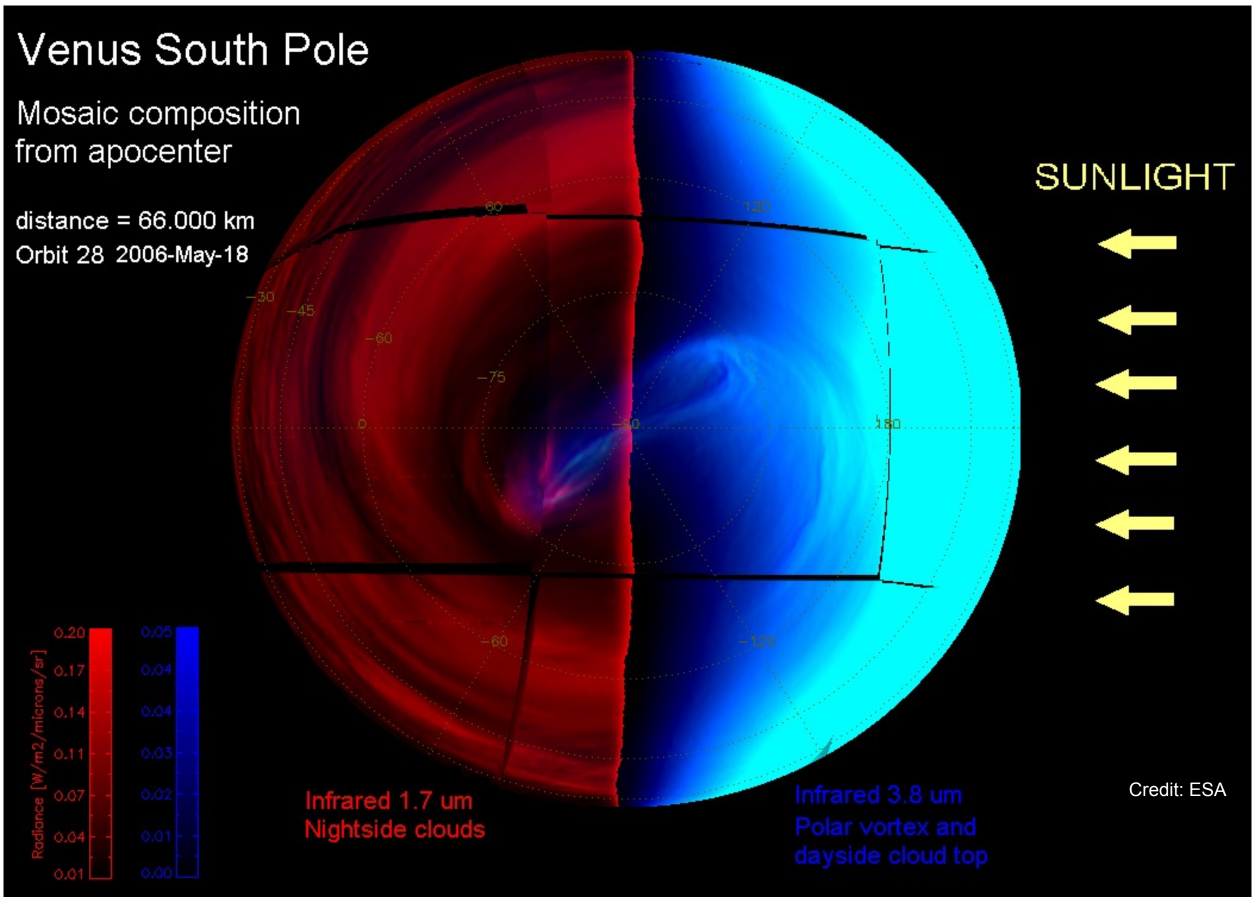
The most beautiful thing we can experience is the mysterious. It is the source of all true art and all science. He to whom this emotion is a stranger, who can no longer pause to wonder and stand rapt in awe, is as good as dead; his eyes are closed.

