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The Effects of Galactic Cosmic Rays on Weather and Climate on Multiple Time Scales

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This article is available on my website: http://www.hartnell.cc.ca.us/faculty/mercurio/

Ed Mercurio
Natural Sciences
Hartnell College
(831) 755-6889
mercurio@jafar.hartnell.cc.ca.us

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Abstract

In this article, evidence is presented that galactic cosmic rays (GCRs) are a major forcing agent on weather and climate on multiple time scales ranging from weekly through glacial-interglacial. Known effects of GCRs are used to explain phenomena and observations in the fields of meteorology, climatology, paleoclimatology and paleoecology. Evidence is presented that primary effects of increases in levels of GCRs are increases in the amounts of low clouds- especially over the tropics, increases in the albedo of low clouds and decreases of the temperature of and increases of the strength of the stratospheric polar vortex. This has widespread effects on atmospheric circulation including the El Nino Southern Oscillation (ENSO). Other effects of increases in levels of GCRs include increases in relative humidities and surface condensation, possible decreases in average amounts of precipitation and increases in storm intensities (vorticity area index). Secondary effects arising from these include decreases in surface temperatures, increases in equabilities and over the long term, a colder, more oscillating (more frequent Enso-Warm Events) tropical Pacific and increases in levels of glaciation. Levels of GCRs in the earth's atmosphere are inversely related to the strengths of the solar magnetic and geomagnetic fields that modulate them. Variations in solar magnetic field structure are used to explain the origin of approximately weekly, monthly, quasibiennial, decadal, bidecadal, multidecadal and millennial scale climatic cycles. Changes in geomagnetism are used to explain glacial-interglacial and ~13,000 year cycles. The sum of the earth's obliquity, inclination of the orbital plane with relation to the invariable plane of the solar system and inclination of the orbital plane with relation to the plane of the solar equator is used to calculate a hypothetical curve of geomagnetism that would result over the last three million years. Higher geomagnetism and lower levels of GCRs are attributed to a greater sum of these factors. The effects of a ~412,000 year geomagnetic cycle modulated by the earth's orbital eccentricity are also considered. The curve obtained is compared to glacial-interglacial chronologies derived from ice core and deep sea core records. Effects of extended periods of very high levels of GCRs are used to explain glacial climates. The cycle of the changing time of the year of the earth's maximum B angle (the maximum angle of inclination of the earth's orbital plane with relation to the solar equatorial plane) is used to calculate the hypothetical 13,000 year cycle of geomagnetism which is used to explain the origin of climate cycles of around this length. Effects of GCR modulated climate are used to explain characteristics of prehistoric biological communities and their variations with glacial-interglacial chronology, the uniqueness of the Holocene, causes of Quaternary megafaunal extinctions and effects of resulting climates, environments and their changes on human prehistory. Predictable levels of GCRs in the future are used to predict future changes in climate.

1. Introduction

There is a growing interest in the effects of galactic cosmic rays (GCRs) on the atmosphere and a growing awareness that GCRs could be a major factor in the determination of weather and climate. Although research on GCRs is in its early stages at this time, GCRs appear to be the best candidate for an extraterrestrial agent of low total energy input that is capable of having major effects on weather and climate. In this article, I take what is known about how GCRs are modulated and about how GCRs, in turn, modulate weather and climate and extend this information beyond what has been done previously to as many possible effects and as many known timescales of periodic change as possible. GCRs appear to fit very well as a primary forcing agent on virtually all of the timescales considered.

GCRs are inversely related in levels and effects to the small changes in solar radiation that, through their heat input, have long been considered the primary agent in climatic forcing. Because of this, GCRs help explain solar related climatic periodicities already established. Svensmark and Friis-Christensen (1997) describe GCRs as "a missing link in solar-climate relationships." When solar radiation is low, GCR levels are high, and both of these result in increased cooling. The magnitude of the effects of GCRs on cooling through increasing low cloud cover and increasing cloud albedo, however, is much greater and increases in levels of GCRs could be the primary cause of global cooling (Svensmark 1998; Landscheidt 1998).

Svensmark (1998) states that the temperature change due to GCR modulation of cloud cover in the years 1975 to 1989 was 3 to 5 times the magnitude of temperature changes due directly to solar radiation. Data from Hartmann (1993) indicates that the change in the earth's radiation budget over a solar cycle due to changes in cloudiness are equal to 80% of the total estimated radiative forcing from the increase in CO_2 concentration during the last century. Fletcher (Pers. Comm.) states that a 1% change in cloud cover is equal in temperature effects to a 10% change in CO_2 levels.

GCRs are the only particles hitting the earth with enough energy to penetrate the stratosphere and troposphere. They are modulated by the sun's and earth's magnetic fields. GCRs are a major determinant of levels of ionization in the troposphere. The ionization of the lower atmosphere by GCRs is the meteorological variable subject to the largest solar cycle modulation (Svensmark 1998).

Levels of ionization affect levels of aerosols suitable as cloud condensation nuclei necessary for cloud formation. Because of this, levels of ionization are a major determinant of relative humidities, levels of condensation, levels of low cloudiness and cloud albedos that, in turn, are major determinants of temperatures, levels of surface moisture and levels of equability. Clouds formed from greater amounts of condensation nuclei, such as sulfate aerosols, are brighter and longer lived and may be more effective at cooling the earth than other clouds because of their greater albedo (reflectivity) (Rodhe 1999; Rosenfeld 2000). These clouds would also be likely to produce less precipitation.

GCRs could affect broader aspects of clouds and atmospheric circulation as well. There is evidence that they may affect storm intensities (vorticity area index) (Herman and Goldberg 1978;

Tinsley and Dean 1991). GCRs also appear to be a major determinant of the temperature and strength of the stratospheric polar vortex that has a strong effect on global atmospheric circulation including the El Nino-Southern Oscillation (ENSO).

Levels of GCRs have changed over past millennia in response to changes in solar magnetic and geomagnetic fields as indicated by levels of Carbon 14 (C^{14}) present in fossils and levels of Beryllium 10 (Be^{10}) present in ice cores and sediments. Higher past levels of GCRs are indicative of cooler conditions and increased glaciation and lower past levels of GCRs are indicative of warmer conditions and decreased glaciation.

In addition to improving understanding of the origins of major aspects of weather and climate and the course of climate history, understanding of levels and effects of GCRs can improve the understanding of past environments and changes in ecosystems, including extinctions. This is because plant community structure is strongly affected by long term changes in levels of condensation and relative humidity, equability and precipitation distribution.

2. GCR Modulation by Solar Magnetism and the ~11 Year and ~22 Year Solar Cycles

Changes in cloudiness and temperatures have been related to the ~11 and ~22 year solar (sunspot) cycles (Ely 1995; Svensmark and Friis-Christensen 1997; Svensmark 1998; Soon et al. 2000). Change in the solar constant over ~11 year sunspot cycles is rather small at ~0.1 % to be able to account for observed changes but changes in levels of GCRs may be able to. Levels of global cloudiness were observed to increase between 3 and 4 % from solar maximum to solar minimum over an ~11 year cycle period studied (Svensmark 1998). A strong correlation is present only in low cloudiness (two miles or lower), which is the type that would increase cooling (Bailunas and Soon 2000). Changes in the brightness of the planet Neptune over the solar cycle appear to be due to similar changes in cloudiness (Bailunas and Soon 2000) and also vary by 3 to 4 % over the solar cycle with maximum brightness at solar minimum. These changes occur because the solar magnetic field is lower at solar minimum, allowing more GCRs to reach the earth and other planets at this time.

The brightness of the earth as measured by changes in earthlight reflecting off of the moon has also been observed to change similarly over the ~11 year solar cycle (Schneider 2001). Interestingly, this measurement of the earth's brightness primarily measures the brightness of the lower latitudes that are the areas where the modulation of low cloudiness by GCRs is the greatest. Bago and Butler (2000) found that there was little correlation of levels of low cloudiness to GCR levels in polar regions, but a significant degree of correlation in the tropics. Kristjansson (2001) also found a correlation to middle latitude oceanic low cloud cover.

~11 year solar cycles alternate between two phases referred to as parallel (-) and antiparallel (+) with the transitions occurring around solar maximum. Consistently greater levels of GCRs reach the earth over most of the antiparallel cycles (Figure1). This results in ~22 year cycles which correlate well to meteorological cycles including such phenomena as major droughts on the western Great Plains and variations in precipitation from cyclonic storms in the westerlies in Southern California. A curve of Los Angeles yearly precipitation totals shows an approximately 22 year cycle with generally progressively increasing totals during antiparallel cycles and generally progressively decreasing totals during parallel cycles (Figure 2). This results in a pattern in which wettest years often occur around antiparallel to parallel solar maxima and the driest years often occur around parallel to antiparallel solar maxima. Generally higher precipitation totals are also seen during ENSO-Warm Event (El Nino) and Pacific Decadal Oscillation (PDO) warm phase years and generally lower totals during ENSO-Cold Event (La Nina) and PDO cold phase years. A PDO warm phase and an ENSO-Warm Event often occur following the antiparallel to parallel transition adding to higher rainfall totals at these times.

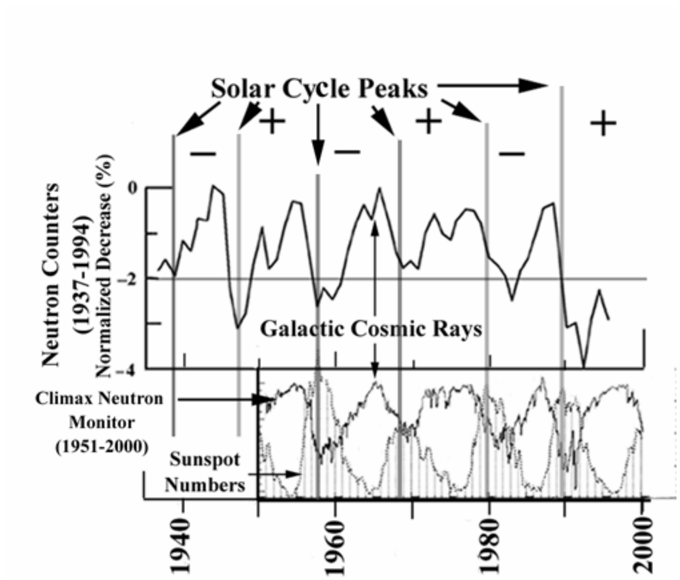


FIGURE 1. The top curve is the annual mean variation in cosmic ray flux as measured by ionization chambers from 1937 to 1994 (adapted from Svensmark 1998). The bottom curves are neutron flux, which is a proxy for galactic cosmic ray flux, from the neutron monitor in Climax, Colorado from 1951 to 2000 and sunspot number (adapted from University of Chicago/LASR GIF image). Note the differences in the shapes of the curves of GCRs in antiparallel (+) and parallel (-) solar cycles and the differences in GCR levels at solar maxima.

It has be observed that longer ~11 year cycles are associated with cooler global temperatures and shorter ones with warmer global temperatures and this may also be due to corresponding variations in the GCR flux (Svensmark and Friis-Christensen 1997). A curve of annual GCR intensities over the last four solar cycles shows higher GCR levels at the sunspot maxima of the longer ~11 year cycles (Figure1). Solar maximum may be the time when the greatest variations in GCR levels occur and this could be an important factor in periods of cooling, especially on century and millennial time scales.

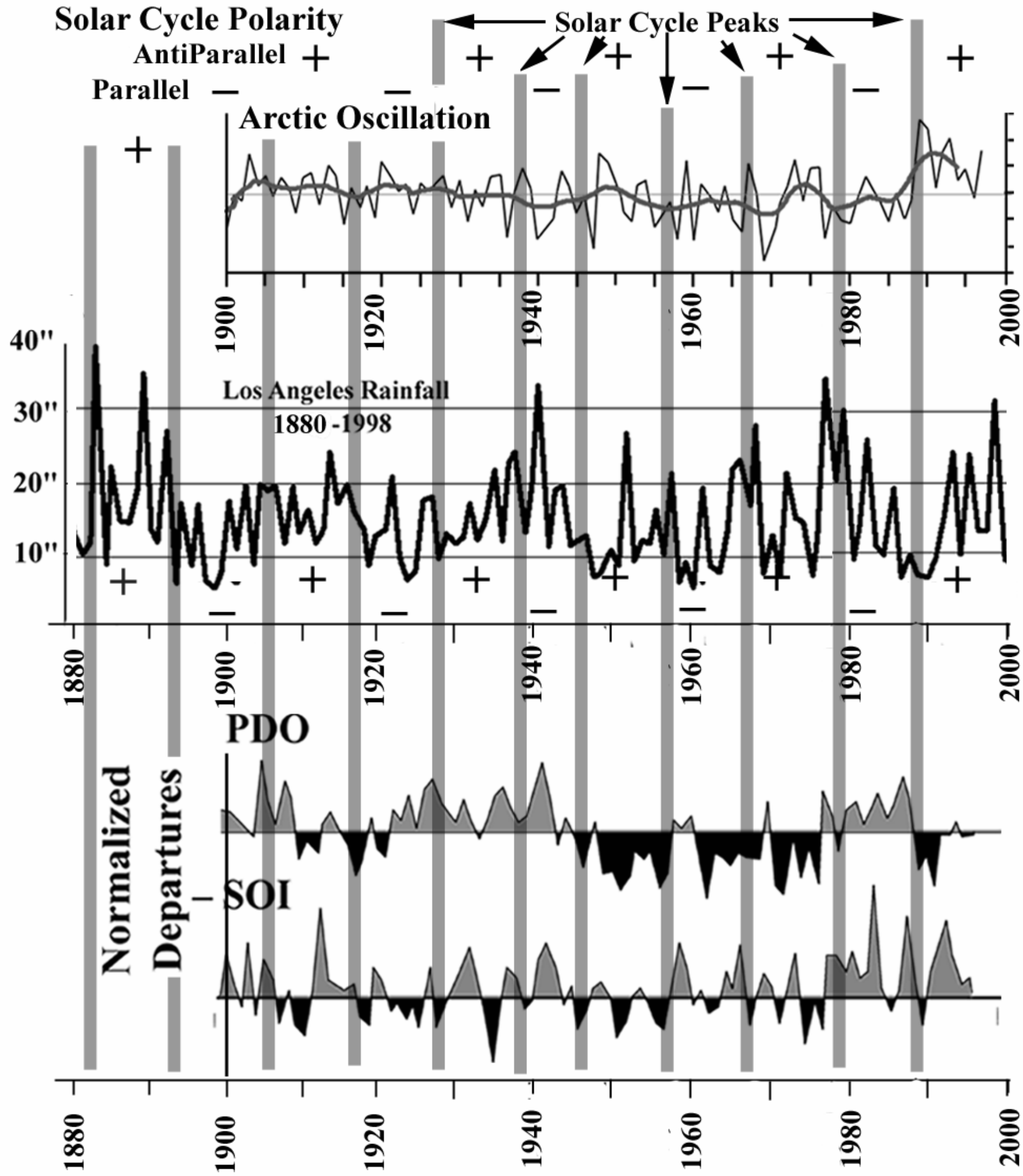


FIGURE 2. The top curve is the Arctic Oscillation Index with average values (adapted from Kerr 1999d). More positive conditions indicative of a stronger, colder polar vortex are up in direction. The upper middle curve is July to June yearly U. S. Weather Bureau precipitation totals for Los Angeles civic center. The bottom curves are the Pacific Decadal Oscillation (PDO) and Southern Oscillation Index (SOI) (adapted from Mantua et. al 1997). In the SOI curve, values indicative of ENSO-Warm Event conditions are above the line and values indicative of ENSO-Cold Event conditions are below the line and in the PDO curve, warmer sea surface temperatures are above the line and colder sea surface temperatures below the line. Note the general relationship between antiparallel (+) solar cycles and a more positive average Arctic Oscillation, progressively increasing Los Angeles precipitation totals, more positive (ENSO-Cold Event) SOI conditions and the opposite for parallel (-) solar cycles. Also note the general relationship between ENSO-Warm Event conditions and higher Los Angeles precipitation totals.

