The **Scientific Guide** to Global Warming Skepticism

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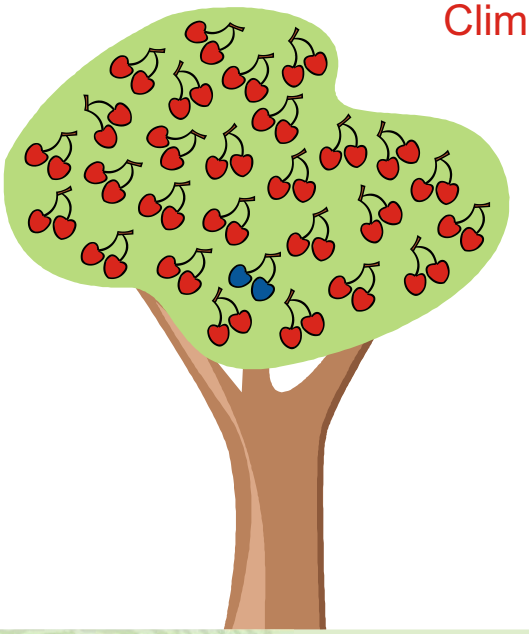
What does it mean to be skeptical?

Scientific skepticism is a good thing. In fact, science by its very nature is skeptical. Genuine skepticism means considering the full body of evidence before coming to a conclusion. However, when you take a close look at arguments expressing climate 'skepticism', what you often observe is cherry picking pieces of evidence while rejecting any data that don't fit the desired picture. This isn't skepticism. It's a denial of science.

This guide looks at both the evidence that human activity is causing global warming and the ways that climate 'skeptic' arguments mislead by presenting only small pieces of the puzzle rather than the full picture.



Climate cherry picking

Selective cherry picking could have you thinking this is a blue cherry tree.

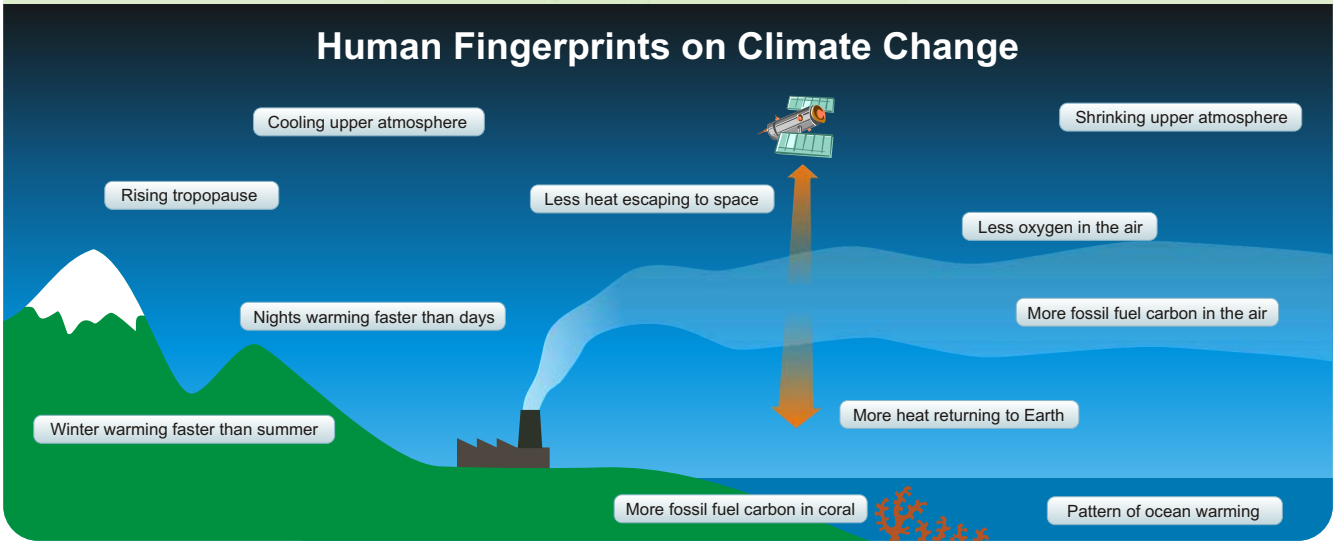
But what does the full body of evidence tell you?

Human fingerprints on climate change

What scientists look for is coherence - independent lines of evidence pointing to a single, consistent answer. The full body of evidence in climate science shows us a number of distinct human fingerprints on climate change.

Measurements of the type of carbon found in the atmosphere show that fossil fuel burning is dramatically raising levels of CO_2 in the atmosphere. Satellite and surface measurements find that extra CO_2 is trapping heat that would otherwise escape out to space. There are a number of warming patterns consistent with an increased greenhouse effect. All these 'human fingerprints' have been **directly observed**.

