Journal of Atmospheric and Solar-Terrestrial Physics 77 (2012) 1–18

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

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

Spatial distribution of auroral precipitation during storms caused by magnetic clouds

O.I. Yagodkina *, I.V. Despirak, V.G. Vorobjev

Polar Geophysical Institute, RAS, Apatity, Murmansk region, 184200, Russia

ARTICLE INFO

Article history:
Received 24 August 2010
Received in revised form
19 May 2011
Accepted 12 June 2011
Available online 2 July 2011

Keywords:
Auroral precipitation
Magnetic storms
Empirical model
Magnetic clouds

ABSTRACT

The global pattern of auroral precipitation and dynamics of precipitation boundaries during three different intensity magnetic storms driven by magnetic clouds were investigated. For the aim of the research, the empirical model (http://pgia.ru/lang/en/webapps/) in which the boundary locations of the auroral precipitation depend on the geomagnetic activity expressed by the AL- and Dst indices was used. The locations of the boundaries derived from DMSP F10–F15 spacecraft observations were compared to those obtained in the model and displayed reasonable agreement. We find a significant displacement to the lower latitudes of the diffuse auroral zone (DAZ) and auroral oval precipitation (AOP) region with the increase of magnetic activity. The planetary pattern of auroral precipitation indicated different dawn–dusk widening of the DAZ and AOP region (asymmetry) during both main and recovery phases of magnetic storms. Differences in the dawn–dusk widening (i.e., asymmetry) of the DAZ and AOP zone during magnetic storms appear to be sensitive to Dst, where the DAZ widens in the morning only, while the AOP widens in the evening under all Dst intensities, and widens significantly in the morning also for Dst < -100 nT. The average energy of precipitating electrons in both MLT sectors and both zones was estimated and compared with DMSP spacecraft data.

1. Introduction

It is known that solar wind flow can vary depending on the state of solar activity. During solar maximum, most common are sporadic flows associated with coronal mass ejections (CME; Pudovkin, 1996). Near the Earth they are observed as magnetic clouds (MC; Burlaga et al., 1982), which are one of the sources of geomagnetic storms (Wilson, 1987). During storms, sharp variations of solar wind parameters and geomagnetic field are accompanied by intensifications of auroral precipitation in the high-latitude ionosphere. The location of the auroral oval boundaries and characteristics of the auroral precipitation within it are the main indicators of the state of the magnetosphere.

At present there are several empirical models of auroral precipitation depending on both geomagnetic activity level (McDiarmid et al., 1975; Spiro et al., 1982; Hardy et al., 1985; Sotirelis and Newell, 2000; Zhang and Paxton, 2008) and estimated hemispheric power (Fuller-Rowell and Evans, 1987; Newell et al., 2009). McDiarmid et al. (1975) developed a model in which data from about 1100 passes of the polar-orbiting Isis 2 spacecraft were used to determine average intensities and electron energies as functions of magnetic local time and invariant latitude for particle energies above 150 eV. The data were grouped according to the particle energy into 1° invariant latitude bins, 2 h magnetic local time (MLT) bins, three pitch angle ranges, and several ranges of Kp. For several Kp indices, planetary distribution patterns of average energy and electron energy fluxes were constructed. However all the results referred to the times with Kp ≤ 3 and therefore the large storm time data were not included.

Spiro et al. (1982) created a model in which the data from the low energy electron experiments on AE-C and AE-D spacecraft during 1974–1976 were used to determine the average global distribution of the energy flux of precipitating auroral electrons and their average energy for different levels of geomagnetic activities. The integral number fluxes of electrons with energies from 200 eV to 27 keV were registered. The measurements were binned according to invariant latitude (1°–2°), MLT (1 h), and geomagnetic activity as measured by the Kp and AE indices.

In the work of Hardy et al. (1985) a statistical study was completed using DMSP F2, DMSP F4 spacecraft data and Satellite Test Program P78-1 to determine the average characteristics of auroral electron precipitation as a function of magnetic local time, magnetic latitude, and geomagnetic activity as measured by Kp. The high-latitude region was studied with better spatial resolution (invariant latitude bin was 1°–2° and MLT bin was 0.5 h). As a result, the model was presented in the plots of selected

---

* Corresponding author. Tel.: +78155579592; fax: +78155574339.
E-mail address: yagodkina@pgia.ru (O.I. Yagodkina).

1364-6826/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jastp.2011.06.009

isocontours of the integral number flux and average energy as a function of magnetic local time and corrected geomagnetic latitude for Kp-index.

These models give the averaged precipitation features in fixed ranges of the corrected geomagnetic latitude (CGL) and MLT. However the position of the regions of different precipitation types varies depending on the magnetic activity and MLT, so that averaging of different precipitation types with different and unknown rate of occurrence took place.

This defect is corrected in the model of Sotirelis and Newell (2000) based on 12 years data of eight DMSP spacecraft. In this model the data were ordered latitudinally according to different precipitation boundaries. An essential advantage of this model in contrast to the earlier published ones is large statistics and greater spatial resolution of the presented data. However for data selection according to magnetic activity level, Sotirelis and Newell (2000) used the latitudinal position of the ion isotropy boundary (φ_{b2i}) to parameterize the observations. The observed b2i was projected to midnight to form a magnetotail stretching index MTd, which is

$$\mathrm{MTd} = |\varphi_{b2i}| - 4.31(1 - \cos(\pi(\mathrm{MLT} - 23.4)/12))$$

This index is analogous to the MT index of Sergeev and Gvozdevsky (1995) and fits the b2i boundary of Newell et al. (1998). Five separate activity levels were defined based on magnetotail stretching as inferred from observations of precipitating ions. The observations for which MTd fell outside the range 59°–71° were discarded.