3. GCRs and the Polar Vortex, Arctic Oscillation and El Nino Southern Oscillation (ENSO)

Levels of GCRs appear to have a relationship to the state of the stratospheric polar vortex and, more indirectly, to the state of the El Nino Southern Oscillation (ENSO). The polar vortex circles the globe at around 45^{0}N, and has widespread climatic effects over the Northern Hemisphere. Higher levels of GCRs are one of several factors that appear to be associated with a stronger, colder polar vortex. Assuming some lag time, some indications of a ~22 year periodicity in winter stratospheric temperatures, with increasingly colder average conditions in antiparallel cycles, can be seen in Figure 3. A stronger, colder polar vortex is in a general way associated with ENSO-Cold Event (La Nina) conditions and, on a short-term basis, a warmer, weaker polar vortex is often associated with ENSO-Warm Event (El Nino) conditions. Some indications of this can also be seen in Figure 3.

An exception to this is ENSO-Warm Events associated with large, sulfurous volcanic eruptions, which are associated with a stronger, colder polar vortex. This is because, in addition to levels of GCRs, volcanic effects on the stratospheric equator to pole temperature gradient are also a determinant of the strength and temperature of the polar vortex. Sulfurous gasses and aerosols heat the stratosphere and can increase the stratospheric equator to pole temperature gradient, which results in a stronger, colder polar vortex (Kerr 1993a). These sulfurous gasses and aerosols also cause high latitude ozone depletion, which can further cool and strengthen the polar vortex. Other effects of volcanic sulfurous gasses and aerosols are changes in atmospheric circulation that can produce an ENSO-Warm Event (Chanin 1993) and lower global tropospheric and surface temperatures after around a year’s time. A major factor in volcanically related ENSO-Warm Events is weakened Trade Winds probably resulting from large positive tropospheric temperature anomalies over North America caused by the sulfurous gasses and aerosols.

The Arctic Oscillation Index is a measure of the variations in the strength of the polar vortex. Its positive phase is the result of a colder polar stratosphere, the effects of which propagate into the troposphere (Schindell et al. 1999). This results in a stronger, colder polar vortex, a northerly path for the polar front jet stream, mild and wet northerly latitudes, limited penetration of cold into continental interiors, dryness in Mediterranean latitudes, stronger trade winds and a weaker subtropical jet stream. The negative phase has the opposite effects and results in a more southerly polar front jet stream, wetter Mediterranean latitudes, a colder midwestern US, Western Europe and Russia, weaker trade winds, and a stronger subtropical jet stream (Stricherz 1999; Chanin 1993). The effects on worldwide weather patterns of the positive phase of the Arctic Oscillation is similar in some ways to those caused by ENSO-Cold Events and the effects of the negative phase are similar in some ways to those caused by ENSO-Warm Events.

The effects of the strength of the polar vortex on the strength of the trade winds actually provides a direct link between GCRs, the polar vortex and ENSO. Effects on ENSO may at least partly occur through effects on the strength of the Trade Winds that are directly related to the strength of the polar vortex (Stricherz 1999; Chanin 1993). Weaker Trade Winds are associated with ENSO-Warm Events.

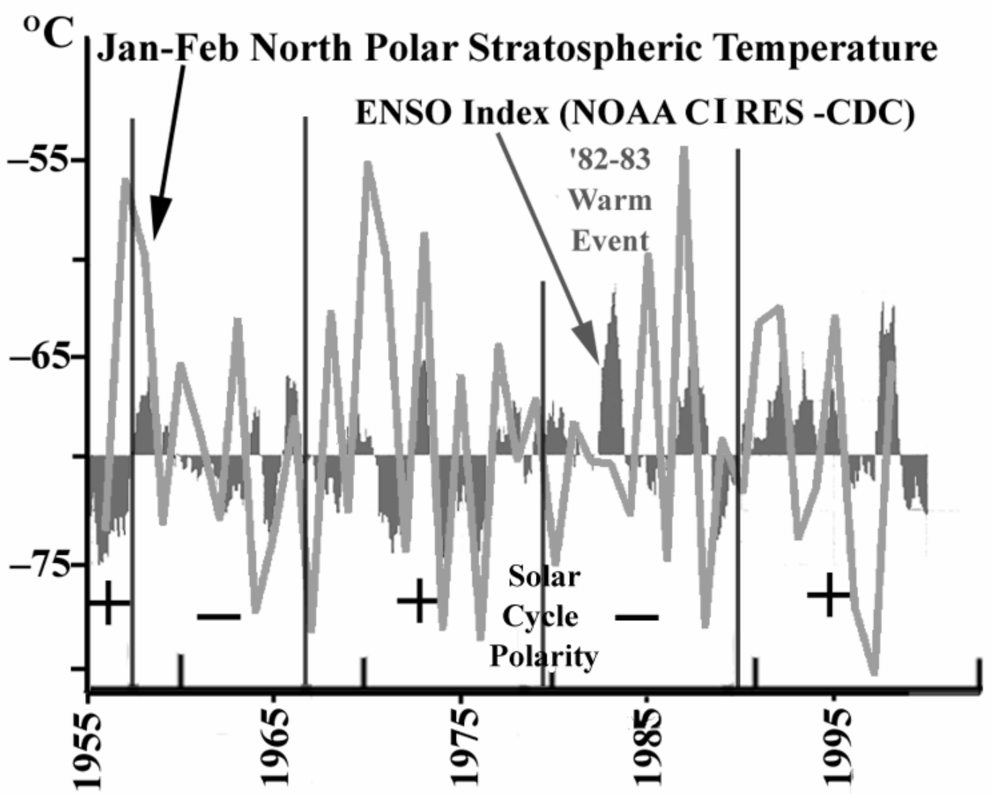


FIGURE 3. Comparison of January-February north polar stratospheric temperatures (adapted from Labizke and Van Loon 1999) and multivariate ENSO index (adapted from a NOAA-CIRES-Climate Diagnostic Center graphic). Note the relationship between higher temperatures and ENSO-Warm Event conditions and lower temperatures and ENSO-Cold Event conditions and ENSO-Warm Event anomalies that occur following large sulfurous volcanic eruptions such as El Chichon in 1982, Mount Pinatubo in 1991 and Mount Agung in 1963. (Unsmoothed data appears to show a closer relationship but is harder to visualize in a graphic, and up to date sources were unavailable).

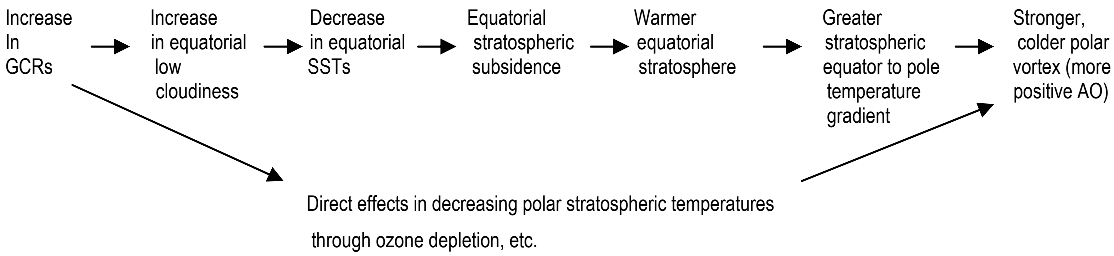
There may be links between GCRs and ENSO through modulation of sea surface temperatures (SSTs) in the tropical Pacific by GCR induced low cloudiness. The state of ENSO is related to SSTs in the tropical Pacific and as already mentioned, sea surface temperatures (SSTs) in the tropical Pacific affect the stratospheric equator to pole temperature gradient, which, in turn, affects the state of the polar vortex. Direct effects of GCRs on levels of cloudiness over the equatorial Pacific may be important here in determining SSTs.

Changes in the state of the polar vortex may provide a way to help forecast future general changes in the state of ENSO. ENSO-Warm Events other than those associated with large, sulfurous volcanic eruptions often tend to be associated with a change from a strong to a weak polar vortex. Data in Kane (1997) indicates that, aside from those associated with large, sulfurous volcanic eruptions, ENSO-Warm Events often tend to be associated with every other easterly phase of the Quasibiennial Oscillation (QBO), an oscillation in equatorial stratospheric winds discussed later. The easterly phase of the (QBO) is associated with a weak polar vortex and the west phase with a strong polar vortex. Also, ~63% of ENSO-Warm Events have occurred during the descending phase of the sunspot cycle (Kane 1997). This is close to the time of the shift in sunspot cycle polarity. It also appears that more ENSO-Warm Events may have occurred during the descending phase of parallel cycles (less GCRs) following the shift from antiparallel (more GCRs).

How do GCRs modulate the strength of the polar vortex? Do they affect its temperature and strength directly, possibly by decreasing ozone levels and/or increasing ice crystal formation and in this way decreasing temperature, or are their effects more indirect, by affecting the stratospheric equator to pole temperature gradient that is strongly influenced by equatorial sea surface temperatures? Both are probably involved.

Levels of stratospheric ozone are directly related to stratospheric temperatures. The longest available total ozone level record from Arosa, Switzerland, which began in 1926, shows a general rise in levels to a peak around 1940 followed by a general drop in levels through the early 70s from which a continuous more pronounced downward trend began due to anthropogenic influences (United States Environmental Protection Agency 1995). Up to the start of anthropogenic changes, this curve is similar to the inverse of levels of GCRs on the ~80 year cycle discussed later. This correlation may be due to the fact that GCRs, as well as solar cosmic rays, produce oxides of nitrogen in the atmosphere. Nitrogen oxides in the stratosphere destroy ozone (Shea et al. 1998; Rampino et al. 1987). Sulfate aerosols of volcanic origin are also known to be a causative factor in decreases in ozone levels, and the possibility of sulfate aerosols produced by GCRs also doing this should be investigated. All of this indicates that not all long term drops in ozone levels in the future can be ascribed to purely anthropogenic influences, but the current one is likely to be predominantly anthropogenic because of its unusual severity and because a rise in ozone levels would have been expected following lows in the 70s.

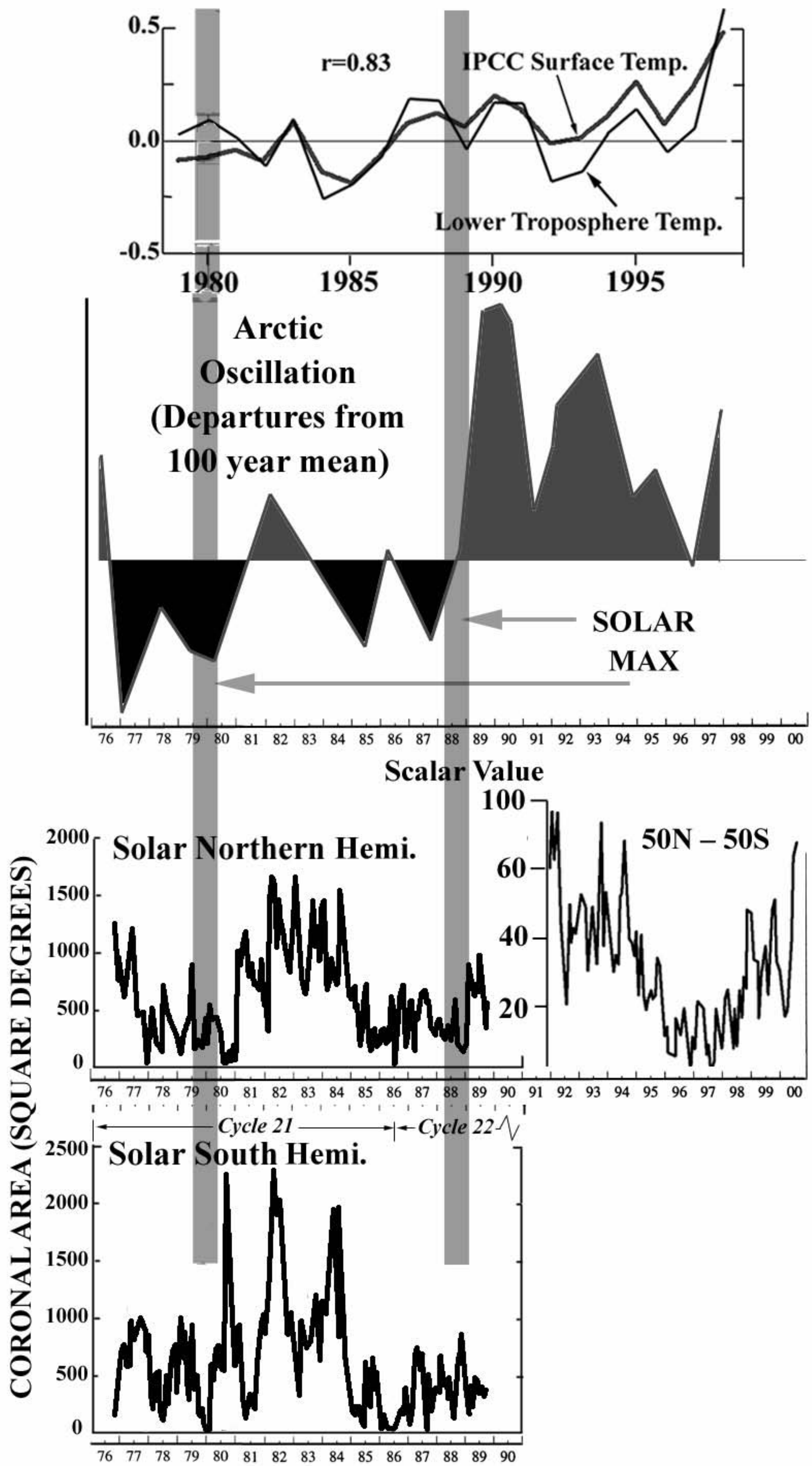
There is evidence for effects of GCRs on the polar vortex arising through the stratospheric equator to pole temperature gradient modulated by equatorial sea surface temperatures. Levels of GCRs appear to be strongly related to levels of equatorial low cloudiness which, in turn, affect equatorial sea surface temperatures. Bago and Butler (2000) found that there was little correlation of levels of low cloudiness to GCR levels in polar regions, but a significant degree of correlation in the tropics. More equatorial low cloudiness would result in lower equatorial sea surface temperatures. This, in turn, would result in subsidence in the equatorial stratosphere that would create warmer conditions there. This would increase the stratospheric equator to pole temperature gradient resulting in a stronger, more isolated and colder polar vortex. Lower levels of GCRs would result in less equatorial cloudiness, warmer equatorial sea surface temperatures, equatorial stratospheric convection, a colder equatorial stratosphere, a weaker stratospheric equator to pole temperature gradient and a warmer, weaker polar vortex. Data from Barnett (1989) indicates ~11 year and ~80 year periodicities in the amplitudes of quasi-biennial variations in global sea surface temperatures corresponding to solar cycles. There is ample literature in support of a major role for tropical sea surface temperatures in the control of world climate and GCRs may have a major role in their modulation.



