Available online at www.sciencedirect.com
ScienceDirect
EPSL
Earth and Planetary Science Letters xx (2007) xxx – xxx
www.elsevier.com/locate/epsl

Discussion

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

Edouard Bard *, Gilles Delaygue

CEREGE (UMR 6635), Collège de France, CNRS, Université Paul-Cézanne Aix-Marseille 3, Europôle de l'Arbois BP80, 13545 Aix-en-Provence Cedex 4, France

Accepted 29 September 2007

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.

1. 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 ~1–2 W m^{-2}. The range for CO_2, which becomes significant mainly after 1800, is ~2 W m^{-2}. » This is clearly a confusion, which could mislead the reader into thinking that the 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 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 ~0.5 W m^{-2} (see Crowley’s Fig. 2), which can be directly compared with the CO_2 forcing, and is much smaller.

2. Point 2: correlation based on matched records

In their Fig. 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 ($\Delta^{14}C$) as well as the record of atmospheric 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. Fig. 7 of Mangini et al. (2005). To prove the correlation and make inferences about solar forcing, only untuned records, i.e. Fig. 1 of Mangini et al. (2005), with their respective and independent time scales, should be used.

3. Point 3: proxies of solar activity

In their Fig. 3, covering the 20th century, Courtillot et al. (2007) compare geomagnetic indices measured at two locations, Eskdalemuir in Scotland and Sitka in

---

DOI of original article: 10.1016/j.epsl.2006.10.032.

* Corresponding author. Tel.: +33 4 42 50 74 18; fax: +33 4 42 50 74 21. *E-mail address:* bard@cerege.fr (E. Bard).

doi:10.1016/j.epsl.2007.09.046

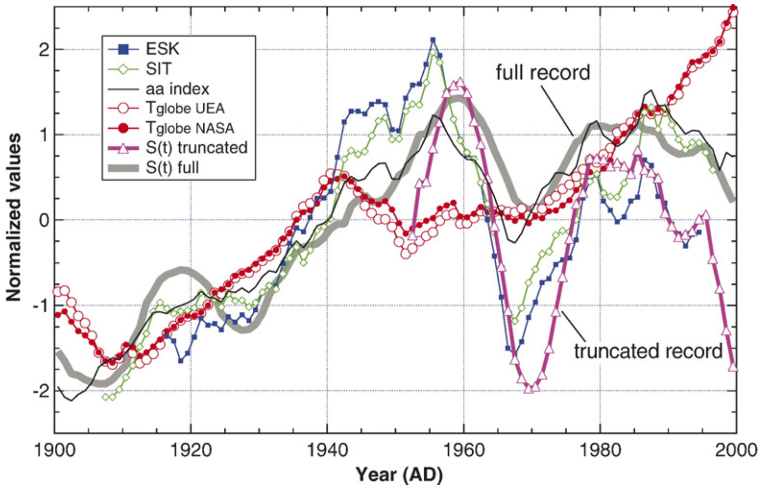

Fig. 1. Time evolution over the 20th century of magnetic indices (Eskdalemuir and Sitka observatories – ESK and SIT –, and *aa* index), compared to total solar irradiance *S*(*t*) and global mean temperature T_{globe} UEA & T_{globe} NASA. This figure compares directly with Fig. 3 by Courtillot et al. (2007). (Incidentally, we note that the smoothed T_{globe} curve used by Courtillot et al. in their Fig. 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 indices 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_{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_{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 Fig. 3 of Courtillot et al. (2007).

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_{globe} reconstructed by Jones et al. (1999) (Incidentally, we note a problem in their Fig. 3 as this smoothed T_{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 Fig. 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 Fig. 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 (Fig. 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 (Fig. 1), the general shape of the irradiance curve *S*(*t*) is broadly similar to the global mean temperature curve T_{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 20th 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_{globe} (Cliver et al., 1998; Lockwood et al., 1999; Lockwood, 2003) as illustrated by Fig. 1.

Please cite this article as: Bard, E., Delaygue, G., Comment on “Are there connections between the Earth’s magnetic field and climate?” by V. Courtillot, Y. Gallet, J.-L. Le Mouël, F. Fluteau, A. Genevey EPSL 253,...,Earth. Planet. Sci. Lett. (2007), doi:10.1016/j.epsl.2007.09.046

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?

4. 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 Fig. 4 links the geomagnetic variability in Western Europe with advances of Alpine glaciers over the last millennium. Their Fig. 5 correlates the magnetic intensity in Mesopotamia over 4000 yrs. 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 Fig. 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. Fig. 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).