Albert Einstein

Venusian Runaway

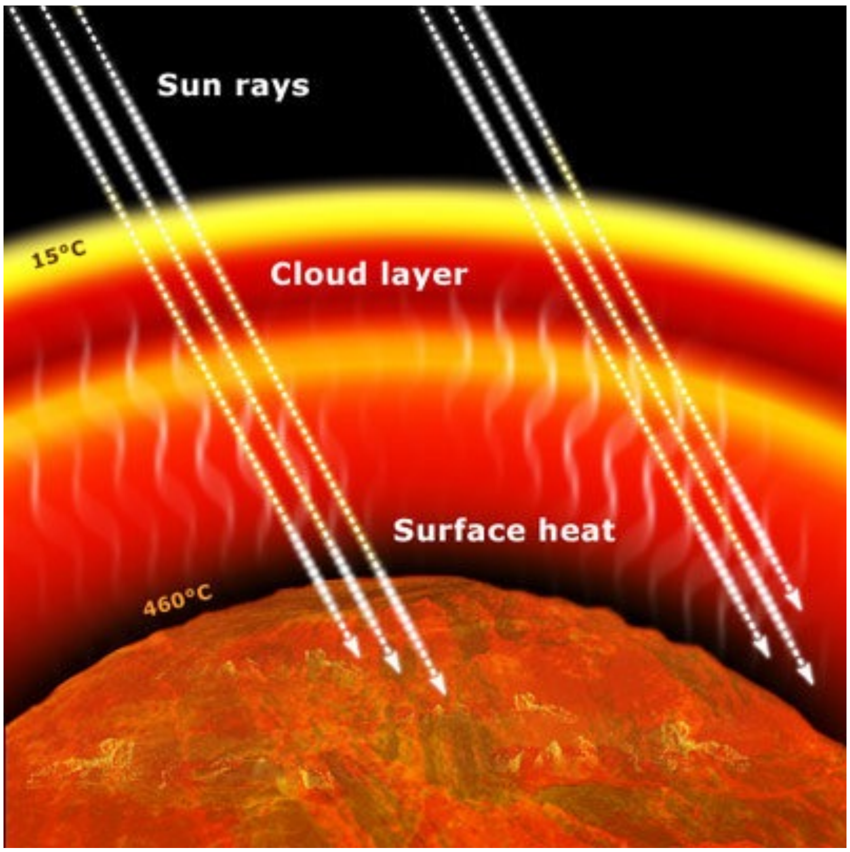
Hello everyone. In this module we'll investigate how Venus got so hot and how Earth currently has an automatically adjusting thermostat. Along the way we'll see where our ozone came from.



Venus has a very thick carbon dioxide atmosphere that creates its very strong greenhouse effect, explaining why it is so hot over and above its "no atmosphere" temperature. It also rotates very slowly. Thus it has weak surface winds and a weak Coriolis effect. It is far too hot for the sulfuric dioxide rain to reach the surface. Its lack of an axis tilt means there are no seasonal changes. So the weather on Venus is pretty boring. No wind, no rain, same searing temperature day and night, crushing pressures, and no seasonal changes. Nice vacation spot.

The image above shows Venus at two different infrared wavelengths. The red half shows the night-side clouds near the South Pole. The clouds here are about 45 kilometers above the surface. The blue half shows the day time clouds, which are about 60 kilometers above the surface. A double polar vortex is also visible Studies such as these explore the evolution of clouds in the Vesuvian atmosphere.

So how did Venus get to be such a nice vacation spot? Well, Venus' distance from the Sun led to a runaway greenhouse effect that made Venus too hot to develop liquid oceans like those on Earth. And without oceans to dissolve the carbon dioxide outgassed from volcanoes, all of Venus' carbon dioxide remain in its atmosphere, creating its intense greenhouse effect. Vesuvian Runaway.



