A Brief (2000 years?) History of Climate Science

A Brief History of Climate Science

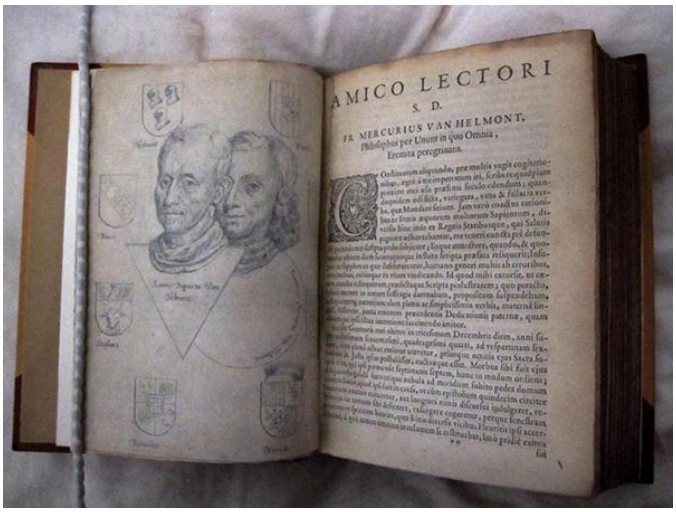
The following is a broad-brush look at how we have come to understand that humans can and are impacting the very climate of the Planet. Progress has been incremental and is based on contributions by tens of thousands of scientists over the centuries. Only a few events and people can be flagged here. Various sources are collected at the end, and are worth your time for further exploration.

4th Century BC - Climates might change at times. From ancient times, people suspected that the climate of a region could change over the course of centuries. For example, Theophrastus, a pupil of Ancient Greek philosopher Aristotle in the 4th century BC, told how the draining of marshes had made a particular locality more susceptible to freezing, and speculated that lands became warmer when the clearing of forests exposed them to sunlight. In the 1st century BC, Roman writer and architect Vitruvius wrote about climate in relation to housing architecture and how to choose locations for cities.

1088 - Climates can change. In his book published in 1088, Northern Song dynasty Chinese scholar and statesman Shen Kuo promoted the theory of gradual climate change over centuries of time once ancient petrified bamboos were found to be preserved underground in the dry climate zone and arid northern region of *Yanzhou*, now modern day Yan'an, Shaanxi province, far from the warmer, wetter climate areas of China where bamboos typically grow.

1300 - Maybe Humans can affect climates. Renaissance European and later scholars saw that deforestation, irrigation, and grazing had altered the lands around the Mediterranean since ancient times; they thought it plausible that these human interventions had affected the local weather

1640 - Carbon Dioxide Discovered. By van Helmolt



AbeBooks Ortus Medicinae, book by van Helmolt published in 1648

1701 - "Newton's Law of Cooling". Sir Isaac Newton is credited with formulating "Newton's Law of Cooling," which describes the rate of heat loss from a body as directly proportional to the temperature difference between the body and its surroundings

1760 - Industrial Revolution Begins

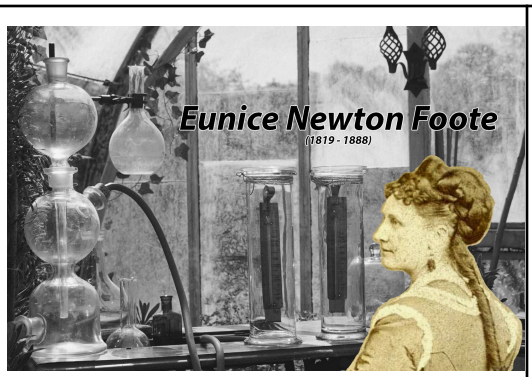
1824 - Warming gasses <u>proposed</u> as being in the atmosphere. Joseph Fourier proposes the existence of atmospheric greenhouse gasses to explain why the Earth is warmer than it would be if it were simply radiating its heat back to space. He based his work on "Newton's Law of Cooling"

1856 - Warming gasses demonstrated and CO2 singled out. Eunice Newton Foote demonstrated that the warming effect of the sun is greater for air with water vapour than for dry air, and the effect is even greater with carbon dioxide. *See CSSG-2.8 Hands-on Part 1 - The 1856 Gas-in-Jars Experiments*

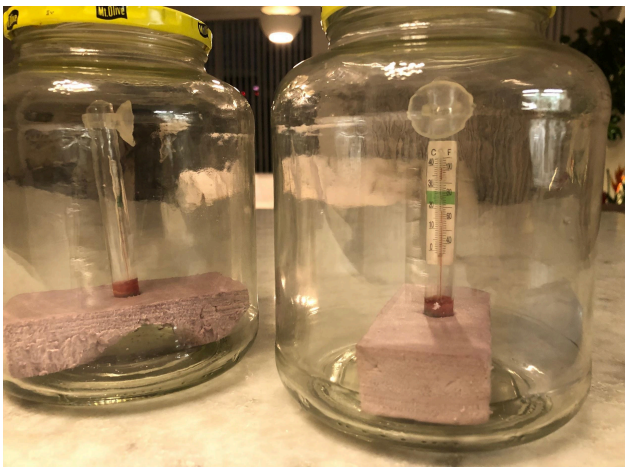
Prof. Henry then read a paper by Mrs. Eunice Foote, prefacing it with a few words, to the effect that science was of no country and of no sex. The sphere of woman embraces not only the beautiful and the useful, but the true. Mrs. Foote had determined, first, that the action of the rays increases with the density of the air. She has taken two glass cylinders of the same size, containing thermometers. Into one the air was condensed, and from the other it was exhausted. When they were of the same temperature the cylinders were placed side by side in the sun, and the thermometers in the con-

- - -

ing the moisture. Thirdly, a high effect of the sun's rays is produced in carbonic acid gas. One receiver being filled with carbonic acid, the other with common air, the temperature of the gas in the sun was raised twenty degrees above that of the air. The receiver containing the gas became very sensibly hotter than the other, and was much longer in cooling. An atmosphere of that gas would give to our earth a much higher temperature; and if there once was, as some suppose, a larger proportion of that gas in the air, an increased temperature must have accompanied it, both from the nature of



Eunice Foote's experiment for her studies on greenhouse gasses, as recreated in the 2018 short film "Eunice."

