

**Comment on “Are there connections between the Earth's magnetic field and climate?”  
by V. Courtillot, Y. Gallet, J.-L. Le Mouél, F. Fluteau, A. Genevey *EPSL* 253, 328, 2007**

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Courtillot et al. (2007) use empirical correlations between geomagnetic records and climatic proxies to propose a connection between the Earth's magnetic field, solar activity and climate. In this Comment, we point out a number of approximations which undermine these correlations and connections.

Point 1: Amplitude of the radiative forcing

On page 330, column 2, of their paper, the authors specifically describe the study of Crowley (2000), who simulated climate variations over the last millennium. Courtillot et al. write that « *Solar variability results in forcing with decadal to millennial fluctuations with an amplitude  $\sim 1\text{--}2\text{ W.m}^{-2}$ . The range for  $\text{CO}_2$ , which becomes significant mainly after 1800, is  $\sim 2\text{ W.m}^{-2}$ . » This is clearly a confusion, which could mislead the reader into thinking that the  $\text{CO}_2$  and solar forcings are similar in size. Crowley did not confuse the total solar irradiance at the Earth-Sun distance with its net component absorbed on average by the Earth system ('net radiative forcing'). Both irradiance and forcing are expressed in  $\text{W.m}^{-2}$ , but the former is 6 times larger than the latter, which is averaged over the Earth's surface and takes into account the albedo. Indeed, the net radiative solar forcing used by Crowley exhibits a range of*

variability of  $\sim 0.5 \text{ W.m}^{-2}$  (see Crowley's Figure 2), which can be directly compared with the  $\text{CO}_2$  forcing, and is much smaller.

### Point 2: Correlation based on matched records

In their Figure 1, Courtillot et al. (2007) reproduce geochemical data measured in a stalagmite from the Central Alps (Mangini et al., 2005), comparing the results with a solar activity proxy ( $\Delta^{14}\text{C}$ ) as well as the record of atmospheric  $\text{CO}_2$  concentration. The purpose of this graph is to illustrate a good match between solar variability and climate changes. Without mentioning it, Courtillot et al. use curves that were finely matched for their chronology in order to maximize their correlation, i.e. Figure 7 of Mangini et al. (2005). To prove the correlation and make inferences about solar forcing, only untuned records, i.e. Figure 1 of Mangini et al. (2005), with their respective and independent time scales, should be used.

### Point 3: Proxies of solar activity

In their Figure 3, covering the 20<sup>th</sup> century, Courtillot et al. (2007) compare geomagnetic indices measured at two locations, Eskdalemuir in Scotland and Sitka in Alaska (ESK & SIT curves), with the total solar irradiance curve  $S(t)$  reconstructed by Solanki (2002) based on sunspot data, and with the global mean temperature curve  $T_{\text{globe}}$  reconstructed by Jones et al. (1999) (Incidentally, we note a problem in their Figure 3 as this smoothed  $T_{\text{globe}}$  curve is different from the global temperature curve published by Jones et al., 1999). The authors propose these geomagnetic indices as new proxies of the solar activity, similar to the *aa* index already used in several studies (Cliver et al., 1998; Lockwood et al., 1999; Lockwood, 2003). Because the units are different, the authors normalize the four curves to a common mean and standard deviation. However, Courtillot et al. (2007) truncate the irradiance curve  $S(t)$  by half its duration, starting only in the year 1952. This truncation is

unnecessary because the cited reference provides a record over the full period 1900-2000. (See Figure 11 page 5.13 of Solanki (2002)). If we use the complete  $S(t)$  curve as originally published by Solanki (2002), or, better, its recent update (Krivova et al., 2007) as shown by our Figure 1, the rise between 1910 and 1950 is much larger than the small decrease centred around 1970 followed by a second increase. Thus, truncating the record gives the false impression that there is a good correspondence between the geomagnetic curves (ESK & SIT) and the total solar irradiance curve  $S(t)$ . This impression is based in particular on the apparent match of the common trough around 1970 (Figure 1). However, it is clear that this match in amplitude is an artefact of data truncation and normalization.

