations around the world in later years. All of the measurements tell a consistent story: CO_2 levels in the atmosphere are slowly increasing.

The following plot of the CO_2 increase at Mauna Loa shows that even though the increase seems substantial in relative terms (left panel), the amount of CO_2 in the atmosphere is so small in absolute terms that the change in concentration is not even visible in a plot (right panel) where percent, rather than parts per million, is used for the vertical scale.

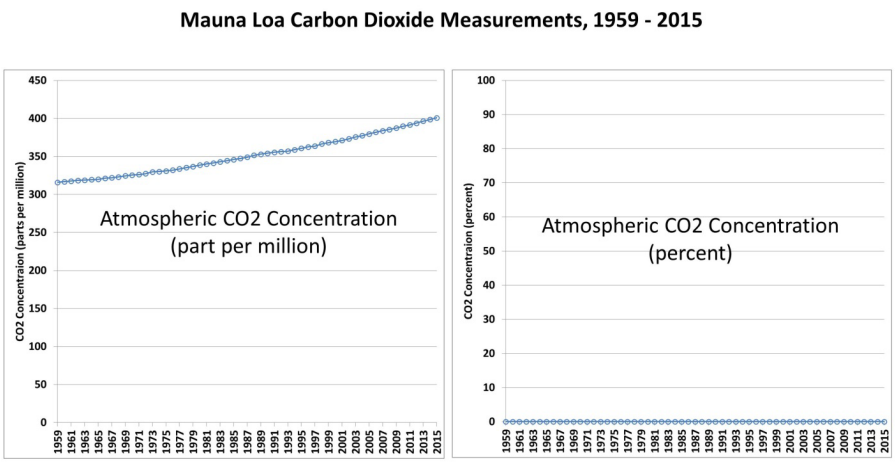

Fig. 1. *The atmospheric concentration of carbon dioxide at Mauna Loa, HI between 1959 and 2015, in parts per million (left panel), and as a percent of the atmosphere (right panel).*

In fact, most people are surprised to learn that humans have so far contributed only about 1 molecule of CO_2 to every 10,000 molecules of air over the last 60 years. About 50 percent of all we emit is absorbed by nature, since CO_2 is necessary for photosynthesis and for life to exist on Earth.

So, how can such a minor atmospheric constituent (technically, a "trace gas") have such a large predicted impact on global temperatures? To answer that question, we must briefly address what causes the temperature (of anything) to change.

The temperature of anything you can think of can be increased in one of two ways: (1) by adding more energy (e.g., turn up the stove top to warm a pot of water; turn up the furnace in your house), or (2) by reducing energy loss (e.g., put a lid on the uncovered pot of water as it is heated; add insulation to your walls).

For the Earth's climate system, the energy input is sunlight, while the energy loss is through infrared (heat) radiation emitted by the surface and atmosphere to the cold depths of outer space. Infrared radiation is the radiant heat you feel at a distance from a fire, and is emitted by all solid objects and by some gases in the atmosphere.

Carbon dioxide is a so-called "greenhouse gas," an admittedly misleading name for the gases which are good absorbers and emitters of infrared (IR) radiation. Water vapor is by far the most important greenhouse gas, while CO_2 and methane have lesser influences.

In the case of global warming theory, the extra CO_2 we have added to the atmosphere is believed to have reduced the rate at which the Earth loses infrared radiation to space by about 1 percent, based upon theoretical calculations backed up by laboratory measurements. It's like covering the pot of water on the stove slightly more with a lid, or adding a little more insulation to the walls of a house.

This human-caused 'radiative forcing' (an imposed imbalance between the energy flows in and out of the climate system) is what is believed to cause global warming, and associated climate change. There are other gases involved in radiative forcing estimates, such as methane and chlorofluorocarbons, but by far most of the effect is from increasing carbon dioxide.

The science supporting *some* warming effect of more CO_2 in the atmosphere is reasonably sound; what isn't well known is just *how much* of a temperature rise will result. This uncertainty is tied up in the holy grail of *climate sensitivity*, which I will address later.

For the time being, suffice it to say that more CO_2 in the atmosphere should cause some warming, but the amount of warming is much more uncertain than the public has been led to believe.

It should be noted that most of what you hear regarding expected global warming and climate change originates from a United Nations-sponsored organization of scientists and policy experts called the Intergovernmental Panel on Climate Change (IPCC). The UN IPCC releases new reports every few years summarizing the state of climate science, and surveys the results of climate models run in many different countries. The IPCC was formed and is still guided with considerable political influence from a variety of world governments, which should be kept in mind when its official views on climate change are being examined. Also, a number of global warming scientists who were originally involved in the IPCC process have either not been invited to continue their participation, or have resigned in protest of the IPCC's biased treatment of the science.

2) Can global temperatures go up naturally, even without rising CO_2 levels?

This is a fascinating question, because of the wholesale change in scientific attitudes over the years in the climate research community. Forty years ago climate researchers mostly studied natural sources of climate change, including warming and cooling episodes in our past. It was widely accepted that climate changes naturally.

Now, however, a newer generation of younger researchers equate any "warming" with "human-caused catastrophic warming". The culture of climate research has fundamentally shifted to a new way of viewing the world. Some suggest this new view is a result of pressure from government science funders.

Natural fluctuations in the climate system can easily rival the human influence. For example, if there is a small change in global-average cloud cover, more or less sunlight will reach the Earth's surface, leading to global warming or cooling. While we know from satellite measurements that such natural cloud fluctuations occur on a month-to-month basis, the possibility that such a thing could happen over an extended period of time, say several decades, is much more controversial. But I believe it is indeed possible, and might help explain historic climate change events.

