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Doppler shifted Alpha transmitter signals in the conjugate hemisphere: DEMETER spacecraft observations and modeling

Frantisek Nemec (1), Ondrej Santolik (2,1), and Michel Parrot (3)

(1) Charles University, Faculty of Mathematics and Physics, Department of Surface and Plasma Science, Prague, Czech Republic (frantisek.nemec@gmail.com), (2) Czech Academy of Sciences, Institute of Atmospheric Physics, Department of Space Physics, Prague, Czech Republic, (3) LPC2E/CNRS Orléans, Orléans, France

Alpha transmitters are three powerful ground based very low frequency (VLF) transmitters operating at mid-latitudes (geomagnetic latitudes between about 41 and 46 degrees). Their radiation pattern consists of three frequencies (11.9, 12.6, and 14.9 kHz). A signal of a given frequency is radiated for 0.4 s, followed by a 0.2 s pause, then another signal at different frequency is radiated. One radiation pattern cycle takes 3.6 s, being repeated all over again. This is particularly useful, as it allows us to i) analyze propagation of signals at three different frequencies coming from the same place under the same conditions, and ii) determine possible time delays between different frequencies and propagation paths.

High resolution wave measurements performed by the low-altitude DEMETER satellite in the geomagnetically conjugate region reveal three simultaneously detected types of signal propagation. These can be readily distinguished from each other by their different Doppler shifts, latitudinal dependences, and dispersions. We use detailed observational analysis and raytracing calculations to explain how these are formed. Specifically, we show that these three signal types can be related to i) ducted propagation between the hemispheres, ii) unducted propagation of originally vertical waves, and iii) unducted propagation of spectrally broadened waves with initial wave normal angles close to the resonance cone.