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Cover: Image of the northern auroral oval taken by the Ultraviolet Imager (UVI) on the Polar spacecraft. The convection pattern is symbolized through the northwest style of two salmon. Image developed by D. Chua, M. Fillingim and J. Cascaden.

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Near-Conjugate Magnetic Substorms at Very High Latitudes Observed by Greenland and Antarctic Ground Magnetometers and Ørsted Satellite

V. O. Papitashvili¹, C. R. Clauer¹, F. Christiansen², Y. Kamide³, V. G. Petrov¹,4, O. Rasmussen², and J. F. Watermann²

¹Space Physics Research Laboratory, University of Michigan
2455 Hayward St., Ann Arbor, MI 48109-2143, U.S.A.
papita@umich.edu, bob.clauer@umich.edu, vpetrov@engin.umich.edu

²Solar-Terrestrial Physics Division, Danish Meteorological Institute
Lyngbyvej 100, Copenhagen, DK-2100, Denmark
fch@dmi.dk, or@dmi.dk, jfw@dmi.dk

³Solar-Terrestrial Environment Laboratory, Nagoya University
Honohara 3-13, Toyokawa, Aichi 442-8507, Japan
kamide@stelab.nagoya-u.ac.jp

⁴Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation
Troitsk, Moscow region 142092, Russia
vpetrov@izmiran.rssi.ru

Abstract. Magnetospheric substorms produce magnetic disturbances on the ground that are, in general, most prominent near magnetic midnight in the auroral oval. Substorm-like disturbances have also been recognized deep in the polar caps. Previous investigations of these high-latitude events suggest that the substorm-like perturbations usually occur during periods of northward IMF or when the solar wind velocity is high. For some events, it appears that the magnetic substorm may reach very high latitudes, starting at auroral latitudes and then leaping poleward. Here we studied a number of very high-latitude, substorm-like events recorded with the Greenland and Antarctic magnetometers in 1999–2000. We also investigated the conjugacy of these disturbances, considering their cause by both magnetic field lines closed far down the magnetospheric tail or through ionospheric currents. Utilizing the Ørsted satellite high-precision magnetic field observations taken during 1999–2000, we investigated the field-aligned currents associated with very high latitude substorm-like events. We found that during substorms the strong field-aligned currents fill the entire polar cap and the substorms leap more easily and deeply into the polar caps during winter conditions when the ionospheric conductivity is low.

1. Introduction

It is well known that substorms produce characteristic magnetic field perturbations on the ground that are, in general, most prominent through the auroral oval and near magnetic midnight. However, the substorm-like disturbances are also seen deep in the polar caps. It appears that substorms always start at auroral latitudes and may then leap poleward to and above 80° corrected geomagnetic (CGM) latitude. However, commonalities or differences in the characteristic and statistical patterns of the near-midnight magnetic substorms observed at auroral (65°–75°) and polar (75°–85°) latitudes in both hemispheres are yet to be studied.

For example, when a substorm is observed leaping above ~80° in the northern hemisphere, what can
we expect to see in the southern hemisphere? Do these substorms remain conjugate through the magnetic field lines footed in both polar caps or are the corresponding ground magnetic perturbations driven only by the ionospheric closure of the substorm wedge? What are the characteristic and statistical features of the field-aligned currents observed in both hemispheres during these substorms? Thus, at least a few outstanding questions of the underlying physics for very high-latitude geomagnetic substorms remain unanswered.

2. Data

The Greenland West Coast magnetometer chain (12 stations maintained by the Danish Meteorological Institute, DMI) extends from Narsarsuaq (NAQ, 66.3° CGM latitude) to Qaanaaq (THL, 85.4°) along ~40° magnetic meridian (http://www.dmi.dk/fsweb/projects/chain/). Accounting for the stations’ ionospheric “field-of-view”, this chain covers about 23° (~2500 km) along the meridian providing a unique opportunity to study the substorm development in its entirety over auroral latitudes and deep into the polar cap.

The Greenland West Coast chain geomagnetically maps to the Eastern Antarctica where five automatic stations and one manned geophysical observatory are located along ~40° geomagnetic meridian. These are the British AGO A81 (−68.5°), the U.S. AGOs P3 (−71.6°), P4 (−80.4°), P5 (−86.6°), and the Russian base Vostok (−83.3°). Details and maps can be found at the DMI Polar Conjugate Facility (http://www.dmi.dk/fsweb/projectspcf). This Antarctic chain of 5 stations covers ~21° along the meridian but a nine-degree gap over the boundary between the southern auroral oval and polar cap significantly weakens the scientific usefulness of that array.

