Carbon dioxide levels and climate change: Is there really a controversy?

July 3 2019, by Guillaume Paris And Pierre-Henri Blard

Credit: Michal Pech/Unsplash

The relationship between atmospheric CO_2 levels and climate change is often perceived as a controversial subject. While there's no real disagreement among climate scientists—around 90% fully agree that human activity is clearly responsible for climate change—in the United States in 2016, barely 50% of the general public came to the same conclusion. Adding to the general confusion, highly active "climate-change deniers" claim that temperature has evolved independently of

CO_2 atmospheric concentrations through Earth's history, and that therefore today's rising CO_2 levels are not an issue.

So did scientists get the story wrong? No. CO_2 has long contributed to controlling the Earth's climate, and its rising concentration in the atmosphere and oceans is a major threat to humanity.

Together with solar activity and albedo, greenhouse gases are a key part of Earth's radiative budget and exert a strong control on surface temperature. Although water vapour is the primary greenhouse gas on Earth, CO_2 draws much more attention because it can actively lead climate change.

Unfortunately, human activity delivers CO_2 to the atmosphere at a rate 70 times greater than all volcanoes on Earth combined. As a result, atmospheric CO_2 concentration (or pCO_2) increases and the surface of the Earth warms up at a pace that no natural factor can explain.

We know that CO_2 is a temperature control and we can demonstrate it in various ways. One of them is through the exploration of Earth's history.

Climate and temperature through geological times

Using rocks, fossils and their chemical and physical properties, geoscientists have reconstructed warm and cold periods throughout Earth's history. To demonstrate the link between climate, temperature and pCO_2 millions of years ago, we need to reconstruct each of them independently. To do so, we use climatic recorders called "proxies."

The isotopic composition of oxygen atoms, written $\delta^{18}O$, measured in ancient calcareous shells, is one of them. It allows us to reconstruct past seawater temperatures with a well-known degree of uncertainty that depends on analytical precision and how parameters such as seawater

$\delta^{18}O$, salinity and pH also affect the $\delta^{18}O$ of shells.

Because geological history affects rocks and their signals, the further we go back in time, the larger are the uncertainties. We thus combine different proxies and formulate hypotheses that continually improve with years of research. Establishing such reconstructions is a slow, complicated (sometimes painful) process but they become more and more reliable every year as uncertainties decrease. If uncertainties are too large, interpretations rely on parsimony: the simplest model must be considered the likeliest. What matters is that scientists know how to estimate uncertainties, and share them.

Overall, seawater temperature reconstructions agree with geological observations of climate history: major ice ages coincide with lower global temperature. In particular, $\delta^{18}O$ indicate a steady cooling from 50 million years onwards, leading to the preindustrial climate.

The history of pCO_2

Proxies exist for pCO_2 as well. For instance, palaeontologists count stomata – apertures through which plants breathe, exchange moisture and take up CO_2 for photosynthesis—on fossil leaves. The more CO_2 is abundant, the fewer stomata are required. One factor that adds a degree of uncertainty is that plants have fewer stomata under drier climates and more under humid ones.

Fossil leaves are rare and atmospheric pCO_2 data are scarce for ancient periods of Earth. In the absence of (sufficient) data, numerical modelling helps explain data with a globally coherent approach that respects the fundamental laws of physics. One of the most famous is GEOCARB, a geological carbon cycle model developed to reconstruct pCO_2 history by Robert Berner and his colleagues.

On timescales greater than 100,000 years, pCO_2 is primarily added from volcanoes, and lost through two carbon pumps: the biological pump and the carbonate pump.

During photosynthesis, plants and algae take up CO_2 to build their organic matter. When they die, this CO_2 might get trapped in sediments. This is the biological pump. The carbonate pump is the coupling between weathering of continents and carbonate rock precipitation. CO_2 acidifies surface waters that dissolve rocks. Dissolved elements are washed to the ocean where they are used to build calcareous material such as shells or corals, which eventually become limestones. Year after year, these pumps store CO_2 away from the atmosphere.

In the past, volcanoes could have been more or less active; continents were in different locations, which affected the carbon pumps. Berner and colleagues quantified how the otherwise known evolution of those parameters affected the carbon cycle and, therefore, atmospheric pCO_2. They knew and displayed their model uncertainty. Their results should be presented with an estimation envelope, not as a given value.

Times of higher pCO_2 are warm periods. Conversely, decrease in atmospheric CO_2 content triggered glacial periods such as of the Carboniferous and modern ice ages, with the possible exception of the Hirnantian (445 million years ago). Recent models suggest that for this remote period, the tectonic configuration played a specific role.

How humans quickly affect climate

Over the time period beginning at the point that dinosaurs went extinct (a relatively recent 66 My ago), geologists can rely on many temperature and CO_2 proxies in addition to $\delta^{18}O$ or fossil leaves. The closer we get to our era, the more proxies there are and the fewer the uncertainties are, until we can connect geological and ice core data that support each other.

Tectonics modified oceanic circulation and led to the building of mountain ranges like the Himalayas. Both factors affected the carbon pumps and forced pCO_2 to decrease, as shown by proxies and in agreement with the GEOCARB trends. This decrease in pCO_2 led to the observed cooling and drove the Earth to the current glacial-interglacial alternation.

We can determine from ice cores and proxies that pCO_2 has been oscillating between 200 and 350 ppm for 2.6 million years and that it suddenly increased from 280 to 410 ppm between 1850 and 2018. pCO_2 is heading toward levels unprecedented for 5, or even 30 million years, when the Earth was much warmer than today and no Atlantic ice caps were present. Reconstructions of temperature and pCO_2 can offer us a glimpse into what lies ahead of us if we don't slow down CO_2 emissions.

On long time scales, when pCO_2 increases, warming stimulates the carbon pumps, thereby helping pCO_2 to decrease. This negative feedback can act as a geological thermostat. Unfortunately, it is too slow to react rapidly enough to compensate for our fast emissions. On the timescale of a decade, warming aggravates CO_2 release to the atmosphere. When temperature increases, oceans warm up and release dissolved CO_2 to the atmosphere. For 2.6 million years, glacial and interglacial cycles have been forced by Earth's orbital fluctuations and CO_2 was only an internal positive feedback. Today, anthropogenic CO_2 leads and amplifies the ongoing warming.

As a result of the pCO_2 increase, the average surface temperature has already increased by almost 1°C between 1901 and 2012. The Earth's surface has been much warmer than today in the past and it will eventually cool off. However, the consequences of the short-term changes are disastrous. In addition to higher surface temperatures, extreme weather events, ocean acidification, ice melting and sea-level rise are about to significantly disrupt our daily lives and harms the ecosystems around us.

Earth science helps us understand the past of our planet. We cannot control Earth's orbit, tectonics or oceanic circulation but we can control our greenhouse-gas emissions. The future is for all of us to build.

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