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The Geologic Record and Climate Change

By Tim Patterson : 01 Jan 2005

The following remarks were delivered at the Risk: Regulation and Reality Conference by Dr. Tim Patterson, Professor of Geology at Carleton University. The conference was co-hosted by Tech Central Station and was held on October 7, 2004 in Toronto, ON.

I am a Quaternary geologist by profession. That is to say that my research interests are focused primarily on about the last 2 million years of Earth's history. An important aspect of my research is assessing past climate conditions. Thus I am also a paleoclimatologist. Earth's climate has varied considerably during the past 2 million years or so as indicated by the more than 33 glacial major advances and retreats that have occurred through this interval. Based on geologic paleoclimatic data it is obvious that climate is and has been very variable. Thus the only real constant about climate is change. It changes continually.

A primary role for climate researchers at present is to try and determine what the magnitude of natural climate variation is, and what sort of variation may be occurring at the present time is due to human induced causes. A major difficulty that we have is that the thermometer record only reaches back to the tail end of the 19th century. Unfortunately, many of the natural trends and cycles that occur in the natural climate system operate at scales that are longer than our thermometer record. A major question that needs to be addressed then hinges on determining whether the climate variability that has been observed through the 20th century -- during a warm-up that occurred at the end of the Little Ice Age that ended in the late 1800's, is unusual if you look at the larger paleoclimate record?

This is where paleoclimatologists like myself come in. Since thermometer records are so short we have to use what are termed proxy records. We look at records contained in the sediments, fossils, isotopes, etc. and then calibrate these records against thermometer records so that we can accurately determine past climate conditions in deep time.

A considerable portion of my research involves going out on research ships like the CCGS Tully to look at various fjords that are found along the British Columbia coast. This research is quite expensive and would not be possible without support in the form of a strategic project grant from the Natural Sciences and Engineering Research Council of Canada and a grant from the Canadian Foundation for Climate and Atmospheric Sciences.

The reason that fjords like Effingham Inlet on the west coast of Vancouver Island are special is that these inlets have shallow sills that restrict circulation of water from the open ocean into deep water interior basins. Because circulation is restricted in these basins, the level of oxygen in the bottom water is greatly reduced, often completely oxygen free. As a result there is no bioturbation. Biotrubation is a technical way of saying that since there is no oxygen, there are no little organisms on the ocean bottom crawling around messing up the sediments.

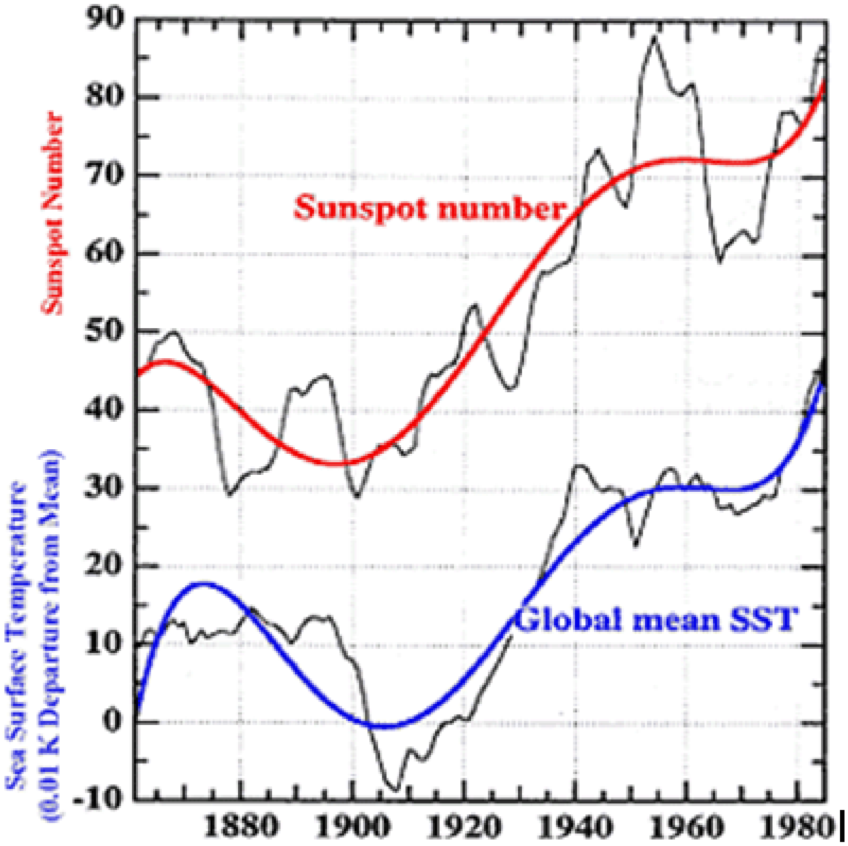
As a result layers of sediment are laid down every year; two different ones in fact. In the summer when the area is influenced by the North Pacific High and nutrient bearing upwelling prevails phytoplankton blooms occur. Diatoms, which make up the majority of the phytoplankton, eventually die, and then sink quietly to the bottom where they are deposited as light colored layers, or bands. During the winter, the Aleutian Low dominates the climate of the area resulting in very rainy conditions. The rain tends to wash sediments in from the nearby land. This detrital material sinks quietly to the bottom of the inlet as well resulting in the darker layers.

