Supernovae – The Force Behind Great Ice Ages

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The Threat

Is the Earth poised to return back to an ice age? Will this event happen abruptly and in our lifetimes? The answer to these questions resides in the field of physics.

The root cause of global cooling is a byproduct of an exploding star, a supernova. Our solar system is currently in an active region of space producing nearby supernova events. This repeating pattern or string of nearby supernova produce and reinvigorate Great Ice Ages. Supernovas produce Galactic Cosmic Rays (GCRs), high-energy charged particles that interact with the lower atmosphere to spawn cloud creation. A burst of GCRs produces a period of intense low cloud cover, which blocks sunlight, reflects solar radiation back out into deep space producing depressed temperatures globally. The clouds form into great storms, which move moisture to higher latitudes where it drives a buildup of solar reflective snow and ice contributing to a prolonged period of cooling.

The Current Ice Age

We live in a Great Ice Age called the Pleistocene Epoch which began around 1.8 million years ago and will continue for several million years into the future. During an Ice Age, the Earth cycles between cold Glacial and warm Interglacial periods. An Interglacial is a short warming period where the Earth thaws between the icy grips of the glacial periods. The present interglacial period (the Holocene) began approximately 14,000 years ago.

ICE AGE TRANSITIONS FOR PAST 600,000 YEARS

Holocene (**interglacia**l, 14,000 years ago - present)
Wisconsinan/Weichsel (or Vistula) (**glacial** period, 70,000 – 14,000 years ago)
Sangamon/Eem (**interglacial**, 130,000 – 70,000 years ago)
Illinoian/Saale (**glacial**, 180,000 – 130,000 years ago)
Yarmouth/Holstein (**interglacial**, 230,000 – 180,000 years ago)
Kansan/Elster (**glacial**, 300,000 – 230,000 years ago)
Aftonian/Cromer (**interglacial**, 330,000 – 300,000 years ago)
Nebraskan/Gunz (**glacial**, 470,000 – 330,000 years ago)
Waalian (**interglacial**, 540,000 – 470,000 years ago)
Donau II (**glacial**, 550,000 – 540,000 years ago)
Tiglian (**interglacial**, 585,000 – 550,000 years ago)
Donau I (**glacial**, 600,000 – 585,000 years ago)

What are Galactic Cosmic Rays (GCRs)?

Galactic cosmic rays (GCRs) are high-energy charged particles that originate outside our solar system. About 85% are protons (nuclei of hydrogen atoms), 12% alpha particles (helium nuclei) and the remainder are electrons and the nuclei of heavier atoms. These cosmic rays typically have energies in the 100 MeV to 10 GeV range. Cosmic rays are produced when a star exhausts its nuclear fuel and explodes into a supernova. These stars are generally new short-lived blue stars of the spectral type O (20-100 solar masses) or blue-white stars of spectral type B (3-20 solar masses). Supernova explosions occur in our Milky Way galaxy about every 50 years.

Our sun also produces cosmic rays in solar winds and in Coronal Mass Ejections (CMEs). A CME is an explosion in the Sun's corona that spew out solar particles and embedded magnetic fields over the course of several hours. These particles are generally less energetic than GCRs, with energies in the range of 10 MeV to 100 MeV.

How do GCRs affect Weather?

Research by Nigel Marsh, Henrik Svensmark and Eigil Friis-Christensen provides a good foundation in understanding the relationship between galactic cosmic rays and cloud formation.
http://www.dsri.dk/~hsv/SSR_Paper.pdf , http://www.dsri.dk/~hsv/prlresup2.pdf , http://www.dsri.dk/~hsv/9700001.pdf

Earth's cloud cover is strongly correlated with Galactic Cosmic Ray (GCR) flux modulated by solar cycle variations.

