Multi-surface Langmuir probe observations WADIS and MTeX rocket campaigns

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Abstract:

We present results from two mesospheric rocket campaigns: MTeX rockets from Poker Flat Research Range and WADIS rockets from the Andoya Rocket Range. The various payloads carried a novel multi-surface Langmuir probe: three fixed bias Langmuir probes, each with a different work function. In addition to collecting thermal electrons, each surface interacts differently with the neutral constituents of the mesosphere: neutral metal atoms, mesospheric smoke particles, ice particles, etc. The WADIS campaign had one rocket each in polar winter and summer, whereas MTeX campaign had two rockets within half hour of each other in polar winter. We show the data from all rockets and estimate various particle densities from the measured current data.

Introduction:

Earth's Mesosphere Lower Thermosphere (MLT) region is the host to several intriguing phenomenon such as Polar Mesospheric Summer Echoes (PMSE), Nocti-Lucent Clouds (NLC), Sporadic-E, charged dust and sporadic metal layers. Rockets that investigate these phenomenon typically use Langmuir probes (Barjatya, 2007) as a tool for plasma density measurement as well as for using plasma density fluctuations as a marker for neutral density turbulence.

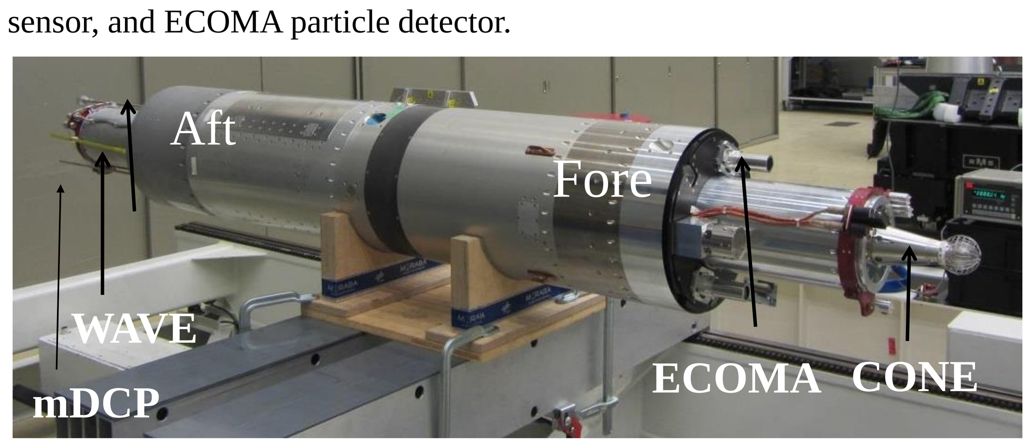
It is known that plasma density fluctuations are not reliable tracers of neutral turbulence within charged ice layers (PMSE/NLC), as well as within mesospheric dust layers. While it is easy to observe the ice phenomenon from ground and remove those suspect altitudes from in situ measured electron density profile, the same cannot be said for dust layers.

A sensitive enough Langmuir probe instrument should be capable of measuring current due to triboelectric charge transfer from the neutral smoke particles, neutral dust and possibly neutral metal atoms as the rocket payload flies through the mesospheric altitudes. Thereby potentially helping remove the suspect altitudes from the electron density profile. We recently built a suit of three fixed bias Langmuir probes, each with a different metal surface that is expected to collect different triboelectric currents from the various heavy mesospheric species. This poster shows preliminary data from 3 separate flights the multi-surface Langmuir probe.

WADIS Campaign:

The German WADIS mission addresses the fundamental question of the energy budget of the MLT by trying to quantify the effect of selected wave events on turbulent heat production and diffusion, subsequent downward transport of atomic oxygen, and corresponding heat production by radiation and chemical reactions.

The WADIS mission achieves the above objectives by two similar instrumented rocket campaigns aided by comprehensive ground based measurements from the Andoya Rocket Range. The WADIS-1 launch was on June 27, 2013 and WADIS-2 was launched March 5, 2015. Each instrumented rocket consists of multi-Surface fixed bias DC Langmuir probe (mDCP), Faraday rotation experiment (WAVE), Ion langmuir probe (PIP), the CONE (Combined measurement of Neutrals and Electrons) sensor, and ECOMA particle detector.