As you might imagine, there are scarcely any two years that are exactly alike. Some years there will be higher plankton productivity. During other years it will be rainier. As a result there will be annual variability in both the thickness and the color of the darker and lighter layers. This succession of annually deposited layers comprises one of the best climate records in the world and are comparable to the records obtained from ice cores. In Effingham Inlet we have an almost complete record that spans the entire Holocene -- nearly 10,000 years!

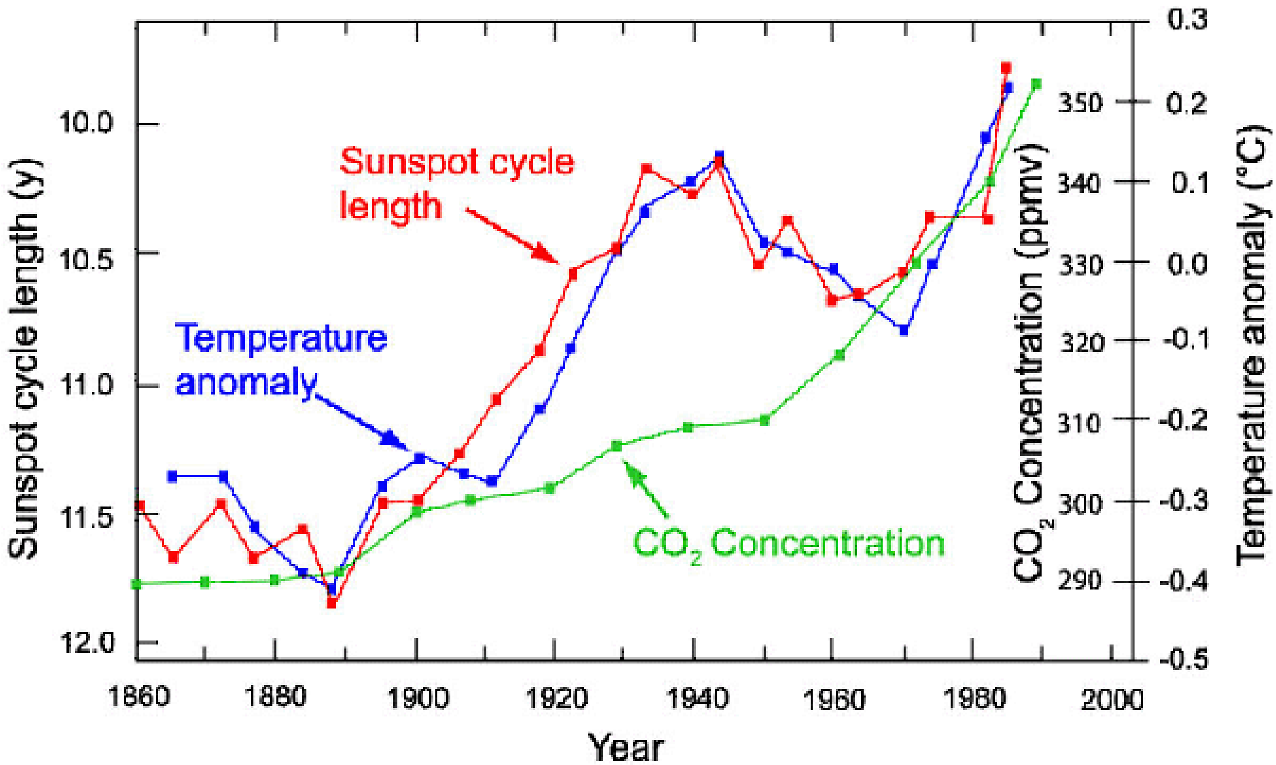
We make x-rays of these yearly deposited laminations and scan them with computers. The computer records several thousand years of records and can recognize patterns, trends and cycles that we cannot discern visually. What we have found is that many of the cycles that we find correspond to various sun spot cycles. A Sunspot cycle is an irregular cycle, averaging about 11 years in length, during which the number of sunspots (and of their associated outbursts) rises and then drops again. We found a correlation between these 11-year sunspot cycles and cycles recognizable in our sedimentary and marine productivity records in Effingham Inlet. As we analyzed our marine records in detail we identified other sunspot cycles as well using a time series analysis technique known as wavelet time series analysis.

We found good evidence of the 75-90 year Gleissberg Solar Cycle, the 200-500 year Suess Solar Cycle, and the 1,100 year Bond Solar Cycle with the shorter wavelength cycles apparently piggybacking on the longer ones. In the records from Effingham Inlet these cycles show up independently in all the isotopic, geochemical, sedimentological and paleontological proxies examined.

Although these British Columbia records, indicating a clear influence of the sun on climate, are very good they not the first studies to make such a correlation. Here are a couple of examples. The first graphic shows a clear correlation between global sea surface temperature and sunspot number. The warming as we came out of the Little Ice Age is very clear.