By using the full century-long record (Figure 1), the general shape of the irradiance curve  $S(t)$  is broadly similar to the global mean temperature curve  $T_{\text{globe}}$ . This point was precisely that discussed by Solanki (2002), following a series of previous studies (e.g. Lean et al. (1995) to list just one). Moreover, a correlation has already been proposed between global temperature variations and geomagnetic changes due to solar activity by considering the  $aa$  index (Cliver et al., 1998; Lockwood et al., 1999; Lockwood, 2003) and cosmogenic nuclides (Lean et al., 1995; Bard et al., 1997; Bard et al., 2000 and references therein).

Taking account of the full 20<sup>th</sup> century record, the main question becomes: why do the ESK & SIT geomagnetic curves exhibit such a large discrepancy in amplitude around 1970, dropping to values equivalent to those observed for the 1920s, while the  $aa$  geomagnetic index curve appears to correlate much better with  $S(t)$  and  $T_{\text{globe}}$  (Cliver et al., 1998; Lockwood et al., 1999; Lockwood, 2003) as illustrated by Figure 1. We propose that this discrepancy may provide clues about some hotly debated questions:

\_ Since the ESK and SIT indices do not show a long term trend, contrary to  $S(t)$  and the  $aa$  index, what is the amplitude of the solar activity baseline over several centuries?

\_ Since these terrestrial indices (geomagnetic indices such as the *aa* index and abundance of cosmogenic nuclides) are proxies of the open magnetic flux of the Sun, whereas  $S(t)$  is more closely linked to its total magnetic flux (Lean et al., 2002), to what extent can we use terrestrial proxies to quantify  $S(t)$  variations?

#### Point 4: Geomagnetic forcing of climate

The second key but qualitative correlation claimed by Courtillot et al. (2007) relates curves of the magnetic intensity and climate-related proxies, over two different time scales. Their Figure 4 links the geomagnetic variability in Western Europe with advances of Alpine glaciers over the last millennium. Their Figure 5 correlates the magnetic intensity in Mesopotamia over 4000 years with a record of ice-rafted detritus from the North Atlantic (Bond et al., 2001).

Courtillot et al. (2007) claim that there is a 'significant' correlation between cooling periods and particular increases in geomagnetic intensity (so-called 'jerks'). According to these authors, this correlation supports the hypothesis of a direct link between cosmic ray flux and cloud cover (Marsh and Svensmark, 2000). However, if we accept the causal chain proposed by Marsh and Svensmark (2000), we would expect exactly the opposite correlation: a high geomagnetic intensity would lead to a decrease of cosmic rays and, hypothetically, a decrease in low cloud cover which would in turn decrease the albedo and thus increase the surface temperature. In their discussion, Courtillot et al. (2007) speculate on other hypothetical mechanisms that could reverse this chain at the local scale. Based on interpretations of biblical accounts, Courtillot et al. (2007) invoke a migration of magnetic poles to lower geographic latitudes during these geomagnetic 'jerks'. However, it should be noted that this additional effect, assumed to generate more clouds, would need to overcome

the more direct effect that would diminish the cloud cover (again, assuming the hypothesis of Marsh and Svensmark (2000) is true).

Thus, a causal link between geomagnetic and climate records, if any, is a very complex matter to unravel. To help grasp how these things are complex, we would like to draw the readers' attention to some more recent studies of ice-rafted detritus in the North Atlantic. Following the pioneering work of Bond et al. (2001), other groups have restudied the history of ice rafting during the Holocene (Moros et al., 2006; Andrews et al., 2006 and references therein). The new records have a better time resolution than those presented by Bond et al. (2001). As illustrated in Figure 2, these new records do not correlate with the geomagnetic 'jerks', especially they do not show the marked oscillations that Courtillot et al. (2007) correlate with increases in geomagnetic intensity, while some even show an opposite trend. Figure 2 also suggests that the records of Bond et al. (2001) may not be representative of the entire northern hemisphere, and that their millennial-centennial variations may not be a direct response to an external forcing (see also Risebrobakken et al. (2003) for a discussion).