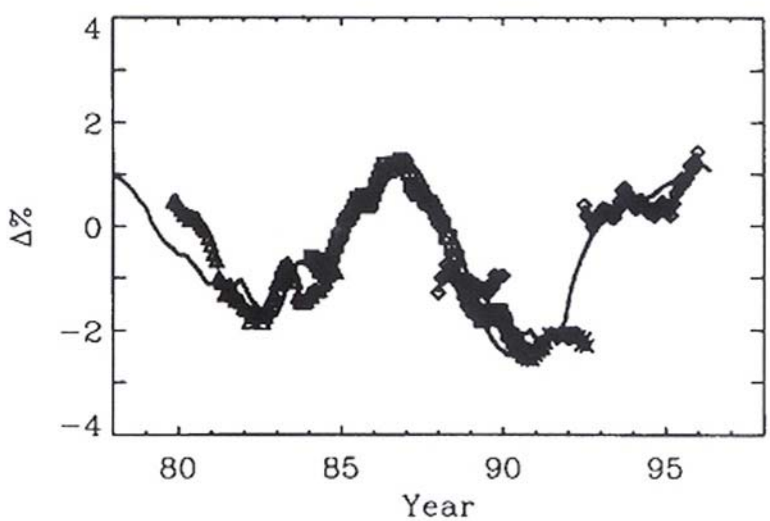

Figure 1. A strong correlation between Galactic Cosmic Rays (GCRs) and Earth's cloud cover. Figure shows cosmic rays fluxes from Climax (thick curve) plotted against four satellite cloud data sets. Triangles are the Nimbus-7 data, squares are the ISCCP-C2 data, diamonds are the DMSP data, and crosses are the ISCCP-D2 data. **Source:** Svensmark, H and Friis-Christensen, E. (1997) *Journal of Atmospheric and Solar-Terrestrial Physics*, **59** (11), 1225-1232

When GCRs collide with the Earth's atmosphere, they release in nuclear collision a cascade of secondary particles (protons, neutrons and muons), which continue to penetrate deeper and deeper into the atmosphere. This cascading effect continues until the particle's energy falls too low to undergo further collisions. This generally ends around 16 kilometers above the Earth's surface in the lower atmosphere. The ions produced within the troposphere by cosmic rays are important element of aerosol production. In the troposphere, ionization contributes to gas-particle formation of ultra fine (<20nm) aerosols that build into cloud condensation nuclei (CCN). Charged raindrops are ten to a hundred times more efficient in capturing aerosols than uncharged drops. In slightly supersaturated water vapor, when aerosol is dissolved in the tiny haze particles the droplets' vapor pressure lowers, which increases droplet growth. The water vapor condenses into larger water droplets that form clouds.

Low clouds tend to be optically thick and are efficient at reflecting sunlight back into space. An increase in low altitude clouds will result in planetary cooling.

GCRs are a very effective amplifying mechanism for climate forcing because the energy needed to change cloudiness is small compared with the resulting changes in solar radiation received at the Earth's surface.

Major Climate Change Variables

The ability of GCRs to produce global cooling is a function of several key variables:

* Proximity of nearby supernova events.
* Strong influence of the Galactic magnetic field lines on GCR travel path.
* Strength of the Sun's magnetic field in deflecting incoming GCRs.
* Strength of Earth's magnetic field in deflecting incoming GCRs.

Great Ice Ages

The circular passage of the solar systems around the galaxy brings the solar system near regions of space where new stars are formed in the galactic spiral arms and later into regions where these large stars die in massive supernova events. The spiral arms of our galaxy contain: atomic hydrogen gas, giant molecular clouds and newly made short-lived O and B stars. These giant stars have short lives measured in tens of millions of years. The Earth periodically comes into close proximity with this active region of nearby supernovas approximately every 145 million years. On average 1-2 supernovas occur in our galaxy every century. But nearby supernovas (less than 2,000 light years away) are less frequent and occur about once per thousand years. Nearby supernova events bath the solar system in a pulse of high-energy galactic cosmic rays. GCRs produce a decline in Earth's temperature. A string of nearby supernova events produces and reinvigorates Great Ice Ages.

The research of Nir J. Shaviv and Jan Veizer correlated galactic cosmic ray flux rates with the Great Ice Ages. http://www.fiz.huji.ac.il/~shaviv/Ice-ages/GSAToday.pdf

