Journal of Atmospheric and Solar-Terrestrial Physics 102 (2013) 157–171

Contents lists available at SciVerse ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Auroral Precipitation Model and its applications to ionospheric and magnetospheric studies

V.G. Vorobjev *, O.I. Yagodkina, Yu.V. Katkalov

Polar Geophysical Institute, Apatity, Murmansk Region 184200, Russia

ARTICLE INFO

Article history:
Received 20 March 2012
Received in revised form
15 March 2013
Accepted 10 May 2013
Available online 23 May 2013

Keywords:
Auroral Precipitation Model
AL and Dst indexes
Magnetic storm
Dayside aurorae

ABSTRACT

Based on statistical treatment of DMSP F6 and F7 spacecraft observations, an interactive Auroral Precipitation Model (APM) parameterized by magnetic activity has been created (available at http://apm.pgia.ru/). For a given level of magnetic activity the model yields a global distribution of electron precipitation and planetary patterns of both average electron energy and electron energy flux in different precipitation zones. Outputs of the model were used to determine the basic variables of the magnetosphere, such as boundary location and the area of the polar cap, magnetic flux transferred from the dayside magnetosphere into the tail, global precipitation power realized by different types of precipitation and others. The model predicts an increase in the polar cap area from about 6.3×10^6 km^2 to 2.0×10^7 km^2, in the magnetic flux from 390 MWb to 1200 MWb, and in the global precipitation power from 3.4 GW to 188.0 GW, when the magnetic activity changes from silence (null AL and Dst) to significant disturbance (AL = −1000 nT, Dst = −200 nT). The use of dayside auroral observations as an input for APM provides an opportunity for continuous monitoring of magnetospheric conditions. Two time intervals on Dec. 27, 2000, and Dec. 12, 2004, of dayside auroral observations with the meridian scanning photometer at Barentsburg (Spitsbergen) were selected to demonstrate derivation of magnetospheric variables with APM. It is shown that the values of the AL index derived from optical observation appear in a reasonable agreement with those published by WDC.

1. Introduction

Spacecraft data obtained in the high-latitude region combined with ground-based observations of auroral luminosity and geomagnetic field variations provide information on the position of precipitating particle zones with different morphological characteristics. Such data reflect structure, dynamics and physical processes in the Earth's magnetosphere at geocentric distances up to tens of terrestrial radii. A statistical treatment of ground-based optical observations resulted in the development of auroral oval concept (Feldstein, 1963, 1966; Khorosheva, 1963). The oval represents average statistical area, where discrete auroral forms are observed in the zenith. The dynamics of auroral oval boundaries depending on the level of magnetic activity was investigated by Feldstein and Starkov (1967).

Ground-based observations of auroral emissions indicate that equatorward (Sandford, 1968) and poleward (Eather, 1969) of the auroral oval there are regions of diffuse auroral luminosity. Diffuse luminosities have been investigated by meridian scanning photometers both from the ground and from the board of polar-orbiting spacecraft (Lui et al., 1973). The luminosity equatorward of the auroral oval is most pronounced. In comparison with the oval, this luminosity is rather uniform but with quite distinct boundaries. Mathematical fits of latitudinal positions of both auroral oval boundaries and equatorward diffuse luminosity boundary as functions of the AL index were published by Starkov (1994).

Observations of polar-orbiting spacecraft are modern tool enabling to carry out statistical analysis of precipitating particle characteristics and their spatial distribution. Planetary models of electron precipitation derived from spacecraft observations were described in a number of papers (McDiarmid et al., 1975; Spiro et al., 1982; Hardy et al., 1985). In those models, the 3 h Kp and/or 1 h AE indices were used as a measure of magnetic activity. However, the time the spacecraft passes through the region of precipitation in any MLT sector is only a few minutes. Therefore the current magnetic activity level during spacecraft measurements may differ considerably from the level indicated by the indices. Thus, in spite of good statistics and relatively high spatial resolution, such models provide only a rough estimate of planetary distribution of auroral precipitation. Another serious drawback of the above models is that averaging of spacecraft observations was performed in fixed areas, usually 1–3° in latitude and 1–2 h in MLT. It is well known that precipitation undergoes a latitudinal displacement as magnetic activity changes, so that in averaging

* Corresponding author. Tel.: +7 8155579204; fax: +7 8155574339.
E-mail address: vorobjev@pgia.ru (V.G. Vorobjev).

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http://dx.doi.org/10.1016/j.jastp.2013.05.007

over fixed area different precipitation types with unknown occurrence rate are mixed.

A different approach was followed in the investigation by Sotirelis and Newell (2000). They developed a model, in which precipitation was ordered relative to various auroral boundaries. Five ranges of the latitudinal position of the *b2i* boundary were used as a measure of activity. The *b2i* boundary has a clear physical sense. It is a good proxy for the ion isotropy boundary which defines a stretching of the magnetosphere (Sergeev and Gvozdevsky, 1995; Newell et al., 1998).

A precipitation model, which separately categorizes two types of discrete precipitation (monoenergetic and broadband spectra) and both electron and ion diffuse precipitation, was developed by Newell et al. (2009). They for the first time presented an empirical model of diffuse precipitation with acceleration events explicitly removed. It allowed a quantitative comparison between four types of precipitation. Those authors showed that the diffuse precipitation is much more important than often realized, constituting more than three quarters of the precipitation energy budget. The average characteristics of different types of precipitation were derived for low and high solar wind driving.

