AURORAL AND MAGNETIC VARIATIONS IN THE POLAR CUSP AND CLEFT – SIGNATURES OF MAGNETOPAUSE BOUNDARY-LAYER DYNAMICS*

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Abstract. By combining continuous ground-based observations of polar cleft/cusp auroras and local magnetic variations with electromagnetic parameters obtained from satellites in polar orbit (low-altitude cleft/cusp) and in the magnetosheath/interplanetary space, different electrodynamic processes in the polar cleft/cusp have been investigated. One of the more controversial questions in this field is related to the observed shifts in latitude of cleft/cusp auroras and the relationship with the interplanetary magnetic field (IMF) orientation, local magnetic disturbances (DP2 and DPY modes) and magnetospheric substorms. A new approach which may contribute to clarifying these complicated relationships – simultaneous ground-based observations of the midday and evening-midnight sectors of the auroral oval – is illustrated. A related topic is the spatial relationship between the cleft/cusp auroras and the ionospheric convection currents. A characteristic feature of the polar cusp and cleft regions during negative IMF $B_z$ is repeated occurrence of certain short-lived auroral structures which seem to move in accordance with the local convection pattern. Satellite measurements of particle precipitation, magnetic field and ion drift components permit detailed investigations of the electrodynamics of these cusp/cleft structures. Information on electric field components, Birkeland currents, Poynting flux, height-integrated Pedersen conductivity, and Joule heat dissipation rate has been derived. These observations are discussed in relation to existing models of temporal plasma injections from the magnetosheath.

1. Introduction

The dynamical processes governing the particle, momentum, and energy transfer from the solar wind to the magnetosphere and upper atmosphere are main topics of solar-terrestrial research. Questions concerning the dynamics of the plasma-sheet of the nightside magnetosphere and its interaction with the auroral zone ionosphere have been studied in some detail (e.g., Akasofu, 1977; Shepherd et al., 1980). In recent years attention has been focused on the physics of the dayside magnetospheric boundary layers (e.g., Paschmann, 1984; Eastman, 1984) and the coupling to the dayside polar ionosphere (e.g., Holtet and Egeland, 1985).

It has been speculated for a long time that the solar wind plasma can penetrate into the magnetosphere through magnetic neutral regions resulting from the coupling between the solar wind and the Earth's magnetic field. The first indication of the existence of a pair of magnetic neutral points (or lines) at high latitudes on the dayside magnetopause was provided by Chapman and Ferraro (1931), in a theoretical discussion of the interaction between a conducting plasma and the geomagnetic field. The first direct evidence for plasma entry in these regions was obtained around 1970 when satellite observations revealed the existence of plasmas of magnetosheath origin at low $B_z$.
altitudes (Heikkila and Winningham, 1971) and at higher altitudes in the dayside magnetosphere (Frank, 1971).

Recent particle measurements from the Swedish spacecraft VIKING has confirmed earlier evidence (e.g., Gussenhoven et al., 1985) of two different particle precipitation regions, one narrow (in longitude) cusp and a much more extensive cleft. The first VIKING results show the following distinguishing characteristics of the cusp 'proper', located in the 1100–1300 MLT sector (cf. Lundin et al., 1987): (1) The hot plasma shows minute signatures of energization, the electrons and ions essentially showing magnetosheath characteristics. (2) The ions show some temporal flux variations, but in general they seem to be mainly affected by a poleward convection field. (3) It is characterized by an escape of ionospheric ions with energies below some 100 eV.

The cleft region, comprising the remainder of the dayside high-latitude portion of the auroral oval near noon, is quite different: (1) A significant amount of energization of both magnetospheric and ionospheric plasma (up to keV energies). (2) Temporal injections of magnetosheath plasma, showing characteristic time-dispersion signatures. (3) A strong ionospheric outflow of both electrons and ions.

During the International Geophysical Year 1957/1958 midday auroral emissions were recorded by all-sky cameras at polar stations (cf. Feldstein and Starkov, 1967). Photometric observations of these emissions were made by Eather and Mende (1971), who showed that the spectroscopic ratio \( I(\text{O I} 630.0 \text{ nm})/I(\text{N} \text{II}^+ 427.8 \text{ nm}) \) is enhanced by an order of magnitude relative to the typical midnight emissions.

There is now strong evidence that these red-dominated midday auroral emissions are due to magnetosheath plasma penetration into the magnetosphere and subsequent precipitation along field lines in the cusp (e.g., Holtet and Egeland, 1985).

Due to the inaccessibility of the polar regions which satisfy the observation conditions, i.e., correct distance to the geomagnetic pole and so far north in geographic latitude that the sunlight does not disturb the observations at magnetic midday, the cusp and cleft auroras have received markedly less attention than the night-time aurora. The only sites in the northern hemisphere which satisfy the above requirements for optical observations of the midday auroras are Svalbard (Norway) and Franz Josef’s Land (U.S.S.R.) (cf. Figure 1).

The form, position and dynamics of the auroras near the cusp are known to reflect statistically the general character of the solar wind and the interplanetary magnetic field (Lassen and Danielsen, 1978). Recent results indicate that there may be a direct relationship between the solar wind interaction process at the dayside magnetopause and individual auroral forms observed near the projection of the magnetospheric cleft on the ionosphere (Sandholt et al., 1985; 1986a). These emissions may then be used as a diagnostic tool in the investigation of plasma entry into the magnetosphere and the subsequent fate of that plasma under various solar wind and IMF conditions.

Concerning parameters like the scale size and recurrence rates of the dynamical plasma injection processes, satellite measurements permit only rough estimates. Continuous ground-based observations of the ionospheric ‘footprints’ may provide the necessary resolution in time and space.