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D region Ionospheric Imaging Utilizing VLF/LF Broadband Sferics

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The D region of the ionosphere (60-90 km altitude) is highly variable on timescales from fractions of a second to many hours, and on spatial scales from 10 km to many hundreds of km. VLF and LF (3-30kHz, 30-300kHz) radio waves are guided to global distances by reflecting off of the ground and the D region, making the Earth-ionosphere waveguide (EIWG). Therefore, information about the current state of the ionosphere is encoded in received VLF/LF radio waves since they act like probes of the D region. The return stroke of lightning is an impulsive event that radiates powerful broadband radio emissions in VLF/LF bands known as 'radio atmospherics' or 'sferics'. Lightning flashes occur about 40-50 times per second throughout the Earth. An average of $\sim$700 lightning storms occur each day with a mean duration of $\sim$15 minutes creating a broad spatial and temporal distribution of lightning VLF/LF sources.

With careful processing, we can recover high fidelity measurements of amplitude and phase of both the radial and azimuthal magnetic field sferic components. By comparison to a theoretical EIWG propagation model such as the Long Wave Propagation Capability (LWPC) developed by the US Navy, with a standard forward modeling approach, we can infer information about the current state of the D region. Typically, the ionosphere is parametrized to reduce the dimensionality of the problem which usually results in an electron density vs altitude profile. For large distances (Greater than 1000 km), these results can be interpreted as path-averaged information. In contrast to studies using navy transmitters to study the D region, the full spectral information allows for more complete information and less ambiguous inferred ionospheric parameters.

With the spatial breadth of lightning sources taken together with a broadly distributed VLF/LF receiver network, a dense set of measurements are acquired in a tomographic sense. Using the wealth of linear algebra and imaging techniques it is possible to produce a 2D image of the D region electron density vs. height profile.