Modeling the High Frequency Propagation environment in Metal Oxide Space Cloud Experiment

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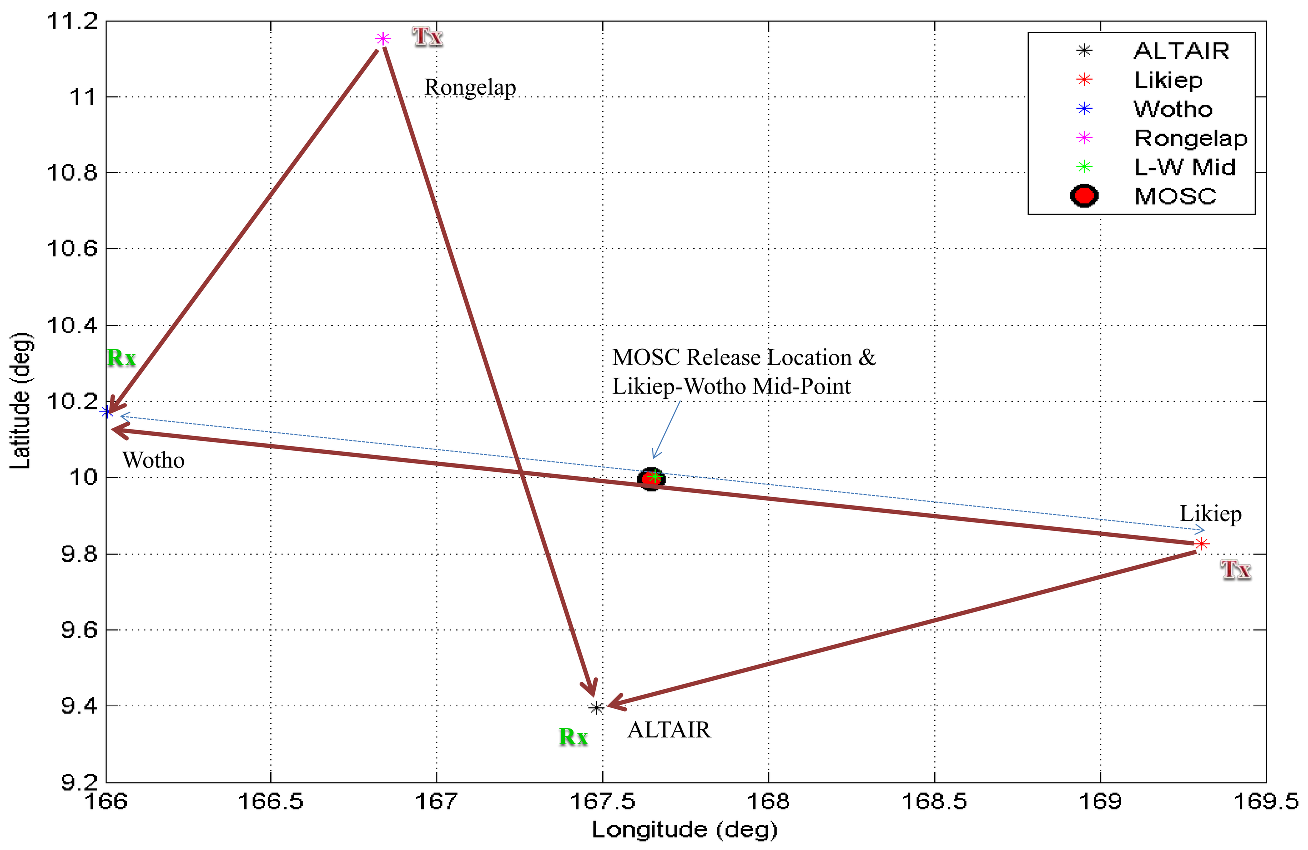
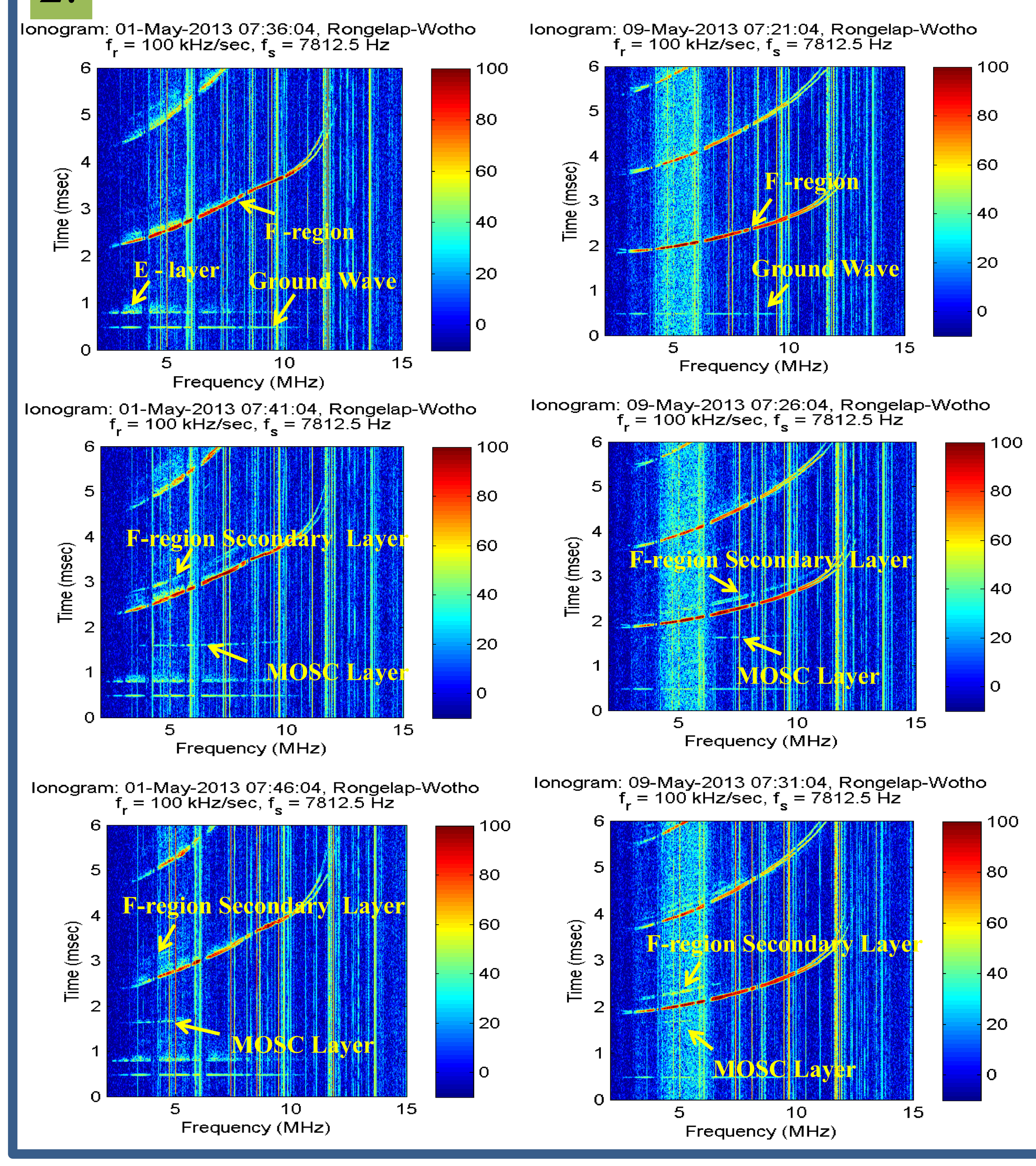
1.

