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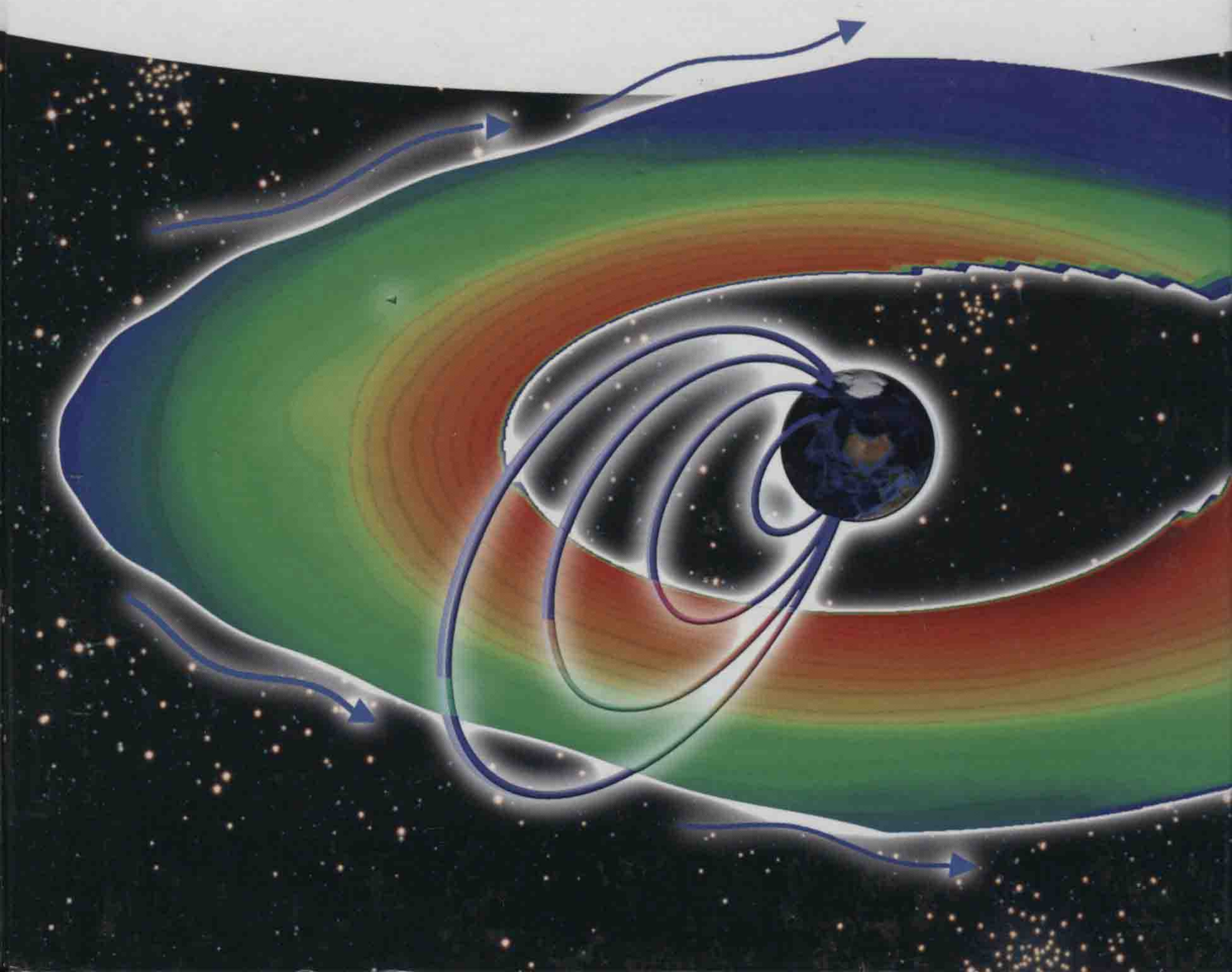
Ground-based remote sensing of Earth's magnetosphere



Frederick W. Menk and Colin L. Waters

Magnetoseismology

Ground-Based Remote Sensing of Earth's Magnetosphere

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Cover

Artist's depiction of geomagnetic field lines mapping from Earth's surface into the magnetosphere, where colors represent mass density in the equatorial plane, which in turn determines the resonant frequency of these field lines. Kindly provided by Matthew Waters.