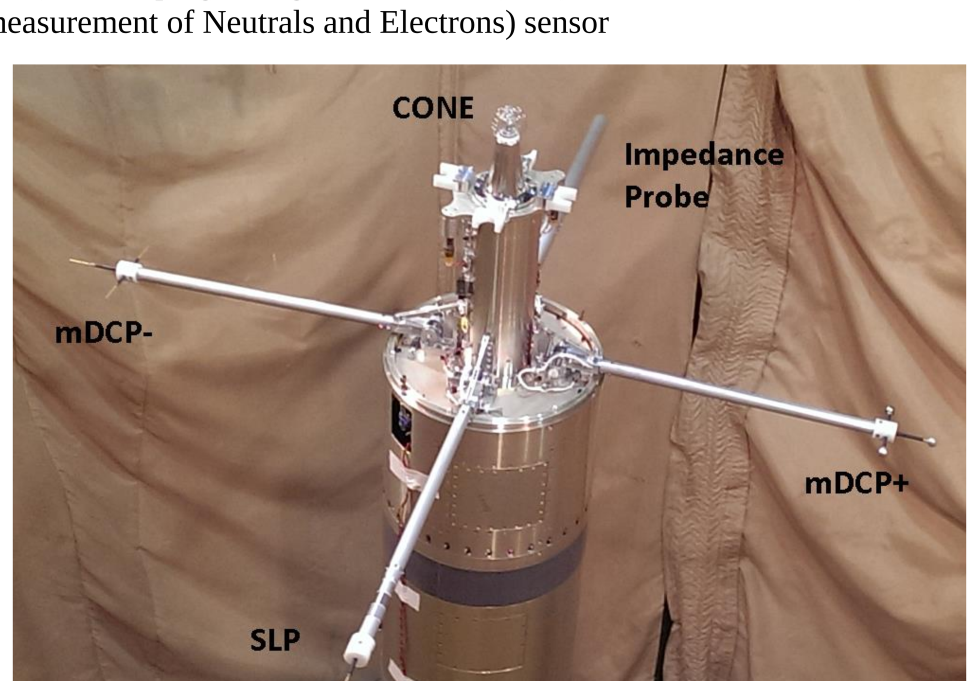


The WADIS instrumented payload

MTeX Campaign:

The NASA MTeX mission addresses the fundamental question of contribution of wave-generated turbulence to energetics and mixing in the mesosphere and lower thermosphere (MLT) in the presence of persistent regions of stability and instability.

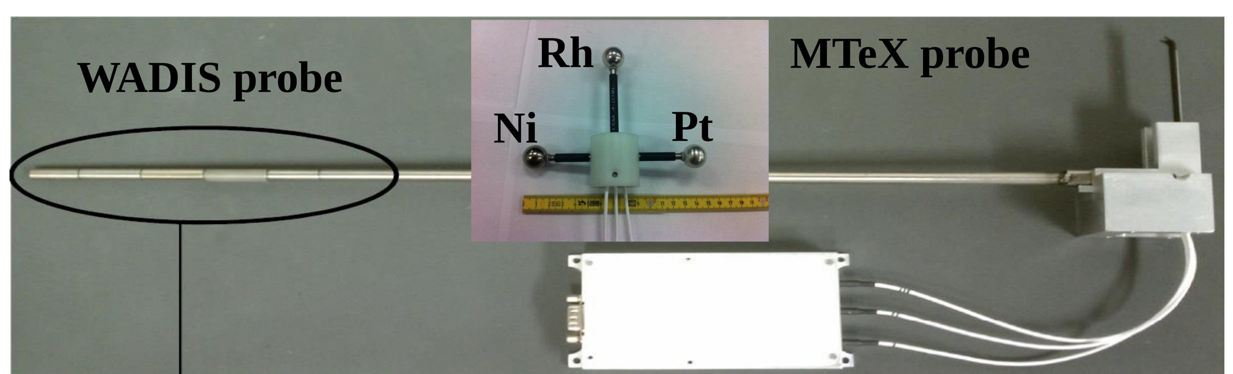
The MTeX mission achieves the above objectives by two similar instrumented rocket campaigns aided by comprehensive ground based measurements from the Poker Flat Research Range. The rockets were launched with a time gap of 35 minutes between them into a persistent MIL on the morning of Jan 26, 2015. Each instrumented rocket consists of multi-Surface fixed bias DC Langmuir probe (mDCP), Swept Impedance Probe (SIP), Sweeping Langmuir Probe (SLP), and the CONE (Combined measurement of Neutrals and Electrons) sensor