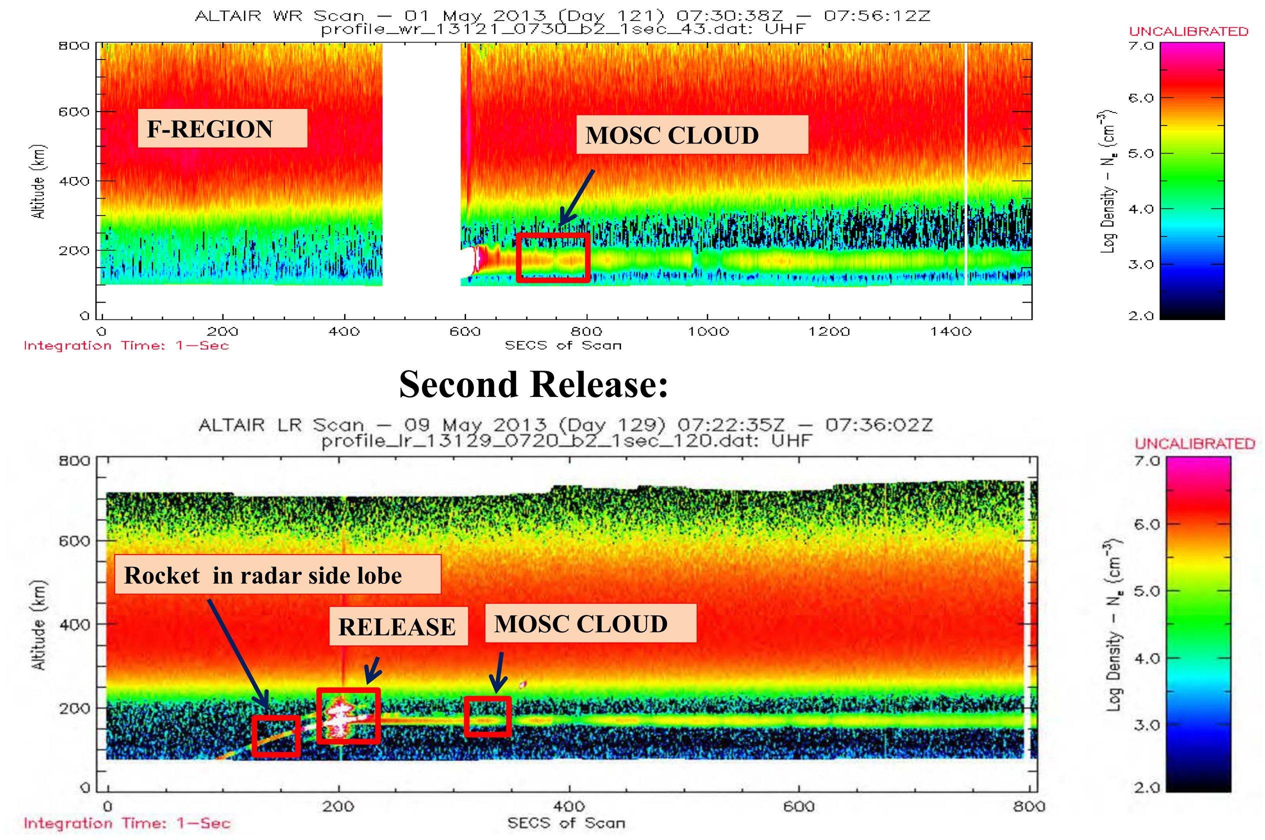
Introduction: In a campaign carried out by the NASA sounding rocket team, the Air Force Research Laboratory (AFRL) launched two sounding rockets in the Kwajalein Atoll, Marshall Islands, in May 2013 known as Metal Oxide Space Cloud (MOSC) experiment. The rockets released samarium metal vapor in the lower F-region of the ionosphere that ionized forming a plasma cloud. Data from ALTAIR incoherent scatter radar and High Frequency (HF) radio links have been analyzed to understand the impacts of the artificial ionization on radio wave propagation. Ray tracing has been used to successfully model the effects of the ionized cloud. We have developed a new method of assimilating oblique ionosonde data to generate the background ionosphere that can have numerous applications for HF systems. Observations and modeling confirm that the small amounts of ionized material injected in the lower-F region resulted in significant changes to the natural propagation environment.



