The **Scientific Guide** to Global Warming Skepticism

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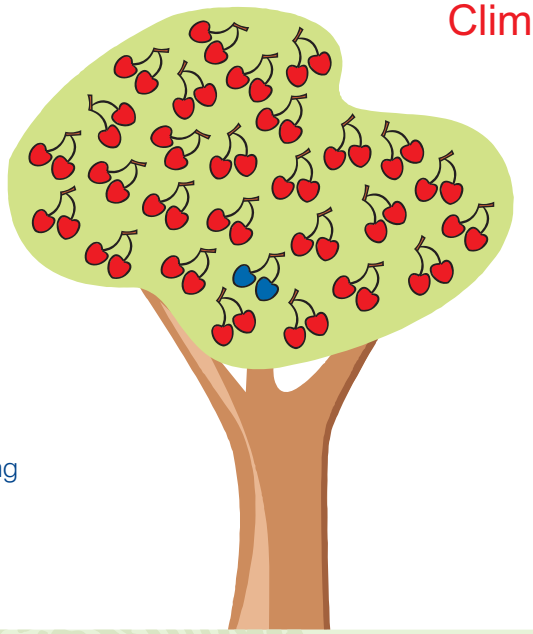
What does it mean to be skeptical?

Scientific skepticism is healthy. 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 of pieces of evidence while rejecting any data that don't fit the desired picture. This isn't skepticism. It is ignoring facts and the science.

This guide looks at both the evidence that human activity is causing global warming and the ways that climate 'skeptic' arguments can 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.

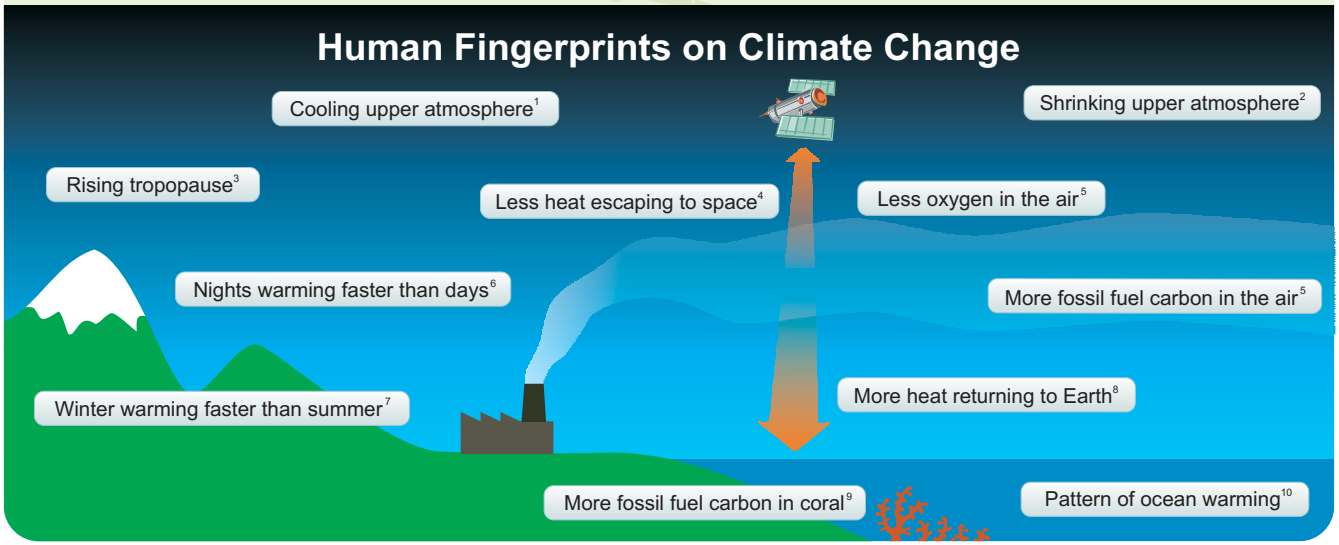
But what does the full body of evidence tell you?

Human fingerprints on climate change

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

Measurements of the type of carbon found in the atmosphere show that fossil fuel burning is dramatically increasing levels of carbon dioxide (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. The whole structure of our atmosphere is changing.

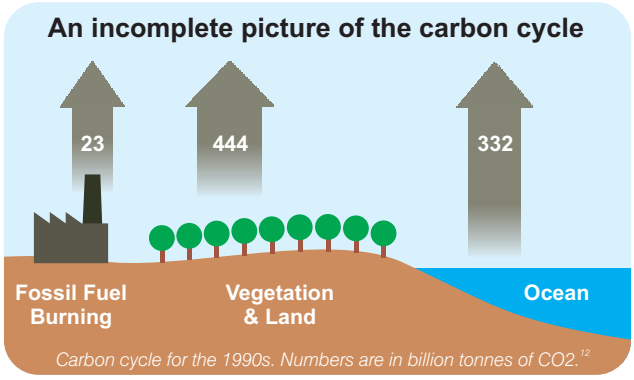
The evidence for human caused global warming is not just based on theory or computer models but on **many independent, direct observations made in the real world**.