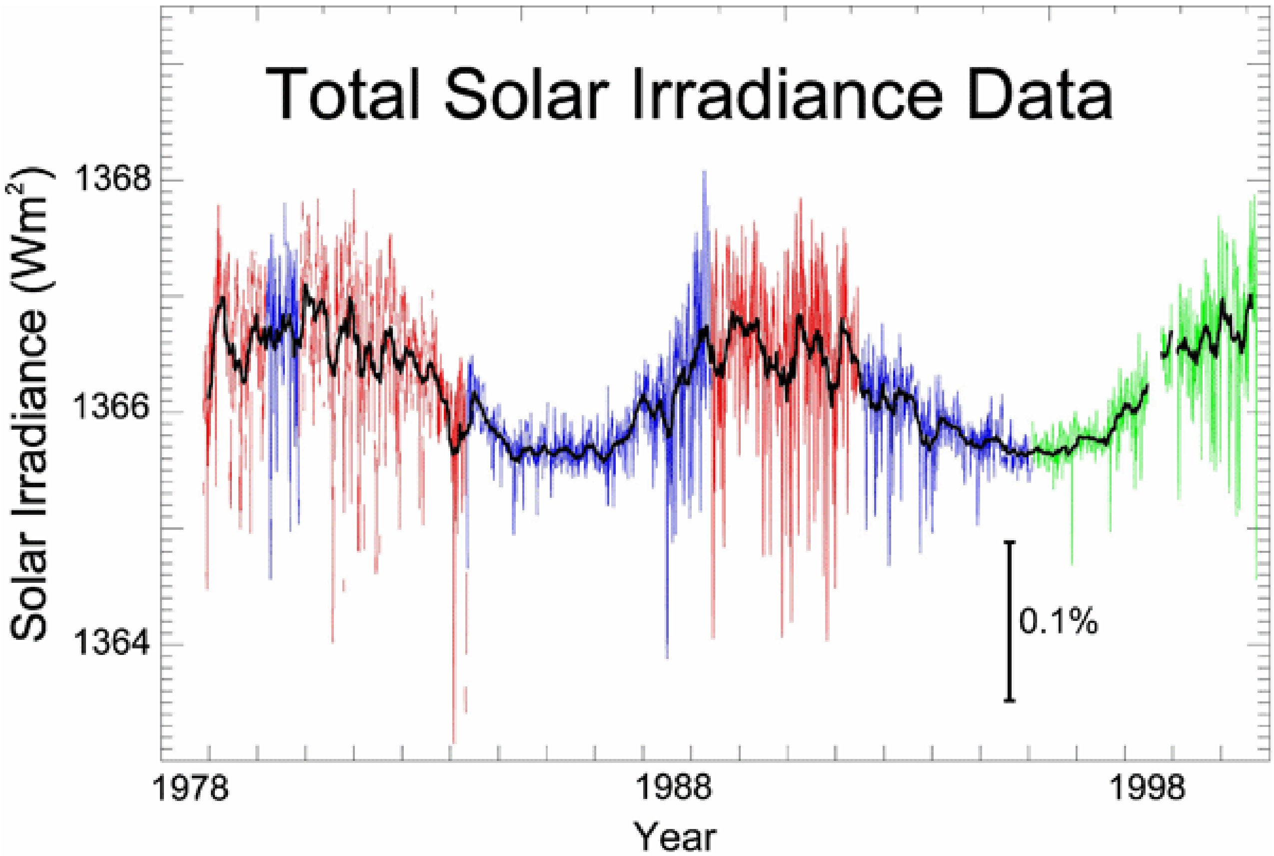


A second example is that of North American land temperature trends. The very close correlation between sunspot number and temperature is very clear. At present there have been literally hundreds of studies carried out showing a similar correlation.