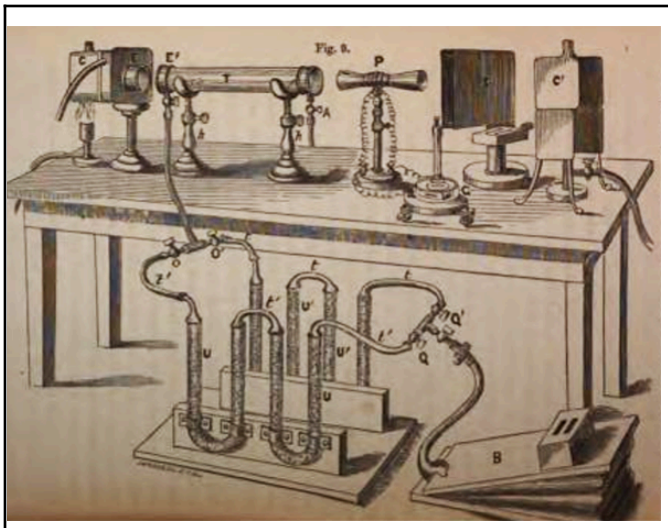


We duplicated her experiment in:

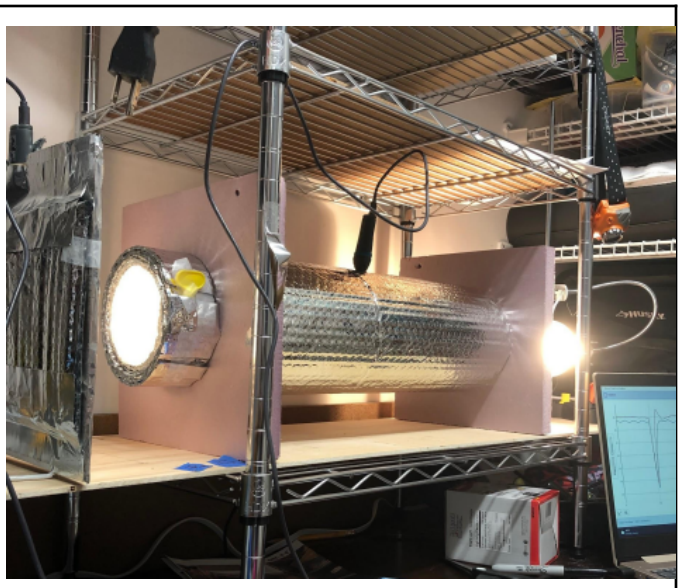
CSSG-2.8 Hands-on Part 1 - The 1856 Gas-in-Jars Experimen

1859 - Infrared absorption of CO2 and other greenhouse gasses measured.

John Tyndal measures these with accuracy.



John Tyndall's ratio spectrophotometer (drawing from 1861) measured how much infrared radiation was absorbed and emitted by various gasses filling its central tube.[1] Such measurements furthered understanding of the greenhouse effect that underlies global warming and climate change.



My independent experiment as seen in:
CPST Presentation Sept 7, 2023.pdf

1896 - First calculation of Earth's sensitivity to doubling CO2.

