29th International Cosmic Ray Conference Pune (2005) **2**, 405-408

^{10}Be Concentration in the Queen Maud Land Ice Shelf, Antarctica

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The radionuclide ^{10}Be is produced in the atmosphere by cosmic rays. When it filters out and settles in polar ice, it becomes a powerful tool to study the variations of the cosmic ray intensity in the distant past and, from that, solar activity before the era of systematic solar observations [6]. The relationship between the cosmic ray intensity and the ^{10}Be concentration is, however, an inferred one, because cosmic rays have only been observed during the past 50 years or so, while there are only a few ^{10}Be records for this period. We report here on a pilot experiment to cut ice from the exposed ice shelf near the South African base, SANAE, in Queen Maud Land, Antarctica, from which this ^{10}Be/cosmic ray relationship may be established better.

1. Introduction

Solar activity has been studied systematically much further back into the past than the cosmic ray era, by observations of the number of sunspots [8]. This firmly establishes the 11-year cycle as a semi-permanent feature, as well as the so-called Grand Minima of solar activity, such as the Maunder (AD 1645 - 1715), Dalton (AD 1800 – 1830), and Gleissberg (AD 1880 – 1910) minima. Sunspots are, however, not directly related to the heliomagnetic processes that cause this modulation [11], and are therefore not the best indicator to infer past levels of the cosmic ray intensity and the parameters that influence it.

When cosmic rays strike the atmosphere, they fragment the nuclei of air molecules, one of the fragmentation products being the isotope ^{10}Be. This ^{10}Be settles in polar ice, and its concentration in cores drilled in Antarctica and Greenland during the past 20 years [5,15] has produced an indirect cosmic ray record that extends over the past 100,000 years [18]. Several aspects of experimental and theoretical ^{10}Be/cosmic ray studies can be found in Caballero-Lopez et al. [6] and McCracken et al. [11].

The relationship between the ^{10}Be concentration in polar ice and the cosmic ray intensity is an inferred one, based on calculations of the ^{10}Be yield by the nuclear processes in the atmosphere [9,17], and its transport to polar regions. This relationship is not well measured in deep, vertically drilled boreholes, which are often protected by casings in the shallowest layers which are not yet sufficiently compacted. Percolation of melt-water in the firn causes additional uncertainties. A further problem in the ^{10}Be/cosmic ray relationship is the uncertainty about how quickly the ^{10}Be settles. Due to the spectrometric effects of the geomagnetic field on the charged cosmic ray particles, the ^{10}Be concentration in polar ice will be different if it settles fast and locally, as opposed to the situation where there is global mixing before it settles after a much longer time [10,11,16]. The ratio between the amplitudes of the 11-year cycles in the ^{10}Be and the data from a high latitude neutron monitor, each expressed as a percentage of the relevant sunspot minimum value, is a sensitive measure of this mixing effect. Thus it varies between ~2.3 for local production, and ~1.7 for global mixing, and an accurate measurement of this ratio is an important goal of the planned experiment. In addition, the distinction between wet and dry deposition [7] might be necessary to explain the transfer of

^{10}Be from the atmosphere into the firn and ice. These processes and their relative importance depend on the accumulation rate of snow at the site [2]. Pits of several meters deep have been dug [4,16] in the polar ice to measure the ^{10}Be concentration deposited in recent times more accurately, while there are also other studies on shallow cores [1]. These experiments have not yet yielded conclusive results on how to reliably infer the galactic cosmic ray flux, because every location seems to be unique and no one is perfect in terms of recording past changes in galactic cosmic ray intensity. To improve our knowledge about ^{10}Be as a tool to reconstruct cosmic ray intensity, it is crucial to enlarge our data base of the past few decades regarding its production and atmospheric transport. It is in this situation that the ice shelf in Queen Maud Land, Antarctica offers a promising and cost-effective opportunity, because it is frequently visited and little investment has to be made in infrastructure and equipment to sample this ice.

2.Pilot experiment

The ice shelf at ~ 70^{o} 15'S, 2^{o}50' W, where the supply vessel SA Agulhas offloads on its annual relief voyage is between 30 and 50 m high, and it contains clearly visible annual accumulation layers of ~ 1m thick. The accumulation is mostly due to drift snow from other regions because the local precipitation is very low; from 1960 to 1994 there were, on average, only 14 snow days per year. This drift is expected to be fairly local in extent, within a few 100 km, and the clearly visible annual melt layer that forms in summer is an indication that different years do probably not get mixed. Due to the height of the shelf, an offloading ramp of between 10 and 15 m deep has to be cut every season. The aim of the main experiment is to eventually cut ice from the face of the shelf, but for the pilot experiment the offloading ramp offers an easy and safe opportunity to test equipment and techniques, and to acquire experience.

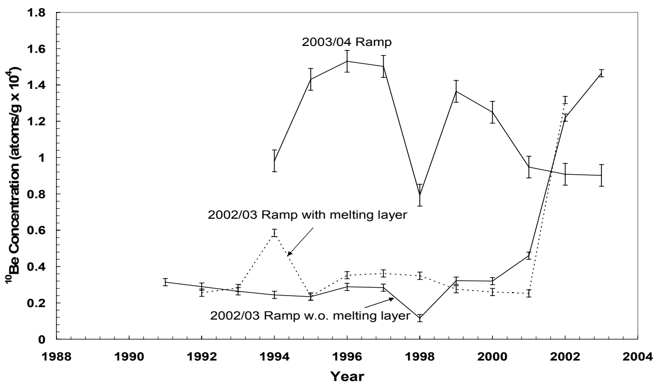

Figure 1. The ^{10}Be concentrations as measured in the two off-loading ramps.