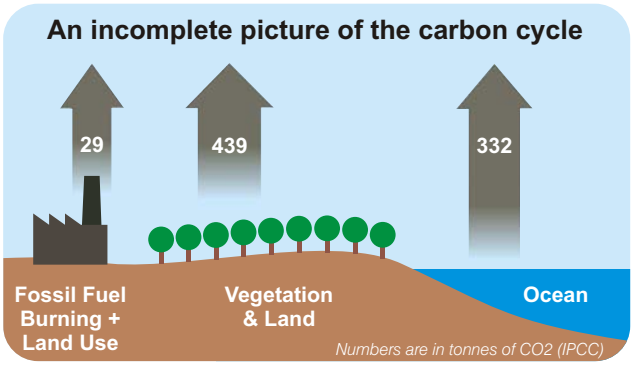
The evidence for human caused global warming is not based on mere theory or computer models but on many independent, direct measurements made in the real world.



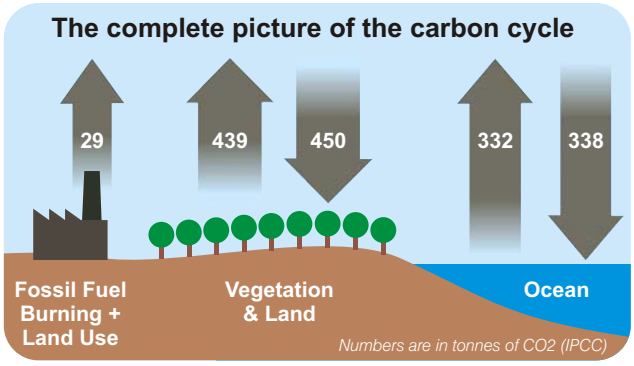
Humans are raising CO_2 levels

When you look through the many arguments from global warming 'skeptics', a pattern emerges. They tend to focus on small pieces of the puzzle while neglecting the bigger picture. A good example of this is the argument that human carbon dioxide (CO_2) emissions are tiny compared to natural emissions.

The argument goes like this. Each year, humans send 29 billion tonnes of CO_2 into the atmosphere. Natural emissions come from plants breathing out CO_2 and outgassing from the ocean.[1] Natural emissions add up to 770 billion tonnes per year.[2] Without a full understanding of the carbon cycle, our emissions seem tiny when compared to nature's contribution.



The missing part of the picture is that nature doesn't just emit CO_2 - it also ***absorbs***. Plants breathe in CO_2 and oceans capture huge amounts of CO_2 that dissolve into their waters. Nature absorbs just over 770 billion tonnes every year. Natural absorptions balance natural emissions. What we do is upset the balance. While some of our CO_2 is being absorbed by the ocean, 17 billion tonnes of extra CO_2 remain in the air each year.

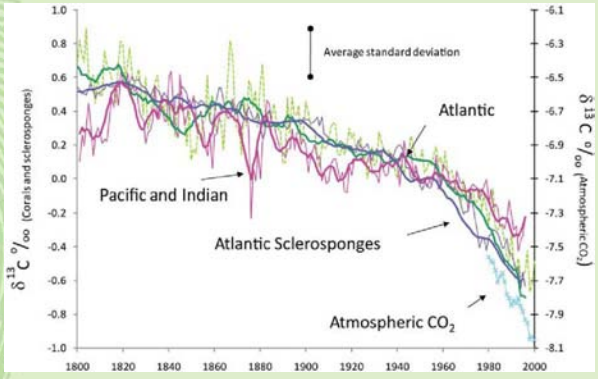


Because of our fossil fuel burning, atmospheric CO_2 is at its highest level in millions of years.[7b] And it's still going up! The "human CO_2 is tiny" argument misleads by only giving you half the picture.

Human Fingerprint #1 Fossil fuel signature in the air

How do we know we're causing the CO_2 build-up in the atmosphere? We can calculate all the CO_2 we've produced over 200 years and work out in principle how much ought to remain in the air.

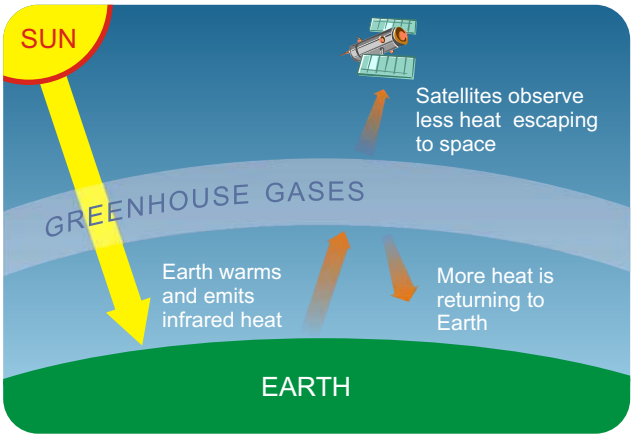
We confirm this by measuring the type of carbon in the air. The carbon atom has several different isotopes (different number of neutrons). Carbon-12 (12C) has 6 neutrons, carbon-13 (13C) has 7 neutrons. Plants prefer to take up the lighter 12C so plant tissues end up with about 2% less 13C than the air they grew in. When we burn fossil fuels such as coal or oil (which come from ancient plants), we should see the ratio of 13C to 12C fall. That is exactly what we do find, in the air as well as in corals and sea sponges which give us a record of atmospheric CO_2 going back centuries.[3]