5. Conclusion: origin of the recent global warming

With their paper, notably its conclusion, Courtillot et al. (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

Please cite this article as: Bard, E., Delaygue, G., Comment on “Are there connections between the Earth's magnetic field and climate?” by V. Courtillot, Y. Gallet, J.-L. Le Mouël, F. Fluteau, A. Genevey EPSL 253,...,Earth. Planet. Sci. Lett. (2007), doi:10.1016/j.epsl.2007.09.046

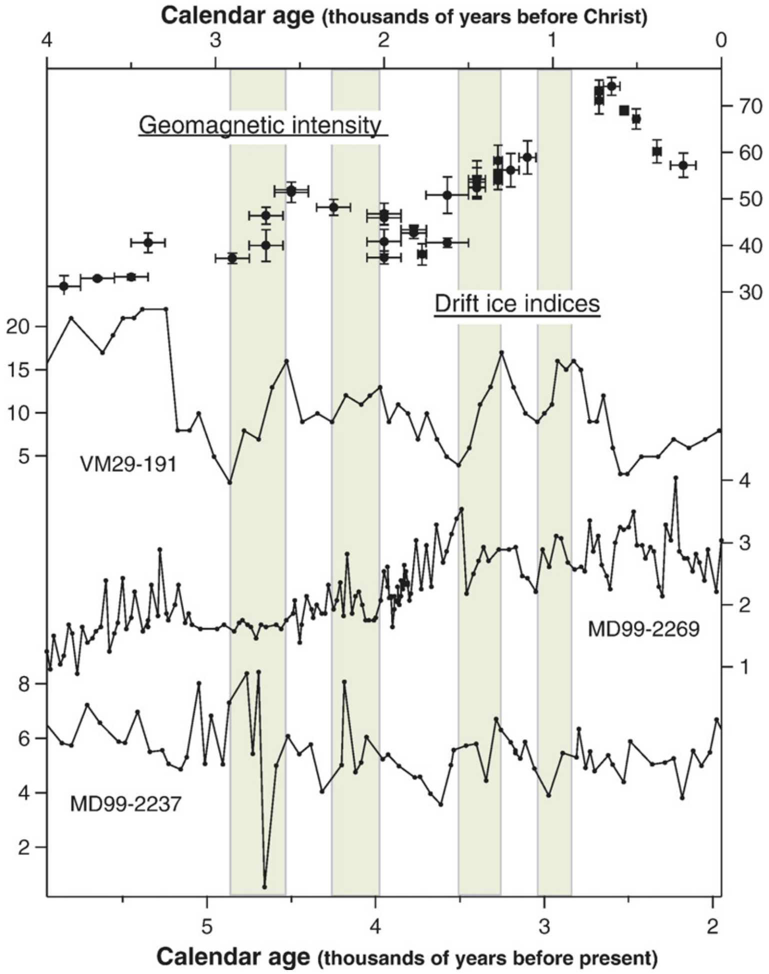

Fig. 2. Marine records from the northern Atlantic region, interpreted as indicators of drift ice flux to the north Atlantic, compared with geomagnetic field intensity reconstructed in the Middle East. This figure compares directly with Fig. 5 by Courtillot et al. (2007). As proposed by these authors, 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/.

driver. The compilation of instrumental data shows that the lower atmosphere warmed by about 0.8 °C during the 20th 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_2, CH_4 and N_2O 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 (Fig. 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 yrs. 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 Fig. 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 yrs. (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).

Please cite this article as: Bard, E., Delaygue, G., Comment on "Are there connections between the Earth's magnetic field and climate?" by V. Courtillot, Y. Gallet, J.-L. Le Mouël, F. Fluteau, A. Genevey EPSL 253,...,Earth. Planet. Sci. Lett. (2007), doi:10.1016/j.epsl.2007.09.046