Humans are raising CO_2 levels

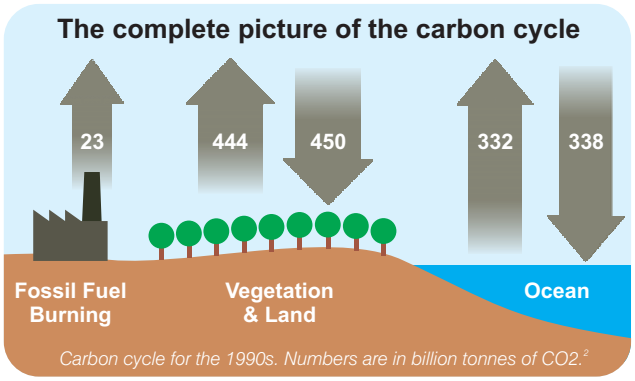
When you look through the many arguments from global warming 'skeptics', a pattern emerges. They tend to focus on small pieces of the puzzle while neglecting the bigger picture. A good example of this is the argument that human carbon dioxide (CO_2) emissions are tiny compared to natural emissions.

The argument goes like this. Each year, we send over 20 billion tonnes of CO_2 into the atmosphere. Natural emissions come from plants breathing out CO_2 and outgassing from the ocean.[11] Natural emissions add up to 776 billion tonnes per year.[12] 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*** CO_2. Plants breathe in CO_2 and huge amounts of CO_2 dissolve into the ocean. Nature absorbs 788 billion tonnes every year. Natural absorptions roughly balance natural emissions. What we do is upset the balance. While some of our CO_2 is being absorbed by the ocean and land plants, around half of our CO_2 emissions remain in the air.

The weight of CO_2 emitted by humans ***each day*** is comparable to 8,000 Gulf of Mexico oil spills.[13]



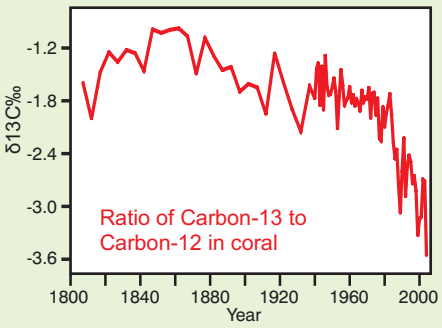
Because of fossil fuel burning, atmospheric CO_2 is at its highest level in at least 2 million years.[14] And it's still going up! The "human CO_2 is tiny" argument misleads by only giving you half the picture.

Human Fingerprint #1 Fossil fuel signature in the air & coral

There are different types of carbon in the air known as carbon isotopes. The most common type is Carbon-12. A heavier type of carbon is Carbon-13. Plants prefer the lighter Carbon-12.

Fossil fuels like coal or oil come from ancient plants. So when we burn fossil fuels, we're sending more of the lighter Carbon-12 into the air. So we expect to see the ratio of Carbon-13 to Carbon-12 fall.

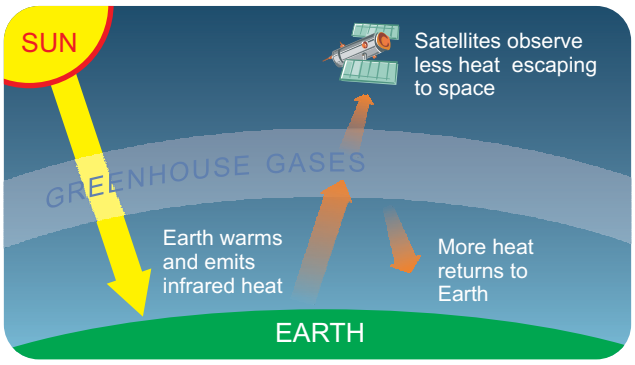
This is just what we observe, in measurements of the atmosphere[5], in corals[9] and sea sponges.[15] So we have strong evidence that the increase in carbon dioxide in the air is directly linked to human emissions.



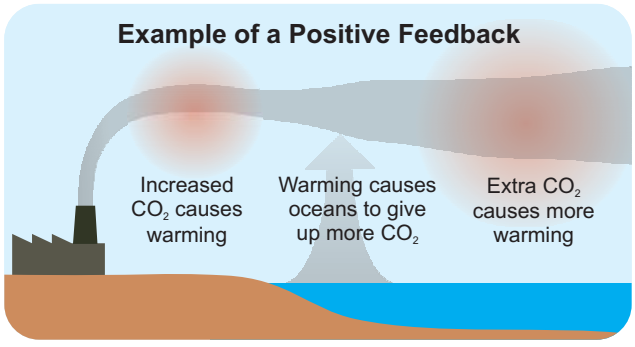
Measurements of δ13C (ratio of Carbon-13 to Carbon-12) from corals in the Great Barrier Reef.[9]

The evidence that more CO_2 causes warming

Carbon dioxide traps infrared radiation (commonly known as thermal radiation). This has been proven by laboratory experiments[16] and satellites which find less heat escaping out to space over the last few decades[4] (see *Human Fingerprint #2*). This is direct evidence that more 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 CO_2 in the air. So warming causes more CO_2 and more CO_2 causes extra warming. Put these two together and you get positive feedback. Positive or negative feedback don't necessarily mean good or bad. Positive feedbacks strengthen any climate change already underway while negative feedbacks suppress (weaken) any climate change.