Over multidecadal and longer time periods, higher levels of GCRs are associated with a colder, more oscillating (frequent ENSO-Warm Events) tropical Pacific and lower levels with a warmer, more stable tropical Pacific. There is evidence for this pattern on glacial-interglacial, ~2400 year and ~80 year cycle timescales. These effects, however, are also observable in the ~22 year solar cycle and many correlations of climate to ~22 year cycles, including droughts on the western Great Plains, are related to an increase in ENSO-Cold Event conditions that develop over the duration of antiparallel solar cycles. Some evidence for ~11 and ~22 year cycles in the Arctic Oscillation, with stronger (and colder) conditions in antiparallel cycles, can be seen in the long-term records presented in Kerr 1999b (Figure 2).

There appears to be a relationship between solar coronal hole area and the strength of the Arctic Oscillation. Areal extents of solar coronal holes change over solar cycles and are directly related to levels of GCRs and therefore directly related to levels of global cloudiness and inversely related to global temperatures (Soon et al. 2000). There is a better correlation between solar coronal hole area specifically between solar latitudes 50^0 north to 50^0 south and the state of the Arctic Oscillation with greater coronal hole area correlated to a more positive state of the Arctic Oscillation (Figure 4).

One effect of anthropogenic gasses that contribute to global warming is to cool the stratosphere, either directly by ozone destruction or indirectly by holding more terrestrial heat radiation in the troposphere (Dameris et. al.1999). In this way they contribute to a more positive Arctic Oscillation. This may be a cause of recent highly positive levels (Figures 2 and 4). Moritz et al. (2002) conclude that anthropogenic influences could have forced the recent upward trend and increased variability in the Arctic Oscillation. The Antarctic Oscillation has also had highly positive levels recently which have been related to ozone depletion over Antarctica (Kerr 2002). This means that at least some of the potential for anthropogenic global warming could be moderated by other climate changes resulting from a more positive Arctic Oscillation (and Antarctic Oscillation) that could lead to greater global cooling.



0.5
0.0
-0.5
r=0.83
IPCC Surface Temp.
Lower Troposphere Temp.
1980
1985
1990
1995
Arctic Oscillation (Departures from 100 year mean)
SOLAR MAX
76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00
Scalar Value
100
60
40
20
50N – 50S
Solar Northern Hemi.
2000
1500
1000
500
0
Cycle 21
Cycle 22
Solar South Hemi.
2500
2000
1500
1000
500
0
CORONAL AREA (SQUARE DEGREES)

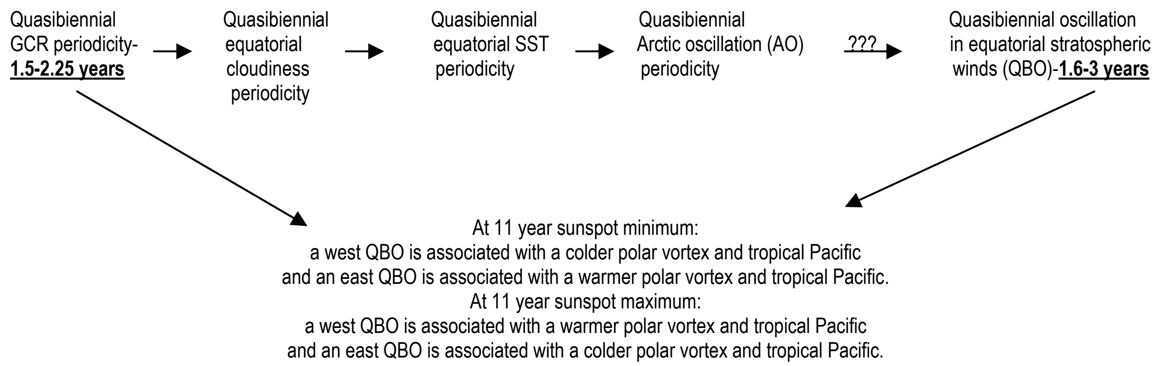
FIGURE 4. The upper curves are anomaly time series for observed surface and lower tropospheric temperature annual temperature data (adapted from Santer et al. 2000). The upper middle curve is the Arctic Oscillation Index (adapted from Kerr 1999d). The left side of the lower middle curve is solar coronal hole area in heliographic degrees between north solar hemisphere latitudes 10^0 to 50^0 (adapted from McIntosh et al. 1992). The right side of the lower middle curve is solar coronal hole area in latitude correlated degrees between 50^0 north to 50^0 south solar latitudes (from K. Harvey, personal communication, 1999, derived from NSO helium 10830 data). The lowest curve is solar coronal hole area in heliographic degrees between south solar hemisphere latitudes 10^0 to 50^0 (adapted from McIntosh et al. 1992). Note the relationship between total coronal hole area and Arctic Oscillation values. Note how the temperatures show an inverse relationship to the Arctic Oscillation Index with a two to three year lag time and how lower tropospheric temperatures are increasingly cooler than surface temperatures the greater the Arctic Oscillation Index and increasingly warmer than surface temperatures the smaller the Arctic Oscillation Index.

4. GCRs and the Quasibiennial Oscillation (QBO)

There are many meteorological phenomena that have quasibiennial periodicities. The Quasibiennial Oscillation (QBO), itself, is an oscillation in equatorial stratospheric winds. Most of these quasibiennial phenomena can be linked in some way to the Arctic Oscillation (AO) which also has a quasibiennial periodicity. Could quasibiennial periodicities have their origin in GCRs? There is a quasibiennial periodicity in levels of GCRs. It is a little shorter than the quasibiennial oscillation in equatorial stratospheric winds (QBO). The quasibiennial periodicity in levels of GCRs could be a causitive factor in a quasibiennial oscillation in equatorial low cloudiness and, of course, this quasibiennial oscillation in equatorial low cloudiness could be a causitive factor in the quasibiennial variations of the Arctic Oscillation (AO) (see page 10).

The periods of greater GCRs on the quasibiennial time scale may be most often associated with the west phase of the QBO. A strong polar vortex is three times more likely when the QBO is westerly and a weak polar vortex is twice as likely when the QBO is easterly (Baldwin and Dunkerton 2001). Also, the west phase of the QBO is longer in duration around solar minimum when there are more GCRs on the ~11 year solar cycle timescale. Data in Kane (1997) indicates that ENSO-Warm Events other than those associated with large, sulfurous volcanic eruptions often tend to be associated with every other easterly phase of the QBO. (Remember: a stronger, colder polar vortex is in a general way associated with ENSO-Cold Event (La Nina) conditions and a warmer, weaker polar vortex is, on a short-term basis, often associated with ENSO-Warm Event (El Nino) conditions.)

The relationship of the temperature of the polar vortex to the phase of the QBO changes over the ~11 year solar cycle. The reason for this could be because the quasibiennial oscillation in GCRs as manifested by solar coronal hole area between solar latitudes 50^0 north to 50^0 south (See Figure 4) is slightly shorter than the QBO. If the variation in GCR levels corresponding to coronal hole area affects the temperature of the polar vortex, the interplay of the two cycles could result in the changing temperature relationship over the solar cycle.



5. GCRs and Weekly and Monthly Solar Cycles

There are cyclic variations of GCRs on approximately weekly and monthly time scales and these may be the cause of reports of periodicities in weather phenomena on these time scales such as those reported by Glanz (1999). These effects arise because of variations in solar magnetism produced during the rotation of the sun. The sun has four magnetic sectors and their boundaries are equidistant from each other. Since the equator of the sun as viewed from earth makes one complete rotation every 27 days (31 days at the solar poles), solar magnetic sector boundaries or heliospheric current sheet crossings rotate past the earth approximately every 7 days. The increase in solar magnetic strength at these boundaries diminishes the levels of GCRs hitting the earth at the times of passage (Tinsley et al. 1989). These decreases in levels of GCRs are called Forbush decreases. Forbush decreases have been correlated with decreases in cloudiness (Veretenenko and Pudovkin 1995) and decreases in the vorticity area index (Herman and Goldberg 1978; Tinsley and Dean 1991). It is likely that these effects are due to diminished levels of GCRs at these times.

There are variations in solar sector structure. One sector boundary will often differ from the others in strength leading to a monthly periodicity.

The regional effects of these solar magnetic sector boundary crossings will vary depending on current climate patterns, and when a pattern of variation for a given area and time period is understood, it can often be used to help forecast weather for particular areas weeks and months in advance with remarkable accuracy.

Tropical intraseasonal oscillations with periods commonly ranging from 30 to 60 days strongly modulate global weather. At present, there is no widely accepted theory to explain their origin. Modulation of the levels of GCRs through solar sector structure may be an important factor in the origin of these oscillations.

6. GCRs and ~80 Year (Gleissberg) Solar Cycles

GCR levels may be a major determinant of climate on multidecadal and longer timescales. Many different lengths of multidecadal cycles of climate have been reported, but most of them center around 70 to 90 years. They are often referred to as Gleissberg cycles. I will refer to them as ~80 year cycles. They appear to vary in length depending on the varying lengths of the ~11 year solar cycles within them.

An interesting thing about ~80 and ~ 2400 year cycles is that they are present in both the sun and the earth. They are apparent in the sun as variations in levels of galactic cosmic rays, solar radiation, sunspot numbers, and lengths of ~11 year cycles. They are apparent in the earth as changes in geomagnetism (Merrill et al. 1996). 2400 years is the estimated time for the nondipole geomagnetic field to rotate 360 degrees due to what is termed westward drift (Damon and Sonnet 1992).

The most recent ~80 year cycle appears to have had peaks in GCRs around 1900 and 1975 and its lowest point around 1940. The following meteorological phenomena related to levels of GCRs can be observed to have varied with ~80 year cycles and especially this most recent one:

1. Global temperatures. Lower temperatures are associated with higher levels of GCRs. Temperatures are probably primarily modulated through levels of global low cloudiness which are modulated by GCR levels and secondarily through levels of solar radiation.
2. Total ozone levels. This can be observed in the longest available total ozone level data from Arosa, Switzerland that began in 1926. Generally lower ozone levels are associated with higher levels of GCRs. This may be a result of the production of oxides of nitrogen by GCRs that destroy ozone.
3. ENSO frequencies and amplitudes. Greater frequencies and amplitudes generally occur with higher levels of GCRs in an overall colder tropical Pacific as explained previously.
4. The state of the Pacific Decadal Oscillation (PDO). This is an important long-term cycle of sea surface temperature distribution in the entire Pacific (Figure 2). It has long been known that the PDO has cycles that average around 20 years, but recently, longer cycles that correspond to the ~80 year cycle have been noticed in longer data sets. An interesting aspect of these variations is that the shift between phases tends to occur at the lowest and highest points of ~80 year cycles. A shift to predominance of the cool phase occurs around the lowest levels of GCRs of the cycle and a shift to predominance of the warm phase occurs around the highest levels of GCRs. This information could be useful in the prediction of these important "regime shifts" in Pacific sea surface temperatures.
5. The size of the circumpolar vortex and monsoon penetration. A larger, more equatorward circumpolar vortex of westerly winds is associated with higher levels of GCRs. This has had profound effects on changes in the penetration of summer monsoon precipitation into Africa, India and Asia. Rainfall totals for areas that receive most of their rainfall from the Indian and African monsoons often show a striking inverse correlation to GCR levels on this timescale (Kumar et al. 1999). The expansion of the circumpolar vortex during last peak in GCRs around 1975 was associated with the Sahelian droughts in Africa that occurred between 1970 and 1985 and killed 1.2 million people.
6. The zonal index. More meridional conditions in the westerlies generally occur with higher levels of GCRs.
7. The earth's rotational velocity (length of day). Rotational velocities are closely related to GCR levels. Slower speeds (longer day lengths) occur at times of more GCRs (Klyashtorin 1998; Courtillot et al. 1982). This is probably due to greater meridionality and an expanded circumpolar vortex at these times. This is because the speed of the earth's rotation is directly related to the overall strength of the westerlies which is directly related to the degree of

zonality. It appears that higher levels of volcanic and earthquake activity are associated with slower rotation speeds on most timescales. A mechanism? Perhaps a slowing down of the earth's rotation may increase pressures in the earth's crust and mantle due to a decrease in outward centrifugal force causing an increase in volcanic and earthquake activity at these times.

7. GCRs and the ~2400 Year Solar Cycle

The longest solar cycles appear to be around 2400 years long. An increase in the exterior solar magnetic field by 230 % since 1901 and by 40% since 1964 parallels the earth's warming over the same period (Suplee 2000) and is probably part of a change on this timescale. These changes would be expected to cause a decrease in levels of GCRs over this period resulting in global warming that, of course, has been seen. Solar radiation over the last century has only increased about 0.1%.

The ~2400 year solar cycle appears to have a solar origin. Historical solar observations show good correlations between climate on timescales of this approximate length and observed solar phenomena such as sunspot numbers and auroras. There are, however, changes in the geomagnetic field on a similar time scale as mentioned previously and observed cyclic changes in Carbon 14 (C^{14}) levels, which are a proxy for GCR levels, have been ascribed to changes in the dipole field in the past (Damon and Sonnet 1992).

~2400 year solar cycles appear to be divided into overall lower GCR, warmer halves and overall higher GCR colder halves, but periodic maxima and minima, also correlated to GCR variations, occur (Eddy 1977). These maxima and minima are variable in strength and appear to occur in a variable periodicity alternating between average times of 220 years and 150 years apart (Damon and Sonnet 1992; Crowley and North 1991). The periodicities of and variations in intensities of maxima and minima often give the appearance of 1400 to 1600 year cycles in paleorecords.

These ~2400 year cycles appear to strongly modulate the amplitudes of ~80 year and ~11 year solar cycles. ~11 year cycles and sunspots appear to have virtually disappeared during the Maunder minimum of around 1650-1710. ~2400 year cycles are strongly modulated by glacial-interglacial cycles. They were approximately 23 times greater in amplitude in the last glacial than the Holocene, sometimes almost duplicating the magnitude of glacial-interglacial transitions. During the last glacial, they were approximately 3 times greater in amplitude in Greenland records as compared to Antarctic records (Figure 5).