2.

First Release **Second Release**



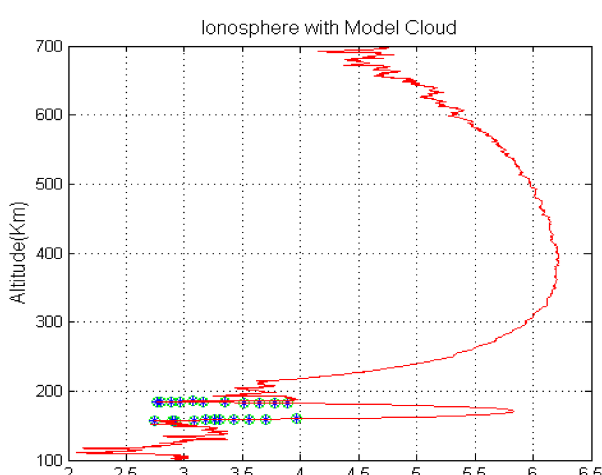


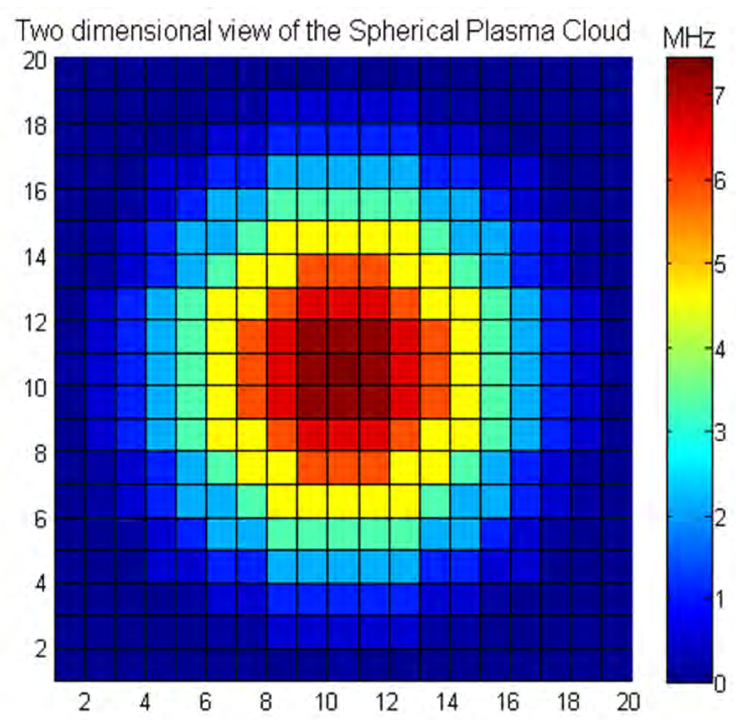
First release: The ALTAIR radar range-time-intensity (RTI) plot (top panel) shows a rising F-layer of the ionosphere (disturbed condition).

Second release: The RTI plot (bottom panel) shows a canonically quiescent ionosphere. Modeling the background ionosphere for the first release is not so straight-forward as the ionosphere was disturbed whereas Parametrized Ionospheric Model (PIM) constrained by the radar data fits the background ionosphere for the second release very well.

The ionograms (left) from the oblique sounder data show the effects of artificial plasma cloud. The first row of the ionograms show clean F-region and ground waves in the pre-release sweeps . The post release sweeps show two additional traces – F-region secondary and MOSC layers which decay rapidly in the following five minutes (2nd and 3rd rows).

3.

