STATISTICAL DISTRIBUTION OF GEOMAGNETIC ACTIVITY LEVELS AS A FUNCTION OF SOLAR PROTON INTENSITY AT EARTH

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Abstract

We have performed a statistical analysis of the geomagnetic activity K_p values over solar cycle 22. We find a significantly different distribution of geomagnetic activity for periods when the solar proton intensity is enhanced. In general the larger the proton flux, the higher the geomagnetic activity level. Implications for space operations will be discussed.

1 Introduction:

The first mission to construct the International Space Station (ISS) was in November 1998. At the present time a total of 43 missions are planned before the construction is completed. Many of these missions include extended periods of extra vehicular activity by the astronauts involved in the construction phases.

In addition to safety measures associated with the actual construction of the station, the increased exposure of personnel to space radiation must also be considered. The original Space Station was to have been in a low inclination orbit; the present station is planned for a higher inclination orbit (51.6 degrees). This higher inclination orbit will have additional particle exposure from both galactic and solar cosmic radiation. Although much of the orbital path is well shielded by the earth's magnetic field, the space station will be exposed to the entire cosmic radiation spectrum above approximately 500 MeV over the high latitude North American region and south of Australia.

Some of the construction missions involve a number of extravehicular sorties. Medical and technical personnel at NASA must plan each mission for maximum effectiveness and minimum radiation exposure since it is conceivable that radiation exposure could restrict the amount of time an astronaut will be permitted to perform specific duties. Three sources of radiation exposure must be considered: galactic cosmic radiation, solar proton events, and the trapped protons in the South Atlantic.

The galactic cosmic radiation is inversely proportional to the solar activity cycle. Technology exists to estimate the amount of exposure from galactic cosmic radiation a few weeks before each mission. Trapped particle flux in the South Atlantic, although more variable than the galactic cosmic radiation, can also be estimated provided interplanetary conditions are relatively quiet.

The third source of radiation is from solar particles. These random events can occur anytime during the solar cycle although they are more probable during the years of solar maximum intensity - precisely the same period of time as construction of the ISS will be accomplished. Although not a "show stopper" as some people believe, these events are operational constraints that must be considered in mission planning.

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2 Solar Proton Events and Geomagnetic Disturbances:

Solar proton events are typically associated with major disturbances on the sun. The distribution of solar protons within the earth's magnetosphere is similar to that of galactic cosmic radiation. The geomagnetic field shields all but the most energetic solar protons from penetrating within a few hundred km of the surface of the earth with the exception of the polar latitudes. However, the spectrum of solar protons is typically much softer than the galactic cosmic radiation spectrum. During a solar proton event, the particulate radiation below ~100 MeV is frequently increased by several orders of magnitude. The particle spectrum and magnitude varies from event to event and is somewhat unpredictable.

Since the quiescent geomagnetic field essentially shields the planned ISS orbit from all but the most energetic solar protons, and since solar proton events occur at random, it would initially appear that solar protons would not be of major concern with respect to ISS construction. However, during periods of geomagnetic disturbances, the geomagnetic cutoff rigidity decreases, the shielding effect is diminished, and energetic protons can penetrate to considerably lower latitudes than during quiescent conditions.

Significant decreases in geomagnetic cutoff rigidities typically prevail for only a day or two and the increased galactic cosmic radiation to the ISS orbit would not significantly contribute to the overall radiation dosage experienced by the astronauts. However, if these decreases occur when solar protons are present, the radiation dosage could be appreciably increased.

The occurrence of a significant solar proton event together with a major geomagnetic disturbance is extremely likely, particularly during solar maximum. Consider the following scenario:

(1) A major solar event (X-ray, radio, etc.) near the central meridian of the sun. A high energy solar proton event and fast interplanetary shock are associated with this activity.

(2) Solar proton increase at the earth within a few hours.

(3) The solar proton flux at the earth remains high, perhaps even increasing, as the fast interplanetary shock moves toward the earth accelerating additional protons.

