What is causing the increase in atmospheric CO2?

What The Science Says:
There are many lines of evidence which clearly show that the atmospheric CO2 increase is caused by humans. The clearest of these is simple accounting - humans are emitting CO2 at a rate twice as fast as the atmospheric increase (natural sinks are absorbing the other half). There is no question whatsoever that the CO2 increase is human-caused. This is settled science.

Climate Myth: CO2 increase is natural, not human-caused

that atmospheric CO2 increase that we observe is a product of temperature increase, and not the other way around, meaning it is a product of natural variation...it may be the Emily Litella moment for climate science and CO2 – *"Never mind..."* (Anthony Watts)

Simple Accounting

The easiest way to prove that the atmospheric CO2 increase is man-made is through a simple accounting approach (i.e. see Cawley 2011). The equation for the change in atmospheric CO2 (ΔC_{atm}) is

$$\Delta C_{atm} = Emissions - Absorption$$

This says that if we 'emit' a ton of carbon by, say, triggering a volcano then the atmosphere will gain a ton. If we 'absorb' a ton of carbon by growing a tree, then the atmosphere loses a ton. We can expand the equation by counting human emissions (HE) and absorption (HA) and natural emissions (NE) and absorption (NA) separately.

$$\Delta C_{atm} = NE + HE - NA - HA$$

This works because carbon is additive. If a volcano emits a ton of carbon and a factory emits a ton then the atmosphere has gained two tons. This is a very simple balance sheet for the carbon cycle and fortunately there are 'accountants' who have measured some of these values for us.

Recently the amount of CO2 in the atmosphere has been rising at ~2 parts per million per year, or around 15 billion tons/year. Meanwhile human emissions excluding land use change (like clearing or planting forests) are 30 billion tons per year. In billions of tons per year we have:

$$\Delta C_{atm} = 15$$

$$HE = 30$$

$$15 = NE + 30 - NA - HA$$

We can rearrange this:

$$NE - NA - HA = -15$$

Humans are also clearing rainforests and changing land use, but here we'll assume that human effects on absorption (HA) are not much different from zero, i.e.

$$NE - NA = -15$$

So Natural Absorption (NA) must be bigger than Natural Emissions (NE). Nature is *absorbing* more CO2 than it is *emitting*. It is not causing atmospheric CO2 to rise *at all* - in fact it is acting to try and *reduce* atmospheric CO2, and thus the long term rise is entirely because of humans.

Ocean Acidification

The oceans are the Earth's largest carbon storage medium, so if the atmospheric CO2 increase were "natural", it would likely be coming from the oceans. But we know the CO2 increase is not coming from the oceans, because the pH of the oceans is dropping (a.k.a. ocean acidification).

When CO2 is absorbed into a solution, it binds with a water molecule to form a molecule of carbonic acid:

$CO_2 + H_2O = H_2CO_3$

H_2CO_3 has a rather strong acidifying effect in that 95% of it turns into HCO_3^-. This loss of an H^+ ion causes the ocean pH to decrease (for more details on ocean acidification, see the OA no OK series).

In short, the fact that the pH of the oceans is decreasing tell us that they are absorbing more carbon than they are releasing, not vice-versa.

Oceanic CO2 Rising Fastest at the Surface

If CO2 were being driven into the ocean from the air, the oceanic concentration would rise fastest at the surface. If CO2 were being expelled from the oceans, we would expect to see the opposite - decreasing concentrations at the surface.

The World Ocean Circulation Experiment (WOCE) and the Joint Global Ocean Flux Study (JGOFS) has observed that as we expect for CO2 being driven into the oceans, concentrations of CO2 in the oceans are rising fastest at the surface.

Atmospheric O2 is Decreasing

Burning carbon requires oxygen (O2), and when we burn an atom of carbon, the required oxygen becomes part of the CO2 molecule. So if the CO2 increase is caused by burning carbon (fossil fuels), we would expect atmospheric O2 levels to decrease at the same rate. And that's indeed what we observe (Figure 1).

