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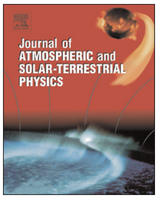

An interpretation of spacecraft and ground based observations of multiple omega band events

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ABSTRACT

The source of the auroral phenomenon known as omega bands is not yet known. We examine in detail five different intervals when omega bands were observed on March 9th, 2008 between 0400 UT and 1100 UT over central Canada using both ground and space-based instrumentation. The THEMIS all sky imagers show the development of some of the omega bands from north–south streamers. Spherical elementary currents derived from ground magnetometer data indicate that the omega bands lie near the interface between the region 1 and region 2 currents in the post-midnight sector. THEMIS spacecraft data from the pre-midnight sector display multiple high speed flows and dipolarization features associated with high levels of geomagnetic activity, whereas four GOES geosynchronous spacecraft show multiple injections and dipolarization features. Magnetic field line tracing suggests that the magnetospheric location of the omega bands is at or just beyond geosynchronous orbit. We discuss in detail two potential source mechanisms for the omega bands: plasma sheet velocity shears and high speed flows in the magnetotail and relate the available data to those mechanisms. Our data and a magnetohydrodynamic (MHD) simulation support high speed flows in the magnetotail as the most likely generation mechanism, although the distribution of the magnetotail spacecraft does not provide unambiguous support for our interpretation of the source mechanism.

1. Introduction

Akasofu and Kimball (1964) were the first to describe the auroral wave-like structures called "omega bands", which appear within the morning sector auroral oval with shapes resembling the Greek letter Ω, and are typically associated with the recovery phase of magnetic substorms (Vanhamäki et al., 2009). To date, the generation mechanism for this auroral phenomenon has not yet been established and the available information comes mainly from ground observations. Omega bands typically consist of several equally spaced structures that propagate from west to east with a speed of 400–2000 m/s (Yamamoto et al., 1993; Opgenoorth et al., 1983; Mravlag et al., 1991) consistent with the average $\vec{E} \times \vec{B}$ plasma drift velocity (André and Baumjohann, 1982). Auroral observations of omega bands have been recorded in both hemispheres on the same day, which suggests they may be conjugate in both hemispheres, but the observations were not at the exact same time (Mravlag et al., 1991).

Saito (1978) was the first to propose a connection between the occurrence of omega bands and magnetic Ps6 pulsations, which have periods of 5–40 min and amplitude from 10 to 1200 nT (Saito, 1977). This connection was confirmed by André and Baumjohann (1982). Ps6 pulsations, which are pulsations associated with substorms, are believed to be the magnetic signature of the ionospheric current system associated with omega bands drifting eastward over a ground magnetometer station. Ground magnetometer observations do not display special characteristics in the *Bx* component that points toward the geographic north pole in the center of a single omega, but the *By* component that points toward geographic east displays a sharp, spike like increase associated with the western edge. The *Bz* component that points into the

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Earth has a sawtooth form, with a minimum eastward of the center of the omega band and a sharp increase on the western side. (see Fig. 3 of Jorgensen et al. (1999)).

The fluctuations observed in all three components of the magnetic field show that a three-dimensional ionospheric current system is present. A great deal of work has been done on the three-dimensional current system of omega bands (Kawasaki and Rostoker, 1979; Gustafsson et al., 1981; André and Baumjohann, 1982; Opgenoorth et al., 1983; Lühr and Schlegel, 1994; Amm, 1996). In general, the brightest edges of the omega bands lie near the interface between the region 1 and region 2 current system in the morning sector.

A number of studies have used magnetic field models to identify the magnetospheric equatorial location of the observed omega bands mapped along field lines (Pulkkinen et al., 1991; Tagirov, 1993; and Wild et al., 2011). Pulkkinen et al. (1991) determined that the omega bands observed on March 25, 1986 mapped to 6–13 R_E with Tsyganenko (1989) (T89) magnetic field model (Tsyganenko, 1989) and Tagirov (1993) found that the omega bands observed on April 9–10, 1986 mapped to 5–6 R_E, also using the T89 model. The omega bands observed over Iceland with the Tjörnes all sky imager on September 28, 2009 (Wild et al., 2011) were found to be conjugate with the Cluster spacecraft at about 8 *Re* down tail on the basis of field line tracing with the Tsyganenko 2001 model (Tsyganenko, 2002a, 2002b).

Ground based observations of omega bands are relatively common; however, spacecraft measurements of the magnetospheric signature of omega bands are less common. The bulk of spacecraft observations are from auroral imagers such as Viking, IMAGE, and Polar (Henderson, 2009, 2012; Henderson et al., 1998, 2002; Opgenoorth et al., 1994; Amm et al., 2005). As far as we are aware, only Wild et al. (2011) study provides spacecraft observations in the magnetotail on or near magnetic field lines conjugate to auroral omega bands. Wild et al. (2011) study did not show a one-to-one correlation between the auroral structures and the in situ plasma or magnetic observations, but did show enhanced Alfvénic Poynting flux and transient bursts of electron differential energy flux with dispersed energy signatures throughout the event when satellite foot points were located in the vicinity of the omega bands.