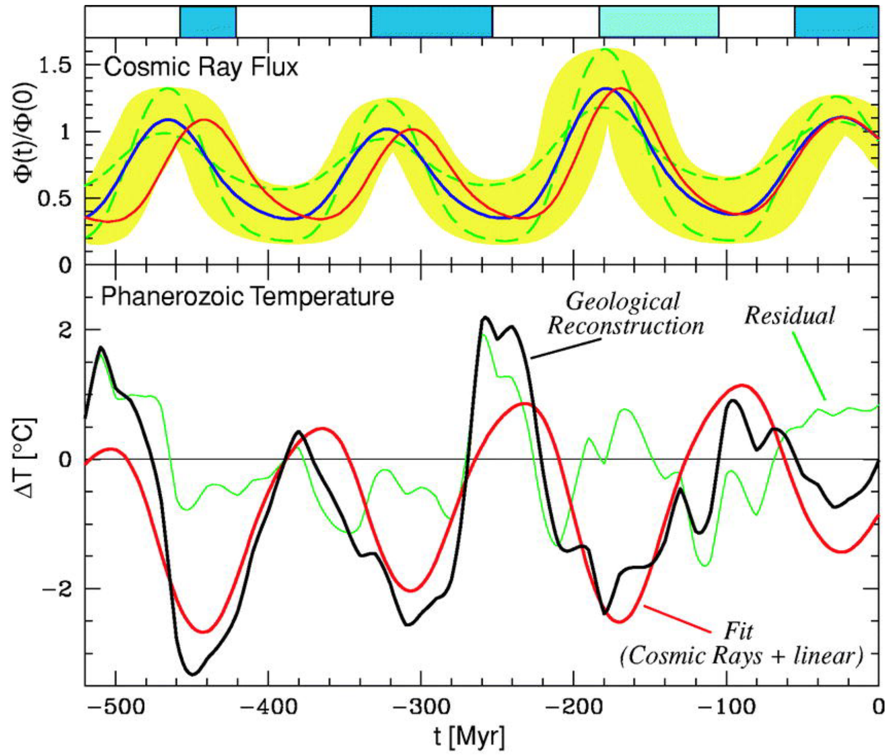

Figure 2. The Great Ice Ages line up with elevated GCR flux rates. Top panel describes the reconstructed Cosmic Ray Flux variations over the past 500 Million years using the exposure age of Iron Meteorites. The bottom panel depicts in **black**, the reconstructed tropical ocean temperature variations using isotope data from fossils. The bar along the top denotes the Great Ice Ages (starting from the left and working right: the Ordovician/Silurian Great Ice Age, the Carboniferous/Permian Great Ice Age, the Jurassic/Cretaceous Cold Period, and the present Pleistocene Great Ice Age). **Source:** Shaviv, N.J. and Veizer, J. (2003) *GSA Today* **13** (7): 4-10.

Solar Magnetic Field

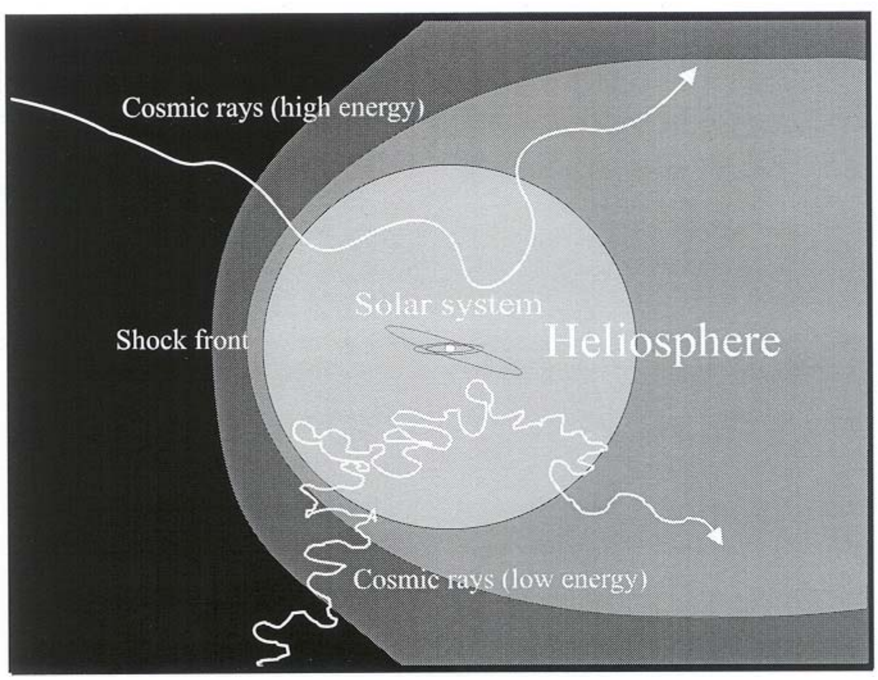

Figure 3. Pictorial of GCR interaction with the Sun's Heliosphere.

