What Causes Climate Change? The Sun, the Solar System, and the Galaxy

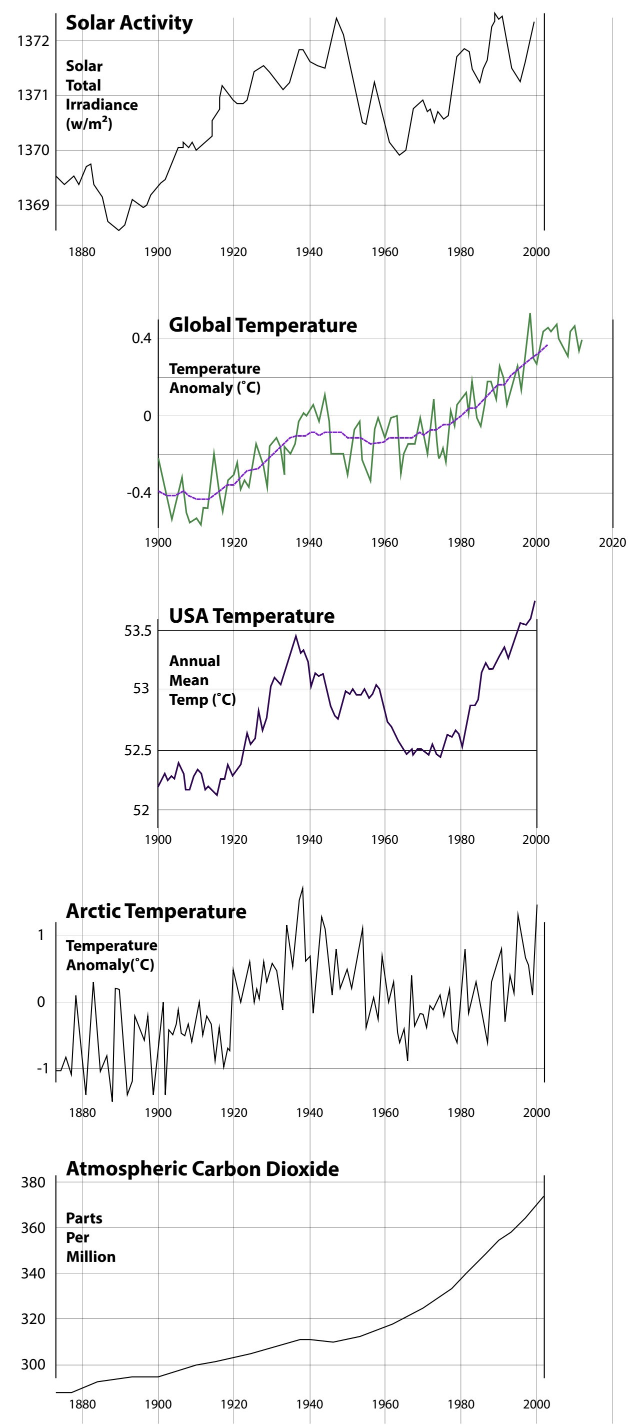
by Benjamin Deniston

Although historical and geological records of CO_2 changes fail to correspond with temperature changes, there are larger-scale, extraterrestrial phenomena that do match climate and related changes quite well. These include shifts in the activity of the Sun, the characteristics of the Solar System, and the Sun's changing position within the Galaxy. This can be clearly seen on a series of different timescales.

On the timescale of the past century, variations in Solar activity match changes in the Earth's temperature (which clearly deviate from the trends in CO_2 emissions). This has been shown with measurements of average US temperature, average Arctic temperature, and average global temperature, compared with changes in solar activity. From around 1900 the temperature increased until about the middle of the century—when CO_2 emissions were relatively low, *but solar activity was on the rise*. From about the 1940s to the mid-1970s, temperature held flat, or even declined—matching the easing of solar activity, but not matching the accelerated increase in CO_2 emissions. The warming from the mid-1970s to the end of the century matches both the increase in solar activity and the increase in CO_2 emissions, but since the turn of the century solar activity has leveled off and temperature has leveled off with it (while CO_2 emissions continue to accelerate). (**Figure 1**).