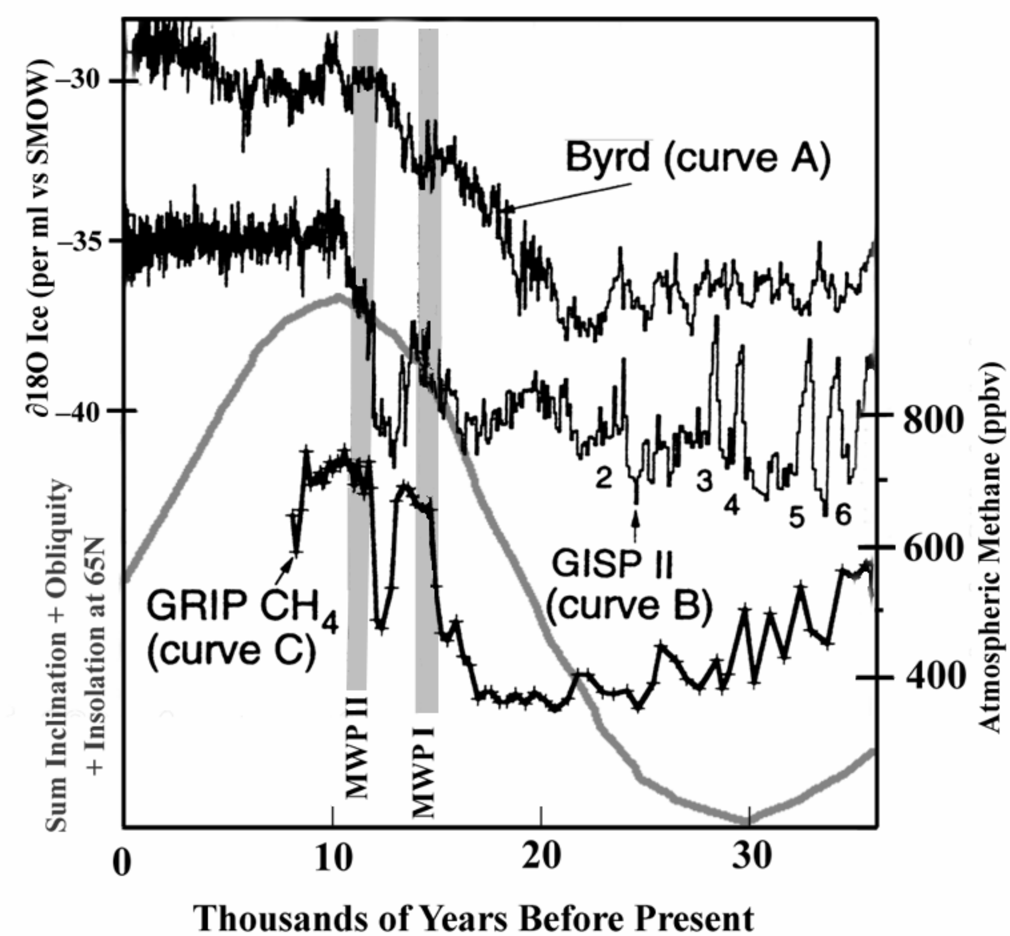


FIGURE 5. Comparison of Antarctic ice core temperature Records- curve A, and Greenland ice core temperature Records- curve B, as indicated by O^{18} levels. Curve C is methane levels from a Greenland ice core. Also shown is the curve of the sum of inclinations + obliquity + insolation at 65N which is hypothesized to indicate glacial-interglacial periodicities by representing geomagnetism which would modulate levels of galactic cosmic rays. Meltwater pulse 1 is shown at 14,500 years ago and meltwater pulse 2 is shown at 11,500 years ago. This figure was adapted from Sowers and Bender (1995). Note how the Antarctic curve more closely follows hypothesized geomagnetism and indicates the effects of known peaks in geomagnetism at around 9000 and 2000 years ago but shows less amplitude in temperature effects of ~2400 year and ~13,000 year cycles than the Greenland curve does. Note how at around 20,000 years ago the stability hypothesized to be caused by the effects of the ~412,000 year cycle reduces amplitudes of fluctuations caused by ~2400 year cycles in both areas. Note how the levels of methane from Greenland follow the temperature profile of the Greenland ice core. Levels of carbon dioxide from the Antarctic ice core (not shown) follow the temperature profiles of the Antarctic ice core very closely.

Effects on weather and climate of these cycles appear to be similar to those already mentioned for ~80 year cycles but greater in magnitude. The most recent extremes in average temperatures occurred in the Medieval Maximum, between around 950 to 1200 AD and the Maunder Minimum from approximately 1650 to 1710. The Maunder Minimum was the coldest part of the broader period from around 1510 to 1850, which includes four minima and is often termed the “Little Ice Age.” This period, and others like it, had extended periods of higher levels of GCRs as indicated by higher levels of Carbon 14 (C^{14}) and Beryllium 10 (Be^{10}) at these times. Records indicate increased cold and cloudiness, glacier expansion and changes in precipitation patterns during the Maunderminimum in many areas. The circumpolar vortex also expanded equatorward at this time and its expansion leading into the Little Ice Age caused profound changes in areas occupied by cultures such as the Vikings of Europe, the Anasazi of the American Southwest and the Easter Islanders of southeastern Polynesia.

Anderson (1992c) reports that ENSO-Warm Events are around twice as common during climatic minima of the ~2400 year cycles and Leroux (1998) reports increased frequencies of ENSO-Warm Events when the Northern Hemisphere circumpolar vortex is strongest and farthest equatorward which is a consequence of these minima. The history of the western tropical Pacific during glacial periods is indicative of more frequent and more severe ENSO-Warm Events during the climatic minima of ~2400 year cycles (stadials) and less frequent and less severe ENSO-Warm Events during the climatic maxima of ~2400 year cycles (interstadials) (Stott et al. 2002).

8. GCR Modulation by Geomagnetism

The longest climatic cycles that appear to be modulated by GCRs are glacial-interglacial cycles and a ~13,000 year cycle. In these cycles, GCRs are modulated by geomagnetism instead of solar magnetism. A relationship was initially found between the position of the earth in relation to solar latitude and glacial-interglacial chronology. The mechanism involved here could be either solar latitudinal variation in GCR levels resulting from latitudinal variations in the solar magnetic field or changes in the earth's inclination with relation to the gravitational fields of the sun and planets affecting the geomagnetic field that modulates entry of GCRs into the earth's atmosphere.

The evidence supports modulation of GCRs on these timescales by geomagnetism. A direct relationship was found between the inclination of the earth with relation to external gravitational attraction and geomagnetic strength and this allowed the calculation of hypothetical curves of the earth's geomagnetic history. These curves are similar to curves calculated from actual records of paleomagnetism. Channell et al. (1998) have correlated changes in geomagnetism to changes in the earth's orbital obliquity and Yamazaki and Oda 2002 have correlated changes in geomagnetism to changes in the earth's orbital eccentricity.

Climate modulation by geomagnetism does not appear to be linear. Instead, geomagnetism seems to have its primary effects at very high and very low values, at which times there are rather sudden and major shifts in climate. This is especially true of glacial-interglacial timescales. A bimodal climatic pattern with sudden large-scale changes appears to be characteristic of geomagnetic forcing of climate. The largest and most rapid shifts most often occur from cold to warm conditions. There is also generally a ~1000 year lag time for major climatic effects but this can be longer for glacial-interglacial timescales.

The dynamo theory of the origin of the earth's magnetic field states that the geomagnetic field is directly related to the difference in rotational motion between the earth's inner core and the rest of the earth with the core rotating faster. Inclination of the earth plays a role here because it causes the inner core to precess. Precession of the inner core is thought by many to be the major motion generating the earth's magnetic field. Fluid energy dissipation in models simulating the earth has been found to be equal to the square of the sin of the angle of inclination, and is capable of producing energy dissipation rates 10^4 times those necessary for an earth dynamo (Vanyo and Paltridge 1981).

In my hypothesis for the control of climatic cycles by geomagnetically modulated GCR levels, greater inclination of the earth with relation to external gravitational attraction results in stronger geomagnetism and therefore lower GCR levels which, in turn, result in less condensation and low cloud cover and generally warmer conditions. Lesser inclination results in higher GCR levels which, in turn, result in more condensation and low cloud cover and generally colder conditions.

Four inclination data series are needed to calculate curves of past geomagnetism (Figures 6 and 7). They are:

1) The inclination of the earth's orbital plane with relation to the invariable plane of the solar system. I used a data series that had already been calculated for the last three million years by Dr. Richard A. Muller for his work on the astronomical forcing of glacial cycles. It has a ~100,000 year periodicity and a range over the last 3 million years of from ~.110^0 to ~2.94^0. It is currently ~1.67^0.
2) The earth's B angle. This is the angle of the inclination of the earth's orbital plane with relation to the solar equatorial plane. I could find no existing data series for this. It was calculated by Dr. E. Myles Standish Jr. for the last three million years for this investigation. It has a ~70,000 year periodicity and a range over the last 3 million years of from ~3.25^0 to ~8.5^0. It is currently ~7.25^0.
3) The earth's orbital obliquity. Data sets for this have been in existence for a long time since this was one of the three data sets used by Milankovitch in his hypothesis. I used a recent calculation of this by A. Berger available on the Internet. It has a ~41,000 year periodicity and a range of from ~22.5^0 to ~24.5^0. It is currently 23.5^0.
4) The times of the year of the earth's maximum B angle value. These times change because of the precessional motions of the earth. I could find no existing data set for this. This was also calculated by Dr. E. Myles Standish Jr. for the last three million years for this investigation. The time of the year of B angle values changes with the ~25,800 year cycle of precession of the earth's axis, but since the earth encounters the same angular relationship twice a year in its revolution around the sun, the cycle of angular change is actually around 13,000 years. There is a ~13,000 year cycle of the two times a year when maximum values occur. Maximal values currently occur in March and September.

Curves and models were produced from this numerical data by Dr. Douglas McLain for this investigation.

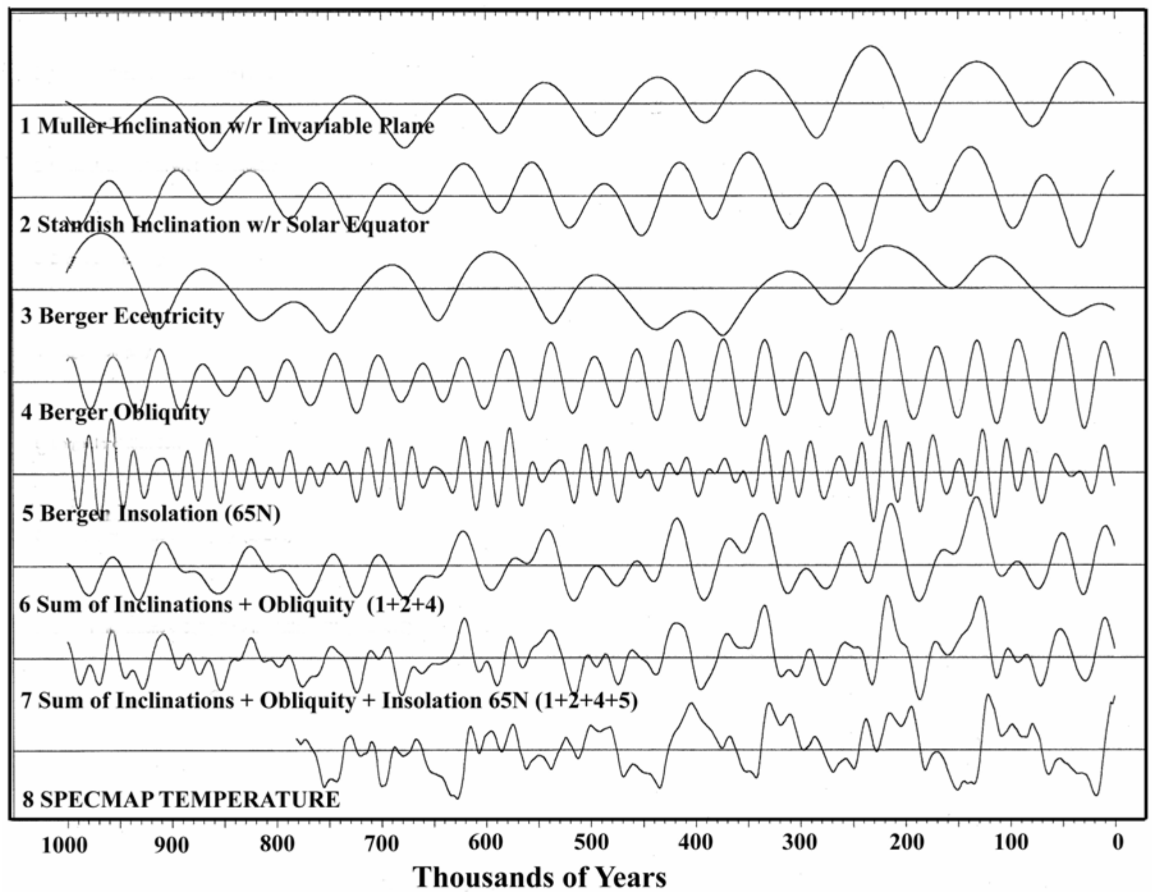


FIGURE 6.

1. Inclination of the earth's orbital plane with relation to the invariable plane of the solar system (by Muller, personal communication).
2. Inclination of the earth's orbital plane with relation to the equatorial plane of the sun (by Standish, for this project).
3. Orbital eccentricity of the earth (by Berger, World Data Center-A for Paleoclimatology).
4. Orbital obliquity of the earth (by Berger, World Data Center-A for Paleoclimatology).
5. June insolation at 65^0 north latitude (by Berger, World Data Center-A for Paleoclimatology).
6. Curve calculated from the sum of the inclination of the earth's orbital plane with relation to the invariable plane of the solar system + the inclination of the earth's orbital plane with relation to the equatorial plane of the sun + the earth's orbital obliquity. The height of this curve is hypothesized to be directly related to geomagnetic strength.
7. Curve calculated from the sum of the inclination of the earth's orbital plane with relation to the invariable plane of the solar system + the inclination of the earth's orbital plane with relation to the equatorial plane of the sun + the earth's orbital obliquity + June insolation at 65^0 north latitude. The height of this curve is hypothesized to be directly related to geomagnetic strength and summer northern high latitude insolation and to have the best direct relationship to paleotemperatures relating to glacial-interglacial chronology. Note the relationship of this curve to the SPECMAP curve. The highest points on this curve correlate to the starts of interglacial periods and the lowest points correlate to the starts of glacial periods and glacial periods get progressively colder until ended by one of the highest points which correlates to the start of the next interglacial.
8. SPECMAP paleotemperatures inferred from Atlantic Ocean sediment cores (by Duffy and Imbrie, World Data Center-A for paleoclimatology).

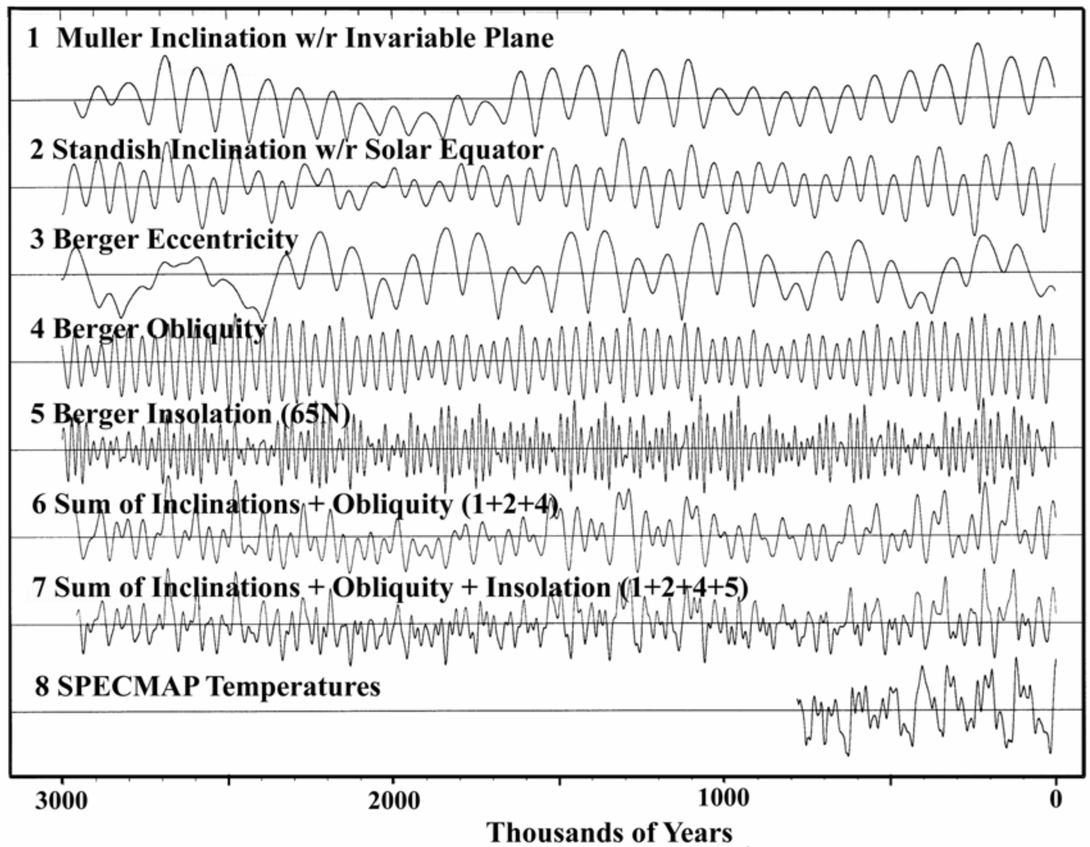


FIGURE 7. Same as Figure 6.

