Climate Change And The Earth's Magnetic Poles, A Possible Connection.

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AUTHOR: Adrian K. Kerton MSc.

akmagnetic@akk.me.uk

AFFILIATIONS: None – Private researcher

ABSTRACT

Many natural mechanisms have been proposed for climate change during the past millennia, however, none of these appears to have accounted for the change in global temperature seen over the second half of the last century. As such the rise in temperature has been attributed to man made mechanisms. Analysis of the movement of the Earth's magnetic poles over the last 105 years demonstrates strong correlations between the position of the north magnetic, and geomagnetic poles, and both Northern Hemisphere and global temperatures. Although these correlations are surprising, a statistical analysis shows there is a less than one percent chance they are random, but it is not clear how movements of the poles affect climate. Links between changes in the Earth's magnetic field and climate change have been proposed previously although the exact mechanism is disputed. These include: The Earth's magnetic field affects the energy transfer rates from the solar wind to the Earth's atmosphere, which in turn affects the North Atlantic Oscillation. Movement of the poles changes the geographic distribution of galactic and solar cosmic rays, moving them to particularly climate sensitive areas. Changes in distribution of ultraviolet rays resulting from the movement of the magnetic field, may result in increases in the death rates of carbon sinking oceanic plant life such as phytoplankton.

KEYWORDS: magnetic poles, drift, climate, cosmic rays.

INTRODUCTION

The cause of the recent rise in global temperature has stimulated considerable debate within the scientific community, and there is a body of evidence that indicates past climate changes have been connected with a number of natural phenomena, including variations in the Earth's orbit [1], cosmic rays [2], and solar activity [3]. However, these mechanisms have difficulty in explaining the accelerated rise in temperature seen from 1876 to 1998 and we do not know we do not know if they are operating

The apparent absence of natural climate change mechanisms has led to the IPCC conclusions that "the understanding of anthropogenic warming and cooling influences on climate has led to a very high confidence that the global average net effect of human activities since 1750 has been one of warming" [4]. There is, however, a natural phenomenon that has also seen an accelerated rate of change since the 1970s, that of the drift of the magnetic poles, particularly the north magnetic pole. This paper examines the positions of the north magnetic and geomagnetic poles and global and northern hemisphere temperature variations, and finds strong correlations suggesting a connection..

METHODS

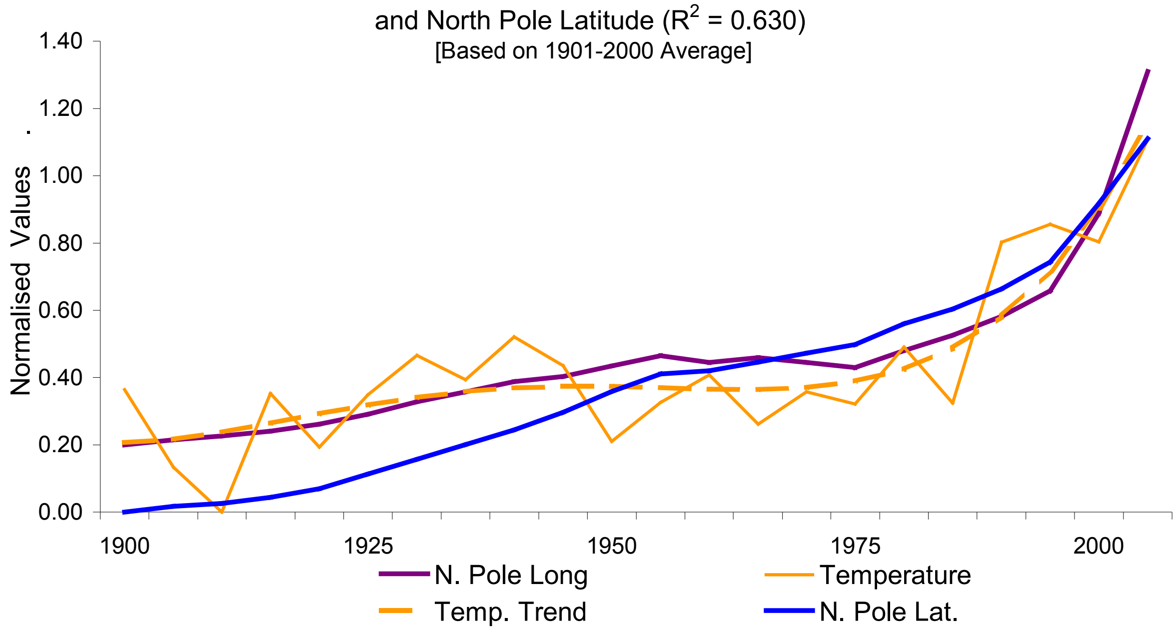
Variation in temperature and the position of the magnetic poles were studied from 1900 to 2005, and there are freely available published data sets for this period. Temperature data were obtained from two NASA sources [5,6]. The temperature variations are quoted as the anomaly from a mean or average for a period in time. The data sets demonstrates divergence in the last two decades The first data set consists of anomalies provided as departures from the 20th century average (1901-2000) [5]. As a comparison, a second data set was used with anomalies computed to the 1951 to 1980 base period [6]. To obtain yearly figures the monthly temperature anomalies for each year are averaged. The temperature anomalies are normalised by effectively adding the maximum negative anomaly to the data set to produce positive values.

