APEP
Eclipse Rocket Campaign

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I. APEP Mission Overview

Abstract:

Solar eclipses present a truly unique opportunity to study the effects of a supersonic cooling shadow and its modulation of the structure and energetics of the ionosphere-thermosphere system. APEP (Atmospheric Perturbations around Eclipse Path) is an eclipse rocket campaign that launched 3 rockets from White Sands Missile Range during the Oct 2023 annular eclipse, and the recovered 3 rockets will be relaunched from the Wallops Flight Facility during the April 2024 total solar eclipse. This campaign will be the first simultaneous multipoint spatio-temporal in-situ observations of electrodynamics and neutral dynamics associated with solar eclipses. For each eclipse, first of the three instrumented rockets will be launched ~35-45 minutes before peak eclipse, second at peak local eclipse, third ~35-45 minutes after peak eclipse. The launches were be supported by ground-based observations from AFRL Digisondes and meteor wind radar for WSMR launch and by VIPIR Dynasonde and Millstone ISR for WFF launch. Observations will be used to constrain comprehensive modeling during data analysis.

This poster presents *preliminary* results from WSMR launches in Oct 2023.

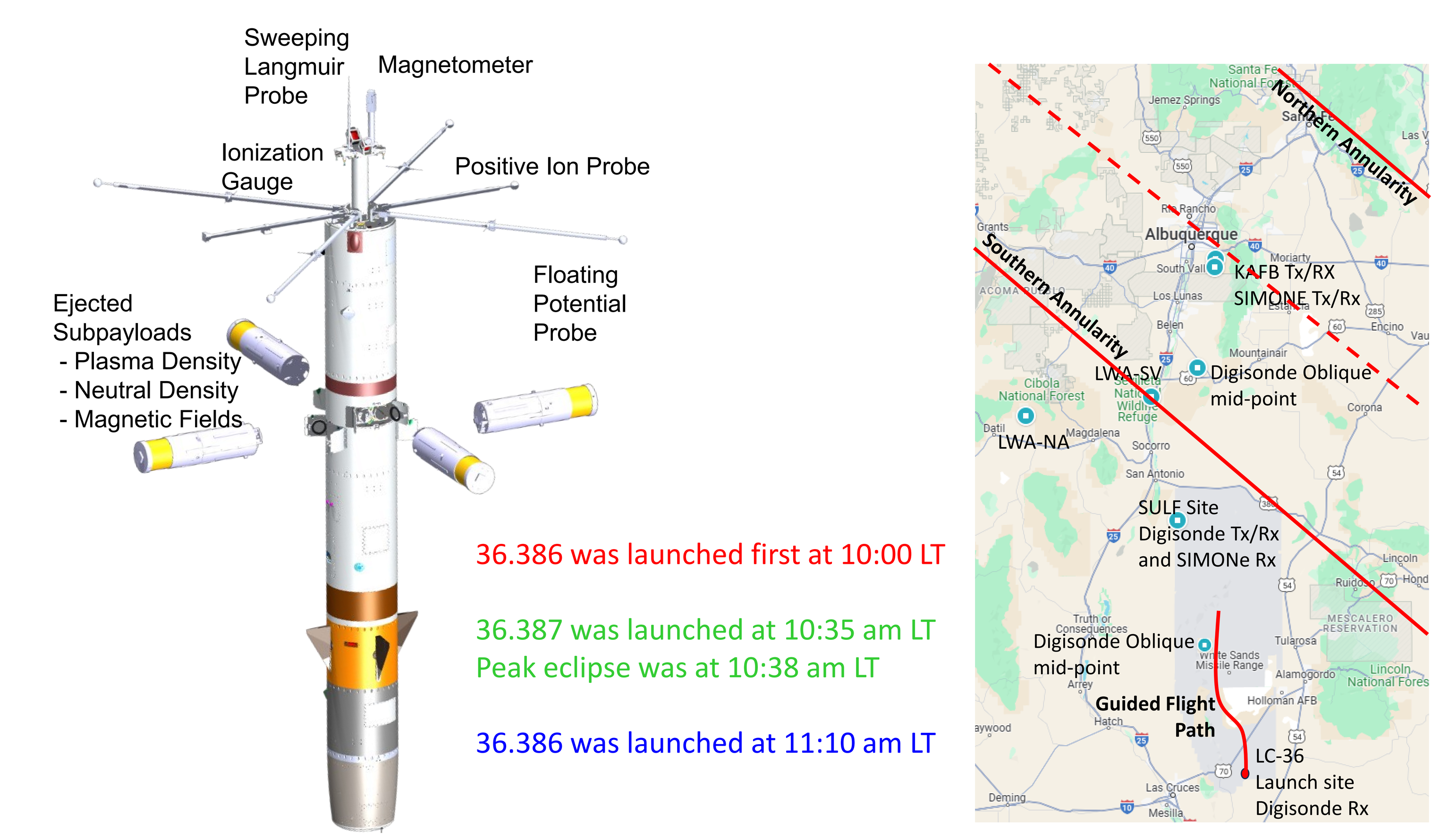


Figure 1
The payload configuration and launch area setup

Payload flip at Apogee
RAM realign Target 90 km
Downleg science start at 325 km to 90 km

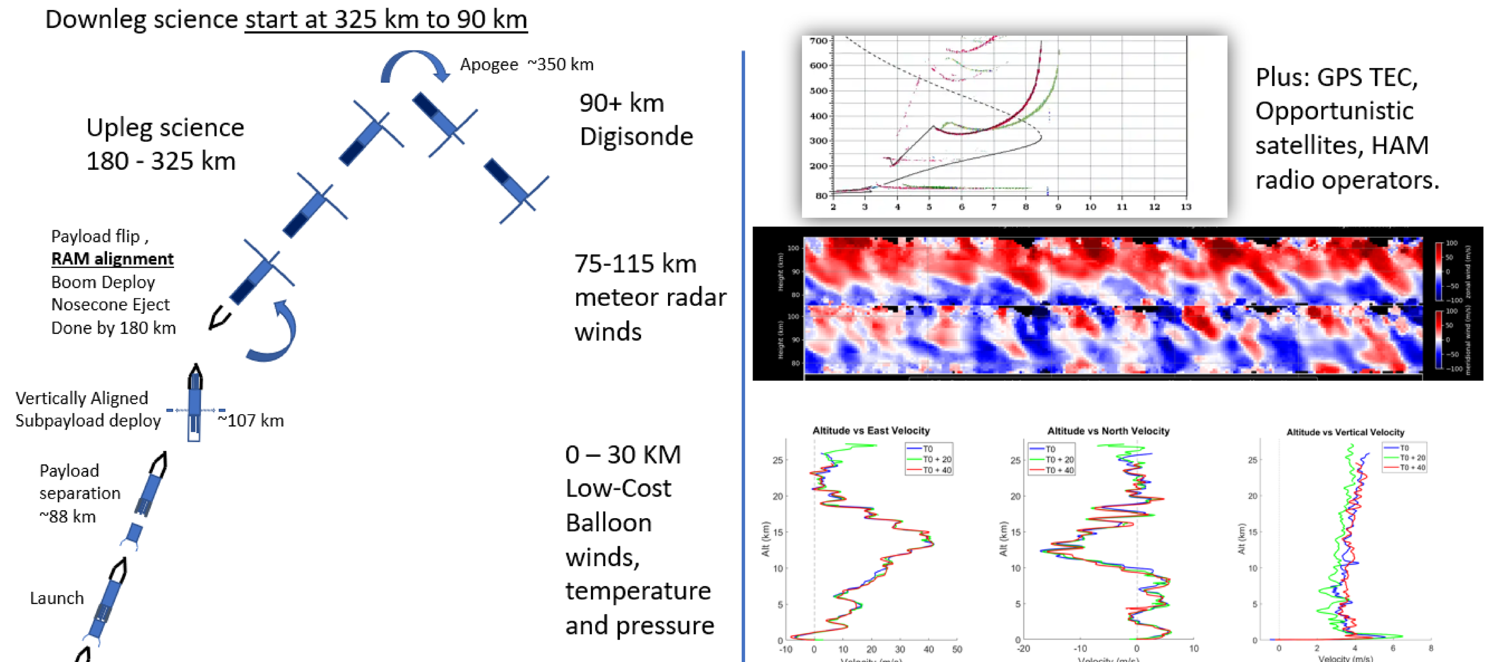
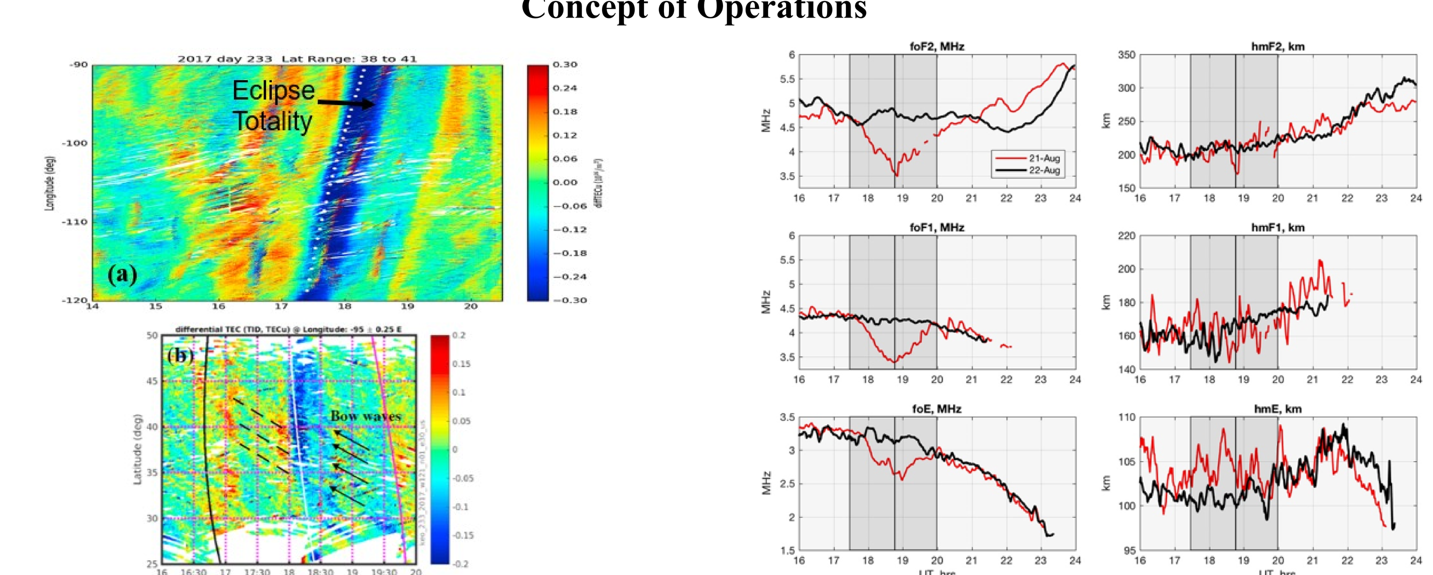