(4) The arrival of the fast interplanetary shock, typically within 20-30 hours, produces a SSC in the geomagnetic field which significantly lowers the cutoff rigidities at high to mid latitudes.

(5) The enhanced flux of solar protons due to local shock acceleration still remains high and penetrates to latitudes lower than before the shock arrival. The major solar proton/geomagnetic storm events of August 1989, October 1989, March 1991, June 1991 and February 1994 are examples of this type of solar/interplanetary phenomena.

Using data from solar cycle 22, we report on the percentage of geomagnetically disturbed periods when significant solar protons would have access to lower geomagnetic latitudes than under geomagnetically quiescent conditions.

3 Method and Results:

The databases used were the three hour geomagnetic K_p values for the 22nd solar cycle (i.e. 29,224 values between 1 October 1986 and 30 September 1996) and the > 10 MeV solar proton intensity recorded by the GOES spacecraft at geosynchronous orbit. In this paper we report on two flux levels: 10 protons/(cm^2-sec-ster), and 100 protons/(cm^2-sec-ster). Whenever the proton flux reached those levels, the entire day (for convenience in calculations) was taken to be a day of enhanced solar proton flux.

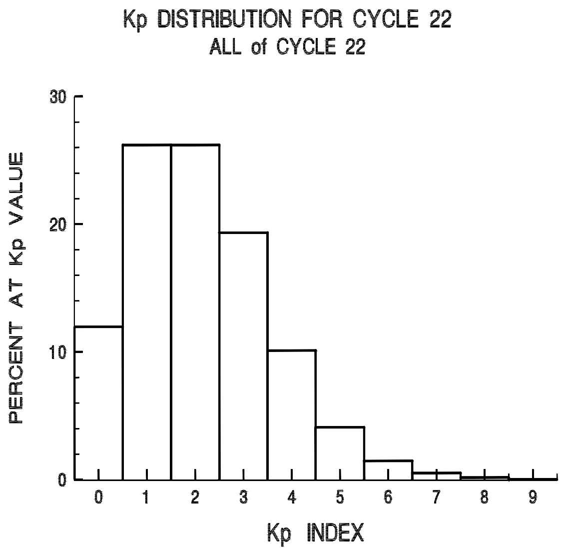

Figure 1. Illustration of the Kp distribution of the geomagnetic activity during solar cycle 22. Note that the geomagnetic field was relatively quiet (K_p values ≤ 2) 64% of the 22nd solar cycle, moderately disturbed ($3 \leq K_p \leq 5$) 34% of the time, and very disturbed ($K_p \geq 6$) the remaining 2% of the time.

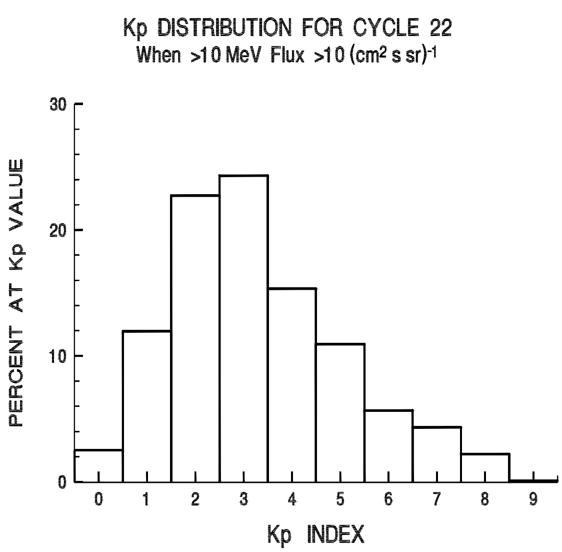

Figure 2. Illustration of the Kp distribution of the geomagnetic activity when a solar proton event is in progress. The geomagnetic field is relatively quiet 37% of the time, moderately disturbed 51% of the time, and very disturbed the remaining 12% of the time.