In the work of Zhang and Paxton (2008) an empirical Kp-dependent global auroral model based on Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED)/Global Ultraviolet Imager (GUVI) FUV data is presented. This FUV-based model covers all Kp ranges (0–9). Due to the large spatial coverage of FUV auroral images, the FUV measurements lead to a more consistent estimation of the auroral hemispheric power, but this model does not give the boundary-oriented auroral precipitation.

Newell et al. (2009) developed an auroral precipitation model, which separately categorizes the discrete aurora and both electron and ion diffuse aurora. The model is not just finer in magnetic latitude (MLAT) and magnetic local time (MLT) resolution than previous models but is parameterized by solar wind driving instead of Kp and based on functional fits to the solar wind coupling function, which best predicts the auroral power. The variation of any types of aurora at any local time can be predicted on the basis of the specific solar wind history of an epoch.

Thus, the existing auroral precipitation models obtained from satellite observations use as measure of magnetic activity either 3 h the Kp-index or 1 h AE index, or auroral hemispheric power and give only rough estimates of the situations. Such models are difficult to use for practical purposes since the level of magnetic activity is traditionally defined by the values of AE (AL) and Dst indices. It is impossible to apply these models for more detailed researches, in particular, for the study of auroral precipitation during storms and substorms.

We have designed and used here a model (http://pgia-webapps-www/apm/), which has smaller spatial/temporal resolution than the above models but it allowed us to construct the planetary distributions (in coordinates MLAT–MLT) of different types of auroral precipitation, average energies and electron energy fluxes depending on the level of geomagnetic activity determined by the AL and Dst indices. To carry out studies of the characteristics of precipitating auroral particles, we earlier created a database of the data from the DMSP F6 and DMSP F7 spacecraft over an entire year (1986), including approximately 35,000 passes in all sectors of local geomagnetic time. It was the year of a minimum in solar activity, however, in 1986 significant magnetospheric disturbances, such as a magnetic storm on February 8–10 with the intensity in the Dst index of about −300 nT, were observed. The data of the DMSP F6 and DMSP F7 spacecraft were taken from pages at http://sd_www.jhuapl.edu. Besides standard values of the boundaries of different types of precipitation and characteristics of precipitating particles (Newell et al., 1991a), our database contains for each spacecraft pass information on parameters of the interplanetary environment, values of the magnetic activity indices (AE, AL, AU, Dst), and the phases of magnetospheric disturbances in the period of conduction of the spacecraft measurements. For the AL-index, its 1 h and 5 min averaged values were included in the database. All phases of magnetospheric disturbances (AL) were divided into three subphases, corresponding to their initial, middle and final stages. In spite of relatively small statistics, such database has no analogs in the world and makes it possible to study the main characteristics of different types of precipitation as a function of both the geomagnetic activity level and the phase of magnetospheric disturbances.

The problem of constructing the global precipitation pattern is complicated by the fact that different terms are used to identify auroral precipitation zones in the day- and nightside sectors based on the same spacecraft observations. Thus Newell et al. (1991a, 1991b) used the denotations of different magnetospheric domains to distinguish different types of dayside precipitation (CPS for the central plasma sheet, BPS for the boundary plasma sheet, LLBL for the low-latitude boundary layer). Since a magnetospheric source for any type of precipitation cannot be determined unambiguously, Feldstein and Galperin (1996) and Newell et al. (1996) proposed a different terminology of nightside boundaries (b1e, b2e, b2i,..., b6) based on features of auroral precipitation with different spectral and morphological characteristics. A similar structure for the nightside auroral luminosity was suggested earlier by Galperin and Feldstein (1991) and Feldstein and Galperin (1993).

By comparing the day- and nightside precipitation patterns with the position of the regions with different types of auroral luminosity, Starkov et al. (2002) proposed a new denotation system that allowed a unified description of the phenomena in all MLT sectors. Those authors distinguished three major zones of precipitation: DAZ—diffuse auroral zone, AOP—auroral oval precipitation; and SDP—soft diffuse precipitation. Precipitation on the Earth's day- and nightside may have different magnetospheric sources; therefore Starkov et al. (2003) joined the day- and nightside boundaries of auroral precipitation regions in dawn and dusk hours of local geomagnetic time.

In the new notation the equatorward boundary of the DAZ region is boundary b1e on the nightside (Newell et al., 1996) and the equatorward boundary of CPS type precipitation on the dayside (Newell et al., 1991b). The DAZ is the zone of hard electron precipitation formed by electrons injected into the near-Earth region on the nightside and then drifted around the Earth. The DAZ is located equatorward of the auroral oval and is spatially coincident with the zone of diffuse aurora. A typical energy of electrons here exceeds 1 keV. The poleward boundary of the DAZ is b2e on the nightside and the poleward boundary of CPS precipitation on the dayside.

The equatorward boundary of the AOP region is b2e and the equatorward boundary of BPS type precipitation on the night- and dayside correspondingly. The poleward boundary of the AOP region is b5e on the nightside and the highest latitude boundary of BPS type precipitation on the dayside. The AOP is the region of structured precipitation, whose equatorward boundary spatially coincides with equatorial boundary of discrete auroral forms. The poleward part of the AOP contains here the mixed precipitation of BPS and LLBL types.

The belt of high-latitude soft precipitation, SDP, adjoins to the poleward boundary of the AOP region. The poleward boundary of the SDP is b6 on the nightside and the poleward boundary of LLBL