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Magnetoseismology

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Preface

One of the joys as a student was building and using relatively simple equipment – magnetometers and ionospheric sounders – to probe the region of space around Earth and gain insight into processes there. This is the essence of this book: remote sensing, mostly using ground-based instruments and techniques, to understand our space environment, the magnetosphere. This region dynamically links interplanetary space with Earth's atmosphere, and is where satellites orbit.

The agents involved are ultralow-frequency plasma waves, since they propagate from the solar wind through the magnetosphere and atmosphere to the ground. These waves transfer energy and momentum and are not only involved in many types of instabilities and interactions but can also be used as a diagnostic monitor of these processes. This book focuses on the second aspect through understanding of the first.

With the move to online data access, undergraduate students can conduct original research using observations from ground arrays, radar networks, and satellites. The magnetosphere is there for everyone to explore. This in turn provides wonderful insight into all the relevant physics, from the cycles of the Sun to the nature of the geomagnetic field and the atmosphere, and exploring other planets.

This book focuses on the underlying principles and their interconnectedness. We do not assume familiarity with physics or mathematics concepts beyond undergraduate level.

Many people have guided our personal journeys. Our scientific mentors include Brian Fraser, John Samson, Keith Cole, and Valerie Troitskaya. Other colleagues include Sean Ables, Brian Anderson, Mark Clilverd, Bob Lysak, Ian Mann, Pasha Ponomarenko, Murray Sciffer, Peter Sutcliffe, and Tim Yeoman. Many students taught us at least as much as we taught them. The development of this monograph was patiently and enthusiastically guided by our editors at Wiley, Nina Stadthaus and Christoph Friedenburg. Of course, this book would not have been possible without the continual support of our families and wives, who suffered in silence a great many evenings while we disappeared into offices to pursue our arcane endeavors.

Newcastle, July 2012

Frederick W. Menk
Colin L. Waters

Color Plates

Figure 1.1 Comet Hale–Bopp, showing a white dust tail and a blue ion tail, resulting from the effect of the solar wind and entrained magnetic field. *Source:* Alessandro Dimai and Davide Ghirardo (Associazione Astronomica Cortina) at Passo Giau (2230 m), Cortina d'Amprezzo, Italy, March 16, 1997, 03:42 UT. e-mail: info@cortinastella.it, web: www.cortinastelle.it - www.skyontheweb.org. (This figure also appears on page 2.)

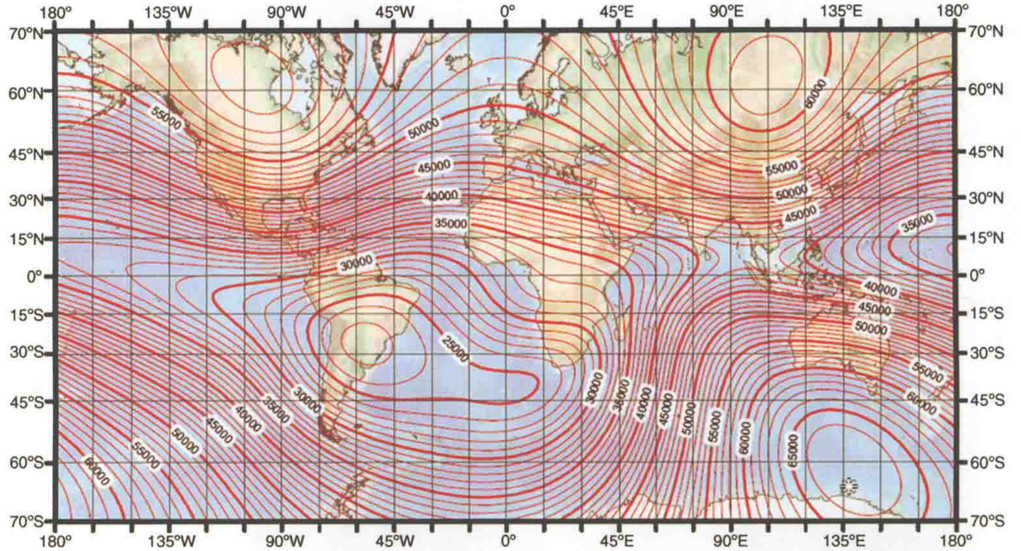

Figure 2.3 Mercator projection of the total intensity *F* of the main geomagnetic field computed using the 2010 World Magnetic Model. Contour interval is 1000 nT. From Maus *et al.* (2010). (This figure also appears on page 17.)

