Climate Change Skepticism and Denial

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1 Introduction

The science behind understanding climate change dates back to the 19th century, when Eunice Foote as well as John Tyndall conducted fundamental experiments on the absorption of infrared radiation by carbon dioxide (CO_2) and water vapor (Jackson 2019), and Svante Arrhenius famously linked CO_2 to warming of the Earth's surface (Arrhenius 1896).

Nowadays, there is a broad scientific consensus about the underlying physical science of global warming, and that anthropogenic (human-induced) emissions of CO_2, methane (CH_4) and other greenhouse gases are the main drivers of the current warming. There have been many attempts to quantify this consensus, and a survey of these studies by Cook et al. (2016) showed that among publishing climate scientists, between 90% and 100% agree "that humans are causing recent global warming".

About every seven years, the current state of the science is summarized in an "Assessment Report", a large review study in the framework of the Intergovernmental Panel on Climate Change (IPCC), which also states the likelihood of scientific findings (Mastrandrea et al. 2011). In its most recent Fifth Assessment Report, the IPCC calls it "unequivocal" that anthropogenic greenhouse gas emissions have "substantially enhanced the greenhouse effect" (IPCC 2013, p. 661).

Yet, over the past four decades, climate change skeptics and deniers have successfully managed to seed doubt about these findings, and have greatly distorted public opinion on global warming. In six polls surveying the opinion about global warming in the United States from 2015 to 2016, only between 51% and 66% of the respondents believed that climate change is mostly caused by human activities (EESI 2016), as opposed to the consensus among climate scientists.

The perceived agreement among scientists itself also strongly differs from the study results cited above: In a 2008 survey by Whitmarsh (2011) in the United Kingdom, 39% of the respondents agreed with the statement that "many leading experts still question if human activity is contributing to climate change". In Germany, the degree of skepticism is somewhat lower, although only few scientific studies (e.g., Engels et al. 2013) have specifically addressed climate change skepticism in this country.

The aim of this paper is to examine climate change skepticism and denial from two perspectives: First, we will take a look at the main strategies of organized climate change denial. In the second part, we will address some common myths about global warming, analyze the fallacies behind these arguments, and present concise counter-arguments.

2 Skepticism or denial?

Skepticism is a key to scientific advance if it is genuine – that is, if the goal is to increase scientific understanding. However, in the words of climate scientist Michael Mann, "the term *skeptic* has been hijacked" (Mann and Toles 2016, p. 1). Because of the importance of constructive scientific skepticism, the term *skepticism* has a much more positive connotation than *denial*, which self-labeled "climate skeptics" successfully exploit.

Mann draws the line between skepticism and denial according to the motivation, differentiating good-faith skepticism from "pseudoskepticism" – or rather denial – motivated by "opinion, ideology, financial interest, self-interest, or all these things together" (Mann and Toles 2016, p. 2).

The environmental sociologist Riley Dunlap puts more emphasis on the process of establishing one's opinion on climate change. He suggests a continuum between skepticism and denial, with "some [...] remaining open to evidence, and others in complete denial mode, their minds made up" (Dunlap 2013).

3 Mechanisms of denial

Much of the strategy used in global warming denial was developed in connection with the public health sector during the 20th century. Already as early as in the 1920s, the lead industry in the United States, facing allegations that lead in indoor paints imposed health risks, cast doubt on the scientific findings on which the health concerns were based (Michaels and Monforton 2005).

The strategy of casting doubt on scientific findings was later perfected by the tobacco industry; during the 1960s, an industry executive coined the phrase *Doubt is our product*, which is widely cited in this context (Michaels and Monforton 2005). The tobacco industry hired scientists and commissioned research to challenge the scientific consensus, and, at the same time, employed an aggressive public relations (PR) strategy to communicate their view to the public.

3.1 Manufacturing uncertainty

The key element of this PR strategy was to seed doubt by manufacturing uncertainty about the link between tobacco smoking and cancer in the general public. In 1955, the PR agency Hill & Knowlton summarized their communication strategy as follows (Michaels and Monforton 2005):

> "That cause-and-effect relationships have not been established in any way; that statistical data do not provide the answers; and that much more research is needed."

More than 60 years later, the key points of this strategy can still widely be found in connection with global warming denial, even in politics. As an example, on December 3, 2002, a *Washington Post* article cited "numerous uncertainties [that] remain about global warming's cause and effect" and reported that then-president George W. Bush called "for a decade of research before the government commits to anything more than voluntary measures to stem carbon dioxide and other greenhouse gas emissions" (cited from Boykoff and Boykoff 2004).

But why does this strategy work, apart from it being communicated by the U.S. president and distributed by a highly reputed newspaper[1]? Why do people believe that "the science isn't settled" despite an overwhelming consensus among climate scientists?

[1]The fact that climate change skeptics and deniers have generally received disproportional attention by the "prestige press" is known as "balance as bias" (Boykoff and Boykoff 2004). Misinterpreting the norm of journalistic balance, media have often given equal weight to the voices of scientists supporting the consensus and skeptics/deniers, even though the latter only represent a small minority among climate scientists.

