Mapping the *D*-region ionosphere with a network of VLF transmitters and receivers

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The Earth and the D-region of the ionosphere form a natural waveguide for the propagation of VLF radio waves. This propagation mode is characterized by low loss and high phase stability over long distances, making VLF radio useful for global communication and navigation systems. These signals are also used to remotely sense the lower ionosphere and aid in the study of this region of the atmosphere and its coupling with higher and lower altitudes. The amplitude and phase of a VLF wave measured by a receiver is related to the vertical electron density profile along the propagation path. The electron density profile is parameterized by an effective height h' and ionosphere sharpness β for the D-region.

We use a network of VLF transmitters and receivers to estimate h' and β on a spatial grid that fills the network. An ensemble Kalman filter inverts the VLF wave amplitude and phase measured at each receiver from each transmitter to estimate the D-region parameters that exist along the propagation paths. The U.S. Navy's Long-Wavelength Propagation Capability (LWPC) is used to predict the amplitude and phase at each receiver location for specified ionospheres. A candidate ionosphere over the region of interest has been identified when the *measured* amplitude and phase at each receiver matches the *predicted* amplitude and phase to within the receiver noise. We demonstrate the ionosphere state can be estimated over a region of interest using the ensemble Kalman filter with simulated receiver measurements, and explore the positioning of receivers to most consistently estimate the true ionosphere.