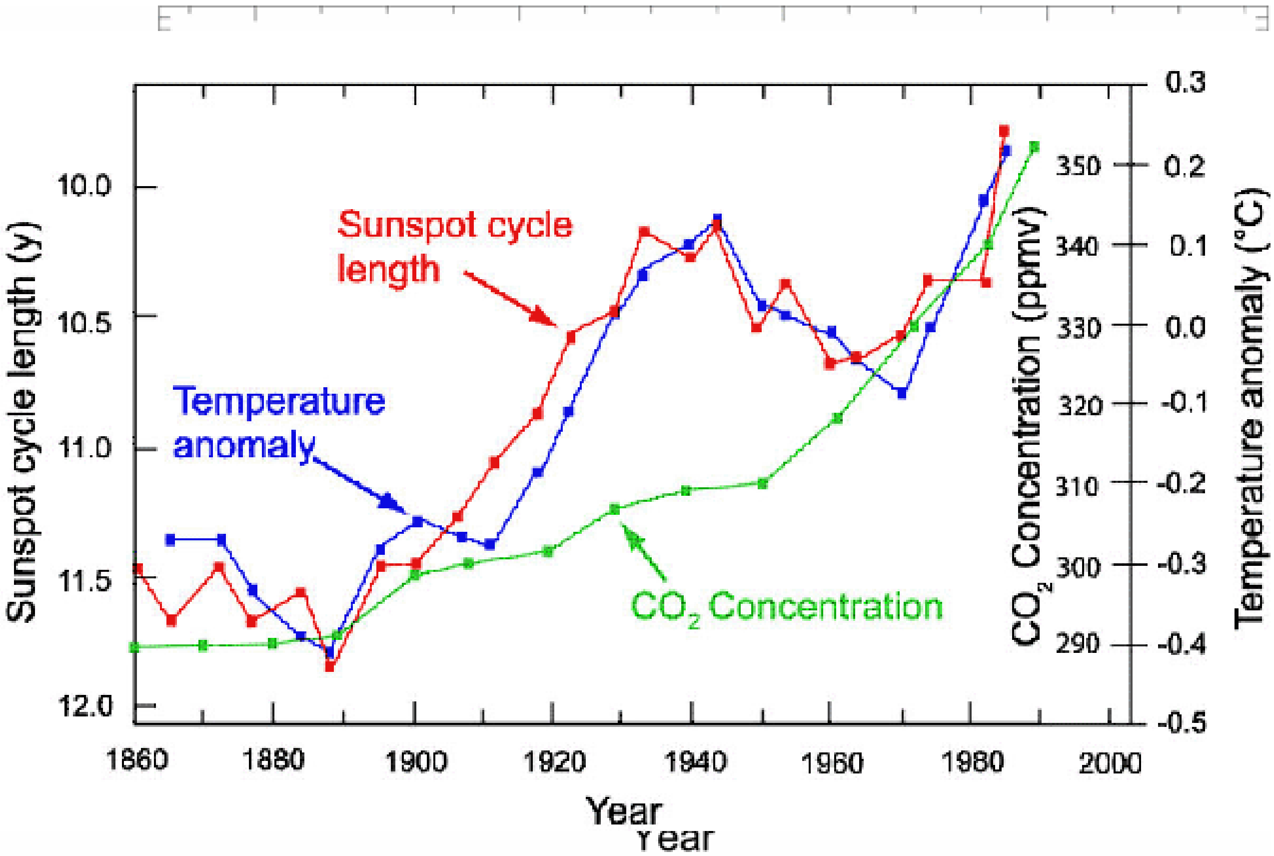
And so, the big question a person on the street might ask is, why hasn't it been acknowledged that the sun is the major control over climate variability? Why do so many fingers point to CO2 as the major climate control? Well, the big problem until recently with a solar forcing scenario for climate change has been that the sun's energy output through an 11-year sunspot cycle varies only by around 0.1 percent. This energy output variability is insufficient on it's own, to cause the 0.6 degree Celsius increase in global temperature observed through the 20th century.

Lets look at what happens through the course of a sunspot cycle. At the beginning of a cycle sunspots appear near the poles of the Sun. As a sunspot cycle progresses more and more develop and they start to migrate toward the sun's equatorial region. There is also a concomitant increase in solar flares as a sunspot cycle moves toward a peak, part of an internal cycle within the sun.



We therefore know the mechanics of what happens through a sunspot cycle and there is an excellent correlation between the sunspot cycle and Earth's climate, but until recently no way to explain the correlation. Before discussing a possible solution to this enigma it would be useful to discuss whether Earth's climate record actually supports the assumption that CO2 is a major climate driver. If one looks at the 20th century climate record some interesting observations merit discussion.

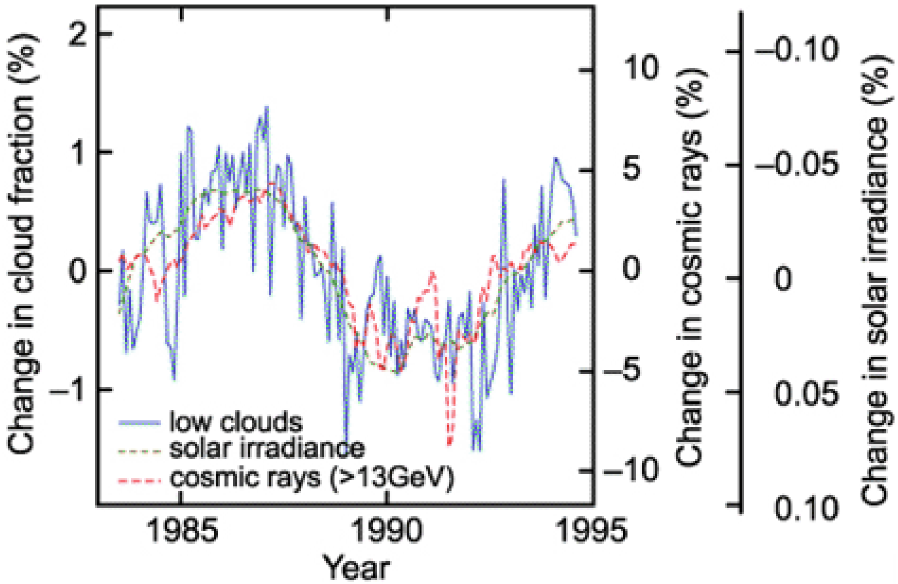
North American Land Temperature



Some questions immediately come to mind:

1. If CO2 is of such critical importance to climate change why was there a large temperature rise prior to the early 1940s when 80 percent of the human produced carbon dioxide was produced after World War II? 2. When CO2 levels finally began to increase dramatically in the postwar years why was there a concomitant interval of about 30 years of cooling? One would think that if CO2 had such critical control over climate that the relative abundance of CO2 in the atmosphere would be in lock step with global temperature. Many researchers realize the difficulties that are presented by trying to make CO2 the key factor in climate change. As a result there has been renewed research, much of it in the past year or so, into the idea that there really is a connection between variability in solar output and global temperature.