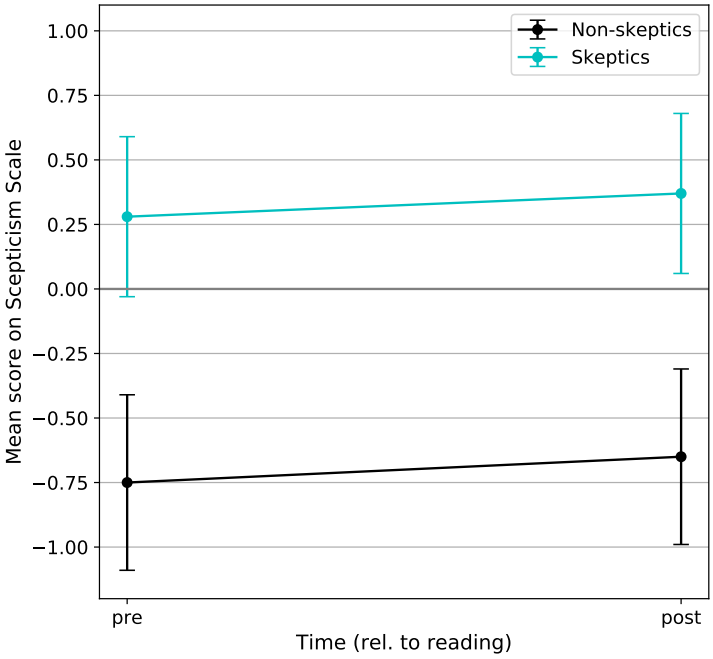


Fig. 1: Mean "skepticism score" before and after reading the two editorials. The skepticism score is calculated from answers to a questionnaire, and measures the agreement to typical skeptics' arguments like *"Many leading experts still question if human activity is contributing to climate change"*.
A score of −2 means that respondents disagreed with all statements, and +2 means that they agreed with all statements. The group was split into two equally large sub-groups, "skeptics" and "non-skeptics", according to their skepticism score in the first questionnaire (adapted from Corner et al. 2012).

To answer these questions, Corner et al. (2012) conducted a psychological experiment on how people with different opinions about climate change assimilate information from newspaper editorials. These editorials presented conflicting opinions (one was skeptical, one supported the scientific consensus) about the science behind climate change. Another pair of contrasting editorials dealt with the political and moral consequences of global warming.

Referring to findings about information assimilation of different controversial topics, Corner et al. (2012) expected two possible reactions to reading those editorials: *biased assimilation* and *attitude polarization*. People generally evaluate sources that are in line with their beliefs as more credible than those that "disconfirm" their views (*biased assimilation*). Moreover, some studies have shown that being presented with conflicting or uncertain evidence can lead to *attitude polarization*, i.e., to strengthen the respective opinion on the controversial topic (Lord et al. 1979). In the context of climate change, this would mean that skeptics become more skeptic and non-skeptics reject the skeptics' arguments even more.

While Corner et al. (2012) did observe biased assimilation, they could not detect attitude polarization in their study. On the contrary, they found that both skeptics *and* non-skeptics became significantly more skeptical after reading the conflicting editorials (Fig. 1). Skepticism also increased regardless of whether the participants read the scientific or political/moral editorials.

3.2 Strategy of climate change denial

However, manufacturing uncertainty is only a part of the strategy of climate change denial. For many years, the now well-known "denial machine" (see the following section) "mask[ed] their efforts as legitimate scientific debate" (Dunlap 2013). In order to increase the credibility of their publications, deniers often made them look like they were relying on peer-reviewed science (Oreskes and Conway 2010, p. 187) by cherry-picking scientific findings.

One example is shown in Fig. 3. James Hansen, a climate modeler who became known to a wider audience by testifying in a public hearing before U.S. congress, and his team had managed to reproduce the ocean temperature anomaly between 1880 and 1980 quite accurately, using a model that included CO_2, volcanic and solar forcing (Hansen et al. 1981). In their figure (Fig.

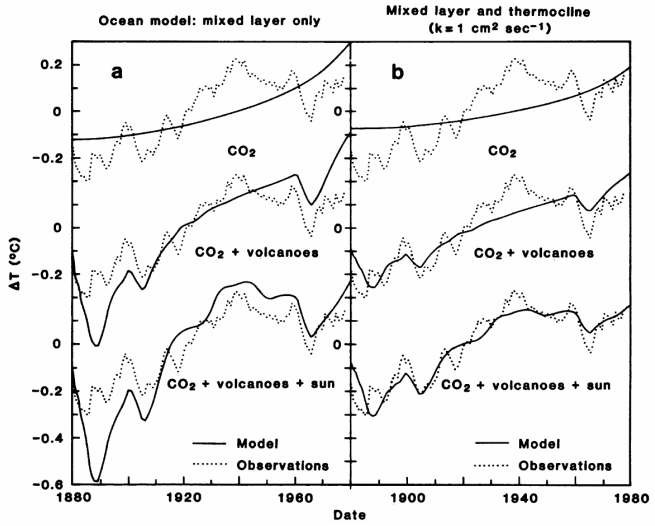


Fig. 2: Original figure from Hansen et al. (1981), showing good agreement of the ocean model with all forcings (last row) and observations.

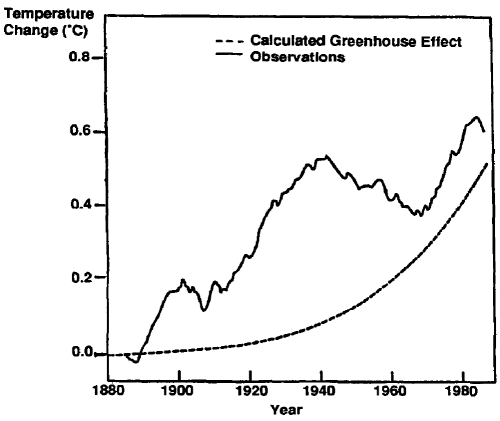


Fig. 3: Distorted version of Hansen et al.'s graphic as published by Jastrow et al. (1991). The authors refer to the bad agreement between observations and the model that only includes CO_2 forcing.

2), they also decomposed the model results and showed that both CO_2 and volcanic aerosols were necessary to explain the observed temperature trend.

Robert Jastrow, Bill Nierenberg, and Fred Seitz referred to this figure in a 1989 report for the *Marshall Institute*, also published in the journal *Energy* two years later (Jastrow et al. 1991). However, they only considered the first row of Hansen et al.'s graph, which showed the model results if only CO_2, and no other factors, were responsible for the temperature trend, and asserted: "If the greenhouse effect were an important factor in climate change after the 1940s, global temperatures in that period would have shown a clear and pronounced upward trend." From this, they concluded that natural causes (like the sun) must drive the observed warming, ignoring Hansen's findings that solar variability only played a very little role. However, Jastrow et al. completely ignored volcanic forcing – the words "volcano" or "volcanic" do not even appear once in their article.