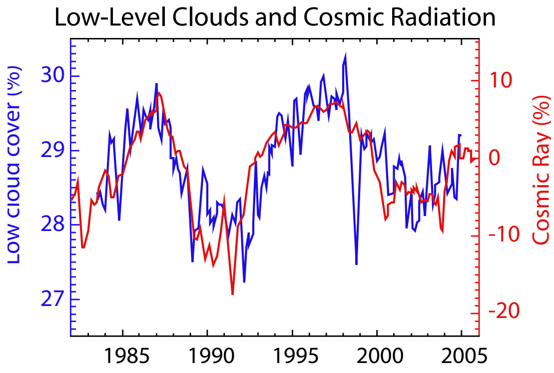
While it has been argued that the measured changes in the amount of sunlight reaching the Earth are too small to account for the observed global climate change, a new body of research shows that an additional process amplifies the effect of the Sun on the Earth's climate: the Sun's role in affecting the flux of galactic cosmic radiation, which then plays a critical role in cloud formation (and, therefore, the climate). Galactic cosmic radiation

FIGURE 1



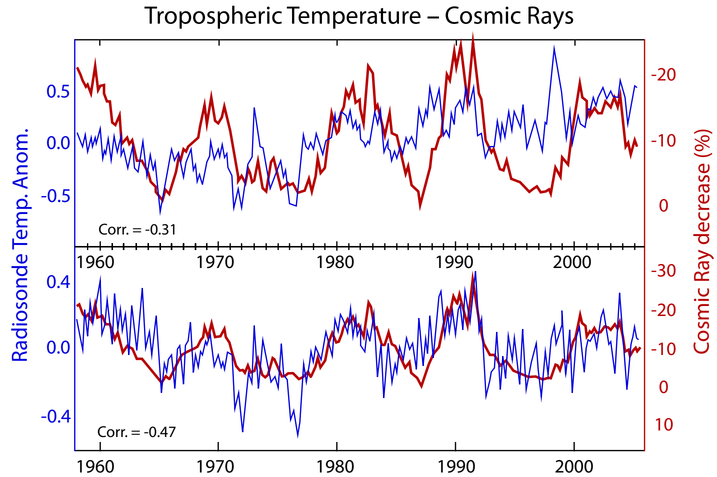
Three different temperature records over the past century show the same general trends, warming in the first half of the century, leveling off or cooling from the 1940s to 1970s, followed by warming which lasted until about the turn of the century. This matches the general changes in solar activity, as measured by the sunlight reaching the Earth (total solar irradiance—TSI), but not changes in CO_2 emissions..

FIGURE 2A



Svensmark & Friis-Christensen, JASTP 1997, Svensmark, PRL 1998, Marsh & Svensmark, PRL, 2000. (update 2005)

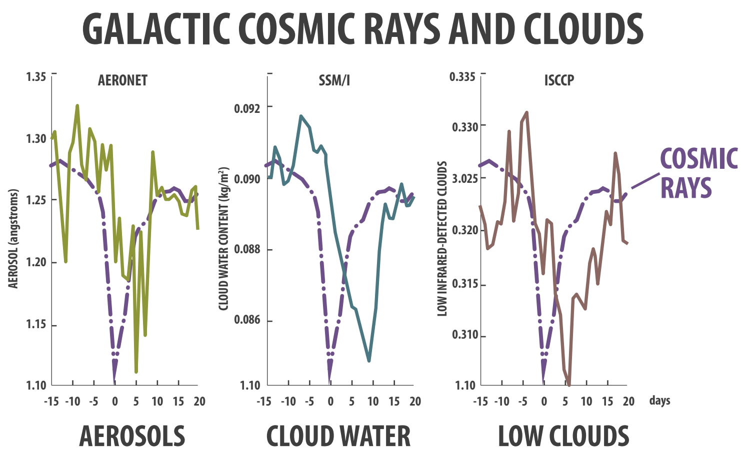
FIGURE 2B



Tropospheric cosmic rays vs. radiosonde temperature anomalies raw and bottom filtered and detrended (Henrik Svensmark and Eigil Friis-Christensen).

"Cosmic ray decreases affect atmospheric aerosols and clouds," Henrik Svensmark, Torsten Bondo, Jacob Svensmark, *Geophysical Research Letters*, 2009; 36 (15).

FIGURE 2C



Svensmark, H. and Friis-Christensen, E., "Reply to Lockwood and Fröhlich – The persistent role of the Sun in climate forcing", Danish National Space Center Scientific Report 3/2007.