In the models of Sotirelis and Newell (2000) and Newell et al. (2009) the DMSP series spacecraft observations for more than 10 years were utilized to examine the precipitation features. Due to large database, the resolution in the magnetic local time (MLT) and magnetic latitude (MLat) in their models was higher than in the previous one, making them of great utility for scientific and cognitive purposes. However, adapted to the *b2i* level or to the solar wind driving as input parameters, such models appear extremely difficult to use in the studies of precipitation characteristics during geomagnetic disturbances, as well as in comparison of precipitation with other geophysical phenomena whose global distributions depend on magnetic activity level.

Recently, Zhang and Paxton (2008) have presented an empirical model of electron precipitation based on TIMED/GUVI data. This model is convenient for users because the authors published the coefficients for calculating the energy flux and the mean energy of precipitating electrons. Some inconvenience of the Zhang and Paxton model is that it is Kp dependent and characteristics of precipitation are deduced from optical ultraviolet observations. Difficulties and uncertainties in the solution of an inverse problem are discussed shortly in Section 4.2.

In the present study, a statistical treatment of DMSP F6 and F7 spacecraft observations in about 35,000 crossings through the auroral zones of both hemispheres was performed to create an interactive Auroral Precipitation Model (APM), which is available at http://apm.pgia.ru/. For a given level of magnetic activity characterized by Dst and 5 min AL indices, which are set by the user, this model yields a global distribution of different types of auroral precipitation and a planetary picture of both average electron energy and energy fluxes in different precipitation zones. Moreover, the model enables to calculate the precipitation power in different zones and MLT sectors, total precipitation power, polar cap area, etc. depending on the magnetic activity level, and to state relations between these parameters.

The database, which was formed to develop APM and a notation of different types of precipitation, is discussed in Section 2. The procedures that were used to create the global pattern are described in Section 3, with the treatments in the pre-midnight and pre-noon sectors shown as examples. Section 4 illustrates APM and its usage in the studies of the ionosphere and magnetosphere. A comparison between precipitation features derived from the model in different MLT sectors and those obtained from spacecraft observations is performed in the final section.

2. Data used and notation of different precipitation types

A special database containing about 35,000 spacecraft crossings of the high-latitude ionosphere in the northern and southern hemispheres has been composed to construct a planetary pattern of auroral precipitation. We used DMSP F6 and F7 observations for 1986 downloaded from JHU/APL website. It was the year of a minimum of solar activity, yet significant magnetospheric disturbances, e.g. a magnetic storm on February 8–10, 1986, with intensity in the Dst index of ~−300 nT, were observed.

In addition to standard information on the coordinates of auroral precipitation boundaries and characteristics of precipitating particles from JHU/APL website, interplanetary medium parameters (if available), indices of geomagnetic activity (AE, AL, AU, Dst) and substorm phases for each satellite crossing through the auroral zone were included to the database. We used hourly averaged solar wind and IMF data from http://omniweb.gsfc.nasa.gov/. The substorm phase was identified from 1 min variations in the AE and AL indices at the moment when spacecraft encountered the equatorward boundary of structured precipitation. In order to increase statistical significance of the results, all crossings were divided according to 3-hour MLT intervals (0000–0300 MLT, 0300–0600 MLT, 0600–0900 MLT, etc.). Latitudinal position of different precipitation boundaries and characteristics of precipitation in each MLT sector were examined versus the level of magnetic activity. In the present investigation Dst and 5-min averaged AL indices were used. Corrected geomagnetic coordinates (Φ' and MLT) were calculated according to AACGM (Baker and Wing, 1989), in which the IGRF magnetic field model is used.

Initially, all types of high-latitude precipitation were classified into several general categories, such as CPS, BPS, LLBL, cusp, mantle and polar rain (Newell et al., 1991), CPS and BPS being the basic types of nightside precipitation associated with diffuse and discrete auroral precipitation, respectively. According to Winningham et al. (1975), it was assumed that CPS precipitations are mapped to the center plasma sheet and BPS precipitation to the plasma sheet boundary layer. In this way, precipitation measured at ionospheric altitudes, by definition, appeared closely connected with magnetospheric domains. From Winningham et al. (1975) it followed that the auroral oval and equatorward diffuse aurora originate from BPS and CPS, respectively. However, according to Feldstein and Galperin (1985) and Galperin and Feldstein (1991), the nighttime auroral oval maps to CPS, while the diffuse aurora to the near-Earth region of quasi-dipolar magnetic field lines. There are other examples of auroral oval mapping to different magnetospheric areas.

Since the researchers used the same terms in quite different ways, Newell et al. (1996) introduced on the JHU/APL website operationally unambiguous algorithms for identification of nighttime precipitation. A brief description of major precipitation boundaries, as defined by Feldstein and Galperin (1996) and Newell et al. (1996), is given in the order increasing latitude.

b1e and *b1i* (for electrons and ions, correspondingly) are the zero-energy convection boundaries;
b2e corresponds to the poleward edge of the region where the electron average energy is neither increasing nor decreasing with latitude;
b2i contours the points where the ion energy flux has maximum;
b4s is the most equatorward latitude of spatially structured electron precipitation (low correlation between neighboring spectra);
b5e and *b5i* are the latitudes where an abrupt drop in the electron and ion energy flux is observed.