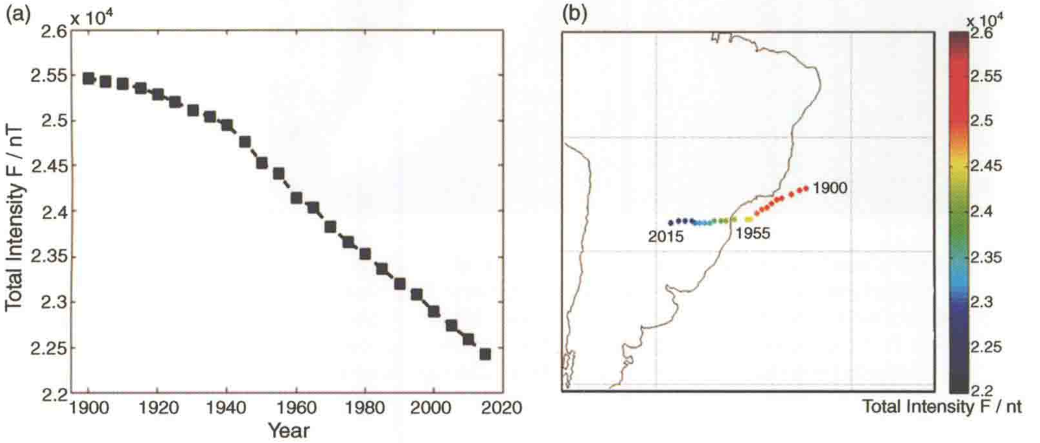

Figure 2.5 Variation in (a) strength and (b) location of the minimum in the total field intensity *F* in the South Atlantic Anomaly region during the past century. From Finlay *et al.* (2010). (This figure also appears on page 18.)

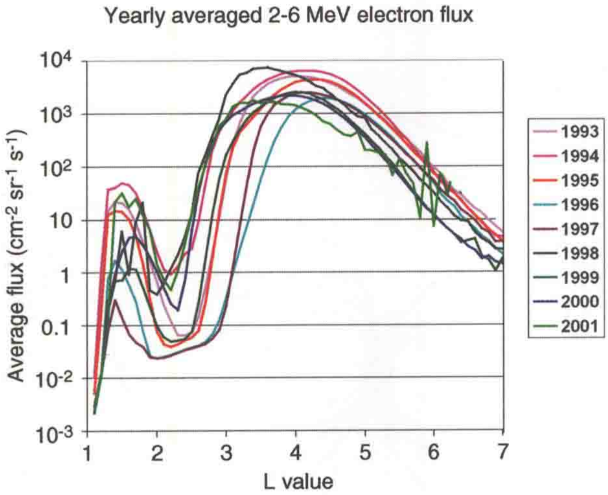

Figure 2.9 Yearly averaged 2–6 MeV electron flux measured at low altitudes by the SAMPEX spacecraft during 1993–2001, showing location and intensity of the radiation belts. Data courtesy of Shri Kanekal and SAMPEX Data Center staff. (This figure also appears on page 28.)

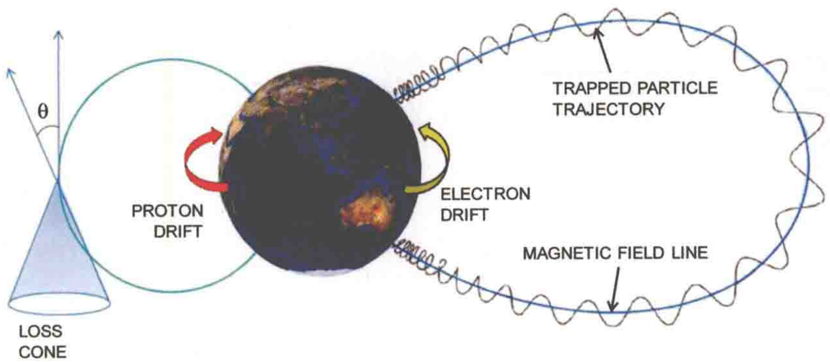

Figure 3.1 Charged particle motions in the magnetosphere, showing gyration around a field line, bouncing between mirror points, and azimuthal drift along L shells. Pitch angle is θ. (This figure also appears on page 47.)