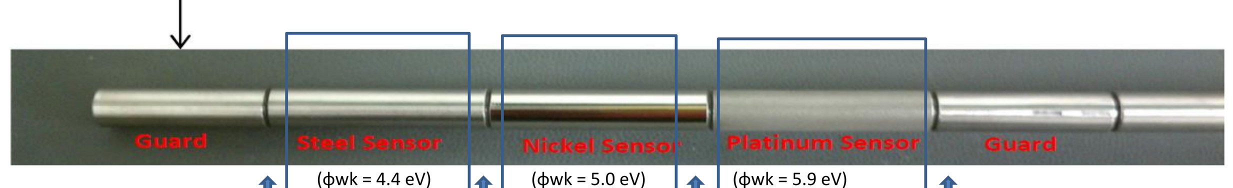


Multi-Surface Fixed Bias DC Langmuir probe:

Charging of metallic surfaces by charge transfer from dust particles, due to differences in work functions or due to frictional contact, is known as triboelectric charging. If two surfaces come merely in contact with each other and then separate, the surface with lower work function loses an electron to the surface with higher work function [Harper, 1967]. This triboelectric current to a surface moving in dusty plasma is in addition to the thermal plasma current. Barjatya and Swenson [2006] have already shown the importance for considering the effects of triboelectrification on the interpretation of Langmuir-type probe datasets in the presence of dusty plasma.

The triboelectric current from neutral dust or neutral meteoric smoke particles to a fixed-bias DC Langmuir probe can also be used to determine a crude relative estimate of the particle number density of various neutral species, and at the very least their altitude profile. Three different surfaces should lead to three different triboelectric currents. The three surfaces were chosen such that we could bin the background neutrals into having four different work function bins. For WADIS probes, each sensor was biased +3V, and there was a guard @ +3V on each side. The probes were cylindrical Langmuir probes. For the MTeX campaign, the probes were spherical Langmuir probe. The steel sensor was replaced with Indium (φ_{wk}= 4.1 eV) and Nickel with Rhodium (φ_{wk}= 5.1 eV).





Mesospheric Smoke Particles (φ_{wk}= 4 ~ 4.6 eV),

Rapp et al (2012) have shown that most MSP will tend to have work function between 4 ~ 4.6 eV. Thus, all MSP will be a current source for Nickle and Platinum which have a higher work function, but a partial current sink/source for Steel sensor. In other words, Nickle and Platinum will collect triboelectric current from MSP in addition to thermal plasma current. Whereas steel will either collect additional current, if the majority of MSP has work function greater than 4.4eV, or it will sink current to the MSP if the majority of MSP have work function less than 4.4 eV. For WADIS experiment we are going to assume that majority of MSP have work function between 4.4 ~ 4.6 eV. For MTeX, as Indium has a work function of 4.1 eV, almost all MSP will be a current sink, i.e. take electron away from Indium surface.

Sodium(φ_{wk}=5.5 eV)

Free sodium atoms have an ionization potential of 5.1eV. (Rapp and Strelnikova, 2009). Thus, these sodium atoms will be a triboelectric current source to Steel and Nickle sensor, but a current sink to Platinum sensor.

Higher work function
(Ice φ_{wk}= 8.7 eV),
(Fe atoms φ_{wk}= 7.87 eV), etc

Work function of ice particles (PMSE/NLC), as well as ionization potential of background Fe atoms is much larger than the work function of platinum. Thus, all these species will be a sink for all surfaces. i.e. all surfaces will give away their electrons thereby reducing their collected current. This is in addition to the electron bite-out current reduction, which simply is reduced thermal plasma current.

