What do we know with very high confidence about Past Global Conditions and Causes ?

Paleo: Part 1 - The last 800,000 Years

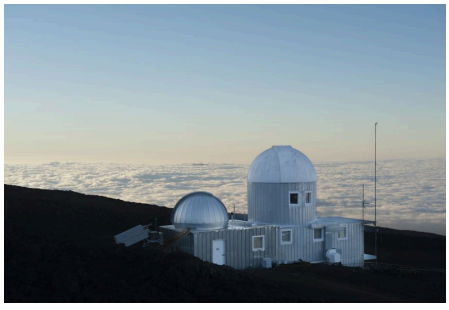
General Note: I often will provide links to source materials, typically shown in hot-link blue. Many will be great and readable expansions of the topic at hand. Others are excellent references for the future, such as up-to-date data on Carbon Dioxide levels, etc. As you read through my thoughts, you'll greatly benefit by at least **skimming the links as you go**. You likely will be amazed at the quality and breadth of information available.

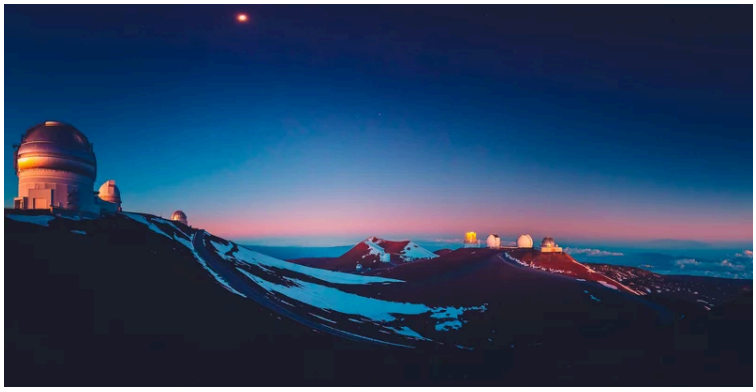
A little history:

It is worth a few minutes to get oriented to Global Warming. From the early 1800s, there was a growing awareness that there must be something in the atmosphere holding some heat in. The planet should have been far colder, even frozen, but it was comfortably not. A nice history is available at; https://www.history.com/topics/natural-disasters-and-environment/history-of-climate-change#early-inklings-that-humans-can-alter-global-climate

Svante Arrhenius (1859-1927) was a Swedish scientist who was the first to claim in **1896** that fossil fuel combustion may eventually result in enhanced global warming. He proposed a relation between atmospheric carbon dioxide concentrations and temperature. History of the greenhouse effect and global warming - Lenntech

By the 1950s instruments had become sensitive enough to accurately measure CO2 in the atmosphere.





This has since been carefully recorded at Mauna Loa Observatory, Hawaii and in the Antarctic. Since CO2 mixes well in the atmosphere, these values closely track the average for the globe. The current level of CO2 in the atmosphere is about **420 parts per million (ppm)**, and is rising steadily.

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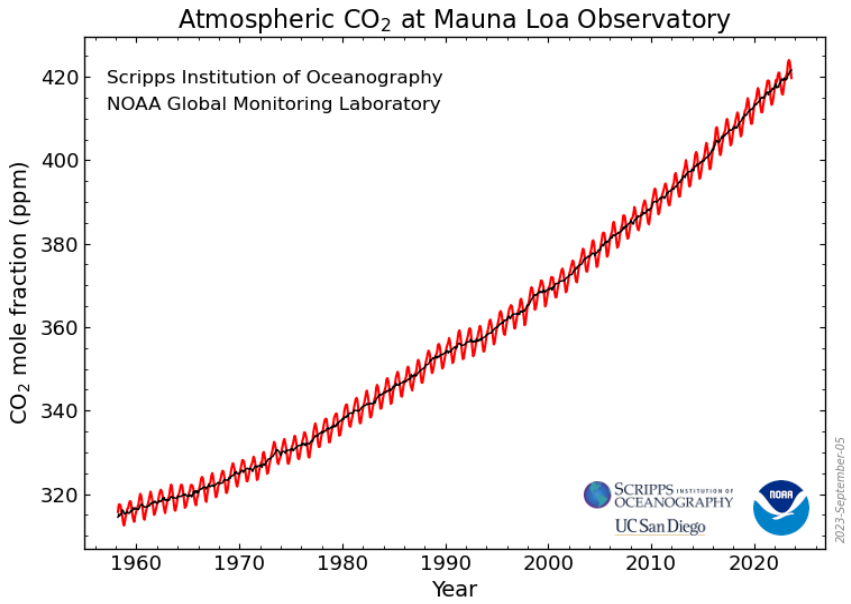
The Mauna Loa data is captured as the famous Keeling Curve, below. Here is the Keeling Curve as of **August, 2023**. You can keep track of it at: https://www.esrl.noaa.gov/gmd/ccgg/trends/.