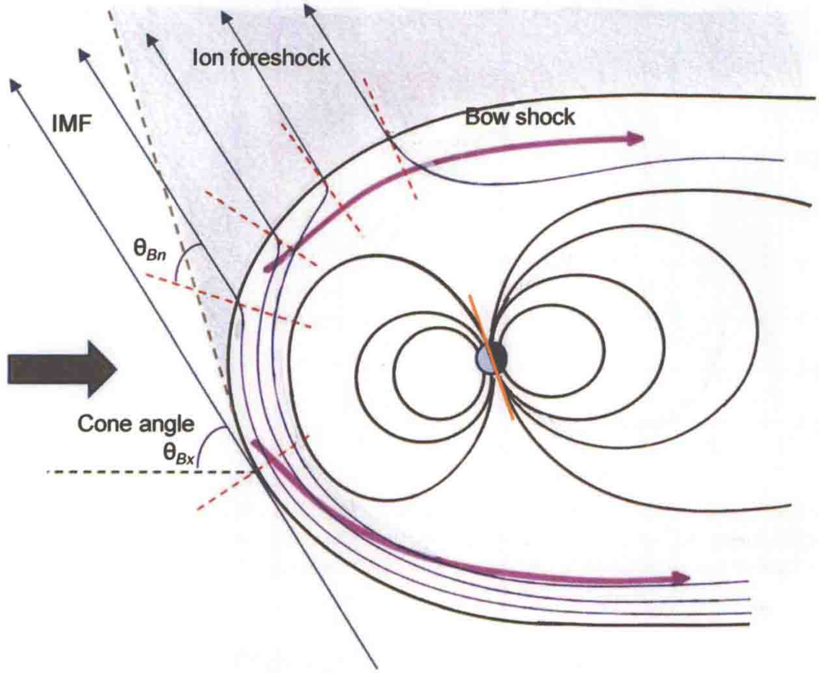

Figure 4.3 Schematic representation of the magnetopause, bow shock, and the ion foreshock region (shaded) where ULF waves are likely generated. The IMF is shown northward, and thick arrows represent plasma streamlines. Field lines (solid) map around the magnetopause and the plasma convects antisunward. (This figure also appears on page 66.)