$$I_{platinum} = e_{th} + v\,A_{cr}\,Q(\,MSP + Na - High) - e_{ph}$$

$$I_{nickle} = e_{th} + v\,A_{cr}\,Q(\,MSP - Na - High) - e_{ph}$$

$$I_{steel} = e_{th} + v\,A_{cr}\,Q(\,-MSP - Na - High) - e_{ph}$$

$$(I_{platinum} - I_{nickle})/2 = I_{Na} + I_{ph\text{-}difference}$$

$$(I_{nickle} - I_{steel})/2 = I_{MSP} + I_{ph\text{-}difference}$$

$$(I_{platinum} + I_{steel})/2 = e_{th} - I_{high} + I_{ph\text{-}difference}$$

The WADIS-1 rocket was launched in polar summer season. Thus, each surface also had a photoelectric current contribution. The MTeX rockets were launched in nighttime conditions. The photoelectric current cannot be removed from the data due to surface patchiness and unknown illuminated area. The best we can do is normalize the various currents to the observed Wave propagation experiment derived absolute electron density at 100 Km. At that altitude particle currents should be low, and photoelectric current difference would be normalized out. Additionally, any wake related density differences will also be normalized out… to the first degree.

The current difference equations now become density difference equations:

$$(I_{platinum} - I_{nickle})/2 = I_{Na} + I_{ph\text{-}difference} \Rightarrow (Platinum - Nickle)/2 = Na\ density$$

$$(I_{nickle} - I_{steel})/2 = I_{MSP} + I_{ph\text{-}difference} \Rightarrow (Nickle - Steel)/2 = MSP\ particle\ density$$

$$(I_{platinum} + I_{steel})/2 = e_{th} - I_{high} + I_{ph\text{-}difference} \Rightarrow (Platinum + Steel)/2 = Electron\ density - High\ work\ function\ particle\ density$$

We can subtract the absolute electron density as derived from the faraday rotation experiment to get an estimate and profile of high work function particle density.

For the MTeX probes the equations remain the same, with the exception that I_{nickle} gets replaced by $I_{rhodium}$, and I_{steel} gets replaced by I_{indium}.

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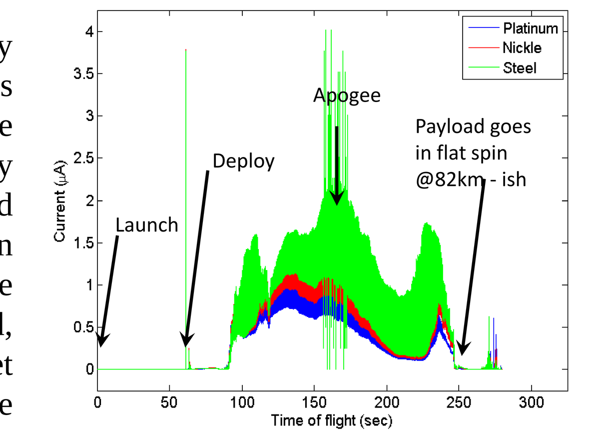
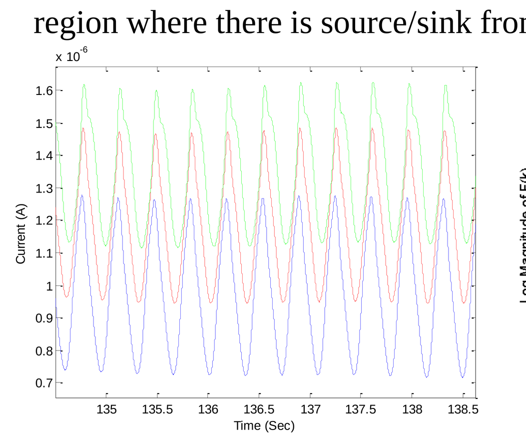
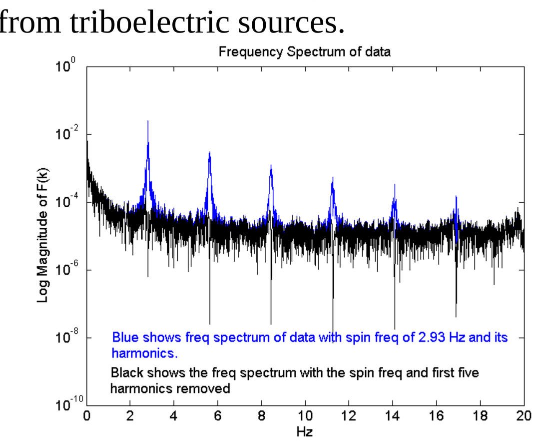
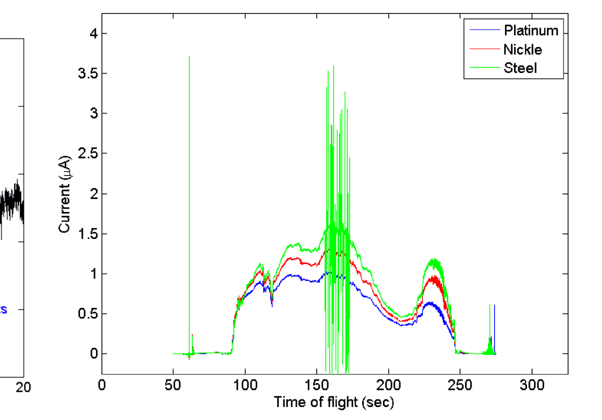
WADIS Data Analysis:

The multi-Surface Langmuir Probe electronics were meticulously calibrated over a broad temperature range. The plot to the right shows the observed currents from all three surfaces as a function of time. The spin modulation in the data is shown in bottom left. The frequency spectrum of the data with the spin frequency and its harmonics removed is shown in bottom middle, and the flight data with spin modulation removed is shown in bottom far right. Since all instruments were calibrated exactly the same way, once the spin modulation is removed, we expect all sensors to collect the same thermal plasma current. Yet Platinum < Nickle < Steel? Their currents should only differ in the region where there is source/sink from triboelectric sources.

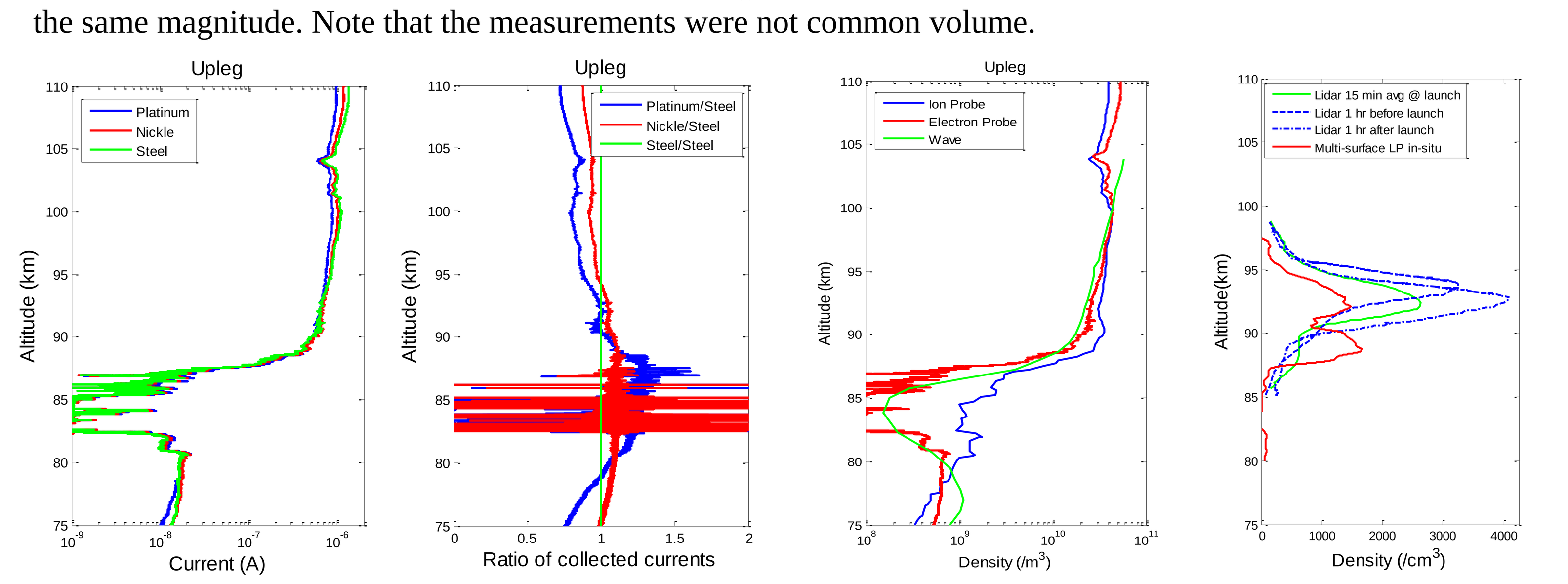






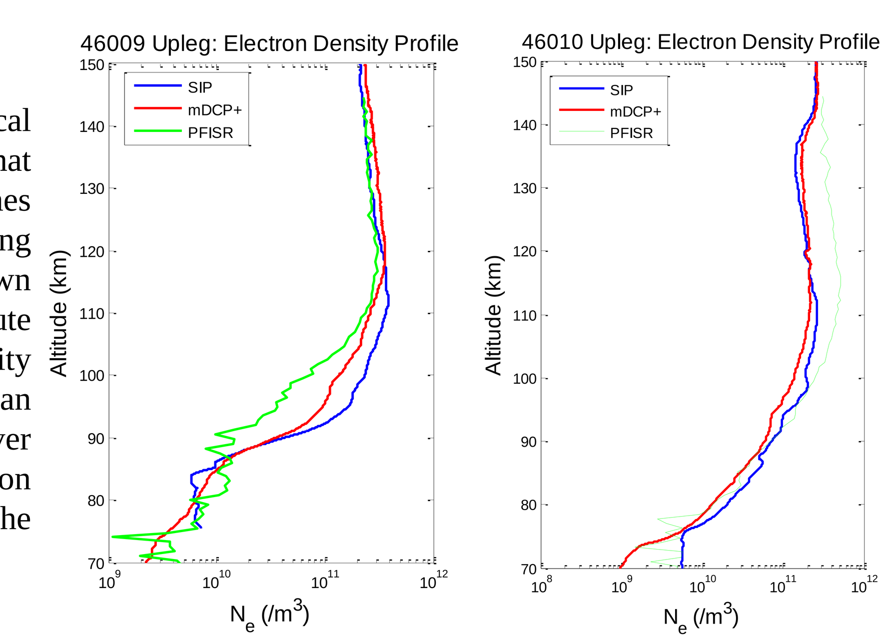


One possible explanation is that as the boom was in the aft, the bow shock created plasma difference in the vicinity of different sensors. As platinum was innermost on the boom, and steel the outermost, the bow shock hypothesis does explain difference in current between three sensors. The left most plot below shows the current vs altitude profile. At first glance it does seem that Steel (in green) current collection is always the greatest. But the plots on its right show current ratio of various surfaces which is clearly indicative of distinction due to triboelectric current collection. This region in the upleg profile is indicative of a severe biteout, and a PMSE was observed at the same altitude from ground based radar. The third plot from left below shows the current from the Steel sensor normalized at 100 km to the absolute electron density derived from the faraday rotation instrument. Also plotted is the density derived from the Plasma Ion Probe which is a fixed bias spherical Langmuir probe in the ion saturation region. The 82-87 km region is clearly indicative of an electron biteout. Finally the right most figure below presents the results of analysis of the currents from the various sensor surfaces as outlined in the middle panel of the poster. The inferred sodium density from in-situ mDCP measurements is overlayed with ground based sodium lidar measurements . The densities are on the same magnitude. Note that the measurements were not common volume.