This pilot experiment was conducted during the December 2003/January 2004 voyage of the SA Agulhas. Samples were cut from the exposed annual layers within the ramp. Two techniques were tested, namely a 10 cm diameter core driller applied horizontally, and a mechanical chain saw to cut vertical wedges of ~ 1 m high (the full thickness of the layer), ~ 30 cm wide at the front face, and ~ 50 cm deep on the two sloping faces of the wedge. This second technique proved to be the fastest and easiest by far. It also yielded an integrated record for the whole year, not just for parts of it. Between 1 and 2 kg of the back portion of this wedge, furthest away from the face, was used as sample. After adding a spike of 0.3 mg ^{9}Be, the samples were melted. Subsequently, the Be was filtered (pore size 45 μm) and separated from the water and retained, using ion exchange columns. This allowed us to transport the samples after the expedition in a convenient way to Dübendorf (EAWAG), Switzerland where they were processed and prepared for measurement with the Zurich AMS facility, jointly operated by the Paul Scherrer Institute and ETH Zurich. Two ramps were actually used: the one cut for the 2003/04 season, as well as the one used for the previous 2002/03 season. Both these ramps were sampled on the same expedition, in the 2003/04 season. This gave an opportunity to test repeatability.

3. Results and discussion

The measurements are summarized in [13] and plotted in Figure 1. There are two results for the 2002/03 ramp, with and without the annual melt layer. The difference between them is marginally significant, but will not be explored here.

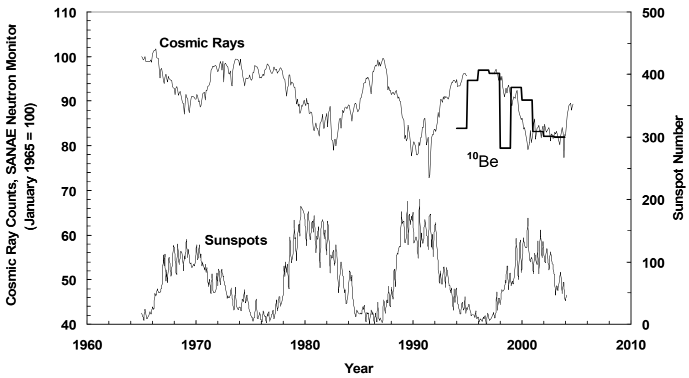

Figure 2. Cosmic ray intensity as recorded by the SANAE neutron monitor since 1965, together with sunspot measurements [8] The histogram in thick lines is the ^{10}Be concentration measured in the pilot experiment, with the concentration scale shown in Figure 1.

There is a large difference in 10Be concentration between the two ramps. In the 2003/04 ramp it is about 4 times higher than in the 2002/03 one, except for the last two years. This difference is puzzling. It would be surprising if this were due to local variations in 10Be deposition because the ramps are only ~ 300 m apart. Another explanation is that the 10Be leaks or filters out of the ice as it stands exposed. This may be due to sea spray and mist penetrating the ice and dissolving the 10Be. This does, however, not explain why the varying concentrations observed in the 2003/04 ramp leak out in such a manner as to produce a fairly constant concentration after a year of exposure in the 2002/03 ramp. It is also unclear why the concentrations in the two uppermost layers are so different, and where the 10Be goes to if it dissolves. It probably cannot penetrate through the annual ice layers. There may also be processes involved which are connected to strong winds leading to air (and ^{10}Be) movement in the firn. These questions must be addressed in follow-up experiments, i.a. by taking surface samples from many different locations in the general vicinity of the Sanae base.

The time variation of the ^{10}Be concentration in the 2003/04 ramp is approximately as expected, as is demonstrated by plotting it as a histogram onto the cosmic ray intensity of Figure 2. It is arbitrarily normalized so that its variation has the same amplitude as that of the cosmic ray variation. In 1998 there is a big discrepancy with the cosmic ray intensity, with a much lower concentration than expected. This discrepancy can not be attributed to any known effect. The 1994 concentration is also low. The other points are in general agreement with the cosmic ray intensity, but the ^{10}Be concentration lags up to one year behind the cosmic ray intensity, which agrees with earlier estimates of the mean atmospheric residence time [3,14]. Determining this phase lag is one of the prime objectives of this experiment.

4. Conclusions

This pilot experiment has established a workable technique to sample ice from the ice shelf, but it has delivered unexpected first results which may be due to a variety of reasons. The experiment was repeated on 23 to 25 January 2005, using the same two ramps, but the samples have not yet been processed. The first aim of this second attempt is to test repeatability and/or whether aging effects can be seen after an additional year of exposure to the atmosphere. If these new results show that the concentration in the 2003/04 ramp is reduced to that of the 2002/03 ramp, it confirms the leakage hypothesis, and further cutting from the exposed ice shelf, as planned for the main experiment, will not be meaningful. If, however, these discrepancies are resolved and the reasons for them are properly understood, sampling from the shelf itself will begin. This will not be done in summer, but in September/October when there is still bay ice from the winter season below the shelf, so that the work, to be done in abseiling mode, can be guided from the top and bottom of the shelf.

5. Acknowledgements

This work was funded by the South African National Antarctic Programme through a research grant and logistical support. It was also supported by the Swiss National Science Foundation, while the Maryland component was funded by NSF grant ATM 1017181.

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