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Whistler Mode Waves of Terrestrial Origin Detected by Low-Altitude Spacecraft: Frequency Limits and Propagation Paths

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A significant portion of electromagnetic waves detected by low-altitude spacecraft is of terrestrial origin. The waves generated during lightning activity and anthropogenic waves generated by very low frequency military transmitters are among the most important. Upon escaping the Earth-ionosphere waveguide, these waves can eventually propagate to the conjugate hemisphere and be thus observed not only close to the source region, but also close to geomagnetically conjugated points. We use electromagnetic wave data obtained by the low-altitude Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions (DEMETER) spacecraft to systematically investigate the measured wave intensities as a function of their frequency, geomagnetic latitude, and local time. There appears to be an upper frequency limit roughly corresponding to half of the equatorial electron cyclotron frequency, where the wave frequency substantially decreases. However, this frequency limit seems to be slightly different during the day than during the night and, moreover, it exhibits a non-negligible longitudinal dependence. We interpret the observations in terms of ducted/unducted wave propagation, and we use a realistic model of the Earth's magnetic field to explain the observed upper frequency limit variations. We further compare the wave intensities measured in the source hemisphere with those measured in the hemisphere magnetically conjugated. Finally, we demonstrate the importance of maximum lower hybrid frequency above the spacecraft and possible Doppler shifts related to the unducted propagation close to the resonance cone.