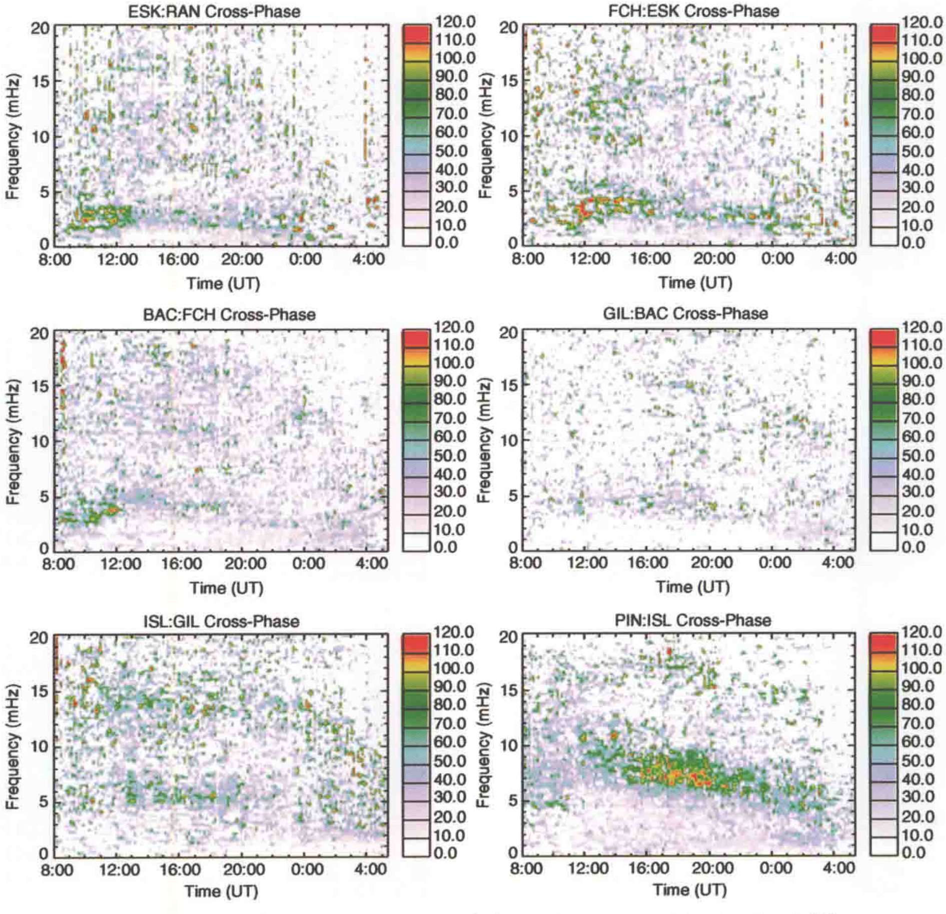

Figure 5.9 Dynamic cross-phase spectra data recorded on February 9, 1995 by the Churchill line of magnetometers of the Canadian array. Time axis is from 0800 to 0530 UT and local noon is at 1800 UT. Cross-phase scale is from 0° to 120°. (This figure also appears on page 99.)

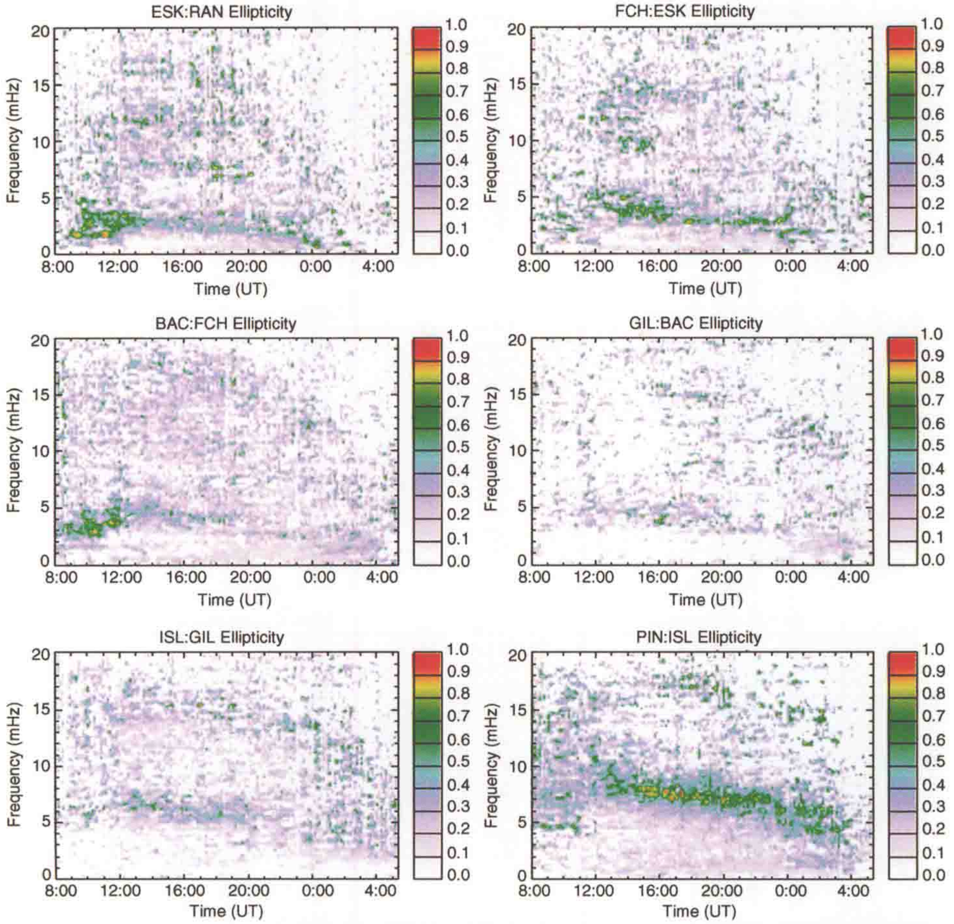

Figure 5.10 The "ellipticity" spectra computed from the north–south component magnetic field data from pairs of latitudinal spaced stations of the Canadian Churchill line. The processing used the same time series as Figure 5.9. (This figure also appears on page 102.)