Hence, in our opinion, both the lack of obvious correlation between geomagnetic 'jerks' and North Atlantic cold phases, and the poorly understood mechanisms invoked by Courtillot et al. (2007), do not yet allow them to propose a geomagnetic forcing of the climate, especially through the modulation of cosmic rays.

The effect of the Sun's variability on climate is a different matter, which has been reviewed recently by several authors (Lean et al., 2005; Bard and Frank, 2006; Foukal et al., 2006). Indeed, Holocene paleoclimatic records suggest that solar changes have contributed to relatively small climate oscillations occurring on time scales of a few centuries (Bard and Frank(2006) and references therein), similar in type to the fluctuations classically described for the last millennium: the so-called Medieval Warm Period (900–1400 A.D.) followed by the Little Ice Age (1500–1800 A.D.). In addition to changes of the total solar irradiance, other

factors could have amplified the climatic response:

\_ Preferential modulation of ultra-violet light and its effect on stratospheric ozone (as modelled for example by Shindell et al. (2001)),

\_ Non-linear behaviours in the climate system, in particular, the ocean-atmosphere couple (as modelled for example by Weber et al. (2004)),

\_ Solar modulation of cosmic rays as hypothesized by Marsh and Svensmark (2000).

### Conclusion: Origin of the recent global warming

With their paper, notably its conclusion, Courtillot and coworkers (2007) express their doubts about commonly accepted facts concerning the climatic evolution over the last century. This leads them to invoke geomagnetism, through its effect on cloud cover, as an additional climate driver. The compilation of instrumental data shows that the lower atmosphere warmed by about 0.8°C during the 20<sup>th</sup> century (Jones et al., 1999; Brohan et al., 2006). This period corresponds in time to the rise of greenhouse gases linked to human activities. However, the CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O curves (Solomon et al., 2007) have exponential shapes suggesting that they are not the main cause of the rapid warming from 1920 to 1940 and of the temperature dip and plateau observed between 1940 and 1970 (Figure 1). Natural causes such as solar or volcanic forcings, as well as anthropogenic aerosols, could have contributed to this initial phase of global warming as well as the transient pause, as modelled for example by Stott et al. (2000) and Meehl et al. (2004). These modelling studies also suggest that the observed acceleration of the temperature rise since ~ 30 years probably exceeds the natural variability. This recent warming phase cannot be explained by natural changes in the Sun's output, which are well constrained over the last three decades. As illustrated on our Figure 3, precise observations of solar irradiance from satellite-borne radiometers, as well as results from neutron monitors recording the influence of cosmic rays

on Earth, indicate that external forcings cannot explain the 0.6 °C rise in global temperature observed over the past 30 years (Brohan et al., 2006). This conclusion agrees with numerical modelling studies indicating that the rise in the content of atmospheric greenhouse gases is very probably the main cause of the significant warming observed during the last three decades (Stott et al., 2000; Meehl et al., 2004).

In summary, as specifically discussed in an abundant literature (Stott et al. (2000; Meehl et al. (2004) to list just two), the climate evolution over the last century can readily be explained by a combination of natural (Sun and volcanoes) and anthropogenic forcings that became significant during the second half of the century. Courtillot et al. (2007) invoked an additional forcing due to a hypothetical link between geomagnetism, cosmic rays and cloud cover. As discussed above, we find no convincing support for such a link in the data and analysis presented by the authors. Indeed, instrumental data on cosmic rays and heliomagnetic modulation do not show a long term trend that could contribute to the global warming observed over the last half-century (Figure 3). Thus, there is still no reason to invoke this speculative forcing.

