Q & A FOR CLIMATE SKEPTICS

Answers to the Most Frequently Stated Concerns

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Background and Table of Contents

Most of the information in this document is edited from: "How to Talk to a Climate Skeptic" a series by Coby Beck containing responses to the most common arguments opposing a belief in or action to resolve global warming.

There are five parts. Each includes numerous objections heard by skeptics followed by answers to them. Responses will appear under multiple headings and may even appear in multiple subcategories in the same heading.

1. CLIMATE CHANGE IS NOT REAL OR CONFIRMED

a. Inadequate evidence

Objection: Despite what the computer models tell us, there is actually no evidence of significant global warming.

Answer: Global warming is not an output of computer models; it is a conclusion based on observations of a great many global indicators. By far the most straightforward evidence is the actual surface temperature record. While there are places -- in England, for example -- that have records going back several centuries, the two major global temperature analyses can only go back around 150 years due to their requirements for both quantity and distribution of temperature recording stations.

These are the two most reputable globally and seasonally averaged temperature trend analyses:

- NASA GISS direct surface temperature analysis
- CRU direct surface temperature analysis

Both trends are definitely and significantly up. In addition to direct measurements of surface temperature, there are many other measurements and indicators that support the general direction and magnitude of the change the earth is currently undergoing. The following diverse empirical observations lead to the same unequivocal conclusion that the earth is warming:

- Satellite Data
- Radiosondes
- Borehole analysis
- Glacial melt observations
- Sea ice melt
- Sea level rise
- Proxy Reconstructions
- Permafrost melt

There is simply no room for doubt: the Earth is undergoing a rapid and large warming trend.

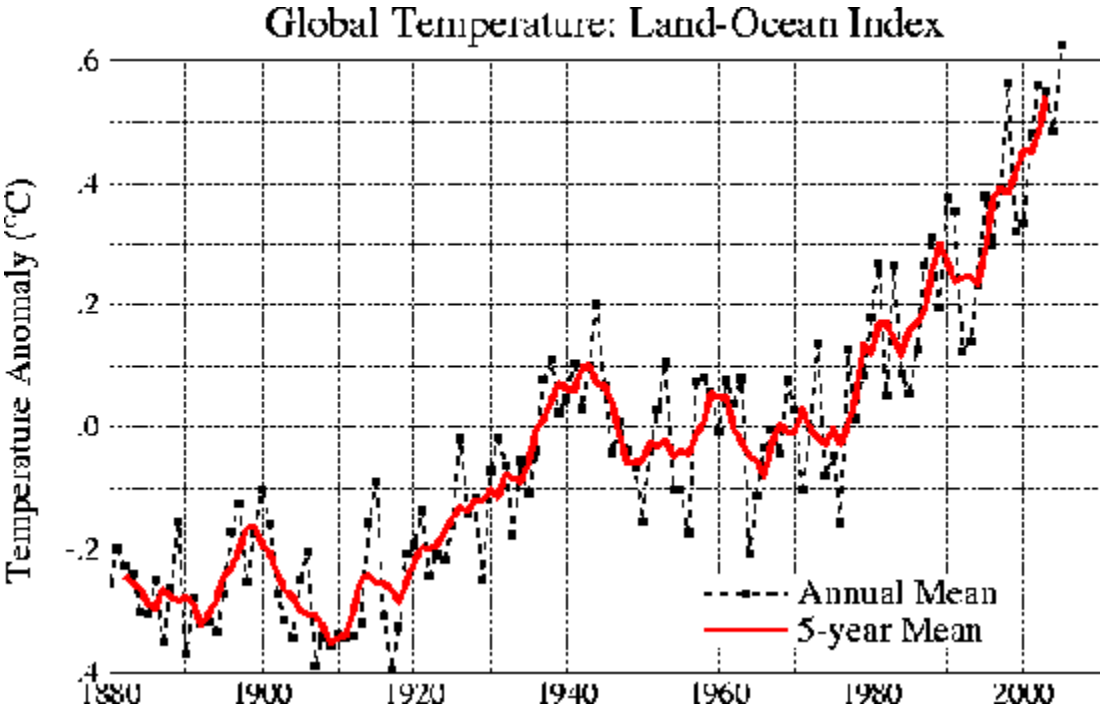
Objection: So 2005 was a record year. Records are set all the time. One really warm year is not global warming.

Answer: This is actually not an unreasonable point -- single years taken by themselves can not establish or refute a trend. So 2005 being the hottest globally averaged temperature on record is not convincing. Then how about:

- every year since 1992 has been warmer than 1992;
- the ten hottest years on record occurred in the last 15;

- every year since 1976 has been warmer than 1976;
- the 20 hottest years on record occurred in the last 25;
- every year since 1956 has been warmer than 1956; and
- Every year since 1917 has been warmer than 1917.

The five-year mean global temperature in 1910 was .8 degrees Celsius lower than the five year mean in 2002. This, and all of the above, comes from the temperature analysis by NASA GISS.



There is an interesting quote from that page:

Record warmth in 2005 is notable, because global temperature has not received any boost from a tropical El Niño this year. The prior record year, 1998, on the contrary, was lifted 0.2°C above the trend line by the strongest El Niño of the past century.

So, yes it is true that one record year does not make a long term trend, but that is clearly not the whole story.

Objection: The surface temperature record is full of assumptions, corrections, differing equipment and station settings, changing technology, varying altitudes, and more. It is not possible to claim we know what the "global average temperature" is, much less determine any trend. The IPCC graphs only say what the scientists want them to say.

Answer: There is actually some truth to the part about the difficulties; scientists have overcome many of them in turning the hundreds of thousands of measurements taken in

many different ways and over a span of more than a dozen decades into a single globally averaged trend.

But this is the nature of science -- no one said it was easy. It's taken the scientific community a long time to finally come out and say that what we have been observing for 100 years is in fact exactly what it looks like. All other possible explanations (for example, the Urban Heat Island effect) have been investigated, the data has been examined and re-examined, reviewed and re-reviewed, and the conclusion has become unassailable.

And while it is true that differing weather station locations, from proximity to lakes or rivers or elevation above sea level, probably make it impossible to arrive at a meaningful figure for global average surface temperature, that is not what we are really interested in. The investigation is focused on *trends*, not the absolute level. Often, as in this case, it is *easier* to determine how much a given property is changing than what its exact value is. If one station is near an airport at three feet above sea level and another is in a park at 3000 feet, it doesn't really matter -- they both show rising temperature and that is the critical information.

So how do we finally know when all the reasoning is reasonable and the corrections correct? One good way is to cross check your conclusion against other completely unrelated data sets. In this case, all the other available indicators of global temperature trends unanimously agree. Go ahead; put aside the direct surface temperature measurements -- global warming is also indicated by:

- Satellite measurements of the upper and lower troposphere
- Weather balloons show very similar warming
- Borehole analysis
- Glacial melt observations
- Declining arctic sea ice
- Sea level rise
- Proxy Reconstructions
- Rising ocean temperature

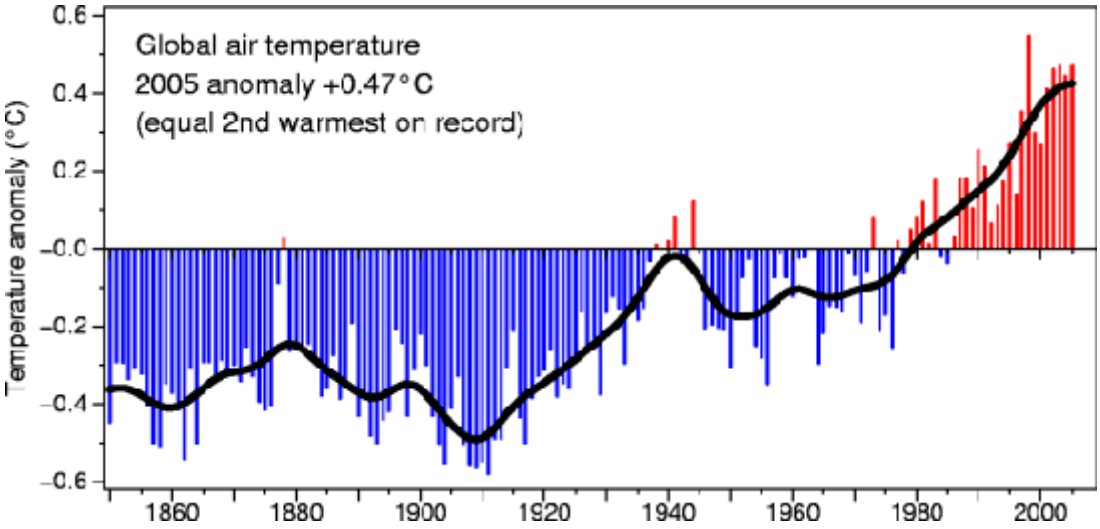
All of these completely independent analyses of widely varied aspects of the climate system lead to the same conclusion: the Earth is undergoing a rapid and substantial warming trend. Looks like the folks at NASA and CRU know what they are doing after all.

Objection: One hundred and some years of global surface temperatures is not long enough to draw any conclusions from or worry about anyway.

Answer: The reliable instrumental record only goes back 150 years in the CRU analysis, 125 in the NASA analysis. This is a simple fact that we are stuck with. 2005 was the warmest year recorded in that period according to NASA, a very close second according

to CRU. Because of this limit, it is not enough to say today that these are the warmest years since 150 years ago, rather one should say 'at least':

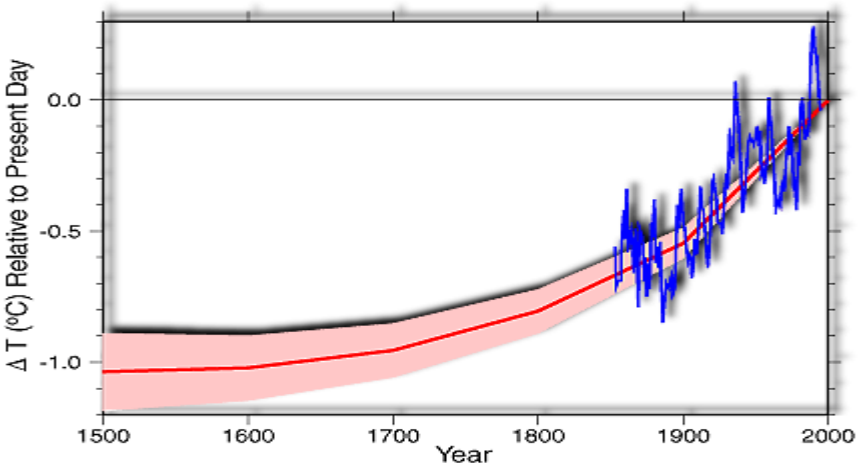
1998 and 2005 are the warmest two years in at least the last 150.



But there is another direct measurement record available that can tell us things about temperature over the last *500* years, and that is borehole measurements. This involves drilling a deep hole and measuring the temperature of the earth at various depths. It gives us information about century-scale temperature trends, as warmer or cooler pulses from long term surface changes propagate down through the crust.

Using this method we can see that temperatures have not been consistently this high as far back as this method allows us to look. This way of inferring surface temperatures does smooth out yearly fluctuations and even short term trends, so we can not know anything directly about individual years. But given the observable range of inter-annual variations recorded over the last century, it is quite reasonable to rule out single years or even decades being far enough above the baseline to rival today.

Using this record, we can reasonably conclude that it is warmer now than any time in at least the last 500 years.

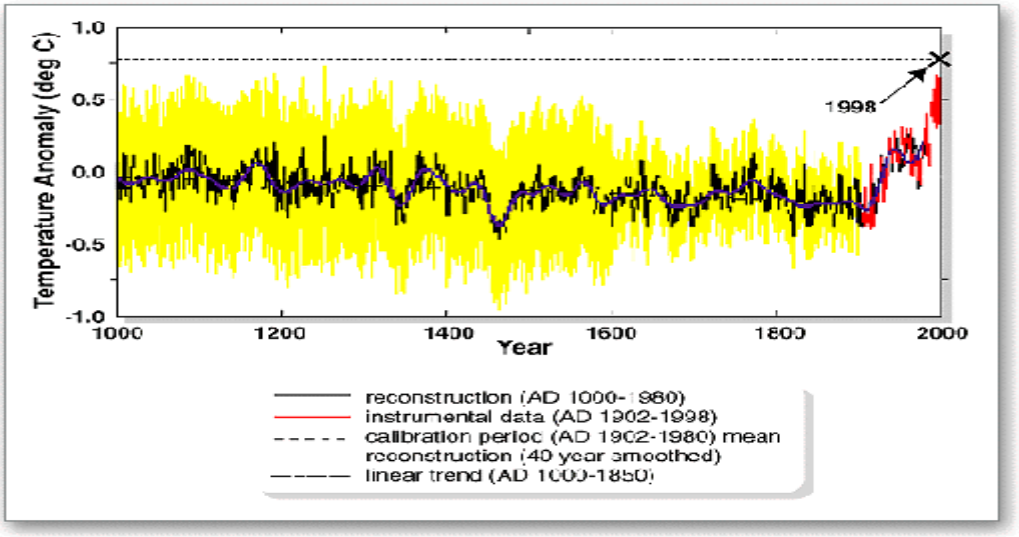


POLLACK RECONSTRUCTION

It is possible to make reconstructions of temperature much further back, using what are called proxy data. These include things like tree rings, ocean sediment, coral growth, layers in stalagmites, and others. The reconstructions available are all slightly different and provide sometimes more and sometimes less global versus regional coverage over the last one or two thousand years. Note: this covers what is often referred to as the Medieval Warm Period. As noted, all these reconstructions are different, but ...

... they all show some similar patterns of temperature change over the last several centuries. Most striking is the fact that each record reveals that the 20th century is the warmest of the entire record, and that warming was most dramatic after 1920.

Thus, we can reasonably say it is warmer now than any other time in at least the last 1,000 years.

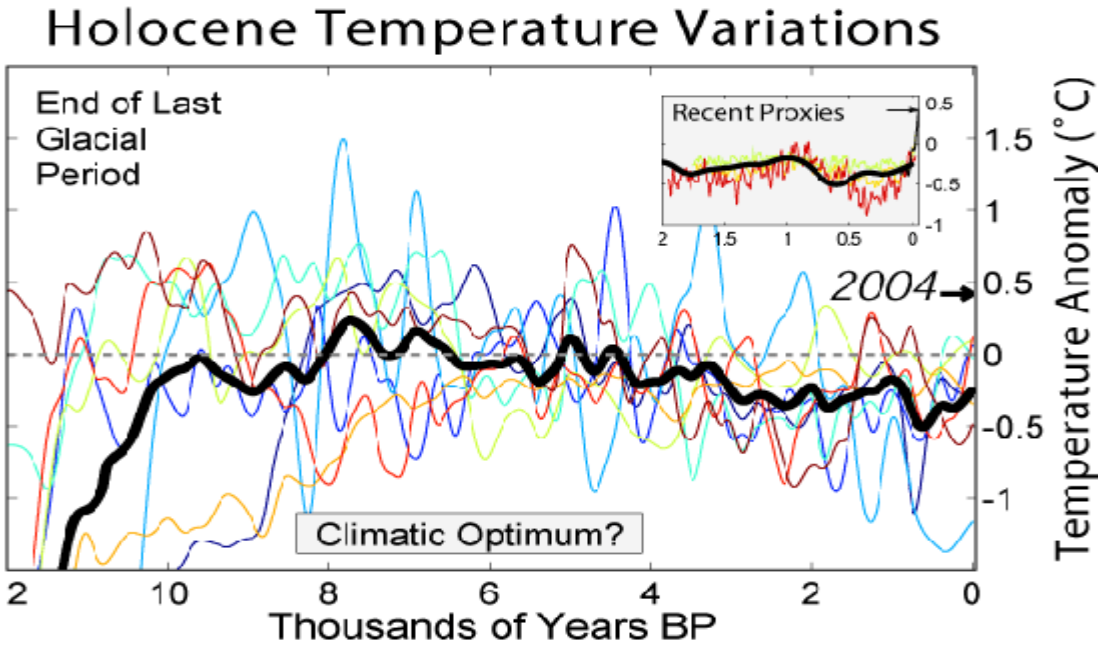


The only other candidate for a higher temperature period -- going back through the entire Holocene (~10,000bp to now) -- is called the Holocene Climatic Optimum some 6,000 years ago. It is not known exactly what the temperatures were then; the farther back in time we try to look, the greater the uncertainties. Even so, the Holocene Climatic Optimum has long been cautiously thought to be almost as warm as or even warmer than now.