Credit: ESA

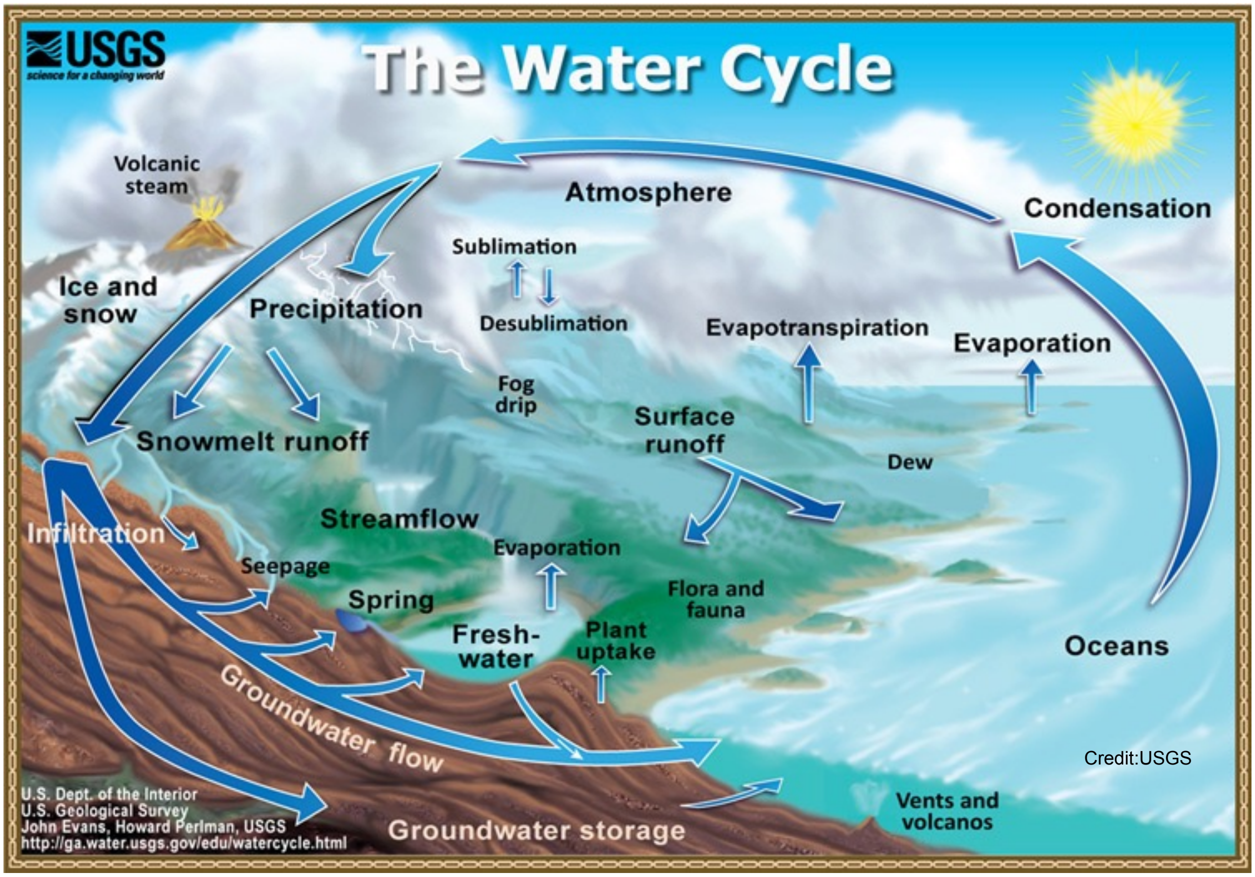
The image shows the net effect of a runaway greenhouse effect. If you took Earth moved it into Venus' orbit, you would get a lot more solar radiation. That solar radiation would start to evaporate the Earth's oceans. Our oceans are mainly made out of water, which is a great greenhouse gas. Now its warmer due to the greenhouse effect, so you evaporate yet more more water. This vicious positive-feedback cycle is why it is called a runaway greenhouse effect. On time scales of about 10,000 years Earth would look like Venus. That would be no fun for life.

How did Earth end up so differently than Venus? Mostly because we are farther from the Sun. The temperatures on Earth are just right for the outgassed water vapor to condense and form oceans. These oceans dissolve carbon dioxide and lock it away in carbonate rocks like limestone and marble. This keeps the greenhouse effect moderate enough so Earth doesn't freeze over, but doesn’t have a runaway green house effect either. Nitrogen outgassed from volcanoes remains in our atmosphere. That’s why nitrogen is the dominant gas in our atmosphere. The image above shows a recent outgassing event.

Where did Earth gets its ample stock of oxygen and ozone then? Well, oxygen and ozone didn't come until later in out atmosphere’s history. Blue-green algae was an early life form. They eat carbon dioxide. Oxygen is their waste product. There was so many of them that they, and others, fundamentally changed the atmosphere of Earth. Life itself caused the great oxidation event! Wow.

Why does Earth's atmosphere remain so stable? Earth's long term climate has been stable because of feedback processes that tends to counter any warming or cooling trends that might occur. The most important process is the water cycle. it regulates the strength of the greenhouse effect by controlling the amount carbon dioxide in our atmosphere.