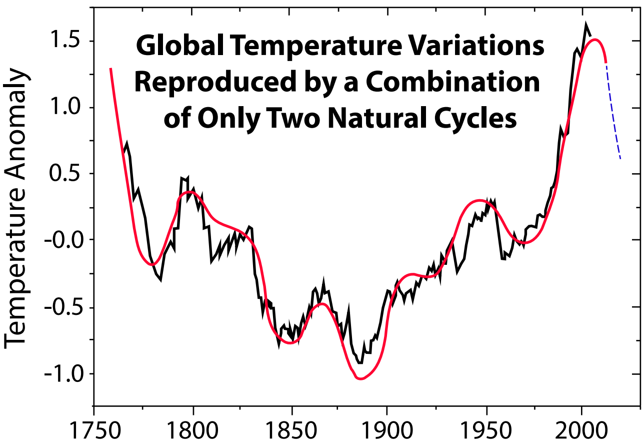
Various atmospheric processes have been shown to respond to changes in the flux of galactic cosmic radiation. This includes low-level cloud formation and atmospheric temperature, as measured over past decades, as well as aerosol formation and the water content in clouds, as measured days after sharp drops in the flux of galactic cosmic radiation. Graphic adapted from originals in Svensmark, H. and Friis-Christensen, E., "Reply to Lockwood and Fröhlich – The persistent role of the Sun in climate forcing", Danish National Space Center Scientific Report 3/2007; and "Cosmic ray decreases affect atmospheric aerosols and clouds," Henrik Svensmark, Torsten Bondo, Jacob Svensmark, Geophysical Research Letters, 2009, 36 (15).

is composed of atomic particles (mostly protons and helium nuclei, with a few nuclei of heavier elements as well) traveling at extremely high speeds throughout the galaxy. Because they are charged, the Sun's magnetic field acts to change their paths, thereby regulating the amount of high energy galactic cosmic radiation reaching the Earth's atmosphere. A stronger Sun (in the sense both of more sunlight and a stronger magnetic field) means that more of these particles are deflected, leading to the Earth receiving less galactic cosmic radiation. Conversely, a weaker Sun deflects fewer of these cosmic radiation particles, allowing more to reach the Earth.

In 1997 Danish scientists Henrik Svensmark and Eigil Friis-Christensen showed that the density of low-level cloud cover appeared to change in response to variations in the flux of galactic cosmic radiation. Since then they continued to develop evidence to support their new theory, showing in laboratory experiments that galactic cosmic radiation affects the processes which lead to cloud formation,[1] and identifying additional responses of the Earth's climate system to changes in the cosmic radiation flux. In a 2007 study, Svensmark and Friis-Christensen showed that the global average temperature of the atmosphere rose and fell in lock step with changes in the flux of galactic cosmic radiation. A 2009 study by Svensmark and col-

1 "Response of cloud condensation nuclei (>50 nm) to changes in ion-nucleation," Henrik Svensmark, Martin B. Enghoff, Jens Olaf Pepke Pedersen, Physics Letters A, Volume 377, Issue 37, 8 November 2013, Pages 2343–2347.

FIGURE 3



The interaction of only two cycles, those of 210 and 65 years, produces the red curve, matching recorded temperature changes extremely well. Graphic adapted from original by Lüdecke et al.

FIGURE 4

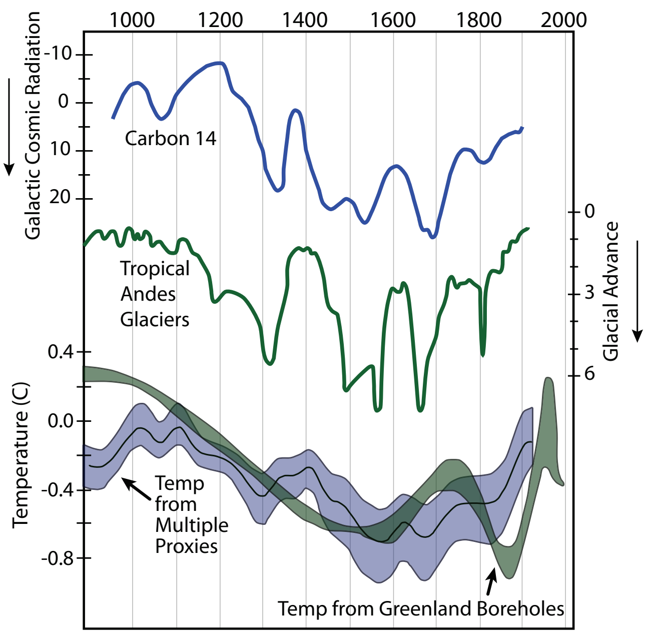


Image adapted from "Cosmic Rays and Climate," by Jasper Kirkby, Surveys in Geophysics *28, 333–375.*