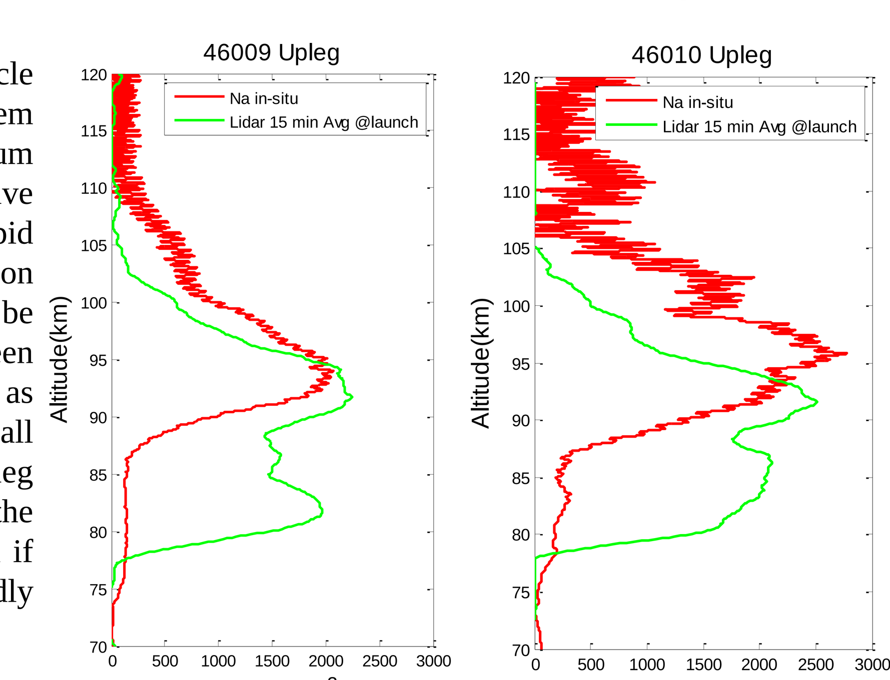


MTeX Data Analysis:

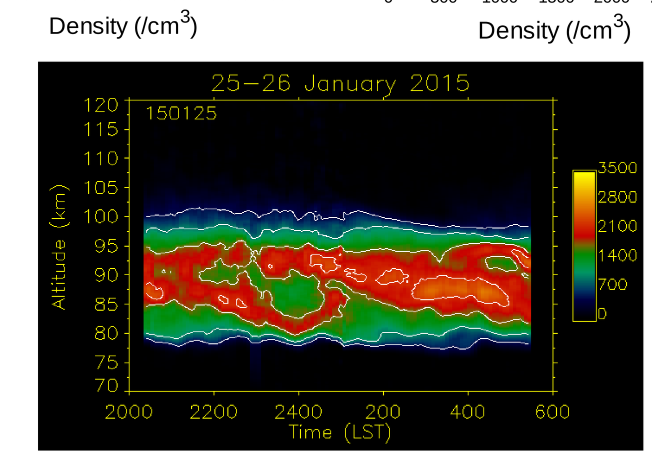
The MTeX mDCP probe was made with spherical Langmuir probe sensors with the specific goal so that the triboelectric current collection area largely becomes angle of attack independent. The initial data processing was similar to that of the WADIS instruments as shown above. The two figures to the right show the absolute plasma density from SIP and normalized plasma density from fixed bias Langmuir probes, as compared with an averaged profile of PFISR measurements directly over PFRR. Note PFRR measurements are not common volume with rocket measurements. Nevertheless, the magnitude of densities match.



For the MTeX, the MSP and High work function particle densities have been challenging to interpret and seem unreliable, potentially due to an imperfect Indium deposition. It is also likely that the relatively reactive nature of the low work function Indium led to a rapid deterioration of the Indium coating between fabrication and actual launch. The Sodium densities however can be inferred from the collection current difference between Platinum and Rhodium coated probes. The densities as derived are shown in the two plots to the right. In all three rockets (one WADIS, and two MTeX) the downleg profiles of the derived particle densities do not match the ground based observations. This brings into question if the coatings, which are only microns thick, rapidly deteriorate during the ~10 minute flight.



The final plot shows the contour of Sodium density profile as measured by the PFRR Lidar through the night that's 15 mins integrated in steps of 5 mins. As the rocket measurements were not common volume, the lack of double hump structure observation is possible. Finally, the few km offset in the in-situ observations is also puzzling.



Summary and future work:

The multi Surface Fixed Bias DC Langmuir probe is a novel technique to use triboelectric currents to a probe surface as a marker of insitu observation s neutral mesospheric particles. The technique could be improved upon by: (a) deploying spherical probes instead of cylinders to maintain constant cross section irrespective of angle of attack, (b) deploying in the payload fore so that the probes could be outside the bow shock, (c) using a metal such as Indium with a work function of 4 eV which is below almost all possible MSP work functions, (d) launch during night time to remove any photoelectric current contribution to the collected currents.