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Letter to the Editor

Comment on "Solar activity during the last 1000 yr inferred from radionuclide records" by Muscheler et al. (2007)

Muscheler et al. (2007) propose a new solar activity record based on stacking ^{10}Be records from different ice cores from Greenland and Antarctica. They claim that their new record is superior to previous reconstructions, in particular that based on a single core from South Pole (Bard et al., 2000). Although the optimal approach involves compiling results from multiple cores obtained at different geographic sites, we feel that the new record presented by Muscheler et al. (2007) is actually of lower quality because the raw records they used and their computations suffer from several weaknesses, in particular a variable and poor resolution.

Muscheler et al. (2007) have included in their stack four records from Greenland. It is evident from their Fig. 7 that these records are mainly responsible for a long-term decrease of ^{10}Be concentration, which thus leads to an increase of solar activity over the past few centuries. This trend is particularly clearly seen in the only high-resolution record from Greenland (Dye-3), which extends up to the modern period and is thus crucial in controlling the overall shape of the reconstruction given by Muscheler et al. (2007). Moreover, there is little consistency between individual peaks observed in these Greenland records. For example, this problem is the source of a spurious spike at ca. 1100 yr AD in the ^{10}Be-based solar modulation curve, which disagrees with the curve based on ^{14}C (Fig. 10 of Muscheler et al., 2007). While this obvious problem of inconsistency between ^{10}Be records is briefly mentioned in Section 6 of their paper, these authors surprisingly opted to retain all the Greenland data in order to compute their solar activity record.

We should stress that Muscheler et al. (2007) omit any reference to the paper by Bard et al. (1997), in which we specifically mentioned the same discrepancies between records from Antarctica (South Pole) and Greenland (Camp Century, Milcent, Dye-3). The Antarctica record discussed in Bard et al. (1997) actually provides the profile used in our subsequent paper published in 2000, allowing us to extend our analysis by tentatively converting the cosmogenic isotope record into terms of total solar irradiance (TSI). Because of the problems associated with the Greenland records, we decided to rely solely on the South Pole data. Indeed, in our 1997 paper we specifically stated: "*For the period between 950 and 1800 yr AD the ^{10}Be-based Δ^{14}C record of Greenland (Beer et al., 1988) is characterized by five excursions while the tree ring Δ^{14}C exhibits only four excursions. There is indeed an anomalous prominent maximum centered at about 1150 yr AD in the ^{10}Be-based Δ^{14}C record by Beer et al. (cf. Fig. 4a in Beer et al., 1988).*" … "*Another puzzling feature of the Greenland record (Beer et al., 1988) is the relative size of the ^{10}Be-based Δ^{14}C excursions: the amplitude of the Maunder Δ^{14}C excursion is on the order of 30‰ while the Spörer and Wolf excursions are slightly less than 10‰. As clearly shown in Fig. 4 the relative amplitude of the 1060, 1320 (Wolf), 1500 (Spörer), 1690 (Maunder) and 1820 yr AD (Dalton) Δ^{14}C excursions are similar in the tree ring record and the Δ^{14}C profile based on the South Pole ^{10}Be data.*"

It should be noted that the Greenland data from the Camp Century, Milcent and Dye-3 ice cores used by Beer et al. (1988, 1990) are the same as those used by Muscheler et al. (2007), except for the minor addition of the medium-resolution record from GRIP. This additional record does not cover the past four centuries, so it is of little use in discussing the long-term trend up to the modern period. Furthermore, Muscheler et al. used published Greenland records and did not take into account the synthetic revision of the chronology of Greenland ice cores recently published by Vinther et al. (2006). Fig. 7 in Muscheler et al. (2007) still clearly reflects the basic problem regarding the size of the Spörer Minimum (ca. 1500 AD) relative to the Maunder Minimum (ca. 1700 AD): in the Milcent ice core, for example, the average ^{10}Be concentration during the Spörer Minimum is even lower than the millennium-average, whereas it is 50% higher than average during the Maunder Minimum. Using these data in a compilation inevitably leads to the problem that we already highlighted in our 1997 article.

Moreover, to explain the large discrepancies between Greenland ^{10}Be records and the ^{14}C in tree rings, we listed three possible explanations in our 1997 paper: "*The differences between the Greenland and South Pole ^{10}Be records could be due to several causes such as the influence of "individual" precipitation events, long-term accumulation changes over a large region of the ice sheets and the contribution of ^{10}Be transported with the dust fraction*".