While fluctuations in the total output of the sun are too small to appreciably impact climate change (about 0.1 percent over the 11-year solar cycle), there are a number of theories of how indirect solar effects such as sunspots could change total cloudiness on the Earth and cause climate change. These theories remain controversial.

Also, the oceans are a potential source of natural climate change, due to the deep ocean being much colder than the near-surface waters (even the tropical oceans are about 40 F over most of their depth, see Fig. 2). There is continuous vertical mixing of the ocean which cools the surface and warms the deep ocean. But that rate of mixing is not always the same, and any change in the naturally occurring rate of exchange between warm surface waters and cold deep waters can cause global warming or cooling. These changes can occur over a period of centuries, so any small changes in the rate of overturning can cause the climate change over long periods of time.

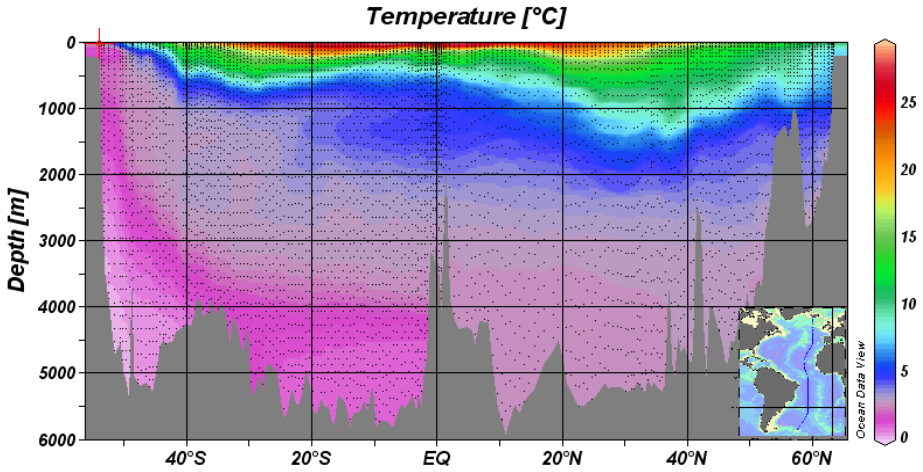

Fig. 2. *North–south vertical cross section of ocean temperature with depth in the Atlantic Ocean, showing that over half of the ocean depth is colder than 40 F (about 5 C on the color scale), even in the tropics.*

For example, changes in overturning happen during naturally occurring El Niño events when warm water builds up at the surface, and also during La Niña when more cold deep water upwells to the surface.

Various scientific methods are used to measure historic climate events, such as ice core data, tree rings, pollen in lake beds, and stalactites in caves. These indirect (proxy) measurements of temperature suggest that there have been natural warming and cooling events over the last 2,000 years, as shown in Fig. 3. The Medieval Warm Period (around 1000 A.D.) and Roman Warm Period (around 0 A.D.) might well have been, on average, just as warm as today, and was generally considered beneficial for humanity. The Little Ice Age occurred more recently, around 1300 to the mid-1800s, and was bad for humans.

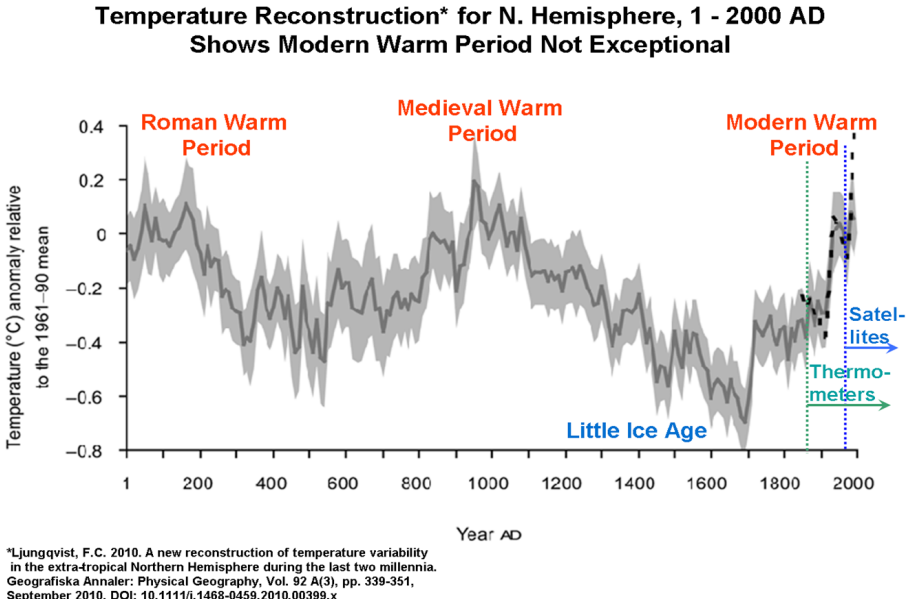

Fig. 3. *Estimates of Northern Hemisphere average temperature over the last 2,000 years. Note that most centuries experienced natural episodes of warming or cooling.*

Note also from this chart that our actual measurements of temperature (e.g. thermometers, satellites) have been developed during a period when it was already warming, as we came out of the Little Ice Age.

We do not know with any level of certainty what caused these natural climate variations. A few scientists have even tried to erase it from the historical record with the famous 'hockey stick' graph of global temperatures estimated from one analysis of tree ring data.

I believe that long-term natural cycles in the climate system would most likely be caused by changes in ocean circulation, which can have time scales of many centuries, rather than in atmospheric circulation which are relatively short lived. How could such changes occur? The answer is something scientists call "chaos".