Figure 2
Concept of Operations



Differential TEC keograms for the solar eclipse of 2017 showing (a) TIDs [Coster et al., 2017] and (b) bow waves [Zhang et al., 2017]

Millstone-Hill digisonde shows increased perturbations superimposed on large scale changes in the different vertical layers of the ionosphere on eclipse day (red) versus a control day (black). [Goncharenko et al., 2018]

Figure 3
Past observations from 2017 Total Eclipse

II. In-situ Measurements

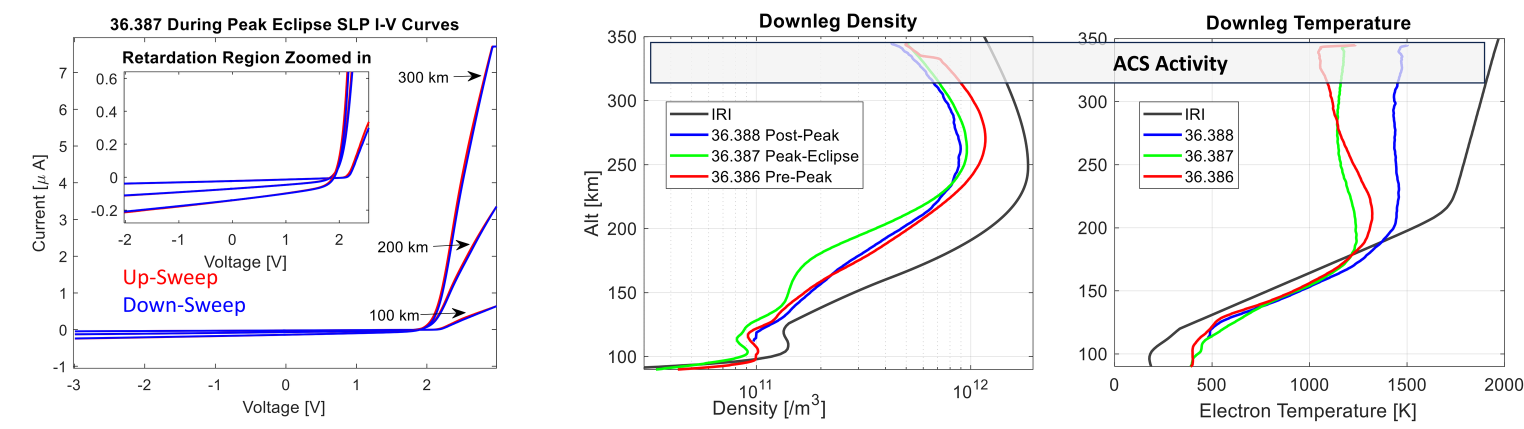


Figure 4
Sweeping Langmuir probe derived absolute plasma densities and electron temperature. The IV curves are low noise, with little spin modulation, and almost no hysteresis.

Four payloads were ejected from each rocket. Three from ERAU and one from Dartmouth. The ERAU subpayloads carried a fixed bias Langmuir probe. Figure 5 shows that all 3 ERAU ejected payloads from the same rocket saw relatively similar density, where as subpayloads ejected from different rockets matched the profiles as seen by the SLP on the main payload. While SLP was swept as 10 Hz, the subpayloads gave density measurements at 5 kHz, thereby making them suitable to see smallest scale perturbations.

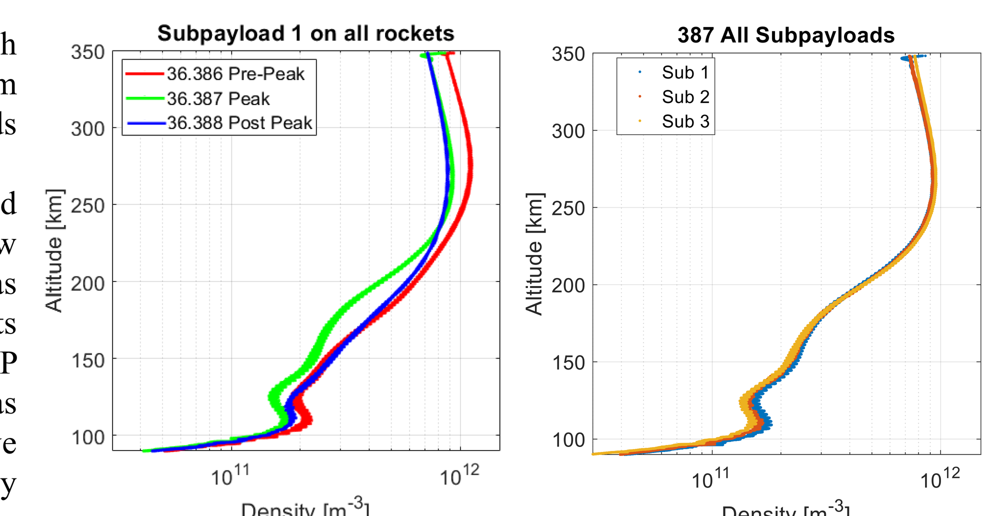


Figure 5
Plasma density profiles from ejected Subpayloads.