We do not yet understand what causes omega bands to develop. It is most likely that the paucity of concurrent magnetospheric measurements has limited our ability to understand why they occur. However, a number of mechanisms, which are reviewed in Amm et al. (2005), have been proposed. The most widely accepted generation mechanisms are that omega bands form as a direct consequence of auroral streamer activity (Roux et al., 1991; Henderson, 2009, 2012), where auroral streamers are the ionospheric projection of earthward flow burst in the plasma sheet (Nishimura et al., 2011), or that they arise through the structuring of magnetic vorticity and field-aligned currents in the ionosphere by the Kelvin Helmholtz instability driven by flow shears at the inner edge of the plasma sheet (Rostoker and Samson, 1984; Janhunen and Huuskonen, 1993). The auroral streamer/high speed flow mechanism predicts that spacecraft in the tail should observe high speed earthward flows with field aligned currents at the flow shears, magnetic field dipolarizations associated with the high speed flows, and particle enhancements near geosynchronous orbit. The flow shear mechanism predicts flow shears within the tail at about 6–13 Re, oscillation in the radial component of the magnetic field near the shear, and the region 1 currents should exceed the region 2 currents prior to the flow shear but the currents are approximately equal during the omega bands.

The goal of our study is to use ground and space-based observations to examine in detail five periods of omega bands that appeared on March 9, 2008 and to suggest a possible generation mechanism. In Section 2 we discuss the ground and space-based instrumentation used in our study. In Section 3 we discuss in detail the available observations and in the last two sections we interpret the observations, then summarize and conclude.

2. Spacecraft and instrumentation

The data for this study come from four sources: the Time History of Events and Macroscale Interactions During Substorms (THEMIS) all-sky image (ASI) array, the THEMIS spacecraft, four Geostationary Operational Environmental Satellites (GOES), and seven ground magnetometer arrays.

THEMIS ASIs are used to identify the omega bands. White light ASIs are obtained from an array of Ground-Based Observatories (GBOs) spread over Alaska and Canada. Fig. 1 shows the location of the ASIs (orange diamonds) as well as the ground magnetometers (black dots), the average location of the GOES spacecraft foot points (yellow squares) determined from magnetic field line mapping with T89, T96, and T01 over 04 UT to 11 UT, and the THEMIS C (green), D (mauve), and E (blue) spacecraft foot points for the events that we investigate. The THEMIS spacecraft foot points start at 04 UT at the lowest latitude and end in Alaska at 11 UT. Each all sky imager has a cadence of 3 s and a spatial resolution of 1 km at zenith. The spatial resolution decreases to about 2.5 km at an elevation angle of 45° and dramatically diminishes to about 15 km at an elevation angle of 15°. More details on the imagers and their geographic positions can be found in Donovan et al. (2006) and Mende et al. (2008). The ASIs are an essential part of the THEMIS spacecraft mission. These imagers, along with the ground magnetometers, and spacecraft instruments provide a global picture of magnetosphere–ionosphere coupling.

The main objective of the THEMIS spacecraft mission is to identify the chain of events that leads to substorms (Angelopoulos, 2008) but the combination of ground-based instrumentation with multiple equatorial spacecraft is of great value for investigation of

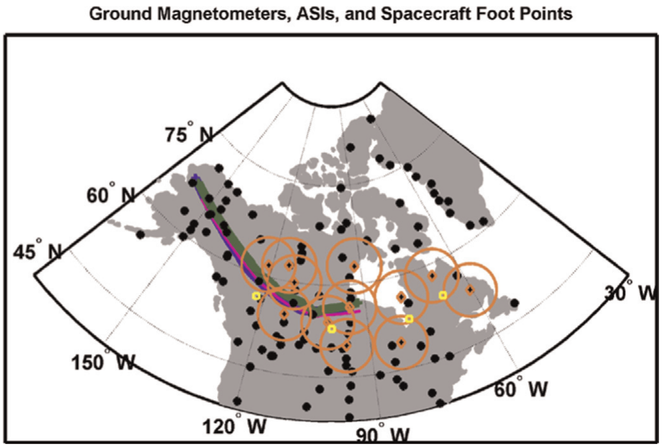

Fig. 1. Distribution of ground magnetometers, all sky imagers, and spacecraft foot points across North America. The coordinate system shown is in geographic coordinates. The black dots indicate the locations of ground magnetometers with good data for the March 9th, 2008 omega bands events. The orange diamonds shows the positions of the all sky imagers used to investigate the omega bands and orange circles indicate the fields of view. The yellow squares give the average foot point locations of the GOES spacecraft determined from magnetic field line tracing for T89, T96, and T01 over the time range of 0400–1100 UT. The green, mauve, and blue curves display the THEMIS C, D, and E foot points, respectively, determined from the T01 magnetic field model from 0400 UT to 1100 UT. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)