In complex systems like our atmosphere and ocean, there can be changes which appear for no apparent reason other than just because that's the way the system works. This chaotic feature of nonlinear dynamical systems has been known for over 50 years. It is what makes weather difficult to predict weeks in advance, and it would make the ocean circulation difficult to predict centuries in advance.

El Niño and La Niña are two examples of climate chaos. In some years, the climate system goes into a warmer, El Niño state, as was the case in 2015-16. In other years, it goes into a cooler La Niña state. In a sense, these represent two different choices the climate system has (called a bifurcation) which involves the upper ocean circulation.

While the El Niño and La Niña states only last a year or two, there might well be alternate climate states involving the deep ocean circulation that can last for centuries, such as we know historically happened with the Roman Warm Period, the Medieval Warm Period, and the Little Ice Age. The huge reservoir of cold, deep ocean water seen in Fig. 2 is always available to cool the atmosphere if ocean overturning increases, or if overturning decreases then warm water will build up at the surface and cause global warming.

3) How are temperature data manipulated?

There are three main methods used to monitor global temperatures, all of which have systematic errors that need to be corrected for.

We have had thermometer data since the mid-1800s, which are our only reliable way of monitoring near-surface temperatures. Over the oceans, the thermometer measurements have mostly come from buoys and ships. Weather balloons (radiosondes) have made measurements of the lower atmosphere only since the 1950s, and for a greatly reduced number of locations. Finally, satellite measurements of the lower atmosphere are our newest technology (since 1979), which have the unique advantage of global coverage.

Unfortunately, all three of these systems have undergone changes with time, and the effects of those changes are often as large as the global warming signal we are trying to measure. That's why it is not really advisable to just analyze the raw data and expect a meaningful result. Adjustments to the data for known changes in the measurement systems are necessary. But, the sizes of those adjustments are quite uncertain, and depending on how they are made, some large differences in calculated global temperature trends can result depending upon who is making the adjustment decisions.

In the case of thermometers, usually placed to measure air temperature about six feet above ground, there have been changes in the time of day that high and low temperatures for the day are reported. Also, natural vegetation around thermometer sites has gradually been replaced with man-made structures, which causes an 'urban heat island' (UHI) effect. This effect is experienced by millions of people every day as they commute in and out cities and towns.

The plot in Fig. 4 shows the average UHI effect in daily surface weather data I computed from weather reporting stations all around the world during the year 2000, based upon daily temperature differences between neighboring temperature stations. As can be seen, even at population densities as low as 10 persons per square kilometer, there is an average warming of 0.6 C (1 F), which is almost as large as the global warming signal over the last
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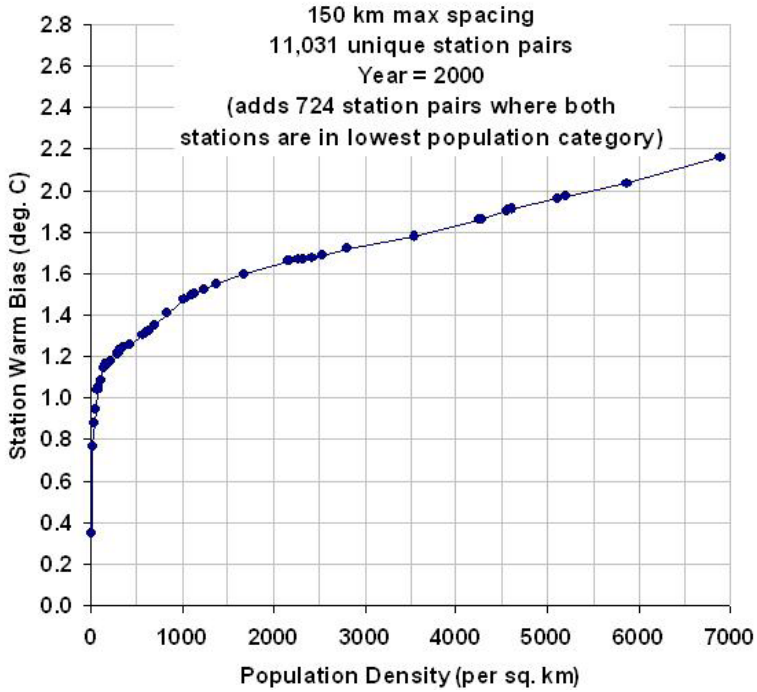

Fig. 4. *Localized warming (Urban Heat Island effect) at temperature monitoring stations occurs as population density increases, as seen in this analysis of one year of daily temperature data from all reporting stations in the world. Note the most rapid warming occurs at the lowest population densities.*

Clearly, to make meaningful estimates of global warming, the UHI effect must be taken out of the data. Unfortunately, the UHI effect is difficult to quantify at individual stations, many of which have obvious spurious heat influences around them like concrete or asphalt paving, exhaust fans, etc. In fact, there is evidence that the UHI effect has not been removed from the surface thermometer data at all. It appears that, rather than the urban stations being adjusted to match the rural stations, the rural stations have instead been adjusted to match the urban stations which then leads to a false global warming signal.

Besides the UHI effect, older mercury-in-glass thermometers housed in wooden instrument shelters (Fig. 5) have been largely replaced with electronic thermistor-type thermometers in smaller metal housings. The newer sensors measure electrical resistance which is then related to temperature. Such instrument changes do not really affect their use for weather monitoring, but can have a significant impact on long-term temperature monitoring.