leagues showed that the number of low-level clouds, the water content in clouds, and the number of cloud-forming aerosols all decreased in the days following sudden drops in galactic cosmic radiation (caused by explosive outbursts of solar magnetic activity). (**Figure 2**).

These studies all show that cosmic radiation plays a critical role in processes of cloud formation and thereby acts as a critical factor in determining the Earth's climate, because clouds regulate the amount of sunlight reaching the Earth's surface. A more active Sun not only puts out more light, but it also blocks more cosmic radiation, meaning fewer clouds and more sunlight reaching the Earth's surface. Svensmark and colleagues have shown that a change of only a few percent in low-level cloud cover (attributable to change in the flux of galactic cosmic radiation) could account for half of the warming in the past century.

This relatively new body of work indicates that much of the climate change over the past century has been largely driven by natural activity, meaning that any affect human CO_2 emissions have had is relatively negligible, and future human CO_2 emissions are not something to worry about. This conclusion is supported by a recent study from a group in Germany which looked for cycles in temperature records covering the last few hundred years. In their own analysis they clearly identified the presence of two already known cycles, an approximately 200-year cycle in solar activity (known as the "Suess cycle" or "de Vries cycle") and an approximately 65-year cycle in Atlantic Ocean temperatures (known as the "Atlantic Multidecadal Oscillation"). When they examined the interaction of these two natural cycles, they found that these two cycles alone accounted for most of the climate change over the past centuries, including the recent warming trends—again, indicating that there is little evidence CO_2 has an effect worth worrying about.[2] (**Figure 3**).

With this in mind, let's look a bit further back in time. If we examine records of climate over the past few thousand years we again see that climate changes match records of variations in galactic cosmic ray flux (and not changes in CO_2). Multiple records of climate over the past thousand years indicate lower temperatures from the 1500s to the 1800s, corresponding to a period of lower solar activity and increased galactic cosmic rays. Additionally, during this time we see periods of increased glaciation in the Andes Mountains, matching periodic increases in galactic

2 "Multi-periodic climate dynamics: spectral analysis of long-term instrumental and proxy temperature records," H.-J. Lüdecke, A. Hempelmann, and C. O. Weiss, *Climate of the Past*, February 22, 2013. "Paleoclimate forcing by the solar De Vries/Suess cycle," H.-J. Lüdeckel, C. O. Weiss, and A. Hempelmann, *Climate of the Past*, February 12, 2015.

FIGURE 5

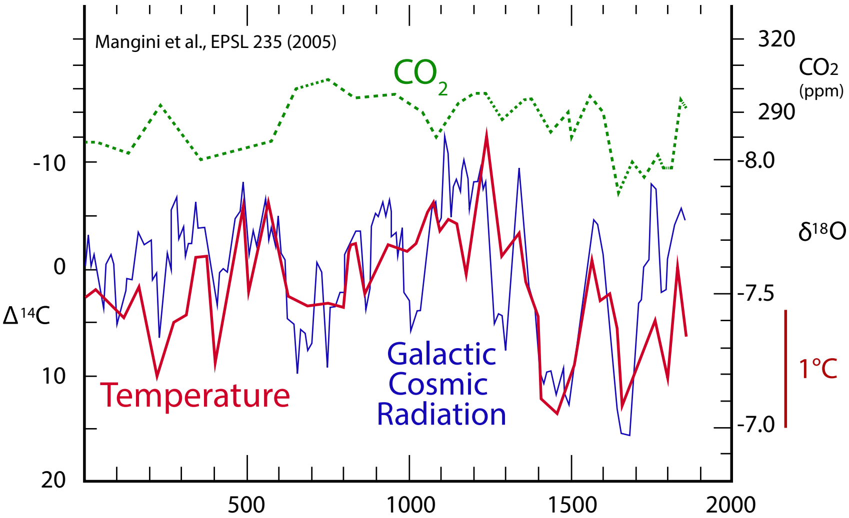
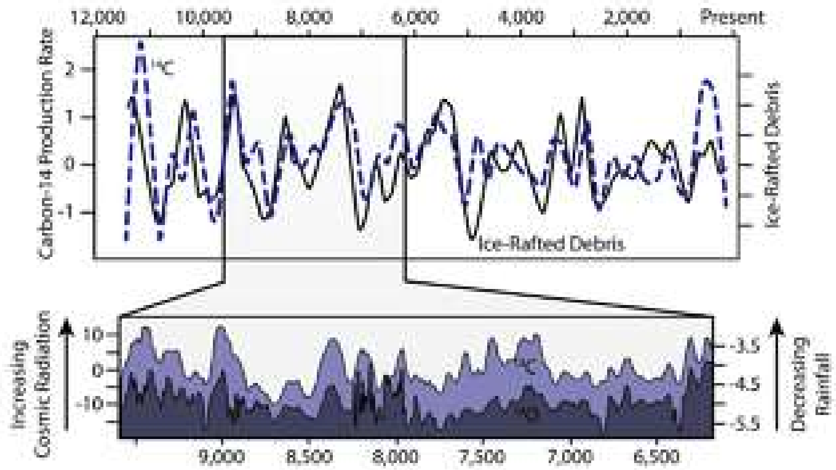