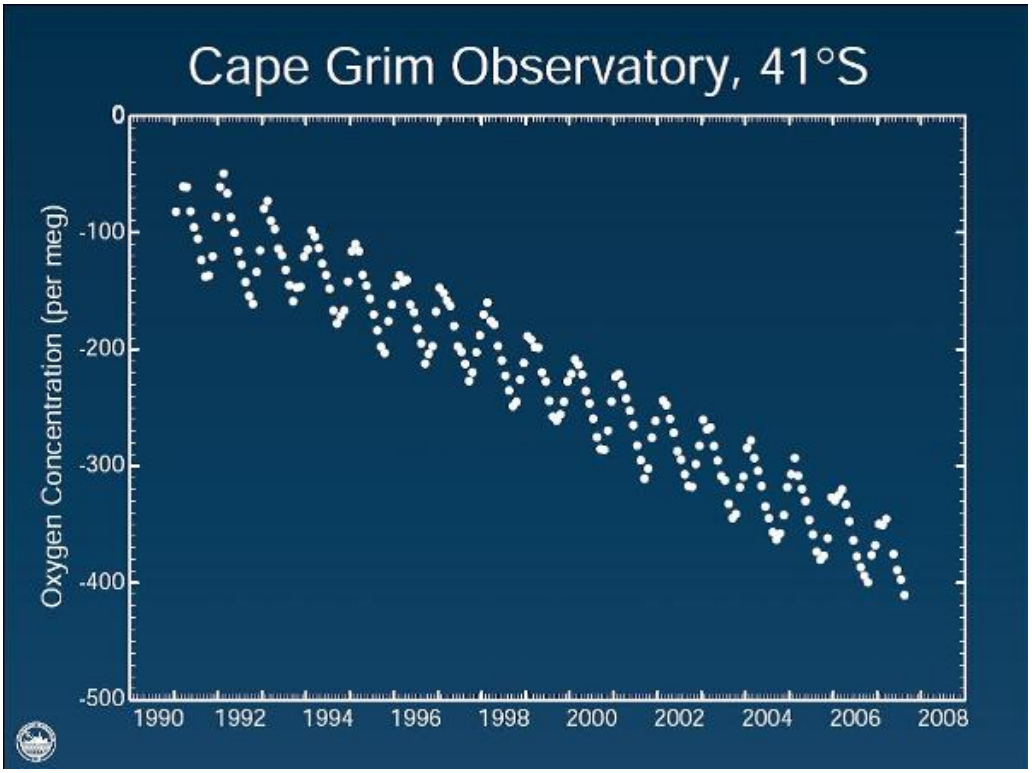

Figure 1: Atmospheric Oxygen Concentration observed from Cape Grim, Tasmania

There's no reason to expect that a natural release of CO2 would have any effect on atmospheric O2 levels. On the other hand, the O2 concentration is changing exactly as we would expect from a fossil-fuel driven CO2 increase.

CO2 Rise is Smoother than Temperature

Some, most recently Murry Salby, have argued that the CO2 rise is in reponse to the temperature rise. However, the temperature rise has been quite erratic (because there are many factors which impact the average global temperature, especially in the short-term). If atmospheric CO2 changes were in response to temperature changes, then we would expect to see an erratic rise in CO2 as well. Instead, the atmospheric CO2 increase is very smooth, similar to the increase in human CO2 emissions.