This new interest in solar forcing of climate centers around ideas put forward by Dr. Jan Veizer of the University of Ottawa that variability in the amount of galactic cosmic rays striking the earth are influential in climate change, acting as an amplifier. Galactic cosmic rays, are not really rays at all, but are basically stripped down neutrons and protons that are given off periodically throughout the galaxy when a supernova occurs. They bombard the solar system and earth continually. An interesting correlation has been observed between the sun spot cycle, galactic cosmic rays, and global cloudiness. The following diagram shows the abundance of low clouds colored in blue, which as you can see is cyclic.



The abundance of low clouds corresponds very closely to the level of solar radiance, as indicated by the green line. Both the proportion of low clouds and the level of solar radiance in turn correspond closely with the proportion of cosmic rays striking the Earth. They are all moving in concert with each other.

Thus the more cosmic rays that strikes the earth at any particular time, the more clouds that form. The more clouds that form, the lower global temperatures become, because they tend to bounce back warming sunlight. Since there is an observed 1.7 percent variation in low cloud formation between a solar maximum and minimum this is a significant variability capable of causing real climate change.

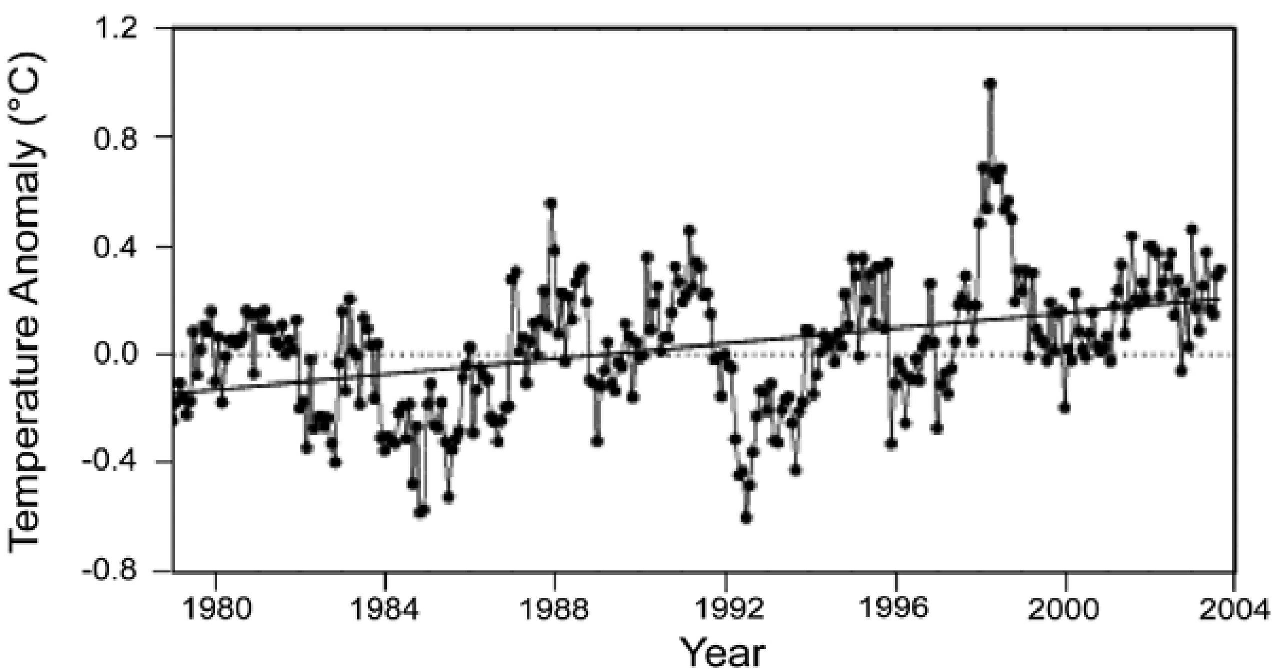
In summary then we have galactic cosmic rays continually striking the earth. Independent of the cosmic rays striking the solar system the sun is continually going through sunspot cycles. As I mentioned previously, the amount of solar flaring follows the 11-year sun spot cycle, and varies even more through the longer Gleissberg, Suess and Bond solar cycles. The larger the number of flares produced by the sun, the fewer the proportion of cosmic rays that strike the earth, as these flares tend to deflect the cosmic rays.

Thus when cosmic rays are deflected away from the Earth there are fewer clouds, which permits a little bit more secondary radiation to penetrate to the surface. Thus we no longer have the problem caused by solar variability only varying by 0.1% through a sunspot cycle, the change in global cloudiness permits more than ample solar energy through, which can significantly change climate. There is now a viable explanation to explain the great correlation that has been observed between solar records and temperature records. The correlation gets even better through longer-scale solar cycles. For example, the intensity of cosmic rays varies by 15 percent through the 11-year sun spot cycle. At the longer wavelength decadal-scale Gleissberg, centennial-scale Seuss, and millennial-scale Bond cycles the cosmic ray intensity varies by up to four times that much, causing significant changes to the climate.