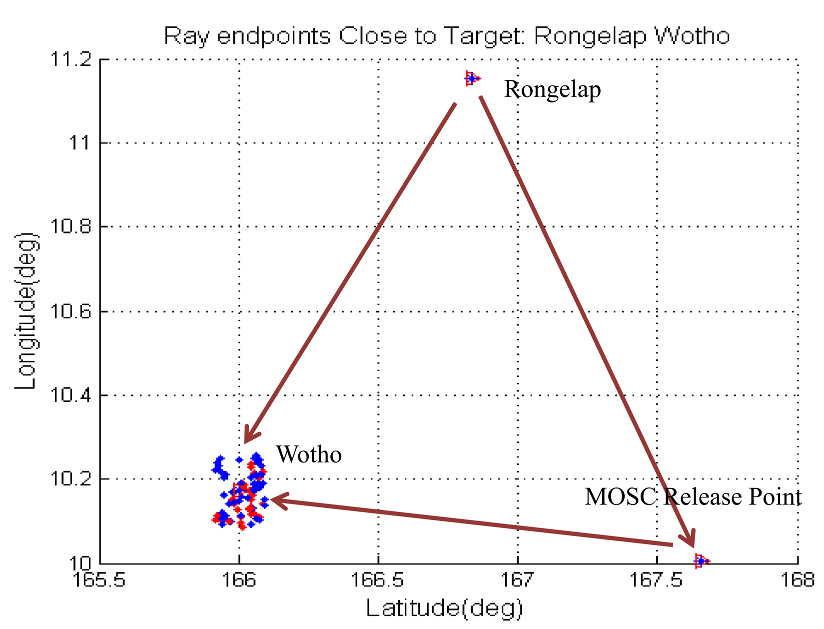


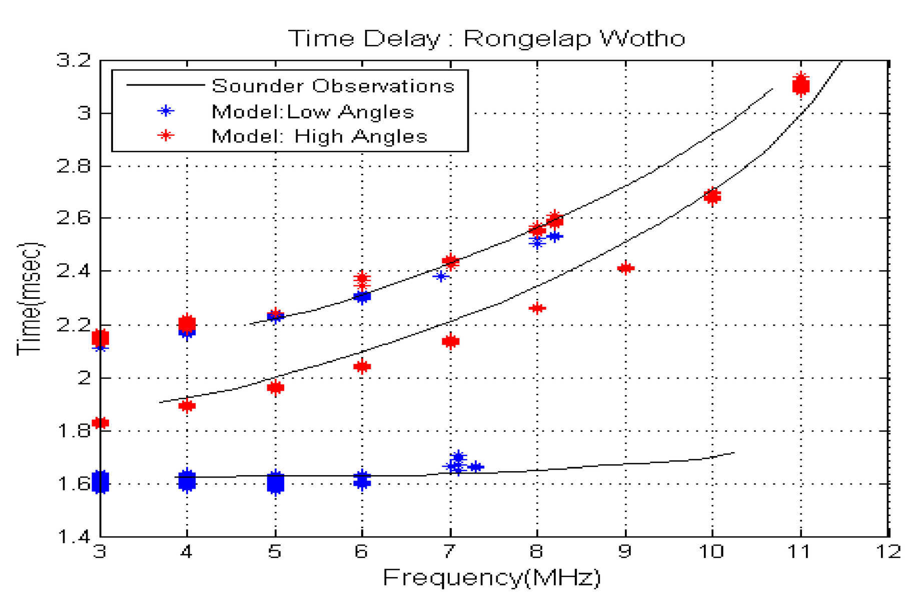


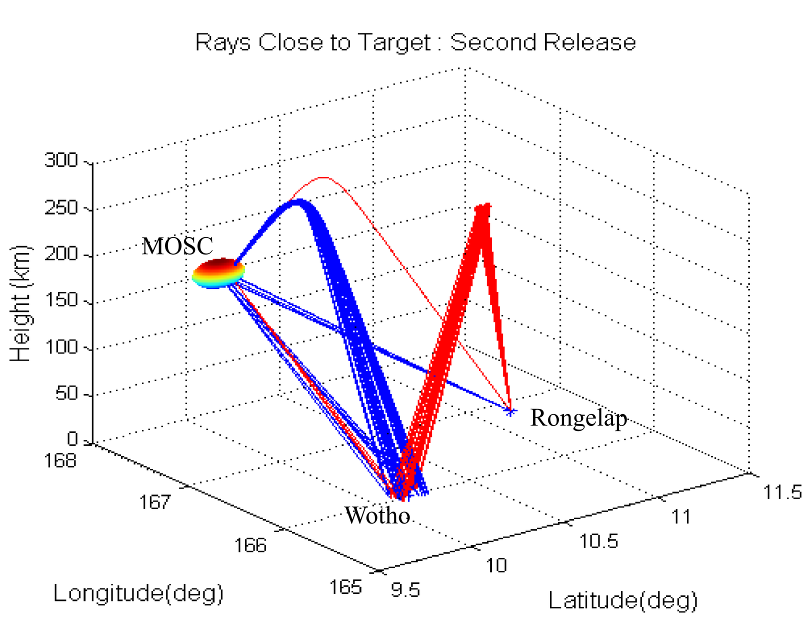
Modeling the Cloud :. The averaged and symmetrized cloud profile (center) from the ALTAIR radar data is used to model the artificial plasma cloud (left – an optical image). In MATLAB , this is implemented with latitude/longitude resolution of 0.0141 degree and height resolution of 1.55 km .
The two dimensional view of the model cloud through its center is shown (right). The central pixel corresponds to f_{pe} = 7.44 MHz .

4. Ray Tracing Results – Second Release :

- The HF radio-wave ray tracing toolbox PHaRLAP is used to trace the rays
- For Rongelap-Wotho (RW) path (right), the 3D plot shows modes of propagation of the radio waves (bottom right)
- The plasma cloud scatters HF energy well off the great circle path. F-region secondary layer is due to both low and high elevation angle paths
- Rays were traced for various frequencies. Ray-tracing gave excellent results which agree with the sounder observations (below)