In the past when 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.[17,18]

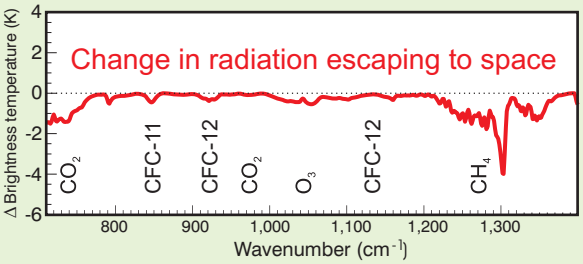
The ice core record is entirely consistent with the warming effect of CO_2. In fact, the dramatic warming as the planet comes out of an ice age cannot be explained without the feedback from CO_2. The CO_2 lag doesn't disprove the warming effect of CO_2. On the contrary, it provides evidence of a positive climate feedback.

Human Fingerprint #2

Less heat is escaping out to space

Satellites measure infrared radiation as it escapes out to space, clearly observing the greenhouse effect. A comparison between satellite data from 1970 to 1996 found that even 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".*[4]

This has since been confirmed by subsequent measurements from several different satellites.[19,20]

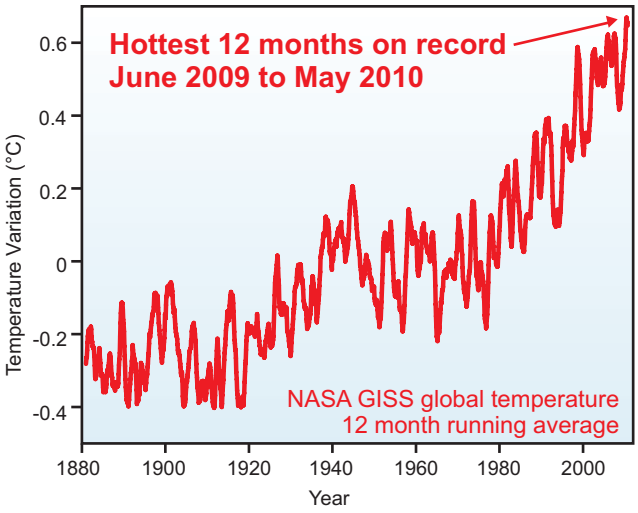


Change in outgoing radiation spectrum from 1970 to 1996 due to increasing greenhouse gases. Negative values mean less outgoing heat.[4]

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".

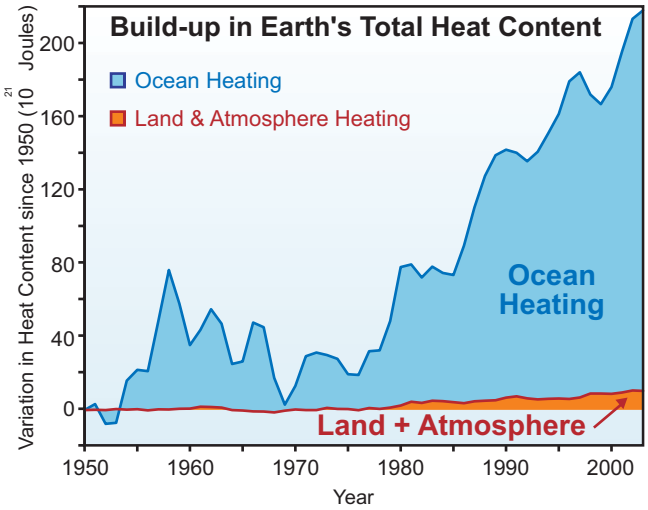
The first cherry pick is that it relies on temperature records that don't cover the entire globe, such as data from the Hadley Centre in the U.K.[21] The Hadley Centre record doesn't include the Arctic region where the fastest warming on the planet is occurring.[22] Records covering the entire planet find the hottest calendar year on record is 2005. The hottest 12 months were June 2009 to May 2010.[23]



12 month running average of global temperature variations.[24]

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.[23,25]

The third cherry pick is looking only at surface temperature, which is a measurement of atmospheric temperature. Over 80% of the extra energy from the increased greenhouse effect goes into warming the oceans. To find out if global warming continued past 1998, look at all the heat accumulating in the climate system. When we add up the heat going into the oceans, warming the land and air and melting the ice, we see the planet continues to accumulate heat.[26]