Normalisation of latitude and longitude is obtained by reducing the range of variation to match the range of variation of temperature. For example if latitude varies from 70 to 84 degrees and the corresponding temperature variation is 0,8 degrees, the latitude variation is converted to a range starting at zero by subtracting the lowest value, 70, and is then reduced by a factor of 0.8/14, so that the latitude variation now becomes 0.8. To test the relationships, correlation coefficients and r-squared values were calculated for temperatures shifted in time and compared to the positions of the poles to determine the closest relationships. For some graphs a constant is added to the normalisation to move a plot on the y-axis to demonstrate the similarity in the data.

The magnetic poles are defined as the points where dip is vertical. The geomagnetic poles (dipole poles) are the pole positions based on the first three terms of the International Geomagnetic Reference Field (IGRF). This is a model of the Earth's main magnetic field which computes symmetric positions where the dipole axis would intersect the Earth's surface [7]. Thus, variations in the north geomagnetic pole are mirrored in the Southern Hemisphere. For the period 1900 to 2000 the pole and geomagnetic pole positions are published at 5 years intervals, therefore my computations of temperature anomalies are based on 5 year intervals. Correlations between temperature and latitude and longitude variations, were computed using the Excel functions CORREL and RSQ. The Excel spread sheet has been criticised for certain aspects of its statistical functions, therefore for the r-squared values, a small sample of the Excel RSQ values obtained were compared with other statistical packages and showed no substantial differences. A non-

Fig 1. Variations: Northern Hemisphere Temperature Anomaly Vs. North Magentic Pole Longitude (R^2 = 0.704), and North Pole Latitude (R^2 = 0.630)

[Based on 1901-2000 Average]



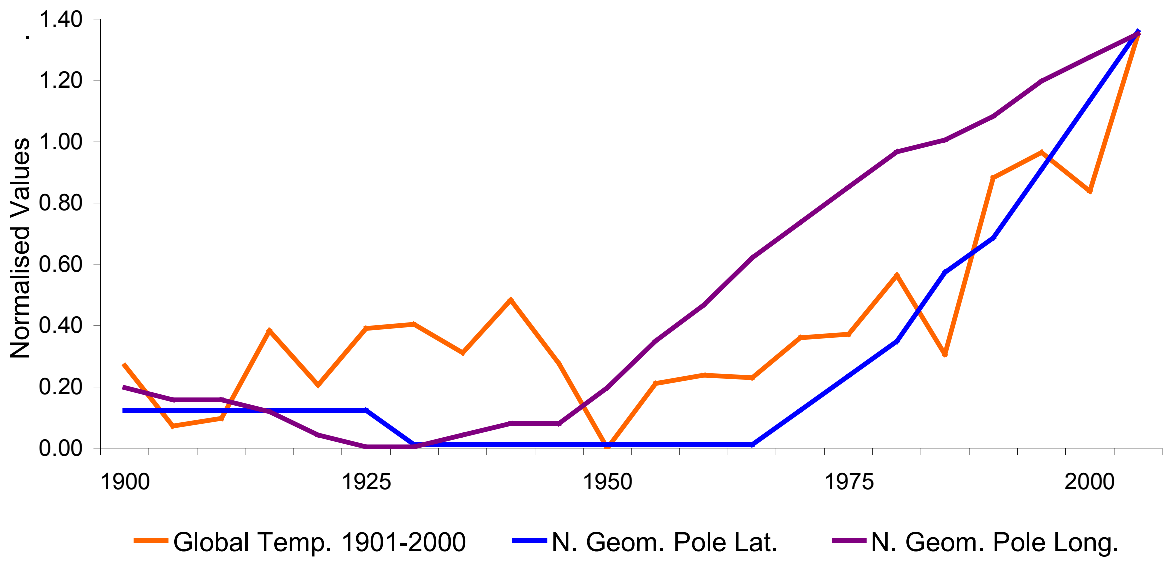
parametric statistical test, the Spearman Correlation Coefficient, was calculated for the most significant correlations to assess the probability that the correlations were due to chance.

The differences obtained using the two data sets for temperature variations were negligible, except where noted below. Therefore for brevity, only the results using the data based on the 1901 to 2000 average are shown.