These **DIRECT measurements** of atmospheric CO2 were soon **supplemented by drilling ice cores** into glaciers and the polar ice caps. It is amazing that tiny air bubbles, with their even tinier parts of CO2 and other gases can be recovered intact from thousands of years ago. The data is high quality.

More and deeper cores drove our understanding further into the past. As an illustration, here are data logs from three different antarctic and glacier sites:

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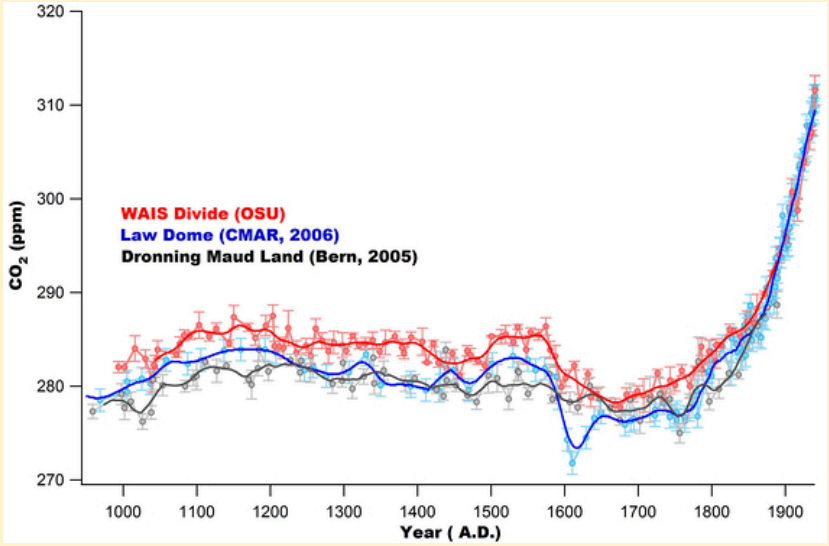
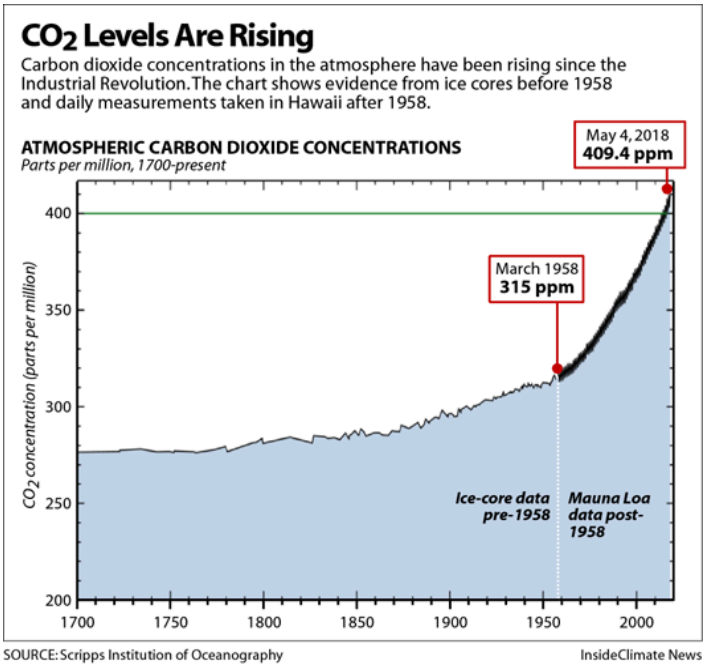


https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2011GB004247

Here is the (smoothed) data from the industrial age (roughly since 1750; since that time, we have been using fossil fuels for heating, industry, transportation, and energy); a much further back look is covered in the next section. https://insideclimatenews.org/content/chart-atmospheric-co2-levels-have-been-rising