Image adapted from "Cosmic Rays and Climate," by Jasper Kirkby, Surveys in Geophysics *28, 333–375.*

FIGURE 6



Variations in the flux of cosmic radiation over the past 12,000 years are measured by changes in the amount of carbon-14 produced. These cosmic radiation fluctuations match variations in glaciation and ice flow in the northern Atlantic Ocean (measured by ice-rafted debris) and variations in rainfall in the Arabian Peninsula. Graphics adapted from Bond et al., "Persistent solar influence on North Atlantic climate during the Holocene," Science 294, 2130–2136 (2001); and Neff et al., "Strong coincidence between solar variability and the monsoon in Oman between 9 and 6 ky ago," Nature 411, 290–293 (2001).

cosmic ray flux quite well. Prior to this, from around the 900s to the 1200s the temperature was warmer (the Medieval Warm Period), galactic cosmic ray flux was less, and glaciation in the Andes was less (see **Figure 4**).

Looking at the past two thousand years, temperature records from the Alps follow changes in galactic cosmic rays very well – while, again, changes in CO_2 levels don't match the temperature records, changing in the opposite directions for hundreds of years (see **Figure 5**).[3]

These records from the past one and two thousand years confirm the picture developed from examining the past 100 years, that changes in the flux of galactic cosmic radiation (regulated by solar activity) govern changes in the climate, not CO_2.

Stepping back even further in time, we see more evidence of galactic cosmic radiation being a driving factor in climate change. An examination of the galactic cosmic radiation flux over the entirety of the current interglacial period (the Holocene epoch, lasting from 12,000 years ago to the present) shows a very strong relation to records of variations in glaciation and ice flow in the Northern Atlantic Ocean.[4] Additionally, shifting to a slightly finer resolution, records of variations in long-term trends in precipitation in the Arabian Peninsula, measured from 6,200 years ago to 9,600 years ago, show a *very strong* relationship to variations in galactic cosmic radiation flux.[5] **Figure 6**

Taken together, we have evidence that critical factors in the Earth's climate system respond to changes in galactic cosmic radiation on timescales of days, years, decades, centuries, and millennia – demonstrated in independent studies.

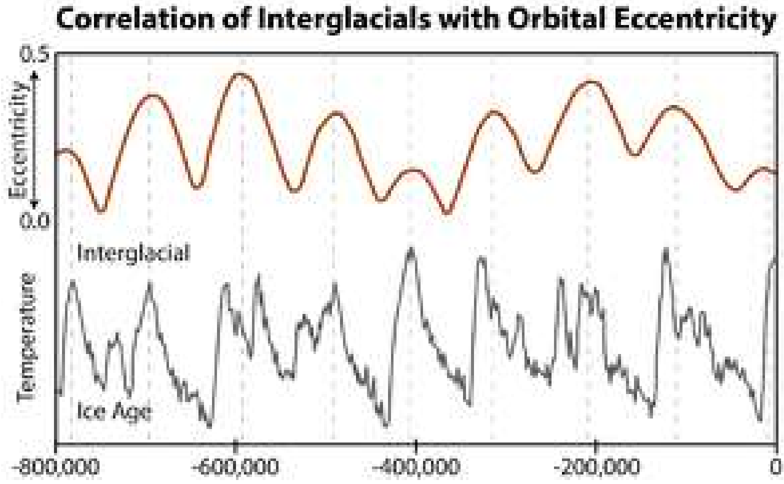
Shifting to longer timescales, the

3. "Cosmic Rays and Climate," Jasper Kirkby, *Surveys in Geophysics*, February 28, 2008