But if the sun is important to climate change what role do greenhouse gases play then? Greenhouse gases are really important. They make up something like 0.1 percent of our atmosphere and are a critical component of the Earths biosphere. If you listen to the rhetoric produced by some environmental groups one would come away with the understanding that , all greenhouse gases must be expunged. However, without them, the earth would be uninhabitable; it'd be too cold.

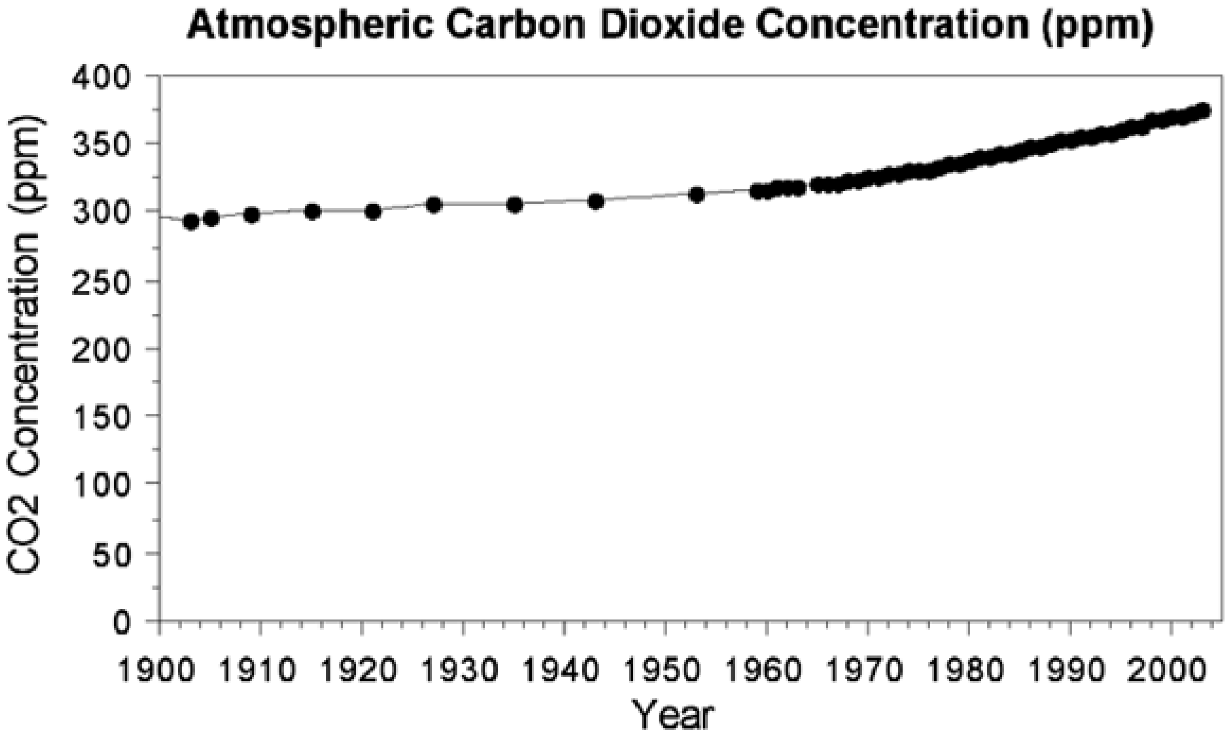
The media, special interest groups, and even some government produced literature all report that CO_2 is the most important greenhouse gas. I was at the Canadian Museum of Nature a few months ago where a traveling display was set up that clearly, and erroneously I might add, indicated that CO_2 was the most important greenhouse gas. The number one greenhouse gas is actually water vapor. It's something like 98 percent, by volume, of all greenhouse gases. I like the way that my colleague, Jan Veizer at the University of Ottawa, a world-renowned expert on the carbon cycle, lists the relative importance of greenhouse gases when he speaks on the topic. He points out that the number one greenhouse gas is water vapor, the number two greenhouse gas is water vapor, the number three greenhouse gas is water vapor, the number four greenhouse gas is water vapor and CO2 is a distant fifth. Of course, this list is somewhat facetious as there is only one type of water vapor. However, he lists the relative importance of greenhouse gases this was to indicate just how insignificant the tiny carbon dioxide cycle is to the water vapor cycle that it piggybacks on. To give you an example of this comparison lets consider the amount of CO2 in the atmosphere. In the 19th century, when the world was relatively unindustrialized the level of CO2 in the atmosphere stood at around 285 ppm. By 2003 the level of CO2 in the atmosphere, primarily the result of industrialization and land use changes, stood at 376 ppm. The resultant influence on climate has been minimal. Computer models say that this increase in CO2 should have heated the Earth up significantly by this stage. However, very little warming that can be attributed to CO2 has actually occurred.

Now lets have a look at what happened during 1997-98. There was a major El Nio on in the equatorial Pacific, that many of you may recall had a significant influence on global weather. However, it also a major influence on global temperatures. They started to go up in response to the enormous amount of water vapor that was pumped up into the atmosphere. In just a few months global temperatures spiked by nearly 1 degree Celsius above what they had been before. If you watched any television at the time you would have heard newsreaders on all networks, almost gleefully exclaiming that we were seeing the major global warming that was supposed to occur. Much to their disappointment temperatures quickly dropped off again, within a few months, as the El Nio ebbed. That collapse in global temperatures didn't get any coverage by the media though. And, so, there we were, right back to normal. This example of El Nio fueled injection of water vapor into the atmosphere provides a very good example of the relative impact of CO2 and water vapor as greenhouse gases.