By eliminating outliers, Muscheler et al. (2007) attempted to resolve the first problem linked to "meteorological noise". However, they did not even mention the two other possibilities: accumulation rate changes and dust transport. There is indeed some strong evidence for

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systematic accumulation changes in Greenland over the last millennium. As argued by Andersen et al. (2006), the Greenland ice-sheet has experienced a millennium-scale decrease of snow accumulation. These authors even proposed that the Little Ice Age and the Maunder Minimum were times of minimal accumulation. In addition, Andersen et al. (2006) pointed out an inherent problem associated with the site located in the southern part of Greenland: "*the Dye-3 site receives a larger proportion of its precipitation from cyclonic activity associated with the Icelandic low than the other cores (Hutterli et al. 2005).*" Overall, the accumulation rate data for Greenland suggest that ^{10}Be concentration in Greenland ice is strongly influenced by a widespread time-varying dilution factor, which may explain the spurious concentration decrease/increase observed in the data compiled by Muscheler et al. (2007).

Muscheler et al. (2007) argue that they can accurately correct for geomagnetic modulation effects in order to extract the pure heliomagnetic component for both ^{14}C and ^{10}Be records. In doing so, they assume that both magnetic components have equal amplitude at all latitudes. In other words, they assume that ^{10}Be is well mixed in the atmosphere before deposition. Indeed, all three carbon-cycle models used by Muscheler et al. (2007) have only one box to represent the atmosphere. Nevertheless, the authors discuss the problem by citing the recent paper by Field et al. (2006), who used a General Circulation Model of the atmosphere (including a detailed treatment of the stratosphere and aerosols). Field et al. (2006) found that, in both Polar Regions, the effect of the geomagnetic modulation is reduced by 20% and that of the heliomagnetic modulation enhanced by 20%, relative to the average global production. Once again, Muscheler et al. (2007) fail to cite our 1997 paper, which specifically introduced a so-called Polar Enhancement Coefficient (PEC) to take account of such effects in a carbon-cycle model. This contrasts with the studies by Beer et al. (1988) and Muscheler et al. (2005), who assumed no latitudinal effects for ^{10}Be.

The extent of geomagnetic modulation in the Polar Regions is a matter of long-standing debate (see discussion by Raisbeck et al., 1992 and references therein). At the time of our 1997 paper, it was unclear that the geomagnetic modulation of ^{10}Be could have a significant effect at the South Pole due to atmospheric mixing (as modelled recently by Field et al., 2006). Moreover, since little information was available in 1997 on the small decrease of the geomagnetic field over the last millennium, we decided not to correct for this minor effect in the ^{10}Be record. By contrast, because $^{14}CO_2$ is well mixed in the atmosphere, we applied a correction by detrending the atmospheric ^{14}C record based on tree-rings. Our model calculations published in 1997 showed that both datasets were in agreement within their respective error brackets.

In their new paper, Muscheler et al. (2007) updated our work by applying a geomagnetic correction to our reconstruction (see their Fig. 13). However, these authors greatly exaggerate the impact of this correction by using the geomagnetic field reconstruction by Yang et al. (2000) and assuming that ^{10}Be is well mixed in the atmosphere (see Fig. 1 of the present paper for an equivalent comparison expressed in terms of TSI). However, the virtual dipole moment record by Yang et al. (2000) was recently criticized and updated by Korte and Constable (2005). The approach followed by these authors allowed them to separate the dipolar field variations from non-dipole contributions to the geomagnetic field. By using the better geomagnetic record of Korte and Constable (2005) and assuming an incomplete ^{10}Be mixing as calculated by Field et al. (2006) (and already proposed by Bard et al., 1997), we find a much smaller difference than that claimed by Muscheler et al. (2007). As shown in Fig. 1, this approach reduces by a factor of three the observed discrepancies at around 1800 AD and between 1000 and 1400 AD. Indeed, Korte and Constable (2005) reported a decrease of ca. 10% in the strength of the geomagnetic dipole over the last millennium. Taking into account the uncertainties, this long-term change is no different from a linear trend at a constant rate. This geomagnetic trend is equivalent to a millennium-scale increase of about 4% in the deposition of ^{10}Be in Polar Regions. This small rate of change of 0.4% per century should be compared with the large changes of 30% per century observed in the ^{10}Be concentration associated with typical transitions into and out of solar activity minima. Expressed in terms of total solar irradiance, this would correspond to very small differences with our previous calculation indicating a change of up to 0.02% for the earlier part of the millennium (see our Fig. 1). More recently, Gubbins et al. (2006) have shown that the geomagnetic field decrease studied by Korte and Constable (2005) actually took place in a step-wise manner, with a very gradual long-term trend followed by a rapid decline since 1840. Fig. 1 illustrates a third additional curve in which we take account of such behavior by assuming that the 10% field decrease over the past millennium occurred in two phases: 5% between 1950 and 1850 and the remaining 5% over the entire millennium.

Altogether, our updated calculations are within error of our previous results, particularly when taking into account the uncertainty based on individual ^{10}Be measurements themselves: 7% for the South Pole measurements (Raisbeck et al., 1990), which corresponds to a minimum error of 0.04% of the TSI. As stated in Bard et al. (2000), this implies that this method cannot allow to distinguish the TSI value at 1950 AD from those reached during previous active phases centered around 1800 and 1200 AD.