Imaging Ionospheric Electric Fields with Coherent HF Radars: A Technique to Advance Research on Cross-Scale Coupling in the M-I-T system.
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Introduction: Cross-scale coupling has emerged as a key theme in the Decadal Survey discussions for achieving breakthroughs in magnetospheric and ITM science. Increasingly it is recognized that the M-I-T system exhibits structure over a vast range of spatial and temporal scales and that critical processes are mediated by cross-scale coupling. The significance of structure and variability in the electric fields for Joule heating and MI coupling has long been recognized but is far from resolved. Satellite observations of FAC's have indicated the existence of significant structure at 10 km scale lengths that must be associated with analogous structure in electric fields and conductivity. Other examples include the electrodynamics of highly structured auroral features such as discrete arcs, oral streamers, and the subauroral STEVE phenomenon. There are also connections between structure and variability in ionospheric electric fields and the occrrence of ionospheric regularities that result in space weather impacts such as scintillations on GNSS signals.

The ionospheric electric field is a critical parameter in the electrodynamics of the M-I-T system. Impressive statistical models of the large-scale pattern of electric field have been derived that show remarkable consistency across the various measurement techniques. However, these models lack the realism at meso- and small-scales to be useful for studying cross-scale coupling. The existence of variability on smaller scales has been demonstrated statistically in a number of studies and its significance amply demonstrated. Instrumentation on satellites observe structure in the electric field on the order of kilometers. Ground-based incoherent and coherent scatter radar systems are capable of more widespread observations but have been limited to coarser resolution by instrumental factors. In order to address the issues in understanding coupling on all scales between field-aligned currents, conductivity, and electric fields, we need higher resolution observations from radars that are spatially distributed. It would be advantageous if these measurements could be obtained continuously so as to capture all manner of M-I-T activity including those events that are relatively rare and impactful for space weather.

SuperDARN HF Radars: The SuperDARN network of HF radars is well known for providing measurements of ionospheric electric field on the basis of coherent backscattering from ionospheric irregularities. These measurements have been used extensively over decades to derive best-fit, high-time resolution maps of the global pattern of electric fields. The data have also been useful for study of electrodynamics on meso and somewhat smaller scales. The resolution that is available routinely is one minute in time and tens of kilometers in space. In certain specialized operations temporal resolution of less than one second and spatial resolution of 6 km have been achieved.

Recent advances in instrumentation have created the possibility for performing imaging with the SuperDARN HF radars, i.e., collecting measurements over wide areas with heightened spatial resolution simultaneously. In the radar imaging paradigm, receivers are installed at each of the elements of the multi-element antenna array. Signals from each element can then be combined and processed using software to resolve returns from all directions simultaneously. The benefits of this approach for resolving structure and variability have been demonstrated with observations from two of the SuperDARN radars [1]. Fig. 1 gives an example of the spatial resolution that is available.

Coordination of White Papers: We propose that investigators with a shared interest in studying cross coupling and enhancing our ability to resolve M-I-T electrodynamics join us in coordinating white papers that speak to these themes.

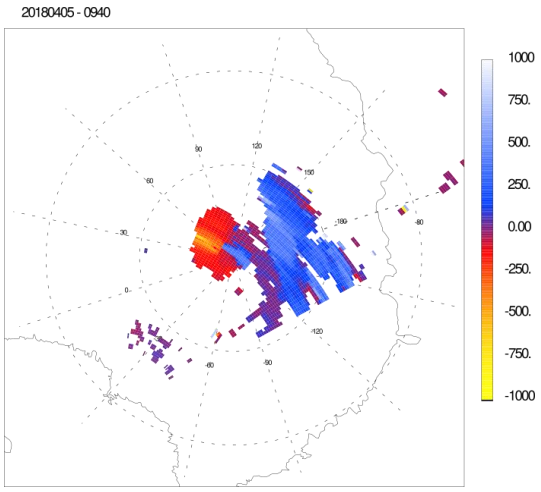

Fig. 1 High-resolution imaging of ionospheric electric fields with the McMurdo SuperDARN radar. From [1].

[1] Bristow, W. A. (2019) *Radio Sci.*, *54*, 692-703.