Proceedings of ICRC 2001: 4060 © Copernicus Gesellschaft 2001

ICRC 2001

Comparisons of E $>$ 20 MeV proton geomagnetic cutoffs observed on SAMPEX with predictions based on the SEPTR model

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Abstract. A computer model, SEPTR (solar energetic particle tracer), has been developed at Rice University to calculate upper rigidity cutoffs of energetic particles entering the magnetosphere. This model may serve as a tool for making space environmental predictions during solar energetic particle (SEP) events and therefore must be tested using SEP data from polar orbiting spacecraft. We use data from the 20 - 29 and 29 - 64 MeV proton channels of the Proton/Electron Telescope on the SAMPEX satellite for a number of polar cap passes during large SEP events to determine the experimental geographic cutoff latitudes for the two energy ranges. These are compared with the calculated cutoff latitudes based on the SEPTR program. With the International Geomagnetic Reference Field (IGRF) of 1995 as the geomagnetic field model in SEPTR, the predicted cutoff latitudes are systematically too far poleward by about 5° to 10°. The differences are considerably reduced with the use of the Tsyganenko magnetospheric field model, but a systematic poleward error remains. We find no trend in the latitudinal cutoff differences with increasing Kp in SEP events accompanied by geomagnetic storms.

1 Introduction

Space radiation is now recognized as a serious hazard for satellite operations, communications, and human space flights. With the construction of the International Space Station (ISS), the vulnerability of the human crews on the ISS to solar energetic particle (SEP) events has become an important problem and was the subject of a recent report by the Space Studies Board of the U.S. National Research Council (NRC) (2000). The ISS orbit is inclined at 51.6° to the equator, placing large parts of its orbit in high-latitude regions accessible to SEPs. At this time only 12 of the 50 ISS flights on the NASA manifest have occurred, and the most recent flight 6A, from 2001 April 19 to May 1 on STS-100, occurred just after two very intense SEP events on April 15 and 18. The ISS report (NRC, 2000) concluded that the probability of a significant high-latitude SEP event during an ISS construction flight is nearly unity.

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The ISS radiation problem is compounded by the statistical tendency for SEP events to occur during periods of high geomagnetic activity, resulting in larger polar impact zones for the SEPs (Shea et al., 1999). The impact zones tend to increase with increasing SEP intensities (NRC, 2000). Two recommendations of the ISS report (NRC, 2000) were the following. Recommendation 2: provide models that use real time data to specify the SEP intensities and the geographical regions to which they have access. Recommendation 5b: extend the range of SEP predictions from the present $\geq$ 10 MeV to biologically effective energy ranges. The report also called for critical evaluation of methods to map the latitudinal cutoffs for SEPs at the ISS altitude. Work reported here addresses these recommendations.

The SEPTR (Solar Energetic Particle Trajectories in Model Magnetospheres) model is based on a PhD thesis of Orloff (1998). That model uses the technique described by Smart et al. (2000) to calculate the vertical proton rigidity cutoffs at 450 km for energies from 1 MeV to 1 GeV. The basic technique is to integrate the equations of motion for a negatively charged particle moving upward from a starting point through the magnetosphere defined by a given geomagnetic field model to determine whether it can reach 25 Ro. If it can, then it is assumed that a positively charged particle from outside the magnetosphere can reach the point in question. The technique was used to calculate the vertical cutoff rigidities for quiet (Smart et al., 1999a) and magnetically disturbed (Smart et al., 1999b,c) times for an assumed ISS altitude of 450 km, although the actual ISS altitude is now 354 km. Those calculations used a Tsyganenko (1989) magnetic field model with an extension to high Kp by Boberg et al. (1995).

Since the SEPTR program calculates vertically incident proton fluxes, the ideal instrument to use for validation of the calculations is a zenith pointing detector of small opening angle. The Proton/Electron Telescope (PET) on the SAMPEX satellite (Baker et al., 1993) is well suited for this purpose since it has an opening angle of 58° and is normally zenith pointed. The orbit of SAMPEX has an altitude of 520 by 670 km and an 82° inclination. The utility of the PET data in determining variations of the cutoff invariant latitudes as a function of Dst has been shown by Leske et al. (1997).

2 Data Analysis

We selected for analysis six events with high SEP intensities and at least moderate peak values of Kp and Dst. Table 1 gives the selected dates and maximum Kp. For each event we determined the geographical cutoff locations for two proton energy ranges of the PET detector, 20 to 29 MeV and 29 to 64 MeV. Each cutoff location was taken to be the point at which the rate of change of the PET intensities was maximum. For each full day of data there were 15 or 16 orbits, so with two cutoff points for each polar pass there were up to 64 cutoff locations per day. All cutoff locations were tabulated and plotted on a world grid.

