Journal of Atmospheric and Solar-Terrestrial Physics 119 (2014) 129–137

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

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

Eastward electrojet enhancements during substorm activity

M. D'Onofrio [a,*], N. Partamies [b], E. Tanskanen [b,c]

[a] Department of Physics, University of Helsinki and Helsinki Institute of Physics, P.O. Box 64, FI-00014 Helsinki, Finland
[b] Finnish Meteorological Institute, P.O.Box 503, FIN-00101, Helsinki, Finland
[c] University of Bergen, Department of Physics and Technology, Allgaten 55, N-5007 Bergen, Norway

ARTICLE INFO

Article history:
Received 27 October 2013
Received in revised form
25 July 2014
Accepted 28 July 2014
Available online 2 August 2014

Keywords:
Auroral electrojet
Substorm
Ground-based magnetometer data

ABSTRACT

In this study, we use a semi-automatic routine to identify negative and positive bays in the IMAGE magnetometer data during seven months in 2003. The IMAGE stations have been divided into three latitude regions to monitor the time evolution and temporal relationship between the regions during substorms. In particular, we focus on the events where both positive and negative ground magnetic deflections are observed in different latitude regions. We found 101 events in total. We examine separately a subset of 32 events, for which the local electrojet index values are larger than the global ones, suggesting that the strongest activity at that time takes place within or very close to the local time sector of IMAGE. We systematically analyze the temporal difference and the intensity of the positive and negative bays. Our results show that the magnitude of the positive bay is on average about half of that of the negative bay. Two thirds of the positive bays within the IMAGE network peak earlier than the negative bays. Because the positive and negative bays occur meridionally very close together, we suggest that the enhancements of the westward current at the poleward part of the auroral oval and the eastward current within the return flow are very tightly coupled through field-aligned currents and closing horizontal currents. The substorm current system appears as a superposition on the large-scale current pattern in the vicinity of the evening sector shear flow region.

1. Introduction

Based on ground-magnetic signatures, substorms had already been introduced by early 1900 (e.g. Birkeland 1908). Later on, Akasofu (1964, 1965) outlined the main auroral displays, the evolution of magnetic variations on the ground and how they depend on the location of the observer with respect to the location of the substorm onset. Just like the report by Akasofu (1965), most substorm studies concentrate on the negative deflection of the X or H component of the ground magnetic field in the breakup region as a signature of the enhancement of the westward electrojet and the substorm current wedge. However, Akasofu already pointed out that at the head of the westward travelling surge, the magnetic signature includes first a positive deflection prior to the more dominant negative bay. Furthermore, he reported that south of the breakup region a positive magnetic deflection occurs. These positive bays are mentioned to be smaller in intensity as compared to the negative bays but otherwise their temporal and spatial relation to the substorm negative bays has not received much attention.

An early work in this topic area by Kamide and Fukushima (1972) described a detailed investigation of five high-latitude positive bays in the early afternoon sector, 12–16 UT in the European sector. They concentrated on a limited number of intense and prolonged events to investigate how the ground magnetic signatures evolve in latitude from station to station. In their study, the negative bays typically occur before the positive bays, whose absolute values in some cases even exceed the strength of the negative bays. The positive bays were associated with ring current enhancements and the development of the dusk sector current within the ionospheric return flow region.

Clauer and McPherron (1974) described the magnetic signatures of substorms in more detail, and especially the events that included a positive mid-latitude (geographic latitudes of about 20–30°) perturbation in the X-component of the ground magnetic field. They concluded that the positive bay is the mid-latitude signature of the substorm onset, but also that the auroral zone negative bay may sometimes precede the positive bay formation.

During substorm events, magnetic positive bays have also been observed during auroral streamers (Lyons et al., 2012). The streamers are related to azimuthally localized earthward flow channels in the plasma sheet and dipolarization of the magnetic field, and they mainly occur during the substorm expansion

---

[*] Corresponding author.

http://dx.doi.org/10.1016/j.jastp.2014.07.007
1364-6826/

phases, at the time of auroral brightening or up to tens of minutes after the substorm onset (e.g. Partamies et al., 2006).

Auroral electrojet index behavior during 34 substorms was investigated by Gjerloev et al. (2004). They correctly emphasized that the upper index (AU) has not received much attention in the substorm studies. Their conclusion was that there is very little or no response in the AU index to the substorm onset. However, the temporal evolution of the electrojet indices was found similar (linearly correlated) even though their magnitudes were different. Later in the substorm expansion and recovery phase the westward jet was found twice as intense as the eastward jet on average. In their study, the contribution of the eastward jet originated mainly at the latitudes south of the substorm activity but in a different time sector than where the westward jet contribution came from.

