Characteristics of near real-time cutoff calculations on a local and global scale

R. BÜTIKOFER, E.O. FLÜCKIGER, L. DESORGHER.
Physikalisches Institut, University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland
rolf.buetikofer@space.unibe.ch

Abstract: A procedure was developed to compute in near real-time the effective vertical cutoff rigidities for a world grid with a mesh size of $5° \times 5°$ in geographic longitude and latitude. The evaluation is made every three hours. The cutoff rigidities are calculated by the backward trajectory tracing method, where the geomagnetic field is represented by the IGRF model for the internal sources and by the Tsyganenko 1989 model for the external part. The Kp indices derived at the U.S. Air Force Space Forecast Center (USAF) are used as input parameters for the Tsyganenko model to describe the current degree of geomagnetic disturbance. In addition to the near real-time results, the procedure also allows to obtain the cutoff values at a specific location during a specific time period in the past. In the paper we investigate the possibilities and limitations of these cutoff calculations, in particular during times with a strongly disturbed geomagnetosphere.

Introduction

In many analyses of ground-based cosmic ray observations a detailed knowledge about the access of cosmic ray particles to the Earth is required. The geomagnetic cutoff rigidity is a parameter that describes the magnetospheric shielding by the Earth's magnetic field against the incidence of charged cosmic ray particles. The effective vertical cutoff rigidity, R_c, at a given location is taken as the lower rigidity limit in the spectrum of cosmic ray particles reaching the top of the atmosphere in vertical direction at this position [3, 11].

The geomagnetic cutoff rigidities vary in different time scales: (1) Short time variations due to disturbances of the geomagnetic field (e.g. geomagnetic storms). Such variations are caused by the passage of shock waves or coronal mass ejections (CME) over the Earth or through the near Earth space, see e.g. [4]. (2) Longtime variations due to changes in the dipole and the non-dipole components of the Earth's magnetic field, see e.g. [10]. As an example, Figure 1 shows the change in R_c from 1955 to 2005. The changes in cutoff rigidity cause a variation in the incident cosmic ray flux at the top of the atmosphere. As cosmic rays directly affect the terrestrial environment and serve as indicators of solar variability and non-anthropogenic climate changes on Earth, knowing the cutoff rigidity and its variability is of great interest.
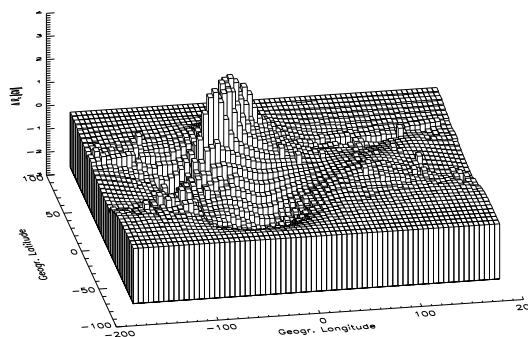

Figure 1: Change in the vertical cutoff rigidity $R_c^{2005} - R_c^{1955}$ as a function of the geographic longitude and latitude.

In view of space weather applications we have developed a procedure to compute in near real-time the effective vertical cutoff rigidities, R_c, for a world grid with a mesh size of $5° \times 5°$ in geographic longitude and latitude. Contour plots of equal R_c are available in near real-time from our webserver http://cosray.unibe.ch. Figure 2 shows a contour plot of R_c taken from our
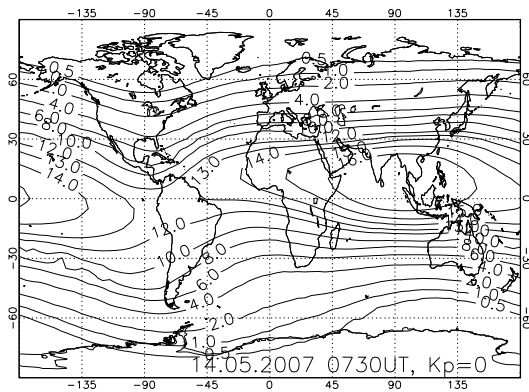
Figure 2: World map with computed geomagnetic vertical cutoff rigidity contour lines for 14 May 2007, 0730 UT, and Kp=0. For details see the text.
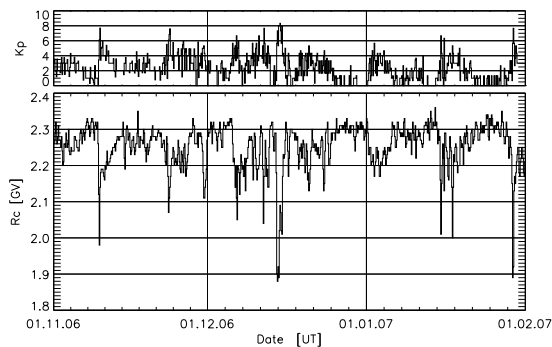

Figure 3: Vertical cutoff rigidity for the NM station Kiel (bottom panel) and Kp index (top panel) for the time interval November 2006 - February 2007.

website. In addition to the near real-time results, the system also provides the world map for a specific time in the past as well as R_c at a user-defined location during a specific time period. As an example, Figure 3 shows such a plot for the location of the NM station Kiel for the time interval November 2006–February 2007.