The Sun's magnetic field modulates the GCR flux rate on Earth. Just as cosmic rays are deflected by the magnetic fields in interstellar space, they are also affected by the interplanetary magnetic field embedded in the solar wind (the plasma of ions and electrons blowing from the solar corona at about 400 km/sec), and therefore have difficulty reaching the inner solar system. The effects from the solar winds are felt at distance approximately 200 AU from the sun, in a region of space known as the Heliosphere.

The Sun undergoes a magnetic pole reversal approximately once every 11 years. The Sun's magnetic field is normally dipolar but during solar maximum, quadrupole and octupole components exist as well. As the Sun's magnetic field weakens, it becomes less effective at shielding the Earth from GCRs.

The strength of the Sun's magnetic field is not constant over geological time. One gauge of solar magnetic field intensity is sunspot activity. The Maunder Minimum (1645-1715 AD) provides insight into the influence of the Sun's magnetic field on global cooling. During the 30-year period from 1672-1699AD, there were less than 50 sunspots detected, whereas during the past century over the same period between 40,000-50,000 sunspots appeared. During the Maunder Minimum, the solar wind was depressed, which allowed greater penetration of GCR into the inner solar system. This period of minimal solar magnetic field resulted in greater cloud formation on Earth and a significant decline in Earth's temperature. The Maunder Minimum is noted as one of the coldest periods during the past 2,000 years.

