THE AURORAL ELECTROJETS

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ABSTRACT

The auroral electrojets are the ionospheric component of three-dimensional current systems through which the outer magnetosphere is coupled to the ionosphere. These current systems permit energy imparted to the convective motion of magnetospheric plasma to be dissipated in the ionosphere through the process of Joule heating. In this paper we shall review the various component three-dimensional current systems which relate to the electrojets and we shall show how their magnetic fields combine to yield the observed magnetic perturbation at the earth's surface. We shall treat the case of the steady-state electrojet system and we shall also show how it is altered during substorms. Finally, we outline the physical processes through which three-dimensional current systems are generated.

INTRODUCTION

The concept that high latitude magnetic perturbations could largely be explained by three-dimensional current systems involving a latitudinally localized ionospheric current in the auroral zone was first developed by Birkeland (1908, 1913). After Birkeland's initial work, most studies concentrated on the ionospheric currents and these investigations led to the conclusions that there was a westward ionospheric electrojet in the morning sector and an eastward ionospheric electrojet in the afternoon sector (Silsbee and Vestine, 1942). Harang (1946) carried out the first definitive study in which the presently accepted electrojet configuration was proposed. Harang's model featured an eastward electrojet which was most apparent near local dusk and which had almost disappeared by midnight. The westward electrojet penetrated into the evening sector at the poleward edge of the eastward electrojet. The westward electrojet in the evening sector has been shown to exist even if substorms are not in progress (Hughes et al., 1978), and it grows both in magnitude and spatial extent when substorm activity penetrates into the evening sector (Rostoker and Kisabeth, 1973).
ionospheric electric field undergoes a poleward to equatorward transition as one moves poleward from the eastward electrojet into the westward electrojet region (Rostoker et al., 1975); the locus of this electric field transition in the midnight and evening sector is known as the Harang discontinuity (Heppner, 1972).

THREE-DIMENSIONAL CURRENT SYSTEMS INVOLVING THE ELECTROJETS

After Birkeland's initial work, and considerably after its support by Alfvén (1939) on the basis of his theoretical studies of magnetohydrodynamic media, the next definitive study of the electrojets was carried out by Boström (1964). He showed that there were two possible elementary three-dimensional current systems which could be expected to exist in the upper atmosphere. The first system (which was that originally proposed by Birkeland) involved current flowing into the ionosphere, eastward or westward along the auroral oval, and eventually back up into the magnetosphere. The second system involved antiparallel field-aligned current sheets linked through the ionosphere by poleward or equatorward ionospheric current. The two possible current configurations are shown in Figure 1. Indisputable evidence for the existence of three-dimensional current systems of the second type was obtained by Zmuda et al. (1967) using magnetometer data from a polar orbiting satellite. A typical magnetic perturbation pattern and inferred field-aligned and ionospheric current system is shown in Figure 2. Subsequent studies of the electrojets and electric fields in the electrojet region have indicated that, away from noon and midnight, the electric field is primarily poleward in the region of the eastward electrojet and equatorward in the region of the westward electrojet. The ionospheric current \( J_\perp \) is given by

\[
J_\perp = \Sigma_P E_\perp + \Sigma_H \hat{B} \times E_\perp
\]

where \( \Sigma_P \) and \( \Sigma_H \) are respectively the height-integrated Pedersen and Hall conductivities, \( \hat{B} \) is a unit vector in the direction of the ambient magnetic field and \( E_\perp \) is the component of the ionospheric electric field normal to \( \hat{B} \). It therefore follows that the ionospheric east-west electrojets are primarily Hall currents while the north-south current flow connecting the anti-parallel current sheets is primarily Pedersen current. Across midnight the electric field has a strong westward component; thus, in this local time regime, the westward electrojet has a significant Pedersen current which is complemented by a poleward flow of Hall current.

In dealing with the sources of field-aligned current flow, it is useful to break down the ionospheric current systems into their Hall and Pedersen components so that one is dealing with three-dimensional current circuits whose ionospheric components are either Hall or Pedersen currents. This is useful because Pedersen currents involve energy dissipation (since \( J \cdot E_\perp > 0 \)) which implies that such circuits