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Ground VLF transmitter wave propagation in the upper atmosphere

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Large and powerful ground-based very low frequency (VLF) transmitters, which operate from 17 kHz to 25 kHz with power ranging from several 100s to 1000 kilo-Watts, have been utilized for maintaining long distance communication with submarines for decades dating back to the era before World War I. The long distance communication is realized by VLF wave propagation in the wave-guide mode between the Earth and the ionosphere (100-1000 km altitude), which is the lower portion of the ionized upper atmosphere. A fraction of the radio wave power can leak through the ionosphere into the near-Earth geospace environment known as the magnetosphere (~1000 km and above), where VLF signals propagate in the whistler-mode. Figure 1a and 1b shows the observation of VLF wave intensity in the ionosphere and the magnetosphere, respectively. In the ionosphere, VLF transmitter emissions can cause ionospheric perturbations, particle precipitation and heating. In the inner magnetosphere, VLF transmitter waves can resonate with energetic electrons and contribute to the loss of energetic electrons in radiation belts. How VLF transmitter signals propagate in the magnetosphere will control distributions of wave power and wave normal, thereby affecting the loss process of energetic electrons. Two propagation modes, ducted mode along the field lines in the presence of small-scale density ducts and nonducted mode in a smoothly varying medium, can lead to distinct transmitter wave power distribution. Using years of observations from Van Allen Probes and DEMETER satellites and simulation from a ray-tracing model, we showed the propagation route for some important VLF transmitters and provided direct evidence of the dominant nonducted propagation [1]. The statistical study of transmitter wave normal angle distribution also supports that the nonducted mode dominates over ducted propagation in both the occurrence and wave intensity [2]. We will discuss the significances of these propagation characteristics to energetic electron losses and space weather [3].

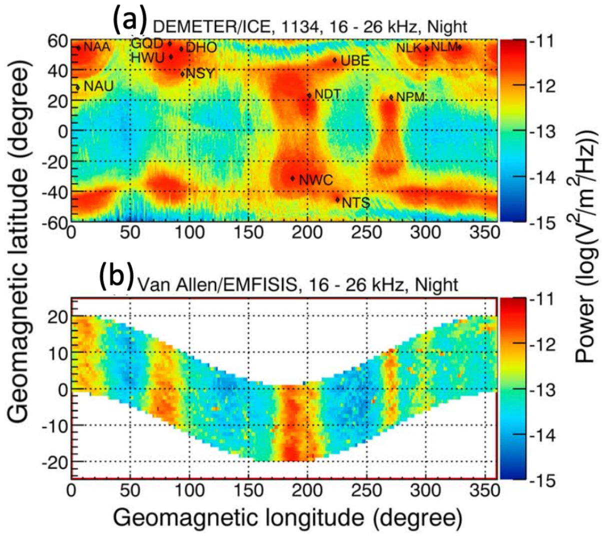

Figure 1. The global map (in geomagnetic coordinates) of averaged VLF wave electric power spectral density over the frequency range of 16-26 kHz at nightside based on the observation of (a) DEMETER satellite [4] (at altitude of ~670 km, 2005-2010) and (b) Van Allen Probes [5] (over altitude of 600-~25000 km, 2012-2017). Locations of powerful ground VLF transmitters are marked by block dots in (a) with call sign denoted by a three-letter combination. Adapted from [1].

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