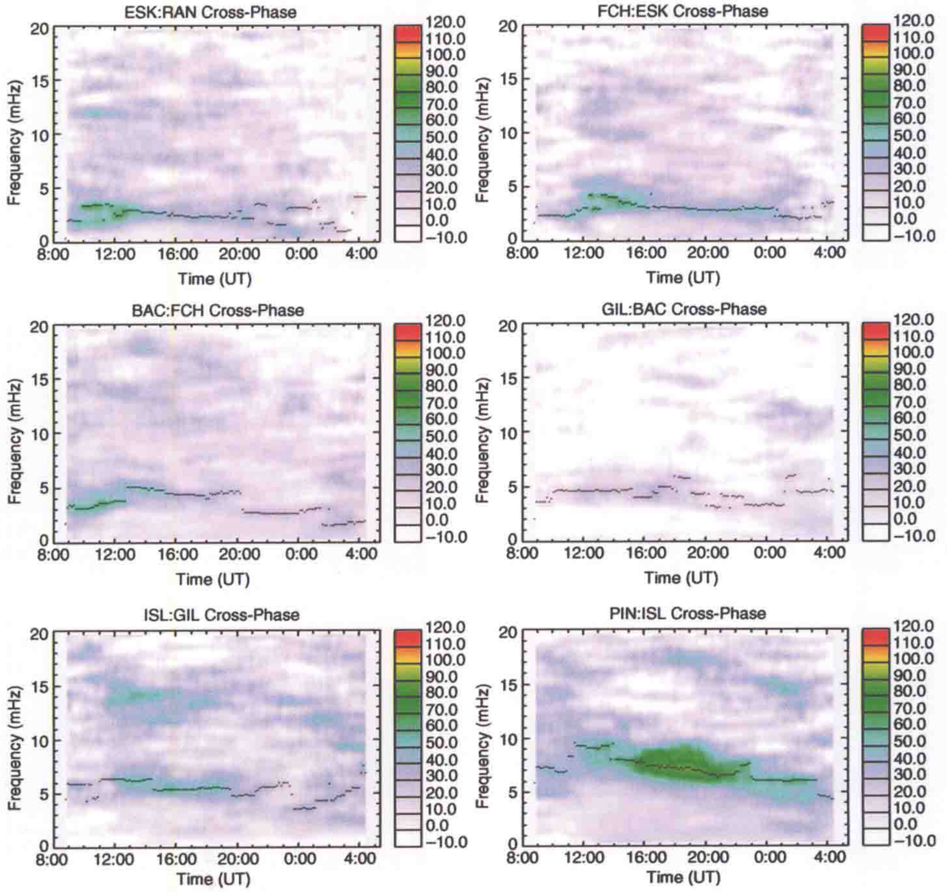

Figure 5.11 The automatic FLR detection algorithm in Berube, Moldwin, and Weygand (2003) applied to the cross-phase data in Figure 5.9. (This figure also appears on page 104.)