In the paper we present the characteristics of the near real-time R_c computations, and we investigate the possibilities and limitations of these calculations, in particular during times with a disturbed geomagnetosphere.

Computations of the effective vertical cutoff rigidity

The effective cutoff rigidity, R_c, is computed by numerical integration of backward trajectories in a model of the geomagnetic field [11]. For the evaluation of R_c for each grid location including the effects of local time, position, and geomagnetic activity, the GEANT4 [8] program MAGNETOCOS-MICS [5] was used. The geomagnetic field was specified by the International Geomagnetic Reference Field (IGRF) [2, 9] for the internal field and by the Tsyganenko 1989 (Tsy89) magnetic field model [12] for the magnetic field caused by external sources. The Tsy89 model provides seven different states of the magnetosphere that are described by the integer Kp indices (0, 1,..., $\geq$6) corresponding to different levels of geomagnetic activity. For the near real-time computations of R_c the current, the observed USAF estimated Kp indices are used. The values for R_c are calculated for a grid of 5°x5° between 80°S and 80°N in latitude and 0° to 360° in longitude and every three hours for the time in the middle of a 3-hour Kp-index time interval, i.e. 0130 UT, 0430 UT, 0730 UT etc. The values of R_c for the user-defined times and locations are determined by linear interpolation in time and location between the adjacent times and grid points for which R_c has been computed and archived in a database.

Evaluation of the near real-time cutoff rigidity computation

Because of their geomagnetic location the count rates of the Jungfraujoch NMs are strongly dependent on variations in the cutoff rigidity. To show the possibilities and the limitations of the R_c calculations in near real-time, we compared the measurements of the Jungfraujoch IGY NM with the corresponding simulated data by using the NM yield function by Flückiger et al. [6] and adopting a realistic flux of galactic cosmic rays outside the magnetosphere for the relevant period for different time intervals.

Results of the investigations are presented in Figure 4 for the time interval 10–20 January 2007. The panel a) shows the time profile of the ob-

served USAF estimated Kp index that is used to compute R_c. Panel b) represents the R_c computed for the NM location at Jungfraujoch. In panel c) the relative measured count rate of the IGY NM at Jungfraujoch is shown, and in panel d) the simulated change in the relative count rate due to the R_c variations are plotted. The measured relative count rate of the IGY NM at Jungfraujoch corrected for R_c variations is shown in panel e). For comparison panel f) shows the relative count rate of the NM station Oulu (the data were downloaded from `http://cosmicrays.oulu.fi`). For this comparison we assume isotropic conditions. Because Oulu has a R_c lower than the atmospheric cutoff, the count rate of the NM at Oulu is not dependent on cutoff rigidity variations. Therefore the observed changes in the count rate of this NM reflect the variations of the cosmic ray flux in near Earth space. As the count rate of the NM station at Oulu shows, a rather smooth cosmic ray flux seems to have prevailed near Earth during the time interval 10-20 January 2007. In the considered time interval, R_c was diminished significantly on 15 and 17 January. On 15 January the near real-time computed R_c result in a ΔR_c of almost $-0.3\ GV$ for Jungfraujoch. Such a ΔR_c would cause an increase in the count rate of the Jungfraujoch NMs of $\sim$3% (panel d) of Figure 4). At this time the data of the NMs at Jungfraujoch showed an increase of only $\sim$1%. During time intervals with disturbed magnetosphere in the considered time interval (days 15 and 17) the depletion of the geomagnetic field was overestimated. The main reason for this overestimation is that the observed USAF estimated Kp indices are significantly higher than the definitive Kp values. In addition it seems that the Tsy89 magnetic field model overestimates the decrease of the geomagnetic field during times with a moderately disturbed geomagnetic field. On 11–12 January 2007 turbulent and high speed winds affected the pressure measurements at Jungfraujoch. This effect caused a decrease in the pressure corrected count rate of the IGY NM. The decrease in the count rate on 18–19 January 2007 compared to the Oulu data is probably due to snow fall at Jungfraujoch.

The cutoff rigidity computations in near real-time with the Tsy89 model and with the observed USAF estimated Kp indices show clear limits. The es-
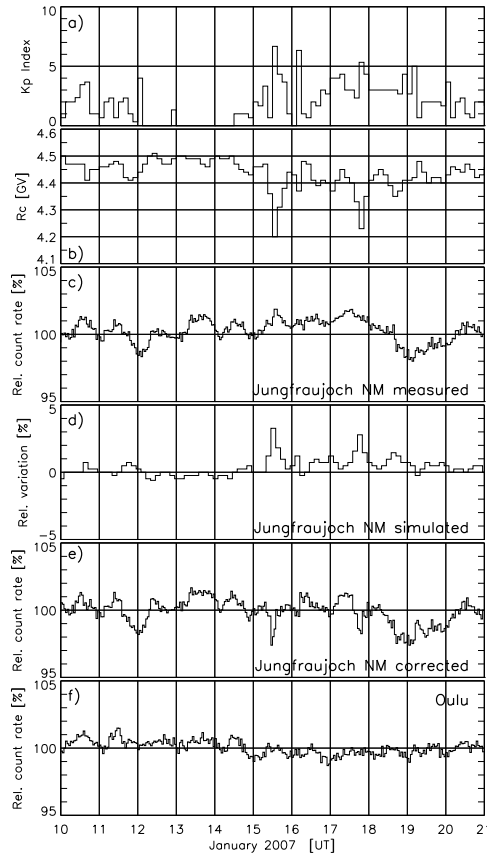