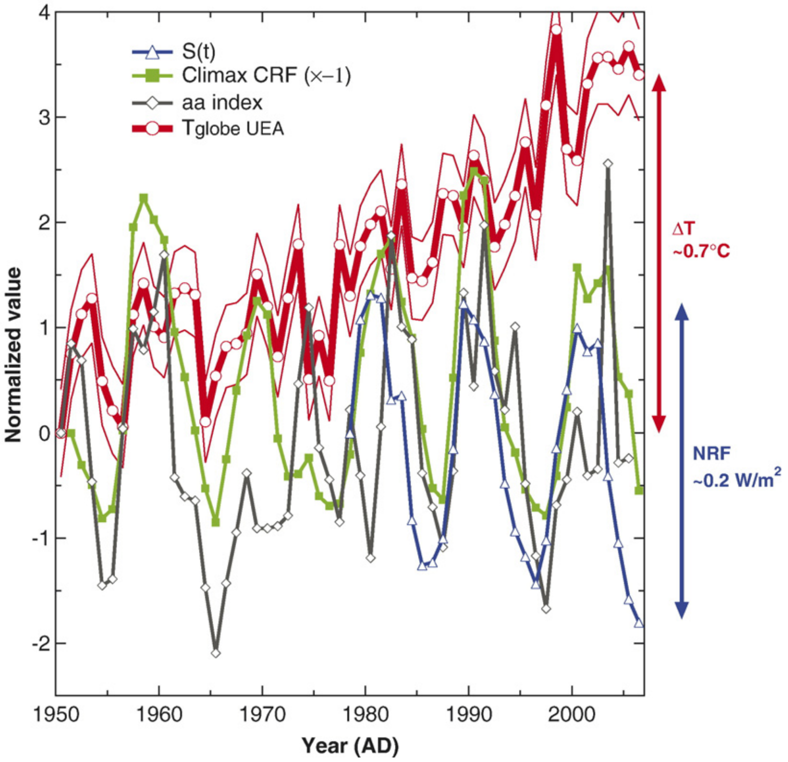

Fig. 3. Time series (annual averages) of solar activity indices and global surface temperature since the year 1950. The total solar irradiance $S(t)$ measured by satellites is a composite distributed by PMOD/WRC, Davos, Switzerland (available at http://www.pmodwrc.ch/). Climax CRF is the cosmic ray flux 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_{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_{globe} curve is characterized by an upward trend (~0.11 °C per decade, $r=0.87$, since 1950). Large dips of the T_{globe} curve occurred just after major volcanic eruptions (e.g. 1963, 1982 and 1991).

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 (Fig. 3). Thus, there is still no reason to invoke this speculative forcing.

Note added in proof

In their Response to our Comment, Courtillot et al. state that for the total irradiance curve $S(t)$ they had used the SOLAR2000 model product by Tobiska (2001) instead of the century-long record by Solanki (2002) cited in their original paper (Courtillot et al. 2007). However, the SOLAR2000 model is restricted to the UV component and their total solar irradiance is severely flawed as pointed out by Lean (2002). For the global temperature Tglobe curve cited from Jones et al. (1999) in Courtillot et al. (2007), these authors now state in their response that they had used the following data file: monthly_land_and_ocean_90S_90N_df_1901-2001mean_dat.txt.

Please cite this article as: Bard, E., Delaygue, G., Comment on "Are there connections between the Earth's magnetic field and climate?" by V. Courtillot, Y. Gallet, J.-L. Le Mouël, F. Fluteau, A. Genevey EPSL 253,...,Earth. Planet. Sci. Lett. (2007), doi:10.1016/j.epsl.2007.09.046

We were unable to find this file even by contacting its putative author who specifically stated to us that it is not one of his files (Dr. Philip D. Jones, written communication dated Oct. 23, 2007).

Acknowledgments

For discussions we thank J. Adkins, A. Berger, R. Bradley, J.L. Dufresne, M. Ghil, D. Hauglustaine, G. Henderson, G. Hoffmann, P.D. Jones, R. Kandel, S. Solomon, E. Steig, T. Stocker, P.J. Reimer and P. Yiou. Work at CEREGE is supported by the Gary Comer Science & Education Foundation.

References

Andrews, J.T., Jennings, A.E., Moros, M., Hillaire-Marcel, C., Eberl, D., 2006. Is there a pervasive Holocene ice-rafted debris (IRD) signal in the northern North Atlantic? The answer appears to be either no, or it depends on the proxy! PAGES Newsletter 14, 7–9.

Bard, E., Frank, M., 2006. Climate change and solar variability: what's new under the Sun? Earth Planet Sci. Lett. 248, 1–14.

Bard, E., Raisbeck, G.M., Yiou, F., Jouzel, J., 1997. Solar modulation of cosmogenic nuclide production over the last millennium: comparison between ^{14}C and ^{10}Be records. Earth Planet. Sci. Lett. 150, 453–462.

Bard, E., Raisbeck, G., Yiou, F., Jouzel, J., 2000. Solar irradiance during the last 1200 yrs. based on cosmogenic nuclides. Tellus 52B, 985–992.

Bond, G., Kromer, B., Beer, J., Muscheler, R., Evans, M.N., Showers, W., Hoffmann, S., Lotti-Bond, R., Hajdas, I., Bonani, G., 2001. Persistent solar influence on North Atlantic climate during the Holocene. Science 294, 2130–2136.