Figure 1 shows the variations of the north magnetic pole, latitude & longitude, compared with the variations in temperature in the northern hemisphere. All three plots have a similar shape and it appears that the temperature variations are very similar to the variations in longitude. The graph uses a constant added to the longitude plot to move it on the y-axis, so that the relationship between the longitude and the temperature variation is more clearly seen. The longitude variation is very similar to the Excel 4th order polynomial trend line of temperature with an r-squared value of 0.704, and an Excel correlation coefficient of 0.839. Together these demonstrate a good statistical correlation.

Figure 2 shows the variations of the north geomagnetic pole, latitude & longitude,

Fig 2. Variations: North Geomagnetic Pole Latitude & Longitude
Vs. Global Temperature Anomaly
[Based on 1901-2000 Average]



compared with the variations in global temperature. Again all three plots have a similar shape and it appears that the temperature variations are very similar to the variations in longitude with a lag of approximately 25 years. Using the temperature data with the 1951-1980 base the results are similar.

Fig 3. Variations: North Geomagnetic Pole Longitude
Vs. Global Temperature Anomaly Shifted 25 years. (R^2 =0.843)
[Based on 1901-2000 Average]

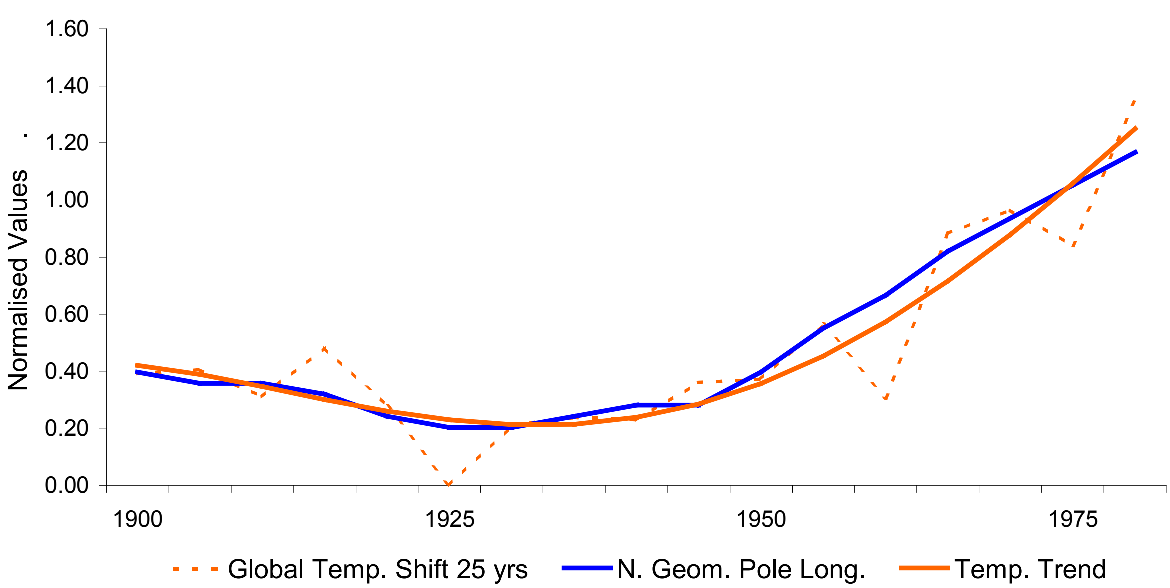


Figure 3 shows the temperature plot shifted back in time 25 years, and a constant is added to the longitude to move it on the y-axis for visual comparison with the Excel 4^{th} order polynomial trend line of the temperature variation. An r-squared value of 0.843, and Excel correlation coefficient of 0.979 together demonstrate a good statistical correlation.

To test for random correlations a Spearman Correlation Coefficient [SCC] was calculated for the two strongest correlations. For variations of the north magnetic pole longitude vs. the Northern Hemisphere temperature anomaly based on 1901-2000 average, the SCC for 22 observations was 0.564. For global temperature vs. the north geomagnetic pole longitude shifted by 25 years, the SCC for 17 observations was 0.865. The Spearman tables for these values gives a less than a 1% probability of the correlations being due to chance alone.

DISCUSSION.

From the statistical correlations, it seems that using either temperature data set, there is little significant difference between the correlations, the main difference being that the best correlation is between temperature-year shifted backwards by 25 years relative to the geomagnetic pole positions. This temperature time lag may be indicative of the time it takes for the northern and southern hemisphere ocean currents to distribute their respective temperature changes, and reflect those temperatures in the global temperature measurements. As the Northern Hemisphere oceans are of less mass than the Southern Hemisphere ones, it is expected that the former have a faster response to heat input than the latter.