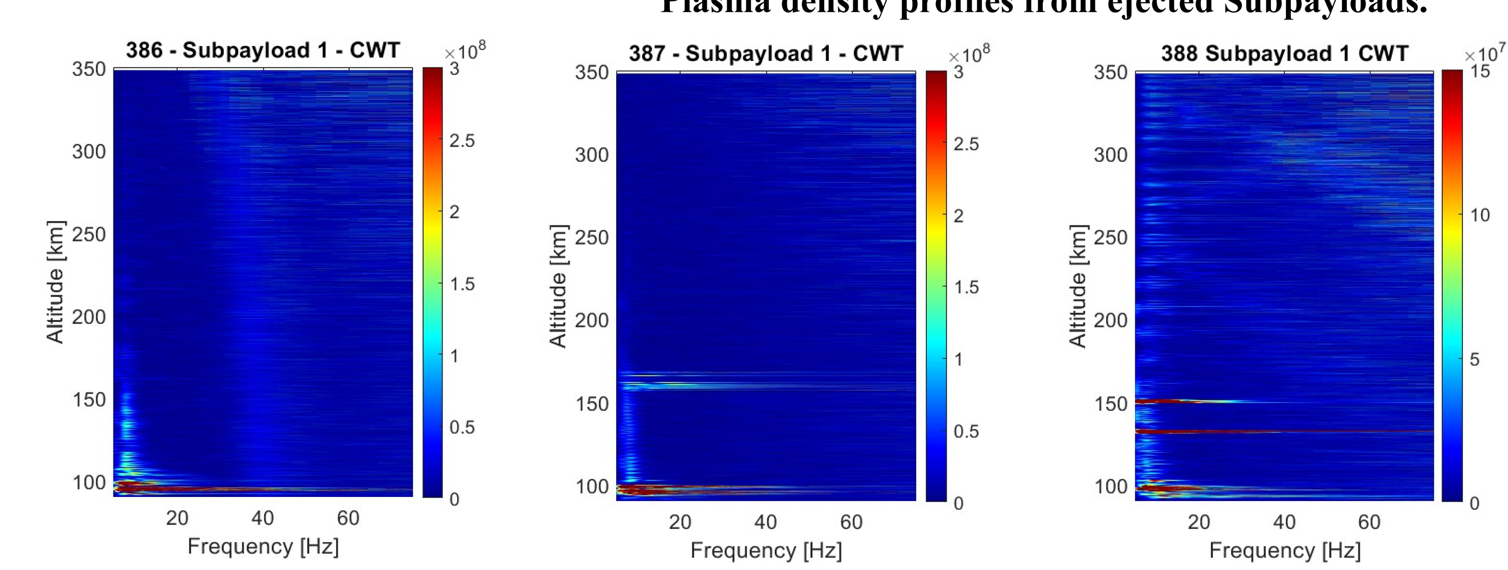


Figure 6
Plasma density CWT spectra profiles from ejected Subpayloads.

Continuous Wavelet Transform of the ejected Subpayload #1 from all 3 rockets shows structure around 100 km. This is consistent with activity seen by the meteor radar around same altitudes. The 387 and 388 ejected subpayloads additionally show structure at the bottom side of the F-region around 150 km in altitude. More work, including simulations and modelling are planned to investigate these features.

APEP carried cold cathode ionization gauges. First plot shows no-ram factor applied raw measurements. After applying the ram factor corrections we study the relative variations between the three flights and compare them to MSIS variations across sunrise and sunset. MSIS 2.0 runs are half hour before and after sunrise and sunset for the day of Oct 14, 2023. Relative density was computed comparing the change in total density (g/cc). The general trends match and preliminarily indicate wave activity.