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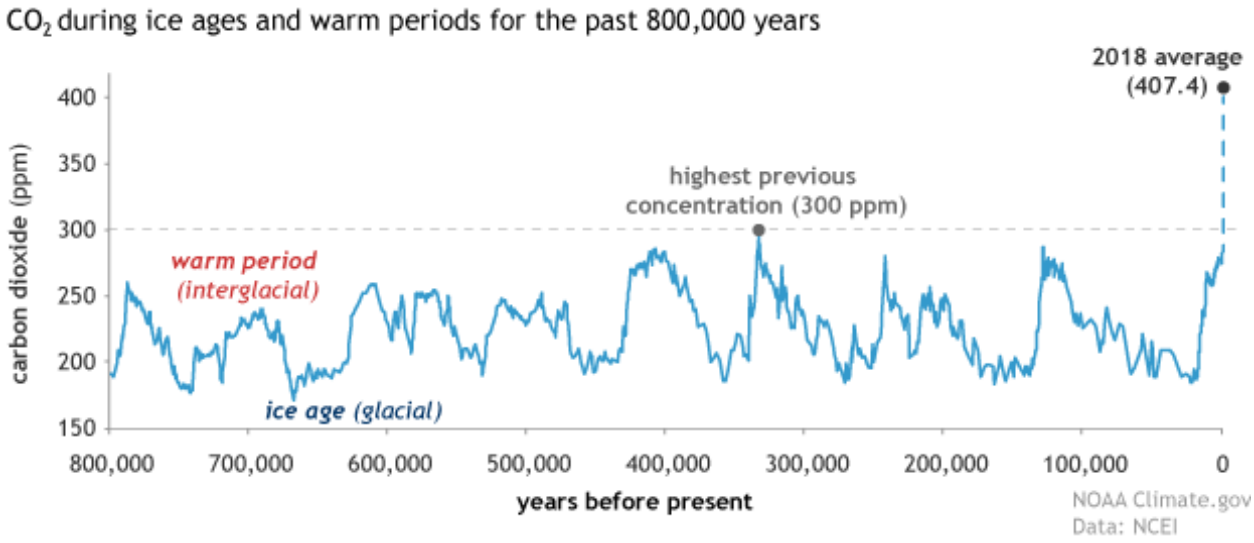
Before historic times, we also know a great deal with surprising accuracy. Atmospheric gases were preserved in the Greenland and Antarctic ice as the ice was laid down and packed. By taking core samples, a clear and direct **800,000 year history** of oxygen and carbon dioxide concentrations, and those of their isotopes (which will be important for a later question), has been documented.

It turns out that over the last **800,000 years, the maximum value for CO2 in the atmosphere was always around or well below 280-300 parts per million (ppm)** and this upper level was only reached approximately every 100,000 years (related to various features of the earth's orbit) . An expanded discussion can be found at https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide and https://climate.nasa.gov/news/2616/core-questions-an-introduction-to-ice-cores/ the results are provided here:



The chart below contains FAR MORE information than is important to understand at this point, so don't get bogged down.

It does contain a single key insight: **DURING THE LAST 800,000 YEARS OF ICE AGES,** THERE IS AN UNBELIEVABLY STRONG CORRELATION AMONG GLOBAL TEMPERATURES, CO2 AND OTHER GASES, SEA LEVELS, AND PERTURBATIONS OF THE EARTH'S ORBIT (eccentricity, obliquity, and precession). These solar/earth interactions are called Milankovitch Cycles, and it turns out that the 800,000+ years of ice ages were definitely driven by these cycles. There is more information below, and we'll discuss these Milankovitch Cycles when we're together.