Brohan, P., Kennedy, J.J., Harris, I., Tett, S.F.B., Jones, P.D., 2006. Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. J. Geophys. Res. 111, D12106.

Cliver, E.W., Boriakoff, V., Feynman, J., 1998. Solar variability and climate change: geomagnetic aa index and global surface temperature. Geophys. Res. Lett. 25, 1035–1038.

Courtillot, V., Gallet, Y., Le Mouël, 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.

Crowley, T.J., 2000. Causes of climate change over the past 1000 yrs. Science 289, 270–277.

Foukal, P., Fröhlich, C., Spruit, H., Wigley, T.M.L., 2006. Variations in solar luminosity and their effect on the Earth's climate. Nature 443, 161–166.

Jones, P.D., New, M., Parker, D.E., Martin, S., Rigor, I.G., 1999. Surface air temperature and its changes over the past 150 yrs. Rev. Geophys. 37, 173–199.

Krivova, N.A., Balmaceda, L., Solanki, S.K., 2007. Reconstruction of solar total irradiance since 1700 from the surface magnetic flux. Astron. Astrophys. 467, 335–346.

Lean, J.L., 2002. Validating the solar EUV proxy, E10.7 by W.K. Tobiska. J. Geophys. Res. 107 (A2), 1027. doi:10.1029/2001JA00137.

Lean, J., Beer, J., Bradley, R., 1995. Reconstruction of solar irradiance since 1610: implications for climate change. Geophys. Res. Lett. 22, 3195–3198.

Lean, J.L., Wang, Y.-M., Sheeley Jr., N.R., 2002. The effect of increasing solar activity on the Sun's total and open magnetic flux during multiple cycles: implications for solar forcing of climate. Geophys. Res. Lett. 29, 2224.

Lean, J., Rottman, G., Harder, J., Kopp, G., 2005. SORCE contributions to new understanding of global change and solar variability. Sol. Phys. 230, 27–53.

Lockwood, M., 2003. Twenty-three cycles of changing open solar magnetic flux. J. Geophys. Res. 108, 1128.

Lockwood, M., Stamper, R., Wild, M.N., 1999. A doubling of the Sun's coronal magnetic field during the past 100 yrs. Nature 399, 437–439.

Mangini, A., Spötl, C., Verdes, P., 2005. Reconstruction of temperature in the Central Alps during the past 2000 yrs. from a δ^{18}O stalagmite record. Earth Planet. Sci. Lett. 235, 741–751.

Marsh, N.D., Svensmark, H., 2000. Low cloud properties influenced by cosmic rays. Phys. Rev. Lett. 85, 5004–5007.

Meehl, G.A., Washington, W.M., Ammann, C.M., Arblaster, J.M., Wigley, T.M.L., Tebaldi, C., 2004. Combinations of natural and anthropogenic forcings in twentieth-century climate. J. Climate 17, 3721–3727.

Moros, M., Andrews, J.T., Eberl, D.D., Jansen, E., 2006. Holocene history of drift ice in the northern North Atlantic: evidence for different spatial and temporal modes. Paleoceanography 21, PA2017.

Risebrobakken, B., Jansen, E., Andersson, C., Mjelde, E., Hevrøy, K., 2003. A high-resolution study of Holocene paleoclimatic and paleoceanographic changes in the Nordic Seas. Paleoceanography 18, 1017.

Shindell, D.T., Schmidt, G.A., Mann, M.E., Rind, D., Waple, A., 2001. Solar forcing of regional climate change during the maunder minimum. Science 294, 2149–2152.

Solanki, S.K., 2002. Solar variability and climate change: is there a link? Astron. Geophys. 43, 5.09–5.13.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L., 2007. IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Stott, P.A., Tett, S.F.B., Jones, G.S., Allen, M.R., Mitchell, J.F.B., Jenkins, G.J., 2000. External control of 20th century temperature by natural and anthropogenic forcings. Science 290, 2133–2137.

Tobiska, W.K., 2001. Validating the solar EUV proxy, E10.7. J. Geophys. 106, 29969–29978.

Weber, S.L., Crowley, T.J., van der Schrier, G., 2004. Solar irradiance forcing of centennial climate variability during the Holocene. Clim. Dyn. 22, 539–553.

Please cite this article as: Bard, E., Delaygue, G., Comment on "Are there connections between the Earth's magnetic field and climate?" by V. Courtillot, Y. Gallet, J.-L. Le Mouël, F. Fluteau, A. Genevey EPSL 253,...,Earth. Planet. Sci. Lett. (2007), doi:10.1016/j.epsl.2007.09.046