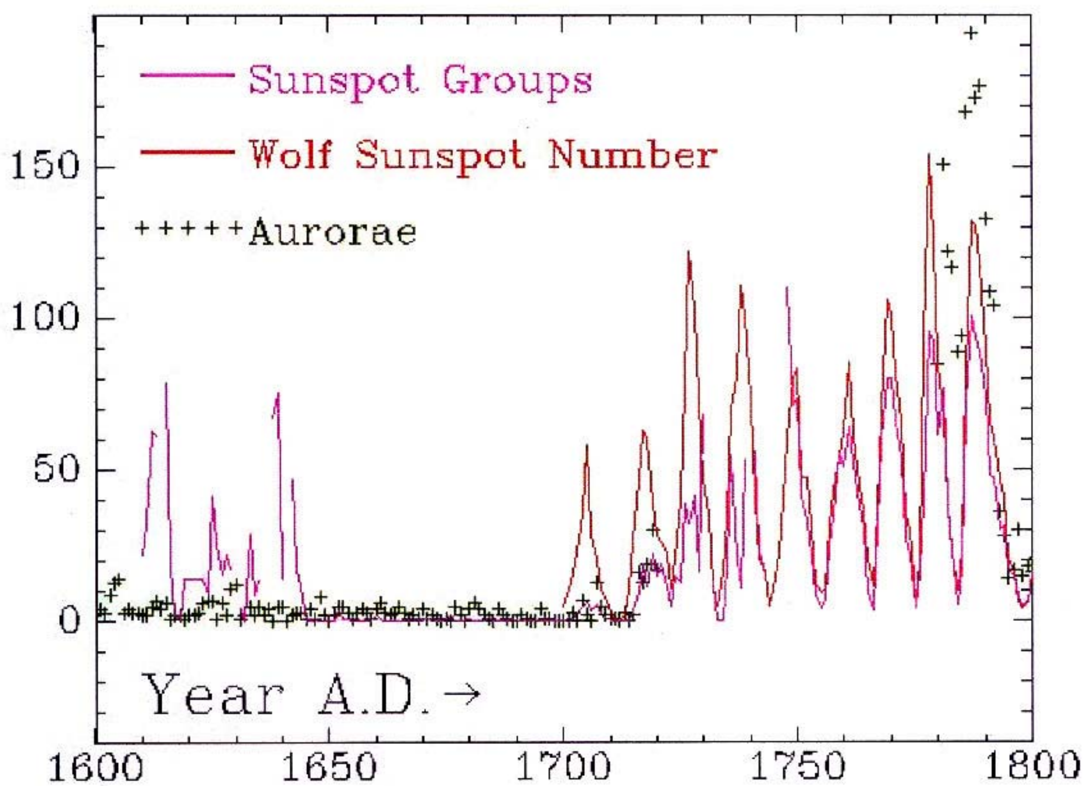

Figure 4. From 1645-1715AD, the sun's magnetic field went quiet. This was known as the Maunder Minimum. This plot shows the variation in the number of observed sunspots during the time period 1600-1800AD. The red curve is the Wolf sunspot number, and the purple line a count of sunspot groups based on a reconstruction by D.V. Hoyt. The green crosses are aurora counts, based on a reconstruction by K. Krivsky and J.P. Legrand.

Earth's Magnetic Field

The Earth's magnetic field varies in intensity and polarity over geological time. During a magnetic field reversal, the Earth's magnetic dipole breaks up into a series of localized mini-dipoles. These mini-dipoles tend to cancel each other out, therefore the Earth as a whole sees the magnetic field strength decline towards zero. During the last 780,000 years that defines the Brunhes Normal period, the strength of the magnetic field has dropped to zero on several occasions. This variation is extremely important in understanding global cooling events. Research at the laboratory at GeoForschungsZentrum (GFZ)Potsdam has provided fine detail of relative paleointensity variations. Figure 5 is a recording of the relative paleointensity of the Earth's magnetic field in the Iceland Sea at the Kolbeinsey Ridge (69.5^{O} N) over the past 300,000 years. When the intensity of the magnetic field is strong, as it was 14,000 years ago, it will shield the Earth from GCRs, reduce cloud cover, produce warmer climates and permit the Earth to transition from a glacial period into an interglacial.

But when the magnetic field is weak near magnetic field reversals, the GCRs can bombard the most protected and most vulnerable area, the equatorial regions. GCR penetration in equatorial region is a robust mechanism for great cloud formation. GCRs interacting with the atmosphere in Polar Regions produce very few cloud formations because the moisture is generally in frozen form. But equatorial temperatures and ocean moisture are a breeding ground for clouds and storms. This area generally has the highest temperatures and the most moisture to work with. A nearby supernova event near a magnetic field reversal on Earth could easily push the planet back into an Ice Age. Even when the sun's magnetic field is strong, significant bleed through during the sun's 11-year cycle would produce great cloud formations. The loss of Earth's magnetic field can greatly amplify global cooling effects. The last two interglacial periods came to an abrupt end when the Earth's magnetic field was weak and at the point of a magnetic field reversal. (~70,000 & ~180,000 years ago).