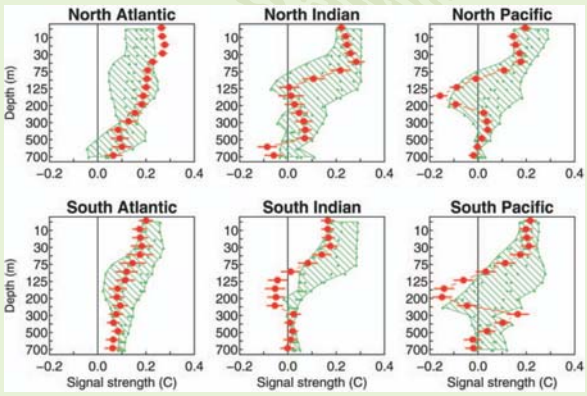


Cumulative heat for the Earth since 1950.[26] *The rate of energy building up since 1970 is equivalent to 2.5 Hiroshima bombs every second.*[27]

Human Fingerprint #3

The ocean warming pattern

The world's oceans have steadily been building up heat over the past 40 years. The specific pattern of ocean warming, with heat penetrating from the surface, can only be explained by greenhouse warming.[10]



Observed ocean temperature (red) compared to model results that include greenhouse warming (green).[10]

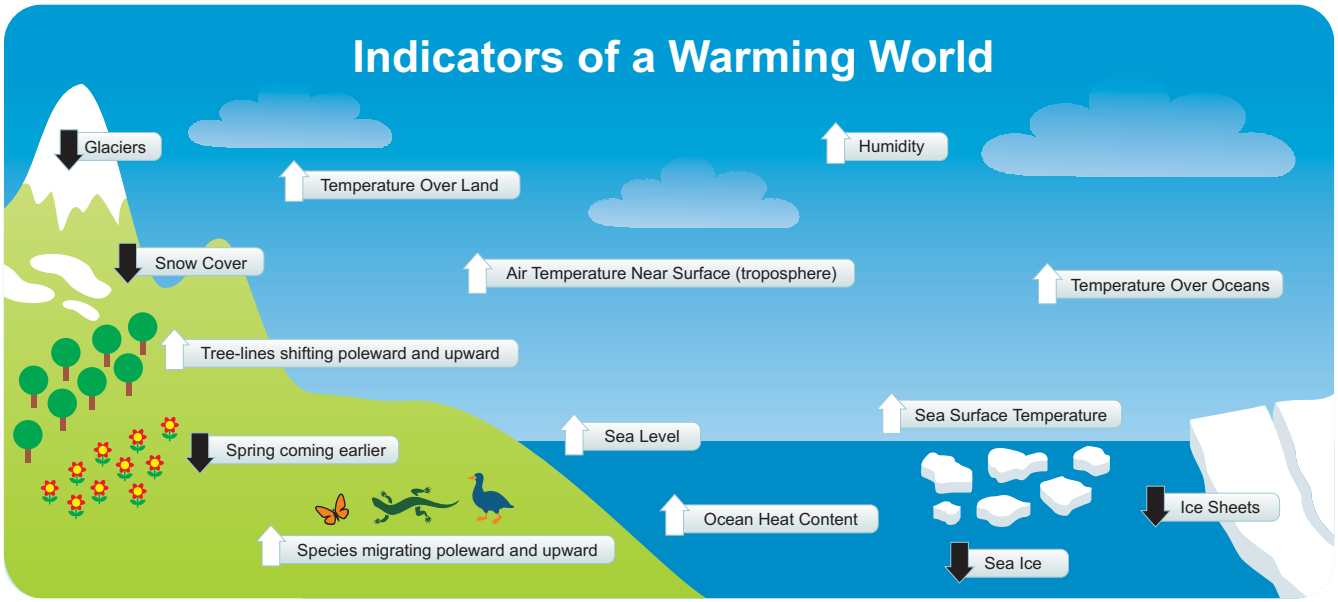
More evidence of the reality of global warming

Some 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.[28]

Another way to check thermometer measurements is to compare them to satellite data. Satellite measurements show a similar rate of global warming.[29] This is confirmation that thermometers are giving us an accurate picture.

As well as the compelling temperature record, we have a large body of observations in many different systems that are consistent with a warming world. Ice sheets are melting, losing billions of tonnes of ice each year.[30] Sea levels are rising at an accelerating rate.[31] Species are migrating toward the poles and glaciers are retreating (threatening water supplies for many millions of people).[32,33]

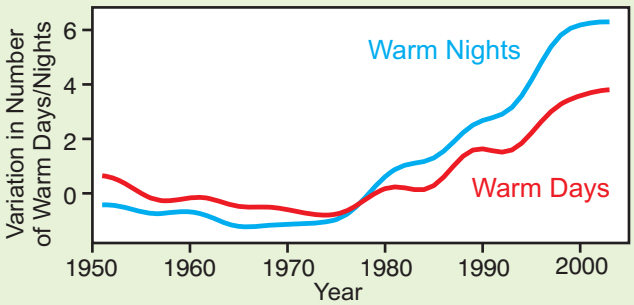
To gain a proper understanding of climate, we need to look at all the evidence. What we see are many independent observations all pointing to the same conclusion - global warming is happening.