During the 1990s, substantial international efforts against global warming got underway with the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 and the Kyoto Protocol in 1997. Facing increasing environmental regulations in the U.S. and internationally, an alliance between the American conservative movement and the fossil fuel industry redoubled their efforts by launching attacks on science and the scientists themselves (Dunlap and McCright 2011). One of these scientists was climate modeler Ben Santer, who was attacked over his role in the 1996 IPCC Second Assessment Report, with the *Wall Street Journal* spreading the attack and only printing a heavily edited version of Santer's reply (Oreskes and Conway 2010, p. 209).

More recently, deniers have labeled the entire field of climate science as "junk science" and launched attacks "on such pillars of science as the importance of peer-reviewed publications" (Dunlap and McCright 2011). A prominent example was the posting of e-mails and other documents, which were illegitimately obtained from the University of East Anglia's Climate Research Unit, and the subsequent attacks on climate science in what was dubbed "climategate" by some media (see Leiserowitz et al. 2012 for an overview).

3.3 The Denial Machine

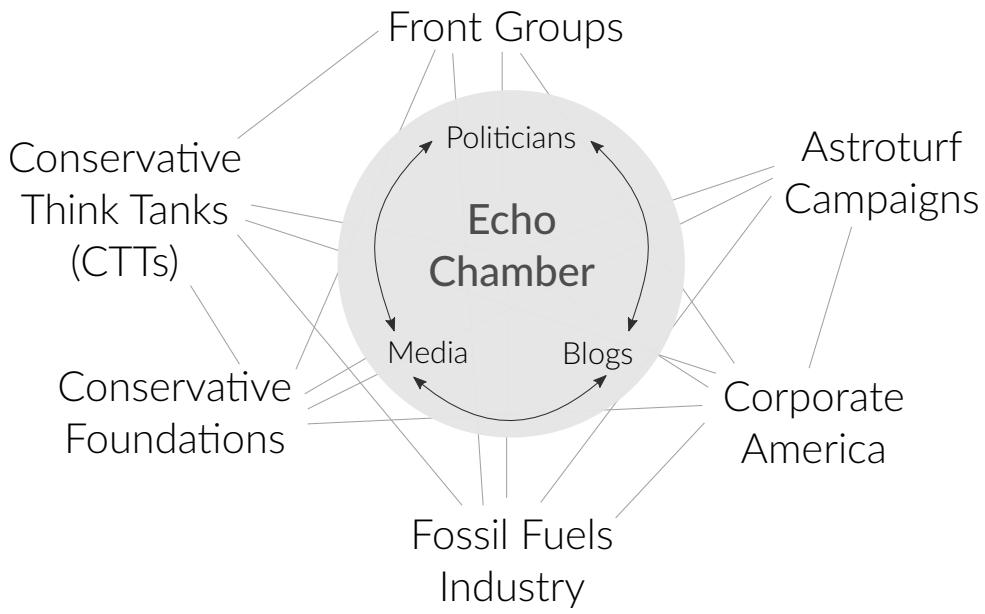


Fig. 4: The climate change "denial machine" (adapted from Dunlap and McCright 2011).

While these attacks, as well as newspaper articles and political initiatives against CO_2 reduction, may seem to simply originate from individual contrarian scientists, journalists or politicians, they are part of a larger "denial machine" (Fig. 4). It has been successively uncovered since 1997, started by investigative journalism such as Ross Gelbspan's book *The Heat is On* and followed by social scientists, historians and climate scientists (Dunlap 2013).

Dunlap and McCright (2011) locate the publicly visible "echo chamber" – (conservative) politicians, media and blogs – at the center of this machine. It spreads climate change denial to the general public and converts its ideas into political action such as congressional hearings and draft bills against environmental protection.

The fossil fuels industry and Corporate America "pioneered" initiatives against climate change policies, realizing the implications of global warming for their businesses early on (Dunlap and McCright 2011). Today, conservative think tanks and foundations also make up a major part of the denial machine, opposing environmental regulations from a mostly ideological standpoint. A significant part of their funding stems from wealthy oil industrialists such as Richard Mellon Scaife and David and Charles Koch. Prominent examples of think tanks involved in climate change denial are the *CO_2 Coalition* (formerly *George Marshall Institute*) and the *Heartland Institute* (Dunlap and McCright 2011).

To mask their activities against environmental regulations, various corporations and think tanks have set up front groups, whose names like *Global Climate Coalition*, *Information Council for the Environment* and *Cooler Heads Coalition* obscure their intent. They have initiated media campaigns, helped launching attacks on climate scientists, hosted press conferences and congressional briefings. Often, they play key roles in astroturf campaigns, artificial campaigns that are "disguised to appear as a spontaneous, popular 'grassroots' effort" (Dunlap and McCright 2011) – just like astroturf (artifical turf) is made to look like natural grass.

Public campaigns initiated by these organizations often rely on contrarian scientists – a small number of (mostly retired) scientists that use their prior credentials in other fields of natural sciences to serve as "credible" advocates against the scientific consensus on climate change. Oreskes and Conway (2010) have shown that some especially prominent figures of climate change

denial – namely Fred Seitz, Bill Nierenberg and Fred Singer – were already employed by other industries' front groups to speak out against the adverse health effects of smoking as well as environmental issues like acid rain and the ozone hole ("Merchants of Doubt").

The denial machine discussed here mostly refers to the U.S., where "climate change denial was born and continues to be most active" (Dunlap and McCright 2011). However, today it is present all over the world, especially in other English-speaking countries like the U.K., Canada and Australia, where American front groups and contrarian scientists have helped set up the structures of organized denial (Dunlap and McCright 2011).