That conclusion is starting to look less likely, as it has been determined that the anomalous warmth of that time was actually confined to the northern hemisphere and occurred only in the summer months.

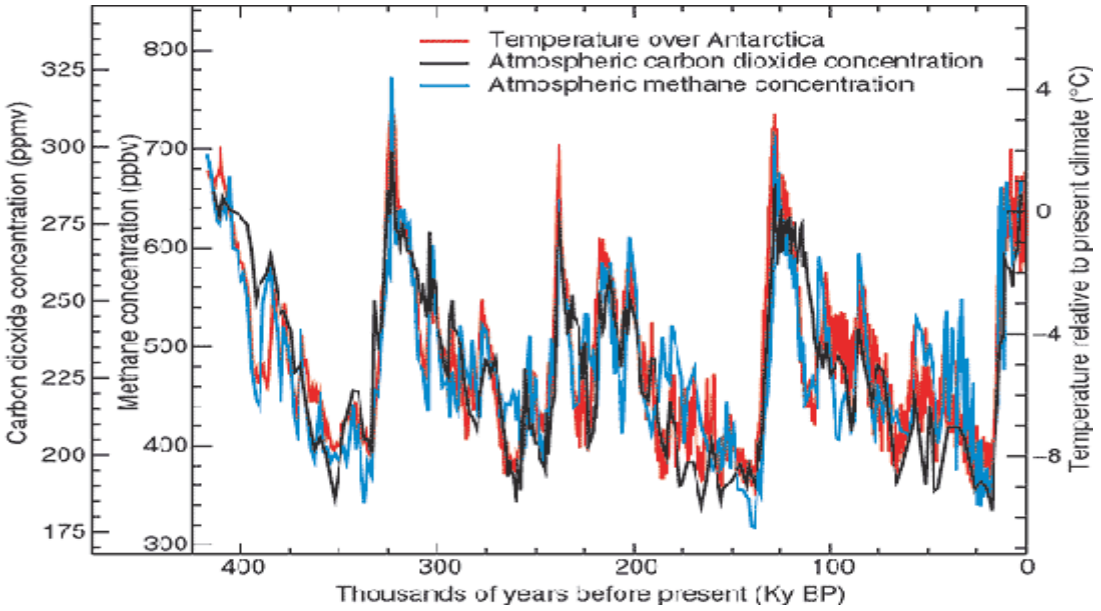
Robert Rohde's website, Global Warming Art, has a nice graph of many reconstructions of Holocene temperature, regional and global, all super-imposed with an average of all of them combined, shown below. This represents the best estimate available of global temperatures in the Holocene.

Thus, we can reasonably believe it is warmer now than at any other time in at least the last 10,000 years.



Before the current interglacial, the planet was in the grip of a much colder glacial period with ice sheets well down into the continental U.S. This period ended just some 11,000 years ago. The record of glacial-interglacial cycles can be read in Antarctic ice core analysis, and it shows these cycles over many 100Kyr periods. The IPCC offers a good version of this graph.

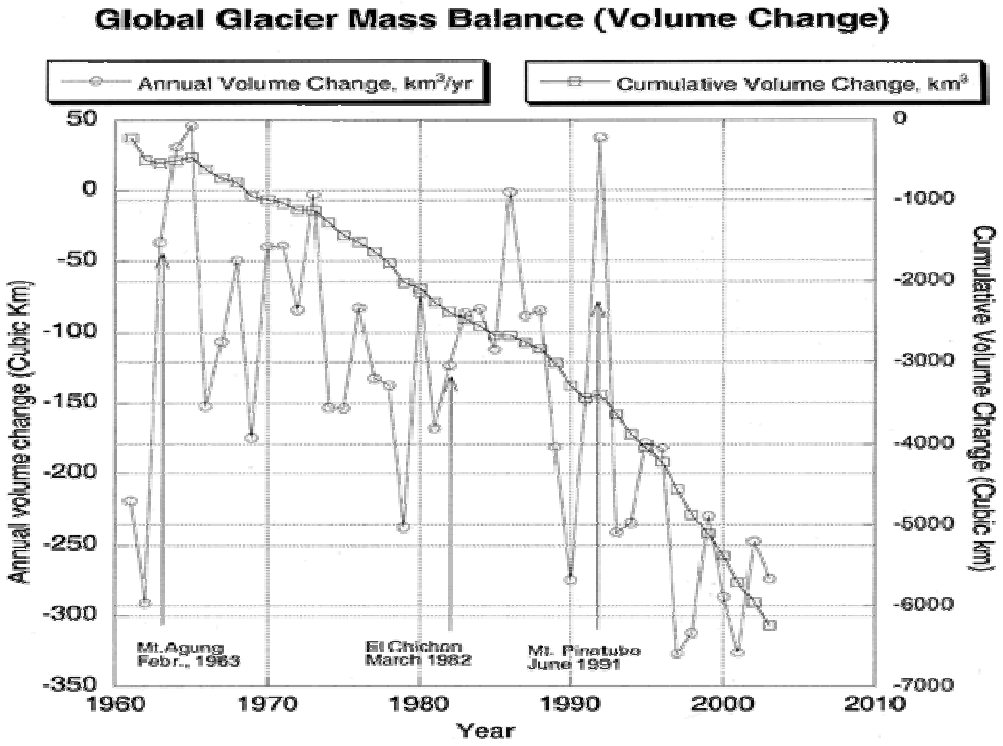
If our reading of the Holocene is correct, it is warmer now than at any other time in over the last 100,000 years.



And that is a bit more than 100 years. It is, in fact, the entire history of our species.

<u>Objection</u>: A few glaciers receding today is not proof of global warming. Glaciers have grown and receded differently in many times and places.

Answer: Firstly, it is more than "a few glaciers" that are receding; it is a pervasive, sustained, and accelerating global trend. The National Snow and Ice Data Centre (NSIDC) maintains a chart of global glacier mass balance, and for as far back as their data allows us to look, all but a few years have shown a loss in ice volume of subpolar and mountain glaciers. Further, annual losses are increasing.



But no one claims that melting glaciers are proof of global warming. Proof is a mathematical concept. In climate science one needs to look at the balance of evidence. The above data is just one piece of evidence that is consistent with global warming.

So what do we find if we look to the other aspects of the cryosphere? It turns out what we find is lots more evidence indicative of world-wide and sustained temperature increases:

- Sea ice in the arctic is reaching new record declines as the year 2006 continues the pattern of sharply decreasing Arctic sea ice.
- Recent measurements by NASA have found that Greenland's massive ice sheet has been losing nearly 100 gigatons of ice annually in recent years.
- Glaciers in Greenland are receding and calving at record rates.
- Ancient permafrost is also thawing (which represents its own dangers).

And of course, this is all consistent with all the other evidence of warming out there. Clearly we are dealing with much more than a few receding glaciers.

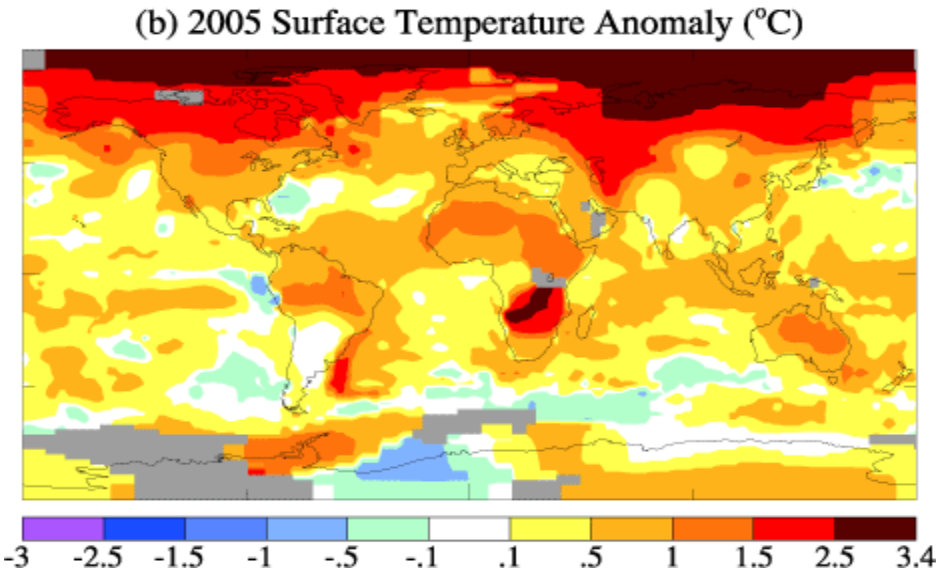
Objection: The apparent rise of global average temperatures is actually an illusion due to the urbanization of land around weather stations, the Urban Heat Island effect.

Answer: Urban Heat Island Effect has been examined quite thoroughly (PDF) and found to have a negligible effect on temperature trends. Real Climate has a detailed discussion of this here. What's more, NASA GISS takes explicit steps in their analysis to remove any such spurious signal by normalizing urban station data trends to the surrounding rural stations. It is a real phenomenon, but it is one climate scientists are well aware of and have taken any required steps to remove its influence from the raw data.

But heavy duty data analysis and statistical processing aside, a little common sense and a couple of pertinent images should put this idea to bed. Here is an image, taken from Astronomy Picture of the Day (a wonderful site, by the way), of the surface of the earth. It is a composite of hundreds of satellite images all taken at night. (The large version is well worth the download time!)

Aside from being very beautiful, it is a perfect indicator of urbanization on earth. As you can see, the greatest urbanization is over the continental United States, Europe, India, Japan, Eastern China, and generally coastal South America.

This next image was taken from NASA GISS. It is a global surface temperature anomaly map which shows warming (and infrequently, cooling) by region.



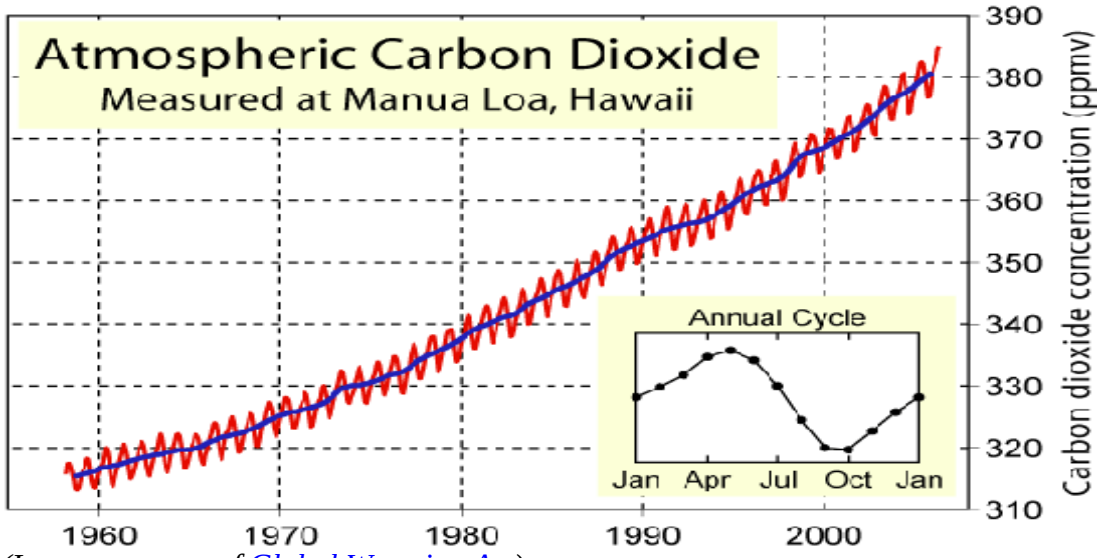
Look at North America, look at Europe, at Asia, Australia, Africa and the Poles and compare them to the urbanization in the image from APOD. There is quite simply no way to discern any correlation whatsoever between urbanization and warming. If the UHI effect were the cause of warming in the globally averaged record, we would see it in this map.

The claim that global warming is an artifact of the Urban Heat Island Effect is simply an artifact of the Urban Myth Effect.

Addendum: Wikipedia has a very good article on this subject. Among all the interesting details it mentions a few papers that directly discuss efforts to identify and quantify UHI influences on the global temperature trend including this one (PDF), which would be a good one to cite:

A 2003 paper ("Assessment of urban versus rural in situ surface temperatures in the contiguous United States: No difference found"; J climate; Peterson; 2003) indicates that the effects of the urban heat island may have been overstated, finding that "Contrary to generally accepted wisdom, no statistically significant impact of urbanization could be found in annual temperatures." This was done by using satellite-based night-light detection of urban areas, and more thorough homogenization of the time series (with corrections, for example, for the tendency of surrounding rural stations to be slightly higher, and thus cooler, than urban areas). As the paper says, if its conclusion is accepted, then it is necessary to "unravel the mystery of how a global temperature time series created partly from urban in situ stations could show no contamination from urban warming." The main conclusion is that micro- and local-scale impacts dominate the meso-scale impact of the urban heat island: many sections of towns may be warmer than rural sites, but meteorological observations are likely to be made in park "cool islands."

Objection: CO2 levels are recorded on top of Mauna Loa ... a *volcano*! No wonder the levels are so high.



(Image courtesy of Global Warming Art)

Answer: Yes, it's true, Mauna Loa is an active volcano. In fact it's the biggest volcano on earth! So, should we suppose that Charles Keeling didn't know that?

Well, no, he did know it. And using subtle scientific indicators like "wind direction," he was even able to ensure that his readings were not contaminated by any out-gassing when it was occurring. OK, to be fair, it is not really always that simple; out-gassed CO2 can be carried far away on a favorable wind, only to return much later on an ill one. But really, these are clever people, these scientists, and while mistakes are made, they are not usually such simple ones.

A quick look at the actual levels recorded makes it pretty hard to believe there is any volcanic influence. We have a nice, slow, steady trend with a regular up and down seasonal variation. No spikes, no dips. Nothing random, as one would expect from an overwhelming volcanic influence. The record is here among other places.

But, let's throw out Mauna Loa. There are dozens of other sampling stations scattered all over the globe, including one in the Antarctic, far from cities, SUVs, cement plants, and active volcanoes. It also shows the same rise [PDF], though the southern hemisphere tends to lag a few years behind the northern hemisphere, where the majority of the CO2 is produced. Here are eight others -- same results.

It's humans, not volcanoes.

Objection: Even the scientists don't *know* that the climate is changing more than normal and if it's our fault or not. If you read what they write it is full of "probably," "likely," "evidence of" and all kinds of qualifiers. If they don't know for sure, why should we worry yet?

Answer: Probability is the language of science. There is no proof; there are no absolute certainties. Scientists are always aware that new data may overturn old theories and that human knowledge is constantly evolving. Consequently, it is viewed as unjustifiable hubris to ever claim one's findings as unassailable.

But in general, the older and more established a given theory becomes, the less and less likely it is that any new finding will drastically change things. Even the huge revolution in physics brought on by Einstein's theory of relativity did not render Newton's theories of classical mechanics useless. Classical mechanics is still used all the time; it is, quite simply, good enough for most purposes.

But how well established is the greenhouse effect?

Greenhouse effect theory is over 100 years old. The first predictions of anthropogenic global warming came in 1896. Time has only strengthened and refined those groundbreaking conclusions. We now have decades of very detailed and sophisticated climate observations, and super computers crunching numbers in one second it would have taken a million 19th century scientists years with a slide rule to match. Even so, you will *never ever* get a purely scientific source saying "the future is certain."