Parmesan & Yohe 2003[32], NOAA[34]

Human Fingerprint #4 Nights warming faster than days

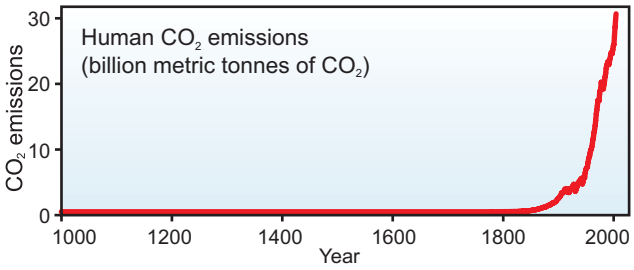
An increased greenhouse effect means nights should warm faster than days. During the day, the sun warms the Earth's surface. At nighttime, the surface cools by radiating its heat out to space. Greenhouse gases slow down this cooling process. If global warming was caused by the sun, we would expect the 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.[6]



Long-term variation in the number of warm days (red) & warm nights (blue) per year. Warm is defined as the top 10%.[6]

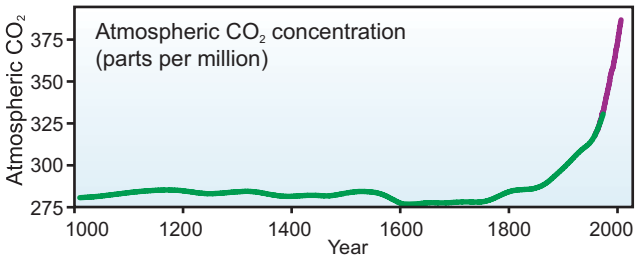
Hockey stick or hockey league?

The 'hockey stick' commonly refers to a reconstruction of temperature going back over the last millennium.[35] The steep warming in recent times is seen as the blade of the stick. However, there are many hockey sticks found in climate science. 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.



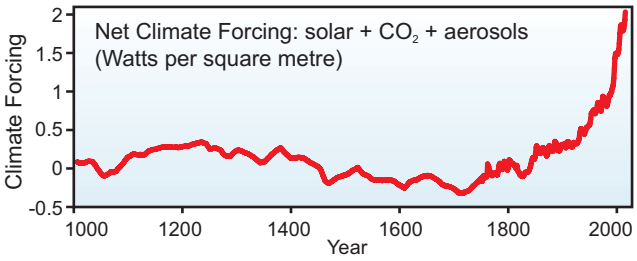
Total yearly CO_2 emissions (billions of tonnes).[11]

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 at least 2 million years.[14]



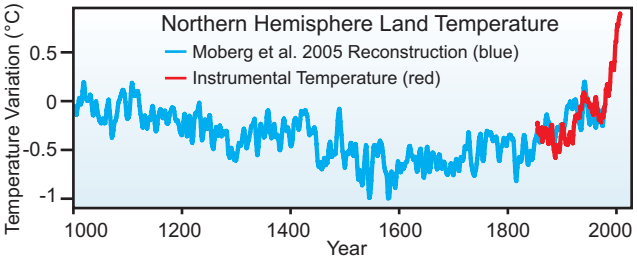
CO_2 levels (parts per million) from ice cores at Law Dome, East Antarctica (green)[36] *and direct measurements from Mauna Loa, Hawaii (purple).*[37]

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 (tiny 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 influences shows a familiar shape.



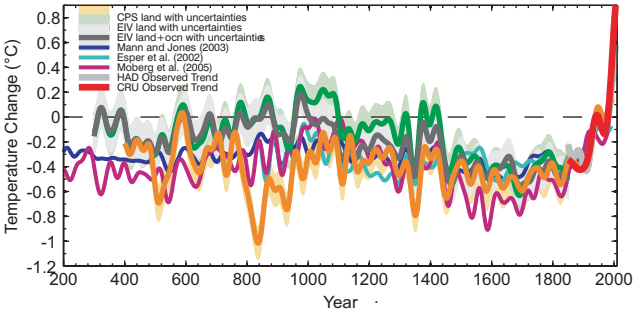
Combined climate forcing from solar variations, CO_2 and aerosols - the short-term effects of volcanoes are omitted.[38]

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



Northern hemisphere temperature reconstruction (blue)[39] *plus instrumental measurements of northern hemisphere land temperature (red - 5 year average).*[21]

Over the last decade, a number of independent studies have reconstructed temperature over the last 1800 years, using a multitude of data and different data analysis techniques.[40]



Various northern hemisphere temperature reconstructions.[40]