Fig. 5. *Surface temperature measurements have changed. A comparison of the wooden Stevensen shelters that used to house traditional liquid-in-glass thermometers, versus the newer enclosures which now contain electronic thermometers (thermistors).*

In the case of weather balloons, which measure the temperature profile up through the lower atmosphere (see Fig. 6), the instrumentation designs have also changed over time. The thermistors themselves have changed, shielding of the thermistors from sunlight has changed, as has the computer software for analyzing the data.

As in the case of the thermometer measurements, these changes have not affected weather forecasting, because they are small (usually a degree or less) compared to the size of day-to-day weather changes. But they are large and detrimental for the purposes of long-term temperature monitoring.

Fig. 6. *A radiosonde (weather balloon) instrument package ready to be launched at Hilo, Hawaii, to measure the temperature profile of the lower atmosphere.*

Finally, sensors flown on satellites (Fig. 7) measure how much thermal radiation is emitted by the atmosphere. But these must be replaced with new satellites every few years, and no two sensors are exactly alike. This means that successively launched satellites must be intercalibrated, that is, adjusted so that the newer satellite readings match the readings from older satellite during the period when both satellites are operating.

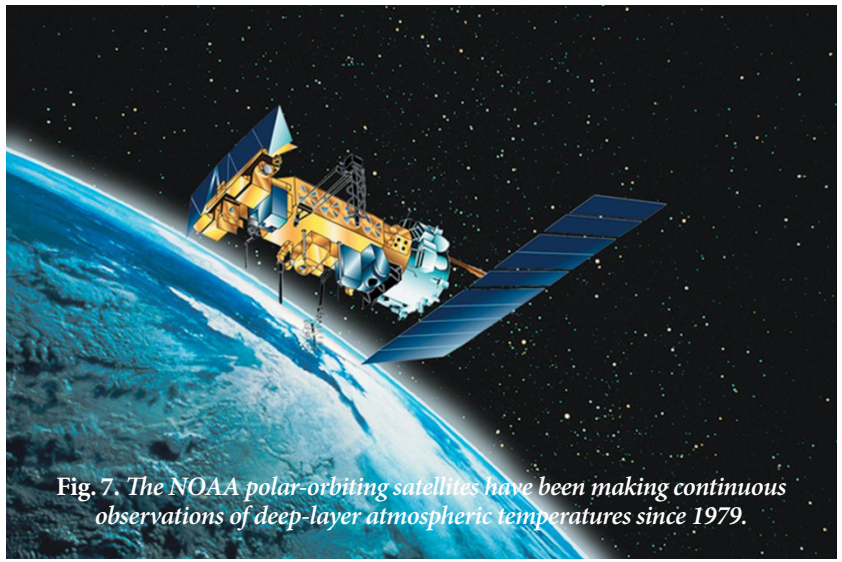

Fig. 7. *The NOAA polar-orbiting satellites have been making continuous observations of deep-layer atmospheric temperatures since 1979.*

Then, most of the satellites slowly drift from measuring temperature at a specific time of day in the early years of a mission to a different time of day in later years, requiring another adjustment. This is due to the satellites slowly falling back to Earth, which takes them out of their original orbit which was intended to keep them measuring at the same time every day.

Finally, some of the satellites show small changes in their calibrated temperatures, usually by only hundredths of a degree, for reasons which are unknown.

The errors for satellites are typically hundredths or tenths of a degree, and so are generally smaller than for ground-based thermometer systems. Nevertheless, differences in how adjustments to the satellite data are made can lead to global temperature trend differences of 50 percent or more between different research groups' results, which has led to some controversy.

While some people criticize the satellite measurements as not really being a 'temperature' measurement, it is no more indirect than surface thermometers which use thermistors to measure electrical resistance, which is proportional to temperature. The satellites instead measure the intensity of thermal microwave radiation, which is also proportional to temperature. (Today, some doctors use a similar method to take your temperature by using an infrared-measuring instrument pointed in your ear.) Both surface thermometers and satellite sensors involve calibration adjustments to relate their measurements to temperature, and have their own relative advantages and disadvantages. One advantage of the satellite sensor is that a single measurement samples about 10,000 cubic kilometers of air, while a single thermometer measurement samples maybe a few cubic feet of air.

So, we can see that the unavoidable adjustments that are necessary to analyze global temperature trends over many years lead to considerable uncertainty. In the case of the UAH satellite dataset I am the co-developer of, we estimate a global temperature trend uncertainty of 0.1 F per decade or less. By way of comparison, the IPCC-expected global warming signal is about 0.5 F per decade over the next 50 to 100 years.

4) Are global temperatures really going up? If so, by how much?

Are global temperatures rising? Actually, the better question is "have they risen"?, because we can only observe temperature change in the rearview mirror, after it has gone by.

Thermometer data, after many adjustments have been made, suggest that the climate system has warmed by about 1.5 F since the mid-1800s.

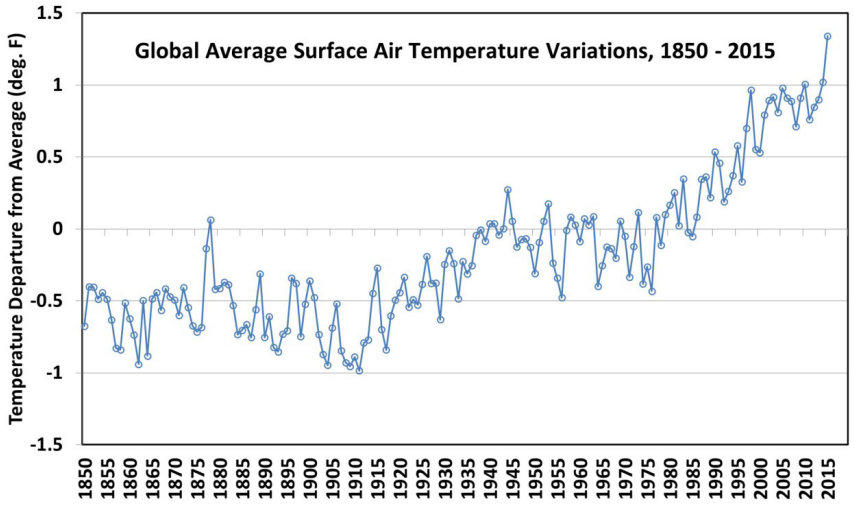

Fig. 8. *Surface-based thermometer estimates of global average temperature, after adjustments, show about a 1.5 F temperature increase over the last 150 years (HadCRUT4 data).*

