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Plasmasphere Tomography

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Lightning energy from individual lightning strokes introduced into the magnetosphere and received on a spacecraft as whistlers provide a method to obtain two-dimensional (2D) images of plasmaspheric electron density and composition (H^+, He^+, O^+). The key to plasmasphere tomography is that (1) the electromagnetic energy from individual lightning in the ELF/VLF range (~1-10 kHz) enters the ionosphere over a range of latitudes (λ_m ~10°-45°) and propagates to a magnetospheric satellite by numerous paths that cover a large part of the plasmasphere; (2) the energy is received on the satellite as a multicomponent whistler (multiple traces) whose dispersion and frequency cutoffs depend on the distribution of electron density and ion composition in the plasmasphere; (3) application of a ray tracing inversion method, developed originally for whistler-mode radio sounding from the IMAGE satellite [1], to the analysis of multicomponent whistler leads to two-dimensional (2D) images of plasmaspheric electron density and ion composition (H^+, He^+, O^+).

The dispersion of the first whistler trace, which reaches the satellite by nonducted propagation at a relatively small wave normal angle, depends primarily on electron density along the ray paths. The dispersion and lower and upper cutoff frequencies of subsequent whistler traces, which reach the satellite after one or more magnetospheric or specular reflections and propagate at large wave normal angles, depend on electron density and ion composition along the ray paths. For an assumed magnetospheric model, the raytracing inversion method involves comparing calculated whistler characteristics (dispersion and cutoff frequencies) as obtained by ray tracing with those measured. Based on the difference between the calculated and measured whistler characteristics, the assumed density model is modified, and the process is repeated until a close match is obtained. Typically 3-4 iterations lead to a close match between the calculated and measured whistler parameters. A ~10% uncertainty in the scaling of the whistler dispersion and cutoffs leads to ~20% uncertainty in the electron and ion densities. The 2D images of plasmaspheric plasma so obtained depend on the assumed geomagnetic field and density models.

Application of plasmaspheric tomography to whistlers observed on Van Allen Probes provided 2D images of electron density and ion composition in the magnetic meridional plane of the satellite for the L-shell range of L~1.1 - 3 and magnetic latitude range of λm ~ 0°±45°), and altitude range covering ~100 - 12,000 km. Electron density measurement matched well with along-the-orbit in situ measurements obtained from the upper hybrid frequency measurements. The electron density and ion composition measurements were consistent with past in situ measurements and empirical models.

Unlike ground-based whistler remote-sensing methods, plasmasphere tomography does not require the presence of ducts and measures both electron density and ion composition. The method applies to whistler data from the past, recent (e.g., OGO 1, ISEE 1, DE 1, POLAR, CLUSTER, Van Allen Probes, DSX), and future satellites. Plasmaspheric tomography provides 2D images of cold plasma density and composition with a temporal resolution of ~10-20 s. With ~100 or more flashes of lightning occurring globally per second, potentially 2D images obtained from along the orbit or multiple satellite observations can be used to construct 3D global images of cold plasma density and ion composition as a function of time. The method also applies to whistlers observed outside the plasmasphere. The technique can potentially lead to the measurement of large- and small-scale irregularities commonly present in the ionosphere and magnetosphere. Plasmasphere tomography promises to be useful in many areas of inner magnetospheric research, such as wave-particle interactions and magnetosphere-ionosphere-thermosphere coupling, that require knowledge of cold plasma.

References

[1] Sonwalkar, V. S., Reddy, A., & Carpenter, D. L., "Magnetospherically reflected, specularly reflected, and backscattered whistler mode radio-sounder echoes observed on the IMAGE satellite: 2. Sounding of electron density, ion effective mass (m_{eff}), ion composition (H^+, He^+, O^+), and density irregularities along the geomagnetic field line," *Journal of Geophysical Research*, **116**, 2011, pp. A11211, https://doi.org/10.1029/2011JA016760.