9. GCRs and the ~13,000 Year Geomagnetic Cycle

The ~13,000 year B angle timing cycle is the shortest of the inclination cycles. Maximal inclination, minimal GCRs and maximum warmth occur in this cycle when maximum B angles are in June and December due to the additive effect of the inclination to the obliquity of the earth's axis at these times. Minimal inclination, maximal GCRs and maximum cold over this cycle occur when maximum B angles are in March and September since they do not add to the tilt of the earth's axis at this time. Of course, the effects of this cycle are greater when the B angle value is larger.

The effects of this ~13,000 year cycle are most easily observed during glacial periods where they correspond to some of what are often termed Bond Cycles. In Figure 9, the curve of B angle times shown in Figure 8 is compared to temperature changes over much of the last glacial period. June-December B angle maxima are associated with major warmings following massive iceberg discharges into the North Atlantic termed Heinrich Events at the ends of Bond Cycles and March-September B angle maxima are associated with colder periods between these major warmings.

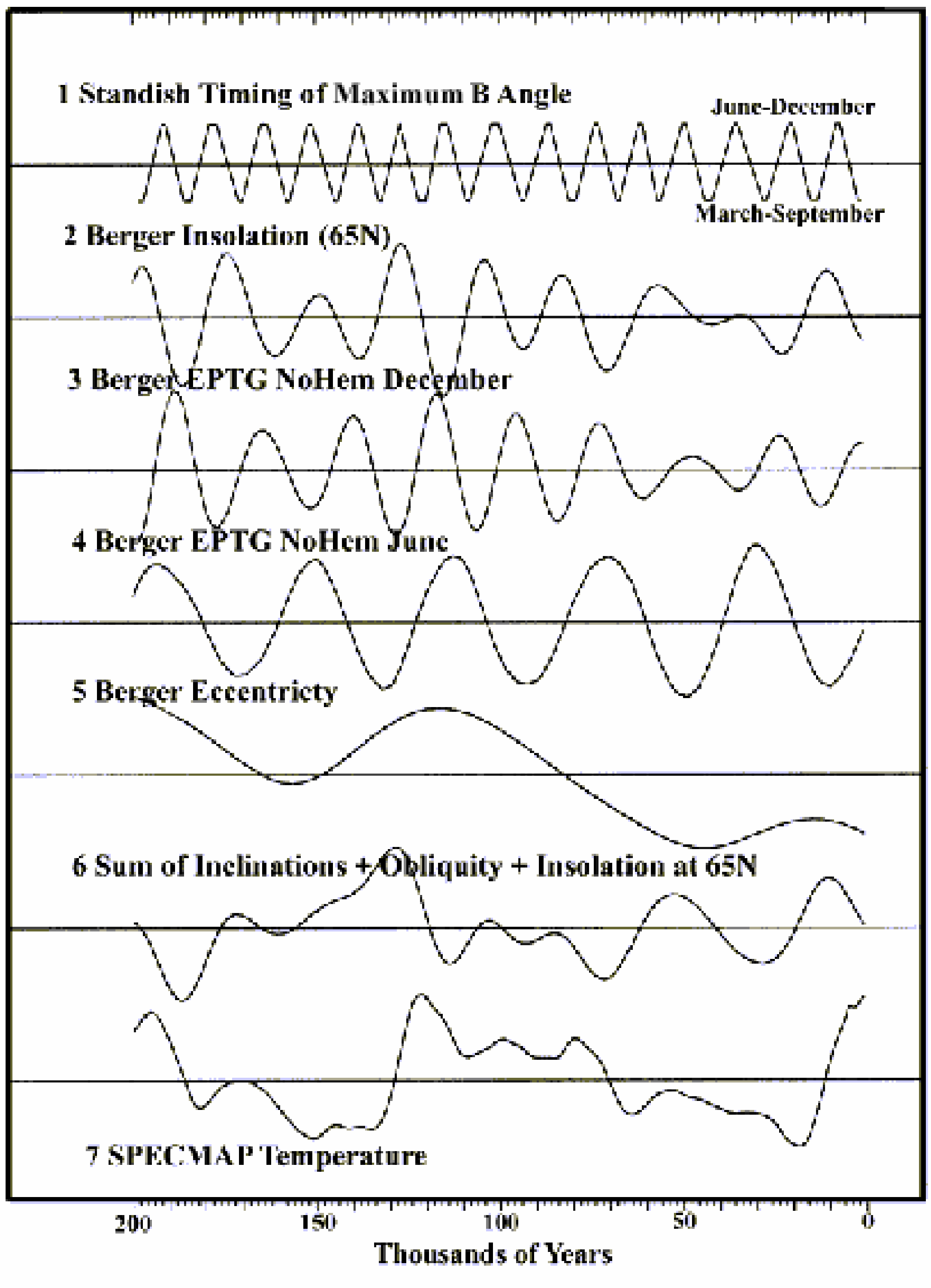
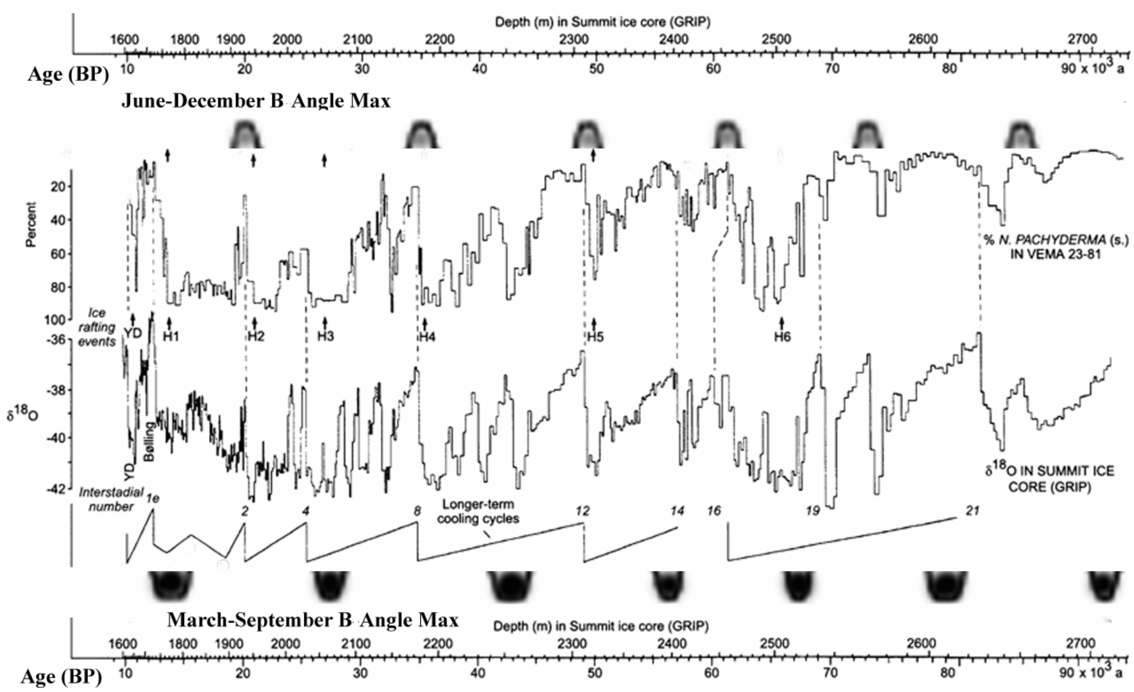

1 Standish Timing of Maximum B Angle
June-December
March-September
2 Berger Insolation (65N)
3 Berger EPTG NoHem December
4 Berger EPTG NoHem June
5 Berger Eccentricity
6 Sum of Inclinations + Obliquity + Insolation at 65N
7 SPECMAP Temperature
200
150
100
50
0
Thousands of Years

FIGURE 8.

1. Curve of the time of the year of the maximum B angle with June-December as top points and March-September as bottom points (by E. Myles Standish Jr. for this project).
2. June insolation at 65^0 north latitude (by Berger, World Data Center-A for Paleoclimatology).
3. Equator to pole temperature gradient for Northern Hemisphere in December (from data from Berger, World Data Center-A for Paleoclimatology).
4. Equator to pole temperature gradient for Northern Hemisphere in June (from data from Berger, World Data Center-A for Paleoclimatology).
5. Orbital eccentricity of the earth (by Berger, World Data Center-A for Paleoclimatology).
6. Curve calculated from the sum of the inclination of the earth's orbital plane with relation to the invariable plane of the solar system + the inclination of the earth's orbital plane with relation to the equatorial plane of the sun + the earth's orbital obliquity (see Figures 6 and 7). The height of this curve is hypothesized to be directly related to geomagnetic strength.
7. SPECMAP paleotemperatures inferred from Atlantic Ocean sediment cores (by Duffy and Imbrie, World Data Center-A for Paleoclimatology).



Times of Year of B Angle Maxima

FIGURE 9. Comparison of times of the year of B angle maxima and minima taken from high and low points of curve 1 in Figure 8 (calculated by Dr.E. Myles Standish Jr. for this project) with the GRIP Greenland ice core temperature record as indicated by O^{18} and a deep sea core temperature record from the North Atlantic as indicated by foraminifera percentages (adapted from Bradley 1999). The bottom curve, also from Bradley 1999, shows general trends in temperatures. Note the general relationship of June-December B angle maxima to periods of rapid warming including some Heinrich events and the general relationship of March-September B angle maxima to cooing events between periods of rapid warming.

The prominent ~2400 year cycles seen during glacials are often called Dansgaard-Oeschger Cycles (D-O Cycles). Each Bond Cycle includes several D-O Cycles in a row and ends with a period distinctly colder than that of a typical D-O Cycle and usually includes a Heinrich event and a drop in sea level (Kerr 1998). These colder periods are immediately followed by a strong and rapid period of warming. The characteristic lengths of Bond cycles are given as from 10,000 to 15,000 years (Hughes 1998).

The term Heinrich Events was originally given to events resulting in unusually thick layers of ice-rafted debris deposited on the floor of the North Atlantic during the last glacial period. It has been generally concluded that these events indicate increases in icebergs carrying this debris over what is the average for the cold phases of ~2400 year cycles due to even colder periods of climate. It appears that the rapid influx of cold, fresh meltwater and icebergs due to the warming induced melting of ice in the North Atlantic area may cause a widespread but short lived cooling of climate before the warming occurs (Broecker 1994). A close look at the geological record indicates a Heinrich Event periodicity of approximately 13,000 years during much of the last glacial period. There are variations, however, since Heinrich Events can also be produced by other climate phenomena such as glacial-interglacial cycle variations. This often produces a record of Heinrich Events occurring at a greater frequency, often around 6000 years, especially around times of glacial-interglacial transitions. Since June-December and March-September B angle maxima are both often associated with colder periods, the June-December followed by rapid warming and the March-September not, this also often gives the appearance of ~6000 year cycles in the paleorecord.

The ~13,000 year cycle of B angle maxima can also be related to events from deglaciation through the Holocene. They are: the start of deglaciation (June-December, 19-20,000 years ago), the Younger Dryas period (March-September, 12-14,000 years ago), the altithermal period (June-December, 6-7000 years ago) and the Little Ice Age, the coldest period since deglaciation (March-September, 1000 years ago to present).

10. GCRs and Ice Age Periodicities

Before I discuss glacial-interglacial cycles, I should say a few words about the longest time scale of cyclic variation in climate, the ice age cycle. This cycle doesn’t affect the incidence of GCRs, but it influences the effects of GCRs on climate through changes in the earth’s surface features. At least nine ice ages can be seen in the earth’s history, with a variable spacing. They have an average spacing of approximately 300 million years and an average duration of approximately 40 million years. Ice ages seem to occur at times when the earth has high mountain ranges in certain configurations. A high, continuous mountain range close to the western coast of a continent with a large landmass in the higher latitudes and with moisture available from oceans to its west, east and south, as is present now in North America is an ideal situation. This produces a continental interior that can get both cold enough and wet enough to build and sustain continental glaciers of great size and area. This continent may then become a “thermal pacemaker” for the entire world as North America has been for the ice age we are currently in. There appears to be a cycle of worldwide tectonic relief with a periodicity that also averages ~300 million years that corellates with the ice age cycle.

Once the earth’s topography surpasses the ice age threshold, the long term effects of increases in GCRs above a certain level on climate are recorded in ice. Colder phases of multidecadal, century and millennial scale cycles have been recorded as glacial ice, but the major climatic oscillations of an ice age are glacial-interglacial cycles.

11. GCRs and Geomagnetic Fluctuations Correlating to Glacial-Interglacial Cycles

Chronology of temperature changes over glacial-interglacial timescales from deep sea cores can be observed for the last ~800,000 years in Figure 6 (SPECMAP) and for the last 3 million years in Figure 10 (Core ODP-607).