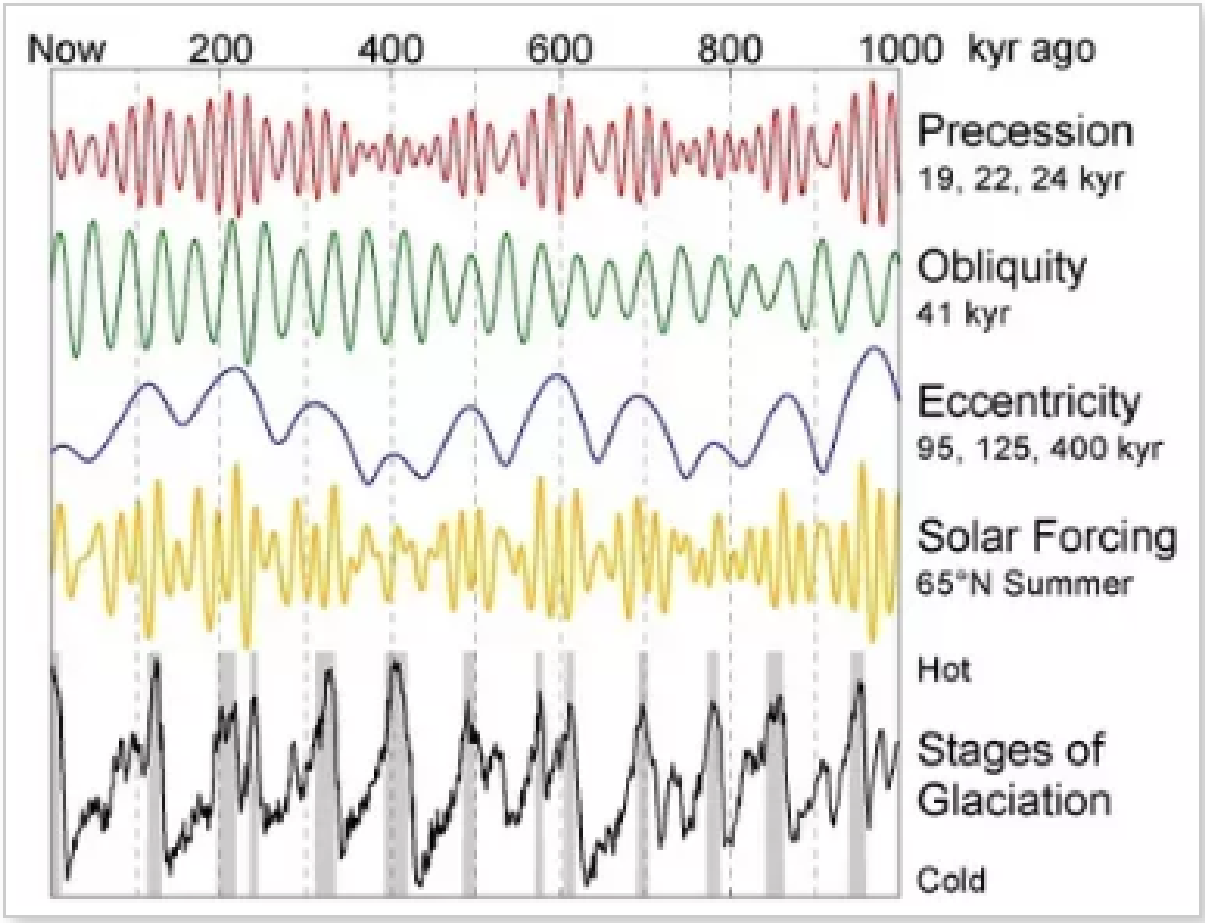
In 1896 Svante Arrhenius used Langley's observations of increased infrared absorption where Moon rays pass through the atmosphere at a low angle, encountering more carbon dioxide (CO_2), to estimate an atmospheric cooling effect from a future decrease of CO_2. He realized that the cooler atmosphere would hold less water vapor (another greenhouse gas) and calculated the additional cooling effect. He also realized the cooling would increase snow and ice cover at high latitudes, making the planet reflect more sunlight and thus further cool down, as James Croll had hypothesized. Overall Arrhenius calculated that cutting CO_2 in half would suffice to produce an ice age. He further calculated that a doubling of atmospheric CO_2 would give a total warming of 5–6 degrees Celsius.

1899 - Scientific Arguments develop that CO2 can cause Climate Change.

Thomas Chrowder Chamberlin developed at length the idea that climate changes could result from changes in the concentration of atmospheric carbon dioxide.[42] Chamberlin wrote in his 1899 book, *An Attempt to Frame a Working Hypothesis of the Cause of Glacial Periods on an Atmospheric Basis*:

1901 - The term "greenhouse effect" for this warming was introduced by Nils Gustaf Ekholm in 1901.

1920 - Milankovitch Cycles explain the Ice ages. Milankovitch cycles describe the collective effects of changes in the Earth's movements on its climate over thousands of years. The term was coined and named after the Serbian geophysicist and astronomer Milutin Milanković. In the 1920s, he hypothesized that variations in eccentricity, axial tilt, and precession combined to result in cyclical variations in the intra-annual and latitudinal distribution of solar radiation at the Earth's surface, and that this orbital forcing strongly influenced the Earth's climatic patterns.



Milankovitch cycles over the past 1 000 000 years. Source: Global Warming Art

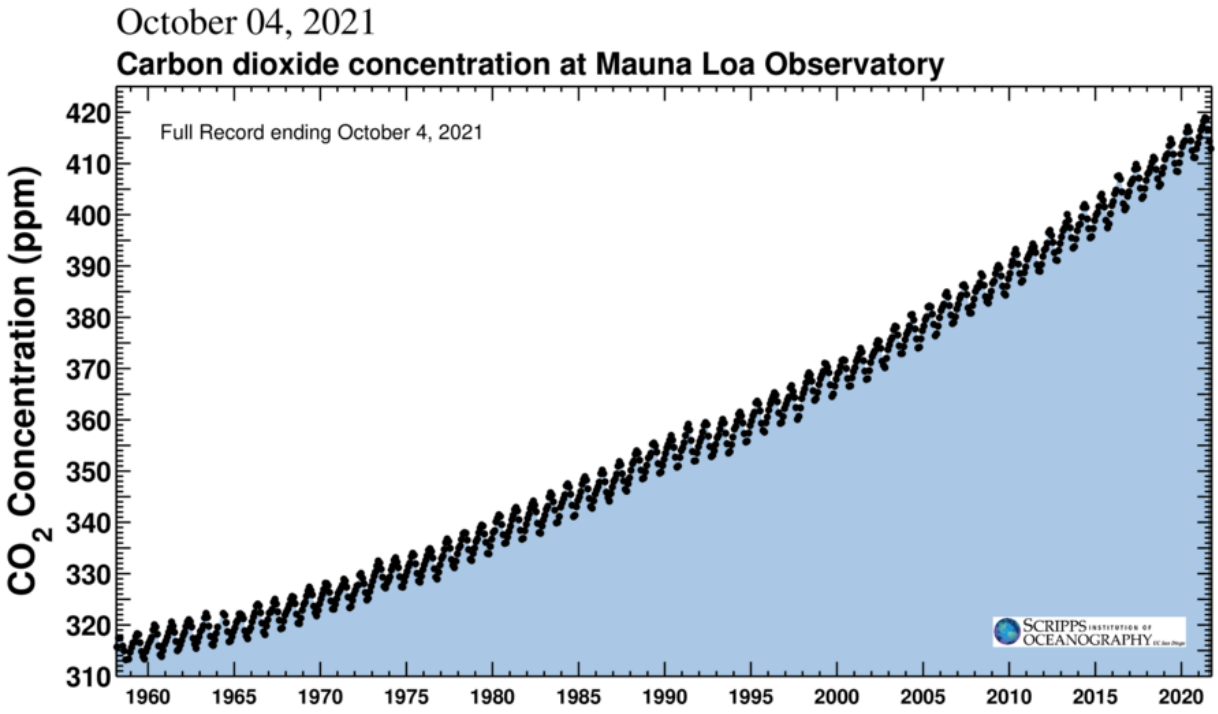
1938 - Proof that global temperatures are rising. In 1938, steam engineer Callendar decided to take a break from his day job and began painstakingly collecting records from 147 weather stations across the world. Doing all his calculations by hand, he discovered that global temperatures had risen 0.3°C over the previous 50 years.