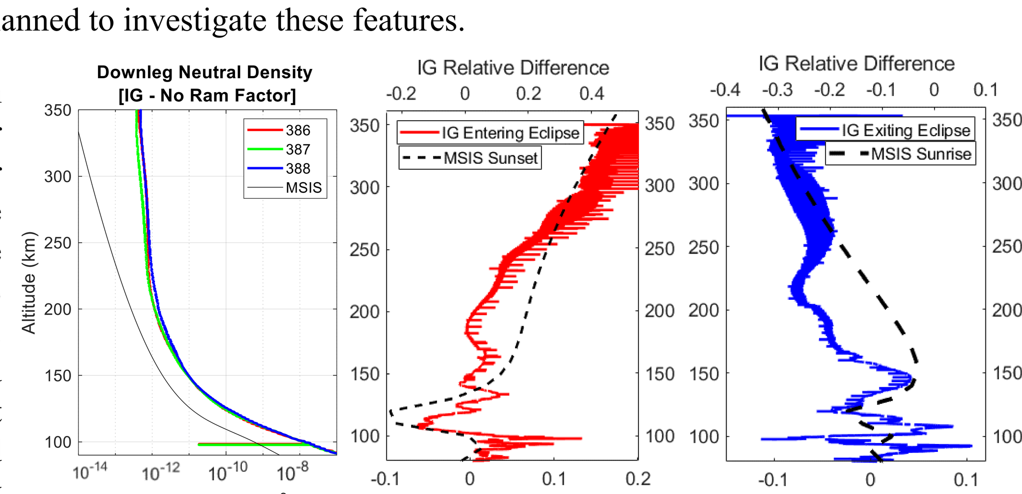


Figure 7
IG raw density data and relative eclipse variation comparison to MSIS variations around sunrise/sunset

In the magnetometer data from all three rocket payloads, there were no features indicative of any significant field aligned current activity. The fluctuation seen right under 100 km is a mode change in the ionization gauge from Cold Cathode to Pirani. The Mag was just over one foot away from the IG and sensitive enough to catch that transition.

