The Contribution of Magnetospheric Currents to $Sq$

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Abstract—Since the discovery of the magnetosphere, it has been known that the currents flowing in the magnetosphere contribute to $Sq$, the regular daily variation in the earth's surface magnetic field. The early models, however, were not very accurate in the vicinity of the earth. The magnetospheric contribution to $Sq$ has therefore been recalculated by direct integration over the three major magnetospheric current systems; magnetopause, tail and ring. The finite electrical conductivity of the earth, which increases the horizontal and decreases the vertical components of the magnetospheric field at the earth's surface, has been taken into account. The magnetospheric currents are found to contribute 12 nanotesla to the day to night difference in the mid-latitude $Sq$ pattern for steady, quiet magnetospheric conditions. They also contribute to the annual variation in the surface field and must be considered an important source of the observed day to day variation in the $Sq$ pattern.

Key words: Magnetospheric currents, $Sq$.

1. Introduction

It has been known for several hundred years that the earth possesses a planetary magnetic field (Gilbert, 1600). It has also been known for over 200 years (Canton, 1759) that there is a daily variation in the strength of the magnetic field at the earth's surface. The earth's surface magnetic field also exhibits changes associated with solar activity (Adams, 1892). Even when the sun is "quiet," however, there is a day to night variation in the earth's surface magnetic field. This daily variation at mid-latitudes is designated by "$Sq$," the Solar Quiet daily variation (Chapman, 1919). Typically, at mid-latitude, the magnitude of this daily variation ranges from 15 to 30 nanotesla (Vestine et al., 1947). This compares with a total surface magnetic field of about 50,000 nanotesla.

Near the turn of the century, the existence of the ionosphere was inferred from the presence of these magnetic variations by Stewart (1882). He suggested that the $Sq$ pattern was caused by ionization in the upper regions of the atmosphere being moved by neutral particles through the earth's magnetic field. This led to the
ionospheric dynamo theory which explained how the diurnal solar heating of the upper atmosphere could produce a global system of electric current responsible for the $Sq$ pattern. Later, when the existence of the ionosphere was proven by experiments which reflected radio waves off of it (Breit and Tuve, 1925), the ionospheric dynamo theory became the accepted explanation for $Sq$.

With the observational discovery of the magnetosphere in the early 1960's, however, it was recognized that other currents flowing above the earth must also contribute to the surface magnetic field variations. In early work it was suggested that the magnetospheric currents produce a magnetic field structure at the earth's surface that is similar to the observed $Sq$ pattern but considerably smaller in magnitude (Mead, 1964; Olson, 1970a,b).

Since that time, much has been learned concerning the nature of the magnetospheric current systems. The purpose of this paper is to quantitatively reexamine the contribution of the magnetospheric currents to $Sq$. An accurate determination of the contribution of these currents to the $Sq$ pattern can serve to place an upper bound on the neutral winds in the upper atmosphere required by the ionospheric dynamo theory. Such a determination is also necessary for the quantitative specification of the earth's main magnetic field. An accurate representation of the main field (to within several nanoteslas) is required for the study of the secular variation in the main field, and for the quantitative specification of magnetic anomalies in the earth's crust. The accurate representation of the magnetospheric contribution to the earth's surface magnetic field may also be of use in the study of magnetospheric dynamics since indices constructed from ground based magnetometer data are routinely used to describe magnetospheric events.

2. The Major Magnetospheric Current Systems

The magnetopause, tail and ring current systems are the three largest magnetospheric current systems. They have been described in detail elsewhere. See, for example, the review by Walker (1979). A brief description of each current system follows.

2.1 The Magnetopause Current System

The largest magnetospheric current system, and the first to be quantitatively modeled, flows on the outer boundary of the magnetosphere, the magnetopause. The magnetopause currents are produced by the interaction of the solar wind with the earth's magnetic field. The electrons and protons that comprise most of the solar wind are deflected from the geomagnetic field in opposite directions, giving rise to a large current system that flows around two foci. The magnetopause currents have