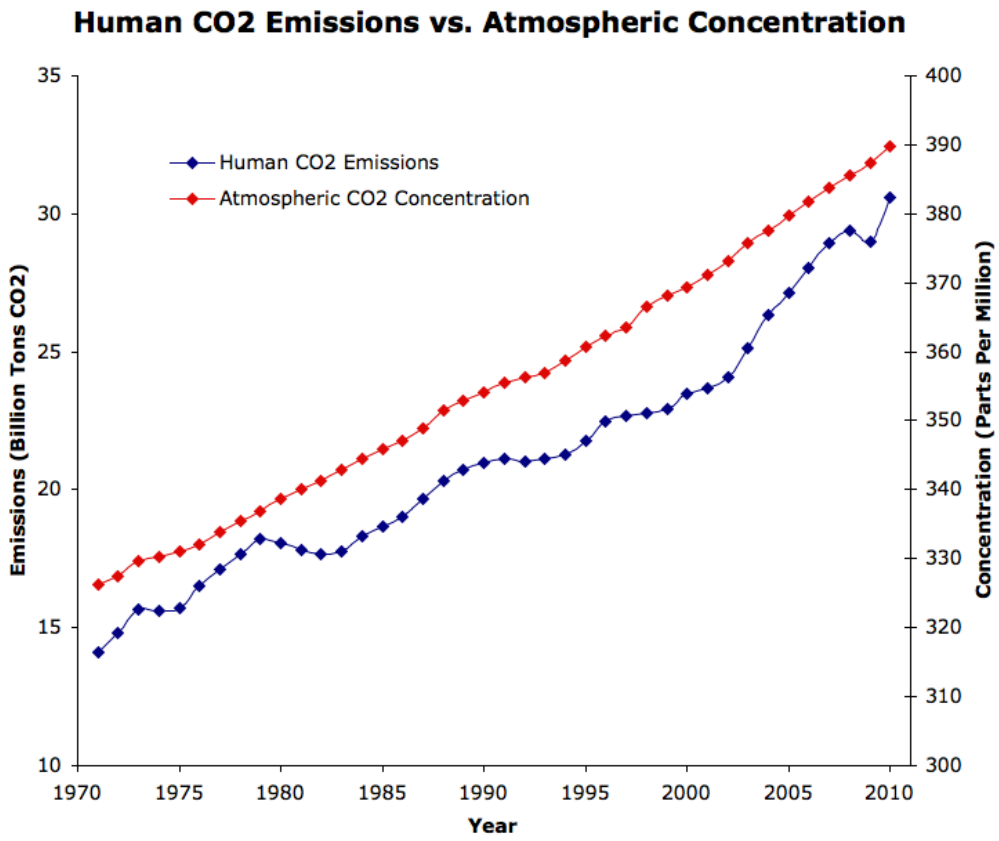

Figure 2: Human CO2 emissions (blue, left y-axis, Source: IEA) vs. atmospheric CO2 concentration (red, right y-axis, Source: Mauna Loa record)

Isotopic Signature

Carbon is composed of three different isotopes: carbon-12, 13, and 14. Carbon-12 is by far the most common, while carbon-13 is about 1% of the total, and carbon-14 accounts for only about 1 in 1 trillion carbon atoms in the atmosphere.

CO2 produced from burning fossil fuels or burning forests has a different isotopic composition from CO2 in the atmosphere, because plants have a preference for the lighter isotopes (carbon-12 and 13); thus they have lower carbon-13 to 12 ratios. Since fossil fuels are ultimately derived from ancient plants, plants and fossil fuels all have roughly the same carbon-13 to 12 ratio – about 2% lower than that of the atmosphere. As CO2 from these materials is released into, and mixes with, the atmosphere, the average carbon-13 to 12 ratio of the atmosphere decreases.

Reconstructions of atmospheric carbon isotope ratios from various proxy sources have determined that at no time in the last 10,000 years are the carbon-13 to 12 ratios in the atmosphere as low as they are today. Furthermore, the carbon-13 to 12 ratios begin to decline dramatically just as the CO2 starts to increase — around 1850 AD. This is exactly what we expect if the increased CO2 is in fact due to fossil fuel burning beginning in the Industrial Revolution.