But what certainty there is about the basic issue is close enough to 100% that for all practical purposes it should be taken as 100%. Don't wait any longer for scientific certainty; we are there. Every major institute that deals with climate related science is saying AGW is here and real and dangerous, even though they will not remove the "very likely" and "strongly indicated" qualifiers. The translation of what the science is saying into the language of the public is this: Global warming is definitely happening and it is definitely because of human activities and it will definitely continue as long as CO2 keeps rising in the atmosphere.

The rest of the issue -- how high will the temperature go, how fast will it get there, and how bad will this be -- is much less certain. But no rational human being rushes headlong into an unknown when there is even a 10% chance of death or serious injury. Why should we demand 100% certainty before avoiding this danger? Science has given the human race a dire warning with all the urgency and certainty we should need to prompt action.

b. Contradictory evidence

Objection: It was way colder than normal today in XXX (date) proof that there is no global warming.

Answer: The chaotic nature of weather means that no conclusion about climate can ever be drawn from a single data point, hot or cold. The temperature of one place at one time is just weather, and says nothing about climate, much less climate change, much less global climate change.

Objection: The Antarctic ice sheets are actually growing, which wouldn't be happening if global warming were real.

Answer: There are two distinct problems with this argument.

First, any argument that tries to use a regional phenomenon to disprove a global trend is dead in the water. Anthropogenic global warming theory does not predict uniform warming throughout the globe. We need to assess the balance of the evidence.

In the case of this particular region, there is actually very little data about the changes in the ice sheets. The growth in the East Antarctic ice sheet indicated by some evidence is so small, and the evidence itself so uncertain, the sheet may well be shrinking.

But even this weak piece of evidence may no longer be current. Some recent results from NASA's GRACE experiment, measuring the gravitational pull of the massive Antarctic ice sheets, have indicated that on the whole, ice mass is being lost.

Second, ice-sheet thickening is not inconsistent with warming! Warmer climates tend toward more precipitation. The Antarctic is one of the most extreme deserts on the planet. As it warms, we would expect it to receive more snow. But even a whopping warming of 20 degrees -- say, from -50 degrees C to -30 degrees C -- would still leave it below freezing, so the snow wouldn't melt. Thus, an increase in ice mass.

While on the subject of ice sheets: Greenland is also growing ice in the center, for the same reasons described above. But it is melting on the exterior regions, on the whole losing approximately 200 km^3 of ice annually, doubled from just a decade ago. This is a huge amount compared to changes in the Antarctic -- around three orders of magnitude larger. So in terms of sea-level rise, any potential mitigation due to East Antarctic Ice Sheet growth is wiped out many times over by Greenland's melting.

Objection: Satellite readings, which are much more accurate, show that the earth is in fact cooling.

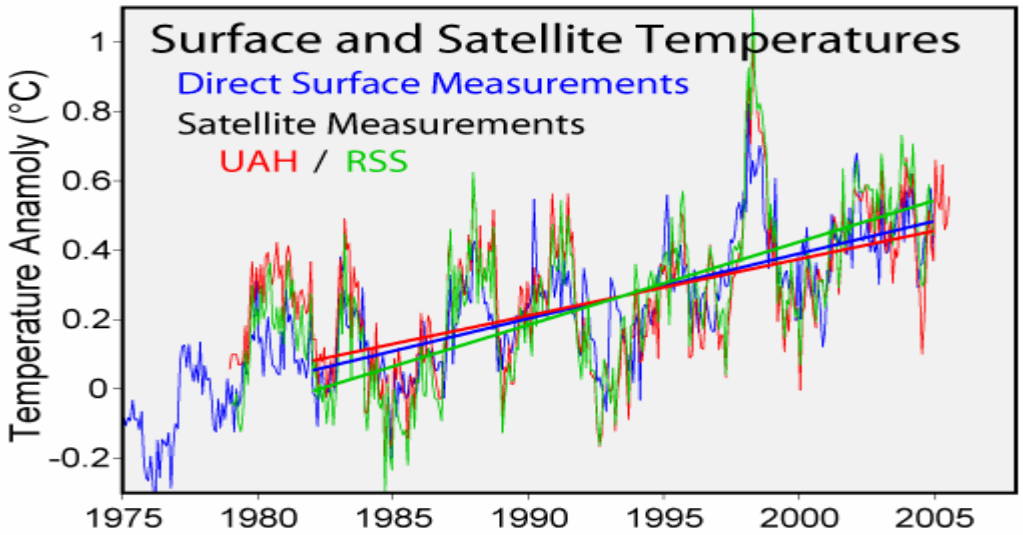
Answer: There are a few advantages to the satellite readings, mainly the more uniform global coverage and the fact that readings can be taken at different altitudes. However, it is an extremely complicated process, which uses microwaves emitted by the oxygen in the atmosphere as a proxy for temperature.

The complications arise from many things, including decay of the satellite orbits, splicing together and calibrating records from different instruments, trying to separate the signals by the layer of atmosphere they originate from, etc. It is a little ironic that the same people who distrust the surface record so happily embrace this even-more-convoluted exercise in data processing!

Anyway, it has been many years since the satellite analysis showed cooling.

Until recently, though, one of the many analyses of tropospheric temperatures did show very little warming and was in direct contradiction to model predictions that say the troposphere should warm significantly in an enhanced greenhouse environment. Something had to be wrong, the observations or the model predictions. Naturally, the skeptics had no doubt it was the models that were off.

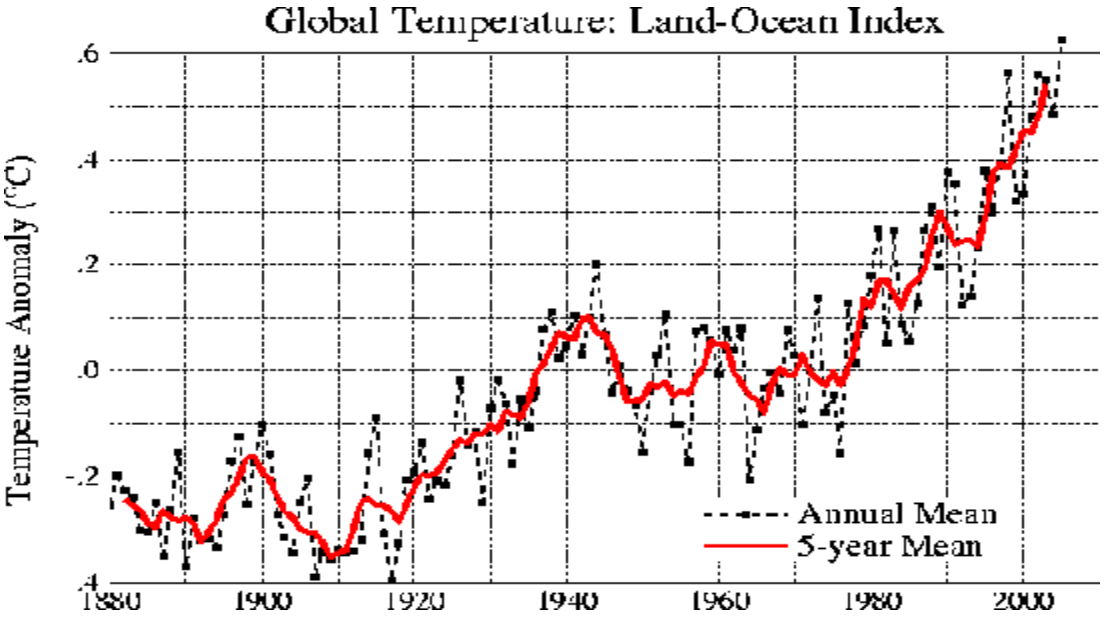
However, it turns out that additional errors were uncovered and the MSU Satellite temperature analysis now shows warming well in line with model expectations. Real Climate has a good rundown of the technical details for those with the stomach for it. In short, this long-running debate turned out to be a great validation of the models and a real death blow to the "earth is not warming" crowd.



(image from Global Warming Art)

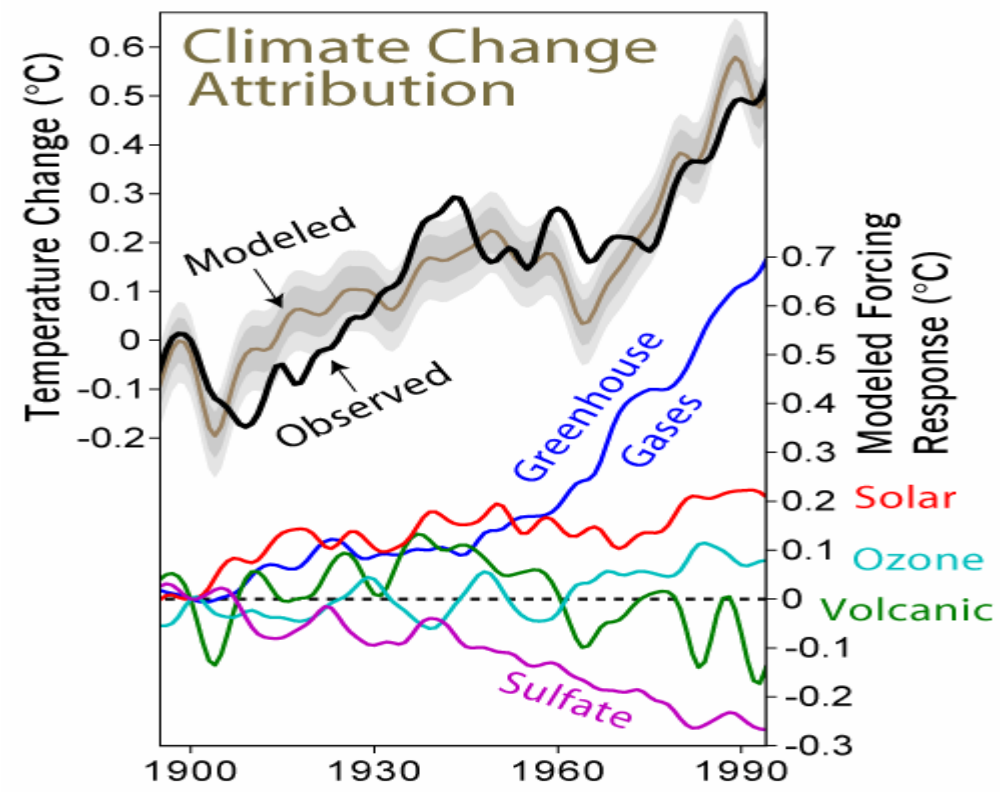
Objection: There was global cooling in the '40s, '50s, and '60s, even while human greenhouse-gas emissions were rising. Clearly, temperature is not being driven by CO2.

Answer: None of the advocates of the theory of anthropogenic global warming claim that CO2 is the *only* factor controlling temperature in the ocean-atmosphere climate system. It is a large and complex system, responsive on many different timescales, subject to numerous forcings. AGW only makes the claim that CO2 is the *primary* driver of the warming trend seen over the last 100 years. This rise has not been smooth and steady -- nor would it be expected to be.



If you look at the temperature record for the 1990s, you'll notice a sharp drop in '92, '93, and '94. This is the effect of massive amounts of SO2 ejected into the stratosphere by Mount Pinatubo's eruption. That doesn't mean CO2 took a holiday and stopped influencing global temperatures; it only means that the CO2 forcing was temporarily overwhelmed by another, opposite forcing.

The situation is similar to the cooling seen in the '40s and '50s. During this period, the CO2 warming (a smaller forcing at the time) was temporarily overwhelmed by other factors, perhaps foremost among them an increase in human particulates and aerosol pollution. Pollution regulations and improved technology saw a decrease in this latter kind of emissions over the '60s and '70s, and as the air cleared, the CO2 signal again emerged and took over. Below, courtesy of Global Warming Art, is an image of the current understanding of the factors and their influence for the climate of the past century.



As the graph shows, in addition to aerosol pollution (the sulphate line), volcanic influences were increasingly negative during the period of global cooling, and solar forcing slightly declined. All forcings taken together and run through the model are a very good match for the observations. (Please see the source page for details of what model and what study this image is derived from.)

Rather than confounding the climate consensus, mid-century cooling is actually a good test for the climate models, one they are passing quite convincingly.

Addendum: The opposing effect of cooling from airborne pollutants is often referred to as "Global Dimming", and Real Climate has a couple of articles on it:

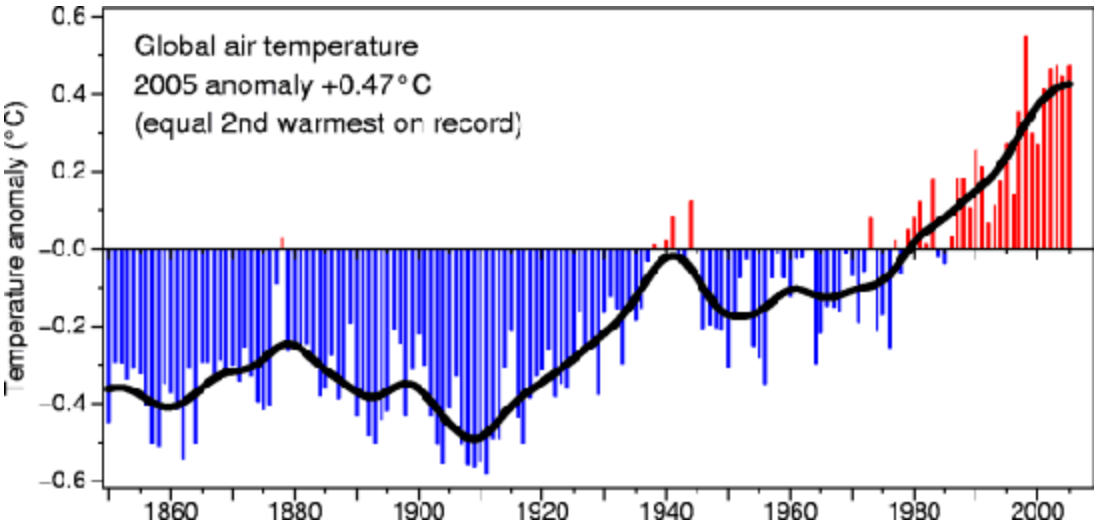
- Global Dimming?
- Global Dimming II

One emerging concern is that as the pollution causing this effect is gradually cleaned up, we may see even greater greenhouse gas warming.

Objection: Global temperatures have been trending *down* since 1998. Global warming is over.

Answer: At the time, 1998 was a record high year in both the CRU and the NASA GISS analyses. In fact, it blew away the previous record by .2 degrees C. (That previous record went all the way back to 1997, by the way!)

According to NASA, it was elevated far above the trend line because 1998 was the year of the strongest El Nino of the century. Choosing that year as a starting point is a classic cherry pick and demonstrates why it is necessary to remove chaotic year-to year-variability (aka: weather) by smoothing out the data. Looking at CRU's graph below, you can see the result of that smoothing in black.



Clearly 1998 is an anomaly and the trend has not reversed. (Even the apparent leveling at the end is not the real smoothing. The smoothed trend in 2005 depends on all of its surrounding years, including a few years still in the future.) By the way, choosing the CRU analysis is also a cherry pick -- NASA has 2005 breaking the 1998 record, though by very little.

Now, this is an excusable mistake for average folks who do not need the rigors of statistical analysis in their day jobs. But any scientist in pretty much any field knows that you cannot extract meaningful information about trends in noisy data from single-year end points. It's hard to hear a scientist make this argument and still believe they speak with integrity in this debate -- seems more like an abuse of the trust placed in them as scientists. Bob Carter is just such a voice, and was the first to trot out this argument in an article in the *Daily Telegraph*. Since then it has echoed far and wide and been used by Richard Lindzen as well as a host of skeptic websites.