As with all correlations there is always the chance that the match is purely random, but the Spearman correlation coefficients give less than 1% probability of these correlations being due to chance alone. The correlations of temperature and pole positions are surprising as the link between them is not obvious, but connections between Earth's magnetic field and climate change were proposed in paleomagnetic studies, [8,9,10,11]. Although they assumed the relationship was between climate and geomagnetic intensity, yet as the poles move, the intensity of the magnetic field at a particular point on the Earth's surface changes, and it may be therefore of interest to attempt correlations between the positions of the poles with the deduced observed changes in temperatures revealed in local paleomagnetic intensities. The problem would be in ascertaining the positions of the poles back in time with significant accuracy. This is illustrated in the significant differences in published estimates of the poles prior to 1830, [12, 13, 14]. For instance, the comparisons of latitude in these estimates show differences of up to 10 degrees, whereas the total span of latitude used in this paper is only 12.7 degrees. In addition, temperatures before this period are based on proxies which also vary considerably [15], thus a longer time period of study is not possible to the accuracies required.

In addition to these paleomagnetic studies, correlations between weather and earth's magnetic field, often without a known mechanism, have also been observed since the magnetic field exerts, through some unknown process, a controlling influence on the average pressure in the troposphere at high latitudes [16]. Similarly, a connection was proposed between geomagnetic indices, the North Atlantic Oscillation (NAO), and stratospheric geopotential heights affecting global temperatures since approximately 1970 [17]. Subsequently, a connection between geomagnetic activity and the North Atlantic Oscillation was also suggested [18].

Climate changes have been correlated with intensity of cosmic ray flux [2]. Thought to affect cloud formation particularly in clean maritime environments [20], the resulting changes in albedo of clouds should alter the energy balance of the planet and thus its climate, either cooling or warming [21].

The effect of cosmic rays on cloud formation is altitude dependent [22], and the cosmic ray induced ionisation is a significant modifier of the properties of the atmosphere, with geomagnetic changes, in turn modifying regional effects on temperature. This impact may be comparable to, or even dominate the solar signal at mid-latitudes [23], reinforcing the proposition that some areas are particularly climate sensitive to changes in the magnetic field.

It is interesting to note that since 1945 the north magnetic pole has moved from the land mass towards the Arctic Ocean and since 1970 the south magnetic pole has been located in the Antarctic Ocean. This may or may not be significant, as it is thought that it is the geomagnetic, rather than the magnetic poles, that influence cosmic rays. Also this paper shows a better correlation of temperature with the smaller change in longitude, rather than with the large changes in latitude. If the cosmic rays are illuminating areas of the atmosphere that are more sensitive to cloud formation, the impact on climate will be more pronounced.

Cosmic rays are known to affect solar irradiance and there is a possibility that the change in their distribution may change the pattern of solar irradiance, thus despite reports that the sun's output is lately no longer increasing [3], the effect of the irradiance may now be greater than in earlier times.

Ozone loss is strongly correlated with cosmic-ray ionisation-rate variations that depends on altitude, latitude and time [24]. Should the increase in ultraviolet radiation, resulting from the ozone loss, effectively move to an area where it can have a greater impact on marine life, it could kill off many aquatic life forms, such as phytoplankton, that play a significant role in the ability of the oceans to sink carbon dioxide, because they account for almost 50% of the carbon fixed by plant life on Earth [25].

The NGDC data for cosmic ray intensity since 1950 [26], shows that there was no maxima or minima correlation with the global temperature variations over the same time period. Any connection between pole positions and global temperatures that would arise from cosmic ray variability over the last 55 years, would presumably originate from the movement of the poles, affecting the geographical distribution or dispersion of the cosmic rays.

As the last alternative, the possibility of some external mechanism that affects both the position of the poles and global temperatures cannot be discounted, although the movement of the poles arising from a convective dynamo with the model yields good correlations with the paleomagnetic observations [27]. This suggests that an external mechanism is not the connecting factor and that the temperature variations over the last 105 years have likely been driven by the changes in the position of the Earth's magnetic field.

SUMMARY

The drift of the Earth's magnetic poles over the last 105 years show strong correlations with the variations in temperature, regardless whether for the northern hemisphere alone or globally, suggesting a potential connection between these phenomena. Statistically there is a less than 1% probability of the correlations being due to chance alone. A connection between climate variability and variations in the Earth's magnetic field has been proposed previously although the exact mechanism is still disputed. Since the movement of poles affects the shape of the geomagnetic field and hence regional patterns of shielding of the Earth from both solar and galactic cosmic rays, the most likely scenario appears to be that the moving poles affect the distribution and dispersion of the cosmic rays to more climate sensitive areas of the atmosphere. If so the dominating influence on climate over the last 105 years may have been natural.

ACKNOWLDGEMENTS

I am indebted to all those scientists who have been kind enough to answer my questions on various aspects of climate change mechanisms and to those who have offered help and support in constructing this paper, unfortunately too many to list here.