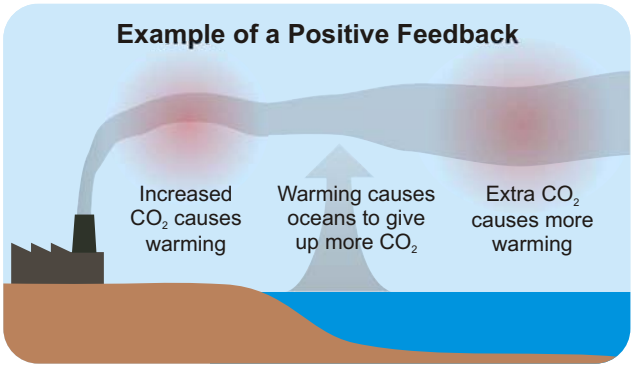
Measurements of δ13C (ratio of C13 to C12) from corals, sclerosponges (sea sponges) & atmosphere.[3]

The evidence that more CO_2 causes warming

Carbon dioxide traps infrared radiation (commonly known as heat radiation). This has been proven by many laboratory experiments[4] and observed by satellites which find less heat escaping out to space over the last few decades (see *Human Fingerprint #2*). This is direct evidence that rising CO_2 is causing warming.[5]



The past also tells an interesting story. Ice cores show that in the Earth's past, CO_2 went up ***after*** temperature initially increased. This "CO_2 lag" means temperature affects the amount of CO2 in the air. So warming causes more CO_2 and more CO_2 causes warming. Put these two together and you get positive feedback.



In the past when our climate warmed due to changes in the Earth's orbit, this caused the ocean to release more CO_2 into the atmosphere resulting in the following effects:

- The extra CO_2 in the atmosphere amplified the original warming. That's the positive feedback.
- The extra CO_2 mixed through the atmosphere, spreading greenhouse warming across the globe.[6,7]

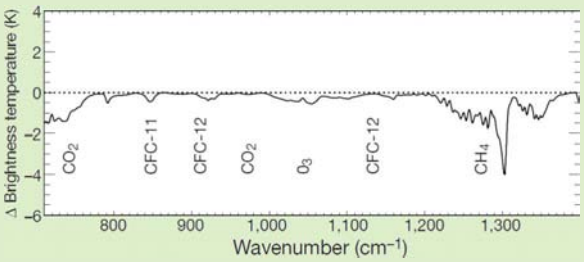
The ice core record is entirely consistent with the warming effect of CO_2. Greenhouse warming explains both the dramatic changes in temperature in the Earth's past and how temperature change is able to spread across the globe. The CO_2 lag doesn't disprove the warming effect of CO_2. On the contrary, it provides evidence of a climate positive feedback.

Human Fingerprint #2

Less heat is escaping out to space

Satellites measure infrared radiation as it escapes out to space. A comparison between satellite data from 1970 to 1996 found that less energy is escaping to space at the wavelengths that greenhouse gases absorb energy. Researchers described this result as *"direct experimental evidence for a significant increase in the Earth's greenhouse effect"*.[5]

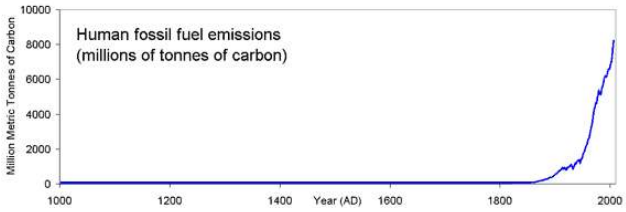
This has since been confirmed by subsequent measurements from several different satellites.[47,48]



Change in outgoing radiation spectrum from 1970 to 1996 due to increasing greenhouse gases. Negative values mean less outgoing heat.[5]

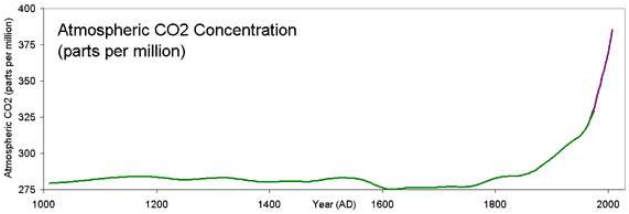
Hockey stick or hockey league?

The 'hockey stick' commonly refers to a reconstruction of temperature going back over the last millennium.[8] The steep warming in recent times is seen as the blade of the stick. But there are many hockey sticks found in our climate. The amount of CO_2 emitted by humans, mostly through the burning of fossil fuels, has a distinct hockey stick shape over the last 1000 years.