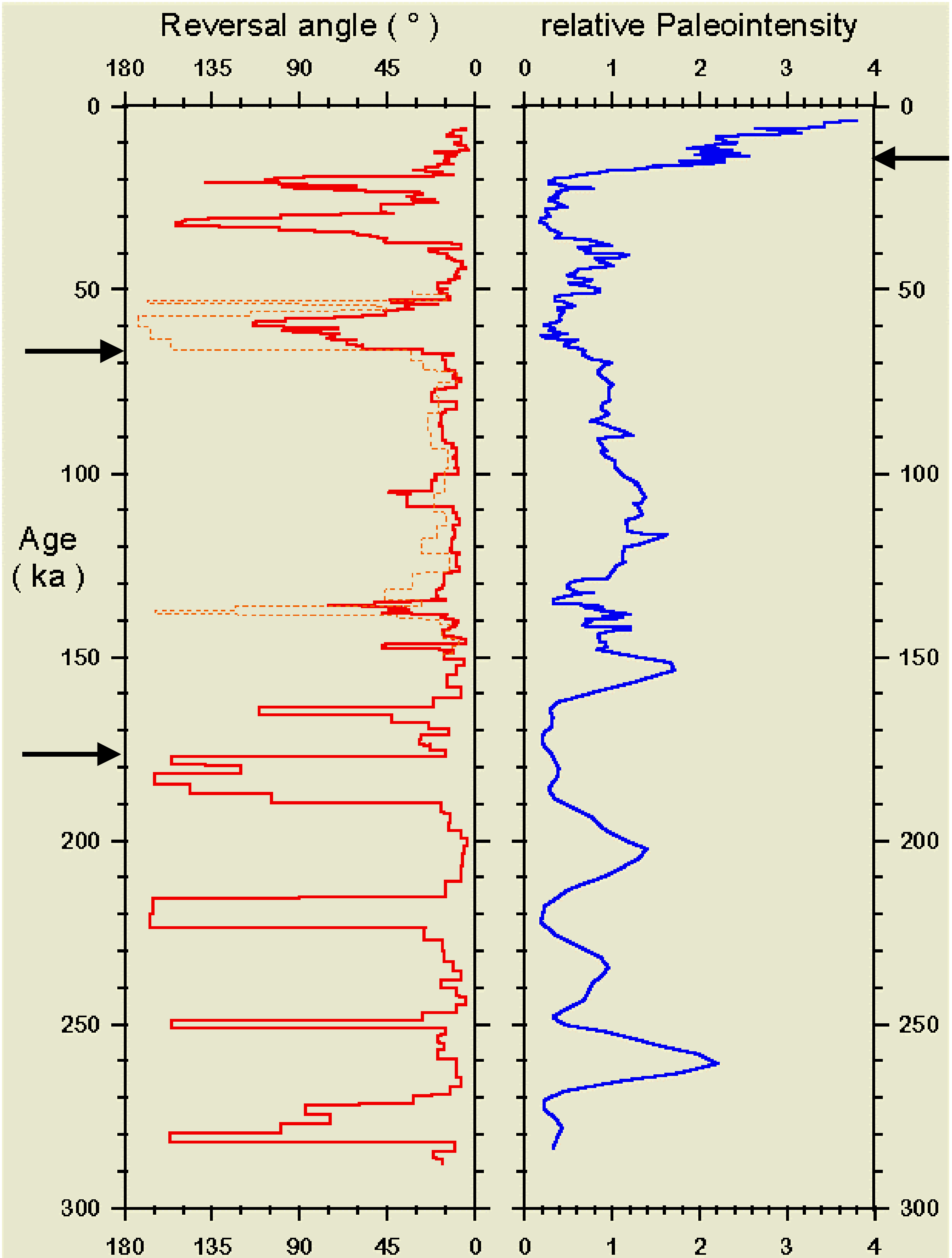

Figure 5. Geomagnetic field variations covering the past 300,000 years at Kolbeinsey Ridge.
Source: Research by GeoForschungsZentrum (GFZ)Potsdam
http://www.gfz-potsdam.de/pb3/pb33/methods/maglab/result_2.html

Planetary Orientation

The Earth's magnetic field is strongest above the equator and weakest above the poles.

Earth's axis is tilted 23.5 degrees to the plane of our solar system. Our solar system ecliptic is oriented approximately 60 degrees tilt angle from the galactic plane. As a result the Earth is presently located with its north pole facing away from the center of our galaxy, Sagittarius A. The center of our universe is only visible from latitudes 55 to –90 degrees. Most of the supernova production resides in the inward galactic spiral arms. Therefore most of the cosmic rays from a nearby supernova event will target the Southern Hemisphere.

Recent Occurrences

According to Sbaffi et al. (Sbaffi, L., Wezel, F.C., Curzi, G. and Zoppi, U. (2004) *Global and Planetary Change* **40**, 201-217), there is evidence of approximately 10 main cold events during the past 14,000 years (Holocene interglacial). Two major millennial-scale climatic oscillations produced the Dark Ages and the Little Ice Age.

The Little Ice Age

The Little Ice Age began in the 1300s and lasted into the 1800s. The rates of famine and mortality increased all over the world during this period. Northern Europe suffered a great famine during the terrible years 1315-1322AD. In 1315 alone, 1.5 million people died of starvation. The poor and hungry resorted to eating cats and dogs. Changing weather patterns produced major flooding, droughts and swamp creation. Cold and erratic weather patterns produced numerous crop failures in northerly areas such as Scotland and Norway. Native American tribes such as the Iroquois relocated their villages to escape the cold. These migrations stirred up political conflict among tribes, leading to the creation of non-aggression pacts like the famous League of the Iroquois, adopted in the 1500s. Perhaps hardest hit were the Norse settlements in Iceland and Greenland. The population of famine-ridden Iceland dwindled during the Little Ice Age to half its previous numbers. Greenlanders fared even worse. Growing sea ice cut off communication with the outside world beginning about 1370, and when German ships landed in Greenland more than a century later, they found a single frozen corpse but no living colonists among the ruins. In the United States, New York harbor froze over in winter, allowing people to walk from Manhattan to Staten Island. In Europe, glaciers expanded in the Alps and Scandinavia, slowly engulfing farms and crushing entire villages. In China's Jiang-Xi province severe winters killed the last of the orange groves that had thrived there for centuries.