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

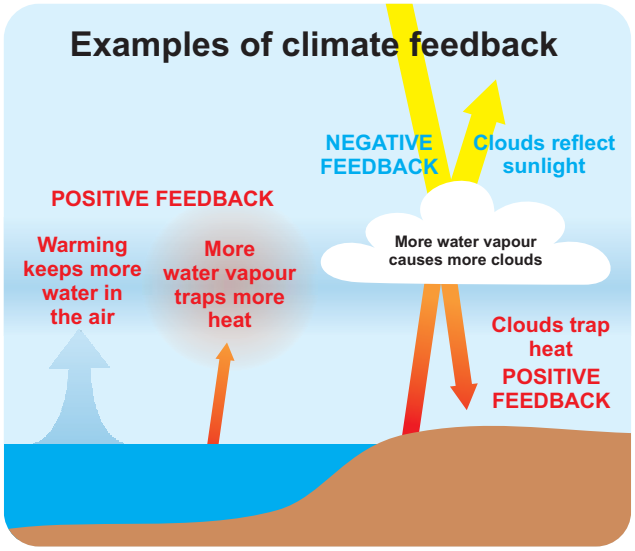
What does past climate change tell us?

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.[41]

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, of which CO_2 is the most important driver of climate change.[42]

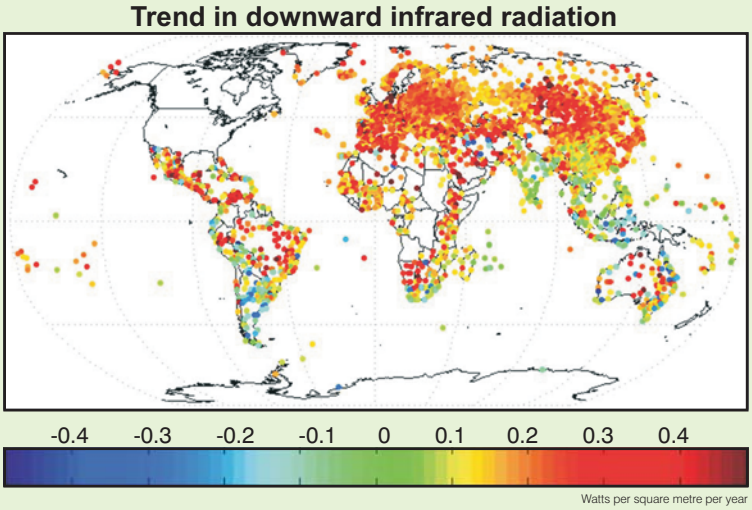
So there is a great irony when past climate change is invoked as disproving the human influence on global warming. The peer-reviewed science actually comes to the opposite conclusion. Past climate change provides strong evidence for positive feedback that amplifies the warming caused by our CO_2 emissions.



Human Fingerprint #5 More heat is returning to Earth

An increased greenhouse effect means we should see more infrared radiation returning down to Earth from the atmosphere. 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." [8]



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.[43]

How sensitive is our climate?

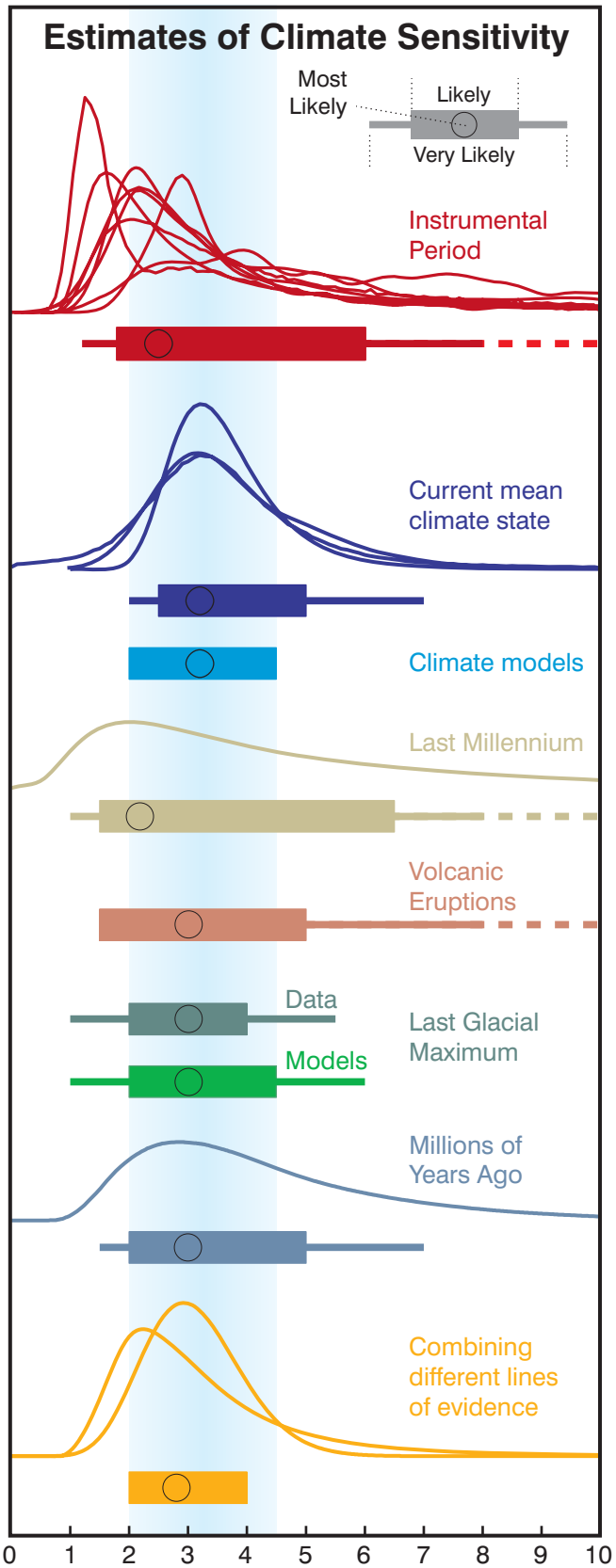
Climate sensitivity is a measure of how much global temperature warms if atmospheric CO_2 is doubled. It's well-established that the direct warming from a doubling of CO_2 (hypothetically assuming no climate feedbacks) is around 1.2°C. The big question is how feedbacks react to this initial greenhouse warming. Do positive feedbacks amplify the initial warming? Or do negative feedbacks suppress warming?