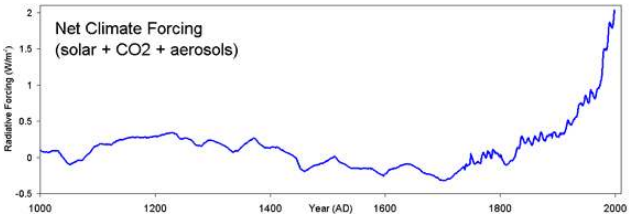
Total yearly CO_2 emissions (millions of tonnes of carbon).[1]

The dramatic increase in CO_2 emissions is matched by a steep rise in atmospheric CO_2 levels, which have now reached levels unseen for millions of years.[9]



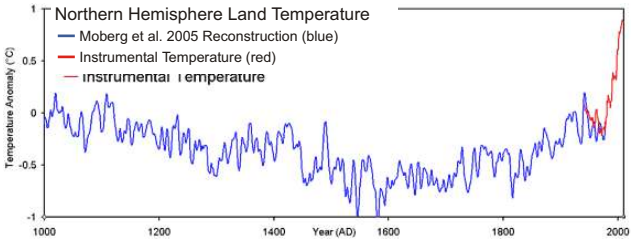
CO_2 levels (parts per million) from ice cores at Law Dome, East Antarctica (green)[10] *and direct measurements from Mauna Loa, Hawaii (purple).*[11]

Climate forcing is a change in the planet's energy balance - when our climate builds up or loses heat. Various factors cause these changes such as variations in solar activity, aerosols (particles suspended in the air), changes in the Earth's orbit and CO_2. Over the past 1000 years, the major drivers of long-term climate change have been the sun, aerosols and CO_2. The ***combined*** climate forcing from these effects shows a familiar shape.



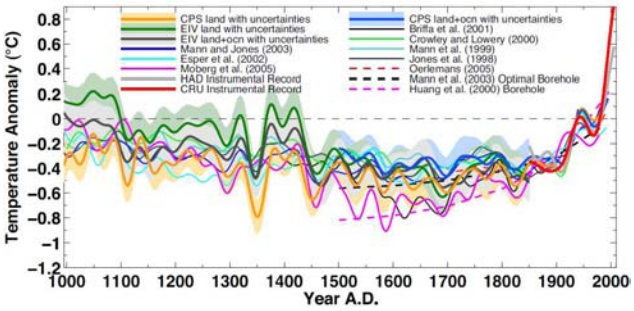
Combined climate forcing from solar variations, CO_2 and aerosols - volcanoes are omitted.[12]

This shows our climate has been building up heat in recent times. We see a corresponding warming:



Northern hemisphere temperature reconstruction (blue)[13] *plus instrumental measurements of northern hemisphere land temperature (red).*[14]

Over the last decade, a number of independent studies have reconstructed temperature over the last 1000 years, using a multitude of data and different data analysis techniques. They all tell a similar story.



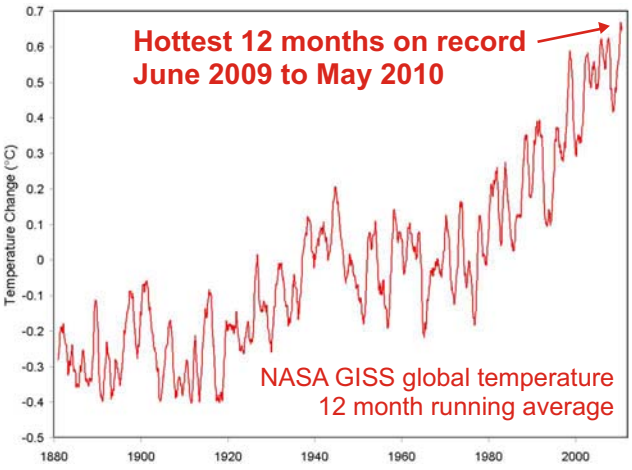
Various northern hemisphere temperature reconstructions.[15]

All these hockey sticks tell us a consistent story - humans have caused a profound disturbance to our climate system.

The evidence that global warming is happening

One 'skeptic' argument is so misleading, it requires three levels of cherry picking. This argument is "global warming stopped in 1998".

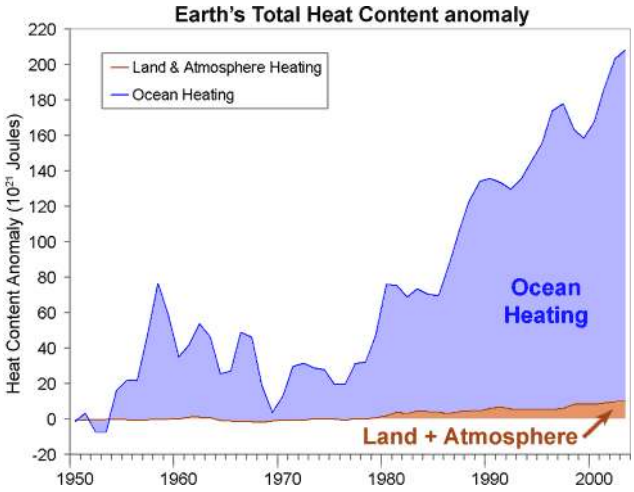
The first cherry pick is that it relies on a single temperature record from the Hadley Centre.[14] This record shows unusually warm temperatures in 1998, caused by the strongest El Niño on record. However, the Hadley Centre record doesn't cover the whole globe. It doesn't include the Arctic region where the fastest warming on the planet is occurring.[16] Records covering the entire planet find the hottest calendar year on record is 2005. The hottest 12 months were June 2009 to May 2010.[17]



12 month average of global temperature anomaly (GISS).[17]

The second cherry pick is asserting a long-term trend based on selected end-point years. Ocean cycles like El Niño exchange massive amounts of heat between the ocean and atmosphere, so surface temperature jumps up and down from year to year. To work out the long-term trend, scientists use techniques such as moving averages or linear regression that take into account ***all the data***. These show that surface temperatures continue to rise since 1998.[18]