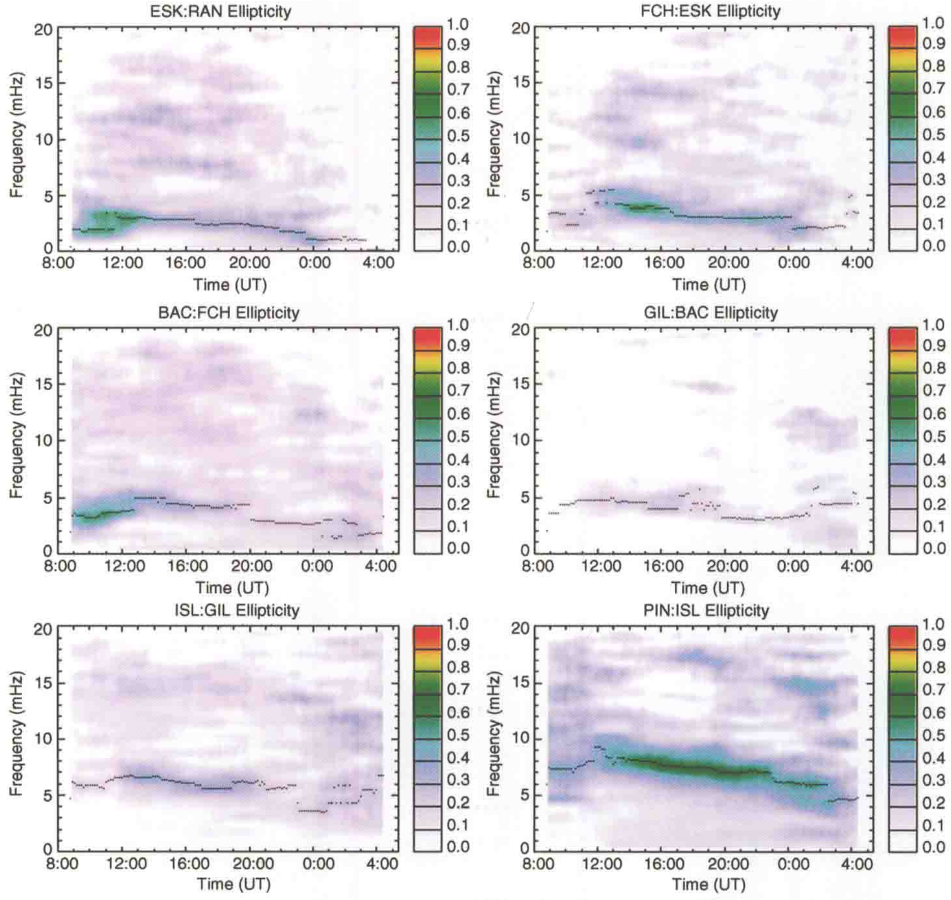

Figure 5.12 The automatic FLR detection algorithm in Berube, Moldwin, and Weygand (2003) applied to the ellipticity data in Figure 5.10. (This figure also appears on page 105.)

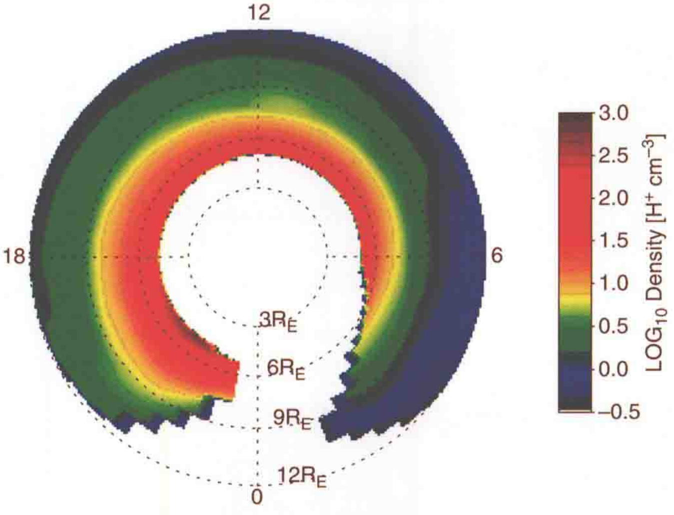

Figure 6.1 Logarithm of magnetosphere plasma mass density in units of H^+ cm^{-3} as a function of radial distance and MLT, derived from FLRs detected with the CANOPUS magnetometer array on February 9, 1995. From Waters *et al.*, (2006). (This figure also appears on page 109.)

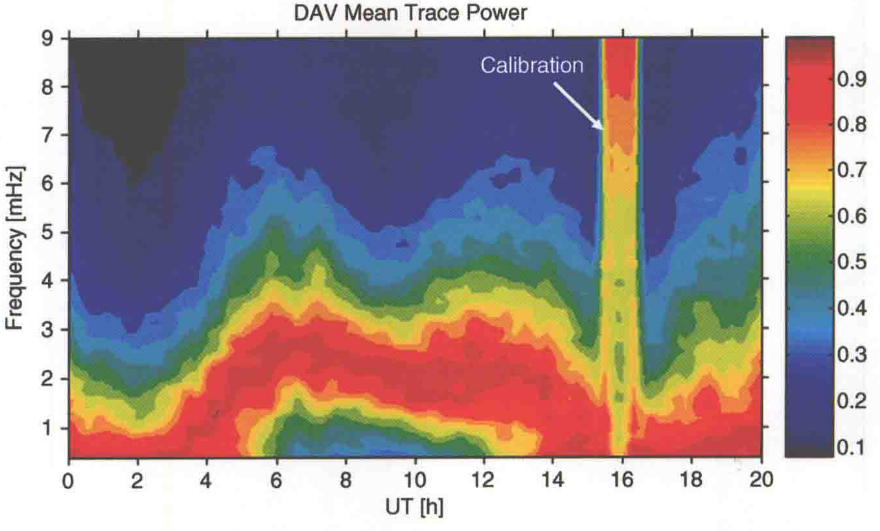

Figure 6.14 Normalized, mean trace spectral power over 0.1–9 mHz from magnetometer data recorded at Davis, Antarctica. The data are for the full year 1996 and local magnetic noon is near 0940 UT. (This figure also appears on page 129.)