But what about CO2 and climate change? Atmospheric CO2 concentrations have increased to 376 ppm in 2003, about a 30 percent increase from pre-industrial times. Most of that increase has been due to fossil fuel burning and land use changes. CO2 is a greenhouse gas. CO2 can and does have an impact upon global temperatures. But what impact will it have? The idea put forward by the IPCC is that CO2 the major greenhouse gas and any increases in the proportion of CO2 in the atmosphere will cause a major warming in earth's climate. This scenario is at odds with the empirical evidence recorded in the geological record.

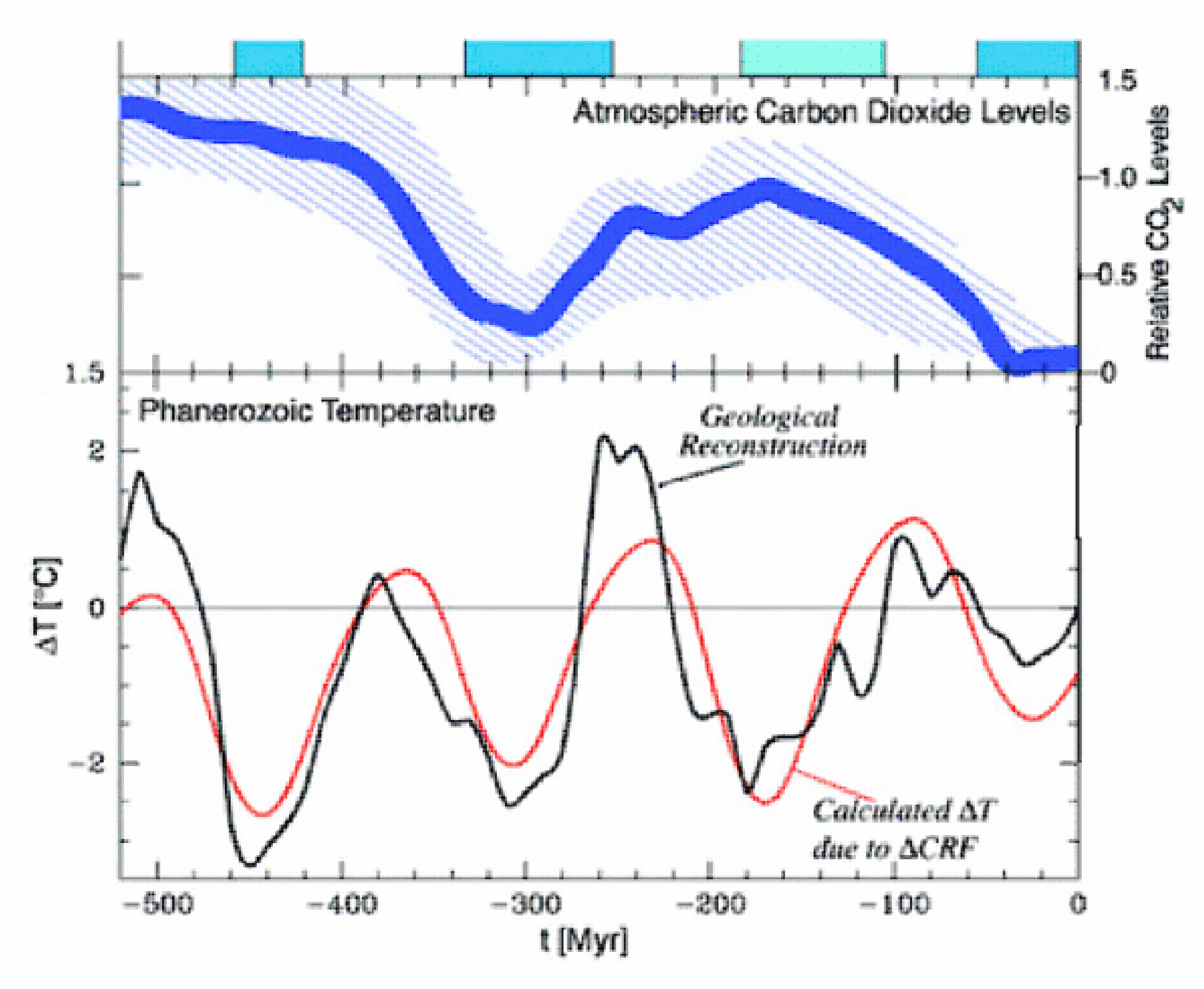
It is important to look at the empirical geological record of climate change and atmospheric CO2 concentrations and see what that tells us about the long-term correlation between climate and CO2 concentrations because that's a lot better than the 100 years of temperature records that we have.