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Abstracts are pre submission only and will not be included in submission

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Abstract Milankovich cycles are cycles in the Earth's orbit that influence the amount of solar radiation striking different parts of the Earth at different times of year. They are named after a Serbian mathematician, Milutin Milankovitch, who explained how these orbital cycles cause the advance and retreat of the polar ice caps. Although they are named after Milankovitch, he was not the first to link orbital cycles to climate. Adhemar (1842) and Croll (1875) were two of the earliest.

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Interstellar-Terrestrial Relations: Variable Cosmic Environments, The Dynamic Heliosphere, And Their Imprints On Terrestrial Archives And Climate.
Space Science Reviews (2006) DOI: 10.1007/s11214-006-9126-6 _C

Abstract. In recent years the variability of the cosmic ray flux has become one of the main issues interpreting cosmogenic elements and especially their connection with climate. In this review, an interdisciplinary team of scientists brings together our knowledge of the evolution and modulation of the cosmic ray flux from its origin in the Milky Way, during its propagation through the Heliosphere, up to its interaction with the Earth's magnetosphere, resulting, finally, in the production of cosmogenic isotopes in the Earth' atmosphere. The interpretation of the cosmogenic isotopes and the cosmic ray – cloud connection are also intensively discussed. Finally, we discuss some open questions.

[3] Mike Lockwood, Claus Fröhlich
Recent oppositely directed trends in solar climate forcings and the global mean surface air temperature, Proceedings of the Royal Society A Proc. R. Soc. A doi:10.1098/rspa.2007.1880,

There is considerable evidence for solar influence on the Earth's pre-industrial climate and the Sun may well have been a factor in post-industrial climate change in the first half of the last century. Here we show that over the past 20 years, all the trends in the Sun that could have had an influence on the Earth's climate have been in the opposite direction to that required to explain the observed rise in global mean temperatures

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Global Surface Temperature Anomalies National Climatic Data Center 6 February 2006
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The published data from 1900 to 2000 is in 5 year intervals.
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Does the Earth's Magnetic Field Influence Climate?
American Geophysical Union, Fall Meeting 2006, abstract #GP51B-02

A number of recent studies raise the possibility of an interaction between climate and the geomagnetic field over a range of time scales from decades to hundreds of thousands of years. Le Mouël et al (2005) introduced new indices which allow to study high frequency variations in the geomagnetic field, principally linked to external currents in the ionosphere and magnetosphere and forced by the solar wind. A largely common “overall magnetic trend” emerges from this study, which mimics the evolution of solar irradiance, the magnetic aa index and the Wolf number from 1900 to the 1980s. Thus, the ionospheric and magnetospheric current systems pulse in rough unison with the Sun. The “overall magnetic trend” also resembles the recent evolution of global temperature. But global temperature departs from all other indicators in the late ‘80s, a signal which may indicate when anthropogenic warming started emerging from noise (as shown earlier by Solanki using irradiance data). The connection between solar activity and temperature is strong but not perfect. Solar irradiance is a complex time function involving respective time changes of intergalactic cosmic rays, changes in solar activity and the modulation due to changes in the geomagnetic field. Based on newly acquired archeomagnetic data all the way from western Europe to the Middle-East, Gallet et al (2003) have noted the coincidence of sharp curvature changes in direction and sharp maxima in the intensity of the ancient field. Gallet et al (2005) have compared the occurrences of these “archeomagnetic jerks” with paleo-climate indicators. There is a remarkable coincidence between jerks (particularly their rising period) and indicators of climate cooling, such as advances of glaciers in western Europe. The robustness of these and other geomagnetic evidences for causal connexions with climate and possible mechanisms will be discussed.

[9] Courtillot, V., Gallet, Y., Le Mouel, J. L., Fluteau, F. & Genevey, A. 2007
Are there connections between the Earth’s magnetic field and climate?
Earth Planet. Sci. Lett. 253, 328–339. (doi:10. 1016/j.epsl.2006.10.032)

Understanding climate change is an active topic of research. Much of the observed increase in global surface temperature over the past 150 years occurred prior to the 1940s and after the 1980s. The main causes invoked are solar variability, changes in atmospheric greenhouse gas content or sulfur due to natural or anthropogenic action, or internal variability of the coupled ocean–atmosphere system. Magnetism has seldom been invoked, and evidence for connections between climate and magnetic field variations have received little attention. We review evidence for correlations which could suggest such (causal or non-causal) connections at various time scales (recent secular variation not, vert, similar 10–100 yr, historical and archeomagnetic change not, vert, similar 100–5000 yr, and excursions and reversals not, vert, similar 103–106 yr), and attempt to suggest mechanisms. Evidence for correlations, which invoke Milankovic forcing in the core, either directly or through changes in ice distribution and moments of inertia of the Earth, is still tenuous. Correlation between decadal changes in amplitude of geomagnetic variations of external origin, solar irradiance and global temperature is stronger. It suggests that solar irradiance could have been a major forcing function of climate until the mid-1980s, when “anomalous” warming becomes apparent. The most intriguing feature may be the recently proposed archeomagnetic jerks, i.e. fairly abrupt (not, vert, similar 100 yr long) geomagnetic field variations found at irregular intervals over the past few millennia, using the archeological record from Europe to the Middle East. These seem to correlate with significant climatic events in the eastern North Atlantic region. A proposed mechanism involves variations in the geometry of the geomagnetic field (f.i. tilt of the dipole to lower latitudes), resulting in enhanced cosmic-ray induced nucleation of clouds. No forcing factor, be it changes in CO2 concentration in the atmosphere or changes in cosmic ray flux modulated by solar activity and geomagnetism, or possibly other factors, can at present be neglected or shown to be the overwhelming single driver of climate change in past centuries. Intensive data acquisition is required to further probe indications that the Earth's and Sun's magnetic fields may have significant bearing on climate change at certain time scales.