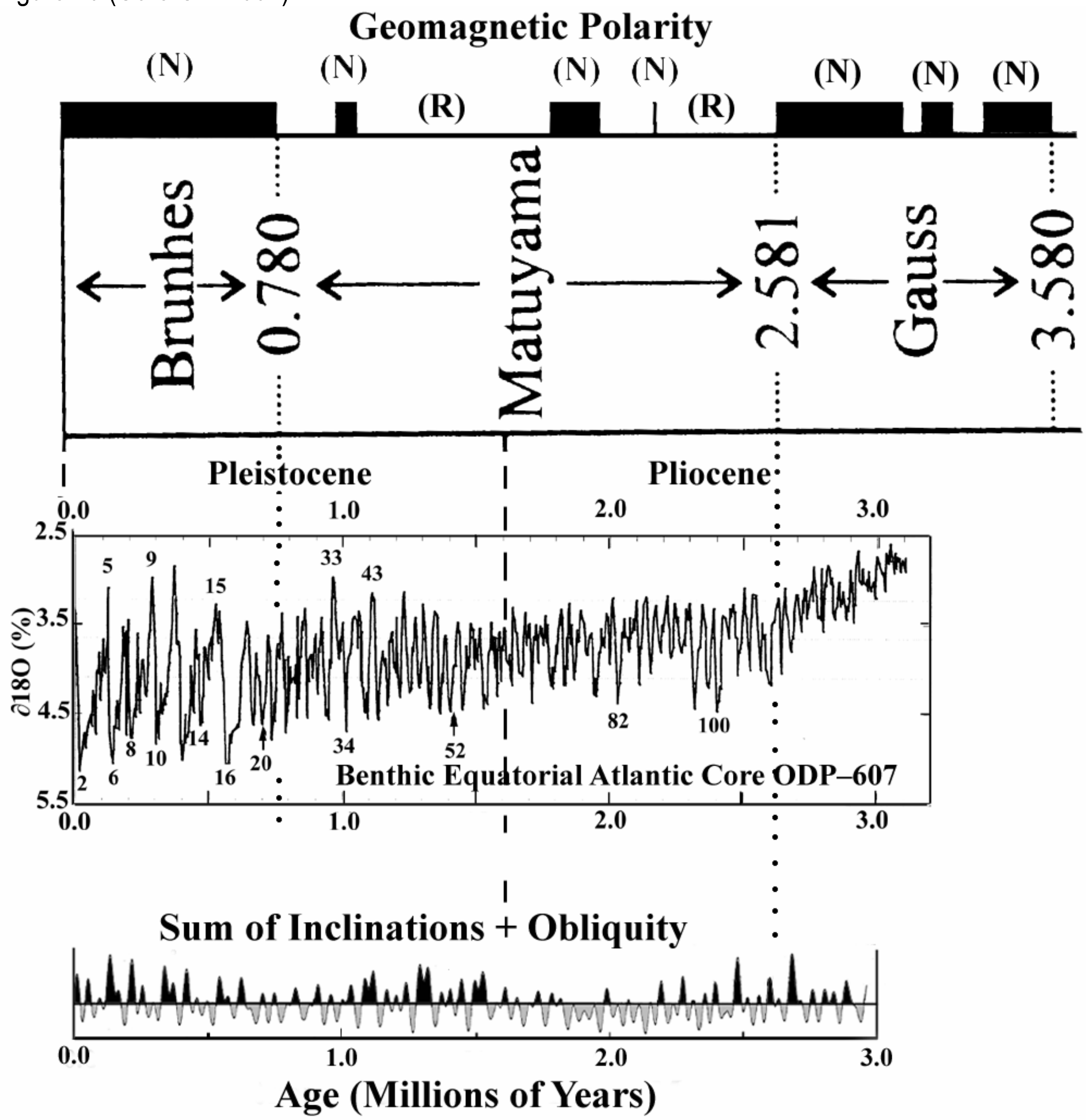


FIGURE 10. Comparison over 3 million years of sum of inclinations + obliquity curve, temperature records indicated by O^{18} from equatorial Atlantic deep sea core ODP-607 (adapted from Bradley 1999) and geomagnetic polarity (adapted from Merrill et al. 1996). Note general relationship of greater amplitudes and more ~100,000 year glacial cycles as opposed to ~40,000 year cycles in temperature variations curve with greater amplitudes in sum of inclinations + obliquity curve, especially in the last 1,200,000 years, and lower frequency of geomagnetic reversals in times of higher amplitudes in sum of inclinations + obliquitiy curve. Also note a relationship in more recent time of greater amplitudes and more ~100,000 year cycles with normal geomagnetic polarity (N) as opposed to reversed (R).

Glaciation gradually increased in intensity during the latter part of the Tertiary along with gradual increases in the heights of mountain ranges, then rapidly increased in the Quaternary along with rapid increases in mountain heights. From ~3 million to ~1 million years ago, a ~40,000 year periodicity in glacial-interglacial cycles dominates, with a few short periods of clusters of somewhat longer cycles. During this period, the maximum sizes of ice sheets were about one quarter to two-thirds the size of those of the last glacial maximum (Oppo et al. 1998). At around 800,000 years ago, however a ~100,000 year cycle becomes dominant and continues to the present. This produces a cycle of glacial periods averaging ~90,000 years and interglacial periods ~10,000 to ~20,000 years. The ever increasing heights of major mountain ranges exceeding a critical threshold is likely to have been one factor in this change.

This ~100,000 year cycle actually appears to be a beat frequency of alternating ~80,000 and ~120,000 year periods. This is most observable over the last 500,000 years. A ~412,000 year cycle is also present.

The Milankovitch Hypothesis for glacial-interglacial periodicity primarily relies on orbitally induced changes in Northern Hemisphere (~65^0N) summer insolation values that vary semiannually only 3 to 4% maximum. It cannot account well for the ~100,000 and ~412,000 year periodicities since corresponding eccentricity induced insolation variations for them are too low at 1% maximum. Also, the largest climate warming responses occur at times of lowest eccentricity related insolation values and the beat frequency is not present in the Milankovitch insolation values. There are other problems as well. Insolation values are opposite for the two hemispheres and the Northern Hemisphere is supposed to determine glacial-interglacial chronology, yet the Southern Hemisphere actually leads in deglaciation by over 3000 years. Some of the glacial-interglacial transitions occur too early to have been caused by 65^0 N summer insolation (Winograd et al. 1992; Karner and Muller 2000; Gallup et al. 2002 and others). None of these are problems if GCRs are considered to be the primary climate forcing agent.

In my hypothesis, the largest variations in the inclination related motions of the earth cause the largest variations in geomagnetism that cause the largest variations in GCR levels resulting in glacial-interglacial periodicities. In my curves, inclination with relation to the invariable plane plus inclination with relation to the solar equator establishes the basic beat frequency of alternating ~80,000 and ~120,000 year periods (see Figures 6 and 7). This is especially observable in comparisons of times of peak interglacial warmth. This is the first explanation for the origin of this specific periodicity that I know of. Adding obliquity to the above mentioned curve gives a curve that includes the ~41,000 year periodicity that is present in glacial-interglacial cycles even when the ~100,000 year periodicity is not. As mentioned previously, the ~41,000 year cycle was dominant prior to ~800,000 years ago. Increasing heights of major mountain ranges was probably the major reason for the change to the ~100,000 periodicity, but another possible influence can be seen in the curves. Fluctuations in the more recent values for inclination with relation to the solar equator and inclination with relation to the invariable plane have been high. It appears that when the inclination values are high they produce the ~100,000 year cycle with the beat frequency, otherwise the ~41,000 year obliquity cycle dominates and this is more true the more recent the time. It may be that the obliquity of the earth itself has a greater influence on geomagnetism than the inclination of its orbit does when the inclination values are low.

Adding summer insolation at 65^{0}N further increases the similarity to the SPECMAP curve by adding the precession related periodicities. Summer high latitude heating may not be the only effect of this precession related orbital variation on climate. Summer high latitude insolation values are matched in time and magnitude by corresponding winter equator to pole temperature gradient values that result in similar effects on climate (see Figure 8). Insolation fits in best at a 1/4 to 1/6 weighting. In the Milankovitch hypothesis, this is usually used as the primary determinant of the timing of glacial-interglacial periodicities. Compare the similarities of the curve of summer insolation at 65^{0}N and my curve to SPECMAP in Figure 6. Note how much better my curve fits the SPECMAP curve.

Other features of the geomagnetic and paleoclimatic record can be explained by the apparent effects on geomagnetism of the ~412,000 year cycle of the earth's orbital eccentricity. Yamazaki and Oda 2002 have correlated changes in geomagnetism to changes in the earth's orbital eccentricity. A possible mechanism? Eccentricity modulates the precessional movements of the entire earth and may thus affect the relative motion between the inner core and the rest of the earth. Through this it may affect geomagnetism through the dynamo theory.

The effects of the 412,000 year cycle are not indicated in my calculated inclination related curves and will be described.

~412,000 year periodicities are present in paleoenvironmental records of periods other than ice ages (Berger 1992; Clemens and Tiedemann 1997 and Zachos et al. 1997). ~100,000 year periodicities are also present in paleoenvironmental records of periods other than ice ages.

The modulation of geomagnetism by the ~ 412,000 year cycle can be observed well in Figures 11 and 12. The Stage 11 interglacial at around 400,000 years ago and the Holocene interglacial are considerably warmer than their inclination based curves on my figures indicate due to the highest geomagnetism induced by the lowest eccentricities of this cycle. Stage 11 was the longest and warmest interglacial on record (Howard 1997), but it has a combined inclinations and obliquity curve of similar height to most of the other recent interglacials. The sea level was 15 to 20 meters higher in Stage 11 than it is today (Chappell 1998) and that interglacial also lasted around 50,000 years longer than the Holocene has so far (60,000 years in all) (Howard 1997). The Holocene also has a rather low curve for its warmth due to the highest geomagnetism induced by the lowest eccentricities of the ~412,000 year cycle. The Holocene combined inclinations and obliquity curve, however, is a little lower than that of the Stage 11 interglacial, so it possibly may not be quite as long and quite as extreme.

Continuous significant cooling could probably not begin until the geomagnetism falls to a level below the interglacial termination threshold and from the looks of where we are now on the combined inclinations and obliquity curve in comparison to past terminations (Figure 6), we could reach that point 5-10,000 years from now. But remember, my curves do not show the influence of the ~412,000 year cycle, so it could be considerably further in the future.

Interestingly, Berger and Loutre (2002) present evidence based on eccentricity values that the Holocene could indeed last 50,000 years longer. They point out that we are in a period of prolonged low eccentricity values for the first time since around 400,000 years ago and that eccentricity will reach almost zero within the next 25,000 years and will remain lower than today's values for over 100,000 years.

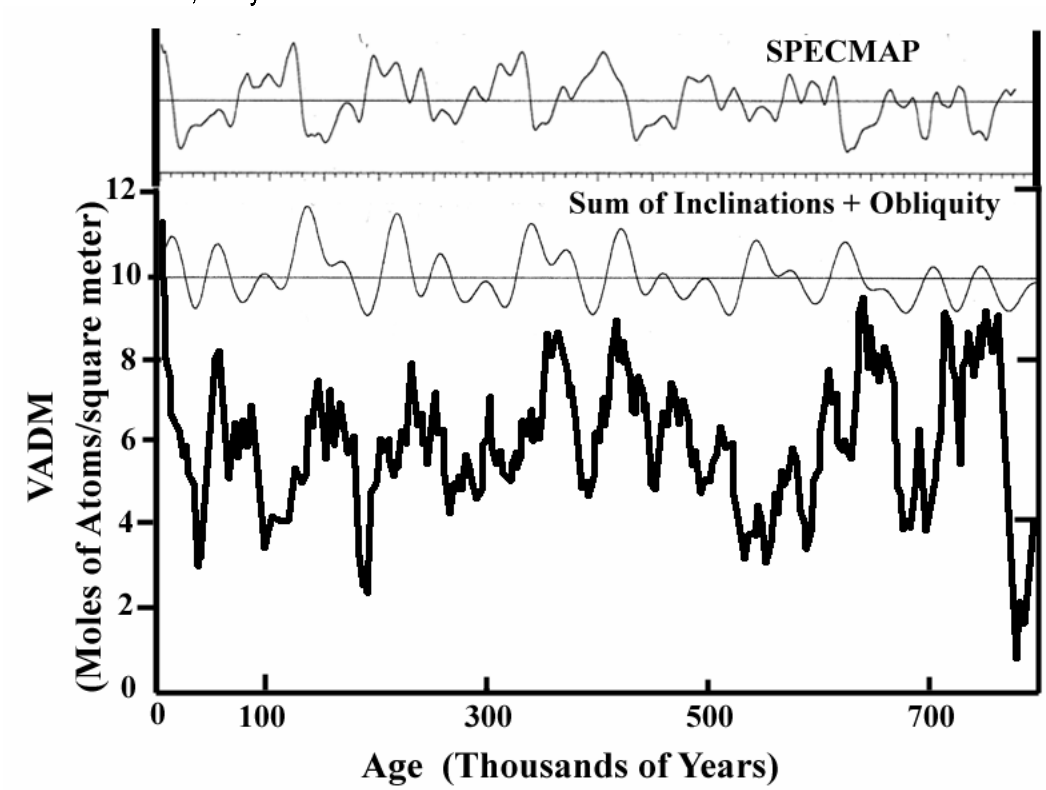


FIGURE 11. Comparison of 800,000 year synthetic curve of geomagnetism derived from 33 records of paleointensity (adapted from Guyodo and Valet 1999) with sum of inclinations + obliquity curve and SPECMAP curve of deep ocean core temperatures. Note general relationship of higher values on the sum of inclinations + obliquity curve with higher geomagnetism. Note how turns towards glacial or interglacial conditions generally occur in SPECMAP at minimal or maximal geomagnetic values respectively.

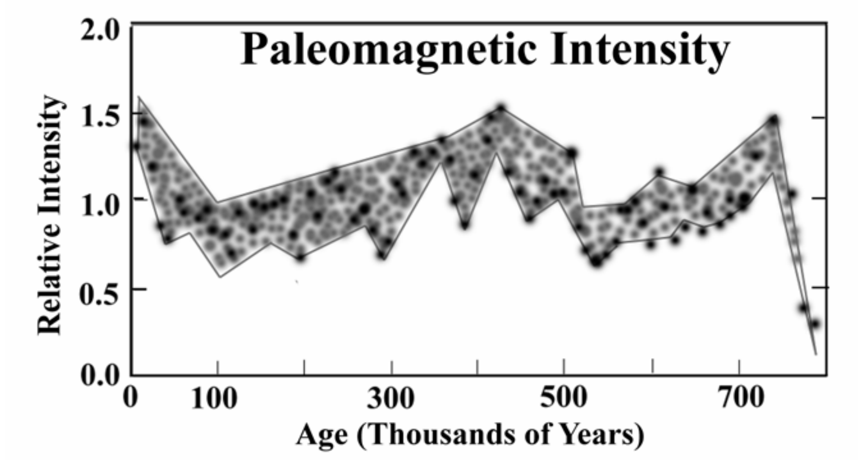


FIGURE 12. This is a curve of paleomagnetic intensity over the last 800,000 years that shows the effects of the ~412,000 year eccentricity cycle (adapted from Yamazaki et al. 1995). Note the high points now, around 400,000 years ago and what may be around 800,000 years ago interrupted by a geomagnetic reversal. Also note the long term, progressively decreasing geomagnetism leading to the lowest values just before the fast increases around the times of maxima.

The glacials preceding these previously mentioned large interglacials may be longer and colder than their curves indicate due to the ~412,000 year cycle. For instance, the Stage 12 glacial that preceded the Stage 11 interglacial was the coldest on record with an ice volume estimated to be 15 to 20% greater than at the peak of the last glacial period and a sea level depression of 140 meters (Chappell 1998). This is 20 meters greater than that of the most recent glacial. The most recent glacial period was also one of the coldest. This is probably due to another aspect of the modulation of geomagnetism by this cycle. A study of four low latitude Pacific sediment cores shows that over the past 800,000 years, the geomagnetism seems to progressively decrease over most of the ~412,000 years, reaching its lowest point before rapidly rising to maximum levels (Yamazaki, et al. 1995) (Figure 12). This means that the glacials before these largest of interglacials are likely to occur, or at least begin, at times of some of the lowest geomagnetism of the ~412,000 year cycle. The glacial periods before at least the last two large interglacials (the Stage 11 and the Holocene assuming the Holocene will be one of the large ones) were also both in the longer ~120,000 year glacial periods which allowed maximum time for cooling. Other contributing factors to their greater cold are the effects of lower precession due to lower eccentricity at these times on summer insolation at higher latitudes.

A crucial test of the validity of my hypothesis is how well the record of paleointensity of the earth's magnetic field conforms to both the paleoclimatic record and the record of changes in the earth's inclination.

