Whistler Mode Sounding of the Magnetosphere: Measurement of Electron Density, Ion Composition (H+, He+, O+), and Density Irregularities Along the Geomagnetic Field

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Summary

Whistler mode (WM) sounding of the magnetosphere from space offers several advantages over free space R-X and L-O mode and Z-mode sounding from space. In particular, WM sounding permits (1) measurement of both the electron density and the ion composition along the geomagnetic field $\boldsymbol{B}$, (2) measurement of field-aligned irregularities (FAIs) over a wide range of scale lengths (10 m – 100 km), (3) hot plasma diagnostics. Measurement of ion composition is made possible by the magnetospheric reflection of WM waves at $f \sim f_{lh}$, where f is the wave frequency and f_{lh} is the lower hybrid frequency that depends on the ion composition. The WM refractive index can vary over a wide range of values (~1-10,000). This leads to refraction and scattering of WM waves by FAI of widely varying scale lengths. Thus measurements of refracted and scattered WM waves provide a method to measure properties of FAIs that lie along the WM wave propagation paths. For magnetospheric cold and hot plasma parameters, WM waves strongly interact with energetic electrons via Landau and gyro-resonance mechanisms, allowing hot plasma diagnostics.

Radio Plasma Imager (RPI) on the IMAGE satellite [1] provided the first opportunity for space-based whistler mode sounding of the magnetosphere [2, 3]. At low altitude (<10,000 km) RPI on IMAGE has observed a variety WM echoes at all latitudes at frequencies up to 300 kHz. A survey of WM echoes observed in the 2000-2005 period during 3.2 ms pulse transmissions in the low frequency (3-300 kHz) range has led to the observations of a variety of WM echoes. Based on the reflection mechanism WM echoes can be classified as: magnetospherically reflected (MR), specularly reflected (SR), or back scattered (BS). Furthermore, based on the characteristic spectral form WM echoes can be classified as discrete, multipath, or diffuse echoes. The MR echoes are reflected at the altitude where the local lower hybrid frequency f_{lh} is equal to the transmitted pulse frequency f. The SR echoes are reflected at the Earth-ionosphere boundary (altitude ~90 km). The BS echoes are the result of diffuse reflections from small scale FAI close to IMAGE. The discrete WM echoes with relatively small spreading in time delays (~5-10 ms) at each frequency occur under relatively smooth plasma density variation along $\boldsymbol{B}$ passing through IMAGE. The multipath echoes with medium spreading in time delays (~10-30 ms) at each frequency occur when large scale (~1-10 km or larger) FAI are present near $\boldsymbol{B}$. The diffuse echoes with large spreading in time delays (~30-40 ms or larger) at each frequency occur when small scale (~10 m - 100 m) FAI are present near $\boldsymbol{B}$. Though most of the WM echoes observed in a typical RPI plasmagram can be classified as above, a significant number of echoes display characteristics of one type of echo at certain frequencies and that of other type at certain other frequencies. We provide examples of the variety of WM echoes observed and explain their generation mechanisms.

A survey of discrete and diffuse SR- and MR-WM echoes observed during geomagnetically quiet and disturbed conditions in the Aug-Dec 2005 period showed that WM echo occurrence pattern for each type of WM echo varied as a function of geomagnetic activity [4, 5]. We found that the occurrence rate of diffuse MR-WM echoes was not significantly affected by geomagnetic activity but the occurrence rate of discrete MR-WM doubled from quiet to disturbed periods. Significantly fewer (one-fourth) discrete SR-WM echoes and slightly larger number of diffuse SR-WM echoes were observed during the disturbed periods compared to that during the quiet periods.

With the help of two case studies we illustrate how the observed dispersion of MR-WM and SR-WM echoes combined with ray tracing simulations leads to the determination of electron density, density irregularities, and ion composition along the field line passing through IMAGE. The significance of WM echo observations on IMAGE lies in its potential for probing an altitude region (<5,000-10,000 km) that is important for understanding the effects of solar variability on the Earth's magnetosphere and ionosphere but which is also elusive in terms of accessibility for measurement by previously applied methods.

This work was supported by a NASA grant G4532 to the University of Alaska Fairbanks.

References

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