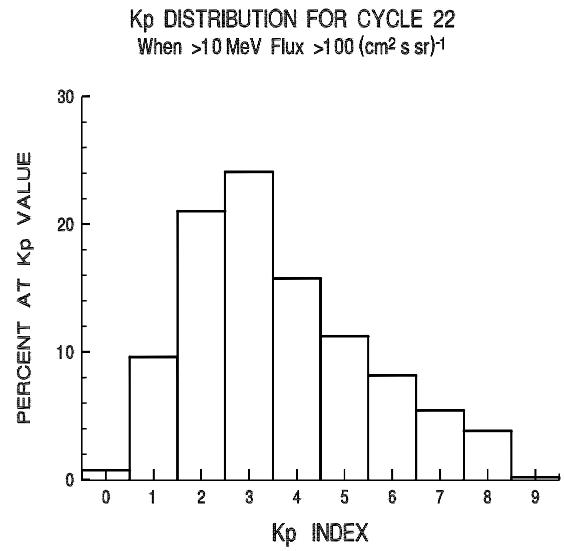

Figure 3. Illustration of the Kp distribution of the geomagnetic activity when a large solar proton event is in progress. Note that there is a low probability of a quiet geomagnetic field.

We first determined the distribution of the entire 29,224 K_p values for the solar cycle. These results are shown in Figure 1. This portion of the study included the periods of enhanced solar proton flux. Next the distribution of K_p values for all days where the > 10 MeV solar proton flux exceeded 10 protons/(cm^2-sec-ster) was determined. These results, shown in Figure 2, include 1272 K_p values (i.e. 159 days). Finally, the distribution of K_p values for those days where the flux exceeded 100 protons/(cm^2-sec-ster) was determined. Figure 3 presents these results; 552 K_p values (69 days) were included.

4 Discussion:

Figure 1 illustrates that the geomagnetic field is relatively quiet (K_p values $\leq$2) 64% of the 22nd solar cycle, moderately disturbed ($3 \leq K_p \leq 5$) 34% of the time, and very disturbed ($K_p \geq 6$) the remaining 2% of the time. Note that these percentages include all K_p values for the entire solar cycle including those periods where solar protons were present.

When we consider only those periods when the 10 MeV flux exceeds 10 protons/(cm^2-sec-ster), we find a different distribution. The geomagnetic field is relatively quiet 37% of the time, moderately disturbed 51% of the time, and very disturbed the remaining 12%. Finally, for the time periods when the 10 MeV flux exceeds 100 protons/(cm^2-sec-ster), we obtain 31%, 51% and 18% for quiet, moderately disturbed and very disturbed geomagnetic conditions.

These results show that when a significant solar proton flux is present, the geomagnetic field is frequently disturbed. During these times, solar protons can penetrate to lower (i.e. equatorward) latitudes than during quiescent periods. This effect is particularly true when the >10 MeV solar proton flux exceeds 100 protons/(cm^2-sec-ster). Major solar activity giving rise to these high proton fluxes is much more likely to be associated with a fast moving interplanetary shock which, if it encompasses the earth, would result in a major geomagnetic disturbance that would continue for many hours.

While radiation dosage from all sources must be considered, the greatest concern is the dosage to blood forming organs. This would be important when proton energies exceed ~30-50 MeV, particularly during extravehicular activity at high latitudes. Many factors must be considered during each mission. While it is difficult to adjust the construction schedule once a mission has been initiated, it may be prudent to delay a specific phase of construction if a major proton event and simultaneous geomagnetic storm is in progress.

4 Conclusions:

Using geomagnetic and solar proton data for solar cycle 22, we have shown that major geomagnetic disturbances are more likely to occur during times of significantly enhanced solar proton fluxes at the earth than during quiescent periods. This decrease in geomagnetic shielding during major solar proton events allows solar protons to penetrate to lower latitudes than during quiescent conditions. Although not "show stoppers", these factors contribute to the overall radiation dosage that astronauts will experience during the construction of the International Space Station.