Solar Particle Fluences over the Solar Cycle

There have been more than 80 large solar energetic particle (SEP) events during the more than seven years since the launch of ACE. These events dominate the integrated fluence particle below 100 MeV/nuc. ACE was launched under during solar minimum conditions in late 1997 and the mission includes essentially all of the solar maximum period during solar cycle 23. We present here SEP fluence measurements from the SIS instrument on ACE (see Stone et al. 1998) extending from late 1997 to mid-2005.

Solar Energetic Particle Data

Daily average intensities of 10 to 90 MeV/nucleon oxygen nuclei are shown in Figure 1 for the period from 1997:240 to 2005:192. These data were obtained from daily-average intensities that are available at (http://www.srl.caltech.edu/ACE/ASC/level2/index.html). The differential intensities of oxygen (in units of particles/cm²-sr-s-MeV/nuc) were multiplied by the energy intervals involved and by $4\pi$ (assuming an isotropic intensity).

This plot is dominated by a series of spike-like SEP events that begin in late 1997, reaching maximum frequency in from mid-2000 thru mid-2002. A few of the more prominent events are identified. In the largest of these (the Bastille Day event July 2000 and the October 28, 2003 events) the intensity is more than $10^5$ times greater than quiet-time levels. A number of the large SEP events during solar-cycle 23 were among the largest observed since 1976. See http://umbra.nascom.nasa.gov/SEP/seps.html.

Minimum Quiet Time Levels

Beneath the SEP events one can see that the underlying quiet-time level varies over the solar cycle. At solar minimum the 10-90 MeV intensity is dominated by anomalous cosmic rays – singly-charged ions.
accelerated at the solar wind termination shock – which vary in intensity by a factor of \( \sim 100 \) over the solar cycle. By mid-2000 the minimum level has decreased by a factor of \( \sim 20 \), and galactic cosmic rays (GCRS) make the largest quiet-time contribution. There are very few quiet days from mid-2000 to mid-2002. The rapid increase in the quiet-time levels in 2004-2005 is due to the recovery of ACR oxygen as solar minimum approaches.

**Integrated Fluences of SEPs**

In Figure 2, the daily intensity of 10 to 30 MeV/nucleon oxygen has been integrated over time, starting with the launch of ACE. The total accumulated fluence of \( \sim 11.5 \text{ million oxygen/cm}^2 \) is made up of a series of step-like increases due to those SEP events with the largest intensity >10 MeV/nuc. There appear to be three large steps that each account for most of the total: the July 14, 2001 (Bastille Day) event; the series of events in Nov-Dec 2001; and the “Halloween events” – a one-week period in late October and early November 2003, well beyond solar maximum, that accounts for almost 1/3 of the 7-year fluence. The largest of these was the October 28, 2003 event, comparable in intensity to the Bastille Day event (see Cohen et al. 2005, Mewaldt et al. 2005). Figure 3 shows the integrated fluence of 10 to 36 MeV/nuc Fe. Although the long-term Fe fluence is \( \sim 10\% \) of that of oxygen, there are significant event-to-event variations in the Fe/O ratio which can be seen by comparison of Figures 2 and 3 (see, e.g., Cohen et al. 1999). For example, the Nov. 6, 1997 event is Fe rich, while the April 20, 1998 event is Fe poor relative to oxygen. It is also clear that the Bastille Day event is more Fe-rich than the October 28, 2003 event.
Listings of the daily-average intensities of O and Fe that went into making Figures 2 and 3, as well as their integrated fluences since the launch of ACE, can be obtained by downloading the following file:


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References


“Heavy ion abundances and spectra from the large SEP events of October-November 2003”, C. M. S. Cohen et al., to be published in Journal of Geophysical Research (2005).