Possible solar influences on the dust profile of the GISP2 ice core from Central Greenland

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Abstract. The Greenland Ice Sheet Project 2 (GISP2) ice core dust profile in glacial (Wisconsinan) ice from Central Greenland has been measured using Laser-Back Scatter (LBS) from ice. This data exhibits considerable high frequency variability. By applying appropriate running averages to the data, certain regularities emerge. Thus, for example, when the data was smoothed with rectangular 4 and 5 year running averages, -11 year dust modulations of considerable amplitude were revealed. In this paper, we show how further smoothing of the data causes very large, longer period dust modulations centered at -91 years in a Gaussian distribution to emerge. We believe that this corresponds to the 80-90 year modulation of the 11 year sunspot cycle first suggested by Gleissberg. We also show how adjacent 11 year dust periods can combine in a unique way to generate a 22 year (Hale) period of dust modulation. The way this occurs is similar to that by which a 22 year modulation of the measured terrestrial neutron flux is generated from two 11 year periods. Taken together with our observation of a -200 year (Suess) dust modulation period, these observations strengthen our claim that the dust modulations we measured in GISP2 ice are solar induced and suggest a mechanism for their production.

1. Introduction
Prominent dust concentration modulations with an average 11 year period were recently reported (Ram et al., 1997) to be present in the GISP2 ice core dust profile (Ram and Koenig, 1997). Most of the dust modulations were found in Wisconsinan (glacial) ice and Ram et al. (1997) attributed them to the 11 year solar cycle. The implication was that changes associated with the solar cycle affected the aridity of the Greenland dust source areas and, as a consequence, modulated the concentration of dust lofted into the atmosphere and subsequently transported and deposited on Greenland ice. Since the only link with the solar cycle was the fact that the dust modulations had an average period of 11 years, more independent evidence is needed to firm up the dust/sun connection. We have now achieved this on two fronts (i) by demonstrating a strong positive correlation between the sunspot cycle and dust concentration modulations in GISP2 ice (Donarummo and Ram, 1998) and (ii) by demonstrating that the 11 year dust concentration modulations are themselves modulated by a strong -91 year average period in the same way that the 11 year sunspot cycle is modulated by the well-known 80-90 year Gleissberg period (Gleissberg, 1944).

In this paper, we report and discuss the second finding and demonstrate how a 22 year (Hale) dust modulation period is generated when two consecutive 11 year periods combine in a very unique way reminiscent of the generation of a 22 year period in the terrestrial neutron flux (Jokipii, 1991).

Regularities in the GISP2 Dust Profile
The most prominent and consistent regularity in our GISP2 dust profile is the annual spring dust peaks which have been used to date the ice core with a high degree of accuracy (Ram and Illing, 1994; Ram et al, 1995; Ram and Koenig, 1997; Meese et al., 1997). This may be viewed as a solar effect inasmuch as it is the result of insolation changes at different latitudes due to the earth's inclination. It is different, however, from the dust modulations (11, 22, 90 and 200 years) we observe since it does not reflect any intrinsic change in the sun itself.

In previous work (Ram et al., 1997), we used equally weighted running averages. In the present work, all the running averages we use have Gaussian weights. This eliminates unrealistic sharp transients that are sometimes encountered at the margins of rectangular averaging windows.

The Gaussian weights we use are characterized by the Gaussian half width $\sigma_{RA}$ and the averaging window breadth is $6\sigma_{RA}$. Figure 1 illustrates how changing the value of $\sigma_{RA}$ causes the different dust modulation periods to emerge. Thus, for example, in Fig. 1(a) we used a high value of $\sigma_{RA} = 15$ years (on yearly averaged dust data) to smooth out the yearly peaks and 11 year modulations and, as the scale in the figure shows, what emerges are large -80 year dust amplitude modulations. The age range we are illustrating is typical of what is observed throughout our Wisconsinan GISP2 dust profile. Figure 1(b) is a blow-up of the boxed area of Fig. 1(a). This figure shows the results of using $\sigma_{RA} = 15$ years (heavy line) and $\sigma_{RA} = 2$ years (light line). The milder value of $\sigma_{RA} = 2$ years is sufficient to smooth out the yearly peaks but still allows the 11 year dust modulations (Ram et al., 1997) to stand out prominently. Figure 1(c) is a blow-up of the boxed area of Fig. 1(b). That figure shows the results of using $\sigma_{RA} = 2$ years (heavy line) and a rectangular window, 2 point running average (light line). The mild 2 point running average allows the annual dust peaks (Ram et al., 1995) to stand out clearly.