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Possible impact of the Earth's magnetic field on the history of ancient civilizations,
Earth and Planetary Science Letters Volume 246, Issues 1-2, 15 June 2006, Pages 17-26
doi:10.1016/j.epsl.2006.04.001

We report new archeointensity results from Iranian and Syrian archeological excavations dated from the second millennium BC. These high-temperature magnetization data were obtained using a laboratory-built triaxial vibrating sample magnetometer. Together with our previously published archeointensity results from Mesopotamia, we constructed a rather detailed geomagnetic field intensity variation curve for this region from 3000 BC to 0 BC. Four potential geomagnetic events (“archeomagnetic jerks”), marked by strong intensity increases, are observed and appear to be synchronous with cooling episodes in the North Atlantic. This temporal coincidence strengthens the recent suggestion that the geomagnetic field influences climate change over multi-decadal time scales, possibly through the modulation of cosmic ray flux interacting with the atmosphere. Moreover, the cooling periods in the North Atlantic coincide with episodes of enhanced aridity in the Middle East, when abrupt societal changes occurred in the eastern Mediterranean and Mesopotamia. Although the coincidences discussed in this paper must be considered with caution, they lead to the possibility that the geomagnetic field impacted the history of ancient civilizations through climatically driven environmental changes, triggering economic, social and political instability.

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Academic Press Inc. (London) Ltd., 1983, 401 pp., ISBN 0-12-49140-0 and ISBN 0-12-491242-7 (Paperback)

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New Scientist Environment Special Report Climate Change 16 May 2007

[15] Vladimir Bakhmutov
The connection between geomagnetic secular variation and long-range development of climate changes for the last 13,000 years
Quaternary International 149 (2006) 4–11. doi:10.1016/j.quaint.2005.11.013

Abstract
One of the possible mechanisms of the connection between long-term climate changes and geomagnetic field variations is discussed.
Climate fluctuations with periods of n_(104–105) years can be explained by Milankovitch's astronomic theory. The fluctuations with periods of n_(102–103) years are discussed in the framework of a hypothesis on the connection with secular variations of the geomagnetic field. On the basis of palaeomagnetic data from N–W Russian lake sediments (basically from Karelia and the Kola Peninsula) for the time interval 13,000–5000 years ago, the drift of virtual geomagnetic poles is calculated. Analysis of this data with regard to palaeotemperature and palaeoclimate phases in N–NE Europe is carried out. The alternation of stadial (cold) and interstadial
(warm) stages as a function of approaching (receding from) the virtual geomagnetic pole to N Europe is established. For the last 5 kyr the correlation is confirmed for archaeomagnetic data from the Ukraine.

[16] J. W. King
Weather and the Earth's magnetic field
Nature 247, 131 - 134 (18 January 1974); doi:10.1038/247131a0

A comparison of meteorological pressures and the strength of the geomagnetic field suggests a possible controlling influence of the field on the longitudinal variation of the average pressure in the troposphere at high latitudes. If so, changes which occur in the pattern of 'permanent' depressions in the troposphere as the magnetic field varies (for example, as the non-dipole component of the field drifts westwards) may be accompanied by climatic changes.

[17] Peter Thejll, Bo Christiansen, and Hans Gleisner
On correlations between the North Atlantic Oscillation, geopotential heights, and geomagnetic activity
Geophysical Research Letters, Vol. 30, No. 6, 1347, Doi:10.1029/2002gl016598, 2003

Abstract. We investigate correlations between geomagnetic activity indices, the North Atlantic Oscillation (NAO), and stratospheric geopotential heights. It is shown that the correlation between the geomagnetic index Ap and the NAO index is high and significant since about 1970, that it is significant the surface while significant correlations still are found in the stratosphere. This might indicate that a solar forcing, primarily acting in the stratosphere, is propagating its influence downward in the later period but not in the earlier during winter only, that it was not significant before about 1970, and that the correlations are dominated by quasi-decadal scales of variability. Analysis of the spatial pattern of correlations, restricted to the Northern Hemisphere and wintertime, shows that significant correlations between Ap and sea-level pressures and between Ap and stratospheric geopotential heights are found for the period 1973–2000. However, for the period 1949–1972 no significant correlations are found at