In Germany, a 2013 study concluded that "climate change denial is not central anymore. The skeptics focus [...] more on the political consequences", especially the transition toward renewable energy sources (Brunnengräber 2013). Since then, however, the right-wing political party *Alternative für Deutschland* (AfD), whose policy on climate change is characterized by "[s]trident refutation of scientific consensus" (Schaller and Carius 2019, p. 84), has entered the German parliament. They are said to have "close links" to the *European Institute for Climate and Energy* (EIKE), an "independent organisation of climate denialists" (ibid.) based in Jena (Deleja-Hotko et al. 2019). EIKE vice president Michael Limburg is said to have "played a key role in developing AfD's positions on climate change" (Schaller and Carius 2019, p. 84).

4 Fallacies behind arguments of deniers and skeptics

There are many arguments recurrently cited by climate change skeptics and deniers, and many books, pocket guides and websites dedicated to debunk them with scientific arguments. A good overview can be found in Cook (2010), which serves as a basis for the following sections. In line with recent findings on countering misinformation, we debunk the myths, but also "provide alternative information to fill the 'gap' created by the correction" (Paynter et al. 2019). Hence, the section headings also refer to these corrections, and skeptics' and deniers' quotes can be recognized by their indent.

4.1 Humans are raising CO_2 levels

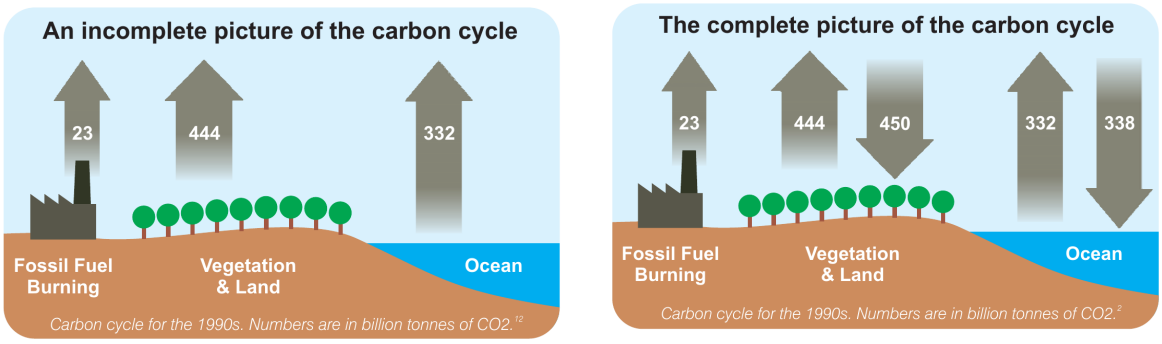
Skeptics have asserted:

> "Only about 3% of atmospheric carbon dioxide is attributable to human sources. The numbers are from IPCC data." [2]

Apart from the fact that the author of this blog post erroneously refers to the CO_2 concentrations instead of emissions, it represents a good example of cherry-picking – or, in this case, the fallacy of **selective representation**. As shown in Fig. 5, the argument only takes into account half of the carbon cycle, the emissions, but disregards the absorption.

The natural greenhouse effect in an equilibrium world, without human influences, would be roughly balanced: emission and absorption by vegetation, land and ocean would level out, respectively, and the atmospheric CO_2 levels would be constant. However, man-made processes, mainly the burning of fossil fuels that emits CO_2, move the carbon cycle out of balance. The vegetation and the oceans actually take up slightly more carbon dioxide than they emit (otherwise, the CO_2 levels in the atmosphere would be much higher today); however, they cannot completely level off anthropogenic emissions. For the decade between 2007 and 2016, this lead to

[2] A. Watts: EPA document supports ∼ 3% of atmospheric carbon dioxide is attributable to human sources. *Watts Up With That*, 29.07.2014, https://wattsupwiththat.com/2014/07/29/epa-document-supports-3-of-atmospheric-carbon-dioxide-is-attributable-to-human-sources/.



(a) (b)

Fig. 5: (a) Incomplete (selectively represented) picture of the carbon cycle, (b) Carbon cycle including sources *and* sinks. Numbers are in gigatonnes of CO_2 per year (one gigatonne of CO_2 equals 0.273 GtC). From Cook (2010) (licensed under CC-BY-NC 3.0).

a net growth of 4.7 GtC yr^{-1} in the atmosphere, corresponding to a rise in CO_2 concentrations by about 2.2 ppm per year (Le Quéré et al. 2018).

4.2 Human fingerprints on climate change

The myth that "the sun is to blame" for global warming is one of the oldest assertions that has been circulated by climate change skeptics and deniers, as evidenced by Jastrow's, Nierenberg's and Seitz's article from the late 1980s (sec. 3.2), in which they ultimately claimed that the warming must be caused by the sun (Oreskes and Conway 2010, p. 187). More than a decade later, an article in the British newspaper *Daily Telegraph* stated:

> "The Earth is getting hotter because the Sun is burning more brightly than at any time during the past 1,000 years."[3]

The article exhibits two fallacies: First, the findings are **quoted out of context**. The authors of the study which the newspaper article refers to explicitly state that "solar variability is unlikely to have been the dominant cause of the strong warming during the past three decades" (Solanki et al. 2004). (Quotes from climate researchers also point this out in the article; however, the "skeptics" frame the article by being quoted at the beginning and the end.)

Second, **correlation does not imply causation**: the fact that the number of sunspots is increasing does not imply that it is the driving factor of global warming. On long time scales from some ten thousand to some billion years, solar irradiation changes (either from increasing solar luminosity or from changes in orbital parameters) do indeed have a strong influence on the Earth's climate (Pierrehumbert 2011, pp. 13, 395). However, in the present era, the temperature anomaly that can be attributed to changes in solar output is only ±0.04 °C and follows the 11-year sunspot cycle (Canty et al. 2013, see also Fig. 9). In comparison, the anthropogenic emissions are responsible for a rise in temperatures of more than 0.8 °C since 1870, nearly all of the observed increase (IPCC 2013, p. 393).