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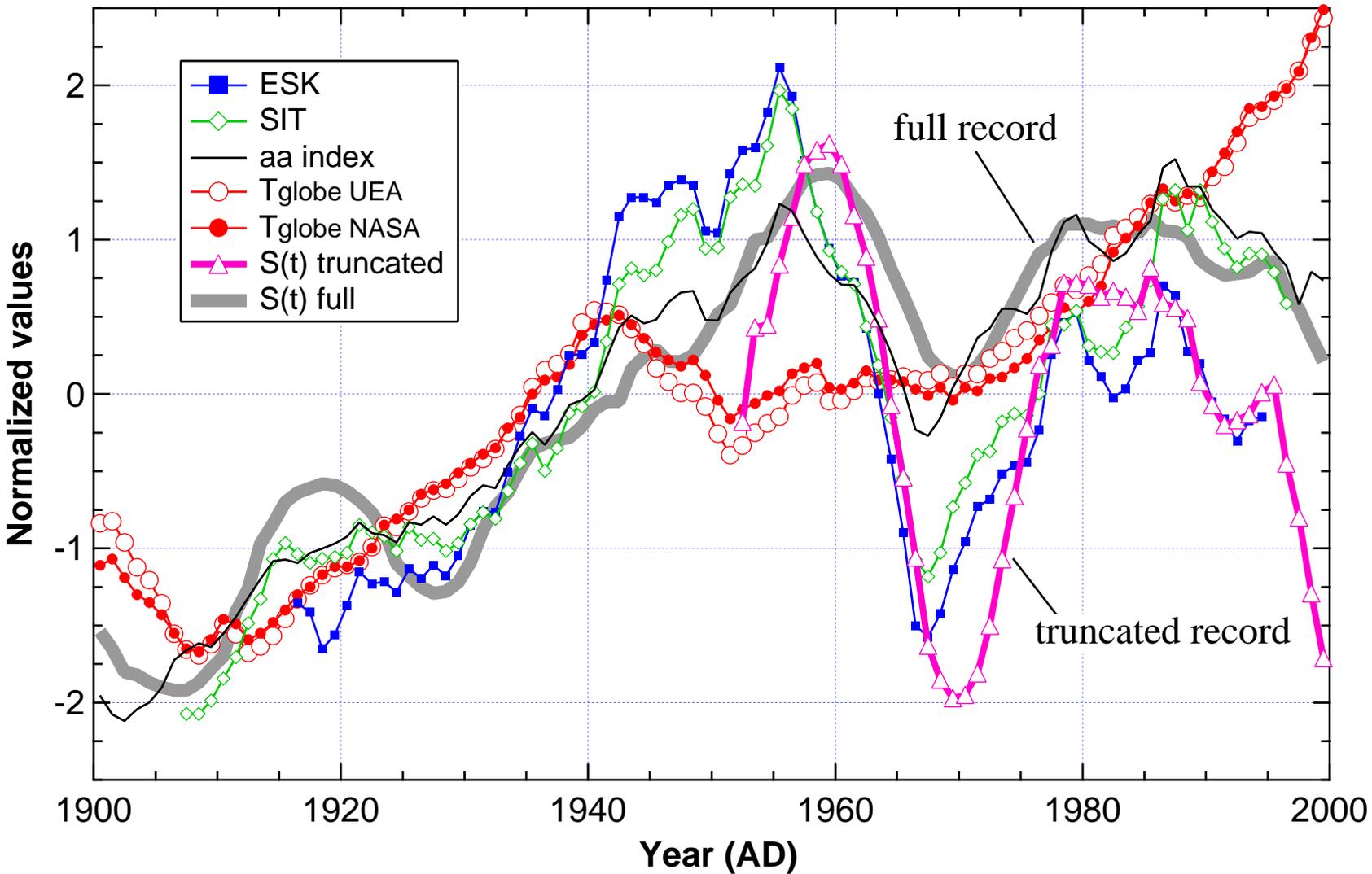
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## Figure captions