The third cherry pick is looking only at surface temperature, which is a measurement of atmospheric temperature. Over 80% of global warming actually goes into the oceans. To find out if global warming continued past 1998, look at all the heat building up in our climate. When we add up the heat going into the oceans, warming the land and air and melting the ice, we see that the planet continues to build up heat.[19]

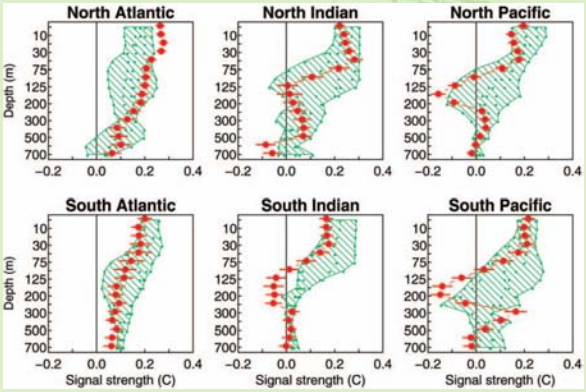


Cumulative heat for the Earth since 1950. The rate of energy building up since 1970 is equivalent to 2.5 Hiroshima bombs every second.[19]

Human Fingerprint #3

The ocean warming pattern

The world's oceans have steadily been building up heat over the past 40 years. The pattern of ocean warming, with heat penetrating from the surface, can only be explained by greenhouse warming.[20]



Observed ocean temperature (red) compared to model results with greenhouse gas (green).[20]

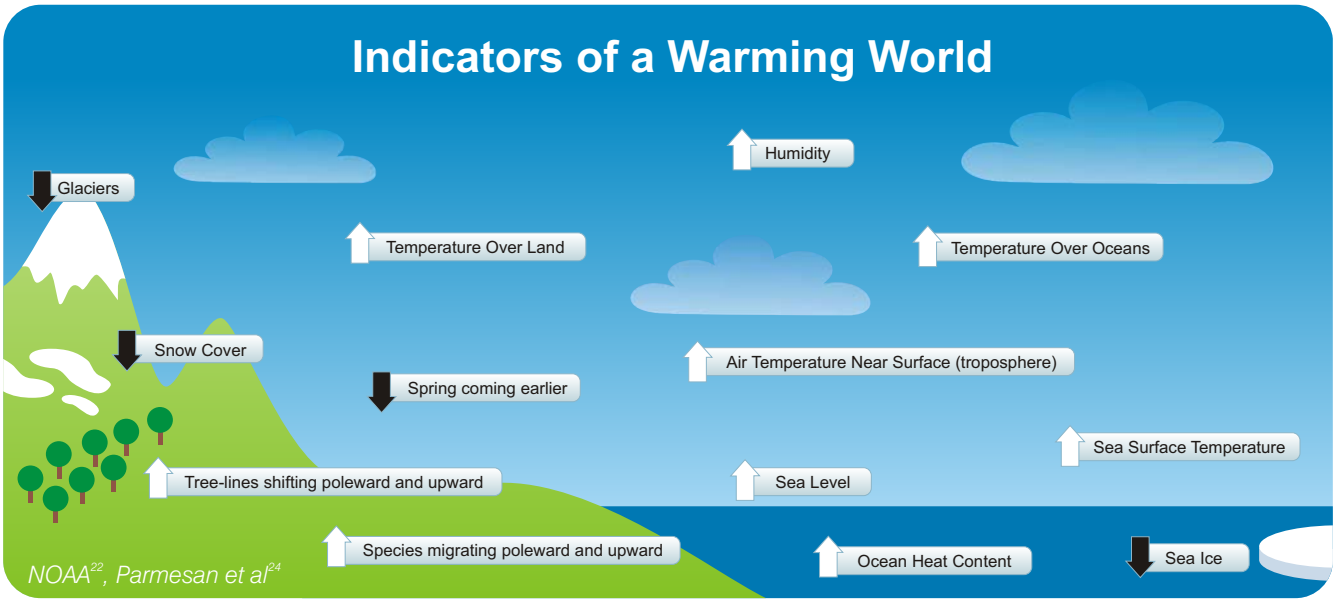
More evidence of the reality of global warming

'Skeptics' claim that much of the measured global warming is due to weather stations positioned near air conditioners and car parks. We know this isn't true for several reasons. We can compare temperatures from well-placed weather stations to the poorly-sited weather stations. Both well-placed and poorly-sited sites show the same amount of warming.[21]

Another way to check thermometer measurements is to compare them to satellite data. Satellite measurements show the same amount of global warming. This is confirmation that the thermometers are giving us an accurate picture.