If the 11-year cycles are averaged out, the observed total solar irradiance, i.e., the solar power per square meter that arrives at the top of the Earth's atmosphere, has even decreased by about −0.04 W/m^2 in the era of satellite measurements (1986–2008) (IPCC 2013, p. 885).

[3] M. Leidig and R. Nikkhah: The truth about global warming - it's the Sun that's to blame. *Daily Telegraph*, 18.07.2004, https://www.telegraph.co.uk/news/science/science-news/3325679/The-truth-about-global-warming-its-the-Sun-thats-to-blame.html.

These attribution studies rely on so-called hindcasts, runs of climate models on time periods in the past that can then be compared to observations, but can also be used to "switch off and on" certain elements of the climate system and evaluate their impact on global temperatures. This was already the key idea behind Hansen et al.'s paper discussed in section 3.2. A recent example of a multi-model hindcast can be seen in Fig. 6. The models reproduce the observed temperatures well when accounting for anthropogenic and natural climate forcings. However, when modeling the temperature trend with only natural forcings, the result is a rather flat line with some dips after volcanic eruptions, which does not follow the observed increase in surface temperatures at all.

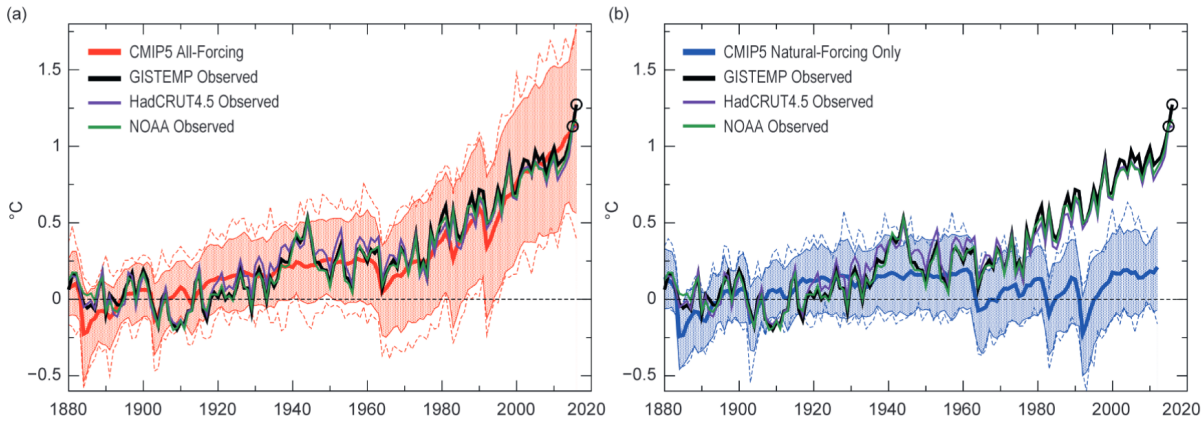


Fig. 6: Observed (thin lines) and modeled (thick lines) temperatures between 1880 and 2016, from the Coupled Model Intercomparison Project 5 (CMIP5): (a) Model including anthropogenic and natural forcings, (b) only including natural forcings (from Knutson et al. 2018). The shaded areas represent a range of two standard deviations.

But even if we completely disregard the complex climate models, a number of distinct "fingerprints" demonstrate that human emissions, rather than natural factors, are the dominant cause of global warming (c.f. Cook 2010). A simple view of the greenhouse effect is that greenhouse gases in the atmosphere trap some of the terrestrial infrared (long-wave) radiation. Therefore, an increase in greenhouse gases should lead to an enhanced flux of infrared radiation towards the surface, which has been shown experimentally by both ground-based and satellite measurements (Wang and Dickinson 2013). The observed number of warm nights has also increased more strongly than the number of warm days (Alexander et al. 2006), whereas we would expect the opposite if the sun was responsible for the warming.

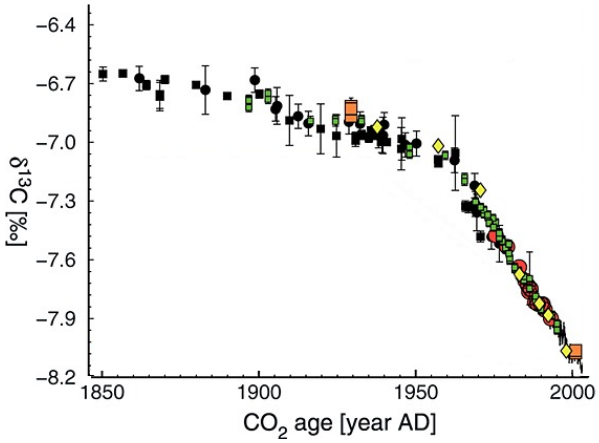


Fig. 7: The $\delta^{13}C$ record reconstructed from Antarctic firn shows a clear downward trend in the atmospheric $\delta^{13}C/\delta^{12}C$ ratio in the industrial era (from Rubino et al. 2013).

Another human fingerprint is the decreasing ratio of the carbon isotopes ^{13}C to ^{12}C, called $\delta^{13}C$. Both isotopes are stable, but plants enrich the lighter ^{12}C to a greater extent. As fossil fuels were produced from ancient plants by geological processes, CO_2 emitted from fossil fuels also shows a lower $\delta^{13}C$, which has lead to a decrease in global $\delta^{13}C$ measured in the atmosphere (Rubino et al. 2013, Fig. 7), in oceans, and corals (Linsley et al. 2019).