A supernova event produces a surge of GCRs with energies up to 10^{15} eV. Most galactic cosmic rays have energies in the range of 100 MeV to 10 GeV. The higher the energies, the faster the GCRs travel.

Table 1. Velocity of Proton

Energy	Velocity (speed of light)
1 MeV	0.046 c
10 MeV	0.145c
100 MeV	0.429 c
1 GeV	0.875 c
10 GeV	0.996 c
100 GeV	0.999957c
1 TeV	0.99999956 c

Figure 6 shows the GCR flux rate during the past 1,000 years.

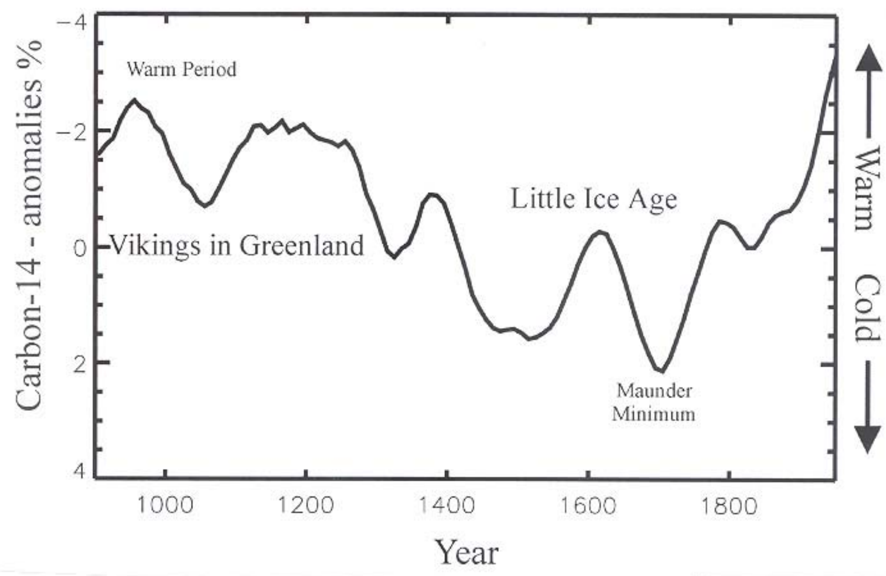

Figure 6. GCR flux rate over the past 1000 years as measured by variation in the C^{14} production rate on Earth. C^{14} is produced through nuclear interactions of cosmic ray particles in the atmosphere. **Source:** Marsh, N. and Svensmark, H. (2000) *Space Science Review* **00**, 1-16.

The Little Ice Age correlates well with a newly discovered type II shell-like supernova remnant (SNR) referred to as RX J0852.0-4622 (also called GRO J0852-4642). This supernova event occurred approximately 685 years ago (the time that the visible spectrum would have reached Earth) and the SNR was located approximately 200pc (650 light years) from Earth. This is the nearest supernova experienced during modern times. Refer to http://aa.springer.de/papers/9350003/2300997/sc1.htm

Evidence of this supernova event has been found in the ice cores taken from the South Pole. GCRs from the supernova ionized the atmosphere and formed nitrate ions (NO_3^-). The nitrates precipitated out of the atmosphere and were preserved in the Antarctica ice sheets. This nitrate signature was observed at the 1320AD layer. (Burgess, C. & Zuber, K (2000) Astroparticle Physics, August 2000)

Overlaying RX J0852.0-4622 SNR over Earth's history beginning in the 14th century, GCRs with energies in the TeVs would arrive simultaneously with the visible spectrum; whereas, 10 GeV GCRs would reach Earth approximately 3 years later. GCRs in the range of 10Gev and above caused the strong downturn in temperature and the beginning of the Little Ice Age. The effects from this initial GCR surge produced the famine of 1315-1322AD. As the years passed, the energy levels of the GCRs began to decline. The cosmic ray flux rate is modulated by variations in the magnetic field of the Earth and Sun. Around 1600AD, the level fell to approximately 400 MeV. At this point, the sun's magnetic shield became effective at deflecting significant quantities of incoming particles. But then from 1645-1715 AD, a very rare event occurred; the suns magnetic field essentially went dormant, the Maunder Minimum. The GCR flux rate shot up dramatically and global temperatures reached their coldest point. The maximum glacial stage occurred in the 1750's. Glaciers became more widespread than at any time since the beginning of the Holocene.

