URSI GASS 2023, Sapporo, Japan, 19 – 26 August 2023

Mesoscale D-region ionospheric imaging with an array of VLF receivers

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Solar X-rays, auroral and radiation belt electrons, and other energetic particles deposit their energy in the atmosphere at altitudes corresponding to the D-region of the Earth's ionosphere. Subionospheric Very-low-frequency (VLF) remote sensing remains the most effective method for continuous observation of the D-region, thanks to the efficient reflection of probe VLF waves from transmitters and lightning at these altitudes. These VLF waves are sensitive to changes in D-region conditions, so that VLF measurements are indicative of the changing D-region state. However, it is extremely challenging to infer properties of the ionization sources (e.g. solar X-ray or radiation belt particle flux) from these VLF measurements, because the ionization process, D-region chemistry, and VLF signal propagation together form a complex and underdetermined system for inversion.

Here we present a new method to estimate the D-region state using an array of overlapping VLF signal paths covering a mesoscale region of thousands of kilometers. This array of VLF receivers is notionally designed to cover radiation belt latitudes over western Canada, corresponding to L-shells between $L = 3$ and $L = 7$, where radiation belt precipitation occurs. The inversion procedure uses the amplitude and phase of VLF transmitter signals measured at these VLF receivers to infer D-region electron density profile parameters in a grid over the array. This inversion procedure uses a Local Ensemble Transform Kalman Filter (LETKF) to estimate the state of the ionosphere by minimizing both data errors and forward model errors. In this talk we describe the design of this array of VLF receivers, the LETKF-based inversion procedure, and some of the limitations of this inversion method. Finally, we describe the design of a new VLF receiver that will be deployed to make up the Array for VLF Imaging of the D-region (AVID) to monitor radiation belt precipitation and measure precipitation scale sizes. Once operational in summer 2023, this array will make continuous observations of the D-region over a large portion of Canada using continuous ground-based VLF observations of transmitter signals.