Table 1. Average Latitudinal Differences for the Six Analyzed SEP Events

Start Date	Max Kp	ΔL 24 MeV	ΔL 46 MeV
30/10/92	6	2.7°	1.6°
06/11/97	7	3.0°	2.2°
25/08/98	8	2.4°	1.7°
30/09/98	6-	2.4°	2.1°
12/09/00	6+	2.5°	1.7°
09/11/00	6+	1.8°	1.6°

For each SAMPEX orbit the cutoff locations were calculated for assumed proton energies of 24.5 and 46.5 MeV and a fixed altitude of 600 km by the SEPTR program using the International Geomagnetic Reference Field (IGRF, 1992) and the combined IGRF and Tsyganenko (1989) reference field. In the latter case, which we refer to simply as the Tsyganenko field, we used as input the Kp value at the time of each cutoff point. The Tsyganenko field accepts only Kp values up to 5, so for Kp $>$ 5 we used only Kp = 5. For each polar pass we compared the observed geographical cutoff latitudes with those calculated from the two reference fields. We could then compare the cutoff predictions of each reference field with the observed cutoff locations for each PET energy range and examine the differences as functions of Kp.

We find that the calculated cutoff latitudes are almost always poleward of the observed cutoff latitudes. Figure 1 shows the comparison for 29 to 64 MeV protons over the period 1992 October 29 through November 5. The IGRF mean difference was 5.7° and the Tsyganenko mean difference was only 1.6°, confirming the result of the calculations by Smart et al. (2000) for this period and showing the clear superiority of the Tsyganenko reference field. In addition, Figure 1 shows only a slight tendency for the differences to

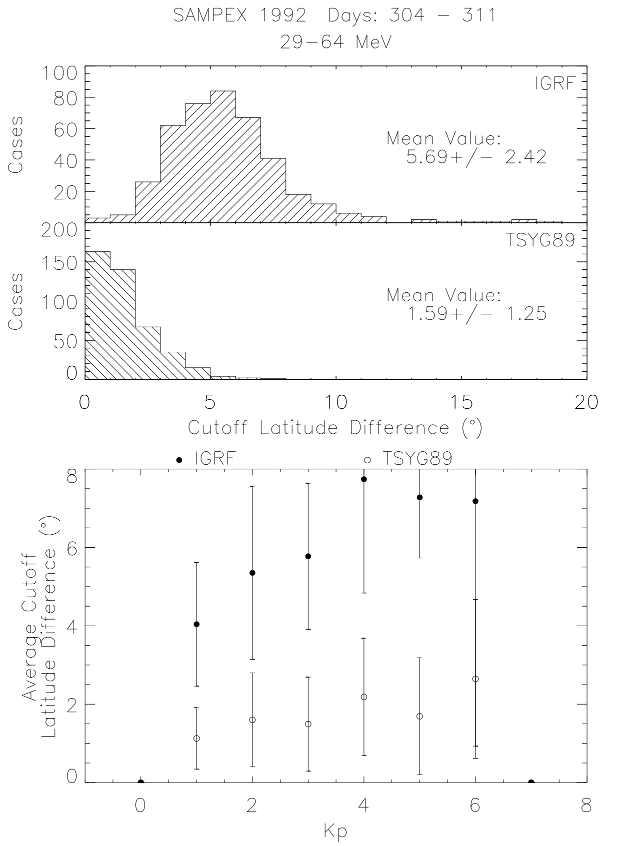

Fig. 1. Top panels: The distributions for all polar passes of numbers of cases of latitude differences for the 29 to 64 MeV protons. The observing period is 1992 October 29 to November 5. Each case is a difference between the calculated (IGRF or Tsyganenko) and observed PET geographic cutoff latitudes. Bottom panel: The distribution of cases as a function of Kp.

increase with Kp. The average latitudinal differences, ΔL, for the Tsyganenko field are given for each of the six events in Table 1.

In Figure 2 we show the results summed over all six periods for the IGRF and the combined IGRF and Tsyganenko field calculations for the 20 to 29 MeV protons. The mean difference for the Tsyganenko distribution is 2.44° $\pm$ 1.92°, with no indication for a systematic variation with Kp, at least below Kp = 6. Note that Figure 3 shows similar results for the 29 to 64 MeV protons. The mean difference of that Tsyganenko distribution is 1.77° $\pm$ 1.64°, again with no indication for a variation with Kp below Kp = 6. In both cases the comparable IGRF differences are larger than the Tsyganenko differences by factors of at least 2.5.

3 Discussion

The PET instrument has been a valuable data source for validation of the SEPTR rigidity cutoff program. We have now