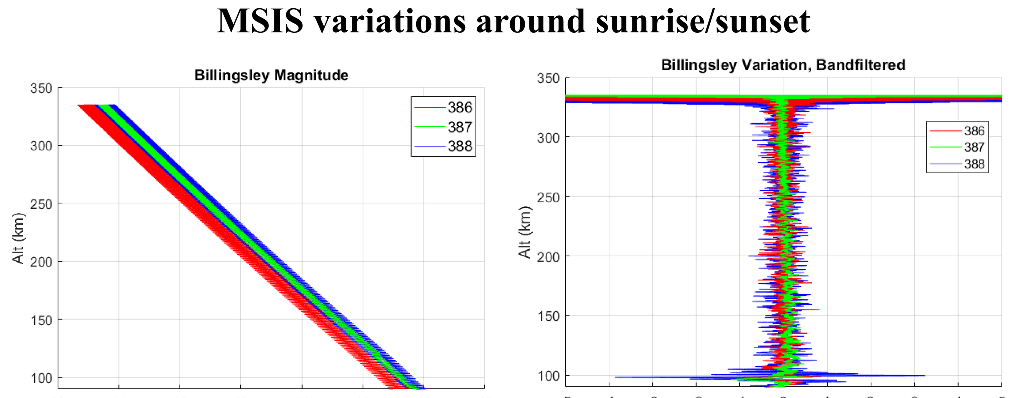


Figure 8
Magnetic Field profiles and residuals

III. Ground Based Measurements

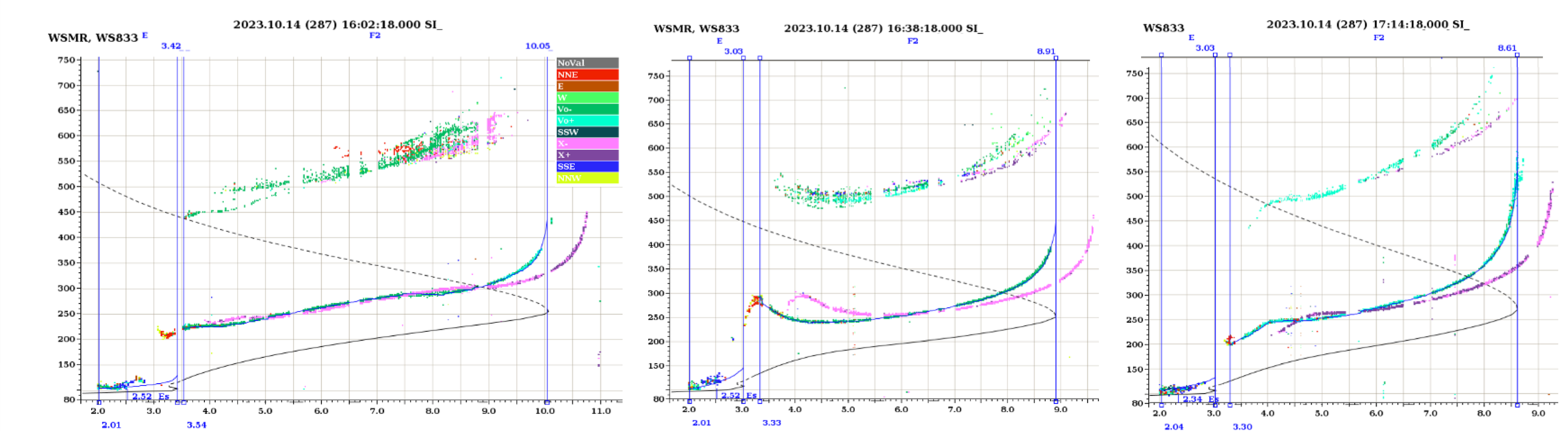
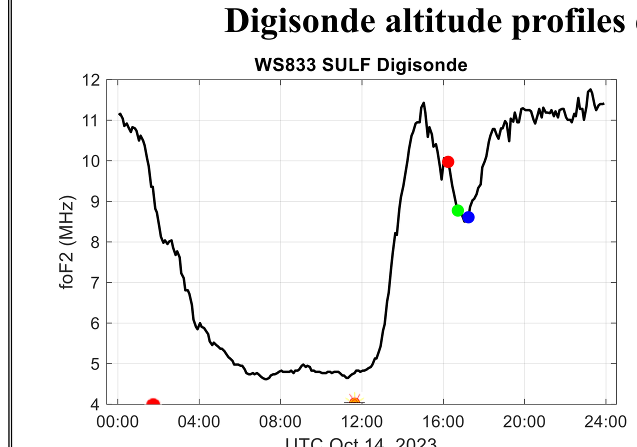


Figure 9
Digisonde altitude profiles during the three launches, as well as foF2 for the entire day



There were two Tx/Rx Digisondes operated by AFRL. One was located at Kirtland and another at SULF site. See Figure 1for mapped locations. A Rx only site was also placed at the LC-36 launch location. This