This is an average warming rate of about 0.1 F per decade, which is hardly alarming. It is unlikely that anyone would notice such a small change over their lifetime. Warming has become more rapid in recent decades, though: about 0.3 F per decade since 1970.

But what is important from an energy policy standpoint is *all our temperature measurement systems indicate warming has been less than that predicted by the computerized climate models relied upon by the UN IPCC.*

This is illustrated in Fig. 9, which plots both observed temperatures and model-estimated temperatures since 1979—the first year we had all three systems in operation (thermometers, weather balloons, and satellites). The surface temperature measurements are compared to the model-produced equivalent, and the measurements of the lower atmosphere (troposphere) are compared to their model-equivalent, giving an apples-to-apples comparison between theoretically modeled and actual observed temperature.

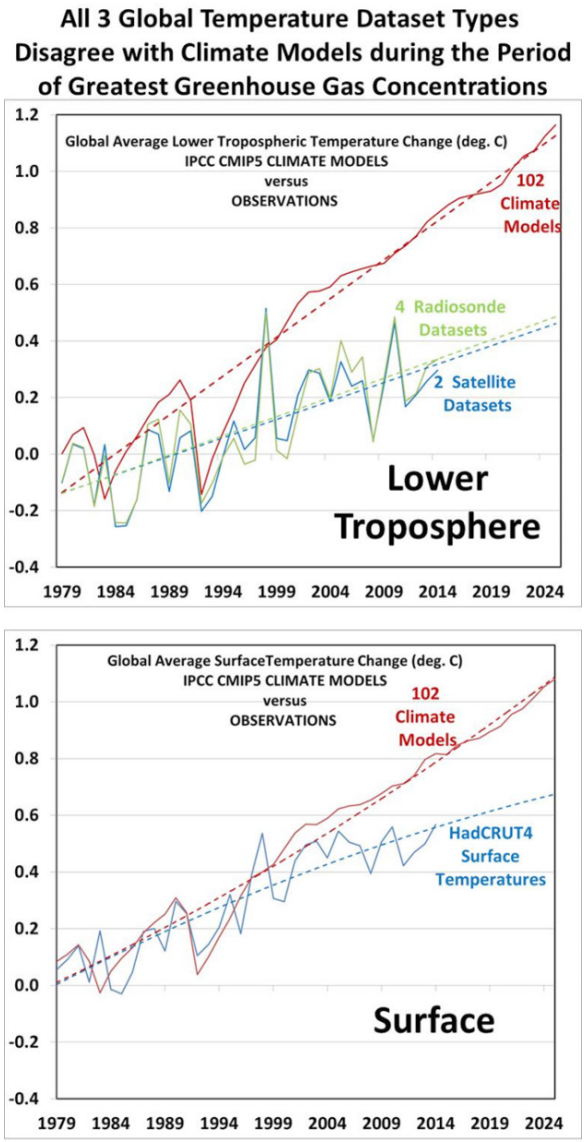

Fig. 9. *Comparison between climate model "predictions" and actual observations of global average temperature since 1979 suggest that models are warming about twice as fast as the real world.*

The average of 102 different climate models clearly shows it has been warming faster than the observations. This discrepancy between models and observations is crucial because *changes in government energy policy, such as an imposed carbon tax, are based upon the models being correct*. So far, the models are off by about a factor of 2. (While a few of the individual models are close to the observations, this is not relevant to the policy discussion because proposed energy policy changes are based upon the average behavior of the models, not individual outlier models).

Those results are for global-average temperatures. Since people are more interested in what's happening where they live, let's look at the U.S. Midwest in the summer. Specifically, what has been happening in the 12-state corn growing region, a region where we have been warned climate change is going to seriously hinder crop productivity?

For the June-July-August growing season, Fig. 10 shows there has been little if any warming, whereas the IPCC climate models have predicted dramatic warming:

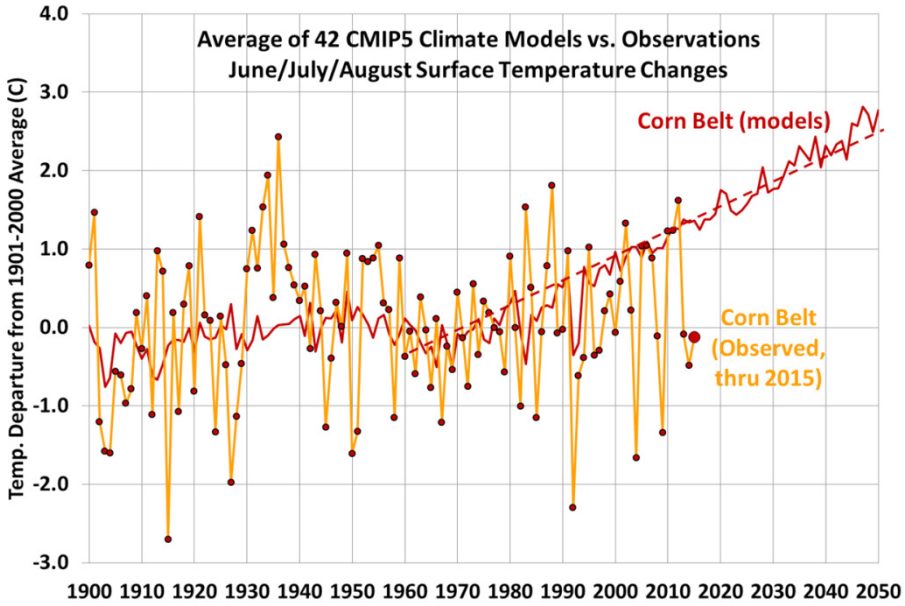

Fig. 10. *Comparison of the average surface temperature predictions across 42 climate models versus observations for the primary U.S. Corn Belt states (IA, IL, IN, KS, MI, MN, MO, NE, ND, OH, SD, WI) also shows the models are warming faster than the real climate system (official NOAA data).*

Similarly, there has been no long-term change in precipitation over the same period of time. Thus, even regionally we find that what little warming has occurred is far below what the models suggest should have happened.

5) Is the warming enough to be concerned about? Is warming necessarily a bad thing?

If the climate system has warmed, and even this warming is 100 percent caused by humans, is it enough for us to be concerned about?

That is not an easy question to answer, since it depends upon qualitative issues like whether warm is better than cold, and whether there is a preferred temperature state for the Earth.

Historically, and geographically, warmer temperatures have been better for humans and for Mother Nature. Most humans choose to live in warmer climates, as do most plants and animals. Despite the media interest in heat waves, cold weather still kills many more people than hot weather. All life on land requires fresh water, though, so we don't find many humans, plants, or animals choosing to live in the world's deserts.

So, modest warming would probably be mostly benign or even beneficial. The reason why Americans consistently rate climate change near the bottom of Gallup Poll rankings of public concerns, year after year, is that people really don't view a couple degree rise in temperature as affecting their lives, when most of them are already used to many tens of degrees of temperature change on a daily or seasonal basis.

Even though the Earth's temperature has been much warmer and much cooler in the past, some people raise the philosophical—or even religious—question of whether humans should be impacting global temperature at all. One way I address this is to point out that the existence of trees on the Earth no doubt affects global temperatures, so why not humans? Do trees have more rights than humans to affect their environment? What about all of the smaller forms of plant life that the trees branches rob of sunlight? Clearly, the philosophical argument over this could go on endlessly.

6) Could the warming be both natural and human-caused?

While the question of the root cause of recent warmth is usually phrased in terms of it being either all natural or all man-made, is it possible that the answer is really 'some of each'?

Yes. Our own published research suggests that the recent warming of the oceans between the mid-1950s and the present was about half caused by stronger El Niño activity, which tends to cause global warmth. And, who knows what other natural climate forces are at work? Shockingly, the U.S. government funds virtually no research into natural causes of climate change, now that human-caused global warming has become so fashionable.

What is a little ironic is that for many years climate researchers discounted the role of Mother Nature in climate change. Then, when global average temperatures essentially stopped rising after about 1997 (the so-called pause or hiatus), those same researchers had to look to Mother Nature to find some sort of natural cooling mechanism that they believed was canceling out the human-caused warming. This has at least had the benefit of bringing the potential role of natural climate change back into the debate.

If human-caused global warming is only one-half (or less) of the problem we are being told it is, that's hugely important to any government energy policy changes. At a minimum, it means we have twice as long to find replacements for fossil fuels.

7) Why would the climate models produce too much warming?

The most recent period of rapid warming was during the 1980s–1990s. Coincidently, this was also the period when climate models were also being rapidly developed.

Since climate models can be "tuned" to produce a rather arbitrary amount of warming (see the next section on climate sensitivity), they were tuned to be "sensitive" enough so increasing carbon dioxide alone was sufficient to cause the observed warming. It was assumed that there was no natural component of the warming, since we really don't know the causes of natural climate variations.

As a result, none of the models were prepared for the global warming "hiatus" we have experienced since about 1997, because their climate sensitivity was set too high. The models continued to warm after 2000, while the real climate system essentially stopped warming, leading to the divergence between models and observations seen in Figs. 9 and 10.

8) What is climate sensitivity?

"Climate sensitivity" is the holy grail of climate research. It usually refers to the amount of warming that will eventually result from a doubling of the atmospheric CO_2 concentration from its preindustrial value, for example from 270 to 540 ppm (parts per million). That doubling will likely occur late in this century.

Climate sensitivity has two components, direct and indirect. Most researchers (myself included) believe that the *direct* warming from doubling CO_2 is about 1 C, which by itself would not be a problem for humanity. But the larger and more uncertain part is the *indirect* effects of warming-induced changes in clouds, water vapor, and anything else in the climate system that can impact temperature. These indirect changes are called climate feedbacks, a subject on which a minority of us climate researchers depart from the majority.

In the climate models most feedbacks amplify the warming, and so increase the IPCC estimate of climate sensitivity to 1.5–4.5 C (2.7–8.1 F), which represents a rather large, factor of three range of uncertainty. A bar chart of the distribution of future warming rates predicted by all of the 100+ computer climate models (Fig. 11) shows an even wider range; again, the higher the model climate sensitivity, the more warming it will predict going into the future.

This figure is like a bell curve, but note that it has a long tail skewed to the right, toward very high climate sensitivities. This is why some people who are concerned about global warming are so alarmed: a few of the models predict very large amounts of warming in our future, 10 C or more.