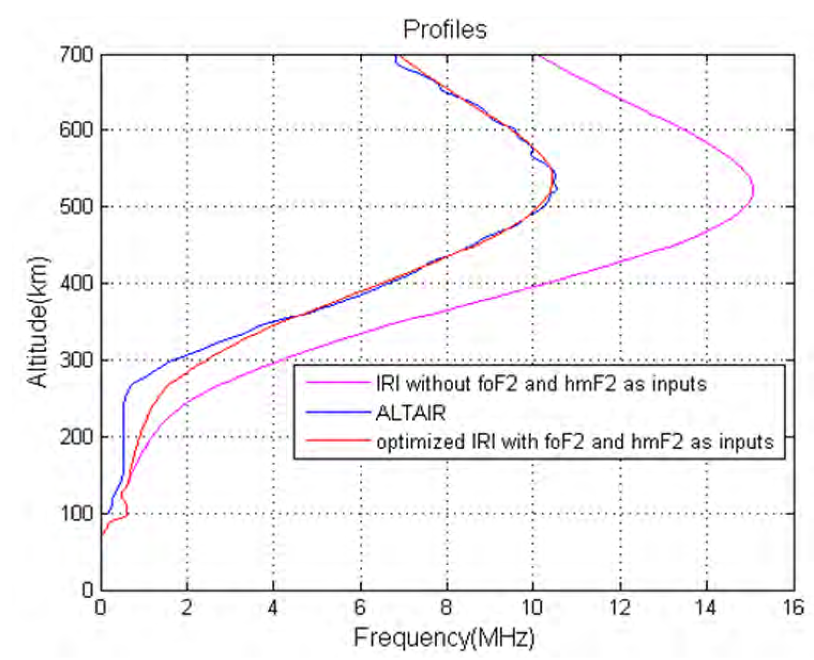


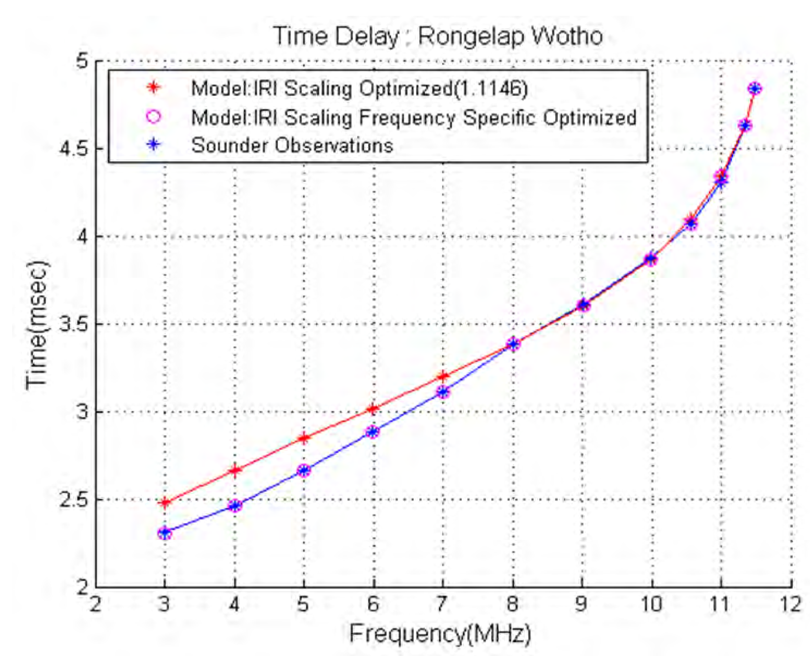


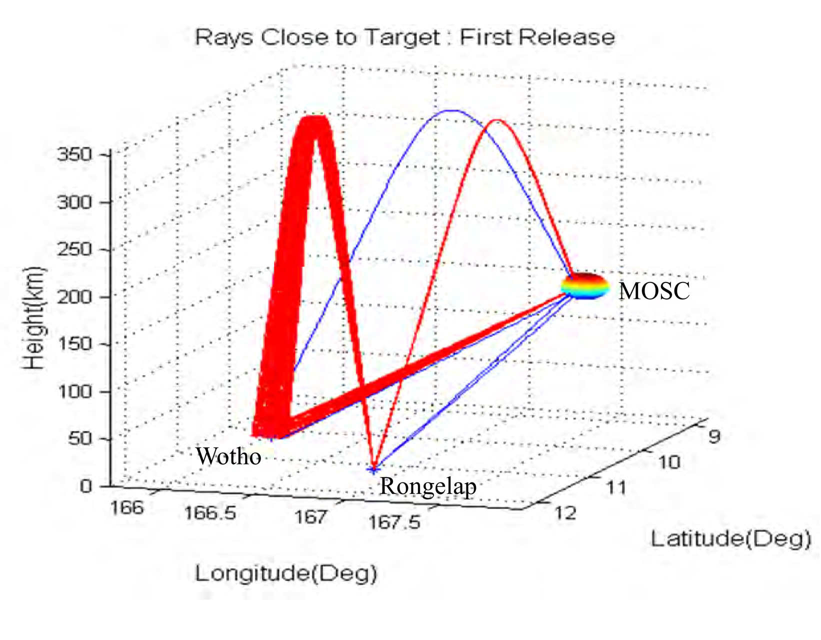


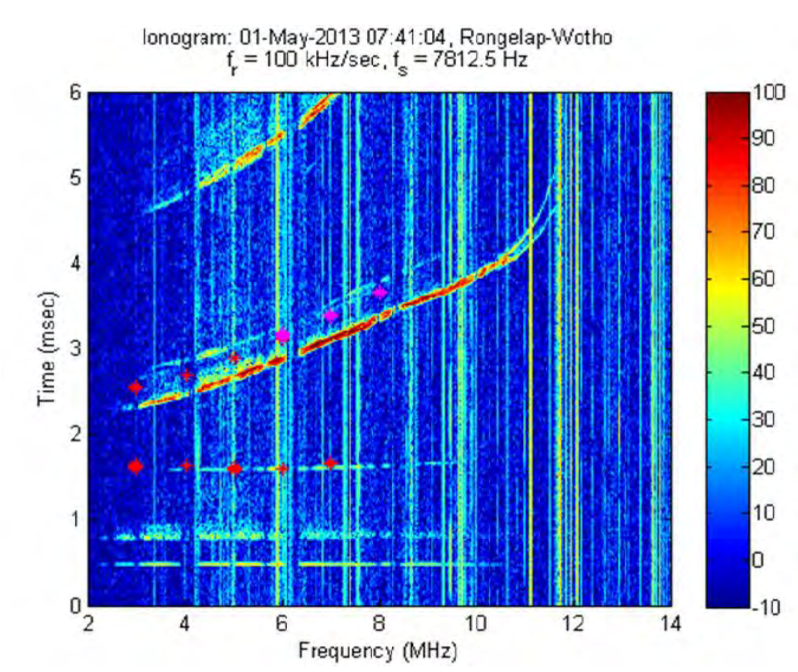
5. Ray Tracing Results – First Release:

- Neither International Reference Ionosphere (IRI) nor Parametrized Ionospheric Model (PIM) were able to reproduce the disturbed background ionosphere in the first release
- The Nelder-Mead Downhill Simplex method was applied to optimize IRI in the vicinity of ALTAIR radar data (top right)
- However, when the optimized results were used on the Rongelap-Wotho path (approx. 150 km NW of ALTAIR scan), the modeled delay did not match observations
- A second frequency dependent optimization procedure was applied to assimilate the sounder data along the R-W path (center right)
- The additional MOSC and F-region secondary layers are also modeled to be close to the observed layers (bottom right) with the F-region secondary layer due to both low and high elevation propagation modes (below)









6. Conclusions:

- Ray tracing confirms the sounder observations to a high degree of fidelity
- PIM constrained by electron density profiles measured with the ALTAIR radar best fits as background ionosphere for the quiet conditions of the 2nd release
- The change in natural propagation environment can be successfully modeled; effects from arbitrary artificial plasma environments can be predicted with accuracy
- Optimization technique represents a new method of assimilating oblique ionosonde data to generate the background ionosphere (numerous applications for HF systems)

Future Work :

- Investigate if metal vapor release suppressed the natural formation of irregularities
- Modeling natural disturbances in the low latitude propagation environment to understand the effects of Traveling Ionospheric Disturbances (TIDs) and Spread F on perpendicular and quasi-parallel (to **B**) paths
- HF Propagation in Natural Plasma: Understanding the seed mechanism of Large Scale Instabilities

Acknowledgements:

- We would like to thank the Air Force Research Laboratory for the opportunity to participate in the MOSC Sounding Rocket Campaign.
- We would also like to thank Dr. Manuel Cervera, Defence Science and Technology Organisation, Edinburgh, SA, Australia for the use of the PHaRLAP 3D raytrace code.
- The principal authors acknowledge the support of NAVSUP Fleet Logistics Center, San Diego, Grant No: N00244-12-1-0049, supporting research for the Naval Postgraduate School, Monterey CA.

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