A statistical study combined with an empirical ionospheric model by Gjerloev and Hoffman (2001) (and references therein) disscuss the electrojet drivers. While the eastward jet is mainly directly driven by the reconnection (ionospheric convection electric field), the westward electrojet consists of directly driven and substorm-related component. The westward jet in the evening and midnight sector includes a contribution of the intense nightside precipitation which enhances the conductivity and thus, strengthens the current. According to their results, the evening eastward current is primarily driven by the poleward convection electric field equatorward of the conductance dominant westward electrojet region. Marghitu et al. (2011) further discussed and modelled the coupling of the electrojets into the field-aligned currents and the divergence of the electrojet Hall currents. The electrojets are often assumed divergence-free but the findings by Marghitu et al. (2011) suggest that although divergence-free may be a reasonable assumption during quiet time, substorm activity is likely to introduce electrojet divergence and coupling of the jet currents to the magnetosphere via field-aligned currents. This process is especially important in the Harang region where the eastward and westward current coexist in the same time sectors. Rather than separating Harang region in the midnight Harang and the high-latitude shear region Harang (Amm et al., 2000), Gjerloev and Hoffman (2001) show that the similar rotation of the poleward to equatorward electric field can be observed from midnight deep into the evening sector.

More recently, the large-scale current system at the time of substorm injection was observed and simulated by Yang et al. (2012). They used Rice Convection Model to study the evolution of the near-Earth magnetotail plasma, ionospheric currents and ground-magnetic deflections related to substorm injections. Their results suggest an increase in the ground-magnetic H component on the western and southern side of the centre of the westward electrojet. Their study emphasized that there is a strong coupling between the Region 1 and 2 field-aligned currents and demonstrated a flow vortex formation in the ionosphere at the surge head (westward end of the substorm current wedge).

In this study, we examine high-latitude positive bays as enhancements of the eastward directed electrojet currents during substorm activity. We focus on the relative timing, location and intensity of the negative and positive bays observed by the ground-based magnetometers in the Fennoscandian sector. While the previous studies described above introduce positive bay observations in a global-scale and at lower latitude stations, the dense station network in Fennoscandia and Svalbard allows high-resolution examination of magnetic positive and negative bay evolution. The close proximity of the opposite deflections refer to Harang region shear which was shown to be favorable for substorm activity (e.g. Zou et al., 2009).

Section 2 describes the data and the event selection, a sample event is described in Section 3, and Section 4 illustrates the main results.

2. Event selection

2.1. Description of the data

International Monitor for Auroral Geomagnetic Effects (IMAGE) is a network of 31 magnetometers (as of 2003), located in northern Fennoscandia and Svalbard (Viljanen and Häkkinen 1997). The data are recorded at 10 second time resolution. Local electrojet indices (IMAGE AL/AU named as IL/IU by Kallio et al. (2000)) are routinely constructed for monitoring electrojet current evolution.

We focus on a period of 7 months scattered throughout the year 2003: January, February, March, June, September, October and December. These months were chosen to cover every season but exclude periods of extraordinary magnetic activity, such as the Halloween storm at the beginning of November 2003 (e.g. Tanskanen 2009). For each day considered in this study, we first searched for a negative bay of substorms. We further focused on events where, in addition to the negative bay, a visually clear positive magnetic deflection is observed in another latitude sector. This left us with 101 events, i.e. one seventh of all (715) substorms.

We divided 19 northern Fennoscandian and Svalbard region stations into three groups according to their geographic latitudes (i.e. separated by the geographic gap between the stations due to the Arctic Sea). This division has previously been used by Tanskanen et al. (2002). The northernmost group includes stations in the Svalbard surroundings: NAL, LYR, HOR and HOP, which are bracketed by the latitudes of 75° and 80° (magnetic latitudes larger than 73°). At the Arctic Sea latitudes of the IMAGE chain there is only the Bear Island (BJN, 74.5°) station, while the southernmost group includes 14 stations at latitudes between 66° and 71° (magnetic latitudes of 63°–68°): SOR, KEV, TRO, MAS, AND, KIL, IVA, ABK, LEK, MUO, LOZ, KIR, SOD and PEL. The locations of IMAGE magnetometers are shown in Fig. 1, where the three groups of North, Centre and South stations have been marked in blue, red and orange, respectively. These three latitude sectors cover the entire average auroral zone. Stations further south primarily detect magnetic activity during magnetic storms.

We combined the magnetograms from the three station groups (North, Centre/BJN and South) to upper and lower envelope curves of single station measurements of the magnetic X-component. The resulting group specific IL and IU indices become:

$$\mathrm{IL}_{N,C,S}(t) = \min(X_{N,C,S}(t))\mathrm{IU}_{N,C,S}(t) = \max(X_{N,C,S}(t)),$$

where $X(t)$ is the geographic north–south component of the magnetic field. These IL and IU indices correspond to the global AL and AU indices in the midnight sector (Kauristie et al., 1996), but are sensitive to the currents over the IMAGE time sector and the latitude regions N, BJN and S.

2.2. Event selection procedure

Our set of 101 substorm events is referred to as the 101-set. In order to make sure that there is no stronger activity going on at the same time in another time sector, we further selected a subset of 32 events, for which IL ⌉ AL, where IL refers to the index of the entire IMAGE network (Kallio et al., 2000). This subset is referred to as the 32-set.

Our major criterion was to require the maximum negative deflection to be larger than 100 nT at least in one of the latitude regions. The substorm end was defined as the time when the intensity had recovered 80% of the maximum-peak intensity value. This allowed us to exactly and univocally determine the end of each substorm and the starting point for the search of the next one. As the result, the substorm events consist of expansion and