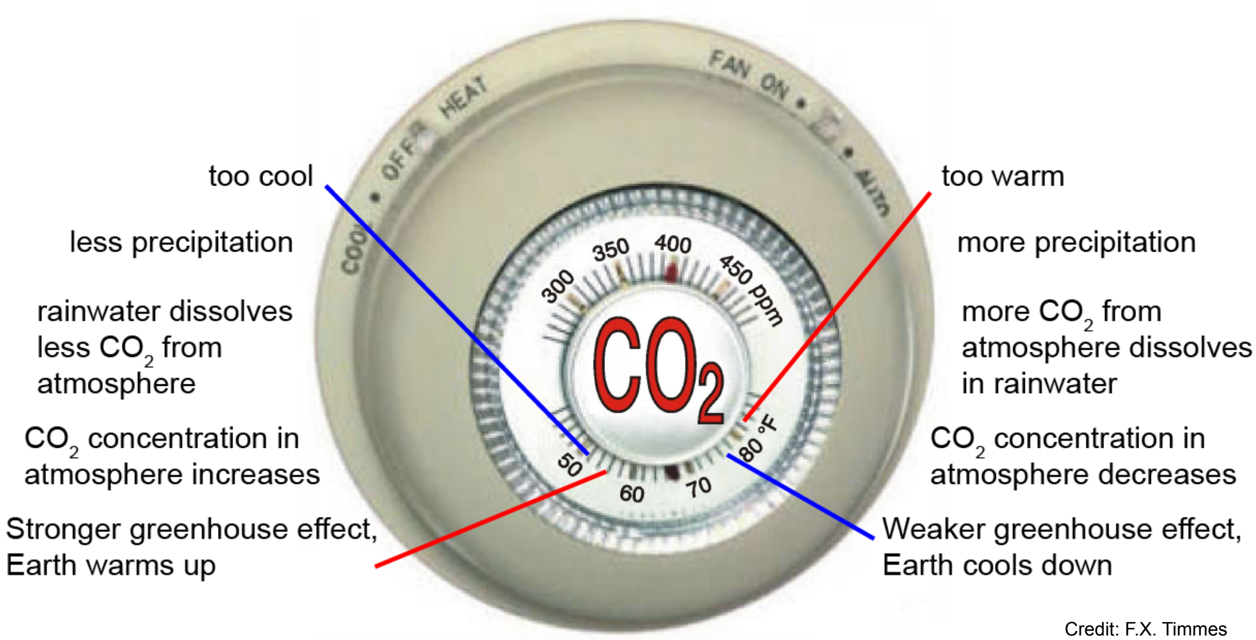
An illustration of the water cycle is shown below. You start with outgassing from volcanoes. Out comes copious amounts of carbon dioxide. That carbon dioxide goes up into the atmosphere where it gets dissolved by water in the clouds. Then it rains. Most of the rain falls into the ocean. Or it falls on the land, which then goes into the ocean. Either way the carbon dioxide has been dissolved and in the ocean. Since carbon dioxide is heavier than water, gravity does it thing and the carbon dioxide sinks to the bottom of the oceans. Under pressure from the weight of the water above, the carbon dioxide solidifies into limestone and maybe later marble if you put the limestone under more pressure. But the limestone is not locked away forever. The limestone participates in plate tectonics, which can move the limestone material under a hot spot known as a volcano.



So its this cycling of carbon dioxide, from volcano to rain to ocean to rock to volcano, that keeps Earth's climate stable on geological time scales.

OK, so that's the cycle, but how does it regulate the temperature?

The feedback cycle lis a bit like the illustration below. Suppose you cool off the Earth somehow. If its cooler then you do not absorb as much carbon dioxide into the rain. In fancy terms the reaction rate is dependent on the temperature. Less carbon dioxide dissolved in the rain means more of it in the atmosphere. The greenhouse effect then does its thing to warm the planet back up.