Climate sensitivity has been determined using a variety of different techniques. Instrumental measurements, satellite readings, ocean heat, volcanic eruptions, past climate change and climate models have all been examined to calculate the climate's reaction to a build-up in heat. We have a number of independent studies covering a range of periods, studying different aspects of climate and employing various methods of analysis.[41]

This variety of methods paints a consistent picture - a climate sensitivity range from 2 to 4.5°C, with a most likely value of 3°C. This means positive feedbacks amplify the initial CO_2 warming.

A few assert that climate sensitivity is much lower than 3°C, citing a study by Lindzen and Choi.[44] This study uses satellite measurements of outgoing radiation, suggesting strong negative feedback. However, it looks only at tropical data. The tropics are not a closed system - a great deal of energy is exchanged between the tropics and subtropics.[45] To properly calculate global climate sensitivity, you need global observations. Several studies analysing near-global satellite data find positive feedback.[46,47]

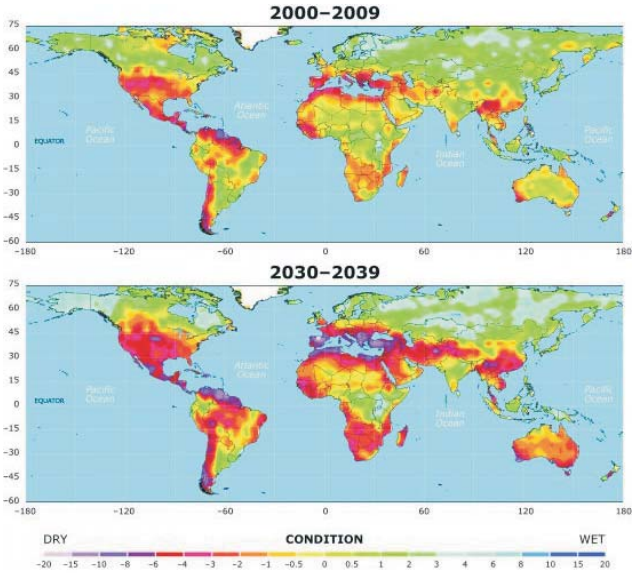
A proper understanding of climate sensitivity requires the full body of evidence. To claim low climate sensitivity based on a single study is to ignore the many lines of evidence that find positive feedback and high climate sensitivity.



Various Estimates of Climate Sensitivity (°C)[41]

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', implying that 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 will be quickly overwhelmed by the negative effects of heat stress and drought, which are expected to increase in the future.[48,49] Over the past century, drought severity has increased globally and is predicted to intensify in the future.[12] Plants cannot take advantage of extra CO_2 if they're dying of thirst.[50]



Past & future drought, using the Palmer Drought Severity Index. Blue represents wet conditions, red represents dry. A reading of -4 or below is considered extreme drought.[51]

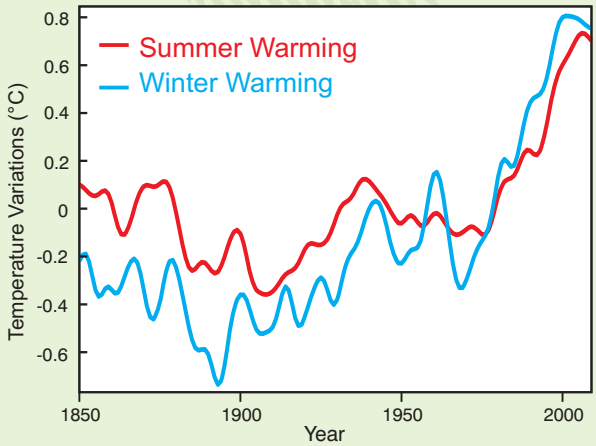
There are many climate change impacts that have no positive aspects. Between 18 to 35% of plant and animal species could be committed to extinction by 2050.[52] Oceans are absorbing much of the CO_2 in the air, which leads to ocean acidification.[53] This is predicted to have severe destabilising effects 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).[54] An estimated 1 billion people depend on the ocean for a substantial portion (>30%) of their animal protein.[55]