should give us two vertical profiles and two oblique mid-point profiles, as well as skymaps. The analysis work is continuing. Shown to the left is the variation of the f0F2 as seen by the SULF site Digisonde. And shown on top in Fig 9 are the three profiles during the launch times for 386, 387 and 388 vehicles. The measurements are consistent with in-situ observations.

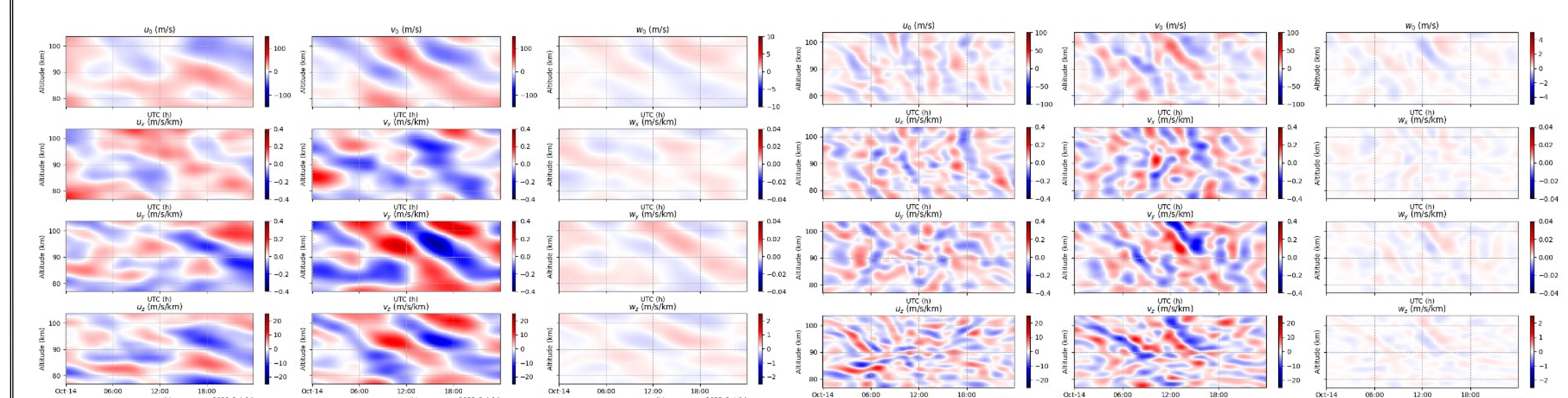


Figure 10
SIMONe Meteor Wind Radar mean 4-hour wind gradients and residual gradients