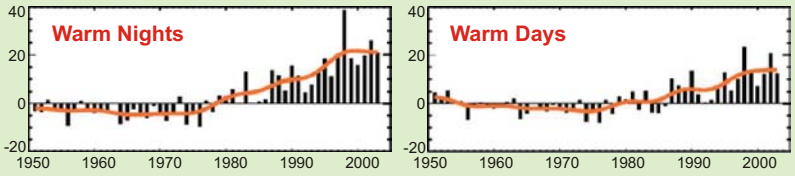
As well as the compelling temperature record, we have a large body of observations in many different areas that are consistent with a warming world. Ice sheets are melting, losing billions of tonnes of ice each year. Sea levels are rising at an accelerating rate.[23] Species are migrating toward the poles and glaciers are retreating (threatening water supplies for many millions of people).[24,40]

To gain a proper understanding of climate, we need to look at all the evidence. What we see are many lines of evidence all pointing to the same conclusion - global warming is happening.



Human Fingerprint #4 Nights warming faster than days

An increased greenhouse effect means nights should warm faster than days. This is because the greenhouse effect operates day and night. If global warming was caused by the sun, we would expect the warming trend to be greatest in daytime. Instead, what we see is the number of warm nights increasing faster than the number of warm days.[25]



Observed trends (days per decade) in the number of extreme warm days and nights per year. Warm is defined as the top 10%. Orange lines show the long-term trend.[25]

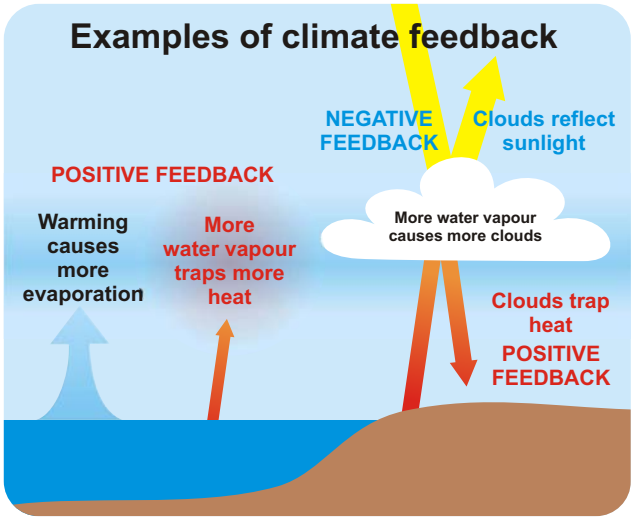
What does past climate change tell us?

A common 'skeptic' argument is that "climate has changed naturally in the past and therefore recent global warming can't be caused by humans". This argument is like saying "forest fires have happened naturally in the past so any recent forest fires can't be caused by humans".

Scientists are well aware that climate has changed in the past. In fact, the past gives us vital clues about how our planet responds to the various drivers of climate. We can see what happens when the Earth builds up heat, whether it be due to more sunlight or rising greenhouse gases. The crucial discovery from examining different periods throughout Earth's history is that positive feedbacks amplify any initial warming.[26]

This is why climate has changed so dramatically in the past. Positive feedbacks take any temperature changes and amplify them. Feedbacks are why our climate is so sensitive to greenhouse gases.

So there is a great irony when past climate change is invoked as if it disproves the human influence on global warming. The peer-reviewed science actually comes to the opposite conclusion. Past climate change provides evidence for positive feedback that amplifies the warming caused by our CO_2 emissions.

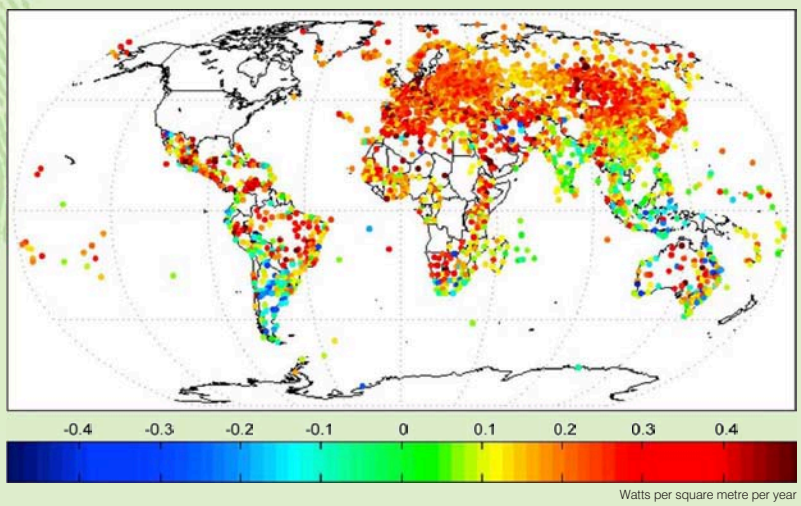


Human Fingerprint #5 More heat is returning to Earth

An increased greenhouse effect means we should see more infrared radiation returning down to Earth. This has been directly observed. When we take a close look at the spectrum of the downward radiation, we can work out how much each greenhouse gas is contributing to the warming effect. From these results, it was concluded:

"This experimental data should effectively end the argument by skeptics that no experimental evidence exists for the connection between greenhouse gas increases in the atmosphere and global warming." [28]

Trend in downward infrared radiation



Trend in downward infrared radiation over 1973 to 2008. North America is blank because data in those regions don't cover the entire 1973 to 2008 period.[27]