In Figure 11, an 800,000 year curve of geomagnetism, which is an integration of 33 records of relative paleointensity over the past 800,000 years from Guyodo and Valet (1999) is compared to my sum of inclinations + obliquity curve and the SPECMAP curve. The following can be observed:

1) The ~412,000 year cycle of geomagnetism is prominent in the curve of geomagnetism with peaks around 800,000 and 400,000 years ago and now. Note how strongly it modulates the curve.

2) The beat frequency of alternating ~80,000 and ~120,000 year cycles can be observed in the curve of geomagnetism within the last ~450,000 years.
3) There is an immediate, more or less linear response of geomagnetism to inclination, while the response of climate as indicated by SPECMAP which primarily reflects ice volumes, to geomagnetism is lagged to a degree and appears to be out of phase. This appearance of the climate response is probably also because climate is mainly responding to the highest and lowest levels of geomagnetism, resulting in the bimodal flip-flop pattern.
4) The similarity between the curves appears to be better the more recent the time. Similarity becomes closer after around 450,000 years ago. This is around the time when the ~100,000 year cycle becomes most dominant.
5) Glacial periods appear to match geomagnetism best. There often appears to be a lack of a strong spike corresponding to peak interglacial climates. This could possibly be due to decreases in sedimentation rates during interglacials. This would result in gaps and underestimations of geomagnetism at these times because of deficits in sediments that provide the geomagnetic records. It is also possible that higher geomagnetic states are more transitory because a faster dynamo may be quickly slowed by friction. This could result in short duration upward spikes that could be difficult to detect in the record. This could also be one reason for the relative brevity of interglacial climates not occurring during highest geomagnetism periods of the ~412,000 year cycle.
6) Within the last ~200,000 years, periods of glacial initiation appear to correspond to well known geomagnetic excursions. This indicates that at least one cause of geomagnetic excursions is the lowest of inclination values.

The curve of geomagnetism over the last 130,000 years in Figure 13 is one of the most accurate and detailed available. It was obtained from four cores taken from two sites in the Sulu Sea. The sediments in these cores provide strong, stable magnetizations at a high sedimentation rate (~10 cm/kyr), a rare combination in the deep-sea environment (Merrill et al.1996). Note how closely it matches the curve derived from the sum of inclinations plus obliquity values alone. Note the similarity of both of these curves to Vostok surface temperatures and the Be^{10} record. Also note the thin spikes at ~120,000 and ~15,000 to ~10,000 years ago that may indicate the presence of short duration high values that exceeded the threshold for interglacial climates. The similarities between the curves in this figure provide strong evidence for the origin of glacial-interglacial periodicity through variations in GCR intensity modulated by geomagnetism. A longer Be^{10} record going back 200,000 years presented in Sharma (2002) shows a good relationship to the sum of inclinations plus obliquity values occurring earlier than those shown in Figure 13.

In Figure 10, it can be observed that over longer time periods ~100,000 year periodicities may be in part due to a greater amplitude in geomagnetic fluctuations. The increasing heights of major mountain ranges is related to the increasing glacial volumes and is probably the major factor in the recent dominance of ~100,000 cycles. Looking further at Figure 10, however, a case could be made for more glacial ice and a greater tendency for ~100,000 year cycles as opposed to ~40,000 year cycles with normal geomagnetic polarity (N) as opposed to reversed (R). A possible mechanism? There has been some speculation that “coupling” or “reconnection” of the earth’s and sun’s magnetic field lines could be facilitated during antiparallel solar cycles and cause higher levels of GCRs in the Northern Hemisphere during periods of normal polarity resulting in greater glacial ice volumes. This should be looked into, but at this time it is very highly speculative and there is little evidence currently available in support of it as a viable mechanism.

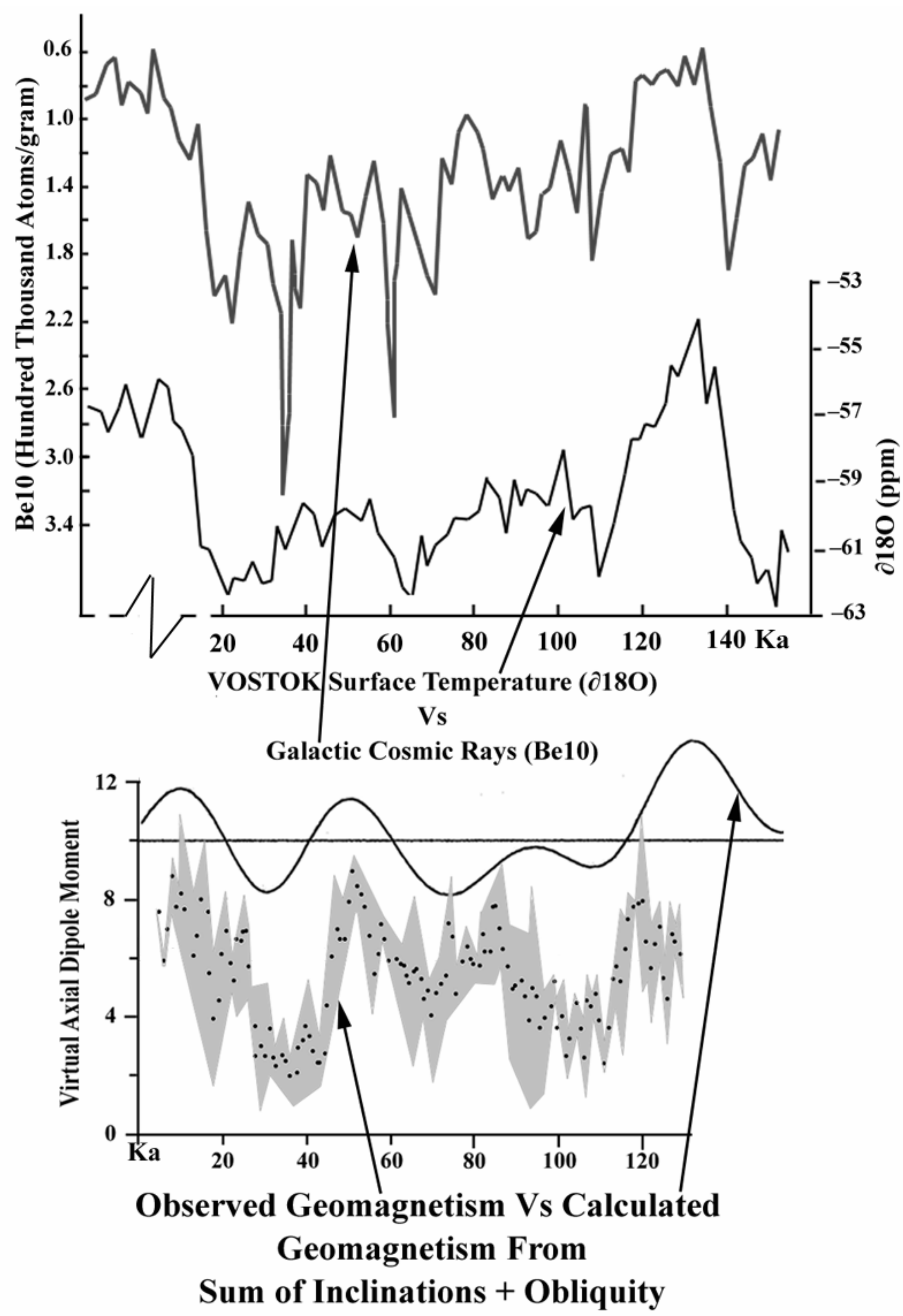

Be10 (Hundred Thousand Atoms/gram)
0.6
1.0
1.4
1.8
2.2
2.6
3.0
3.4
∂18O (ppm)
−53
−55
−57
−59
−61
−63
20
40
60
80
100
120
140 Ka
VOSTOK Surface Temperature (∂18O)
Vs
Galactic Cosmic Rays (Be10)
Virtual Axial Dipole Moment
12
8
4
0
Ka
20
40
60
80
100
120
Observed Geomagnetism Vs Calculated
Geomagnetism From
Sum of Inclinations + Obliquity

FIGURE 13. Comparison of observed geomagnetism obtained from four deep sea sediment cores from the Sulu Sea (Philippines) (adapted from Merrill et al. 1996) with theoretical geomagnetism (not on the virtual dipole moment scale) as indicated from the calculated sum of inclinations + obliquity curve. The geomagnetism curves are compared to temperatures as inferred from O^{18} levels from the Vostok Antarctic ice core and the Be^{10} concentration from the Vostok ice core which provides a record of galactic cosmic ray intensity (adapted from Raisbeck et al.1987). Note the inverted scale for the Be^{10} curve indicating greater galactic cosmic ray intensity in a downward direction. The sediment cores from the Sulu Sea show strong, stable magnetizations at high sedimentation rate and provide a geomagnetic history regarded as one of the most accurate available. Note the similarity between the curves providing evidence that inclinations + obliquity modulate geomagnetism, geomagnetism modulates galactic cosmic ray intensity, and galactic cosmic ray intensity modulates climate, in this case glacial-interglacial periodicity.

12. Magnitudes of GCR Levels and their Effects

I do not know whether the values of geomagnetic intensity on my curves indicating glacial-interglacial chronology are what would be necessary to modulate GCRs to develop the climates predicted for them. I hope that this article will encourage research to answer this question. It is possible, however, to calculate the levels of GCRs that would result from differing levels of geomagnetism and the levels of atmospheric ionization that would result from the GCR levels. I have not been able to find enough information at this time to be able to reliably calculate the changes in cloudiness that would result from the changes in ionization. However, the maximum estimate of the percent change in low cloudiness over the last solar cycle (~4%) was approximately one-third of the percent change in GCR levels (~12%) and approximately one fifth of the percent change in ionization at tropopause levels (~20%) over the same period and these relationships are used below to obtain some very rough estimates.

The current geomagnetism as measured by the dipole moment (in 10^{22} A m^2) is 8, but over the last 40,000 years, it has ranged from a low of 1 between 30,000 and 40,000 years ago to a high of at least 12 in a brief peak at around 14,000 years ago and a peak at around 2000 years ago and possibly briefly as high as 15 in a peak at around 9,000 years ago (Mankinen and Champion 1993). Data from Lingenfelter and Ramaty (1970) indicate that the GCR levels at a dipole moment of 1 at sunspot minimum would be approximately 200% of today's values as measured by C^{14} at 73^0 latitude and at a dipole moment of 15 would result in approximately 73% of today's values. Data from Volland (1995) indicate that the atmospheric ionization at tropopause levels produced by 200% of today's GCR levels would be approximately 306% of current ionization levels and 73% of today's GCR levels would result in approximately 46% of today's levels of ionization.

Rough extrapolations from the changes in GCR levels as compared to cloudiness over the last solar cycle give an increase in low cloudiness at the above mentioned conditions of around 33% at a dipole moment of 1 and a decrease of around 9% at a dipole moment of 15.

GCR variations due to solar magnetic field variations on the ~2400 year timescale can be substantial also. The peak values of the little ice age occurred in the decade of the 1690s when the Be^{10} levels, which like C^{14} levels are proportional to GCR levels, were 70% above levels before and after according to measurements in Greenland ice cores (Tinsley et al. 1989). A rough extrapolation of this from the changes in GCR levels as compared to cloudiness over the last solar cycle would give an increase in low cloudiness at the peak of the little ice age of around 23%.

At today's levels of geomagnetism, (dipole moment 8) there is approximately a 12% difference in GCR levels between sunspot maximum and minimum. Theoretically, there is currently about a 20% difference in ionization at tropopause levels between sunspot maximum and minimum, but a 50% difference has been reported (Tinsley et al. 1989). At a dipole moment of 1, the differences between sunspot maximum and minimum would be much greater. Data from Lingenfelter and Ramaty (1970) indicate that the range in GCR levels would be approximately 243% of today's and data from Volland (1995) indicate that the theoretical range in ionization at tropopause levels at 73^0 latitude would be approximately 340% of todays.

This is interesting because a 60 year precipitation record inferred from tree rings from Rancho La Brea in the Los Angeles area near the end of the last glacial period shows both substantially higher precipitation totals at times and substantially greater precipitation variability than today (Templeton 1977). The ~22 year cycle is evident in this record with the wettest periods (presumably antiparallel to parallel transitions) reaching a maximum of 75 inches per year and the driest periods (presumably parallel to antiparallel transitions) reaching a minimum of 10 inches per year. The wettest periods in this record could also have occurred during ENSO-Warm Events, which were frequent and severe during glacial periods.

13. GCRs and Glacial and Interglacial Environments

The very high levels of GCRs present during full glacial periods would be expected to produce a strong, consistent ENSO-Cold Event pattern that includes a greatly expanded circumpolar vortex and a very cold polar vortex. The presence of the continental glaciers would be expected to further stabilize the equatorward position of the circumpolar vortex and further enlarge it as ice sheets grow towards glacial maxima. Evidence for the dominance of glacial ENSO-Cold Event conditions can be found by looking at the paleoenvironmental record of glacial sea surface temperatures in the tropical Pacific (Lea et al. 2000). The CLIMAP reconstruction of Pacific sea surface temperatures during the last glacial period as presented in Bradley (1999) reveals a pattern very similar to what is seen in the cold phase of the Pacific Decadal Oscillation.

As expected, however, there is evidence of frequent and severe ENSO-Warm Events in the Pacific during the last glacial period and an absence of these conditions during the early Holocene when GCR levels were probably at their lowest (Kerr 1999a; Athanasios et al. 2002). During the last glacial period, ENSO-Warm Events were much more frequent and severe during the stadials (~2400 year cycle minima) than the interstadials (~2400 year cycle maxima) (Stott et al. 2002).

Greatest ice volumes were, in general, present in areas expected to receive maximum precipitation under ENSO-Cold Event conditions with a maximally expanded circumpolar vortex. Paleoenvironmental evidence indicates that the circumpolar vortex of glacial times in general resulted in the expansion of the zone of ample ENSO-Cold Event pattern precipitation to at least 300 miles further equatorward than is seen today under ENSO-Cold Event conditions. The evidence also appears to show dryness in many areas that are today dry under ENSO-Cold Event conditions.

With a few exceptions, most areas of the world appear to have had substantially less precipitation during glacial periods than during interglacials. Records from the Greenland and Antarctic ice cores indicate that precipitation decreased by about 50% in polar regions during glacial periods (Crowley and North 1991). At least some of the ice accumulation may have been from surface condensation in the form of rime ice under relatively mild temperatures from greatly increased low cloudiness with higher albedo but less precipitation potential. Of course, the reduced evaporation and increased cold from greatly increased low cloudiness allowed continental glaciers to form under the conditions of decreased precipitation.

In addition to a climate pattern consistent with persistent ENSO-Cold Event conditions, glacial paleoenvironmental records indicate worldwide consistently high relative humidities and equabilities. These conditions are consistent with the increased low cloudiness and condensation that would be a consequence of high levels of GCRs. The increased cold of glacial periods is probably primarily a consequence of the increased low cloudiness.

Consistently high relative humidities, condensation and equabilities and lower average amounts of precipitation present in glacial periods would help explain what are often called “paradoxical glacial environments with no modern analogs.” These environments have been termed “heterogeneous mosaic savannas” (Guthrie 1984). This type of environment often appears to be associated with considerable dryness but it is also characterized by long growing seasons, year round high biological productivity and high species diversity. Abundant superficial moisture appears to have been available from surface condensation during periods of low precipitation. This would be expected with increased condensation at lower levels that produced greatly increased levels of low cloudiness, including fog, that may have had a lower precipitation potential. Even environments at the margins of continental ice sheets were highly productive, mostly free of snow cover year round and had much milder winter temperatures than the same areas do today.