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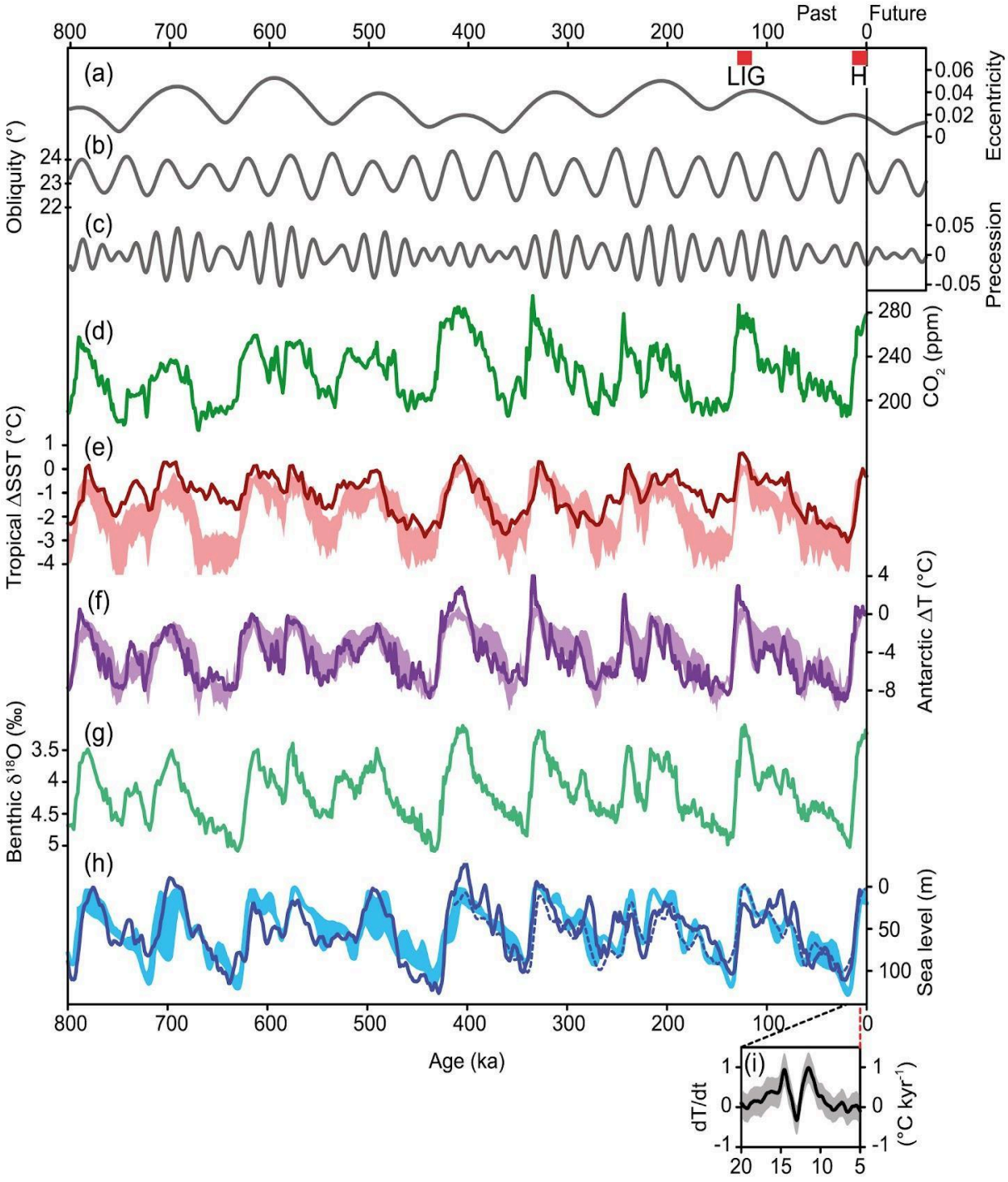
IPCC 2013 WG1 Figure 5.3



[Info only: 2013 IPCC WG1 Figure 5.3 Orbital parameters and proxy records over the past 800 kyr. (a) Eccentricity. (b) Obliquity. (c) Precessional parameter. (d) Atmospheric concentration of CO2 from Antarctic ice cores. (e) Tropical sea surface