[18] J. Bochnıcek, P. Hejda
Journal of Atmospheric and Solar-Terrestrial Physics 67 (2005) 17–32
The winter NAO pattern changes in association with solar and geomagnetic activity

Abstract
The North Atlantic Oscillation (NAO) is considered to be a very robust phenomenon. The analysis of tropospheric pressure deviations, temperature deviations and prevailing wind deviations from their long-term averages, carried out on the data set of winter (January–March) periods of 1963–2001, however, indicates a close association between high geomagnetic activity and the positive NAO phase. The composite maps of the North Hemisphere winter troposphere pressure and temperature deviations, plotted at geopotential heights of 1000 and 100 mb, together with the composite maps of vertical sections along the profiles Atlantic–polar region–eastern Asia and Europe–polar region–Pacific indicate a distinct relation between the spatial distribution of the pressure and temperature deviations and the geomagnetic as well as the solar activity level. An attempt was made to explain these phenomena by the mechanisms based both on the propagation of planetary and gravity waves and on the changes in the ‘‘global electric circuit’’.

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Low cloud properties influenced by cosmic rays.
Phys. Rev. Lett. 85, 5004 - 5007 (2000). (doi:10.1103/PhysRevLett.85.5004)

Abstract. A correlation between a global average of low cloud cover and the flux of cosmic rays incident in the atmosphere has been observed during the last solar cycle. The ionising potential of Earth bound cosmic rays are modulated by the state of the heliosphere, while clouds play an important role in the Earth's radiation budget through trapping outgoing- and reflecting incoming radiation. If a physical link between these two features can be established, it would provide a mechanism linking solar activity and Earth's climate. Recent satellite observations have further revealed a correlation between cosmic ray flux and low cloud top temperature. The temperature of a cloud depends on the radiation properties determined by its' droplet distribution. Low clouds are warm (□□ 273K) and therefore consist of liquid water droplets. At typical atmospheric supersaturations (_ 1%) a liquid cloud drop will only form in the presence of an aerosol, which acts as a condensation site. The droplet distribution of a cloud will then depend on the number of aerosols activated as cloud condensation nuclei (CCN) and the level of super saturation. Based on observational evidence it is argued that a mechanism to explain the cosmic ray - cloud link might be found through the role of atmospheric ionisation in aerosol production and/or growth. Observations of local aerosol increases in low cloud due to ship exhaust indicate that a small perturbation in atmospheric aerosol can have a major impact on low cloud radiative properties. Thus, a moderate influence on atmospheric aerosol distributions from cosmic ray ionisation would have a strong influence on the Earth's radiation budget. Historical evidence over the past 1000 years indicates that changes in climate have occurred in accord with variability in cosmic ray intensities. Such changes are in agreement with the sign of cloud radiative forcing associated with cosmic ray variability as estimated from satellite observations.

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Cosmic rays, clouds and climate,
Science, 298, pp.1732-1737. Doi:10.1126/science.1076964

It has been proposed that Earth's climate could be affected by changes in cloudiness caused by variations in the intensity of galactic cosmic rays in the atmosphere. This proposal stems from an observed correlation between cosmic ray intensity and Earth's average cloud cover over the course of one solar cycle. Some scientists question the reliability of the observations, whereas others, who accept them as reliable, suggest that the correlation may be caused by other physical phenomena with decadal periods or by a response to volcanic activity or El Nin˜o. Nevertheless, the observation has raised the intriguing possibility that a cosmic ray–cloud interaction may help explain how a relatively small change in solar output can produce much larger changes in Earth's climate. Physical mechanisms have been proposed to explain how cosmic rays could affect clouds, but they need to be investigated further if the observation is to become more than just another correlation among geophysical variables.

[21]   Luis Eduardo Antunes Vieira

Geomagnetic modulation of clouds effects in the Southern Hemisphere Magnetic Anomaly through lower atmosphere cosmic ray effects
Geophysical Research Letters, Vol. 33, L14802, Doi:10.1029/2006gl026389, 2006

The study of the physical processes that drive the variability of the Earth's climate system is one of the most fascinating and challenging topics of research today. Perhaps the largest uncertainties in our ability to predict climate change are the cloud formation process and the interaction of clouds with radiation. Here we show that in the southern Pacific Ocean cloud effects on the net radiative flux in the atmosphere are related to the intensity of the Earth's magnetic field through lower atmosphere cosmic ray effects. In the inner region of the Southern Hemisphere Magnetic Anomaly (SHMA) it is observed a cooling effect of approximately 18 W/m2 while in the outer region it is observed a heating effect of approximately 20 W/m2. The variability in the inner region of the SHMA of the net radiative flux is correlated to galactic cosmic rays (GCRs) flux observed in Huancayo, Peru (r = 0.73). It is also observed in the correlation map that the correlation increases in the inner region of the SHMA. The geomagnetic modulation of cloud effects in the net radiative flux in the atmosphere in the SHMA is, therefore, unambiguously due to GCRs and/or highly energetic solar proton particles effects.

