Whistler Mode Radio Sounding from the RPI Instrument on the IMAGE Satellite

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Abstract

This paper presents the results obtained to date on the whistler mode (WM) sounding from the RPI instrument on the IMAGE satellite. Based on their reflection mechanism, the WM echoes are classified as magnetospherically reflected (MR), specularly reflected (SR), or back scattered (BS) echoes. The MR echoes are reflected at altitudes 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 near ~90 km, either with wave vector at normal incidence (NI echoes) or at oblique incidence (OI echoes). The MR and OI echo paths form narrow loops, while the NI echo follows the same ray path down and back. The BS echoes are the result of scattering from small scale plasma density irregularities close to IMAGE. The echoes are described as discrete, multipath, and diffuse, depending upon the amount of travel time spreading caused by the presence of field aligned density irregularities (FAIs) along echo ray paths. A large number (>2000) WM echoes have been observed at all latitudes below ~7000 km during both low and high geomagnetic activity. The upper altitude limit (7000 km) is the result of experimental limitation. The WM sounding provides a new remote sensing method to measure the plasma density and ion composition along the geomagnetic field line $\mathbf{B_0}$ passing through the satellite and to determine the locations of FAIs of varying scale sizes present along the echo ray paths.

In a direct interpretive approach, we employ a combination of refractive index diagrams, ray tracings, and a plasma density model to predict the detailed frequency versus group time delay (*f-tg*) properties of echoes detected when the sounder is either above or below the altitude of the maximum *flh* along $\mathbf{B_0}$ and when the sounding frequency is varied over the range of possible whistler mode frequencies. We then consider the inverse problem, estimation of the parameters of the prevailing plasma density model from the observed echo properties. Thanks to variations in the sensitivity of the various echo forms to the altitude profiles of electron density (N_e) and effective ion mass m_{eff}, we use the observed *f-tg* details of simultaneously received MR and SR echoes to infer the properties of a diffusive equilibrium model of the plasma, including estimates of the ion composition in the important transition region from the O^+ dominated ionosphere to the light ion (H^+ and He^+) regime above. We also demonstrate a method of estimating the scale sizes and locations of FAIs (10 m – 100 km) located along or near WM echo paths.

We demonstrate/illustrate the power/potential of the WM radio sounding method by applying it to two cases when MR and OI echoes were received by RPI: 22 Oct 2005 (Alt=3403 , λ_m= 31.9□ N , MLT= 11.2) and 26 Oct 2005 (Alt=2574 , λ_m=38.8□ N , MLT= 12.1). The inversion of radio sounding data has yielded the following new results: (1) electron density and ion effective mass between the satellite altitude and 90 km along the field line passing through IMAGE. (2) Measurement of O^+ - H^+ transition heights of ~ 1100 km (22 October) and ~ 1150 km (26 October). (3) Measurement of H^+, O^+, and He^+ density, assuming diffusive equilibrium density model in which the scale heights of individual ion species are inversely proportional to their atomic weight. (4) Measurement of scale sizes (~ 10-100 m) and locations (~ 1400-2500 km) of field aligned irregularities on 26 October 2005. (5) Our results in both cases agree well with N_e and H^+, O^+, and He^+ density measurements on DMSP-15 satellite at 850 km along the same L-shell and nearby MLT and F2 peak electron density and height measured by ionosondes on nearby L-shells, and electron and ion densities obtained from IRI model up to 2000 km. These results establish WM sounding as new magnetospheric tool for measuring electron and ion densities along the geomagnetic field in the important O^+-H^+ transition region, not accessible by other radio sounding methods. We believe that our findings about WM propagation and echoing in an irregular medium have important implications for the connection between WM waves and the Earth's radiation belts.

This work was supported by a NASA grant NNX08AN51A to the University of Alaska Fairbanks.

978-1-4244-6051-9/11/$26.00 ©2011 IEEE