SIMONe Meteor Wind Radar was operated at Kirtland AFB with four receivers spread around (See Figure 1). The plots above show the mean 4-hour wind gradients and residual gradients on eclipse day. The winds that day were highly dynamic and there is an interesting signature at upper altitudes around the time of the eclipse although it is uncertain whether this is due to the eclipse.

III. 3D GEMINI Simulations

Methodology:

- 28-hour 3D GEMINI model simulation starting from a day before the eclipse
- Simple eclipse lat/lon mask applied to GEMINI with basic time dependence
- Results sampled onto a geographic grid for comparisons to campaign data

Notable points:

- Density roughly consistent with rocket results illustrating rapid erosion of F1-region during eclipse
- Temperatures reduce during eclipse as in the data; however, the model is overestimating these quite a lot. We think this is due to poor EUV specifications in the model.
- Numerous approximations made with the purpose of simply testing the model's ability to simulate an eclipse - it appears to work well which justifies further, more complicated treatment of the eclipse input based on EUV observations and a fully 3D mask.

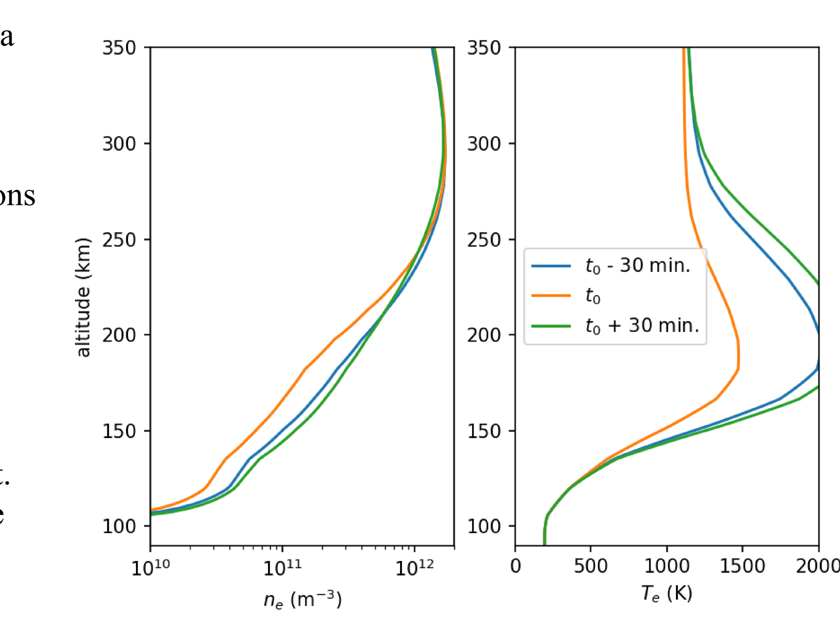


Figure 11
Vertical profiles over WSMR Lat-Lon after a 28-hour 3D GEMINI run

References

Coster, A. J., Goncharenko, L., Zhang, S. R., Erickson, P. J., Rideout, W., & Vierinen, J. (2017). GNSS observations of ionospheric variations during the 21 August 2017 solar eclipse. *Geophysical Research Letters*, *44*(24), 12-041.

Zhang, S. R., Erickson, P. J., Goncharenko, L. P., Coster, A. J., Rideout, W., & Vierinen, J. (2017). Ionospheric bow waves and perturbations induced by the 21 August 2017 solar eclipse. *Geophysical Research Letters*, *44*(24), 12-067.

Goncharenko, L. P., Erickson, P. J., Zhang, S. R., Galkin, I., Coster, A. J., & Jonah, O. F. (2018). Ionospheric response to the solar eclipse of 21 August 2017 in Millstone Hill (42N) observations. *Geophysical Research Letters*, *45*(10), 4601-4609.