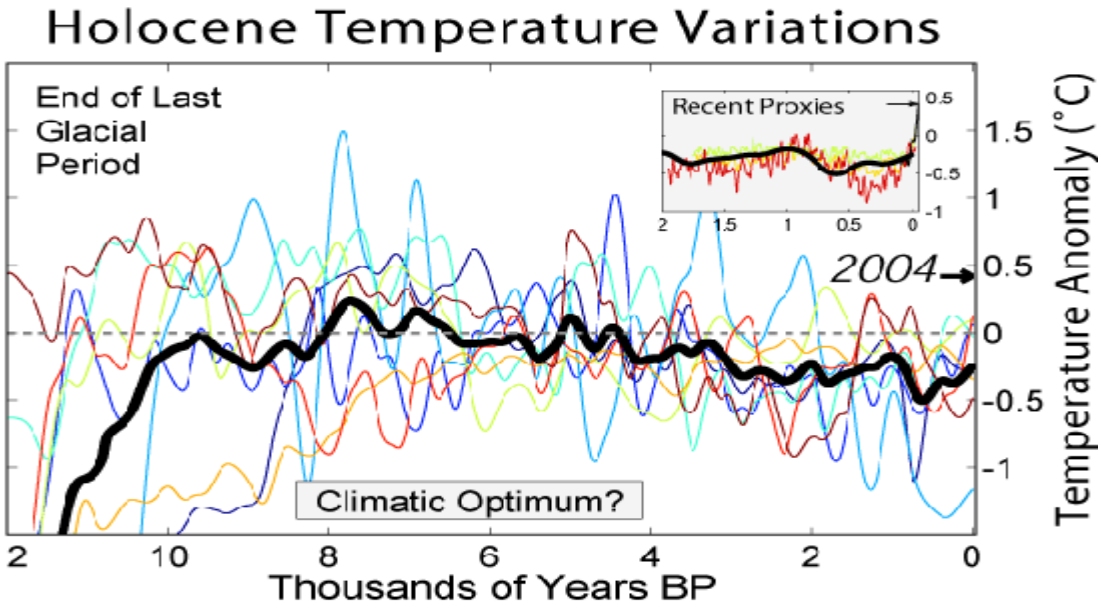
Interestingly, Bob Carter seems to know what he is doing. He tries to pre-empt objections in his article by insinuating that *any* choice of starting point (say, 1978) will just be a cherry pick with the opposite motive! But cherry picking is about choosing data for the sole purpose of supporting a pre-conceived conclusion. It is not the simple act of choosing at all. One must choose *some* starting point. In the case of his example year, 1978, it's often chosen simply because it is the first year that satellite records of tropospheric temperatures were available.

So what choices are there? What are the reasons for those choices? What conclusions we can draw from them?

1. As mentioned above, you could choose to examine the last 30 years -- that is when both surface and tropospheric readings have been available. We have experienced warming of approximately .2 degrees C/decade during this time. It would take a couple of decades trending down before we could say the recent warming ended in 1998.
2. You could choose 1970 in the NASA GISS analysis -- the start of the late 20th century warming, and as such a significant feature of the temperature record. The surface temperature over this period shows .6 degrees C warming.
3. You could choose 1965 in the CRU analysis -- when the recent warming started in their record. It shows around .5 degrees C warming of the smoothed trend line.
4. You could choose 1880 in the NASA record -- it shows .8 degrees C warming.
5. You could choose 1855 in the CRU record -- it shows .8 degrees C warming. As with the trend above, we can not say it is over without many decades more data indicating cooling.
6. You could choose to look at the last 500 years in the bore hole record analysis -- that is its entire length. It puts today about 1 degree C above the first three centuries of that record. In that kind of analysis, today's record will be hidden from view for many decades.
7. You could choose to look at the last 1,000 years, because that is as far back as the dendrochronology studies reliably go. Then the conclusion is:

   Although each of the temperature reconstructions are different (due to differing calibration methods and data used), they all show some similar patterns of temperature change over the last several centuries. Most striking is the fact that each record reveals that the 20th century is the warmest of the entire record, and that warming was most dramatic after 1920.

8. You could choose to look at the entire period of time since the end of the last ice age, around 10,000 years ago. Then the conclusion is that GHG warming has reversed a long and stable period of slight downward trend, and we are now at a global temperature not experienced in the history of human civilization -- the entire Holocene. It will be many centuries until such a long view of today's climate is available. The situation is a bit more urgent than that!

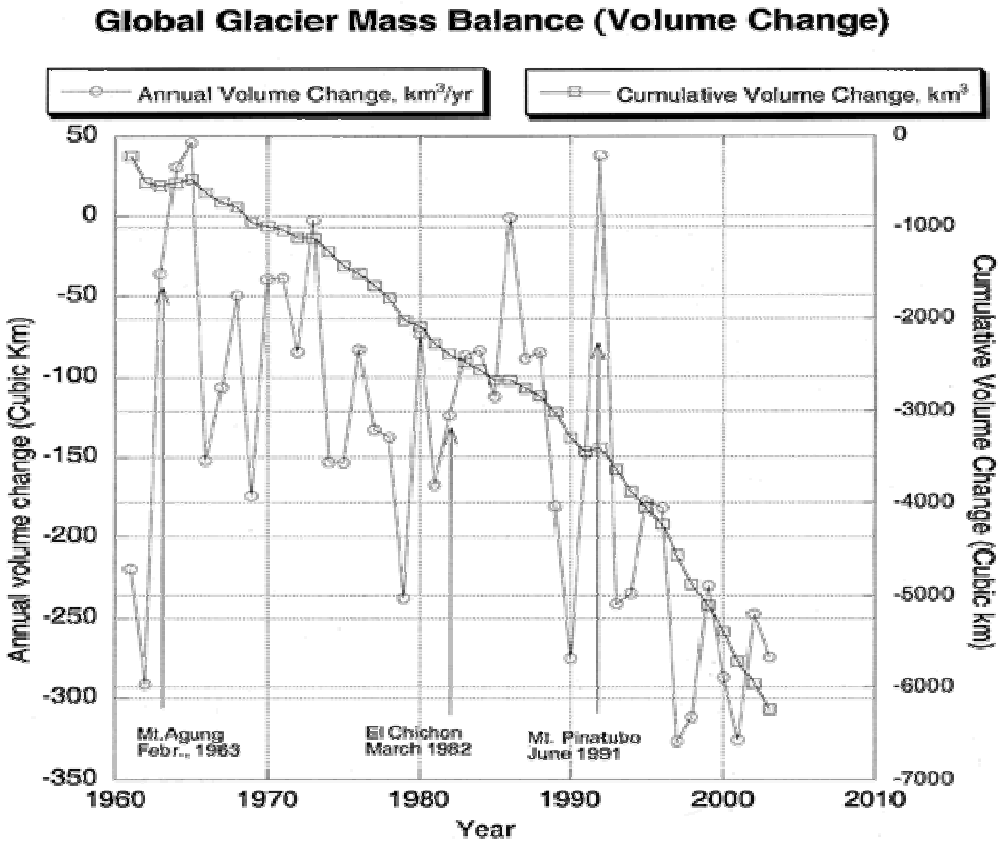


That about covers any period of time relevant to today's society. "It has stopped warming" is only supported by selecting a single year out of context and using a seven-year window to look at multi-decadal trends in climate. That's a classic cherry pick.

Objection: Sure, some glaciers are melting. But if you look at the studies, most of those for which we have data are growing.

Answer: This is simply not true, rumors on "the internets" aside. The National Snow and Ice Data Centre and their State of the Cryosphere division, on their Glacial Balance page, report an overall accelerating rate of glacial mass loss. The World Glacier Monitoring Service has similar findings, the most recent data coming from 2004.

While there surely are some growing glaciers, studies like these are designed to determine a global trend by ensuring glaciers from all regions of the globe are assessed. There are 67,000 glaciers in the World Glacier Inventory. Not all, or even most, have quality data for many decades, but there are enough with adequate data, located in enough regions of the globe, to know the average trend.



Don't forget: there is similar evidence from other parts of the cryosphere. It's also worth noting that given the right circumstances, warming can actually cause glacier growth, with accumulation of increased winter snowfall outweighing increased summer melting.

Check this page for some good before-and-after images of glaciers over the last century, as well as other images of visible effects of global warming. There are also some compelling animations of changes in Glacier Bay National Park here.

Objection: Sure, sea ice is shrinking in the Arctic, but it is growing in the Antarctic. Sounds like natural fluctuations that balance out in the end.

Answer: Overall, it is true that sea ice in the Antarctic is increasing.

Around the peninsula, where there is a lot of warming [PDF], the ice is retreating. This is the area of the recent and dramatic Larsen B and Ross ice shelf breakups.

But the rest of the continent has not shown any clear warming or cooling and sea ice has increased over the last decade or so.

This is not actually a big surprise.

In fact, it is completely in line with model expectations that CO2-dominated forcing will have a disproportionately large effect in the north. The reasons lie in the much larger

amount of land in the northern hemisphere and the fact that the ocean's thermal inertia and ability to mix delay any temperature signal from the ongoing absorption of heat. The local geography also plays a dominating role. The circumpolar current acts as a buffer preventing warm water from the tropics from transporting heat to the South Pole, a buffer that does not exist in the north. You can read some more details about that here.

Does it "balance out" in the end? Not really. Sea ice in the Arctic is reaching dramatic record lows. There are other components of the cryosphere that we can look at as well, permafrost, the Greenland ice sheet, global glacier mass, and these all carry the Global Warming signal.

One must look at the balance of evidence, not just those bits one likes. And this balance is clearly in agreement with all other indicators that warming is real and rapid.

Objection: Taking into account the logarithmic effect of CO2 on temperature, the 35 percent increase we have already seen in CO2 concentrations represents about three-quarters of the total forcing to be expected from a CO2 doubling. Since we have warmed about 0.7 degrees Celsius so far, we should only expect about 0.3 degrees more for a doubling from pre-industrial levels, so about 1 degree total, not 3 degrees as the scientists predict. Clearly the climate model sensitivity to CO2 is much too high.

Answer: Even without addressing the numbers in this argument, there is a fundamental flaw in its reasoning.

We don't yet know exactly how much the climate will warm from the CO2 already in the air. There is a delay of several decades between forcing and final response. Until an equilibrium temperature is reached, present day observations will not tell us the exact value of the climate's sensitivity to CO2.

The reason for this is primarily the large heat capacity of the oceans. The enhanced greenhouse effect from higher CO2 levels is indeed trapping energy in the climate system according to expectations, but the enormous quantity of water on earth is absorbing most of the resulting heat. Due to water's high heat capacity, this absorbed energy shows up as only a modest ocean warming, which in turn dampens the temperature change on land and lowers the global average trend.

This is commonly referred to as the climate system's thermal inertia. According to model experiments and consistent with data from past climate changes, this inertia results in a lag of several decades between the imposition of a radiative forcing and a final equilibrium temperature.

Now let's look at a couple of further details. CO2 is not the only factor affecting global temperature. There is a phenomenon called "global dimming" counteracting greenhouse gas warming. Global dimming refers to the blocking of incoming sunlight by particulate pollution in the troposphere and airplane contrails in the stratosphere. It is not a well

quantified effect, but it may well be masking a great deal more warming; it is definitely masking some.

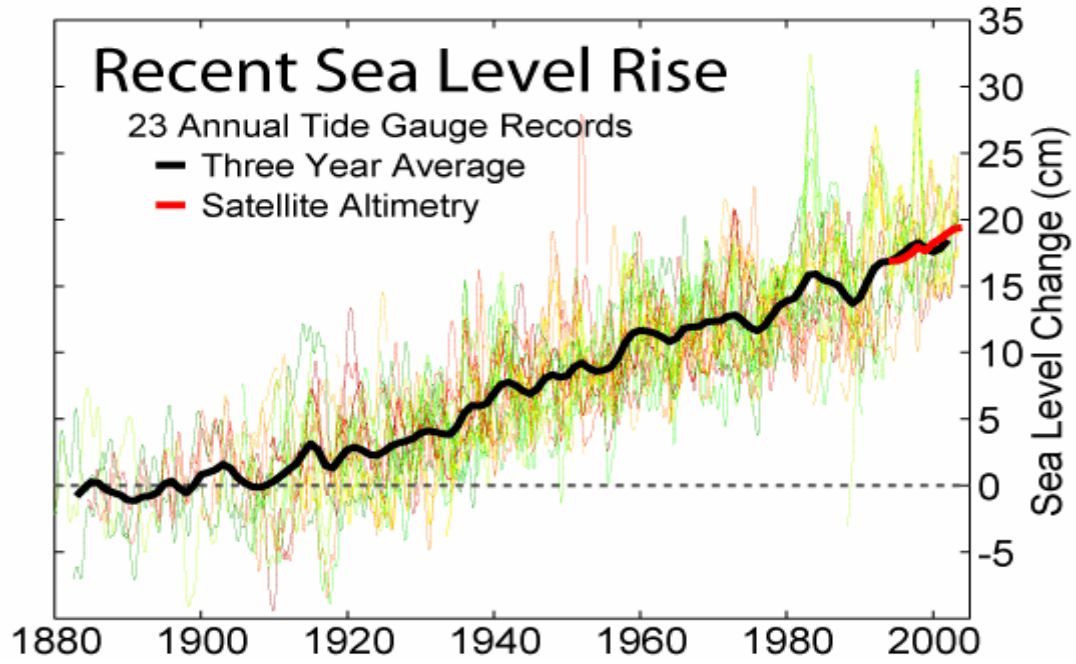
This is just one example of why we cannot attribute global temperature trends entirely to CO2 -- the same mistaken premise that fuels arguments about the mid-century cooling trend.

Richard Lindzen first made this argument [PDF] about climate sensitivity. The numbers he uses don't add up. A 35 percent increase in CO2 should correspond to 43 percent of the forcing from two times CO2 (ln(1.35)/ln(2)= 43%), which is not three-fourths.

The original article for this Skeptic Guide entry had an extremely interesting discussion under it, for anyone interested.

Objection: According to the latest state-of-the-art satellite measurements from over the Arctic, sea levels are falling! Guess all that ice isn't melting after all.

Answer: Yes, a new study using Europe's Space Agency's ERS-2 satellite has determined that over the last 10 years, sea level in the Arctic Ocean has been falling at an average rate of about 2 mm/year. This is very new and very interesting news, though it is preliminary and not published in any peer-reviewed journals yet. But even if these results hold up to time and scrutiny, it is not evidence that globally sea levels are not rising, because they are.



(courtesy of Global Warming Art)

Sea level and sea level change is not uniform around the globe.

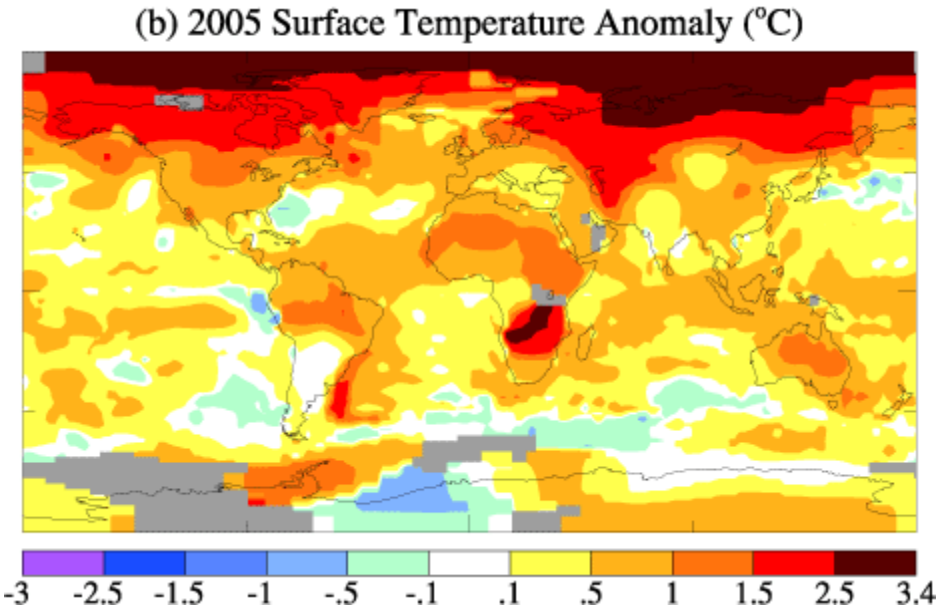
Local sea levels are subject to many influences including: wind and ocean currents that can "pile up" the ocean water locally, temperature anomalies like El Niño, local gravity wells of ice sheets and land masses, and regional salinity levels that alter the water's density. Measurement of these levels is further complicated by changes in land height as the Earth's crust moves up or down from tectonic motion and rebounds after long and recently ended glaciation, although these complications are avoided by using satellite measurements.