4. Bond, et al., "Persistent solar influence on North Atlantic climate during the Holocene," *Science* **294**, 2130-2136 (2001); Kirkby, *op cit.*

5. Neff,et al., "Strong coincidence between solar variability and the monsoon in Oman between 9 and 6 ky ago," *Nature* **411**, 290-293 (2001).

FIGURE 7



Over the past one million years, changes in the eccentricity of the Earth's orbit around the Sun match the periodic climate changes from ice ages to relatively brief interglacial periods.

cycles of transition between ice ages and shorter interglacial periods are closely associated with changes in the *Earth's orbit* around the Sun and with changes in the *tilt* and *orientation* of the Earth's spin axis – together known as the Milankovitch Cycles. For the past one million years ice age cycles have had the strongest correlation with changes in the eccentricity of the Earth's orbit around the Sun. For the two million years prior (from three to one million years ago) the Earth's climate changes best correlated with changes in the tilt of the Earth's axis. (**Figure 7**)

Taking one more step to larger timescales, even larger climate changes over tens and hundreds of millions of years correspond with the motion of our Solar System through the galaxy – likely due to larger changes in galactic cosmic radiation flux. While changes in the strength of the Sun's magnetic field modulate the amount of galactic cosmic radiation on the order of ten percent, in different regions of the galaxy the Solar System (and the Earth therein) can experience much larger fluctuations in galactic cosmic radiation – bringing changes on the order of one hundred percent. In accordance with the work of Svensmark and his associates, this larger variation in cosmic radiation flux over geological timescales should drive large-scale climate variations. This is exactly is what the records show.

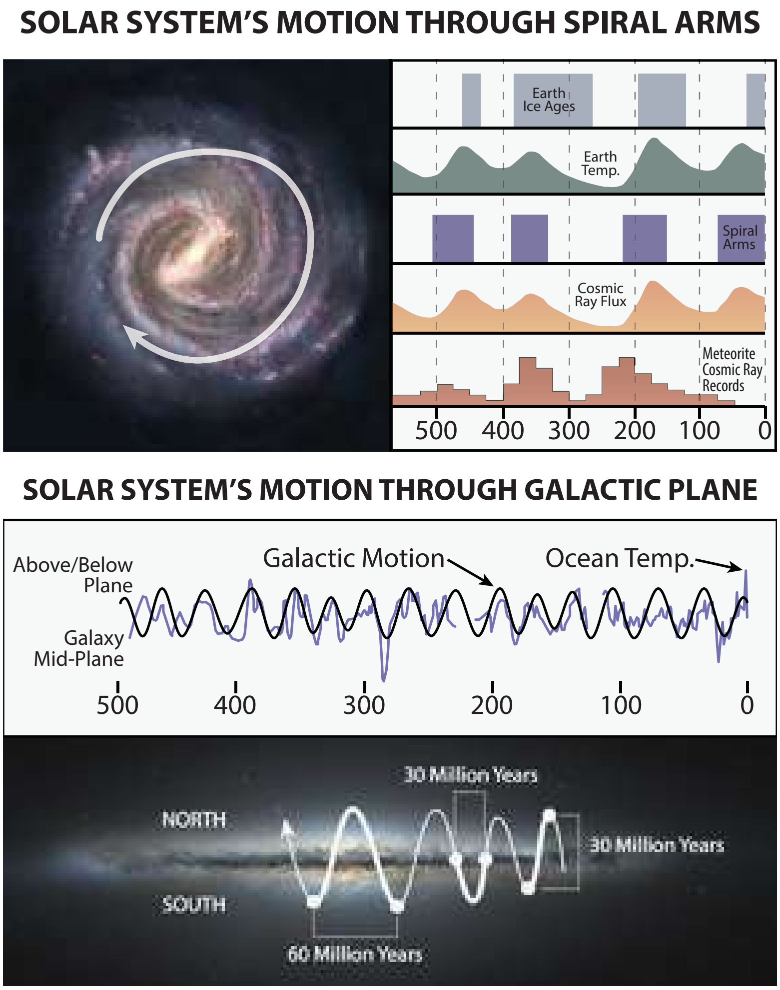
Over the past 540 million years (the Phanerozoic Eon) the Earth's climate has shifted back and forth four times between two general climate modes, icehouse and hothouse. During the hothouse modes there are no continental glaciers on Earth and temperatures are significantly higher. During the icehouse modes the climate is colder and glaciers develop and expand. We are currently in an icehouse mode, with the ice sheet over Antarctica starting to form around 34 million years ago, and the Arctic ice sheets forming only two million years ago.