Mauna Loa Observatory, Hawaii

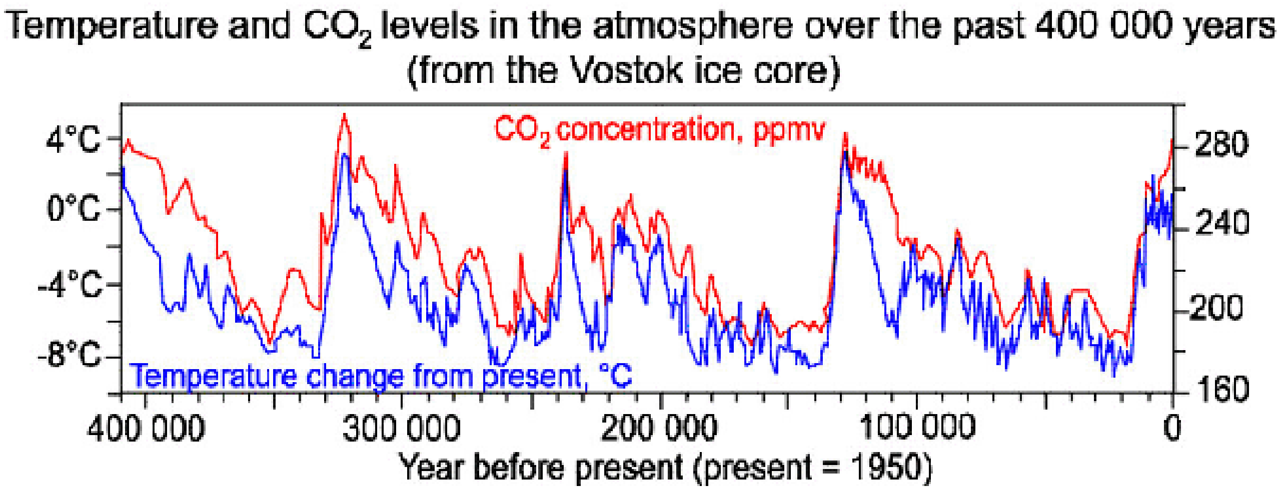
Before looking at the geological record of CO2 it is useful to look at a schematic of our current understanding of the carbon cycle. Fossil fuel emissions coming from smokestack industries contribute about 5.5 gigatons (plus or minus 0.5 gigatons), land use changes contribute another 1.6 gigtons (plus or minus 0.7 gigatons), with a certain amount coming back into the biosphere again. About 2 gigatons (plus or minus 0.8 gigatons) of this returning CO2 is taken up by an oceanic sink. On top of this there is a mysterious, unaccounted for sink here of 1.8 gigatons (plus or minus 1.2 gigatons). As you might note there are significant error bars attached to all of these estimates meaning that considerable further research needs to be done on the dynamics of the carbon cycle. The average yearly increase of CO2 in the atmosphere ends up being about 3.3 gigatons of carbon staying in the atmosphere as part of a flux that totals around 730 gigatons.

Now let's look at the geologic record. I only want you to look at a couple of things on this diagram. First of all, please note in the top chart the varying amounts of carbon dioxide in the atmosphere through the last 500 million years. At times in the past CO2 levels have been up to 16 times higher than at present.



The bottom chart shows the range of global temperature through the last 500 million years. There is no statistical correlation between the level of carbon dioxide in the atmosphere through the last 500 million years and the temperature record in this interval. In fact, one of the highest levels of carbon dioxide concentration occurred during a major ice age that occurred about 450 million years ago. Carbon dioxide concentrations at that time were about 15 times higher than at present.

Let's move to a little bit more recent geological history. There have been about 33 glacial advances and retreats through the last two million years or so. Through the last 10,000 years we have been in the Holocene interglacial, a warm episode between the last glaciation and the next one that will begin in the relatively near, geologically speaking, future. The last glaciation peaked about 18,000 years ago with the ice sheets retreating rapidly over just a few thousand years. Before that there was another interglacial that began about 130,000 years ago and lasted about 10,000 years. In Europe that interglacial is known as the Eemian. Here in North America it is known as the Sangamon. As one goes back in time these intervals of about 10,000 years of interglacial interspersed with episodes of about 100,000 years of glaciation continue.



What I would like to draw your attention to is the level of CO2 levels, as preserved in prehistoric air bubbles, from very high quality ice core records from Antarctica. When researchers first looked at the results from these cores they observed a repeating correlation between CO2 and temperature through several glacial/interglacial cycles. However, when they began to look at higher resolution cycles they say something different. They observed that temperature would go up first comes up first, with CO2 coming up later. This correlation indicates that as one might expect as temperatures warm biological productivity increases resulting in more CO2 in the atmosphere. The lag between CO2 and rising or falling CO2 levels is something like 800 years.

I teach a general climate change course. To get the significance of this correlation over to the students I use the following analogy. I tell the students that based on these records if you believe that climate is being driven by CO2 then they probably would have no difficulty in accepting the idea that Winston Churchill was instrumental in the defeat of King Herold by Duke William of Orange at the Battle of Hastings in 1066. If you can believe that this historical temporal incongruity could be feasible then you can have no problem believing that CO2 is what's driving Earth's climate system.

In conclusion, the geologic record clearly shows us that there really is little correlation between CO2 levels and temperature. Although CO2 can have a minor influence on global temperature the effect is minimal and short lived as this cycle sits on top of the much larger water cycle, which is what truly controls global temperatures. The water cycle is in turn primarily influenced by natural celestial cycles and trends.