Callendar argued that carbon dioxide (CO_2) emissions from industry were responsible for global warming. However, this was largely ignored by other scientists who didn't believe that humans could impact such a large system as the climate.

ABOVE: Amateur scientist Guy Callendar's crude estimates of global warming were extremely accurate – and in line with modern assessments. **Picture:** G.S. Callendar Archive, University of East Anglia

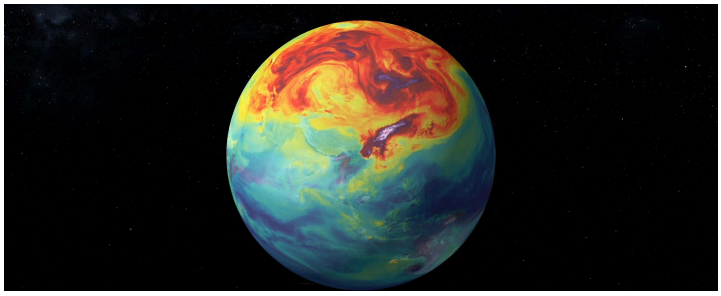
1958 - Proof that CO2 levels are rising, and fossil fuels are to blame

Measurements of the amount of CO2 in water and in the air, made over five years in the 1950s and 60s by Charles David Keeling, provided unequivocal proof that CO2 concentrations were rising. It led to the Keeling Curve, which has documented daily changes in CO2 levels for over six decades. Keeling's discovery is acknowledged as one of the most important scientific works of the 20th century. **What's more, by analyzing the CO2 in his samples, Dr Keeling was able to attribute this rise to the use of fossil fuels.**



1967 - the world's first accurate computer model of planet Earth's climate.

In 1967, researchers Syukuro Manabe and Richard Wetherald produced the world's first accurate computer model of planet Earth's climate – it predicted that doubling concentrations of CO2 in the atmosphere could raise global temperatures by 2 degrees.



1968 - Scientist predicts melting ice caps. Dr John Mercer, a glaciologist at Ohio State University in Columbus, warns that global warming could cause Antarctic ice sheets to collapse, leading to a disastrous rise in sea levels

In 1968, Dr Mercer was conducting fieldwork at the Reedy Glacier in West Antarctica when he **discovered evidence of a former freshwater lake**, 1,400 meters high up in the Transantarctic Mountains. Dr Mercer took that as evidence that the entire West Antarctic Ice Sheet had once melted away, something that previously had been thought to be impossible. He warned that current atmospheric warming could once more cause the ice shelves to disintegrate, causing a sea level rise of about five meters.

Picture: Getty Images

1968 - Petroleum Industry fully aware of penalty of burning fossil fuels.
American Petroleum Institute Study performed by Stanford Research Institute

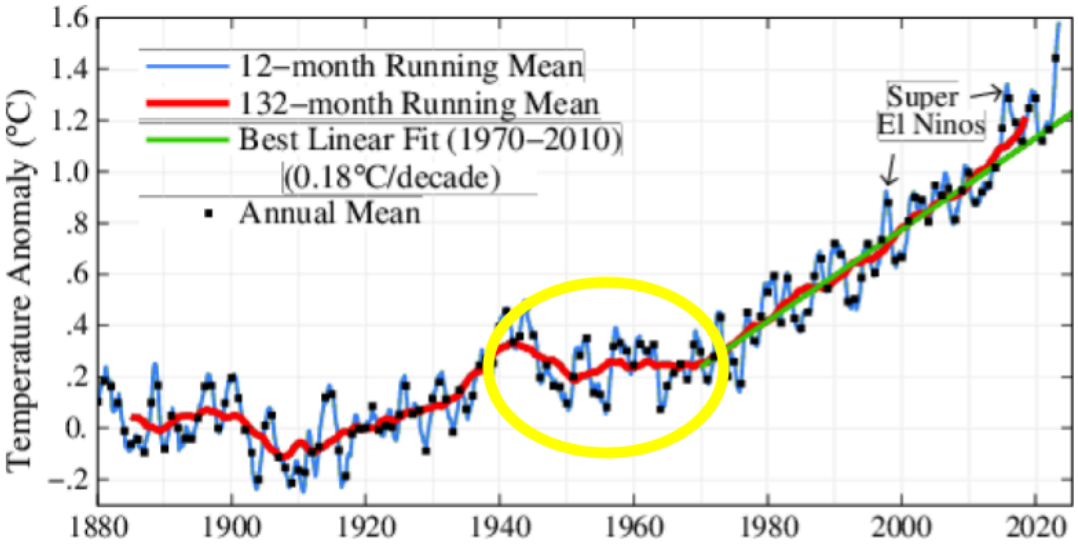
> “If the earth's temperature increases significantly, a number of events might be expected to occur, including the melting of the Antarctic ice cap, a rise in sea levels, warming of the oceans, and an increase in photosynthesis. ... Revelle makes the point that man is now engaged in a vast geophysical experiment with his environment, the earth. Significant temperature changes are almost certain to occur by the year 2000 and these could bring about climatic changes.”

