The Accuracy of Cosmogenic ^{10}Be as a Quantitative Measurement of the GCR

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Abstract

A mathematical model is used to study the variations in the cosmogenic ^{10}Be that are of terrestrial origin. The effects studied are due to *(1)* the known changes in the geomagnetic field since 2000BC; *(2)* various degrees of atmospheric mixing, particularly during the "little ice ages"; *(3)* temporal changes in the response function. The ^{10}Be data are frequently derived from 4-8 year ice samples, and it is shown that these will exhibit up to 35% pseudo-random variability as a consequence of the unresolved 11 year variation.

1. Introduction

The variations in the cosmogenic ^{10}Be recorded in polar ice reflect the time dependent modulation of the GCR by heliospheric magnetic fields, and a number of time dependent terrestrial factors [1,7]. The purpose of this paper is to provide the means to minimize the effects of the terrestrial effects prior to the use of the ^{10}Be to study the modulation of the GCR.

2. Method

A mathematical model has been developed that computes the ^{10}Be flux precipitated to the polar caps based upon *(1)* the time varying geomagnetic field (scalar magnitude and location of pole) derived from archeomagnetic observations [8]; *(2)* a number of models of the inter-latitudinal mixing in the atmosphere; *(3)* the averaging effects of the circumpolar motion of the atmosphere; and *(4)* values of the modulation parameter in the range $0< \phi < 1000$MV. The model computes the ^{10}Be production on a 1080 point grid at a spacing of 5° in latitude and 30° in longitude, using the dipole approximation to the geomagnetic field. The response function used in the calculation of the ^{10}Be production was computed using the results of Masarik and Beer [6], and is given in Figure 1A.

3. Results and Discussion

The response function in Figure 1A shows that the ^{10}Be measurements sample a lower portion of the GCR spectrum than does the ground level neutron

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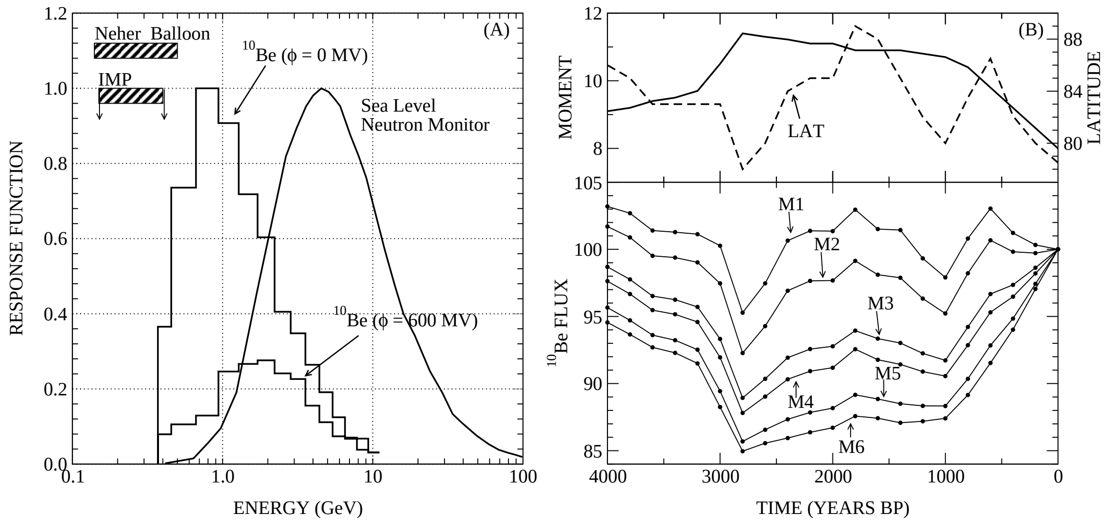

Fig. 1. A. Comparison of the response functions of the ^{10}Be measurements; a high latitude neutron monitor; and other instruments. **B.** The computed variation of the ^{10}Be flux into the polar regions due to geomagnetic effects; and the causal changes in the geomagnetic field.

monitor [9]. Thus the peak response is at 1.8 GeV/nucleon for contemporary times (ϕ = 600MV), shifting to the vicinity of 0.8 GeV/nucleon for $\phi = 0$.

Figure 1B displays the variability introduced into the ^{10}Be measurements by the known variations of the geomagnetic field over the past 4000 years [7,8]. These calculations are for six different models for inter-latitudinal mixing in the atmosphere prior to the precipitation of the ^{10}Be in the polar caps. Model M1 is the case where all the ^{10}Be is from latitudes above 60°; M6 is where the flux represents the global average production; and M2, 3, and 4 represent contributions that extend to 40°, 20°, and the equator, respectively. Note that polar wander is the primary contributor to the variability in the case of the ^{10}Be produced in or near the polar cap (Models 1 and 2); while scalar changes in the geomagnetic dipole moment dominate the global average, M6.

Figure 2A displays the computed dependence of the ^{10}Be flux upon mixing model (for ϕ=0). This shows that changes in inter-latitudinal mixing will result in large changes in the ^{10}Be measurements that might be interpreted as changes in the GCR. The ^{10}Be record exhibits a large decrease since the Maunder and Dalton minima (1700 and 1810), which were coincident with the “little ice ages”, and it has been proposed that this was largely due to changes in latitudinal mixing [3]. For example, Figure 2A shows that if the inter-latitudinal mixing changed from Model 1 to Model 2, the ^{10}Be flux to the polar caps would decrease by 10%. Two methods are used now to set a limit on such changes.