Shooting the messenger

In November 2009, the email servers at the University of East Anglia were hacked and emails were stolen. When a selection of emails between climate scientists were published on the Internet, a few suggestive quotes were taken out of context and interpreted as revealing global warming was all just a conspiracy. This has been labelled 'climategate' by some. To determine if there had been any wrong-doing, a number of independent groups from England and the United States have investigated the stolen emails. Every single investigation cleared the climate scientists of any wrong doing.[29,30,31,32]

> *"...no evidence of any deliberate scientific malpractice in any of the work of the Climatic Research Unit."*
>
> UNIVERSITY OF EAST ANGLIA IN CONSULTATION WITH THE ROYAL SOCIETY[30]

The most quoted email is Phil Jones 'hide the decline', which is commonly misinterpreted. The 'decline' actually refers to a decline in tree-ring growth since the 1960s. Tree-rings are used as a proxy for temperature and closely match thermometer measurements in the past. However, some tree-ring proxies diverge from thermometer measurements after 1960. This issue has been openly discussed in the peer-reviewed literature as early as 1995.[33] When you look at Phil Jones' email in the context of the science discussed, it is not conspiratorial scheming but a technical discussion of data-handling techniques readily-available in the peer-reviewed literature.

> *"The scientists' rigour and honesty are not in doubt."*
>
> INDEPENDENT CLIMATE CHANGE EMAIL REVIEW[31]

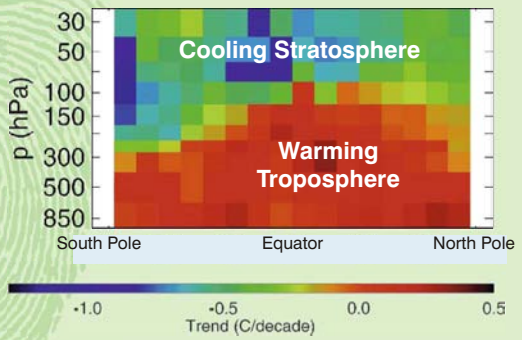
It's important to put the stolen emails in perspective. A handful of scientists discuss a few pieces of climate data. Even without this data, there is still an overwhelming and consistent body of evidence, painstakingly compiled by independent scientific teams across the globe. A few suggestive quotes taken out of context may serve as a distraction for those wishing to avoid the physical realities of climate change, but change nothing about our scientific understanding of humanity's role in global warming. Climategate attempts to point the finger at scientists but deflects attention from what matters: the science.

> *"There exists no credible evidence that Dr. Mann had or has ever engaged in, or participated in, directly or indirectly, any actions with an intent to suppress or to falsify data."* [32]
>
> PENN STATE UNIVERSITY

Human Fingerprint #6

Cooling upper atmosphere

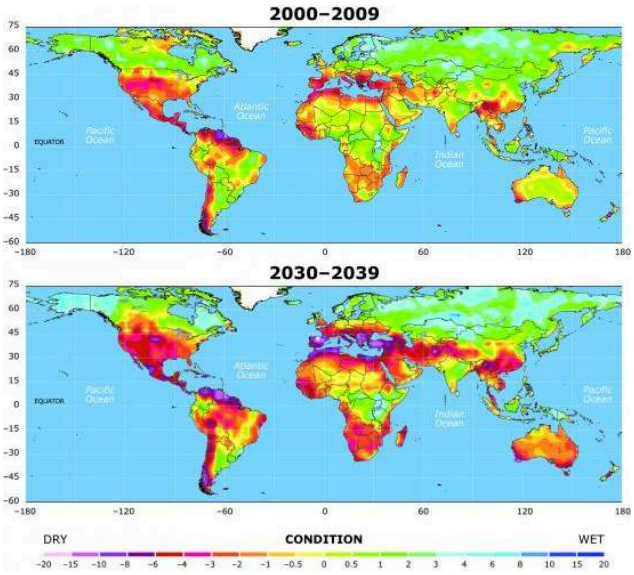
As greenhouse gases trap more heat in the lower atmosphere, less heat reaches the upper atmosphere (the stratosphere and higher layers). Thus we expect to see a warming lower atmosphere and cooling stratosphere. This is what we observe.[34]



Latitude–height temperature trend, 1959 to 2005.[35]

Impacts of global warming

To claim that global warming will be good for humanity is to turn a blind eye to the many negative impacts. The most common argument along these lines is that carbon dioxide is 'plant food', so CO_2 emissions are a good thing. This ignores the fact that plants rely on more than CO_2 to survive. The "CO_2 fertilizer" effect is limited and is quickly overwhelmed by the negative effects of heat and drought. Over the past century, drought severity has increased globally and predicted to intensify in the future.[2] Plants cannot take advantage of extra CO_2 if they're dying of thirst.