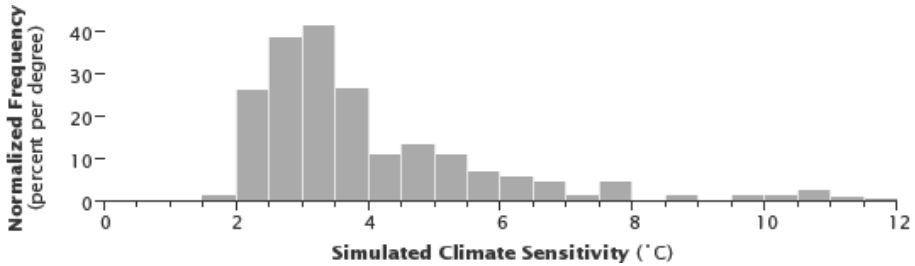

Fig. 11. *Frequency histogram of the climate sensitivities of ~100 climate models tracked by the IPCC, revealing large uncertainty in how much warming we can eventually expect from a doubling of atmospheric carbon dioxide late in this century.*

But these large rates of warming are not directly from the extra carbon dioxide, which all scientists agree will result in only minor warming. They are instead from those very uncertain feedbacks. One of the most uncertain feedbacks is from clouds; will global cloud cover increase or decrease with warming? If clouds increase, which I believe will happen, that's a negative feedback and the result will be less warming. If clouds decrease, a position the IPCC tends toward, that's a positive feedback and it will increase warming. I've written an entire book on the subject of cloud feedbacks.

A minority of climate scientists like me believe climate sensitivity could be 1 C (1.8 F) or less, due to negative feedbacks in the climate system. But no one really knows. This is a field of science that is highly uncertain, and there are very few true experts. If someone tells you that climate models should be believed because they are based upon real physics, that is *mostly* true. But their treatment of cloud feedbacks (for example) is so uncertain that it makes all the difference in their predictions of global warming and climate change.

The models are only as good as their weakest link. And the old adage about computers—"garbage in, garbage out"—remains true today.

It should be noted that most climate researchers who are polled on the subject of the seriousness of the global warming threat don't really know enough to give an independent, informed opinion…they simply go along with what they have heard others say. Most of them do not perform research on feedbacks and climate sensitivity, let alone understand those issues.

I like to say that climate science isn't rocket science—it's actually much harder.

9) But don't 97 percent of climate researchers agree that global warming is a serious man-made problem?

The claim that 97 percent of climate experts agree on global warming and climate change is not true, and was based upon a study with flawed methodology.

Nevertheless, I'm quite sure a fairly large majority of climate experts believe that recent warming is mostly man-made, and could be a potentially serious problem in the distant future. A recent survey of members of the American Meteorological Society found that 67 percent believe that recent warming is mostly (or completely) human-caused. That leaves 33 percent who believe that less than half of climate change is the fault of humans, which is a big difference from the 97 percent survey which would suggest only a 3 percent minority opinion.

Besides, if global warming is settled science, like gravity or the Earth not being flat, why isn't the agreement 100 percent? And since when is science settled by a survey or a poll?

The hallmark of a good scientific theory is its ability to make good predictions. From what we've seen, global warming theory is definitely lacking in this regard.

If you claim that at least the *existence* of warming (not its magnitude) was successfully predicted by the models, how is that any different than flipping a coin?

10) Haven't ocean temperatures been going up, too?

Most of the Earth is covered by oceans, and we now have a network of thousands of automated buoys monitoring ocean temperature at depths down to 2,000 meters. Called the Argo floats, the sensors dive down as currents carry them around the world, taking measurements, then they rise to the surface and transmit the data to satellites. They then start the measurement cycle all over again.

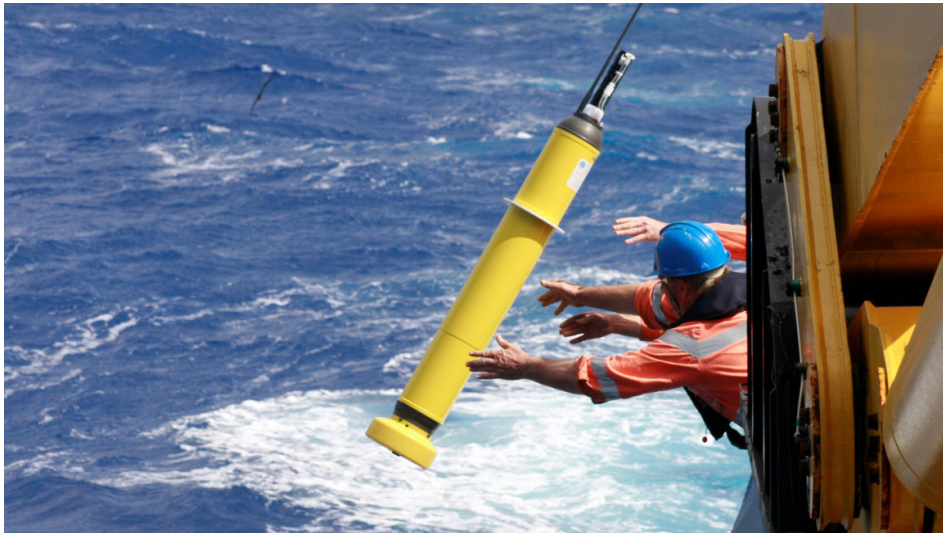

Fig. 12. *An Argo float being deployed to measure ocean temperature to depths of 2,000 meters.*

The trouble with monitoring ocean temperatures over a long period of time, though, is that we only have a few measurements made from ship expeditions back to the 1950s, and the Argo floats weren't fully deployed until about 2005. Nevertheless, they suggest there has been a tiny warming of the oceans, at a rate of about 0.04 F per decade averaged over the layer from the surface to 2,000 meters depth.