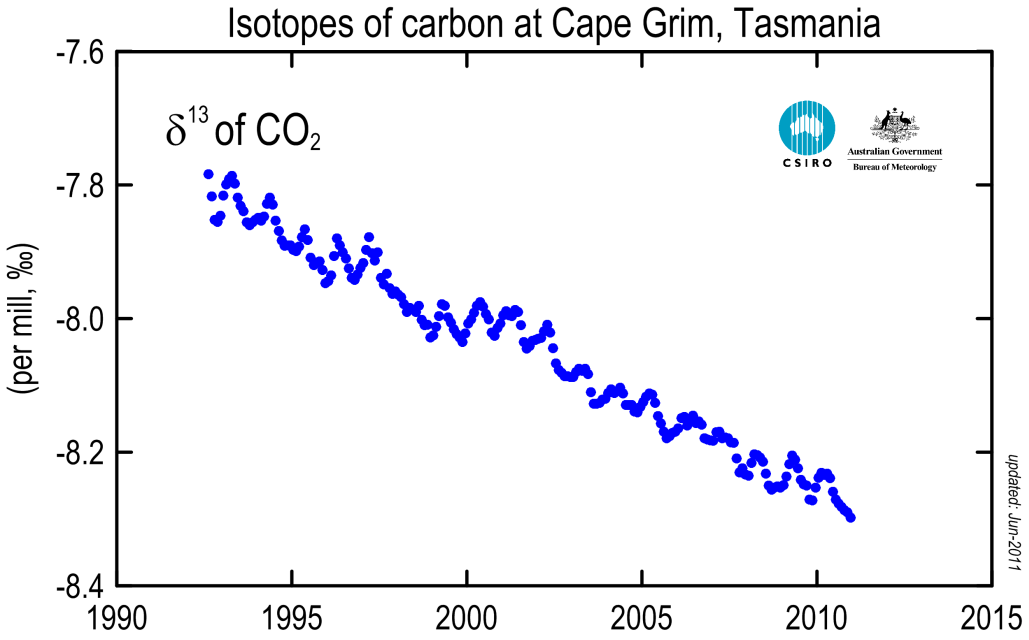

Figure 3: Atmospheric carbon-13 ratio observations from Cape Grim, Tasmania

These isotopic observations confirm that the increase in atmospheric CO2 comes from biogenic carbon, not from the oceans or volcanoes. Some "skeptics" like Murry Salby argue that the carbon-13 ratio isn't unique to fossil fuels. However, because the carbon-14 ratio has also decreased significantly (Figure 4), we know it's from old (fossil fuel) sources, not modern sources. This is not new science either, it's something we've known for over half a century (Revelle and Suess 1957), and there have been many studies confirming these results. For example, Levin & Hesshaimer (2000):

> "It has been erroneously argued that the observed atmospheric CO2 increase since the middle of the 19th century may be due to an ongoing natural perturbation of gross fluxes between the atmosphere, biosphere, and oceans. That the increase is in fact a predominantly anthropogenic disturbance, caused by accelerated release of CO2 from burning of fossil fuels, has been elegantly demonstrated through 14C analyses of tree rings from the last two centuries (Stuiver and Quay 1981; Suess 1955; Tans et al. 1979)."

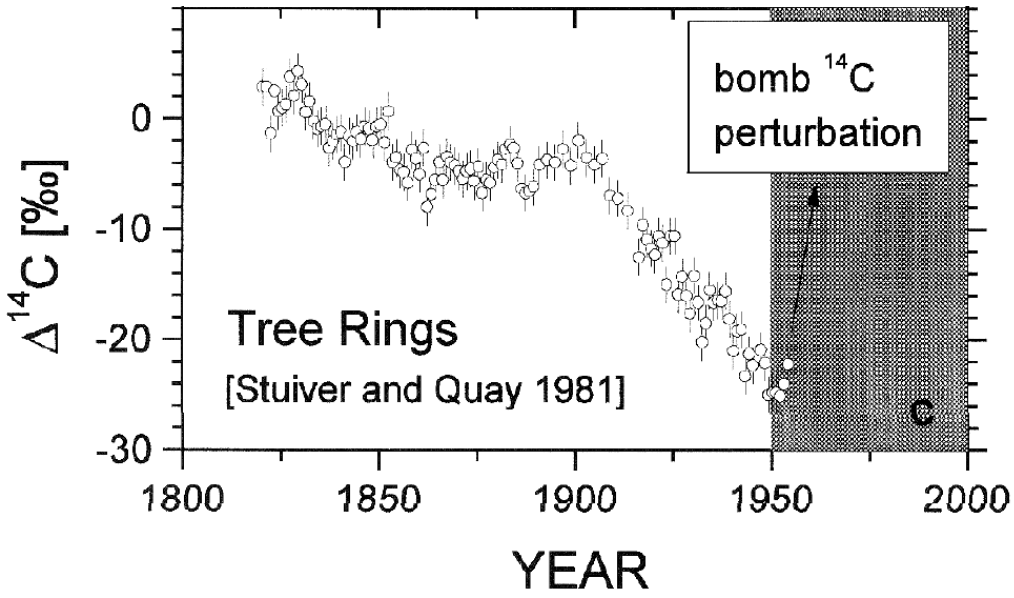

Figure 4: Temporal change of carbon-14 ratio in tree rings grown at the Pacific coast (Levin & Hesshaimer 2000)

Settled Science

As you can see, there are many lines of evidence showing that the increase in atmospheric CO2 is due to human fossil fuel combustion. Each one of these lines of evidence is very conclusive on its own, and when all put together, it's abundantly clear that the science is settled on this issue.

Intermediate rebuttal written by dana1981

Update July 2015:

Here is a related lecture-video from Denial101x - Making Sense of Climate Science Denial

Additional videos from the MOOC

Andy Skuce: The CO2 rise is man man-made

Interviews with various experts

Expert interview with Corinne Le Quéré

Skeptical Science explains the science of global warming and examines climate misinformation through the lens of peer-reviewed research. The website won the Australian Museum 2011 Eureka Prize for the Advancement of Climate Change Knowledge. Members of the Skeptical Science team have authored peer-reviewed papers, a college textbook on climate change and the book Climate Change Denial: Heads in the Sand. Skeptical Science content has been used in university courses, textbooks, government reports on climate change, television documentaries and numerous books.