SOLAR-PROTON FLUXES RECENTLY NEAR THE EARTH. Robert C. Reedy[1],
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Summary: The event-integrated fluences of energetic solar protons during the first part of the current solar cycle, which started in 2009, have been compiled and compared with results for the previous 5 solar cycles (1954-2008). The average fluxes for the last 5 years are lower than all of the previous solar cycles except 1976-86. These low fluxes are consistent with other recent solar activities (e.g., sunspots) being low.

Introduction: After a very slow start, the current solar cycle (number 24), which started on about Jan. 2009, has picked up activity [1].

The solar-proton fluxes near the Earth since 2009 were compiled from various sources, mainly the archives for the daily energetic particle data at websites for NOAA and the OMNIWeb at GSFC's Space Physics Data Facility. The data at these sources were incomplete, with data gaps or not being recently updated (a problem getting worse with budget crunches!). Thus, the results reported here are preliminary, and no tables for event-integrated fluences are presented. They are adequate to allow one to compare solar particle data for the current solar cycle with previous data.

The daily fluxes of solar protons above energies of 10, 30, and 60 MeV are plotted for the last 4 years in Fig. 1. There were no solar-proton events (SPEs) in 2009 [1]. Some data are missing, and there are no data after 30 Nov. 2013. During this period, the fluxes of galactic-cosmic-ray (GCR) particles were decreasing as solar activity increased, as seen in the fluxes when there are no solar protons.

There was a weak SPE in early Aug. 2010. The year 2011 had higher fluxes of SPEs. The 2 biggest SPEs were in late January and the middle of March of 2012. The next largest events depend on the proton energy, being the end of Sept. 2013 for >10 MeV but being for several other SPEs for higher energies.

Event-Integrated Solar-Proton Fluxes: The available data for daily particle data were compiled. In some cases, the results for several sources could be compared and generally agreed well. Differences were seldom great, and suggest that data from one website is probably good without checks. Later reports will try to use more data and include data evaluations.

Results were only used if the event-integrated fluences above 30 MeV were about 2×10^6 cm^{-2} or more. As before, the energy of 30 MeV was selected because it has been shown it to be more relevant than the often previously used 10 MeV.

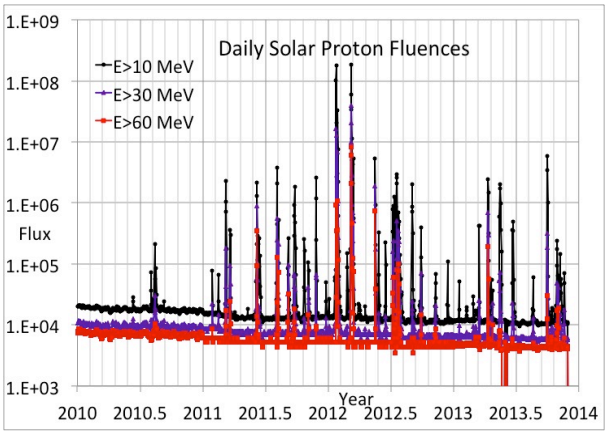

Fig. 1. The daily-integrated solar-proton fluxes are plotted versus date from Jan. 2010 through Nov. 2013 above 3 energies, 10, 30, and 60 MeV. There are some data gaps in 2013 for the >60 MeV data.

Average fluxes for each solar cycle. Table 1 gives the sums of event-integrated fluences at 1 AU from the Sun and their sum divided by the time in that period for recent solar cycles. Solar-cycle boundaries were selected to be the months with the lowest monthly smoothed sunspot numbers. The selection of this boundary is not critical as few SPEs occur within about 2 years of this boundary, as seen in the left of Fig. 1. For each SPE, the event-integrated fluences above 10-, 30-, and 60-MeV were used.

Table 1. Solar-cycle-averaged solar-proton fluxes >10, >30, and >60 MeV and the exponential-rigidity spectral shape (R_0, in MV) are given for the last 5 full solar cycles [2] and the first 5 years of the current solar cycle. Dates are months and year. The number of events used for each cycle is given (#). Average fluxes are in units of proton/cm^2/s using the actual length of each solar cycle (to the nearest month).

SC	Dates	#	>10	>30	>60	R_0
19	5/54-9/64	63	≈196	71	≈26	100
20	10/64-4/76	45	89	24	8	83
21	5/76-2/86	56	59	10	3	75
22	3/86-7/96	31	97	18	5	72
23	8/96-12/08	44	216	46	11	69
24	1/09-11/13	16	63	10	2	60

For the whole of solar cycle (SC) 19, the fluences >10 and >60 MeV were calculated using the >30 MeV results and an exponential rigidity spectra shape of 100 MV [3]. Those fluences and average fluxes are very uncertain. The fluences and average fluxes for the last 4.4 solar cycles are based on satellite measurements and are probably not better than about 20%. The values of the exponential rigidity parameter (R_0), the parameter that describes fairly well the energy spectral shape of solar protons, are similar to those over the last 10^4 to 5×10^6 years [2].

Results: The average proton fluxes for the current solar cycle are low. All solar cycles but SC 21 had average fluxes higher than the current cycle. The low level of solar-proton fluxes recently is consistent with the trend for sunspots, which have also been lower than typical. The recent low levels of solar activity have resulted in the highest fluxes of galactic cosmic rays in over a half a century as observed in terrestrial neutron monitor data [e.g., 4].

The high fluxes of SPEs in late 2011 and early 2012 produced high activities of short-lived solar-proton-produced radionuclides in the Sutter's Mill meteoroid, such as ^{56}Co, before it fall on 22 April 2012 [5,6]. Meteorites that fall soon should be quickly counted to look for short-lived radioactivities that could be made by solar protons. Smaller objects are especially good because they tend to have less ablation (which usually removes the outer ~1 cm of the surface where most solar-proton-produced activities are made).

These high fluxes of solar protons were also observed by the STEREO spacecraft on the other side of the Sun from the Earth and by the Gamma Ray and Neutron Detector (GRaND) on the Dawn spacecraft before and during its orbit as the asteroid 4 Vesta [1]. The GRaND data during SPEs could not be used for elemental mapping [7].

Discussion: The event-integrated fluences of solar protons for the current solar cycle are low, consistent with other data such as sunspot numbers. For the last 60 years, only solar cycle 21 (1976-1986) was similarly low. SC21, like the current SC, did not have any huge solar particle events, unlike most solar cycles.

However, as in SC20 (the Aug. 1972 SPEs), a huge SPE late in the current cycle can occur in the next about 4 years, greatly increasing the average fluxes. Given the relatively low levels of solar activities to date, it is very possible that this current solar cycle will be a relatively mild one.

Fresh meteorite falls, especially smaller objects, should be quickly counted to look for short-lived radionuclides made by solar protons. The Sutter's Mill meteorite that fell in Apr. 2012 had some samples with high activities of such radionuclides; consistent with the high solar-proton fluxes the year before it fell.

The lack of very large solar particle events recently has been good for space missions like Dawn because spacecraft have not been seriously affected by high dose of energetic particles. Also, gamma-ray detectors, like those in GRaND, have not had high levels of solar-proton-produced radionuclides made in them. The data from the Mars Odyssey gamma ray detector was often of little value for martian elemental mapping because of the high levels of short-lived solar-proton-produced radionuclides, such as ^{48}Ti, or because of radiation damage in the detector [8].

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