This is an exceedingly small warming rate, and one can legitimately question whether the Argo system can measure such a small warming rate with very much certainty. Furthermore, if you run the math, the warming is considerably less than is expected from the 1 percent decrease in the rate of energy loss that has theoretically materialized from our carbon dioxide emissions. It is closer to a 0.1 percent effect (1 part in 1,000 energy accumulation rate).

So, like the atmospheric temperature we have already discussed, the situation in the ocean is similar: *the evidence suggests modest warming, at a rate that is not terribly alarming.*

One question I see frequently is whether ocean warming (if it really exists) could be due to undersea volcanoes and lava vents. But this geothermal source of heat is generally considered to be very small by geophysicists who have averaged it over the global oceans. Furthermore, it would have to be increasing over time to cause a warming trend. So, while not out of the realm of possibility, I don't currently see undersea geothermal heating as a significant source of warming.

11) What does it mean when we hear "the highest temperature on record?"

We often hear reports on the nightly news of "record high temperatures". But record high temperatures aren't a terribly useful way of establishing evidence for climate change, especially if they refer to a specific location, which is what we usually hear about during our daily weather forecast.

Since our temperature measurements haven't been around that long (100 years or so at most), temperature records can be expected to be broken from time to time just due to the chaotic nature of weather variations, without global warming.

But let's imagine that we were breaking the same high temperature records every year, year after year. Would *that* be cause for alarm?

Well, if there wasn't any natural weather variability involved, and we had a very slow rate of global warming occurring, say 0.01 F per year, then each year would be warmer than the previous year. Each year would set a new record.

But who would care? What matters is how much warmer it's getting, and how fast.

Also, not all records are created the same. For a given weather station, there can be a record high for the date (not a difficult record to break), a record for the calendar month, or an all-time record high (that's harder to achieve). These kinds of records are also broken for low temperatures as well.

If we examine the U.S. where the best thermometer data exist, the period with the most high temperature records was in the 1930s, during the Dust Bowl days. While that climate anomaly is believed to have been largely natural in origin, some believe it was made somewhat worse by farming and land use practices at that time. So, clearly, Mother Nature still has a large role in not only weather, but climate variations that do impact human affairs.

Record high temperatures in the *global average* are a somewhat more useful indicator of climate change. For example, 2015 was the warmest year in the surface thermometer record (in the last 100+ years); and only the third warmest year in the satellite record, which only started in 1979.

But the best measure is probably the temperature *trend*, which takes into account all of the data over many years (usually ten or more). An individual record warm year for the whole Earth really tells you very little about the long-term trend, which is what we primarily use to monitor global warming.

In summary, while newsworthy, record high temperatures are not a particularly useful way to determine whether global warming is occurring. In fact, they can be quite misleading. They usually have more to do with weather than with climate.

12) Is there a difference between weather and climate?

There are no strict definitions that distinguish between weather and climate. The main difference is the length of time being addressed.

It's reasonable to say that *climate is weather averaged over a month or longer*.

If you experience a cold snap, that's weather. If the cold snap lasts for the entire month of April, then that would be considered more of a climate-type variation.

So, we usually talk about climate variations as having time scales from one month to many years. Less than one month duration, we call it weather.

In today's culture, major weather events are increasingly being blamed on climate change. This isn't just an invention of an increasingly sensationalized media, as some scientists are even making such claims.

But the fact is that there has been a long-term decrease in strong tornadoes, no obvious changes in global hurricane activity, heat waves, or droughts, and no decrease in snow cover. The current drought in California is not nearly as bad as tree ring evidence suggests for centuries past. Even sea ice, which has indeed decreased in the Arctic, has increased in the Antarctic; the net global change has been near-zero since we started satellite monitoring in 1979.

The exaggeration of weather events as some sort of indication of climate change represents a clear bias on the part of some media-savvy scientists, and their colleagues do not call them on it for fear of losing funding.

13) Why would climate science be biased? Isn't global warming research immune from politics?

It would be hard to imagine an area of scientific research more prone to political bias than climate research.

Everything humans do requires access to energy. Climate research results are used to influence decision about how much and what kinds of energy are produced, how much it will be taxed, etc.

Remember, virtually 100 percent of climate research is ultimately managed by either politicians in Congress who appropriate the research funds, or political appointees heading up the funding agencies who decide in more detail what kinds of research will be supported. Congress does not provide research funds for non-problems… if the global warming threat was to cease to exist, the funding would disappear. This means the scientists also have a vested interest in keeping the global warming issue alive.

Therefore, there is an inherent bias to interpret data in ways that keep the climate change threat going. Because there is so much uncertainty regarding what climate data mean in terms of cause and effect, this can be done without lying or outright deceit. Scientists convince themselves that even if they are wrong about the science, getting humanity off of fossil fuels is the right thing to do anyway. (I've actually had

mainstream climate scientists tell me this).

Conclusion

It should be clear that the science of global warming is far from settled.

Uncertainties in the adjustments to our global temperature datasets, the small amount of warming those datasets have measured compared to what climate models expect, and uncertainties over the possible role of Mother Nature in recent warming, all combine to make climate change beliefs as much faith-based as science-based.

Until climate science is funded independent of desired energy policy outcomes, we can continue to expect climate research results to be heavily biased in the direction of catastrophic outcomes.

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