4.3 Global warming *is* happening

During the late 2000s and early 2010s, the myth of an apparent "global warming hiatus" was spread by skeptics, in mass media and even by some members of the scientific community (as evidenced by this quote by Hans von Storch):

> "Climate change seems to be taking a break. We're facing a puzzle."[4]

The hypothesis was that the climate supposedly did not warm between 1998 and 2012, which, as Cook (2010) puts it, "is so misleading, it requires three levels of **cherry-picking**."

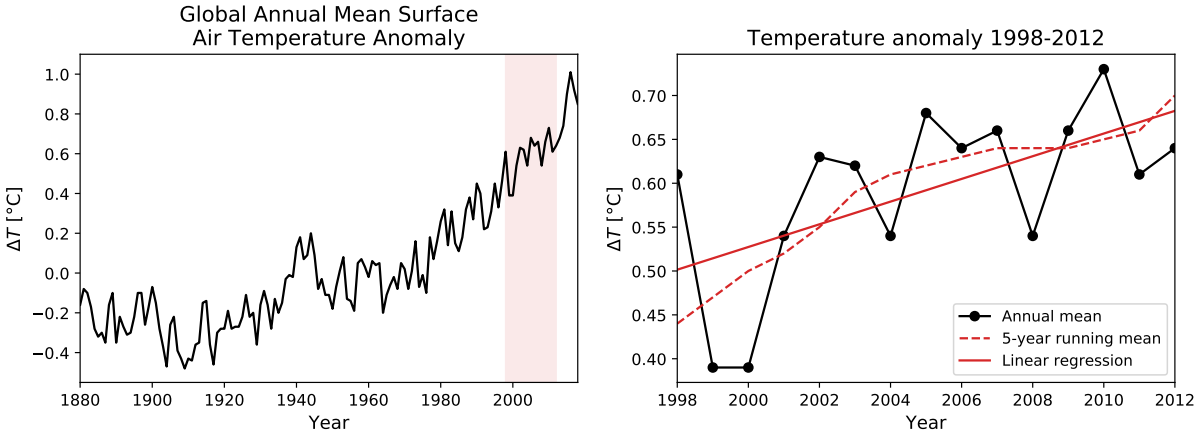


Fig. 8: Surface air temperatures from 1880 to 2018, and the extract from 1998 and 2012 to which the "skeptics" refer (own graphic, based on data from https://data.giss.nasa.gov/gistemp/graphs/graph_data/Global_Mean_Estimates_based_on_Land_and_Ocean_Data/graph.csv).

The surface air temperature record from 1880 to 2018 is shown in the left of Fig. 8, with a clear upward trend since the 1960s. The selectively chosen period between 1998 and 2012 is shown on the right-hand side. Even during this period, a simple linear regression shows a significant upward trend of about 0.13 °C per decade – only if one connected the starting and the end point, one could come up with a "global warming hiatus" theory.

The high temperature anomaly in 1998 is explained by the 1997–98 El Niño event, one of the strongest on record. (During El Niño, an element of natural climate variability, ocean temperatures sharply increase in the tropics, which also leads to a short-term global air temperature increase.) It was followed by a colder La Niña event in 1998–99 (Wang and McPhaden 2001), which can also be recognized in Fig. 8.

Besides the fact that many time series that were used to illustrate the "hiatus" used fewer data from high latitudes, where warming is generally most pronounced, this myth also disregards that the climate system consists of more than just the atmosphere. In fact, only a tiny part of the energy in the climate system is taken up by the atmosphere – the majority is stored in

[4] O. Stampf and G. Traufetter: Why Is Global Warming Stagnating? Spiegel Online, 20.06.2013, https://www.spiegel.de/international/world/interview-hans-von-storch-on-problems-with-climate-change-models-a-906721.html.

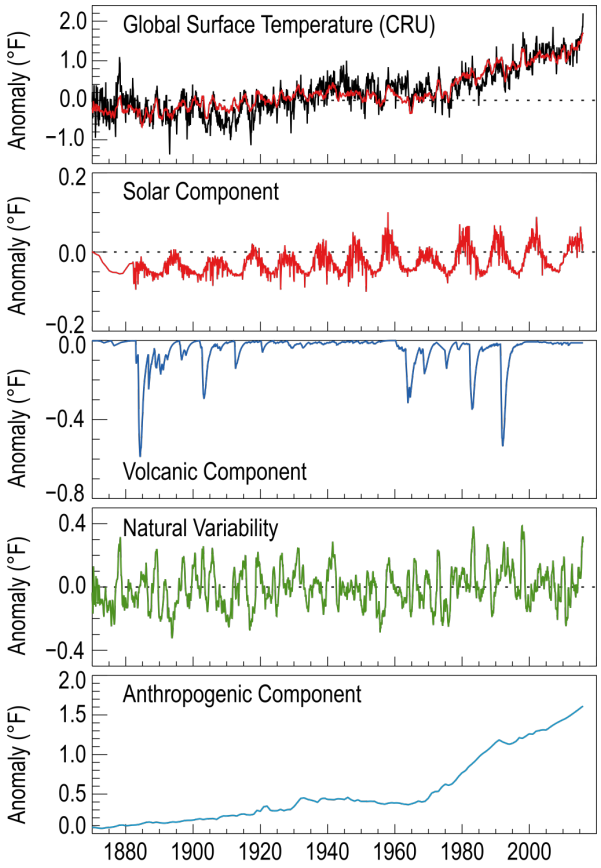


Fig. 9: Observed global surface temperatures (first row) and estimated contributions to temperature anomalies from four factors (from Knutson et al. 2017).

