Generation, Propagation, and Detection of ELF/VLF Waves

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This tutorial talk will review the basics of Extremely Low Frequency (ELF, 0.3-3 kHz) and Very Low Frequency (VLF, 3-30 kHz) radio wave generation, propagation, and detection by lightning strokes and manmade transmitters. Lightning is by far the most powerful radiator of ELF/VLF waves. The return stroke of lightning may reach hundreds of kA, and since the timescales for the pulse is on the order of 10s-100s of μs, intense ELF/VLF waves result. Globally, there are ~40 lightning flashes per second, or ~3.5 million per day, on average. Thanks to efficient reflection from the D-region of the ionosphere (60-90 km altitude) ELF/VLF waves are guided in the so-called Earth-ionosphere waveguide, and can be detected at global distances. Detection of the ELF/VLF radio pulse from lightning, known as a radio atmospheric (or sferic), allows geolocation of lightning strokes around the world. Furthermore, the sferic itself serves as a diagnostic both for the lightning stroke at the source, as well as the D-region conditions between source and receiver. A number of VLF transmitters are also maintained in the 15-30 kHz range, which can also act as ionospheric diagnostic tools. A small fraction of ELF/VLF energy does escape the ionosphere, and enters the magnetosphere in the form of a 'whistler' wave. We will review recent research efforts to quantify the energy escaping the ionosphere, using theoretical modelling and satellite data.