As with the 11 year dust modulations (Ram et al., 1997), the longer period (~90 year) modulations also exhibit considerable variability. This is illustrated in Fig. 2 which shows the long period modulations for three representative time intervals. In these figures, we used a value of $\sigma_{RA} = 10$ years (on yearly averaged dust data) to average out the 11 year dust modulations. The individual modulation periods for each of the
cycles is determined by measuring the time span between adjacent minima of the averaged data. Figure 2(d) is a histogram of the 469 periods measured for the time interval 13,900 to 91,555 YBP (years before present). We fitted this period distribution to a normal distribution

\[ f(x) = \frac{A}{2\pi \sigma^2} \left[ \exp\left(-\frac{(x-a)^2}{2\sigma^2}\right) \right] \]

and determined that \( A = 5777, \sigma = 32.80 \) and \( a = 91.26 \). This shows that the most likely period in the distribution is 91.26 years, but the large value of the standard deviation, \( \sigma = 32.80 \) years, is indicative of the wide range of variability in the measured long period dust modulations (clearly evident in Fig. 2).

Since the long period dust modulations modulate the 11 year periods (Fig. 1(b)), we associate them with the 80 - 90 year Gleissberg period that is believed to modulate the sunspot cycle (Gleissberg, 1944). The record studied by Gleissberg was very short and he had only two periods to work with. In contrast, our dust record is much longer and we measured 469 long period dust modulations. Assuming our association of dust concentration changes in GISP2 ice and the 11 year solar cycle is correct, we see that Gleissberg type solar modulations existed up to and beyond ~90,000 YBP and that their periods exhibited considerable variability about a mean of ~91 years.

**A 22 Year (Hale) Dust Modulation Cycle**

By appropriately adjusting the value of \( \sigma_{RA} \) in our Gaussian weighted running averages, we can demonstrate how two adjacent 11 year periods can combine to give what looks like a 22 year (Hale) dust concentration cycle. Figure 3 illustrates how this comes about when we use running averages with \( \sigma_{RA} = 1.5 \) and 2 years (broken line) and \( \sigma_{RA} = 4 \) years (continuous line) on yearly averaged dust data. Note the remarkable way in which the grouping occurs. Thus, for example, in Fig. 3(b) 11 year cycles 1 and 2, 3 and 4, 5 and 6 and 7 and 8 combine to generate 22 year cycles. Eleven year cycles 2 and 3, 4 and 5 and 6 and 7 do not! This is reminiscent of the behavior of the terrestrial neutron flux where adjacent ~11 year modulations (probably due to the modulation of the incident cosmic proton flux by the solar magnetic field) with sharp peaks are separated by a flat-topped ~11 year modulation (Jokipii, 1991) thus producing, effectively, a 22 year terrestrial neutron flux (hence cosmic ray) cycle. We are therefore led to conclude that the dust modulations we are observing in the GISP2 ice dust profile are a result of solar modulations of the cosmic ray flux. We have suggested (Ram et al., 1997) that the GISP2 dust concentration modulations are a consequence of changes in the aridity of the Greenland dust-source areas induced by the solar cycle. Taken together with the present work, this implies that the 11 year dust concentration modulations may be a consequence of solar modulation of the cosmic ray flux which can influence the generation of cloud condensation nuclei (Dickinson, 1975) and the effectiveness of ice-forming nuclei (Tinsley, 1998), hence affecting cloud cover and, consequently, precipitation and aridity. This mechanism is consistent with the work of Svensmark and Friis-Christensen (1997) who demonstrated that global cloud cover was well correlated with the solar modulated cosmic ray flux during the most recent solar cycle. In summary, our work, and that of Svensmark and Friis-Christensen (1997), seems to show that changes in cloud cover due to solar influences affects terrestrial precipitation patterns and, as a result, the aridity of the Greenland dust source areas.

**A ~200 Year (Suess) Dust Modulation Period**

Figure 2(d) exhibits a small secondary peak at ~200 years. To search for the presence of a ~200 year period, we used a running average with \( \sigma_{RA} = 35 \) years. This smoothed out the ~90 year peaks and we could see peaks with a period of ~200 years emerging. Figure 4 is a histogram of the ~200 year periods we measured for the time interval 14,000 to 91,555 YBP. These peaks can be associated with the well-known 200 year Suess radiocarbon line (Damon and Sonett, 1991; Sonett,
in press). The presence of this radiocarbon period reinforces our claim that the GISP2 dust concentration profile is strongly affected by solar influences.

**Conclusions**

We have demonstrated that the GISP2 dust profile is strongly modulated by ~11 year, ~91 year and ~200 year periods. These are all well-known radiocarbon periods (Damon and Sonett, 1991; Sonett, in press). In addition, we showed how adjacent 11 year periods in the GISP2 dust profile can combine to produce a 22 year (Hale) dust modulation period in a way that suggests that the underlying mechanism for this is solar modulation of the proton cosmic ray flux. This last observation was only made possible by the special approach we used of working directly with the smoothed dust data rather than using mathematical algorithms to search for periodicities.

**Fig. 3:** Illustration of how adjacent 11 year dust modulation cycles can combine to generate a 22 year (Hale) dust modulation period.
Fig. 4: Histogram of the ~200 year dust modulation periods measured for 14,000 - 91,555 YBP.

Acknowledgments. We thank John Donarummo, Jr., Charles Sonett and Brian Tinsley for helpful discussions. This work was supported in part by a grant from the Office of Polar Programs at the National Science Foundation.

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(Received January 20, 1999; revised February 26, 1999; accepted March 6, 1999.)