So in short, this is undoubtedly of interest to specialists in several fields, but it does not in any way alter the Global Climate Change picture.

Real Climate has a more detailed write-up on this here.

Objection: Some stations, in the U.S. for example, show cooling trends. If there were really global warming, it would be warming everywhere.

Answer: Global warming is the long-term increase in globally and seasonally averaged surface temperatures. It is not the case, nor is it expected, that all regions on the planet, let alone all weather stations, will show the same changes in temperature or rainfall patterns. Many stations have shown cooling, and some small regions have shown modest cooling as well. This does not invalidate global warming theory; it is merely the result of regional variation, and an example of how varied and complex the climate system is.



The contrarian website CO2 Science makes this fallacious argument part of its homepage by featuring a "Station of the Week" that's exhibited trends significantly different from the global one. Given the effort and technical content behind that website, and the fact that they prominently display this intellectual sleight of hand, I think it is safe to say they are simply being dishonest.

All of the various global temperature trend analyses show significant warming in the average temperature:

- NASA GISS
- CRU
- Hadley Centre

These analyses agree with the expectations of climate theory, as well as all the other lines of evidence.

c. No Consensus

Objection: Global warming is a hoax perpetrated by environmental extremists and liberals who want an excuse for more big government (and/or world government via the U.N.).

Answer: Here is a list of organizations that accept anthropogenic global warming as real and scientifically well-supported:

- NASA's Goddard Institute of Space Studies (GISS): http://www.giss.nasa.gov/edu/gwdebate/
- National Oceanic and Atmospheric Administration (NOAA): http://www.ncdc.noaa.gov/oa/climate/globalwarming.html
- Intergovernmental Panel on Climate Change (IPCC): http://www.grida.no/climate/ipcc_tar/wg1/index.htm
- National Academy of Sciences (NAS): http://books.nap.edu/collections/global_warming/index.html
- State of the Canadian Cryosphere (SOCC) - http://www.socc.ca/permafrost/permafrost_future_e.cfm
- Environmental Protection Agency (EPA): http://epa.gov/climatechange/index.html
- The Royal Society of the UK (RS) - http://www.royalsoc.ac.uk/page.asp?id=3135
- American Geophysical Union (AGU): http://www.agu.org/sci_soc/policy/climate_change_position.html
- American Meteorological Society (AMS): http://www.ametsoc.org/policy/climatechangeresearch_2003.html
- American Institute of Physics (AIP): http://www.aip.org/gov/policy12.html
- National Center for Atmospheric Research (NCAR): http://eo.ucar.edu/basics/cc_1.html
- American Meteorological Society (AMS): http://www.ametsoc.org/policy/jointacademies.html
- Canadian Meteorological and Oceanographic Society (CMOS): http://www.cmos.ca/climatechangepole.html

Every major scientific institution dealing with climate, ocean, and/or atmosphere agrees that the climate is warming rapidly and the primary cause is human CO2 emissions. In

addition to that list, see also this joint statement (PDF) that specifically and unequivocally endorses the work and conclusions of the IPCC Third Assessment report. The statement was issued by:

- Academia Brasiliera de Ciencias (Brazil)
- Royal Society of Canada
- Chinese Academy of Sciences
- Academie des Sciences (France)
- Deutsche Akademie der Naturforscher Leopoldina (Germany)
- Indian National Science Academy
- Accademia dei Lincei (Italy)
- Science Council of Japan
- Russian Academy of Sciences
- Royal Society (United Kingdom)
- National Academy of Sciences (United States of America)

You can also read this statement [PDF], which includes all the above signatories plus the following:

- Australian Academy of Sciences
- Royal Flemish Academy of Belgium for Sciences and the Arts
- Caribbean Academy of Sciences
- Indonesian Academy of Sciences
- Royal Irish Academy
- Academy of Sciences Malaysia
- Academy Council of the Royal Society of New Zealand
- Royal Swedish Academy of Sciences

But if scientists are too liberal and politicians too unreliable, the opinion of key industry representatives may be more convincing:

- BP, the largest oil company in the UK and one of the largest in the world, has this opinion:

  There is an increasing consensus that climate change is linked to the consumption of carbon based fuels and that action is required now to avoid further increases in carbon emissions as the global demand for energy increases.

- Shell Oil says:

  Shell shares the widespread concern that the emission of greenhouse gases from human activities is leading to changes in the global climate.

- Eighteen CEOs of Canada's largest corporations had this to say in an open letter to the Prime Minister of Canada:

> Our organizations accept that a strong response is required to the strengthening evidence in the scientific assessments of the Intergovernmental Panel on Climate Change (IPCC). We accept the IPCC consensus that climate change raises the risk of severe consequences for human health and security and the environment. We note that Canada is particularly vulnerable to the impacts of climate change.

Have the environmentalists seized the reigns of industrial power, in addition to infiltrating the U.N., the science academies of every developed nation, and the top research institutes of North America? That just doesn't seem very likely.

Objection: Climate is complicated and there are lots of competing theories and unsolved mysteries. Until this is all worked out, one can't claim there is consensus on global warming theory. Until there is, we should not take any action.

Answer: Sure there are plenty of unsolved problems and active debates in climate science. But if you look at the research papers coming out these days, the debates are about things like why model predictions of outgoing longwave radiation at the top of the atmosphere in tropical latitudes differ from satellite readings, or how the size of ice crystals in cirrus clouds affect the amount of incoming shortwave reflected back into space, or precisely how much stratospheric cooling can be attributed to ozone depletion rather than an enhanced greenhouse effect.

No one in the climate science community is debating whether or not changes in atmospheric CO2 concentrations alter the greenhouse effect, or if the current warming trend is outside of the range of natural variability, or if sea levels have risen over the last century.

This is where there is a consensus.

Specifically, the "consensus" about anthropogenic climate change entails the following:

- the climate is undergoing a pronounced warming trend beyond the range of natural variability;
- the major cause of most of the observed warming is rising levels of the greenhouse gas CO2;
- the rise in CO2 is the result of burning fossil fuels;
- if CO2 continues to rise over the next century, the warming will continue; and
- a climate change of the projected magnitude over this time frame represents potential danger to human welfare and the environment.

While theories and viewpoints in conflict with the above do exist, their proponents constitute a very small minority. If we require unanimity before being confident, well, we can't be sure the earth isn't hollow either.

This consensus is represented in the IPCC Third Assessment Report, Working Group 1 (TAR WG1), the most comprehensive compilation and summary of current climate

research ever attempted, and arguably the most thoroughly peer reviewed scientific document in history. While this review was sponsored by the UN, the research it compiled and reviewed was not, and the scientists involved were independent and came from all over the world.

The conclusions reached in this document have been explicitly endorsed by ...

- Academia Brasiliera de Ciências (Bazil)
- Royal Society of Canada
- Chinese Academy of Sciences
- Academié des Sciences (France)
- Deutsche Akademie der Naturforscher Leopoldina (Germany)
- Indian National Science Academy
- Accademia dei Lincei (Italy)
- Science Council of Japan
- Russian Academy of Sciences
- Royal Society (United Kingdom)
- National Academy of Sciences (United States of America)
- Australian Academy of Sciences
- Royal Flemish Academy of Belgium for Sciences and the Arts
- Caribbean Academy of Sciences
- Indonesian Academy of Sciences
- Royal Irish Academy
- Academy of Sciences Malaysia
- Academy Council of the Royal Society of New Zealand
- Royal Swedish Academy of Sciences

... in either one or both of these documents: PDF, PDF.

In addition to these national academies, the following institutions specializing in climate, atmosphere, ocean, and/or earth sciences have endorsed or published the same conclusions as presented in the TAR report:

- NASA's Goddard Institute of Space Studies (GISS)
- National Oceanic and Atmospheric Administration (NOAA)
- National Academy of Sciences (NAS)
- State of the Canadian Cryosphere (SOCC)
- Environmental Protection Agency (EPA)
- Royal Society of the United Kingdom (RS)
- American Geophysical Union (AGU)
- American Institute of Physics (AIP)
- National Center for Atmospheric Research (NCAR)
- American Meteorological Society (AMS)
- Canadian Meteorological and Oceanographic Society (CMOS)

If this is not scientific consensus, what in the world would a consensus look like?

(Addendum: One could legitimately argue that such policy statements by necessity hide possibly legitimate internal debate while trying to present unity of position. Science is ultimately determined in peer reviewed journals. Fortunately, there is a bit of research that looked specifically at this very question -- the subject of another guide entry.)

Objection: All those institutional position statements are fine, but by their very nature they paper over debate and obscure the variety of individual positions. The real debate is in the scientific journals.

Answer: This is a fair point. Group position statements are designed to present a united front. The best indicator of what individual scientists think is in the current scientific literature, where *new and different* is the paramount value and scientists are free to express their own ideas, as long as they're supported by data and logic. What does the literature look like in terms of the climate debate? Sounds like a good topic for research.

Naomi Oreskes took on just this topic. She did an ISI database search with the keyword phrase "global climate change," and then surveyed those resulting abstracts published between 1993 and 2003 in refereed scientific journals. There were 928.

She then divided the papers into six categories:

1. explicit endorsement of the consensus position,
2. evaluation of impacts,
3. mitigation proposals,
4. methods,
5. paleoclimate analysis, and
6. rejection of the consensus position.

The details can be read here. Oreskes' key finding is that *none* of the papers fell into the last category, while 75% fell into the first three. This is a surprisingly robust consensus of opinion, especially considering that the start date was a full two years before the 1995 IPCC report, eight years before the more recent 2001 report.

A lot has happened since then, and none of it casts any doubt on the finding that the world is warming and it is primarily due to human actions.

Objection: More and more, climate models share all the same assumptions -- so of course they all agree! And every year, fewer scientists dare speak out against the findings of the IPCC, thanks to the pressure to conform.

Answer: The growing confluence of model results and the increasingly similar physical representations of the climate system from model to model may well look like sharing code or tweaking 'til things look alike. But it is also perfectly consistent with better and better understanding of the underlying problem, an understanding that is shared via scientific journals and research. This understanding is coming fast as we gather more and

more historical and current data, all of which provides more testing material for model refinement.

Viewing the increasing agreement among climate models and climate scientists as collusion instead of consensus is a rather conspiratorial take on the normal course of scientific investigation. I suppose that fewer and fewer scientists disagreeing with the status quo is indeed consistent with some kind of widespread and insidious suppression of ideas, but you know, it is also consistent with having the right answer.

Objection: Sure, Oreskes found no one bucking the consensus, but her paper was refuted by Benny Peiser, who did the exact same survey and found very different results.

Answer: True, Benny Peiser did attempt a similar study and submitted it as a letter to *Science* responding to the Oreskes study. But for very good reasons, it was not published.

Peiser claimed to find 34 articles in his "reject or doubt the consensus view" category. That's 3 percent of the total, so even taken at face value it doesn't cast much doubt on the consensus. But it is greater than the 0 percent Oreskes found, and serves as ammunition for the "there is no consensus" crowd.

Tim Lambert has already done an excellent dissection of Peiser's letter here, and because Peiser was forthcoming enough to disclose the 34 abstracts in question, I encourage everyone to draw their own conclusions (they can all be seen on Tim's blog). I will quote a few and let that speak for itself.

Benny Peiser thinks the following abstracts reject or doubt the scientific consensus on anthropogenic global warming:

- (14) - The variations of global mean sea level are an important indicator of global climate change, and their measurement can provide important information for determining the socioeconomic impact of sea level change on coastal land use ... [snip] ... Future research will focus on establishing a realistic error budget for these measurements of global mean sea level, so that they can be put in the proper context with other observations of global climate change.
- (18) - The relationship of global climate change to plant growth and the role of forests as sites of carbon sequestration have encouraged the refinement of the estimates of root biomass and production. However, tremendous controversy exists in the literature as to which is the best method to determine fine root biomass and production. This lack of consensus makes it difficult for researchers to determine which methods are most appropriate for their system ... [snip] ... Until the different root methods can be compared to some independently derived root biomass value obtained from total carbon budgets for systems, one root method cannot be stated to be the best and the method of choice will be determined from researcher's personal preference, experiences, equipment, and/or finances.

- (22) - The paper discusses annual to decadal climate variability and change in the European Alps by utilizing the procedure of synoptic downscaling, i.e. it investigates the influence of global to continental scale synoptic structures and processes on the regional climate of the Alps ... [snip] ... There is a question over whether this phenomenon is a consequence of natural climate variability or the beginning of an anthropogenic climate change.
- (24) - Global climate change does not necessarily imply that temperature or precipitation is increasing at specific locations. [snip]
- (25) - This paper addresses the representation of scientific uncertainty about global warming and climate change in the U.S. popular press. An examination of popular press articles about global warming from 1986 to 1995 reveals that scientific uncertainty was a salient theme. [snip]
- (30) - Vegetation productivity and desertification in sub-Saharan Africa may be influenced by global climate variability attributable to the North Atlantic Oscillation (NAO) and El Nino Southern Oscillation (ENSO) ... [snip] ... The combined indices explained much of the interannual variability in vegetation productivity in the Sahelian zone and southern Africa, implying that both the NAO and ENSO may be useful for monitoring effects of global climate change in sub-Saharan Africa.

Those are just the ones that have no excuse whatsoever being categorized as doubting or rejecting AGW. Many others are highly questionable.

But there are a couple in his list that do indeed reject the notion of human-caused climate change. Why did Oreskes ignore those? Well, it turns out that they are editorials or letters, not peer-reviewed papers, and should not have been included except that Peiser altered the search criteria. Peiser included "all documents" in the ISI Web of Science database rather than just scientific articles, as Oreskes did, but Oreskes searched only "Sciences," while Peiser included "Social Sciences" and "Arts & Humanities."

If anything, Peiser's effort strengthens Oreskes' finding of a widespread consensus -- this questionable interpretation of an inappropriate dataset was the strongest argument he was able to make.

[Update] Since this was first written, there have been a couple of developments. First, I crossed Benny Peiser's path on the Prometheus blog. In the course of a lengthy thread under this post, I asked him directly about abstract (18) above, to which he replied, "I accept that it was a mistake to include the abstract you mentioned (and some other rather ambiguous ones) in my critique of the Oreskes essay."

Second, it appears he has since gone even further when pressed by an Australian television program, Media Watch. The transcript is here, and Tim Lambert summarizes it here. The gist is that he has backed down to the position that just one of his 34 abstracts fit his description as rejecting the consensus view on climate change -- and it was an editorial, not research of any kind.

The reason I still present this article in full, despite the backpedaling, is that as far as I can tell the retraction has been quiet and not proactive. Citations of Peiser's "work" continue to show up all over the place.

2. We Don't Know Why It's Happening

a. Models don't work

Objection: Why should we trust a bunch of contrived computer models that have never had a prediction confirmed? Talk to me in 100 years.

Answer: Given the absence of a few duplicate planets and some large time machines, we can't test a 100-year temperature projection. Does that mean the models can't be validated without waiting 100 years? No.

The climate is an extremely complex system. Our observations of it are by no means complete -- even with regard to what's going on today.

This is a shortcoming we need to work hard to correct, but it is also an opportunity for validating model predictions: Find a measurement we've never taken, see how the models say it should turn out, and then go take it and compare.

Still, there are global temperature predictions that have been validated. We can start with one of the pioneers in climate science. Over 100 years ago, in 1896, Svante Arrhenius predicted that human emissions of CO2 would warm the climate. Obviously he used a much simpler model than current Ocean Atmosphere Coupled Global Climate models, which run on super computers.

Arrhenius overestimated the climate's sensitivity to CO2 by a factor of 2. At the same time, he hugely underestimated the degree of warming, assuming CO2 would rise very slowly (who could have predicted the emissions the future held?). Still, it was a pretty impressive early success for models.