1969 - Earth's temperature measured with satellites for first time. NASA's Nimbus III satellite is launched into orbit – it provides the world's first accurate measurement of global atmospheric temperatures. The Nimbus satellites revolutionized how scientists study the Earth's climate, weather systems and atmosphere.

First launched in 1964, over the course of 30 years the series of satellites provided us with never-before-seen data on global temperatures, the concentration of greenhouse gases in the atmosphere, the ozone layer, as well as sea ice thickness. It also allowed scientists to develop computer models that could forecast weather a week, or even two weeks, in advance, virtually impossible beforehand.

The Nimbus III satellite was the first to include instruments that could measure atmospheric temperature. This provided an independent satellite record confirming that the Earth's lower atmosphere was warming.

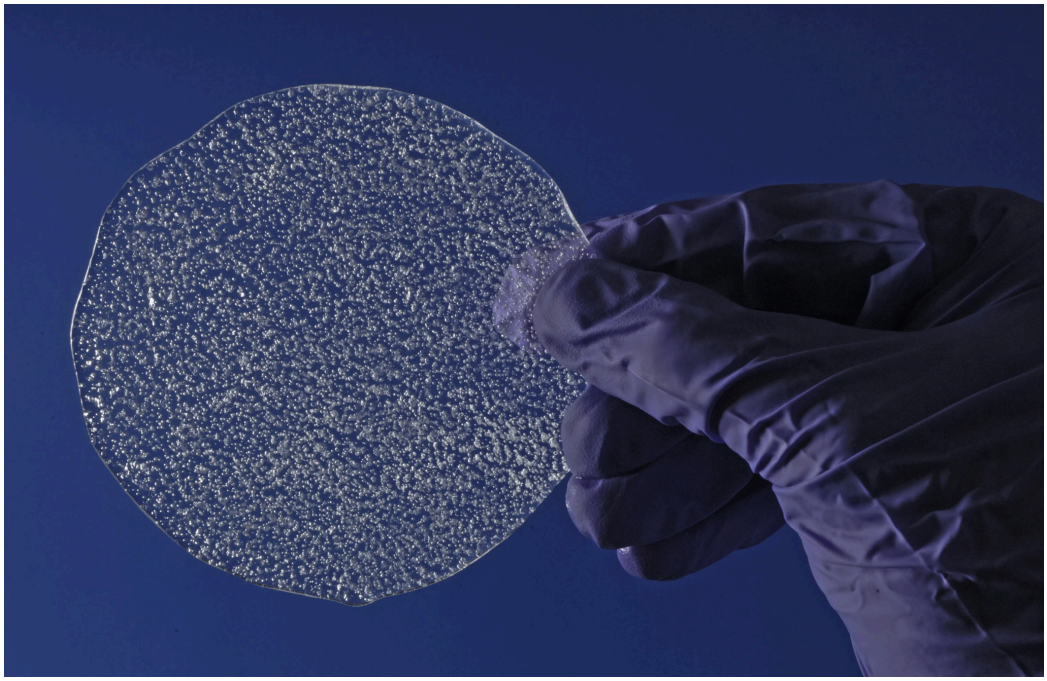
1970s - Scientists increasingly predict warming vs. cooling



Note the “Cooling Period” from 1940 - 1975. It turns out this was a result of aerosol pollution from burning fossil fuels reflecting incoming sunlight and not ice-age cycle cooling.

In the early 1970s, evidence that aerosols were increasing worldwide and that the global temperature series showed cooling encouraged Reid Bryson and some others to **warn of the possibility of severe cooling**. The questions and concerns put forth by Bryson and others launched a new wave of research into the factors of such global cooling.[59] Meanwhile, the new evidence that the timing of ice ages was set by predictable orbital cycles suggested that the climate would gradually cool, over thousands of years. Several scientific panels from this time period concluded that **more research was needed to determine whether warming or cooling was likely**, indicating that the trend in the scientific literature had not yet become a consensus.[69][70][71] For the century ahead, however, a survey of the scientific literature from 1965 to 1979 found 7 articles predicting cooling and 44 predicting warming (many other articles on climate made no prediction); the warming articles were cited much more often in subsequent scientific literature.[59] Research into warming and greenhouse gasses held the greater emphasis, with nearly six times more studies predicting warming than predicting cooling, suggesting concern among scientists was largely over warming as they turned their attention toward the greenhouse effect.[59]

1985 - Direct Measurements of Ancient Atmospheres. Drilling 150,000 years deep into the ice. Ice cores extracted from Antarctica confirm that CO2 and temperature have gone up and down together over the past 150,000 years. Ice cores provide key information about what the Earth's climate was like in the past.



ABOVE: Ice cores provide key information about what the Earth's climate was like in the past. The deeper you dig the further back in time you go. This slice shows the bubbles of trapped air thousands of years ago. This provides key information about what the Earth's climate was like in the past. Picture: Pete Bucktrout, British Antarctic Survey

In 1998 the team extracted an even longer ice core, extending the climate record back to **420,000 years** ago. Both cores showed a clear relationship between levels of atmospheric greenhouse gases and Antarctic temperature over time. As greenhouse gases had gone up, so had temperatures. What's more, they showed that present levels of CO2 and methane in the atmosphere are above anything seen in the past 420,000 years.