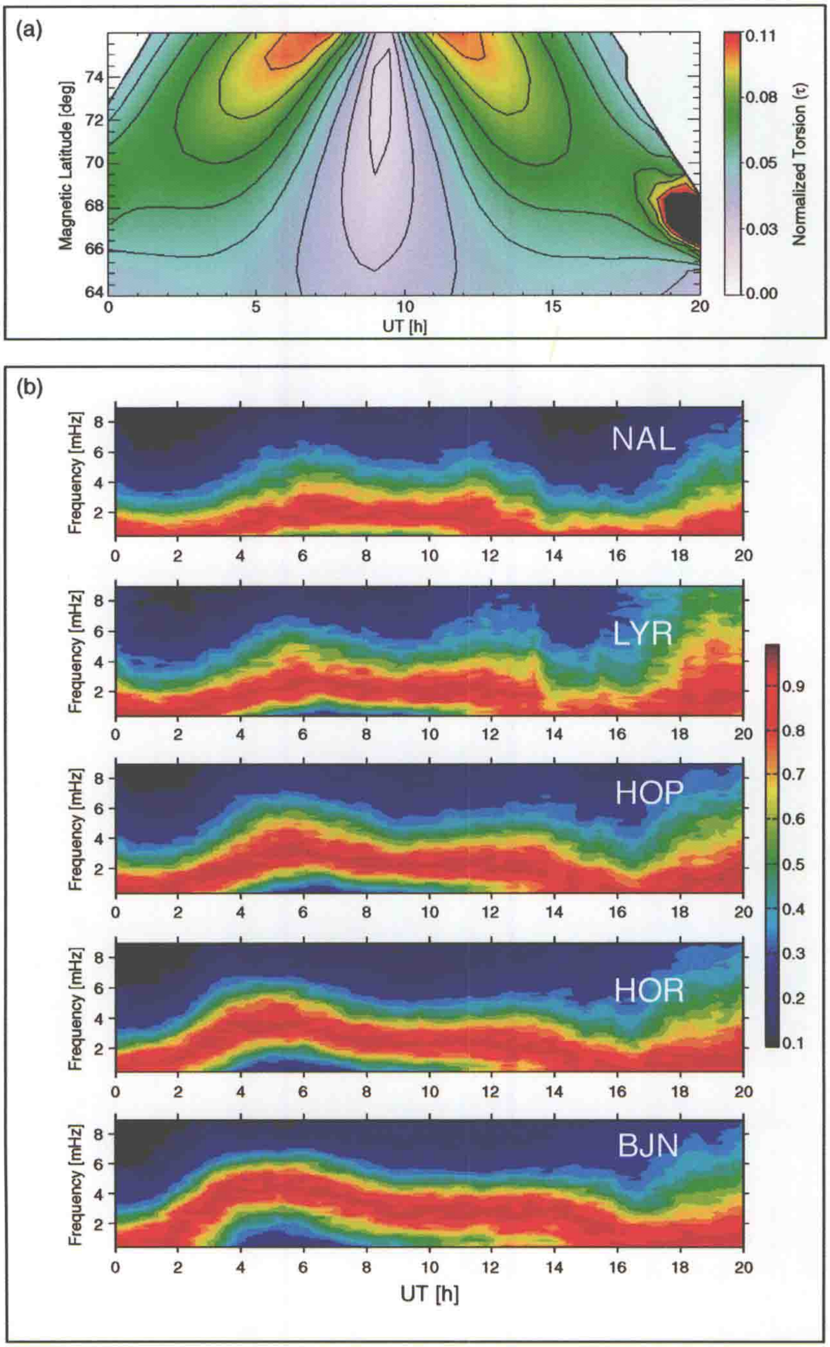

Figure 6.16 Extent in latitude of field line tension and torsion that affects FLR frequencies. (a) Estimates using the Tsyganenko 1996 model. (b) Normalized trace spectra of the horizontal components of magnetometer data from various stations in the Scandinavian IMAGE magnetometer array for the year 1996. (This figure also appears on page 131.)