Running the clock forward: in 1988, James Hansen of NASA GISS fame predicted [PDF] that temperature would climb over the next 12 years, with a possible brief episode of cooling in the event of a large volcanic eruption. He made this prediction in a landmark paper and before a Senate hearing, which marked the official "coming out" to the general public of anthropogenic global warming. Twelve years later, he was proven remarkably correct, requiring adjustment only for the timing difference between the simulated future volcanic eruption and the actual eruption of Mount Pinatubo.

And let's face it, every year of increasing global mean temperature is one more year of success for the climate models. The acceleration of the rise is also playing out as predicted, though to be fair, decades will need to pass before such confirmation is inarguable.

Putting global surface temperatures aside, there are some other significant model predictions made and confirmed:

- models predict that surface warming should be accompanied by cooling of the stratosphere, and this has indeed been observed;
- models have long predicted warming of the lower, mid, and upper troposphere, even while satellite readings seemed to disagree -- but it turns out the satellite analysis was full of errors and on correction, this warming has been observed;
- models predict warming of ocean surface waters, as is now observed;
- models predict an energy imbalance between incoming sunlight and outgoing infrared radiation, which has been detected;
- models predict sharp and short-lived cooling of a few tenths of a degree in the event of large volcanic eruptions, and Mount Pinatubo confirmed this;
- models predict an amplification of warming trends in the Arctic region, and this is indeed happening;
- and finally, to get back to where we started, models predict continuing and accelerating warming of the surface, and so far they are correct.

It is only long-term predictions that need the passage of time to prove or disprove them, but we don't have that time at our disposal. Action is required in the very near term. We must take the many successes of climate models as strong validation that their long-term predictions, which forecast dire consequences, are accurate.

If we seek even more confidence, there is another way to test a model's predictive power over long time periods: hindcasting. By starting the model at some point in the past -- say, the turn of the 20th century -- and running it forward, feeding it confirmed observational data on GHG, aerosol, solar, volcanic, and albedo forcing, we can directly compare modeled behavior with the actual, observed course of events.

Of course, this has been done many times. Have a look at this page and judge for yourself how the models held up.

Would a prediction made in 1900 of temperature for year 2000 have been validated? Would politicians in 1900 have been wise to heed the warnings of science, had science had today's climate models then?

Clearly, yes.

Objection: Clouds are a large negative feedback that will stop any drastic warming. The climate models don't even take cloud effects into account.

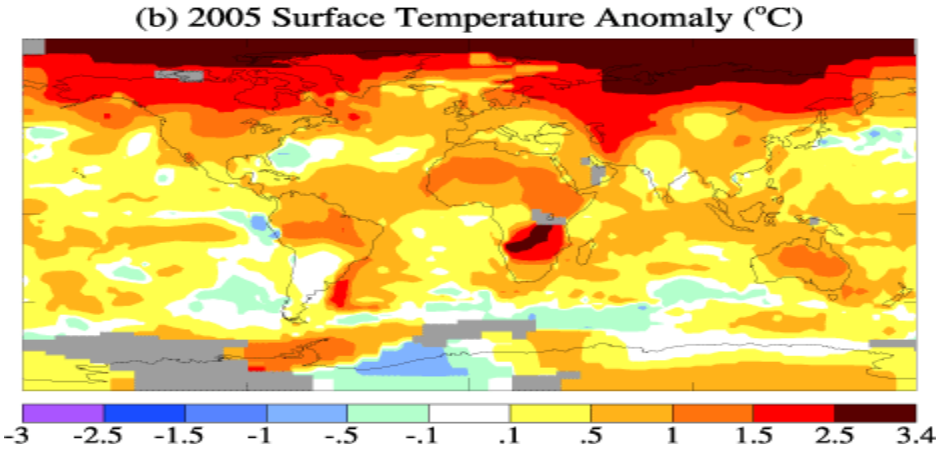
Answer: All of the atmospheric global climate models used for the kind of climate projections synthesized by the IPCC take the effects of clouds into account. You can read a discussion about cloud processes and feedbacks in the IPCC TAR.

It is true, however, that clouds are one of the largest sources of uncertainty in the GCMs. They are complicated to model because they have both positive feedbacks, preventing surface heat from escaping back into space, and negative feedbacks, reflecting incoming sunlight before it can reach the surface. The precise balance of these opposing effects depends on time of day, time of year, altitude, size of the water droplets and/or ice particles, latitude, current air temperature, and size and shape.

On top of that, different types of clouds will interact, amplifying or mitigating one another's effects as they coexist in different layers of the atmosphere. There are also latent heat considerations -- water vapor condenses during cloud formation and precipitation events, and water droplets evaporate when clouds dissipate.

The ultimate contribution of clouds to global temperature trends is highly uncertain, but according to the best estimates is likely to be positive over the coming century. There is no indication anywhere that any kind of cloud processes will stop greenhouse-gas-driven warming, and this includes observations of the past as well as modeling experiments.

Objection: Scientists claim that global warming from greenhouse gases is being countered somewhat by global dimming from aerosol pollution. They even claim that aerosol pollution caused the cooling in the mid-century. But GHGs are evenly mixed around the globe, while aerosols are disproportionately concentrated in the Northern Hemisphere. It follows that warming should be greater in the Southern Hemisphere -- but that's the opposite of what is happening. Clearly climate scientists do not know what is really going on.



Answer: Aerosol cooling does indeed affect the Northern Hemisphere, where most aerosols are produced, more than the southern hemisphere. It is also true that GHGs are well-mixed in the atmosphere -- apart from a lag of a few years, southern hemispheric concentrations are rising just the fast as northern.

Where the argument goes wrong is in its assumption that uniform CO2 concentrations imply uniform heating.

It is completely in line with model expectations that CO2-dominated warming disproportionately affects the north. The reasons lie in those complications plaguing the climate system that everyone is so fond of highlighting when it suits the argument and ignoring when it doesn't. This particular complication is well enough understood to explain what we observe.

GHG forcing has a greater effect over land. The ocean can absorb far more heat without warming nearly as much. It can distribute heat quickly in the upper layers via convection, moving the heat into lower waters rather than warming the upper waters. On land, most extra heat is transferred directly to the air, thus showing up immediately as greater atmospheric warming.

It so happens there's a disproportionate amount of land in the Northern Hemisphere. The land area of North America, Europe, Asia, the Middle East, most of Africa and the top of South America are all in the north, while the south has Antarctica, Australia, and the rest of South America and Africa.

Another factor is differing ocean dynamics in the north and south. More heat mixes into deeper waters of the Southern Ocean. And sea-ice feedbacks are much greater in the arctic than in the Antarctic.

The arctic also exhibits a polar amplification, which has been observed and modeled. Real Climate has a good article on this.

In short, it's simply incorrect to say we should see now, or expect to see later, more warming in the Southern Hemisphere. There are mysteries left to solve, but greater warming in the Northern Hemisphere is not one of them.

b. Prediction is impossible

Objection: Scientists can't even predict the weather next week, so why should we believe what some climate model tells us about 100 years from now?

Answer: Climate and weather are very different things, and the level of predictability is comparably different.

Climate is defined as weather averaged over a period of time -- generally around 30 years. This averaging smoothes out the random and unpredictable behavior of weather. Think of it as the difference between trying to predict the height of the fifth wave from now versus predicting the height of tomorrow's high tide. The former is a challenge -- to which your salty, wet sneakers will bear witness -- but the latter is routine and reliable.

This is not to say it's *easy* to predict climate changes. But seizing on meteorologists' failures to cast doubt on a climate model's 100-year projection is an argument of ignorance.

Objection: Climate is an inherently chaotic system, and as such its behavior can not be predicted.

Answer: Firstly, let's make sure we define climate: an average of weather patterns over some meaningful time period. We may thus discount the chaotic annual fluctuations of global mean temperature. That's weather, and one or two anomalous years does not represent a climate shift.

Quite a few people believe that climate is a chaotic system, and maybe on some large-scale level it is. But it is not chaotic on anything approaching the time scales of which humans need to be mindful.

The notion that climate is chaotic tends to be taken as a given, with little supporting argument. Certainly the march of the seasons is nice and regular, determined directly by the orbital inclination of the earth. If a large volcanic eruption occurs, global temperature drops for a few years quite predictably. Diurnal cycles show the direct influence of insolation changes on the system.

Clearly, if you turn down the sun, the temperature drops. Clearly, if you throw a bunch of SO2 into the stratosphere, the temperature drops. Clearly, if you turn the surface completely white, the temperature drops. And clearly, if you double the amount of an important GHG in the atmosphere, the temperature rises.

What about longer timeframes, say, glacial/interglacial cycles? These are by no means perfectly regular, but they are far from random. They are also a broadly deterministic effect following from a known cause: orbital variations.

Granted, the data is quite chaotic on the multi-century time scale, though it clearly follows a 120Kyr cycle. But who's to say that if we had enough data and understanding, these spikes and dips could not be thoroughly explained by solar influences, volcanic eruptions, greenhouse gas changes, ice sheet dynamics, etc.?

The ocean-atmosphere climate system is certainly a *complex* system, and capable of some surprising behaviors, but there is no evidence that it is chaotic in the formal sense.

I see no problem with speaking in a meaningful way about future expectations. Model outputs do produce specific year-to-year fluctuations -- fluctuations that are not hindcasted well (that's the weather, after all) -- but nobody's interested in knowing the exact temperature of any particular year. It is the decadal and century trends we want to anticipate.

It is the climate's broadly deterministic responses to forcings that are of interest, and all evidence points to such determinism.

(The original article has a great deal of interesting discussion under it, for those with the stomach for talk of strange attractors, dynamical systems, and stochastic processes.)

c. We can't be sure

Objection: There is no indication of how much confidence we should have in the models. How are we supposed to know if it is a serious prediction or just a wild guess?

Answer:
There is indeed a lot of uncertainty in what the future will be, but this is not all because of an imperfect understanding of how the climate works. A large part of it is simply not knowing how the human race will react to this danger and/or how the world economy will develop. Since these factors control what emissions of CO2 will accumulate in the atmosphere, which in turn influences the temperature, there is really no way for a climate model to predict what the future will be.

What modelers can do, however, is talk about and estimate the climate's sensitivity to CO2, usually in terms of how high the temperature will rise given a doubling of CO2. See the Real Climate glossary entry for climate sensitivity.

So how much certainty is there? This varies from model to model but typically a projection is given as a most likely temperature together with a range that encompasses all the likely values. In the IPCC report "likely" is defined as a 70% probability. If you want a specific number and range, you must chose a specific scenario of emissions over time and a specific model. The IPCC does note that:

The globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100. These results are for the full range of 35 SRES scenarios, based on a number of climate models.

But what about the certainty of this summary of model predictions? Well, a recent paper by James Annan et al. has attempted to clarify this question by statistically combining the certainties of a wide variety of models in a variety of situations. Focusing on climate sensitivity, they conclude that in terms of the climate's response to a doubling of CO2, the model's say:

"The resulting distribution can be represented by (1.7,2.9,4.9) in the format used throughout this paper. That is to say, it has a maximum likelihood value of 2.9oC, and, using the IPCC terminology for confidence levels, we find a likely range of 2.2-3.9oC (70% confidence) and a very likely range of 1.7-4.9oC (95%). We can also state that climate sensitivity is very likely to lie below 4.5oC(95%). These results represent a substantial decrease in uncertainty over those originally presented in NAS [1979] and in subsequent research. They also imply that the sensitivity range of modern GCMs (2.1-4.4oC) is likely to include the correct value (with greater than 80% confidence)"

So, most likely value is 2.9oC with a 95% probability of falling between 1.7oC and 4.9oC.

Objection: In 1988 Hansen predicted dire warming over the next decade and he was off by 300%. Why in the world should we listen to the same doom and gloom from him today?

Answer:
While it may well be simply ignorant repetition of misinformation in some instances, at its source, this story is a plain and simple lie.

In 1988, James Hansen testified before the US Senate on the danger of Anthropogenic Global Warming. As part of that testimony he presented a graph that was a part of a paper published soon after. This graph had three lines on it, representing three scenarios based on three projections of future emissions and volcanism. Line A was a temperature trend prediction based on rapid emissions growth and no large volcanic event and was a steep climb through year 2000 and beyond. Line B was based on modest emissions growth and one large volcanic eruption in the mid 1990's. Line C represented reductions in the growth of CO2 emission, the result of hypothetical government controls, and the same volcanic eruption as scenario B.

As it happens, Mt Pinatubo did erupt in the 1990's, though early, not mid-decade, and emissions have grown at a modest rate in the years since Hansen made this testimony. In other words, the forcings scenario of Line B in this graph was remarkably similar to what actually came to pass. It also just so happens that the observed temperature trend has matched very closely with the prediction represented by Line B. James Hansen was right on the money and the models he used proved successful.

Unfortunately, when Patrick Michaels made his testimony before the congress in 1998, ten years later, he saw fit to erase the two lower lines, B and C, and show the Senators only Line A. He did so that his testimony that Hansen's predictions had been off by 300% would be believable. He lied by omission. This lie was picked up by Michael Crichton in his novel "State of Fear" (as one of many omissions, confusions and falsehood presented in that book, see this Real Climate article).

To my knowledge Patrick Michaels has never owned up to this, either with an apology and retraction or with an explanation, and consequently this urban myth continues to this day.

Objection: Climate science can't even fully explain why the climate did what it did in the past. How can they then claim they know what is going on today?

Answer:
There are two requirements to understanding what happened at a particular climate change in geological history. One is an internally consistent theory and the other is sufficient data. It is very hard, in some cases impossible, to gather sufficient data about every aspect of the climate system for periods of time or events in the distant past, especially at a temporal resolution adequate for a full explanation. The record in the ice cores is extraordinarily rich in variety and detail of the data it preserves but it only goes

back as far as the age of the ice sheets, actually even less as there is melting from the bottom as well as the accumulation from the top. Past that, about a million years in the Antarctic, the records must come from ocean sediment, rock layers, fossils and other imaginative sources. These are harder to decipher and coarser in temporal resolution. The spatial extent is often far from global.

In contrast, today we are closely monitoring everything we can think of and have a much greater chance of quality reconstructions of those factors we did not think of until now. We know how the sun is behaving. We know when and how hard the volcanoes are erupting. We know the levels of ozone, CO2, CH4, NO2 etc to an extremely high degree of precision and on a month to month basis across the globe.

Consequently, our understanding of what is going on today is truly leaps and bounds ahead of any other point in the past and there is no surprise at all that we can speak with much greater confidence about today than we can about yesterday. The real test that the past can provide is some data that can not be explained by the current theories and this happens frequently in the finer details of climate theory, but the basics only become more and more certain.

So far, although we are far from perfect understanding due to inadequate data, there is no climate change in the past that contradicts the theories of atmospheric and oceanic science that underpin the theory of Anthropogenic Global Warming.

Objection: The alarmists were predicting the onset of an Ice Age in the 70's, now it's warming! Why should we believe them?

Answer:
It is true that there were some predictions of an "eminent ice age" in the 1970's but what does this tell us about today's warnings?

A very cursory comparison of then and now reveals a huge difference. Today, you have a widespread scientific consensus supported by national academies and all the major scientific institutions solidly behind the warning that the temperature is rising, anthropogenic CO2 is the cause and the warming will worsen unless we reduce emissions. In the 1970's, there was a book in the popular press, a few articles in popular magazines, and a small amount of scientific speculation based on the recently discovered glacial cycles and the recent slight cooling trend from air pollution blocking the sunlight. No daily headlines. No avalanche of scientific articles. No United Nations treaties and commissions. No G8 summits on the dangers.

There quite simply is no comparison, I'm sure you could find better evidence of a "consensus" of a coming alien invasion.

Real Climate has discussed this, and William Connelly has made it a hobby to gather everything that

3. Climate Change Is Natural

a. It happened before

Objection: It was even warmer than today during the Holocene Climatic Optimum without any human influence.

Answer:
Actually, it turns out that though there may have indeed been some temperatures in the same range as today, this was regional to the northern hemisphere and confined to the summer months! What's more, the cause is understood (orbital forcing similar to what controlled the Ice Ages), just as today's cause is understood (CO2 emissions), and these causes are different.