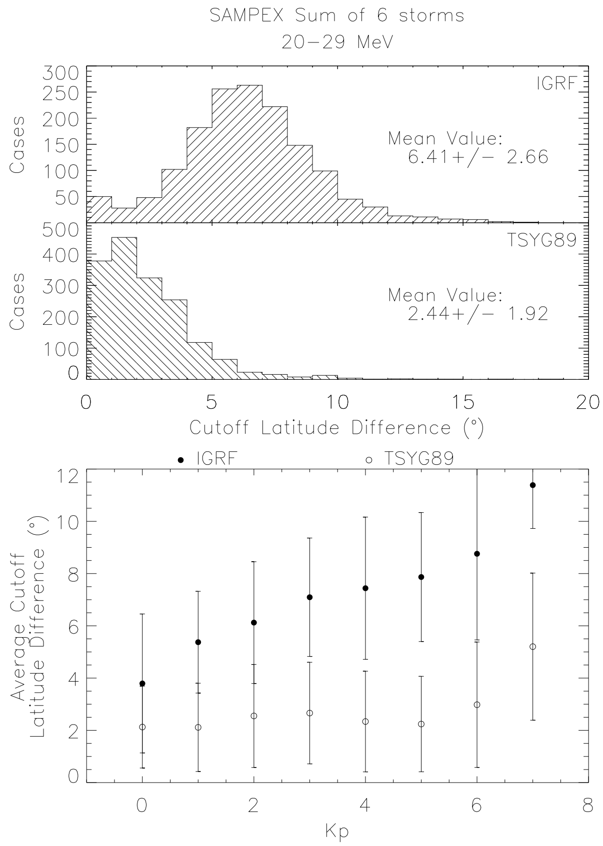

Fig. 2. Top panels: The distributions for all polar passes of numbers of cases of latitude differences for the 20 to 29 MeV protons. All six events of the study are included. Each case is a difference between the calculated (IGRF or Tsyganenko) and observed PET geographic cutoff latitudes. Bottom panel: The distribution of all cases as a function of Kp.

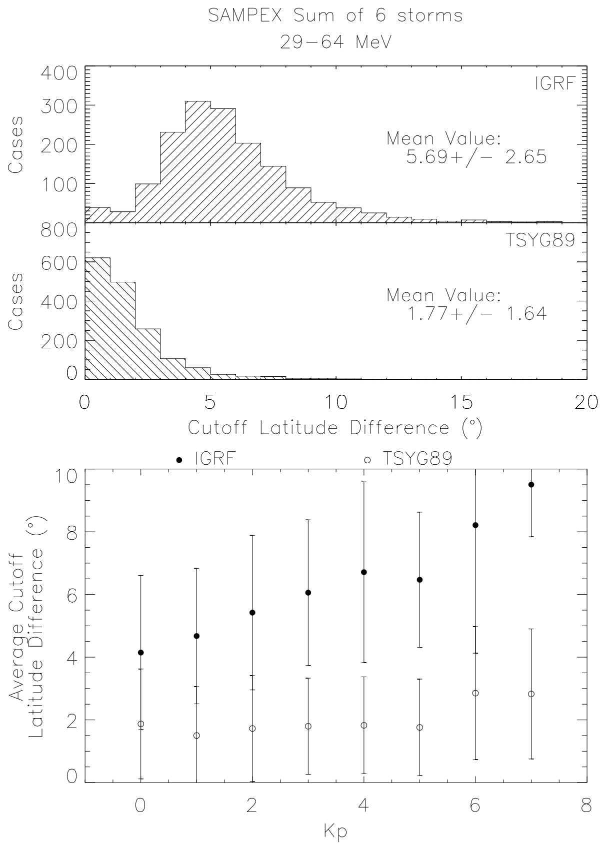

Fig. 3. Same as Figure 2, but for the 29 to 64 MeV protons.

examined PET data for 6 events with a total of about 1600 cutoff points. We intend to look at more recent SEP events, but thus far we find that the SEPTR program using the combined IGRF and Tsyganenko (1989) fields is yielding cutoff latitudes that are too far poleward by about 2.4° for the 20 to 29 MeV protons and 1.8° for 29 to 64 MeV protons. There appears to be no dependence of the latitude differences on Kp up to Kp = 5, which is the limit of the Tsyganenko program.

Acknowledgements. We thank R. Mewaldt for making the PET data available to us and S. Kanekal for the preliminary processing of the event data.

References

Baker, D.N., Mason, G.M., Figueroa, O., Colon, G., Watzin, J.G., and Aleman, R.M., IEEE Trans. Geosci. Remote Sensing, 31, 531, 1993.

Boberg, P.R., Tylka, A.J., Adams, J.H., Jr., Fluckiger, E.O., and Kobel, E., Geophys. Res. Let., 22, 1133, 1995.

IGRF, Eos, Trans. Amer. Geophys. Union, 73, No. 16, 182, 1992.

Leske, R.A., Mewaldt, R.A., Stone, E.C., and von Rosenvinge, T.T., 25th ICRC, 2, 381, 1997.

National Research Council, Radiation and the Space Station, National Academy Press, Washington, DC, 2000.

Orloff, S., PhD thesis, Rice University, 1998.

Shea, M.A., Smart, D.F., and Siscoe, G., 26th ICRC Proc., 7, 390, 1999.

Smart, D.F., Shea, M.A., and Fluckiger, E.O., 26th ICRC Proc., 7, 394, 1999a.

Smart, D.F., Shea, M.A., Fluckiger, E.O., Tylka, A.J., and Boberg, P.R., 26th ICRC Proc., 7, 398, 1999b.

Smart, D.F., Shea, M.A., Fluckiger, E.O., Tylka, A.J., and Boberg, P.R., 26th ICRC Proc., 7, 337, 1999c.

Smart, D.F., Shea, M.A., and Fluckiger, E.O., Space Sci. Rev., 93, 281, 2000.

Tsyganenko, N.A., Planet. Space Sci., 37, 5, 1989.