In 2004, ice core scientists at British Antarctic Survey (BAS) were part of a team that extracted a three-kilometer ice core from the Antarctic. This core contains a record of the Earth's climate stretching back **800,000 years**, giving us by far the oldest continuous climate record yet obtained from ice cores.

1980–1988 - Consensus begins to form

James Hansen during his 1988 testimony to Congress, which alerted the public to the dangers of global warming

By the early 1980s, **the slight cooling trend from 1945 to 1975 had stopped**. Aerosol pollution had decreased in many areas due to environmental legislation and changes in fuel use, and it became clear that the cooling effect from aerosols was not going to increase substantially while carbon dioxide levels were progressively increasing.

Hansen and others published the 1981 study *Climate impact of increasing atmospheric carbon dioxide*, and noted:

It is shown that the anthropogenic carbon dioxide warming should emerge from the noise level of natural climate variability by the end of the century, and there is a high probability of warming in the 1980s. **Potential effects on climate in the 21st century** include the creation of drought-prone regions in North America and central Asia as part of a shifting of climatic zones, erosion of the West Antarctic ice sheet with a consequent worldwide rise in sea level, and opening of the fabled Northwest Passage.

1988 - The Intergovernmental Panel on Climate Change (IPCC)

ABOVE: Formed in 1988, the Intergovernmental Panel on Climate Change heralded a new era of climate research. Its reports provide policymakers with regular scientific assessments on the current state of knowledge about climate change. NERC scientists have authored and reviewed key chapters in every report to date. Picture: Getty Images

Established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO), the Intergovernmental Panel on Climate Change (IPCC) is the United Nations body responsible for assessing the science related to climate change. The IPCC provides policymakers with regular scientific assessments on the current state of knowledge about climate change

So far, the IPCC has published six Assessment Reports written by the world's most renowned experts on climate change. These are the most comprehensive scientific reports produced about climate change worldwide. The reports have been the cornerstone upon which international climate change negotiations have relied. Each Assessment Report includes analysis of several thousand published scientific papers, written and edited by the very best experts in their field. For the latest three IPCC Special Reports, IPCC authors assessed around 20,000 publications and considered around 100,000 comments from more than 2,500 experts.

Since 1990 these reports have consistently found that the Earth is warming, and that the release of greenhouse gasses by humans is responsible.

1990 - Treaty: United Nations Framework Convention on Climate Change

In 1990, the First IPCC Assessment Report played a decisive role in the creation of the United Nations Framework Convention on Climate Change, a key international treaty to reduce global warming and cope with the consequences of climate change.

The United Nations Framework Convention on Climate Change was the first international treaty designed to limit greenhouse gas emissions. It led directly to the 1995 Kyoto Protocol, which committed industrialized countries and economies to limit and reduce greenhouse gasses emissions.

1992 - Coral reefs at threat

ABOVE: When CO2 dissolves in the ocean, it raises the water's acidity level. High acidity can kill any creature that forms a shell, including coral. Coral provide a vital ecosystem for life underwater as well as a crucial source of income for millions of people. **Picture:** NERC

Scientists realize that higher levels of CO2 in the ocean will make it harder for corals and other animals to build reefs. When CO2 dissolves in the ocean, it raises the water's acidity level. This stops corals from sucking in a vital mineral called calcium carbonate, which they use to build their skeletons.

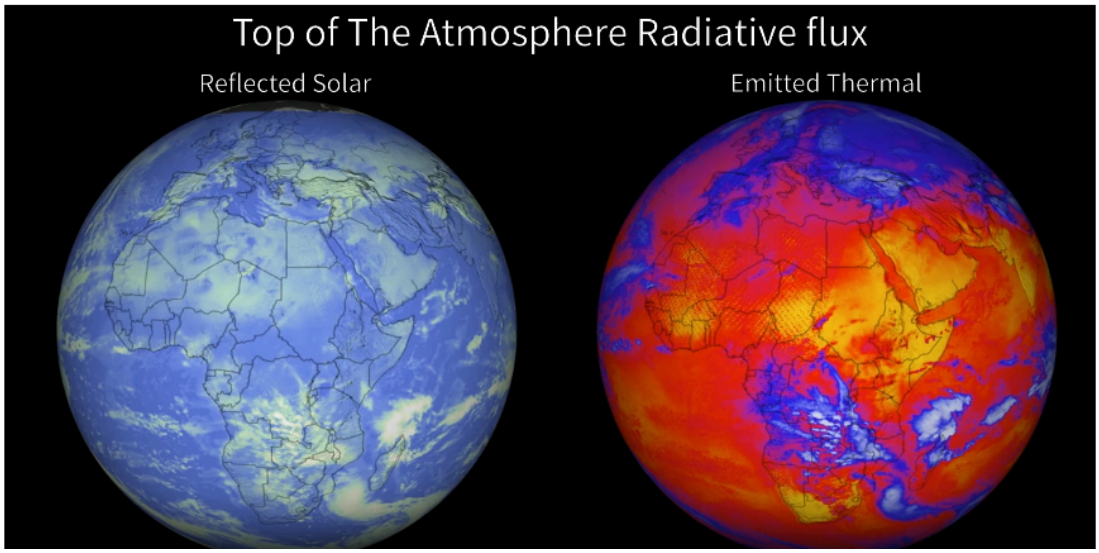
US scientists Professor Stephen Smith and Professor Robert Buddemeier were the first to warn of this consequence of ocean acidification. Since then, evidence that there's a problem has continued to mount. **It's not just corals that are at risk; all creatures that form shells are in danger, including oysters, mussels, clams and some planktonic species.**

1994 - First climate change legislation comes into force. 197 countries signed up to the first global treaty to combat climate change. The United Nations Framework Convention on Climate Change (UNFCCC) was the first international treaty designed to limit greenhouse gas emissions and prevent climate change. It entered into force on 21 March 1994, and has been ratified by 197 countries.