**Figure 1.** Time evolution over the 20<sup>th</sup> century of magnetic indices (Eskdalemuir and Sitka observatories - ESK and SIT-, and *aa* index), compared to total solar irradiance  $S(t)$  and global mean temperature  $T_{\text{globe UEA}}$  &  $T_{\text{globe NASA}}$ . This figure compares directly with Figure 3 by Courtillot et al. (2007). (Incidentally, we note that the smoothed  $T_{\text{globe}}$  curve used by Courtillot et al. in their Figure 3 looks different from the global temperature curve published by Jones et al. (1999) cited by Courtillot et al. (2007)). The ESK and SIT geomagnetic indice curves are the same as used by Courtillot et al. (2007). The *aa* index is a geomagnetic index prepared by the International Service of Geomagnetic Indices, CETP/IPSL (available at <http://www.ngdc.noaa.gov/stp/SOLAR/> ). The total solar irradiance curve based on sunspot data  $S(t)$  is an update of Solanki (2002) by Krivova et al. (2007). The  $T_{\text{globe UEA}}$  curve is HadCRUT3, an update of Jones et al. (1999) by Brohan et al. (2006) (available at <http://www.cru.uea.ac.uk/cru/data/temperature/> ). For the sake of comparison, we also plot  $T_{\text{globe NASA}}$ , the NASA-GISS global temperature index available from <http://data.giss.nasa.gov/gistemp/> . All curves are eleven-year running averages (any given year is averaged with the 5 previous and 5 following ones), and have been normalized over their respective periods. The total solar irradiance curve  $S(t)$  is also shown truncated in 1952 as in the Figure 3 of Courtillot et al. (2007).

**Figure 2.** Marine records from the northern Atlantic region, interpreted as indicators of drift ice flux to the north Atlantic, compared with geomagnetic field intensity reconstructed in the Middle East. This figure compares directly with Figure 5 by Courtillot et al. (2007). As proposed by these authors, the green bars underline periods of drift ice increase, coincident with rapid geomagnetic variations (so-called 'jerks'). VM29-191 record of IRD content published by Bond et al. (2001); MD99-2237 IRD record published by Andrews et al. (2006); MD99-2269 record published by Moros et al. (2006) and available at <http://www.ncdc.noaa.gov/paleo/> .

**Figure 3.** Time series (annual averages) of solar activity indices and global surface temperature since the year 1950. The total solar irradiance  $S(t)$  measured by satellites is a composite distributed by PMOD/WRC, Davos, Switzerland (available at <http://www.pmodwrc.ch/> ). Climax CRF is the cosmic ray flux measured at Climax in Colorado (data available at <http://ulysses.sr.unh.edu/NeutronMonitor/> ). The *aa* index is a geomagnetic index prepared by the International Service of Geomagnetic Indices, CETP/IPSL (available at <http://www.ngdc.noaa.gov/stp/SOLAR/> ).  $T_{\text{globe UEA}}$  is the global surface temperature anomalies HadCRUT3 with its total uncertainty at the 95% level (Brohan et al. (2006), available at <http://www.cru.uea.ac.uk/cru/data/temperature/> ). For plotting purposes, each time series has been normalized over the 1950-2006 period (except for  $S(t)$  which is available only since 1978 and was thus normalized over 1978-2006). All curves have been vertically shifted to start from zero, in order to concentrate on temporal trends since the year 1950 (except for  $S(t)$  which starts from 0 in year 1978). The CRF is multiplied by -1 to underline the correlation with the other solar indices and because the hypothesis by Marsh and Svensmark (2000) is that a drop of cosmic ray flux should decrease the low cloud cover and increase surface temperature. NRF stands for the net radiative forcing of the Sun (i.e.  $S(t)$  divided by 4 and multiplied by 0.7 as in Crowley (2000)). Note that only the  $T_{\text{globe}}$  curve is characterized by an upward trend ( $\sim 0.11^\circ\text{C}$  per decade,  $r = 0.87$ , since 1950). Large dips of the  $T_{\text{globe}}$  curve occurred just after major volcanic eruptions (e.g. 1963, 1982, 1991).



# Calendar age (thousands of years before Christ)

4 3 2 1 0

Geomagnetic intensity

Drift ice indices

VM29-191

MD99-2269

MD99-2237

# Calendar age (thousands of years before present)

5 4 3 2

