OBSERVATION OF BIRKELAND CURRENTS WITH
THE TRIAD SATELLITE*

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Abstract. The intimate connection between geomagnetic storms and the aurora was appreciated by many early scientists including Edmund Halley and Anders Celsius, but the first serious study of this phenomena was made by Kristian Birkeland who, during his polar expeditions of 1902–1903, determined that large-scale ionospheric currents were associated with the aurora. Birkeland was also the first to suggest that these currents originated far from the Earth and that they flowed into and away from the polar atmosphere along the geomagnetic field lines. The existence of such field-aligned or Birkeland currents was widely disputed because it was not possible to unambiguously identify current systems that are field-aligned (Alfvén, 1939, 1940) and those which are completely contained in the ionosphere (Vestine and Chapman, 1938) only from a study of surface magnetic field measurements. During the last decade, the presence of Birkeland currents has been absolutely confirmed with particle and magnetic field observations acquired from a variety of rocket and satellite instruments. The vector magnetometer on the low-altitude (~ 800 km) polar orbiting TRIAD satellite has been used to determine for the first time the flow direction, spatial distribution, and intensities of Birkeland currents in the north and south auroral regions. These observations support the mechanism originally proposed by Alfvén (1939, 1940) – later expanded by Shield et al. (1969) – to drive Birkeland currents in the auroral regions, and they demonstrate the important role that these intense currents (ranging between 10^6 and 10^7 amperes) play in the coupling of energy between the magnetosphere and the lower ionosphere and atmosphere.

1. Introduction

According to Chapman and Bartels (1940) the connection between aurora and magnetic storms was first suggested by Halley in 1716. Similar independent discoveries were made by Celsius, Hörter and Wilcke in the same century (Störmer, 1955). Inspired by his famous terrella experiments and by his extensive studies of geomagnetic data recorded during magnetic storms, Birkeland suggested at the end of the 19th century that the aurora was due to cathode rays or similar electric corpuscular rays sent out from the Sun and deflected to the polar regions of the Earth by the geomagnetic field. Birkeland recognized that the geomagnetic disturbances recorded on the Earth’s surface below the auroral region were due to intense currents flowing horizontally above (referred to today as auroral electrojets). In Birkeland’s (1908) words: ‘We consider it to be beyond doubt that the powerful storms in the northern regions, both those of long duration, and the short, well-defined storms that we have called elementary, are due to the action of electric currents above the surface of the Earth near the auroral zone. These currents, as far as the elementary storms are

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concerned at any rate, act, in the districts in which the perturbation is most powerful, as almost linear currents, that for a considerable distance are approximately horizontal.' He went on to compute the current strength to vary between $5 \times 10^6$ and $10^8$ A and determined the altitude of these currents to be above 100 km. Present values are $3 \times 10^5$ A for the westward electrojet (Nagata et al., 1966), $2 \times 10^6$ to $5 \times 10^6$ A for the total system of field-aligned Birkeland currents (Iijima and Potemra, 1978), and $2 \times 10^8$ to $4 \times 10^8$ A for the ring current (Akasofu, 1969; Sugiura and Poros, 1973).

Birkeland was concerned, however, about these horizontal currents as reflected in his writing: 'With regard to the further course of the current, there are two possibilities that may be considered. (1) The entire current-system belongs to the Earth. The current-lines are really lines where the current flows upon the Earth's surface, or rather at some height above it. (2) The current is maintained by a constant supply of electricity from without. The current will consist principally of vertical portions. At some distance from the Earth's surface, the current from above will turn off and continue for some time in an almost horizontal direction, and then either once more leave the Earth, or become partially absorbed by its atmosphere.' Birkeland apparently favored the second suggestion from his terrella experiments and Störmer's calculations, and proposed the field-aligned current system reproduced here as Figure 1. But his two suggestions were to prophesize a controversy concerning the current system which

![Fig. 1. The system of field-aligned currents originally suggested by Birkeland in 1908. Figure 50a represents those in which the current-directions at the storm-centre are directed westwards, and 50b those in which the currents move eastwards' (Birkeland, 1908).]