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USA Journal Of Geophysical Research, Vol. 107, No. A7, 10.1029/2001ja000248, 2002.

[1] The indirect radiative forcing of atmospheric aerosols is sensitive to particle size and concentration, which are influenced significantly by nucleation processes. Via its role in aerosol formation, cosmic ray may affect the cloud condensation nuclei abundance and hence the global cloud properties and climate. Systematic variations in ionization rates due to the modulation of cosmic ray radiation by the solar cycle are sufficient to cause notable variations in aerosol production, and we find that the signs of such variations are altitude dependent. Our study indicates that an increase in cosmic ray fluxes generally leads to an increase in particle production in the lower troposphere but a decrease in particle production in the upper troposphere. The main reason of such an altitude-dependent influence is that the dependence of particle production rate on ionization rate is a complex function of ionization rate itself, as well as precursor gas concentration and ambient conditions. The implications of altitude variations of cosmic ray-induced aerosol production on global cloudiness and climate are discussed. In addition to the reported
positive correlation between cosmic ray variations and low cloudiness, our analysis
reveals that high cloudiness may be anti-correlated with cosmic ray variations if volcano
and El Nin˜o impacts are excluded. The observed different correlations between cosmic ray variations and low, middle and high cloud anomalies appear to be consistent with the
predicted different sensitivities of particle production to cosmic ray changes at different
altitudes. A systematic change in global cloudiness may change the atmosphere heating
profile, and if confirmed, may provide the external forcing needed to reconcile the

different surface and troposphere temperature trends. Much more work is needed to understand how and how much the cosmic ray variations will affect the global cloud properties and climate.

[23] Usoskin, I. G., M. Korte, and G. A. Kovaltsov
Role Of Centennial Geomagnetic Changes In Local Atmospheric Ionization
Geophysical Research Letters, doi:10.1029/2007GL033040

Many studies of solar-terrestrial relation are based on globally (or hemispherically) averaged quantities, including the average cosmic ray flux. However, regional effects of cosmic ray induced ionization due to geomagnetic changes may be comparable to or even dominate over the solar signal at mid-latitudes on centennial-to-millennial time scales. We show that local changes of the tropospheric ionization due to fast migration of the geomagnetic axis are crucial on centennial time scale, and the use of global averages may smear an important effect. We conclude that changes of the regional tropospheric ionization at mid-latitudes are defined by both geomagnetic changes and solar activity, and none of the two processes can be neglected. This substantiates a necessity for a careful analysis of the regional, not global, indices at mid latitudes and offers a new possibility to disentangle direct (solar radiation) and indirect (via cosmic rays) effects in the solar-terrestrial relations.

[24] Q. -B. Lu and L. Sanche
Effects of Cosmic Rays on Atmospheric Chlorofluorocarbon Dissociation and Ozone Depletion

Data from satellite, balloon, and ground-station measurements show that ozone loss is strongly correlated with cosmic-ray ionization-rate variations with altitude, latitude, and time. Moreover, our laboratory data indicate that the dissociation induced by cosmic rays for CF2Cl2 and CFCl3 on ice surfaces in the polar stratosphere at an altitude of _15 km is quite efficient, with estimated rates of 4.3 3 1025 and 3.6 3 1024 s21, respectively. These findings suggest that dissociation of chlorofluorocarbons by capture of electrons produced by cosmic rays and localized in polar stratospheric cloud ice may play a significant role in causing the ozone hole.

[25] Antonio Mannino
Exploring the Organic Carbon Cycle of the Coastal Ocean from Space. NASA Goddard Space Flight Center Hydrospheric & Biospheric Sciences Laboratory Greenbelt, MD 20771
http://phytoplankton.gsfc.nasa.gov/risingtides/pdf/RisingTides_page41-46.pdf

[26] [NGDC] National Geophysical Data Centre
http://www.ngdc.noaa.gov/stp/SOLAR/COSMIC_RAYS/cosmic.html#DATA

[27] Glatzmaier, G.A.
Geodynamo simulations - How realistic are they?
(2002) Ann. Rev. Earth Planet. Sci. 30, 237-257.

Abstract The past seven years have seen significant advances in computational simulations of convection and magnetic field generation in the Earth's core. Although dynamically self-consistent models of the geodynamo have simulated magnetic fields that appear in some ways quite similar to the geomagnetic field, none are able to run in an Earth-like parameter regime because of the considerable spatial resolution that is required. Here we discuss some of the subtle compromises that have been made in current models and propose a grand challenge for the future, requiring significant improvements in numerical methods and spatial resolution.

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