Figure 4: a) Kp index for January 2007. b) Effective cutoff rigidity, R_c, at NM location Jungfraujoch. c) Relative measured count rate of the IGY NM at Jungfraujoch. d) Estimated count rate changes due to variations of R_c. e) Relative measured Jungfraujoch NM count rate corrected for R_c variations. f) Relative measured count rate of Oulu NM station.

timated Kp indices may differ considerably from the definitive values mainly during times with a disturbed geomagnetic field. The Tsy89 model is only parametrised by the Kp index, and Kp values > 6 are not considered. Moreover the R_c computations with the Tsy89 model are not able to model disturbances of the geomagnetic field with positive Dst index when an increase of R_c is expected. The Tsyganenko model version 2005 [13] takes into account the variation of the Dst index and therefore gives a better description of the disturbed geomagnetic field. However, this model is

ICRC 2007 Proceedings - Pre-Conference Edition

presently not suited for near real-time computations of R_c as the trajectory computations with this model take roughly 20 times more computing time than the computation using the Tsy89 model, and it requires input parameters that are not easily available in real-time.

Conclusions

This analysis shows that the near real-time computation of R_c by using observed USAF estimated Kp indices and the Tsy89 magnetic field model has only limited reliability. The reasons for these limitations are threefold: (1) The observed USAF estimated Kp indices may considerably differ from the definitive values. (2) The Tsy89 model seems to overestimate variations in the geomagnetic field during times with a moderately disturbed geomagnetosphere (Kp $\sim$ 4–6). (3) The Tsy89 model can not describe the magnetic field contributions of the external sources during times with strongly disturbed geomagnetic field (Kp>6). Some of the newer Tsyganenko models proposed to be valid for higher geomagnetic disturbances are unfortunately not well suited for near real-time R_c computations. A possible improvement could be the use of the Boberg correction of Tsy89 model [1] or the procedure to estimate ΔR_c proposed by Flückiger et al. [7].

Acknowledgements

References

[1] P. R. Boberg, A. J. Tylka, J. H. Adams, Jr., E. O. Flueckiger, and E. Kobel. Geomagnetic transmission of solar energetic protons during the geomagnetic disturbances of October 1989. *Geophys. Res. Let.*, 22:1133–1136, 1995.

[2] S. Chapman and J. Bartels. *Geomagnetism*. Oxford University Press, Oxford, 1940.

[3] D. J. Cooke, J. E. Humble, M. A. Shea, D. F. Smart, and N. Lund. On cosmic-ray cut-off terminology. *Nuovo Cimento C Geophysics Space Physics C*, 14:213–234, 1991.

[4] H. Debrunner, E. Flückiger, H. von Mandach, and M. Arens. Determination of the ring current radii from cosmic ray neutron monitor data for the 17 December 1971 magnetic storm. *Planetary and Space Science*, 27:577–581, 1979.

[5] L. Desorgher. User guide of the MAGNETO-COSMICS code. *http://cosray.unibe.ch/ ̃laurent/magnetocosmics*, 2004.

[6] E. O. Flückiger, M. R. Moser, R. Bütikofer, L. Desorgher, and B. Pirard. A set of parameterized neutron monitor yield functions for space weather applications. In *30th International Cosmic Ray Conference Mérida, México*, 2007.

[7] E. O. Flueckiger, D. F. Smart, and M. A. Shea. A procedure for estimating the changes in cosmic ray cutoff rigidities and asymptotic directions at low and middle latitudes during periods of enhanced geomagnetic activity. *Jour. Geophys. Res.*, 91:7925–7930, 1986.

[8] Geant4 Collaboration. Geant4-a simulation toolkit. *Nuclear Instruments and Methods in Physics Research A*, 506:250–303, 2003.

[9] IAGA Division V. Working Group V-MOD, IGRF Model.

[10] D. F. Smart and M. A. Shea. Geomagnetic Cutoff Rigidity Calculations at 50-Year Intervals between 1600 and 2000. In *28th International Cosmic Ray Conference*, volume 7, pages 4201–4204, 2003.

[11] D. F. Smart, M. A. Shea, and E. O. Flückiger. Magnetospheric Models and Trajectory Computations. *Space Science Reviews*, 93:305–333, 2000.

[12] N. A. Tsyganenko. A magnetospheric magnetic field model with a warped tail current sheet. *Planetary and Space Science*, 37:5–20, 1989.

[13] N. A. Tsyganenko and M. I. Sitnov. Modeling the dynamics of the inner magnetosphere during strong geomagnetic storms. *Jour. Geophys. Res.*, 110:3208–3223, 2005.