1997 - Kyoto Protocol commits nations to action. The Framework Convention and the Second Assessment Report in 1995 led directly to the 1995 Kyoto Protocol, which committed industrialized countries and economies to limit and reduce greenhouse gasses emissions in accordance with agreed individual targets.

2001 - Present: Direct <u>measurements</u> of the Earth's Energy Imbalance. For the first time, scientists (from satellites) can directly measure the i**ncoming energy** striking the earth from the sun and, at the same time, measure the **outgoing energy** from the earth. This tells how much excess energy the planet will have to deal with.

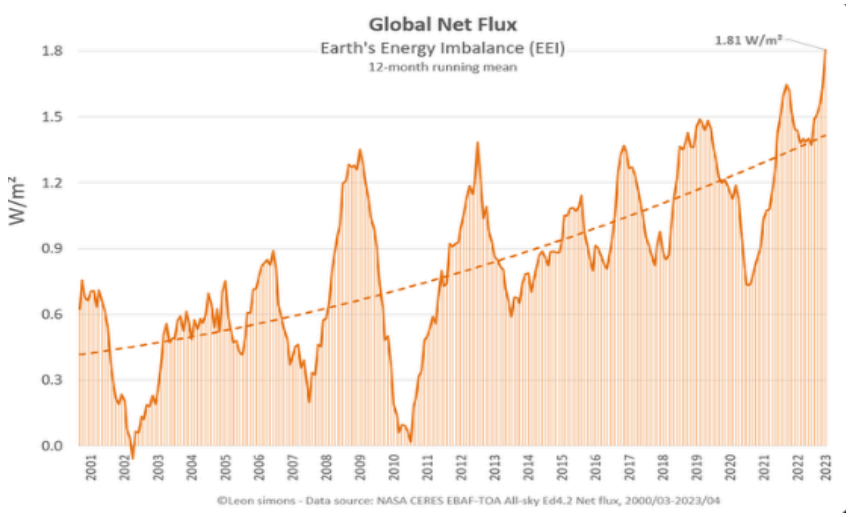
CERES Top of Atmosphere Radiative Flux



These measurements from the Clouds and Earth's Radiant Energy System (CERES) satellite instruments are calibrated to the actual ocean heating. The result is that we know how much excess energy is impacting the earth.

(W/m^2 averaged over the Earth's surface)

It is increasing over time ⇒ Accelerated Warming [a]



This graph records estimates of net top-of-the-atmosphere annual energy flux from the CERES satellite. Credit: NASA

2003 - Scientists link extreme weather to climate change. A heatwave in Europe kills tens of thousands of people – scientists say that climate change is to blame. Up until a few years ago, it wasn't possible to draw a link between extreme weather and climate change with any degree of accuracy. However, that changed in 2004 when Professor Pete Stott, a scientist at the UK Met Office, published a paper in the scientific journal Nature **showing that climate change had doubled the risk of the 2003 European heatwave** that killed tens of thousands of people.

His finding led to a growing scientific movement called **extreme event attribution**. This is where researchers point to an extreme weather event and use climate modeling to say whether the likelihood of the event happening would be the same in a world without climate change. **Today's scientists are able to calculate the impact of global warming on droughts, heatwaves and floods with remarkable accuracy.**

2007 - The Arctic is warming twice as fast as the rest of the planet

Polar regions are warming twice as fast as the rest of the Earth, putting polar bears and other wildlife at risk. The **International Polar Year 2007-2008** was the largest campaign ever mounted to explore Earth's polar regions. Around 50,000 scientists, students and support staff from over 60 nations convened to unlock the secrets of the Arctic and Antarctic.

ABOVE: The Greenland and Antarctic ice sheets are melting at an accelerating rate. Their collapse could raise sea levels by 10 meters. Picture: Picture: Danielle Barnes, Unsplash

What they found was alarming. The Greenland ice sheet, parts of the Antarctic ice sheet, and Arctic sea ice are melting at rates that are unprecedented in the last 10,000 years. The poles are also warming faster than the rest of the planet, one of the key predictions of climate models. One of the reasons for this increased warming is due to something called Ice-albedo feedback. Ice is highly reflective, so a lot of solar radiation that hits the polar regions bounces back into space.

2015 - Paris agreement supersedes Kyoto

The Kyoto Protocol was then superseded by the Paris Agreement in 2015, which legally required countries to reduce their carbon emissions in order to limit global warming to 1.5°C compared to pre-industrial levels. Finally, the Fifth Assessment Report provided the foundation for the 2015 Paris agreement where 195 countries agreed to limit global warming to less than 2°C above pre industrial levels.

2018 - Attribution of weather severity to Climate Change

ABOVE: Research by Dr Friederike Otto at the UKRI-funded Environmental Change Institute showed that the 2018 heatwave that engulfed northern Europe was made twice as likely due to climate change. She also found that the risk of extreme rainfall in any given winter has risen by 25%. **Picture:** Brad Wakefield

Dr Otto showed that the 2018 heatwave that engulfed northern Europe was made twice as likely due to climate change. She also found that the risk of extreme rainfall in any given winter has risen by 25%.