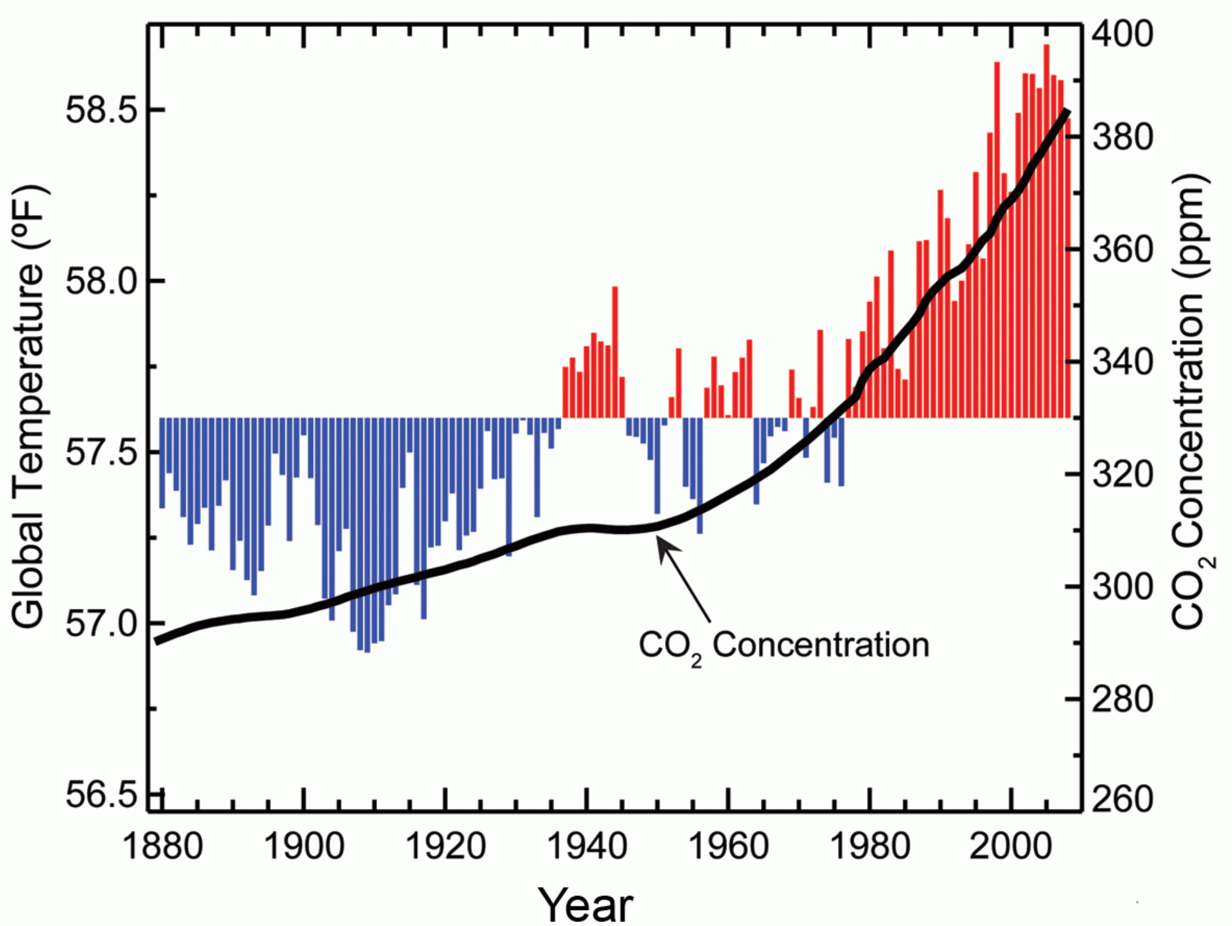


Credit: F.X. Timmes

Suppose now you heat up the planet somehow. Warmer temperatures mean more carbon dioxide will be dissolved into the rain. So more gets stuffed into the rocks and less is in the atmosphere. The greenhouse effect is then not as strong and the planet beings to cool.

So this gorgeous thermostat mechanism self-regulates the temperature on Earth. On long time scales. On geological time scales. Not on human time scales.

It should come as no surprise that we release greenhouse gases into the atmosphere, mainly by the use of fossil fuels. Our past emissions have mostly been in the noise of what the water cycle handles. But that has probably not been true for the past 50 years or so. The plot below shows the carbon dioxide history of our atmosphere. The rise in the past 30 years easily exceeds any known natural cause.