The Dark Ages

Beginning in the year 535AD, according to historical and archeological records, the weather was colder and drier, sunlight diminished, snow fell in summer and regions of persistent drought suffered floods.

From Rome to China observers noted that the sun went dark for more than a year and all the crops failed. Limited historical records from that time period describe, "the Sun was dark and its darkness lasted for eighteen months; each day it shone for about four hours, and still this light was only a feeble shadow" (Michaelthe – Syrian historian). "The Sun gave forth its light without brightness, like the Moon, during this whole year, and it seemed very much like the Sun in eclipse, for the beams it shed were not clear," wrote Procopius of Greece in 536 A.D. “Obscure skies and summer frost” (Chinese historian). "We have had a winter without storms, spring without mildness, summer without heat. Whence can we hope for mild weather, when the months that once ripened the crops have been deadly sick under the northern blasts? ... Out of all the elements, we find these two opposed to us: perpetual frost and unnatural drought." (Cassiodorus of Rome).

Plant growth almost stopped between 536AD to 545AD. Dendrochronological (tree-ring) evidence in oak trees salvaged from Irish peat bogs indicates a sequence of colder than average summers at this time. A similar effect is seen in Fennoscandian pine trees and a study of European oak tree data as a whole shows that the event starts in 536AD and lasts until 545AD. North American bristle-cone and foxtail pines, Mongolian tree rings and Argentinean tree-ring data all show the same effect. The decrease in rate of growth in these years corresponds to a global temperature decrease of up to 3 °C. In fact, 536AD is noted as one of the coldest two or three years globally in the last 2000 years.

The 6th century was a turbulent, unsettling period in human history. The Roman Empire began to crumble; nomads of central Asia migrated to Europe and the Near East; civilizations in Persia, Indonesia and South America collapsed; major religions experienced considerable change as natural events were viewed as omens. This period coincides with a mass population decrease in Europe. This is commonly known as the Justinian plague, and is believed to be the first appearance of the Black Death in Europe.

(When a supernova is further out, the Earth will experience of initial surge of high energetic particles >10 GeV but then the intensity will rapidly drop off and become a component of GCR background noise. This is due to space and time dilution. Let’s compare the case of a supernova event at 650 light years to that of one at 2,000 light years from Earth. By comparing the area of spheres, we can see that the distant supernova would generate only 10% of the GCRs as a supernova closer to Earth. But the spread of particles is also diluted by time. The charge particles in the 100MeV to 10 GeV range would spread out 3 times longer for the distant supernova (2643 years vs. 859 years). Thus for the distant supernova event, only the initial burst of energetic particles 10 GeV and above (that would arrive within the first 8 years) would cause observable cooling effects. A distant supernova would create a condition like the Dark Ages.

Summary:

The Earth is currently in the middle of a Great Ice Age referred to as the Pleistocene Epoch. Our solar system is in an active region spawning nearby supernovae. Galactic Cosmic Rays (GCRs) from nearby supernova events produce increased cloud formations on Earth. Increased low cloud cover reflects sunlight, which produces a drop in global temperatures. Clouds also provide a conveyor belt for moving moisture to higher latitudes where it produces snowfall and ice. Snow and ice buildup is also highly reflective and further contributes to dropping global temperatures and the process towards glaciations.

Global Cooling Events occur on a millennia scale (~1000-1500 years) and happen very abruptly. The initial burst of very energetic GCRs produce a decade long period of harsh climatic conditions irrespective of the strength of the Suns/Earths magnetic shielding. This harsh environment can continue for hundreds of years if either the Sun or the Earth’s magnetic field is in a weak state, which can drive the world back into full ice age conditions. In my opinion, the Earth’s magnetic field even though it has substantially weakened, presently remains with sufficient strength to constrain the long-term effects from the next Global Cooling Event.