In this study, we utilized both the Greenland and Antarctic magnetometers for investigating various characteristics of geomagnetic substorms developing over the Greenland West Coast in the range of ±6 hours of local magnetic midnight (at ~0220 UT). First, we developed a technique where we plot geomagnetic perturbations of the local H-component as a contour map in CGM Lat.–Universal Time (UT) coordinates. These maps resemble auroral keograms obtained from the scanning photometer data; in our case, the meridional chain of magnetometers “scans” the substorm development along the meridian with time. The PCF Web site at DMI allows us to produce a stack-plot of Greenlandic and Antarctic magnetograms.

3. Results

Figure 1 shows two near-midnight magnetic substorms that occurred at polar and auroral latitudes. Using the Greenland West Coast magnetic keograms, we identified 568 such substorms in 1999–2000 and investigated how far into the polar cap they may propagate.

Figure 2 shows a histogram where we plot the substorm occurrences (binned by months) as the substorms develop either only over the auroral latitudes or over both auroral and polar latitudes. The
“purely auroral” substorm occurrence varies around 63% (rms=16%) but peaks up to 90% in mid-summer. At that time the occurrence of “auroral-polar” substorms goes down to 10%.

What strikes in this figure is that the two substorm types are evenly distributed during the winter months (Oct–Feb) and unevenly over the rest of the year (Mar–Sep). This result suggests that the substorms may leap more easily and deeply into the polar caps during winter and equinoctial months when the ionospheric conductivity over the nightside polar cap is low.

What are the implications of the revealed behavior on the substorm development in both the northern and southern polar caps? One can expect that during equinox the “polar” substorms should propagate poleward equally in both hemispheres granting approximately equal illumination conditions over the nightside polar caps. Then in winter in either hemisphere, we may expect that the “polar” substorms will leap to higher latitudes more often than in the “summer” hemisphere.

Figure 3 shows an example of an “auroral-polar” substorm that leapt far into both polar caps during equinox. The few other equinoctial events that we studied were in agreement with this finding.

Another example is shown in Figure 4 where the substorm penetrated well into the northern (winter) polar cap but remained at auroral latitudes in the southern (summer) polar cap. Note that in the latter case, some high latitude geomagnetic perturbations are also seen deep in the southern polar cap; we think they are related to ionospheric convection changes rather than to the substorm activities. Although the gap between AGO P3 and AGO P4 could be crucial for this evaluation, more than a dozen events that we studied generally support our statistical finding on the “winter” preference for the more frequent substorm penetration deeper into the polar caps.

In addition to the ground magnetometer study, we extracted all available Ørsted satellite passes which occurred during the development of the selected 568 substorms in 1999–2000. Then we calculated
statistical distributions of the field-aligned currents derived by a technique described in Papitashvili et al. [2001, 2002] and Christiansen et al. [2002].

Figure 5 shows these statistical distributions divided into the “purely auroral” (low, <75°) and “auroral-polar” (high, >75°) substorms sorted by the winter (Oct–Feb) and summer (Mar–Sep) months. It is marginal but it seems that the “high” field-aligned currents propagate to slightly higher latitudes in the pre-midnight MLT sector than the “low” currents. However, it is clearly seen that a well-developed three-sheet FAC structure [e.g., Iijima and Potemra, 1976] in pre-midnight exists only during winter; this structure becomes patchy during summer months. This allows us to conclude that the well-known nightside three-sheet FAC structure is likely a substorm-related feature.

4. Summary

In this study, we learned from Greenland and Antarctic near-conjugate magnetic observations that near-midnight substorms seem to leap more easily and deeply into the polar caps during winter when the ionospheric conductivity is low. This suggests
that abilities of magnetic substorms to propagate deeply into the polar caps to some extent controlled by the ambient ionospheric conductivity.

In addition, the statistical, IMF-dependent patterns of field-aligned currents (not shown) derived from Ørsted observations [Papitashvili et al., 2002] suggest that the Iijima-Potemra 3-sheet FAC structure is not observed in the pre-midnight sector. Instead, this three-sheet structure is clearly seen in the pre-midnight sector in the substorm-related FAC distributions during winter but not in the sunlit polar cap. It also seems that the substorm-related near-midnight upward field-aligned currents move to slightly higher latitudes in winter as far as the ambient conductivity allows. This raises another outstanding question: could this three-sheet FAC structure in pre-midnight be only a substorm-related, wintertime feature?

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References


Figure 5. The “polar” (65°–85° CGM latitudes) and “auroral” (65°–75°) substorm occurrences by months over the Greenland west Coast magnetometer chain in 1999–2000.