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Probabilistic space weather forecast of the relativistic electron flux enhancement at geosynchronous orbit

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Abstract

An operational technique has been developed for a probabilistic space weather forecast of relativistic electrons at geosynchronous orbit, following a concept of a daily precipitation probabilistic weather forecast. In this paper, we use the arrival time of stream interfaces as a precursor of corotating interaction regions to make the probability diagram for flux enhancement of relativistic electrons at geosynchronous orbit, and the probability is defined by the number of events with the daily maximum flux above the NOAA alert levels. The probability diagram associated with the stream interfaces is constructed to achieve an efficient probabilistic forecast, based on the two fundamental parameters of oncoming streams; whether the solar wind speed is higher than average (500 km/s) or not, and which sector polarities the interplanetary magnetic field belongs to, according to the so-called "Spring-Toward Fall-Away" rule.

Keywords: Radiation belts; Space weather forecast; Stream interactions; Coronal hole

1. Introduction

Modern life depends on space satellites such as metrological satellites, global positioning system satellites, and broadcasting satellites. Satellite operations often malfunction possibly due to the hazardous environment of energetic particles. In fact, during an extreme flux enhancement of relativistic electrons, a broadcasting program of the 1994 winter Olympic game was halted for about 1 h, and more recently, a Japanese meteorological satellite at geosynchronous orbit has temporarily stopped transmitting the data for about one day on April, 2006 due to a trouble of the attitude control. Therefore, one of the most important issues of the space weather research field is to develop the forecasting techniques as soon and as correct as possible, when and how the flux of relativistic electrons increase at geosynchronous orbit.

Two operational methods have been developed and are operational to forecast the relativistic electrons at geosynchronous orbit. NOAA/SEC has continuously forecasted the daily flux variation of MeV electrons for maximum of 2 days using a linear prediction filter with the solar wind speed as an input (Baker et al., 1990), combining the Wang–Sheeley–Arge solar wind model (Wang and Sheely, 1990; Arge and Pizzo, 2000) to extend the

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model-estimated inputs of the solar wind speed up to next several days. The University of Colorado has also made a 2-day forecast of the flux variation of relativistic electrons based on the radial diffusion simulation. The simulation is solved with the given boundary conditions using the solar wind speed and interplanetary magnetic field (IMF) as input parameters for the radial diffusion coefficient with six adjustable parameters and ad hoc adjustment to predict fluxes at geosynchronous orbit (Li et al., 2001; Li, 2004).

Recently, Miyoshi and Kataoka (2005) showed evidence that the flux variation in the outer belt depends on the large-scale solar wind structures such as coronal mass ejections (CMEs) and corotating interaction regions (CIRs). They indicated that the relativistic electrons in the outer belt show faster and stronger enhancement on average during CIR-driven storms rather than CME-driven storms. These results are useful for reducing the forecasting error to operate more correctly because the results add another important information to estimate a long-term tendency of the flux enhancement in the outer belt.

Extending the above results, Kataoka and Miyoshi (2006) proposed a simple probabilistic forecasting methods using the arrival times of the interplanetary shocks and stream interfaces as a precursor for the CME- and CIR-driven storms, respectively. Kataoka and Miyoshi (2006) made a diagram for the variation of the probability for the occurrence of the NOAA flux alert level from the historical data set of intense isolated storms. The NOAA flux alert level is defined as 1000 PFU (1 PFU = $1/\mathrm{cm}^2$ sec str) of >2 MeV electrons at geosynchronous orbit. The diagram shows a probability of the NOAA flux alert level after the arrival of shock or stream interface for up to five days. Note that the probabilistic forecast of Kataoka and Miyoshi (2006) is a similar concept of daily and weekly probability of the meteorological precipitation forecast. McPherron and Siscoe (2004) and McPherron et al. (2005) proposed similar probability forecast for the prediction of the Dst index.

As a limitation, however, Kataoka and Miyoshi's diagram is only applicable to the subsets of intense storm events with the minimum Dst < -100 nT. It is well known that CIRs rarely cause intense storms but moderate/weak storms, and therefore more general forecast diagram, especially on the stream interface crossing, without the limitation on the value of the Dst index is required for the space weather forecast. In this paper, we show flexible diagrams of the probabilistic forecast for the stream interface events with no restrictions on the Dst index, extending the work of Kataoka and Miyoshi (2006).

2. Probabilistic forecast diagram

Stream interface events are detected from the OMNI-2 data using simple criteria of (1) a large change in the azimuth angle of the solar wind velocity ($>5^\circ$ per hour), (2) positive (negative) slopes in the speed and temperature (density), and (3) the magnetic field strength higher than weekly average. We further restrict our selection of the events with relatively stable magnetic fields for 72 h after the stream interface crossing, where 75% of the magnetic fields directing in the away quadrant where the IMF azimuthal angle from X-axis ranges from 90° to 180° or 75% of the magnetic fields directed in the toward quadrant where the IMF azimuthal angle from X-axis ranges from 270° to 360°. A total of 177 stream interface events are identified from 11 years of 1995–2005.

The flux enhancement in the outer belt after the stream interface crossing is expected to be controlled by the IMF sector polarity via the Russell–McPherron effect (Russell and McPherron, 1973). The Russell–McPherron effect is a dipole tilt effect associated with the IMF polarity. The geomagnetic activity is enhanced during the time intervals of the so-called "Spring-Toward Fall-Away (STFA)" because the IMF negative (positive) By-component has a large projection on the southward IMF during the spring (fall) equinox. A good example of the effect of the STFA rule on the evolution of relativistic electrons in the outer belt was given by Miyoshi et al. (2007). According to the STFA rule, we divide the stream interface events into three groups; (A) spring (February, March, April and May)-toward and fall (August, September, October and November)-away, (B) all of the solstice events (June, July, December and January), and (C) vice versa of group A. As a result, the number of stream interface events for groups A, B and C is 75, 60 and 42, respectively.

We use the GOES >2 MeV electron flux data to construct the forecast diagrams. We use the data of GOES-7 for 1995, GOES-8 from 1996 to June 2003 and GOES-10 after July 2003. We eliminate the time period when the energetic protons may contaminate