As glaciers and snowfields dwindle, so does the water supply for millions of people who are deeply reliant on those freshwater supplies, especially for irrigated agriculture.[33] Similarly, sea level rise and increased storm activity 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.[56]

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 #6
Winter warming faster

As greenhouse warming increases, winters are expected 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.[7,68]



Smoothed temperature variations for winter and summer, averaged over land only, from 1850 to 2009.[21]

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, six independent enquiries from England and the United States have investigated the stolen emails. Every single investigation cleared the climate scientists of any wrong doing.[57,58,59,60,61,62]

> *"...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[58]

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. As tree growth is affected by temperature, tree-ring widths closely match thermometer measurements in the past. However, some tree-rings diverge from thermometer measurements after 1960. This issue has been openly discussed in the peer-reviewed literature as early as 1995.[63] 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[59]

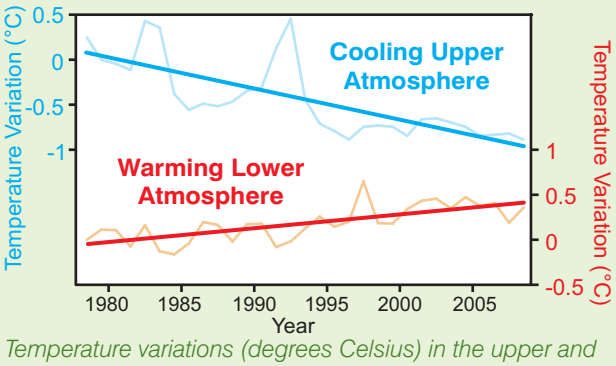
It's important to put the stolen emails in perspective. A handful of scientists discuss a few pieces of climate data. Even without this data, there is still an overwhelming and consistent body of evidence, painstakingly compiled by independent scientific teams across the globe. A few suggestive quotes 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."*[60]
>
> PENN STATE UNIVERSITY

Human Fingerprint #7

Cooling upper atmosphere

As greenhouse gases trap more heat in the lower atmosphere, less heat reaches the upper atmosphere (the stratosphere and higher layers). So we expect to see a warming lower atmosphere and cooling upper atmosphere. This has been observed by satellites and weather balloons.[1]



Temperature variations (degrees Celsius) in the upper and lower atmosphere, measured by satellites (RSS).[64]

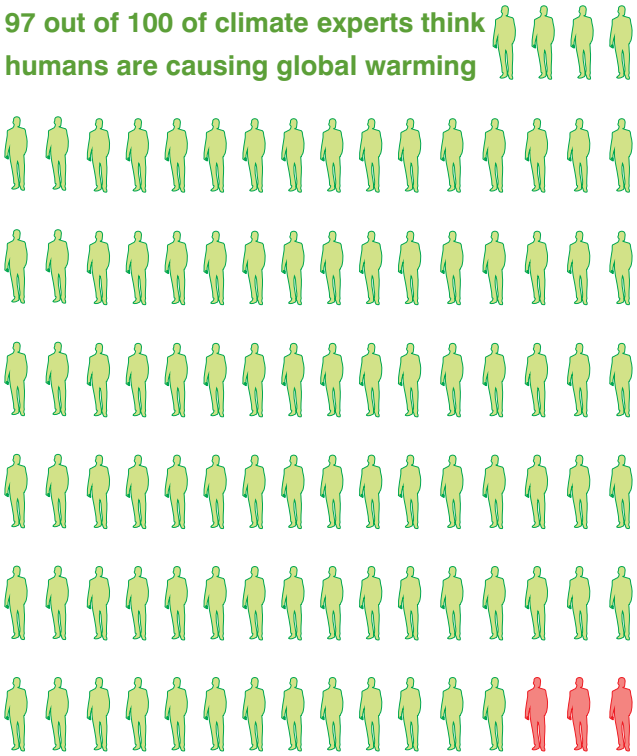
The scientific consensus on global warming

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

So what do the real 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.[65,66]

This is confirmed by peer-reviewed research. A survey of all peer-reviewed research on the subject 'global climate change' published between 1993 and 2003 found that among the 928 papers found, *not a single paper* rejected the consensus position that human activities are causing global warming.[67]

97 out of 100 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. Multiple, independent lines of evidence all point 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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The case for human-caused global warming is based on many independent lines of evidence. Global warming 'skepticism' often focuses on narrow pieces of the puzzle while denying the full body of evidence.

Our climate is changing and we are the major cause through our emissions of greenhouse gases. The facts about climate change are essential to understand the world around us, and to make informed decisions about the future.

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