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Formation of wedge-like pattern on VLF spectrograms observed by DEMETER

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The DEMETER satellite has almost circular polar orbit, with the altitude $\sim$ 700 km. At middle latitudes, DEMETER typically stays in the region where the height-dependent variation of the lower hybrid resonance (LHR) frequency profile forms a trough, i.e. inside the so-called LHR waveguide. In this region, LHR phenomena reveal themselves most distinctly. A striking example of such phenomena is provided by wedge-like events (WLE) registered sometimes on overview VLF spectrograms (time duration $\sim$ 2 minutes, frequency range $0 - 20$ kHz) during thunderstorm activity. A characteristic feature of these spectrograms is the presence of unusual upper and lower cutoff frequencies. The upper cutoff frequency varies rapidly, approximately in proportion to L^{-3}, where L is McIlwain parameter on the satellite orbit. On the contrary, the lower cutoff frequency is almost constant, so that the cutoffs cross at larger L. Between these cutoffs, which thus form a wedge, intense whistlers are observed, whereas only 0_+ whistlers and, probably, ducted whistlers are found outside the cutoffs. We present numerous examples of such spectrograms, and explain the formation of wedge-like structures by the wave propagation features in the inner magnetosphere, and specific position of the satellite with respect to the LHR maximum. In general terms, this explanation is as follows. WLE consists of whistler mode waves originating from lightnings and, thus, is related to thunderstorm activity. The wedge as such is formed by quasi-resonance whistler waves that cannot propagate in the region where the wave frequency is below local LHR frequency. Then, the lower frequency cutoff is determined by the LHR maximum, as quasi-resonant waves with lower frequencies originating in opposite hemisphere do not reach the satellite due to LHR reflection above it. The appearance of an upper cutoff frequency is due to another feature of unducted VLF wave propagation, which consists in trajectories merging into a limiting trajectory for waves with the same frequency, but starting from different latitudes in the opposite hemisphere. As the further increase of the initial latitude does not lead to an increase of the final L-shell in the opposite hemisphere, there appears a maximum L-shell on which the waves with the given frequency can be observed. This L-shell decreases with the increase of wave frequency due to a more pronounced bending towards lower L-shells for higher frequency waves. As the result, the accessible domain for quasi-resonance whistler-mode waves on the $(L-f)$-plane takes the wedge-like shape. The observed features of spectral intensity are also explained consistently by the above suggested model.