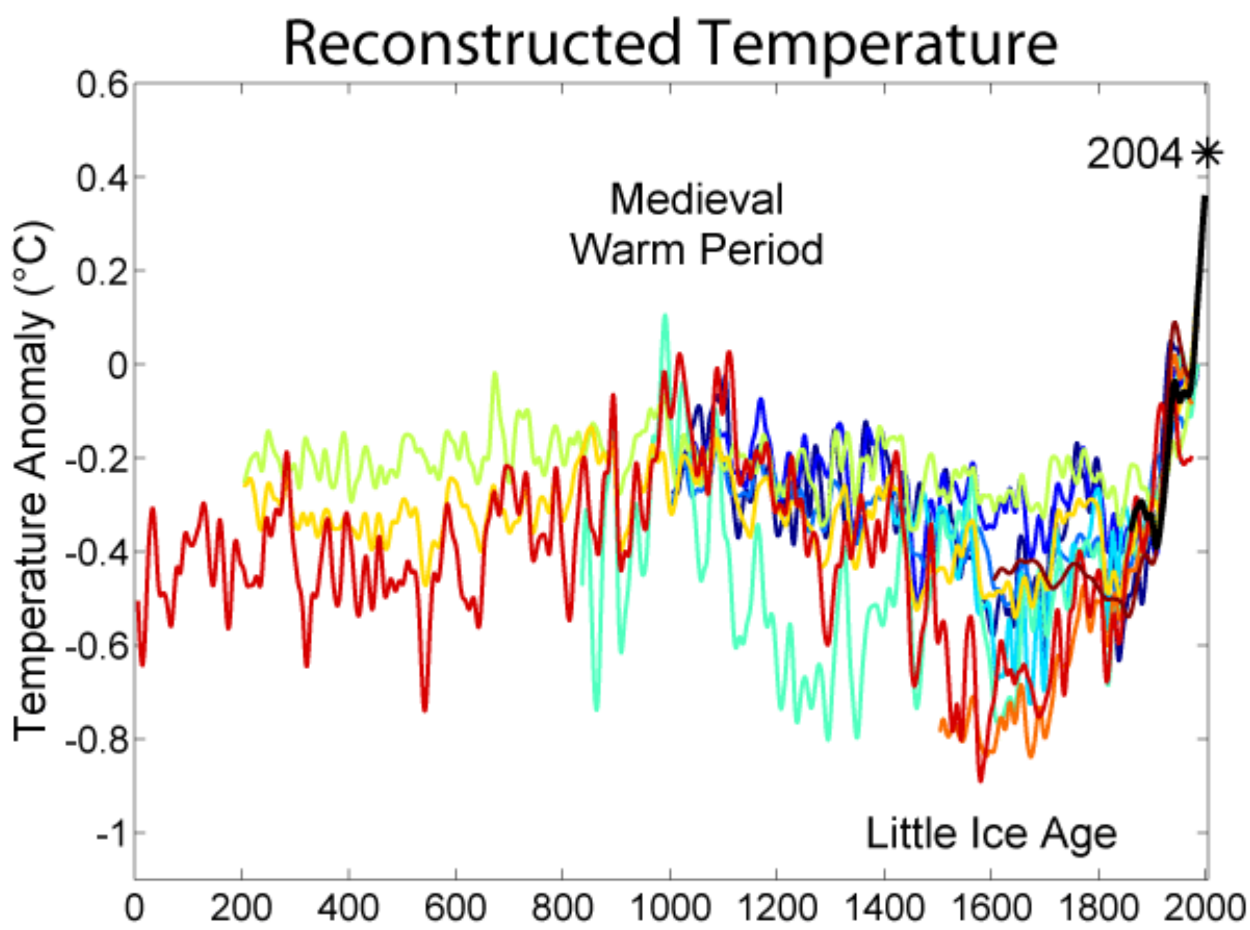
NOAA/NCDC[32]

Also shown in this plot is the temperature deviation below (blue) and above (red) the historical average temperature. The increase in global temperatures these past 50 years or so is measured fact. Its hard to mess up changes of this size. The key question is if our carbon dioxide emissions, through the greenhouse effect, are causing the undeniable increase in the global temperature. Data for the past 150 years or so is shown above. What does the natural scientist within you conclude?

Let's look at longer timescales, say the past 2000 years or so. Still far shorter than geological timescales, the time scale of the water cycle. Here the measured temperatures are less certain and more indirect. But still useful. The plot below shows the "temperature anomaly", which is simply the temperature above or below the average temperature. Each of the 11 models shown uses the more uncertain measured temperature data in different ways and does the temperature reconstruction differently. Still, the plot shows that all 11 models more-or-less agree. It was warmer during the “medieval warm period” and cooler during the “little ice age”. All 11 models agree more for the the past 150 years because that’s where the measured temperature data is far more certain. Its also where the temperature curves rise rapidly upwards.

The consequences of that rapid rise is probably an experiment we don't want to run for too much longer. Venus is a stark reminder. Hence all of the concern about minimizing the amount of carbon dioxide we put into the atmosphere.

Thanks. Bye Bye.



Credit: Wikipedia
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