Method 1. Using a mathematical model, J. Haigh has shown that the 11

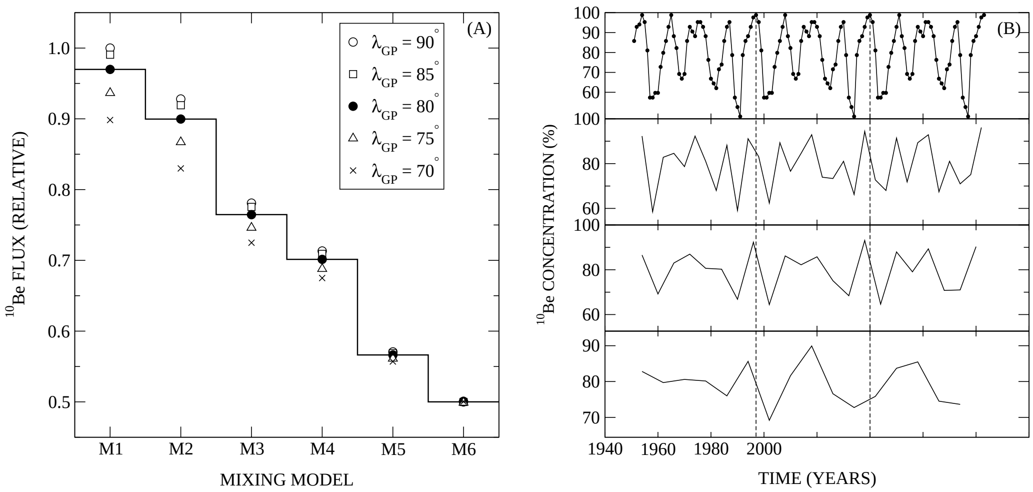

Fig. 2. **A.** The computed dependence of the ^{10}Be flux to the polar regions as a function of 6 different mixing models (M1-6; see text), and the location of the geomagnetic pole. **B.** The input 11 year variation of the ^{10}Be, and the results obtained when 4, 6, and 8 year samples of the ice are used to measure the ^{10}Be.

year variation in solar irradiance results in a 1° poleward shift of the atmospheric structure at sunspot maximum, which is in accord with observation [2]. Lean [4] has estimated that the change in the ultraviolet spectrum between the Maunder minimum and the present was a factor of three greater than used by Haigh. Allowing a factor of two for uncertainties, this suggests a limit of 6° for the poleward shift of the atmospheric structure since 1700AD. Figure 2A indicates that a poleward shift of the atmosphere equivalent to a change from model 3 to 2 would result in a 13% increase in the ^{10}Be flux. The change of $\leq 6°$ estimated above is smaller than the 20° shifts implicit in the models in Figure 2A, and pro-rata allowance predicts a $\leq 4\%$ increase in the ^{10}Be flux between the Maunder minimum and the present. That is, the effects of changes in atmospheric transport are too small, and the wrong sign, to explain the observed decrease.

Method 2. The production of nitrate ions in the equatorial stratosphere exceeds the production in the polar cap by a factor of 10, and is only weakly dependent on solar activity [10]. Both the ions and the ^{10}Be attach themselves to aerosols and then participate in identical transport and mixing within the stratosphere and troposphere. The aerosols are precipitated eventually, taking the nitrate and ^{10}Be with them, and sequestered in the polar ice. The nitrate can therefore be used as an independent detector of changes in atmospheric mixing. Consider the hypothesis that the higher values of ^{10}Be corresponding to the Dalton and Maunder minima were due to changes in atmospheric mixing [3]. Reduced stratospheric transport from lower latitudes would result in an increase in the polar ^{10}Be flux, and a concomitant reduction in the nitrate precipitated in the polar regions. Measurements show that the concentration of nitrate at the South Pole was constant to within the statistics (±3%) over the period that includes the Dalton and Maunder minima [5]. This result, together with Figure 2A, indicates that the changes in mixing during these events resulted in <3% change in the ^{10}Be flux.

In practice, ice samples may represent between 4 and 8 years of ice. This is near, or below the Nyquist sampling frequency required to resolve the 11 year variation; and as a consequence the 11 year variations will contribute a large "noise-like" variability to the observed data. To evaluate this, the Climax neutron monitor data for the period 1954-1997 were used as an input time series; converted to the equivalent ^{10}Be time series using the regression given elsewhere in these proceedings; and processed through 4, 6 and 8 year box car averages. The resulting output series are given in Figure 2B. Note that *(1)* the character of the 11 year variation has been lost; *(2)* the output series resembles random noise ; *(3)* the range is a large percentage of the amplitude of the 11 year variation used as the input. Beer *et. al.* have estimated that annual ^{10}Be data contains 4-10% of measurement and sampling noise [1], and therefore Figure 2B shows that the unresolved 11 year variation can be the largest source of noise in the ^{10}Be data. Signal processing techniques allow this pseudo-noise to be eliminated.

4. Conclusions

It is concluded that *(1)* the response function of ^{10}Be data has its maximum in the range 0.8-1.8 GeV/ nucleon; *(2)* known changes in the geomagnetic field have introduced up to 15% variations into the ^{10}Be data over the past 4000 years; *(3)* less than 4% variability is introduced into the ^{10}Be data by climate controlled changes in atmospheric circulation; *(4)* under some circumstances, the dominant "random noise" in the ^{10}Be data is due to the 11 year variation of the GCR.

5. References

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