2019 - Ice collapse may <u>already be 'irreversible'</u>. Ice sheets in Antarctica and Greenland may have already passed the point of no return; their collapse could raise sea levels by 10 meters

A special report by the Intergovernmental Panel on Climate Change (IPCC) warns that part of an ice sheet known as the **Amundsen Sea embayment of West Antarctica** might have already passed a tipping point, with collapse now unavoidable.

Climate models suggest that when this sector collapses, it could destabilize the rest of the West Antarctic ice sheet like falling dominoes. This would cause sea levels to rise by three meters over a timescale of centuries to millennia.

The report says that part of a separate **East Antarctic ice sheet** known as the Wilkes Basin might also be unstable.

The **Greenland ice sheet** is also melting at an accelerating rate, and could add a further seven meters to sea levels. Models show that the Greenland ice sheet will collapse when the Earth warms to 1.5°C above pre-industrial levels, which could happen as soon as 2030.

The collapse of these three ice sheets will raise sea levels by around 10 meters over the period of thousands of years. However, how quickly they rise depends on the magnitude of global warming.

If we limit warming to 1.5°C, it could take 10,000 years to unfold. Above 2°C it could take less than 1,000 years.

2019 - Variety of life on Earth being lost at "unprecedented" pace. A 2019 report by the UN found that the number of native species on the planet has plummeted since 1900. Up to **one million animal and plant species are now threatened with extinction,** and many could die out within decades.

ABOVE: Sumatran tigers are a critically endangered carnivore restricted to the island of Sumatra. Like many other large mammals on the Indonesian archipelago, they are threatened by high levels of poaching and widespread habitat degradation. **Picture:** Mark Mallett, UKRI

The report, written by 145 experts from 50 countries, is the most comprehensive assessment of global biodiversity ever to take place. It found that at least 680 vertebrate species have been driven to extinction since the 16th century. **The rate of species extinctions is also accelerating, with grave impacts on people around the world.**

More than 40% of amphibian species are now at risk of extinction. Over a third of all marine mammals and 33% of reef-forming corals are also threatened.

The main factors driving this mass extinction are changes in land and sea use, direct exploitation of organisms, climate change, pollution and the introduction of invasive alien species.

2021 - Many aspects of climate change are now inevitable and irreversible

Scientists predict the world will reach 1.5C of warming by 2040, earlier than initial warnings. That level of warming will lead to more heatwaves, intense storms, droughts and floods

The findings are reported in the latest Assessment Report by the IPCC, the world's leading authority on climate science. The report delivers scientists' starkest warning yet about the deepening climate emergency. It warns that we are already observing changes in the Earth's climate that are unprecedented in thousands, if not hundreds of thousands of years.

They include more intense rainfall and associated flooding, more intense drought in many regions, sea level rises in coastal areas, permafrost thawing, ocean acidification and others.

The report says that these changes are 'unequivocally' caused by humans burning fossil fuels.

The assessment predicts that temperatures are likely to rise to more than 1.5°C above pre-industrial levels within just two decades.

This means that many changes such as sea level rises, the melting of Arctic ice and the warming and acidification of the oceans, are now irreversible and set in stone.

It's not too late to prevent further warming of 2°C; through drastically reducing carbon emissions in the next decade.

The 1.5C target is crucial, because beyond this point climate tipping points become more likely. Tipping points are when rising temperatures trigger a series of cascading events with dire consequences. For example melting Arctic permafrost releases methane into the atmosphere, which causes even more warming.

2024 - Direct measurement of CO2 action in Atmosphere

Direct observational evidence from space of the effect of CO2 increase on longwave spectral radiances: the unique role of high-spectral-resolution measurements

Punchlines

- **Scientist prior to the industrial age had laid a foundation for understanding what might happen**
- **Before global warming was observed, it was predicted**
- **Measurements showed pre-historical and real-time climate changes**
- **In the 1970s, scientists pursued indications of possible cooling as well as warming, and, with improved measurements and understanding concluded that human-caused warming is what is happening.**
- **Worldwide concerns inspired global treaties for study and action.**
- **Direct measurements of accelerated warming show we are only impacting the planet more.**

References for this Study

A brief history of climate change discoveries
Overlooked No More: Eunice Foote, Climate Scientist Lost to History - The New York Times
History of climate change science - Wikipedia
Milankovitch (Orbital) Cycles and Their Role in Earth's Climate - NASA Science
History of Climate Science Research
CSSG-2.8 Hands-on Part 1 - The 1856 Gas-in-Jars Experiments
Milankovitch cycles
Science – CERES
Timing and Impacts Study - Latest Update

Approximate "Cheat Sheet":

1 meter → 3 feet **1 degree Celsius (^{0}C)** → 2 degree Fahrenheit (^{0}F)
ppm = parts per million **CO_2** = Carbon Dioxide
1 tonne = 1000 kilograms = 2205 pounds **1 gigatonne (1 Gt)** = 1 billion tonnes
1 trillion tonnes (1Tt) = 1000 gigatons

GOOD NEWS CORNER

Some intellectual good can come from melting ice sheets: ancient artifacts.

Climate change reveals secrets of our ancestors hidden in the ice

Our Natural World

https://www.sciencefocus.com/nature/wildlife-photographer-of-the-year-at-60

Winner of Behaviour: Mammals category

This baby toque macaque (Macaca sinica) is so relaxed suckling milk from its mother that it has fallen asleep. Toque macaques easily adapt to human foods, and the encroachment of plantations into their habitat has seen an increase in incidents of shooting, snaring and poisoning by farmers trying to preserve their crops. Photographed at the Wilpattu National Park, Sri Lanka. Photo by Hikkaduwa Liyanage Prasantha Vinod/WPOTY