Constraining VIPER Sounding Rocket Ionospheric Conditions with Ground-based VLF Transmitter Observations

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Very Low Frequency (VLF) electromagnetic waves propagate efficiently in the Earth-Ionosphere (EI) waveguide. While little energy escapes the EI waveguide into the magnetosphere during daytime, satellite measurements have shown geophysically significant VLF power leakage through the ionosphere at night. This leakage from artificial VLF transmitters can drive the scattering and loss of relativistic radiation belt electrons at low L-shells, thus impacting space weather phenomena.

The leakage of VLF waves through the ionosphere has been modeled a number of different ways leading to ranges of absorption that vary by factors of 2 - 100 (3 - 20 dB), depending on the model. The primary source of uncertainty in these models comes from a lack of knowledge about the vertical profile of the D-region ionospheric electron density and, separately but just as important, the neutral density at D-region altitudes. Past sounding rocket experiments have attempted to address these shortcomings, but failed to fully characterize a vertical profile of EM field measurements and their relationship to the local and global structure of the ionosphere.

Designed to address these gaps in knowledge, the NASA VLF Trans-Ionospheric Propagation Experiment Rocket (VIPER; Bonnell 46.028 UE) launched in late May 2021. Among other things, VIPER measured height-resolved amplitude and phase of the 24.0 kHz VLF signal originating from the NAA transmitter in Cutler, Maine. In conjunction with the VIPER experiment, two ground-based magnetic loop air-core VLF receivers were installed: one in Machias, Maine, just 15 km from the NAA transmitter, and one at the NASA Wallops Flight Facility in Virginia, near the VIPER launch site. Data from a third site in Dover Delaware was provided by Dr. Morris Cohen from Georgia Tech.

The Machias receiver provided reference amplitude and phase information about the transmitted NAA signal. The Wallops ground receiver then provided baseline VLF data at the range of VIPER to constrain any changes in the signal measured by VIPER to the altitude of measurement. Data gathered from these ground receivers, along with the Georgia Tech VLF site in Dover, are used to bound full-wave modeling work [1] to determine a Wait and Spies density profile of the nighttime ionosphere during VIPER's launch. Independent of the results bounded by ground receivers, we present a second ionospheric profile derived utilizing first results of VIPER's E-field data, tracking the same 24.0 kHz NAA signal. This profile is similarly derived by way of a full-wave model. Finally, we present a profile derived considering both measurement sources, ground and rocket, together as one system. Comparison of these three estimates of the D- and lower E-region ionosphere electron density profile during the VIPER launch illustrate some of the complexities in lower ionosphere estimation from VLF observations.

W. Xu, R. A. Marshall, J. Bortnik, and J. W. Bonnell, "An Electron Density Model of the D - and E - Region Ionosphere for Transionospheric VLF Propagation," Journal of Geophysical Research: Space Physics, vol. 126, no. 7, Jun. 2021.