"In summary, the mid-Holocene, roughly 6,000 years ago, was generally warmer than today, but only in summer and only in the northern hemisphere. More over, we clearly know the cause of this natural warming, and know without doubt that this proven "astronomical" climate forcing mechanism cannot be responsible for the warming over the last 100 years."
http://www.ncdc.noaa.gov/paleo/globalwarming/holocene.html

Objection: It was just as warm in the Medieval Warm Period as today, in fact Greenland was green and they were growing grapes in England.

Answer:
There is actually no good evidence that the MWP was indeed a globally warm period comparable to today. Regionally, there may have been places that did exhibit notable warmth but all of the various global proxy reconstructions agree that it is warmer now and the temperature is rising faster than at any time in the last one or even two thousand years. Anecdotal evidence like that above can never tell you a global story.

NOAA presents a whole selection of proxy studies together with the data they are based on and these can be found here: http://www.ncdc.noaa.gov/paleo/paleo.html

Specifically, they have this to say about the MWP:

"The idea of a global or hemispheric "Medieval Warm Period" that was warmer than today however, has turned out to be incorrect."

http://www.ncdc.noaa.gov/paleo/globalwarming/medieval.html

In specific answer to the "grapes used to grow in England" bit, I like to point people here:

http://www.english-wine.com/index.html

Objection: Greenland used to be a lovely hospitable island when the Vikings settled it. It was not until the Little Ice Age that it got so cold and it was clearly not the frozen wasteland it is today.

Answer:
Firstly, Greenland is just a part of a single region and as such can not be assumed to represent any kind of global climate shift. See the article on the Medieval Warm Period for a global perspective on this time period. In short, the available proxy evidence indicates that globally this period was not particularly pronounced though certainly some regions may have experienced greater warming than others.

Secondly, a quick reality check shows that Greenland's ice cap is hundreds of thousands of years old and covers 95% of that island, so just how different could it have been only 1000 years ago?

Greenland was called Greenland by Erik the Red who was in exile and wanted to attract people to a new colony. He believed that you should give a land a good name so that people want to go there! It very likely was a bit warmer when he landed for the first time than it was when the last settlers starved due to a number of factors, climate change a likely major one. But it was never lush and their existence was always harsh and meager, especially due to the Viking's disdain for other peoples and other ways of living. They attempted to live a European lifestyle in an arctic climate side by side with the Inuit who easily out survived them. For heaven's sake, these people starved surrounded by oceans and yet never ate fish! (Note: this is not a European thing and is in fact a bit of a mystery to this day).

Instead of hunting whales in kayaks, they farmed cattle, goats and sheep despite having to keep them in a barn 24-7 for 5 months out of the year! It was a constant challenge to get enough fodder for the winter and starvation of the animals was frequent, emaciation routine. The pressures of grazing pasture and growing fodder for the winter led to over production of pastures, erosion and the need to go further and further afield to sustain the animals. Deforestation for pastures and firewood was unsustainable leading, after a couple of centuries, to having to cut and burn precious sod for fuel and housing construction.

When finally confronted with a few severe winters, they, along with the little remaining livestock, simply starved. Much as you can not judge a book by its cover, you can't determine the climate of Greenland from its name.

(My account comes from reading the Chapter on Vikings in Greenland in Jared Diamond's "Collapse".)

Further indications of their stubborn reluctance to learn from the natives is that there is no evidence of any kind of trade whatsoever. In fact, the first of only three accounts of encounters the Norse had with the natives refers to them as "skraelings" (wretches) and

describes matter of factly how strangely and differently they bleed when stabbed with fatal and non-fatal wounds. How's that for diplomacy!?

Objection: Global Warming has been going on for 20,000 years.

Answer:
It is quite true that 20Kyr ago the temperature was some 8 to 10 oC colder than it is today, but it is highly arbitrary and dubious to simply draw a line from that point to today and say "Look! 20K years of Global Warming!". If you have look at this nice graph of temperature starting at a point when we were finishing the climb out of deep glaciation, you can clearly see that rapid warming ceased around 10,000 years ago (rapid relative to natural fluctuations, but not compared to warming today). After a final little lift at 8000 years bp the temperature trended generally downward for the entire period of the Holocene. So the post industrial revolution warming is really the reversal of a many thousand year trend.

A closer view of today's trend with the context of the last 1000 and 2000 years attached makes it even clearer that today's trend is striking and opposite to what one might expect without an anthropogenic disturbance.

If you really wanted to play this game you could talk about how we are reversing a five million year cooling trend, or go crazy and track global temperatures right back to the origins of the planet! But I don't recommend it...

Objection: The Hockey Stick graph, the foundation of global warming theory, has been refuted and shown to be scientifically invalid.

Answer:
The infamous "Hockey Stick" graph was featured prominently in the IPCC TAR Summary for Policymakers. It was important in that it overturned the concept of a global Medieval Warm Period warmer than the 20th century and a pronounced Little Ice Age, both long time (cautiously) accepted features of the last 1000 years of climate history.
http://www.grida.no/climate/ipcc_tar/wg1/005.htm

This caused an uproar in the skeptic community, not least because of its visual efficacy. Two Canadians, an economist and a petroleum geologist, took it upon themselves to verify this proxy reconstruction by getting the data and examining the methodology used for themselves. They found that there were errors in the description of data used as published in Nature. Mann et al., the Hockey Stick's creators, published a correction in Nature, noting where the description of the study did not match what was actually done. The Canadians, McIntyre and McKitrick, then proceeded to publish a paper that purported to uncover serious methodological flaws and problems with data sets used. Everything from this point on is hotly disputed and highly technical.

All the claims made by M&M have been rebutted in detail by many other climatologists and they insist that these folks are completely in error. This of course fits nicely with the expectations of both sides of the Global Warming issue, the conspiracy theorists as well

as the champions of peer review. All the rebuttals have been objected to and the objections denied and the denials rejected. The issues are highly technical and require considerable time and energy to truly investigate. Steve McIntyre has a website devoted to his continued probe of this study and Michael Mann is a contributor to Real Climate which devotes considerable web space to refuting the attacks. In short, M&M raise many specific and technical objections and the climate scientists seem pretty unified in denying the charges. To my knowledge, the worst indictment from the climate science community came from a study led by Hans Von Storch that concluded M&M was right about a particular criticism of methodology but correcting it did not change the study results.
http://www.climateaudit.org/
http://www.realclimate.org/

If you want to try to evaluate this issue fairly you must read the copious material at the sites mentioned above. You must also be prepared to get into dendrochonolgy and statistical analysis.

Where does that leave the rest of us?

I will confess immediately that the technical issues are over my head, I don't know PCA from R^2 from a hole in the ground. But I think the most critical point to remember, if you are researching this in the context of determining the validity of AGW theory, is that this row is about a single study that was published 8 years ago. This is starting to be ancient history. If you feel it is tainted (as I prefer to just assume, because as I said I do not want to put the required effort into unraveling it all for myself) then simply discard it.

The fact is there are dozens of other reconstructions. These other reconstructions do tend to show some more variability than MBH98, i.e. the handle of the hockey stick is not as straight, but they *all* support the general conclusions that the IPCC TAR came to in 2001: the late 20th century warming is analogous in the last one or two thousand years and the 1990's are very likely warmer than any other time in the last one or two thousand years.

Here is a nice superimposition of numerous global, hemispheric and regional reconstructions for the last 2000 years and the last 12000 years together with an average. References are all presented at the bottom of the pages. Regional variations are of course greater than global so don't be surprised by how wavy some of the lines in there are. Does the 20th century stand out?
http://en.wikipedia.org/wiki/Image:2000_Year_Temperature_Comparison.png
http://en.wikipedia.org/wiki/Image:Holocene_Temperature_Variations.png

I have read as much about this controversy as I ever will, and I have come to the firm conviction that I do not have the technical background and/or time required to make a scientific judgment on this issue one way or another. That is the best objective opinion I can offer you. I suspect 95% of the people you will come across arguing about this have chosen their position ideologically.

And while MBH, in my mind, are in no way guilty of fraud or incompetence until solidly

proven to be so (many of the accusations do go this far), the judgment of their research must be approached in reverse: given a reason to doubt, I will not accept it until it is proven to me that the criticisms are invalid. Neither case can I decided for myself until I devote the required time to both the statistical background and the technical details of M&M vs. MBH98.

So where does that leave us? It leaves me with the dozens of other proxy reconstructions, some by the same team or involving members, some by completely different people, some using tree rings, some using corals, some using stalactites, some using borehole measurements, all of which support the general conclusions. And it is that general conclusion which is important to me, not whether or not one Bristlecone pine was or was not included correctly in a single 8 year old study.

The general conclusion is:
"Although each of the temperature reconstructions are different (due to differing calibration methods and data used), they all show some similar patterns of temperature change over the last several centuries. Most striking is the fact that each record reveals that the 20th century is the warmest of the entire record, and that warming was most dramatic after 1920."
http://www.ncdc.noaa.gov/paleo/globalwarming/paleolast.html

I also urge anyone worried about this study and what its conclusion means for the theory of Anthropogenic Global Warming to remember this: the study of the past can be very *informative*, but it is not *explanatory* of the present or *predictive* of the future.

The scientific basis for the dangers we face and their cause is about much more than a few tree-rings and the temperature during the Medieval Warm Period.

Objection: Newfoundland was so warm in the Medieval Warm Period that when the Vikings landed they called it Vineland and brought boatloads of grapes back to Europe.

Answer:
One can not infer a global climate from an anecdote about a single region, or even a few regions, you need detailed analysis of proxy climate indicators from around the world. These proxy reconstructions have shown that the Medieval Warm Period (around the time the Vikings were said to have discovered North America) was in fact not as warm or pronounced as today's temperatures. From NOAA's website:

What records that do exist show that there was no multi-century periods when global or hemispheric temperatures were the same or warmer than in the 20th century....

...In summary, it appears that the 20th century, and in particular the late 20th century, is likely the warmest the Earth has seen in at least 1200 years.

http://www.ncdc.noaa.gov/paleo/globalwarming/medieval.html

As for the notion that Vineland was a warm land where grapes grew wild, like Greenland, Vineland's name was most likely a kind of marketing ploy. Doing a bit of googling I came across this article by Robert McGhee for Canadian Geographic, from 1988 archived here:

http://www.collectionscanada.ca/2/16/h16-4223-e.html

It had this interesting thing to say:

There has been much argument over the location of Vinland, with scholars and local enthusiasts placing it anywhere between Labrador and Florida, and even in the Great Lakes or the Mississippi Valley. The geographical descriptions in the Norse sagas are too vague to allow certain placement on a modern map, but there is growing consensus that they best fit Newfoundland and Labrador (formerly Newfoundland). The main problem with a Newfoundland and Labrador (formerly Newfoundland) site is the absence of wild grapes. Still, there is a strong suspicion that what Leif found were only berries, and that he followed the practice of his father in "giving a land a good name so that men would want to go there".

I got to that article from this page with a lot of good resources on the Viking expansion:

http://www.isidore-of-seville.com/vinland/6.html.

b. It's part of a natural change

Objection: The current warming is just a natural cycle.

Answer:
While it is undoubtedly true that there are some cycles and natural variations in global climate, anyone who wishes to insist that the current warming is purely or even just mostly natural has two challenges. Firstly, they need to identify just what this alleged natural mechanism is because absent a forcing of some sort, there will be no change in global energy balance. So natural or otherwise we should be able to find this mysterious cause. Secondly, a "natural cause" proponent needs to come up with some explanation for how a 30% increase in the second most important Greenhouse Gas does not itself affect the global temperature.

In other words, there is a well developed, internally consistent theory that predicts the effects we are observing, so where is the skeptic model, or theory whereby CO2 does not affect the temperature and where is the evidence of some other natural forcing?

There is a fine historical example of a very dramatic and very regular climate cycle that can be read in the ice core records taken both in Greenland and in the Antarctic. A naive reading of this cycle indicates we should be experiencing a *cooling* trend now, and indeed we were very gradually cooling over the length of the pre-industrial Holocene, something around .5C averaged over 8000 years. It is informative to compare those fluctuations to

today's changes. Leaving aside the descents into glaciation, which were much more gradual, the very sudden (geologically speaking) jumps up in temperature every ~100Kyrs actually represent a rate of change roughly *ten times slower* than the rate we are currently witnessing.

So could the current change be natural? Well, there is no identified natural cause (and they *have* been looked for), there is no theory of climate where CO2 does not drive the temperature and the natural cycle precedents do not show the same extreme reaction we are now witnessing. The answer is no.

Objection: Global warming is happening on Mars and Pluto as well. Since there are no SUV's on Mars, CO2 can't be causing Global Warming.

Answer:
Warming on another planet would be an interesting coincidence but it does not necessarily have to have the same cause. The only relevant factor the Earth and Mars share is the sun, so if the warming were real and related it would have to be due to the sun. The sun is being watched and measured very carefully back here on earth and it is *not* the primary cause of the current climate change.

As for this alleged finding, there is *very* little evidence to go on when it comes to discerning a global climate change on Mars. The only evidence out there that I am aware of is a series of photographs of a single icy region in the southern hemisphere that shows melting over a two year (~1 Martian year) period. Here on earth we have direct measurements from all over the globe, widespread glacial retreat, reduction of sea ice and satellite measurements of the lower troposphere up to the stratosphere. To compare this mountain of data to a few photographs of a single region strains credulity. In fact, scientists studying Mars believe this is a regional change caused by Mars' own orbital cycles.

See Global Warming on Mars? from Real Climate for more details.

As for Pluto, a cursory glance at Pluto's orbit and atmosphere reveals how ridiculous it is to draw any conclusions about climate, much less climate change, from two occultation observations 14 years apart way out there in the ice cold and lonely Kuiper Belt!

Back to Mars, here is a nice and succinct way to compare the available evidence:

On Earth, we have poles melting, surface temperature rising, tropospheric temperatures rising, permafrost melting, glaciers world wide melting, CO2 concentrations increasing, borehole analysis showing warming, sea ice receding, proxy reconstructions showing warming, sea level rising, sea surface temperatures rising, energy imbalance, ice sheets melting and stratosphere cooling which leads us to believe we have GHG driven global warming.

One Mars we have one spot melting which leads us to believe...one spot is melting.

Objection: One good volcanic eruption puts out more CO2 than a decade of human emissions. It is ridiculous to think reducing human CO2 will have any effect.

Answer:
Not only is this untrue, but it is obviously untrue when you examine the CO2 record from any of the dozens of sampling stations around the globe. If this were true, then that CO2 record would be full of spikes, one for each eruption. The fact is, it is a very smooth trend.

The sum total of all volcanoes emit CO2 at a rate about 1/150th that of anthropogenic emissions.

- The USGS Volcano Hazards program
- Volcano World from the University of N. Dakota

Objection: Natural variability is the "null" hypothesis and an anthropogenic CO2 warming effect needs compelling evidence shown over and above that null scenario before there is any reason to take it seriously.

Answer:
The null hypothesis is a statistical test and might be a reasonable approach if we were looking only for statistical correlation between increasing CO2 and increasing temperature. But we're not, there are known mechanisms involved whose effects can be predicted and measured. These effects are the results of simple laws of physics even if their interactions are quite complex.

But putting the inappropriate application of the Null Hypothesis aside, we are indeed well outside the realms of natural **global** variability as seen over the last two thousand years and even over the last 12,000 years. We can go back several hundreds of thousands of years and we still see that the temperature swings of the glacial/interglacial cycles were an order of magnitude slower than the warming rate we are now experiencing. In fact, outside of catastrophic geological events like the Paleocene Eocene Thermal Maximum there are no known precedents for warming this fast on a global scale. I'd say the case for "it's all natural" is the one that needs explaining.

And there is compelling evidence.

Objection: Climate has always changed, why are we worried now and why does it have to be humans fault?

Answer:
Yes, climate has varied in the past and it has varied for many different reasons, some better understood than others. The present day climate change is very well understood and is different. Simply noting that something happened before without humans does not in any logical way show that humans are not causing it today.