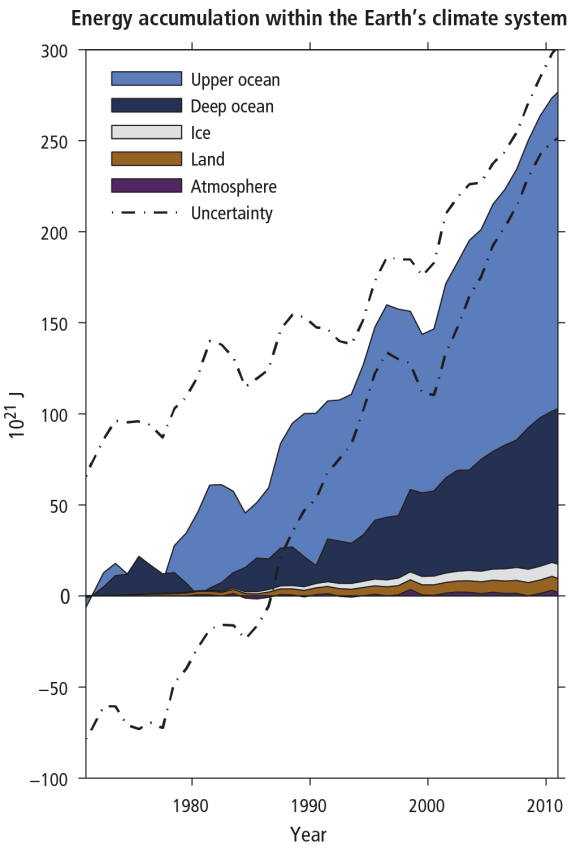


Fig. 10: Heat content of the climate system (from IPCC 2013, p. 264).

the oceans (Fig. 10). Overall, the energy accumulated within the Earth's climate system has continuously increased since 1999.

4.4 What can we learn from the climate of the past?

Sometimes, you might come across a sentence like this, taken from a recent position paper by the AfD, whose stance on global warming was discussed in section 3.3:

> "The climate has always been changing and will continue to change."[5]

Of course, this statement is not technically wrong, as it is also free of any information. What the sentence suggests, however, is that because the climate has changed naturally in the past, the present changes are not caused by humans. In his *Scientific Guide to Skepticism*, John Cook points out a good analogy: "This argument is like saying 'forest fires have happened naturally in the past so any recent forest fires can't be caused by humans' " (Cook 2010).

On a little more sophisticated level, climate change deniers like former Austrian FPÖ politician H.-C. Strache have brought up the argument that the temperatures in *some* places, notably in Greenland, had been higher in the past ("Greenland once was a green land, with viticulture"[6]). Indeed, today's temperatures in Greenland resemble the local conditions during the Medieval Warm Period around 1000 AD, even though the Nordic settlers certainly didn't grow any wine. (Weymann 2015). However, the contemporary, anthropogenic global warming differs from other warm periods by its *global* dimensions. Today, coherent warming is observed all over the globe, whereas warming was a relatively local phenomenon during the Medieval Warm Period (Neukom et al. 2019).

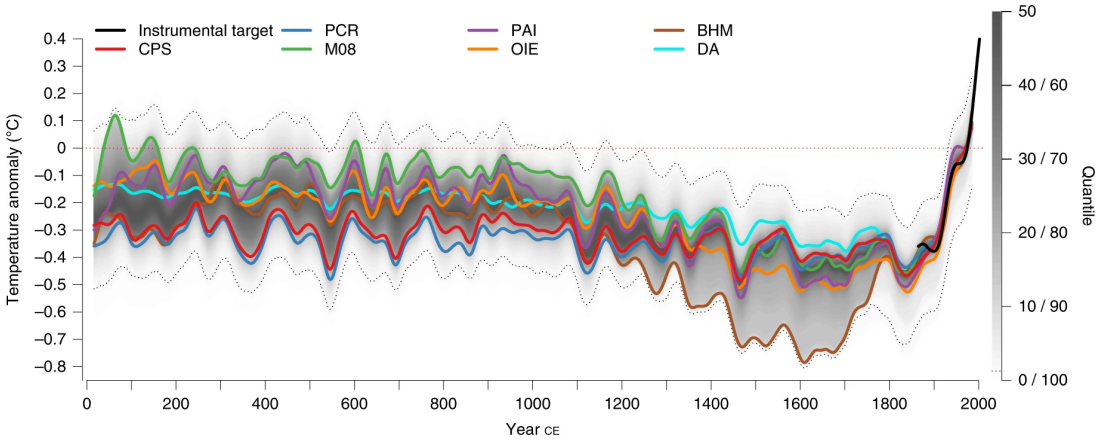


Fig. 11: Global temperature anomalies (with respect to 1961–1990) obtained by different reconstruction methods, and instrumental data starting in 1850 (from PAGES 2k Consortium 2019).

However, we can learn about many things by studying the paleoclimate, for example feedback mechanisms or the lag between CO_2 emissions and temperature change. We can also put the current warming into perspective by comparing global temperatures and atmospheric CO_2 concentrations. By comparing reconstructions of the global mean temperature from different proxies such as tree rings, corals, ice cores and sediments, it was shown that the current temperatures are higher that at any time during at least the last 2000 years (PAGES 2k Consortium

[5] F. Grobe: Studie [sic!] der AfD RTK – Fakten statt Fake News – 2. Teil. AfD Kreisverband Rheingau-Taunus, 06.05.2018,https://rtk.afd-hessen.org/studie-der-afd-rtk-fakten-statt-fake-news-2-teil/.

[6] P. Gensing: Die Legende vom Wein aus Grönland. Tagesschau.de, 09.06.2017, https://www.tagesschau.de/faktenfinder/ausland/strache-wein-groenland-101.html.

2019, Fig. 11). The atmospheric CO_2 concentrations, currently at 412 ppm (December 2019), are also at their highest level in more than 2.5 million years (IPCC 2013, p. 395; Fig. 12).