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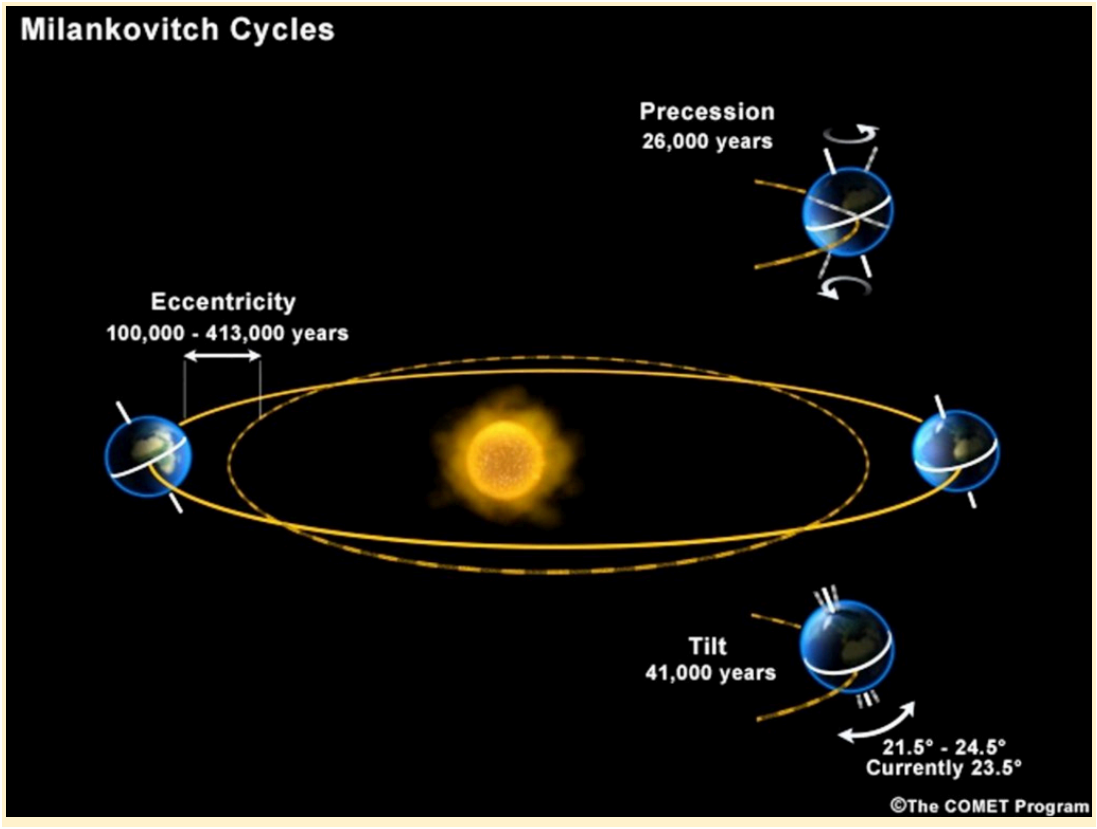
temperature stack. (f) Antarctic temperature stack based on up to seven different ice cores. (g) Stack of benthic δ18O, a proxy for global ice volume and deep-ocean temperature. (h) Reconstructed sea level. Lines represent orbital forcing and proxy records, shaded areas represent the range of simulations with climate models, climate–ice sheet models of intermediate complexity and an ice sheet mode forced by variations of the orbital parameters and the atmospheric concentrations of the major greenhouse gases. (i) Rate of changes of global mean temperature during Termination I.]

https://www.carbonbrief.org/explainer-how-the-rise-and-fall-of-co2-levels-influenced-the-ice-ages

I mentioned the Milankovitch Cycles above. We will talk through how these odd perturbations of the earth's orbit end up driving the ice ages. Here's one twist to think about: We're used to hearing that the Earth's tilt causes summer and winter, etc. If summer in the Northern Hemisphere happens at the same time the eccentricity of the orbit places the planet closest to the sun, summers can be extra warm for thousands of years. This results in more summer melting of ice and the earth can move out of a long period of cold summers (ice ages).



It is these Milankovitch Cycles which drove the ice ages for the last 800,000 years.

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Here's the Punchline at this point:

We know an enormous amount about the last 800,000+ years concerning temperatures, sea levels, etc. This confirms a very strong correlation between global temperature and greenhouse gases.

We also know even more about the planet since the late 1800s when instrumentation came of age. The new injection of CO2 since the beginning of the Industrial age (up to 420 parts per million from the 280 ppm average all during the ice ages) with the burning of fossil fuels has thrown the planet out of the control of the Milankovitch Cycles!

We will see later that the last time the earth was in this situation was before the ice ages - around 3 million years ago.