For example, we see in ice core records from Antarctica and Greenland that the world cycled in and out of glacial periods over 120Kyr cycles. The cause for that climate cycle's timing is fairly well understood to be the results of changes in the orbit of the Earth, though the mechanism behind the resulting response has not been conclusively established. These orbital cycles are regular and predictable and they are definitely not the cause of today's warming. The other important difference between the glacial-interglacial cycles and today is the rapidity of the current change. The rate of warming is on the order of 10 times faster today than seen in the ice cores.

Such rapid warming on a global scale is very rare in the geological record, and while it may not be unprecedented, there is very strong evidence that whenever such a change has happened, whatever the cause, it was a catastrophic event for the biosphere.

Objection: According to the IPCC, 150 billion tons of carbon go into the atmosphere from natural processes every year. This is almost *30 times* the amount of carbon humans emit. What differences will any reductions we try to do make?

Answer:
This is quite true that the natural fluxes in the carbon cycle are much larger than anthropogenic emissions. But in the natural process, for roughly the last 10K years until the industrial revolution, every giga tons of carbon going into the atmosphere was balanced by one coming out. What we have done is to alter only one side of this cycle. We put some ~6 giga tons of carbon into the air but, unlike nature, we are not taking any out.

Thankfully, nature is actually compensating in part for our emissions, because only about half of the CO2 we are emitting is staying in the air. Nevertheless, since we began burning fossil fuels in earnest over 150 years ago, the atmospheric concentration that was relatively stable for the previous several thousand years has now risen by over 35%. So whatever the total amounts going in and out on their own, humans have clearly upset the pre-existing balance and altered significantly an important part of the climate system.

Objection: It's clear from the ice cores and other geological history that CO2 fluctuates naturally. It is a bogus assumption that the rise now has to be from humans.

Answer:
It should not be hard to understand that since we emit billions of tons of CO2 into the air and, lo and behold, there is more CO2 in the air, therefore the CO2 rise is our fault. But if this simple common sense is not enough there is more to the case than that and that case has been well made. (Note, the investigation of just this issue by the climate science community is a pretty good indication that they are not just making assumptions, not even the reasonable ones!)

It is true that CO2 has gone up on its own in the past, most notably during the glacial interglacial cycles. During this time CO2 rose and fell by over 100 ppm, ranging between

~180 and ~300ppm. But these rises, though they look steep over a 400Kyr timeframe, took 5 to 20Kyrs depending on which glacial cycle you are looking at. By contrast, we have seen an equivalent rise of 100ppm in just 150 years! Check this plot for a very dramatic juxtaposition of the slow glacial termination versus the industrial revolution.

But there is still more to the case than the initial common sense argument and the circumstantial evidence above. By analyzing the isotopes of the carbon and oxygen atoms, in a process similar to carbon dating, scientists can, and have, detected a human "fingerprint" of the carbon dioxide that is now accumulating in the atmosphere. What we have found, via the isotope signatures in the CO2 molecules can be thought of as "old" carbon, which could only come from fossil fuel deposits, combined with "young" oxygen, as is found in the air all around us. So, present day combustion of fossilized carbon deposits (i.e. coal and oil) are most definitely the source of the CO2 that we see accumulating, just as common sense tells us.

For more of the nitty gritty technicalities straight from the climate scientists, including links to the actual research that has established this, please visit RealClimate's article on how we know the CO2 is ours.

Of all the pillars holding up the theory of Anthropogenic Global Warming, this really is one of the most unassailable.

Objection: The current warming is just a recovery from the Little Ice Age.

Answer:
I point to a post by Andrew Dressler that covers this issue nicely. In a nutshell this argument assumes some kind of natural level that the climate system automatically gravitates back to. Like almost all of the skeptic arguments, this one is inconsistent with many others, especially those trying to say nothing new here, the climate is always changing or the climate is chaotic.

Objection: If you look back over the last 600 million years you see that there really is not much correlation between temperatures and CO2 levels. Clearly CO2 is not a climate driver.

Answer:
With regards to geological history, I don't believe there are any demonstrable contradictions to greenhouse theory to be found. What we do have is an unfortunate lack of comprehensive and well resolved data. There is always the chance that new data will turn up shortcomings in the models and new aspects to climate theory, and I guarantee you scientists in the field are working hard to uncover such things. Every scientist relishes the thought of uncovering new data that overturns current understanding. But I don't think that it makes any sense at all to reject CO2 as a primary driver of climate change *today* because it looks, through the foggy glasses of time, like CO2 has not always completely controlled climate changes in the past.

The climate system is complicated, even the configuration of the continents has a big effect, so you should not expect complete correlation between temperatures and any single factor throughout such a long and varied history.

Objection: In the geological record, CO2 never causes temperature changes, temperature causes CO2 changes. Why should it be any different now?

Answer:
Given the fact that humans and our industrialization is rather unique in the history of planet Earth, do we really need to see some kind of historical climate change precedent before believing in the impact we are already observing? Regardless, history does provide some valuable insights and some rather dire warnings.

During the glacial/interglacial cycles, CO2 concentrations and temperatures show a remarkable correlation. Closer examination, however, reveals that CO2 does not lead the temperature changes, but actually lags by many centuries. All of the mechanisms proposed by which CO2 increases in the atmosphere are reactions to a warming climate.

There are however, events in geological history where this is not the case. The Paleocene Eocene Thermal Maximum is such a case. Roughly 55 million years ago, ocean pH levels drop drastically and global temperatures rapidly rose 5C. The resolution of proxy records that are available indicate that this happened in a period of time no longer than 5K years, but it is not possible to know if it happened even faster. The likely cause of this event was massive releases of methane from the ocean floors, perhaps due to some smaller warming or changes in sea level. It took over 100K years for the ocean, atmosphere and temperatures to return to their previous state. The result was a mass extinction event that took millions of years to recover from.

We can also look at the formation of the Deccan Traps. This massive and sustained volcanic action also altered the atmospheric chemistry and caused a drastic climate change, one that lead to the extinction of the dinosaurs. The theories of Snowball Earth involve the buildup of GHGs as the mechanism by which the earth eventually escaped this state.

So it is simply not true that history does not provide some precedent for Greenhouse Gas driven warming and in fact the precedents that are there are dire warnings.

Objection: The sun is the source of all the warmth on earth. Any increase in temperature is most likely due to changes in solar radiation.

Answer:
It's very true that the earth is warmed, for all practical purposes, entirely by solar radiation. So if the temperature is going up or down a reasonable place to find the reason why would be the sun. It turns out that it is more complicated than one might think to detect and measure changes in the amount or type of sunshine reaching the earth. After all, one good cloud passing overhead can cause an instant shiver on an otherwise

beautiful, warm day, but not because the sun itself changed. The best way to detect changes in the actual output of the sun versus changes in the radiation reaching the earth's surface because of clouds, smoke, dust or pollution is by taking readings from space.

According to PMOD at the World Radiation Center there has been no increase in solar irradiance since at least 1978 when satellite observations began. This means that for the last thirty years, while the temperature has been rising fastest, the sun has shown no trend.

There has been work on reconstructing past trends in solar irradiance over the last century before satellite records were available. According to the Max Plank Institute there has been no increase in solar irradiance since around 1940. This reconstruction does show an increase in the first part of the 20th century that coincides with the warming from around 1900 until the 1940's. This trend in irradiance is responsible for large portion of that trend, together with around the same portion from CO2 forcing. See this chart of the observed trend, the modeled trend and the variations in the major forcings that contributed to 20th century climate.

4. Climate Change Is Not Bad

a. The effects are good

Objection: The Earth has had much warmer climates in the past, what is so special about the current climate?

Answer:
It is difficult to find a meaningful way to define an "optimum" average temperature. Surely it is better on Earth now, not having as much land trapped beneath ice sheets as there was 20K years ago. But between the climate 100 or 200 years ago and the worst one we may be heading for with tropical forests inside the arctic circle, one global mean temperature seems just as good as any other. But the critical issue with what is going on today is not where the temperature is or is not at, but how fast it is moving.

Rapid change is the real danger. Human habits and infrastructure are suited to particular weather patterns and sea levels, as are ecosystems and animal behaviors. The rate at which the global temperature is rising today is very likely unique in the history of our species. It is also very rare in geological history though perhaps not unprecedented. But, once you look at the impact similar changes had on biodiversity at the time, the existence of some historical precedent or another becomes anything but reassuring.

What we know about ecosystems and what geologic history demonstrates is that such dramatic changes - up or down or sideways - are a tremendous shock to the biosphere and cause mass extinction events. And that, all in all, is not likely to be a good thing.

b. The effects are minor

Objection: Even if the ice caps melt, the sea level won't rise that much because the melt water will be absorbed in the aquifers underneath.

Answer:
This is a ridiculous notion, both for making the assumption that no glaciologist or ice sheet expert or climatologist in general could not have thought of it themselves and for getting it so wrong that a minute adding up numbers could have saved some embarrassment.

97% of the world's water is ocean, let's ignore it. 68.7% of the remaining fresh water is locked up in glaciers and ice caps, the vast majority in ice caps. 30% is currently groundwater. (*See here*.)

The total area of land on earth is about 148.3 million sq km. The Antarctic is about 14 million, Greenland 2.2 million. So the portion of land under ice sheets is around 11% (easily googled)

So in short, for this theory (cough) to work we need one tenth of the land area on earth to absorb twice as much water as has been absorbed by all the other nine tenths together. It somehow does not seem to pass the sniff test.

Those calculation further assume that there is no ground water there already, which I don't know but I really doubt it. The bottom of the Antarctic ice is only a couple of degrees below freezing due to geothermal heat and the insulating effect of thousands of meters of ice. Why wouldn't there be liquid water in the ground (which is bedrock btw)? And if it is too cold, why wouldn't any aquifers already be full of frozen water?

No, this theory is no Copernican Revolution, we should accept the calculations and warnings of the experts. If the Greenland Ice sheet melts completely it will add ~7 meters, WAIS will add about 8 (it is already mostly below sea level) the EAIS would add around 65m (*see here*)

Not that they will all melt anytime soon.

5. Climate Change Can't Be Stopped (or Its Too Costly to Stop It)

a. Its too late

Objection: The Kyoto treaty, even if fully implemented, would only save us half a degree of future temperature rise many decades from now.

Answer:
There are three big problems with this claim.

Firstly, this is really a red herring. The purpose of Kyoto is to establish an international mechanism for dealing with global warming by taking the first tentative steps towards a difficult goal. You may as well time me waking to the side walk where I parked my car and then tell me at this rate I will never get home.

Secondly, Kyoto is a step by step process whose second, much less third, fourth etc. stages have not even been negotiated yet, so how can anyone claim anything about how effective it is going to be? Junk Science and other sources of this myth are starting their dubious calculations from the assumption that Kyoto ends in 2012 when round one is over, this is just Plain Wrong.

Thirdly, the temperature in 2050 is to a large extent already determined by the current energy imbalance due to the extra CO2 already in the atmosphere right now, so short of a complete cessation of emissions today, there is no way to avoid the bulk of the warming that is "in the pipeline. This is mostly the result of the extremely large thermal inertia of the oceans and means that action today (in either direction) will have consequences felt several decades hence.

In general I have a big credibility issue with people who simultaneously criticize Kyoto and propose nothing in its place. You'd think if they were sincerely so concerned about how ineffective Kyoto is (as they should be!) they would be agitating for more action, rather than shrugging their shoulders and saying "I guess we should just sit it out". It makes me think of some guy standing on the sidewalk watching all the neighbors fight a house fire, saying "you'll never do it, there aren't enough of you."

b. It's someone else's problem

Objection: According to the US Department of Energy, the United States actually absorbs more CO2 into the land than it emits into the air. The world should be grateful.

Answer:
According to the US Department of Energy the land use changes taking place in that country between 1952 and 1992 have resulted in a net absorption of *natural* CO2. That is in the natural fluxes of CO2 into and out of forests and peat bogs and soil (fluxes that are actually much larger than anthropogenic emissions) , there is more carbon being absorbed than being emitted. This also includes carbon that has been sequestered as lumber and other wood products.

However, this net sink has only been sufficient to offset around 25% of the industrial and domestic *fossil fuel* emissions such as from automobile exhaust and coal-fired power plants. In Chapter 7 of this 1996 report, the DoE notes:

For purposes of comparison, this estimated amount of sequestered carbon offset approximately 17 percent of the 1,381 million metric tons of carbon (or 5,068 million

metric tons of carbon dioxide) emitted in the United States in 1992 from the burning of fossil fuels.

So, at least for 1992, that leaves 83% of fossil fuel burning emissions that are left in the atmosphere to spread throughout to globe or to be absorbed into the oceans. In the 2003 report, this has increased to 88.1% not sequestered on American lands:

The U.S. Environmental Protection Agency (EPA) estimates annual U.S. carbon sequestration in 2003, based on data generated by the U.S. Department of agriculture (USDA), at 828.0 million metric tons carbon dioxide equivalent (MMTCO2e), a decline of approximately 21 percent from the 1,042.1 MMTCO2e sequestered in 1990 (Table 33). Land use, land-use change, and forestry practices offset approximately 16.9 percent of total U.S. anthropogenic carbon dioxide emissions in 1990 and 11.9 percent in 2003.

With a starting per capita emissions level five times greater than that of the global average, that leaves a lot that the world does not have to thank the US for.

c. The world economy will be destroyed

Objection: Any actions to mitigate Global Warming will result in the destruction of the global economy and the deaths of billions of people.

1. You cannot come to a rational decision about the reality of a danger by considering how hard it might be to avoid. First things first, understand that the problem is real and present. Once you acknowledge the necessity of taking action, those actions suddenly become less daunting.

2. Given that famine, droughts, disease, loss of major coastal cities and a tremendous mass extinction event are on the table as possible consequences of unmitigated Global Warming, it may well be we are faced with a choice between the lesser of two evils. But I challenge anyone to conclusively demonstrate that such catastrophes await us if we try to reduce fossil fuel usage. Would such projections be based on an economic computer model? This just seems a bit "alarmist" don't you think?

But in terms of conservation and a generalized switch over to alternative fuels, people opposed to doing this for climate change mitigation are forgetting something rather important. Fossil fuels are a *non-renewable resource***,** and as such we must, sooner or later, make this global economic transformation. Many bright minds inside the industry think we are already at Peak Oil. So even if it turned out that climate mitigation actions were unnecessary, we would nevertheless be in a better place as a global society by making the coming switch sooner rather than later.

3. The landmark *Stern Review on the Economics of Climate Change* produced by the British government found that it will be much less expensive to solve climate change *now*--about 1 percent of world GDP in 2050--than to wait 5-10 years. Waiting will reduce world GDP by 5-10 percent by mid-century, a decline equal or greater to the great

depression or either world war. This suggests that *not* acting to resolve the problem is what will harm the environment. In contrast, resolving the problem will generate numerous new business and job opportunities industry experts believe will be a $500 plus billion market for low carbon goods and services by 2050.

4. Finally, resolving climate change involves a shift in the world's energy regimes. Shifts in the types of energy that power societies have long been at the heart of many of history's defining moments. The upheaval and stress that accompany these transformations typically marshal in legions of naysayers and doomsayers. Yet, looking back, one can see that each major energy transition offered the gifts of increased prosperity and well-being.

The first major energy shift came about 230,000 years ago when humans discovered how to control fire. The ability to use fire to kill germs by cooking food and to provide warmth in cold and damp weather dramatically reduced illness and death. The change from wood and organic material, for most of human history the dominant source of energy, to coal over 200 years ago launched the industrial revolution. The transition from coal to oil, and then from the direct use of fuels to electricity in the early part of the twentieth century, triggered wealth creation over the past one hundred years or so on a scale never before seen in human history (at least in industrialized nations).

Despite the turmoil and difficulty involved, changing conditions provided an offering that, with a suitable response, not only avoided the social calamity predicted by the pessimists, but dramatically improved human health and well-being.

(Number 3 from *How to be Good When its Easier to Be Bad; Thinking Sustainably in a Non-sustainable World.* Doppelt B., in press).