Past & future drought, using the Palmer Drought Severity Index. Blue represent wet conditions, red represents dry. A reading of -4 or below is considered extreme drought.[36]

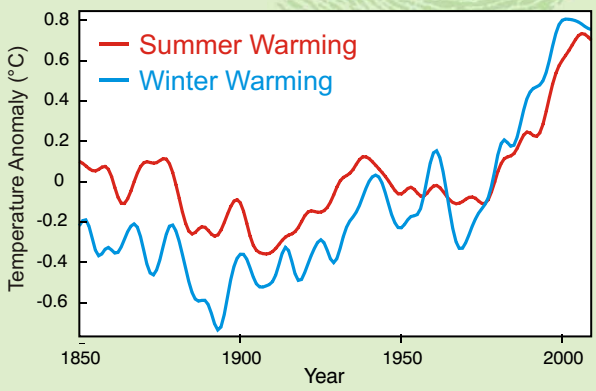
There are many climate change impacts that have no positive aspects. Between 18 and 35% of plant and animal species could be committed to extinction by 2050.[37] Oceans are absorbing much of the CO_2 in the air, which leads to ocean acidification.[38] This is predicted to have severe destabilising effects on the entire oceanic food-chain, on top of the negative effects of coral bleaching from warming waters (a one-two punch from global warming). An estimated 3.5 billion people depend on the ocean for their primary source of food.[39]

As glaciers dwindle, so does the water supply for millions of people who currently rely on the fresh water consistently supplied by glacial melt.[40] Similarly, sea level rise will affect millions over this century as rice paddies are inundated with salt water, seawater contaminates rivers, aquifers become polluted and populations are displaced. This will force many millions of people to move inland, increasing the risk of conflict.[41]

When someone says global warming is a good thing, citing isolated positive impacts, remember that the full body of evidence indicates the negatives far outweigh the positives.

Human Fingerprint #7
Winter warming faster

Greenhouse warming is expected to cause winters to warm faster than summers. This is because the greenhouse effect has a greater influence over winter. This is what is observed in the instrumental record.[42,49]



Smoothed temperature variations for winter and summer, averaged over land only, from 1850 to 2009 using data from HadCRUT3.[43] *Polar regions are excluded using a fixed data mask.*[49]

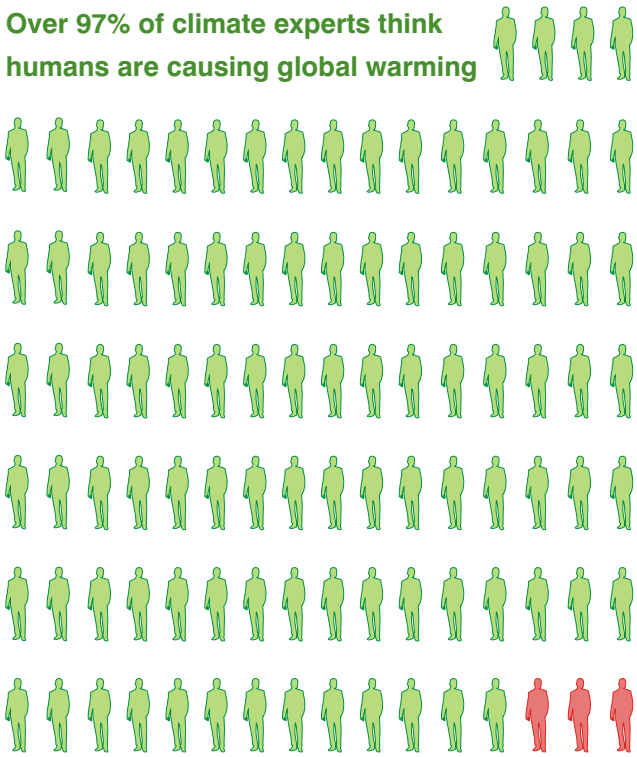
The scientific consensus on global warming

Occasionally, you might encounter petitions listing scientists who are skeptical of human-caused global warming. However, very few on these lists are actual climate scientists. There are medical scientists, zoologists, physicists and engineers but very few whose area of expertise is climate science.

So what do the experts think? Several studies have surveyed climate scientists who are actively publishing climate research. Each study found the same answer - over 97% of climate experts are convinced humans are changing global temperature.[44,45]

This is confirmed by peer-reviewed research. A survey of all peer-reviewed abstracts on the subject 'global climate change' published between 1993 and 2003 shows that not a single paper rejected the consensus position that human activities are causing global warming.[46]

Over 97% of climate experts think humans are causing global warming



The consensus of evidence

The case for human-caused global warming isn't based on a show of hands but on direct observations. There are multiple lines of evidence, all pointing to the same answer.

There's a consensus of evidence that humans are raising carbon dioxide levels in the atmosphere. This is confirmed by measuring the type of carbon in the air. What we find is more of that carbon is coming from fossil fuels.

There's a consensus of evidence that rising CO_2 is causing warming. Satellites measure less heat escaping to space. Surface observations find more heat returning to Earth. This is happening at the exact wavelengths where CO_2 traps heat - a distinct human fingerprint.

There's not just a consensus of scientists - there's a consensus of evidence.

There's a consensus of evidence that global warming is happening. Thermometers and satellites measure the same warming trend. Other signs of warming are found all over the globe - shrinking ice sheets, retreating glaciers, rising sea levels and shifting seasons.

The pattern of warming shows the tell-tale signatures of an increased greenhouse effect. Nights are warming faster than days. Winters are warming faster than summers. The lower atmosphere is warming while the upper atmosphere is cooling.

On the question of whether humans are causing climate change, there's not just a consensus of scientists - there's a consensus of evidence.

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