In 2000 scientist Ján Veizer and his associates showed that the four hothouse-icehouse transitions over the past half billion years do *not* correspond with changes in CO_2 levels, and in 2003 Veizer together with Nir Shaviv showed that these climate transitions *do* correspond with the periods of the Solar System's passage through our Galaxy's spiral arms. This is consistent with Svensmark's work, since the Galaxy's spiral arms are expected to have significantly higher concentrations of galactic cosmic radiation, and we see that the Earth's four most recent icehouse modes correspond with the times when the Solar System is thought to have been traveling through a spiral arm. Shaviv was also able to provide additional evidence by examining iron meteorites, which showed records of having been exposed to higher galactic cosmic radiation levels at times when the Solar System is believed to have been traveling through the spiral arms (recorded when the meteorites were still orbiting though interplanetary space as part of an asteroid).[6]

Together, records of higher galactic cosmic radiation flux recorded in iron meteorites, correspond with the time when we think the Solar System has been passing through the Galaxy's spiral arms (where we'd expect more cosmic radiation), which both correspond with the recent icehouse periods on Earth – all consistent with the work of Svensmark and associates on the relation between cosmic radiation and climate through cloud formation. Shaviv and Veizer showed that this

6. "Evidence for decoupling of atmospheric CO_2 and global climate during the Phanerozoic eon," Ján Veizer, Yves Godderis, Louis M. François, Nature 408, 698-701 (7 December 2000). "Cosmic Ray Diffusion from the Galactic Spiral Arms, Iron Meteorites, and a Possible Climatic Connection?" Physical Review Letters, vol. 89, Issue 5 (2002). Shaviv NJ, Veizer J (2003) Celestial driver of Phanerozoic climate? GSA Today, Geol Soc Am 4–10

FIGURE 8



"Is the Solar System's Galactic Motion Imprinted in the Phanerozoic Climate?" Nir J. Shaviv, Andreas Prokoph & Jan Veizer, Nature Science Reports, August 21, 2014; and "The spiral structure of the Milky Way, cosmic rays, and ice age epochs on Earth," by Nir J. Shaviv, New Astronomy 8 (2003) 39–77.

could account for most of the large scale temperature changes over the past half billion years (whereas CO_2 was shown to have little effect, if any).

More recently, Shaviv has also shown that records of ocean temperature exhibit a 30 million year periodicity, corresponding to the bobbing motion of our Solar System above and below the plane of our Galaxy. When the Solar System is either above or below the galactic plane the galactic cosmic radiation flux is expected to be less, and ocean records show relatively warmer temperatures (as would be expected from Svensmark's hypothesis); when the Solar System is passing through the galactic plane, galactic cosmic radiation flux is thought to be higher, and ocean records show relatively cooler temperatures (as would be expected from Svensmark's hypothesis). **Figure 8**

Taken together, a growing body of evidence indicates that galactic cosmic radiation plays a major role in affecting climate change (by controlling critical aspects of cloud formation). On shorter timescales of days, to decades, to centuries, to thousands of years, changes in the strength of the Sun's magnetic field regulate the flux of galactic cosmic rays reaching the Earth; and on much longer timescales, tens to hundreds of millions of years, different galactic environments experienced by our Solar System have much larger variations in the density of galactic cosmic radiation. For time periods in between, the most important factor appears to be related to changes in the Earth's orbit and spin axis. Climate change (across all these timescales) is driven by cosmic processes – solar, orbital, and galactic changes – not by CO_2.