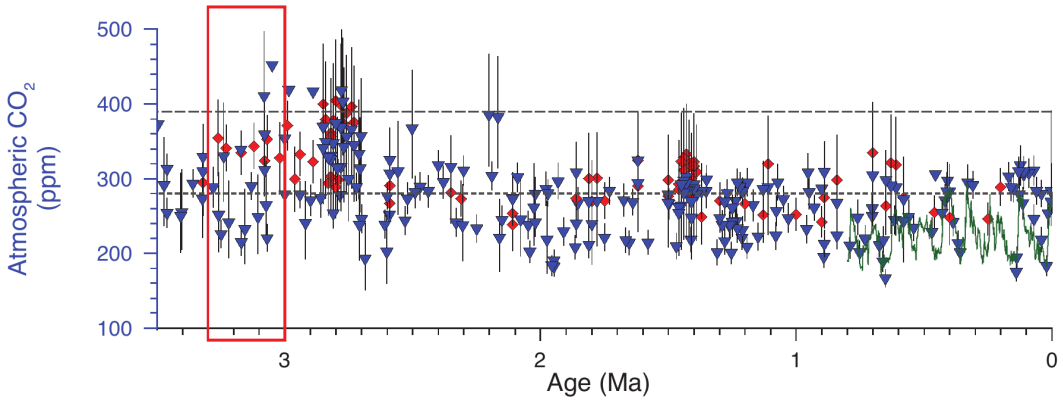


Fig. 12: Reconstructions of atmospheric CO_2 levels during the last 3.5 million years, using phytoplankton (red) and boron from marine sediments (blue) as proxies. Measurements from Antarctic ice cores are shown by the green curve. The red box indicates the mid-Pliocene Warm Period, about 3.0 to 3.3 million years before present (from IPCC 2013, p. 395).

4.5 Impacts of global warming

Global warming does not only have an impact on the entire climate system, but also on the ecosystem, agriculture, the water cycle, public health, and socio-economical systems. The IPCC dedicates an entire working group to *Impacts, Adaptation, and Vulnerability*, which reviews the numerous effects (both negative and positive) of global warming. However, "skeptics" often claim that the positive effects of global warming such as CO_2 fertilization, the enhanced growth of plants due to more CO_2 available for photosynthesis, are not taken into account. In their official party program, the AfD even views a conspiracy to suppress the effects of CO_2 fertilization:

> "The IPCC and the German government conveniently omit the positive influence of CO^2 [sic] on plant growth and world nutrition."[7]

First, the conspiracy theory does not hold as the IPCC does indeed discuss the positive effects of CO_2 fertilization in its Fifth Assessment Report (e. g., IPCC 2014, pp. 158, 513). Second, in a real-world setting, the effects of additional CO_2 on plant growth cannot be seen in a vacuum. There are other limiting factors to plant growth such as nitrogen availability and precipitation – not taking them into account can lead to an overestimation of the CO_2 fertilization effect (Rosenthal and Tomeo 2013). It has also been shown that elevated CO_2 levels lead to a decrease in protein content in wheat and rice grains (Myers et al. 2014).

More importantly, heat waves, droughts and extreme precipitation events are becoming more frequent and more intense due to climate change, and can offset the positive effects on agriculture. Overall, the IPCC predicts "reductions in mean crop yields because of climate change and increases in yield variability" with *high confidence* (IPCC 2014, p. 519).

In summary, the "CO_2 is good for plant growth" argument is another example of cherry-picking one positive example from a large number of effects, most of which impact the systems named above in a negative way. An overview of the key global risks from climate change over

[7] AfD: *Manifesto for Germany. The Political Programme of the Alternative for Germany.* 30.4./1.5.2016, p. 78 https://cdn.afd.tools/wp-content/uploads/sites/111/2017/04/2017-04-12_afd-grundsatzprogramm-englisch_web.pdf.

the 21st century can be found in IPCC (2014, p. 64–65). Here, we only cite some findings to which the IPCC has assigned "high confidence":

"Increased risk of species extinction; Urban risks associated with water supply systems, energy systems, and housing; Displacement associated with extreme events; Violent conflict arising from deterioration in resource-dependent livelihoods; Water scarcity and increasing competition for water" (ibid.).

5 Conclusion

In this paper, we discussed some of the most popular myths around climate change, and how to debunk them with relatively simple scientific arguments. To satisfy the need for alternative narratives to fill these "gaps" with scientifically founded information, we have presented, e.g., anthropogenic "fingerprints" in the climate system (section 4.2), the steady rise in ocean heat content since 1999 (section 4.3), and the elevated global temperatures and CO_2 levels compared to the past 2000 or even millions of years (section 4.4).

In many cases, fallacies like selective representation or cherry-picking, or findings that are quoted out of context, represent the foundation of "skeptics' " arguments. Thus, when discussing global warming (especially in the media), it is always important to sit back for a second and think about how findings fit into the "big picture" of the global climate system. For these discussions, the arguments presented in this paper can be helpful.

Spreading the science behind climate change is a key to decreasing the degree of "skepticism" in the public, i.e., the number of people who believe that climate change is not mostly caused by human activities, or that there is no consensus among climate scientists. Citing that a "fundamental understanding of science [...] is essential for our society", Lugger (2020) advocates for "dialogues between researchers and the general public".

With regards to climate change, communicating uncertainties is an important element of science communication, and there have been attempts to construct protocols which are easy to deploy for scientists and easy to understand for science communicators and decision makers (Fischhoff and Davis 2014). It is a common misconception among scientists that communicating (high) uncertainties lead to a distrust in science (Frewer et al. 2003). On the contrary, in a study by Rabinovich and Morton (2012), people that perceived science as debate (rather than a search for absolute truth) were "more motivated by higher (rather than lower) uncertainty in climate change messages". Therefore, the nature of science taught in schools and transported by the media plays an important role.

On the other hand, as we saw especially in section 3.3, misinformation is systematically being diffused by a complex, global network of organized climate change denial. People involved in this network do not fit into the definitions of skeptics introduced in section 2, their minds about climate science being made up. Therefore, it is also important to communicate what sociologists, historians and others have found out about organized climate change denial during the past two decades.

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