These heterogeneous mosaic savannas appear to have had unusually high productivity and unusually high numbers and diversities of species, often including species together that are characteristic of very different environments today. It is common to find species characteristic of present day arctic, tropical, humid and desert environments together in the same glacial deposits. In late glacial Europe, for instance, African hyenas roamed the British Isles with arctic reindeer and leopards were associated with musk oxen in southwestern Europe (Guthrie 1984). In Tennessee, tapir and jaguar have been found associated with caribou (Guthrie 1984).

One need only to look at where the greatest numbers of Pleistocene relict species, greatest total numbers of species and greatest diversities of species are found today to see the strong connection to consistently high relative humidities, low cloudiness, condensation and equabilities. Good examples of this can be found in the east African highlands and coastal California.

What about the extinctions of Pleistocene large mammals (megafauna) that occurred around the start of the Holocene? Is there anything unique climatically about the late glacial-Holocene transition or the Holocene involving GCRs that could shed some light on this event? As mentioned previously, due to the ~412,000 year geomagnetic cycle, the Holocene is unique in having the consistently highest levels of geomagnetism since those of Interglacial Stage 11 around 400,000 years ago. These consistently high levels of geomagnetism have created a Holocene environment that is unique in its climatic stability and environmental segregation and zonation. The Holocene environment is very different from those of interglacials occurring at other times in the ~412,000 cycle which were characterized by climate fluctuations as great as those seen in glacial periods (Kerr 1993b). It is only during the extreme climates of interglacials occurring during these highest periods of geomagnetism of the ~412,000 year cycle that the heterogeneous mosaic savannas of worldwide distribution that supported the Pleistocene megafauna largely disappeared.

The last major extinctions and migrations to occur before those of the last glacial-Holocene transition were the Irvingtonian that occurred between Glacial Stage 12 and Interglacial Stage 11 a little over 400,000 years ago (Webb 1984). This was the last time geomagnetic conditions, and hence environmental conditions, were similar to those of the late glacial-Holocene transition. This is strong evidence for modulation of glacial-interglacial environmental conditions by geomagnetic modulation of GCR levels.

The fact that the Holocene is unique among the three most recent interglacials negates one of the main arguments in favor of Pleistocene overkill by humans and other hypotheses for the late Quaternary extinctions not involving major changes in environmental factors. That argument is: "the megafauna survived other interglacials, so the transition from the last glacial to Holocene interglacial environmental conditions could not have been a major factor in these extinctions."

Was the climate during the transition to the Holocene or in the early Holocene responsible for the extinctions? Although the last glacial-Holocene transition at around 11,550 years ago was extremely rapid in the Northern Hemisphere, this does not appear to have been a causative factor in these extinctions. Most extinctions actually occurred shortly after the start of the unique Holocene climatic and environmental conditions around 11,000 years ago. Most last records are seen between the start of the Holocene and before the peak in geomagnetism at around 9,000 years ago. Megafaunal extinctions were also severe in the Southern Hemisphere where the transition was more gradual, and most events generally occurred more than 3000 years earlier. They were considerably earlier than this in Australia as described below.

The start of civilization coincides with the decline of the hererogeneous mosaic savanna and the extinction of the megafauna that was probably a consistently dependable resource. This "fall from Eden" was probably a major factor in the start of agriculture and a sedentary existence. Other related factors were the shortening of growing seasons and the simplification and zonation of ecosystems. All of these made a sedentary existence in optimal areas and agriculture to augment environmental deficiencies desirable. The anomalous stability of Holocene climate made it possible.

The peak on the combined inclinations and obliquities curve at ~50,000 years ago during the last glacial was somewhat lower than the peak that correlates to deglaciation and was short of the interglacial threshold (Figure 8). Nonetheless, the intensification of geomagnetic effects due to the lowest eccentricity of the 412,000 year cycle appears to have already been in effect at this time. The extinction of the Pleistocene megafauna of Australia occurred around this time (Roberts et al 2001). In some places such as Britain, there is evidence that temperatures at least briefly reached present day levels around this time (Bradley 1999) and the Australian monsoon appears to have been more effective than it is today (Johnson et al. 1999).

Both paleontology and human genetics point to a rapid emergence and expansion of modern humans out of Africa and into most of the Old World at this time and the eventual expansion into Europe where they replaced the Classic Neandertals during the ensuing progression to glacial maximum conditions (Wade 1999). Of course, during the last glacial-Holocene transition that followed, some of the most widespread human migrations of all occurred including the major peopling of the New World. These migrations of humans into new areas were much less a cause of megafaunal extinctions than they were a result of them.

As mentioned previously, there is considerable evidence that the Holocene could follow a course similar to that of interglacial stage 11 around 400,000 years ago and be one of the longest and warmest, possibly lasting up to 50,000 years longer.

Geomagnetism in the Holocene has varied somewhat, but has generally plateaued at high levels. The Be^{10} curve covering the Holocene shows this well (Figure 14). The peak in geomagnetism around 9000 years ago is shown as well as a later peak at around 2000 years ago. Antarctic ice core records show the temperature effects of this later peak well but it is not evident in the Greenland records (Figure 8). The most pronounced climatic and environmental changes of this event, however, appear to be associated with the Medieval Maximum or Little Climatic Optimum that occurred between 950 and 1200 AD. As mentioned previously, climatic responses to geomagnetic events on timescales other than glacial-interglacial seem to average around a 1000 year lag time. More subtle climatic and environmental changes were probably occurring earlier than the Medieval Maximum and the messages of hope of Jesus and Buddah around 2000 years ago and Mohammed several centuries later may have been influenced by this as was the widespread migrations of people into new areas that resulted in the Dark Ages in Europe before and around the time of the Medieval Maximum.

If we only look at extinctions due to climate related environmental changes, there appears to be another group of extinctions in the late Holocene that may be related to the peak in geomagnetism at around 2000 years ago. Many of these occur on islands, which because of their maximal relative humidities and equabilities due to being surrounded by water, became refugia after the start of the Holocene. Of course, one must always be aware of possible human involvement in island extinctions and island extinctions occurring within the last 2000 years are often cited as some of the most conclusive evidence of a major role for humans in faunal extinctions. As mentioned previously, however, environmental change coinciding with the presence of humans in new areas does not necessarily indicate that humans are totally responsible for all the changes. Periods of large-scale environmental change are often a cause for widespread human migrations and some important island extinctions are associated with environmental changes after long human occupation.

On Madagascar, there is evidence of dessication and faunal changes occurring starting at around 2300 to 2000 years ago as geomagnetism neared its peak (Dewar 1984). Humans probably colonized Madagascar around 500 AD and coexisted with the endemic fauna for around 600 years before extinction occurred around the time of the Medieval maximum at 1000 AD. The islands of New Zealand in the South Pacific were colonized by Polynesians around 1000 AD. The period of extinction for the moas there was during the Little Ice Age from 1500 to 1800 AD (Cassels 1984). There is evidence of environmental changes associated with changes in forest composition occurring at this time (Cassels 1984).

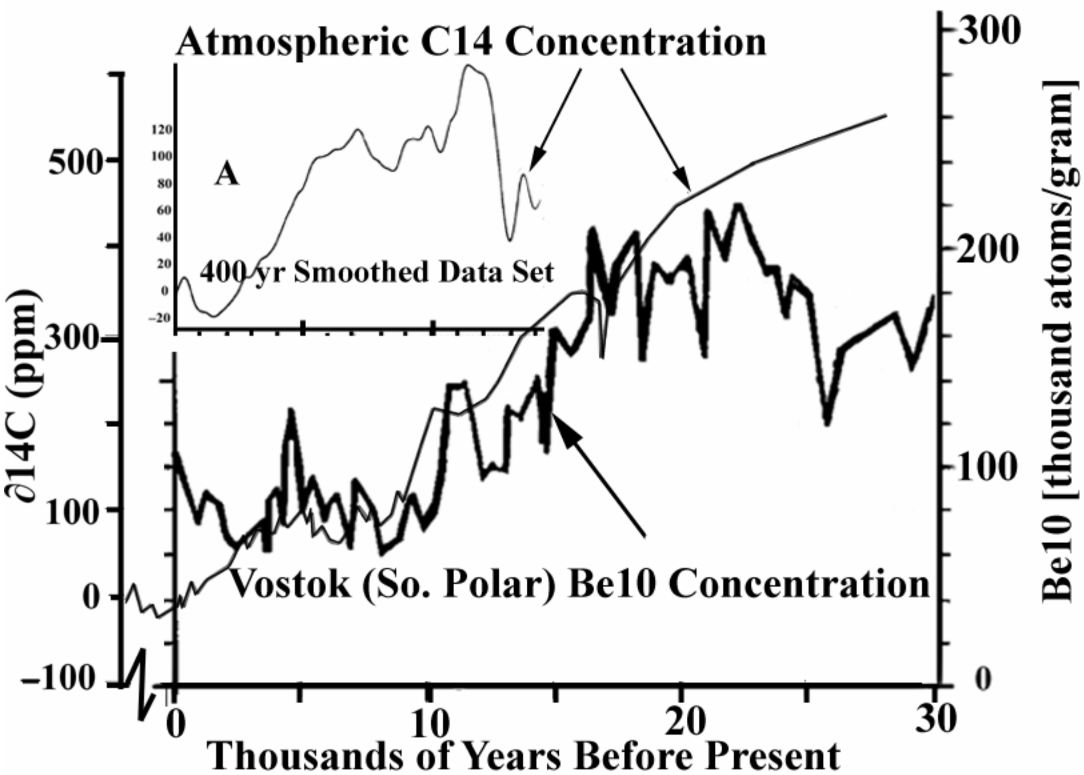


FIGURE 14. The main figure shows levels of Be^{10} and C^{14} over the last 30,000 years (adapted from Bradley 1999). Note the Be^{10} records which appear to indicate the Younger Dryas period 12,600 to 11,600 years ago, high points in geomagnetism around 9000 and 2000 years ago, an intervening mid-Holocene cold period and the start of the Little Ice Age. Inset curve A is the smoothed long term trend in C^{14} approximating a 400 year moving average as derived from varve chronologies and a floating tree ring chronology (adapted from Stuiver et al. 1991). Note the higher C^{14} during the Younger Dryas period. Note the difference between the C^{14} and Be^{10} curves. This is primarily because variations in levels of atmospheric carbon dioxide affect C^{14} values while atmospheric beryllium levels remain constant.

Probably the most famous of these later extinctions is of the mammoths on Wrangel Island in the Arctic Ocean. This island was a Holocene refugium for mammoths where they survived for around 6000 years longer than the last records of around 10,000 years ago for the nearby Siberian mainland. The latest calibrated C^{14} derived dates for Wrangel Island are around 4000 years ago (Vartanyan et al. 1995). Musk ox and horse became extinct in Siberia approximately 1000 years later. This is a time when the geomagnetism was rapidly rising to its late Holocene peak around 2000 years ago from mid-Holocene lows. Perhaps at this point, the threshold for maintenance of the environment of the last mammoth refugium had finally been exceeded. There are other late records for proboscidians. The latest American records for mammoths is around 4900 years ago and for mastodonts around 6000 years ago and recent evidence from bone collagen dating indicates that dwarf mammoths on some of the Mediterranean islands became extinct as late as 5000 years ago (Ward 1997).

14. GCRs and Climates of the Future

So, we can probably count on a considerably longer and warmer interglacial than the usual, but what about the influence of GCRs on shorter term changes in climate ignoring effects of future volcanic eruptions, ENSO-Warm Events and anthropogenic effects?

We are currently around 650 years into the colder phase of a ~2400 year cycle, assuming the colder phase began around 1350 AD. That gives us around 550 more years in the colder phase before we switch to the warmer phase. The Little Ice Age from around 1510 to 1850 was in this cold phase and was probably the coldest period since the end of the last glacial period. This is probably because of the current March and September B angle maximum effects. Although we appear to be on the way to a temperature maximum now, there will likely be more colder than average minima in the next ~550 years we have left in this colder phase.

The next ~80 year cycle maximum is likely to be around the year 2013 and this is one of the reasons it has been getting warmer over the last several decades since the last minimum around 1975. A shift to predominance of the cool phase of the Pacific Decadal Oscillation is likely to occur around this time. This warming trend on the ~80 year level is superimposed on the warming trend on the ~2400 year level, since we are still in the rise in temperatures coming out of the Little Ice Age. This has created a rather steep rise in temperatures that has helped fuel global warming hysteria.

GCRs will continue to decrease for the next year or so as we reach solar maximum, and with it, average global cloudiness, coolness and precipitation in some areas. The next solar cycle to start shortly after solar maximum will be a parallel one. This means that there will be less GCRs and they will rise from relatively low levels to a sharp peak at solar minimum instead of remaining high for most of the cycle as they do in antiparallel cycles. In places like Los Angeles where almost all precipitation is from the more equatorward extent of winter cyclones in the circumpolar vortex, precipitation averages will generally stay high through solar maximum and then gradually decline over the next ~11 years as the westerlies retreat poleward. This will culminate in a series of dry years there and in similar areas around the next solar maximum centering around 2013. As mentioned previously, solar maxima associated with parallel to antiparallel solar magnetic polarity transitions are associated with dryness in places like Los Angeles.

There will likely be a generally warmer tropical Pacific and less intense ENSO fluctuations in the next solar cycle. Since parallel cycles have less consistent ENSO-Cold Event conditions, Dust Bowl type droughts on the North American western Great Plains and Southwest as occurred on and off for several years following the last solar minimum around 1997 should not occur in the years following the next solar minimum around 2007. Dust Bowl type droughts could be expected around and after the minimum of the following antiparallel solar cycle around 2020 or a little over 22 years from 1997.

15. Conclusions

I have attempted to show that there is good evidence that GCRs are a primary forcing agent on weather and climate on virtually all time scales. The addition of the effects of GCRs into investigations of weather and climate has the potential to explain much of what cannot be explained at present and to better relate the major aspects of weather and climate, past, present and future, together in one simple unifying context.

The effects of GCRs offer better correlations to times and amplitudes of climatic events than insolation or other factors as primary forcing agents. Understanding the timing and effects of GCRs can help in the prediction of the timing and amplitudes of weather and climate changes including those related to ENSO. Here we also finally have a forcing agent operating on solar cycle timescales that can explain solar related effects on climate and that may be able to amplify small, low energy changes in solar activity into large-scale atmospheric changes.

It has also been shown here that, in addition to the effects of solar energy, geomagnetic energy may be important in modulating long-term climate changes. This provides a context for better understanding one of the most perplexing mysteries in the atmospheric sciences; the reason behind the timing and amplitudes of glacial and interglacial cycles. It also indirectly helps in the understanding one of the long-standing mysteries of the earth sciences, how the earth's magnetic field is generated.

There are also indirect applications to some of the mysteries of the life sciences, such as the environmental determinants of paradoxical glacial environments, the reasons behind the environmental changes of the Pleistocene and Holocene and why the Quaternary extinctions occurred. It also provides a better context in which to understand some of the mysteries of anthropology and human history.

This hypothesis could provide a simple, unifying context that could improve the understanding and forecasting of weather and climatic change on all time scales. In this way it could help prevent the great loss, displacement and degradation of lives projected to occur in the future due to unforseen weather events and climate changes. There are few causes more important than this, and this is why we cannot afford not to test this hypothesis and hopefully, incorporate its content into meteorological and climatological theory.

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