In-situ observations of neutral shear instability effects in the mesosphere/lower thermosphere during the SuperSoaker experiment

Rafael Mesquita

Department of Physics and Astronomy, Clemson University

Miguel Larsen[1], Irfam Azeem[2], Michael Stevens[3].

[1]Clemson University, [2]ASTRA, [3]U.S. Naval Research Laboratory.

Abstract

Trimethil Aluminum (TMA) has been used as a chemical tracer since the late 1950's. Two rockets, flown northward of the Poker Flat Research Range and a half hour apart from each other, released 4 TMA trails for the Super Soaker campaign. This measurement campaign took place on January 26 2018 and it had as its main goal to investigate the effects of an artificial noctilucent cloud (190 kg of water released around 80 km on board a third rocket) on the mesospheric temperatures. Two ground-based and one airborne sites were used to track the motion of the TMA trails, which led to the calculation of the meridional and zonal wind profiles between 80 and 160 km. Zonal winds measurements ranged from -93 to 102 m/s and meridional winds from -134 to 107 m/s. Calculated maximum shears for each of the wind profiles occur between 98 and 106 km with a maximum value of 90 $ms^{-1}km^{-1}$ (for the first downleg trail around 5:16 LT). Evidence of the eddies associated with Kelvin-Helmholtz Instability was detected for the first downleg at 102 km and triangulated to a maximum height of 4 km.

Introduction

One the most reliable ways to measure the wind profiles in the mesosphere/lower thermosphere at nighttime is through rocket-borne Trimethil Aluminum (TMA) trail releases [1].

Figure 1: Camera setup from Coldfoot/AK with the TMA releases on the background.

Images from 3 camera sites, NASA-8 (airborne), Coldfoot and Poker Flat (setup similar to the one shown in Figure 1) were used to create 3 sets of images to calculate the profiles in Figure 3. The trail position for any given image pair is calculated assuming constant vertical winds using astrometry to determine the lines-of-sight.

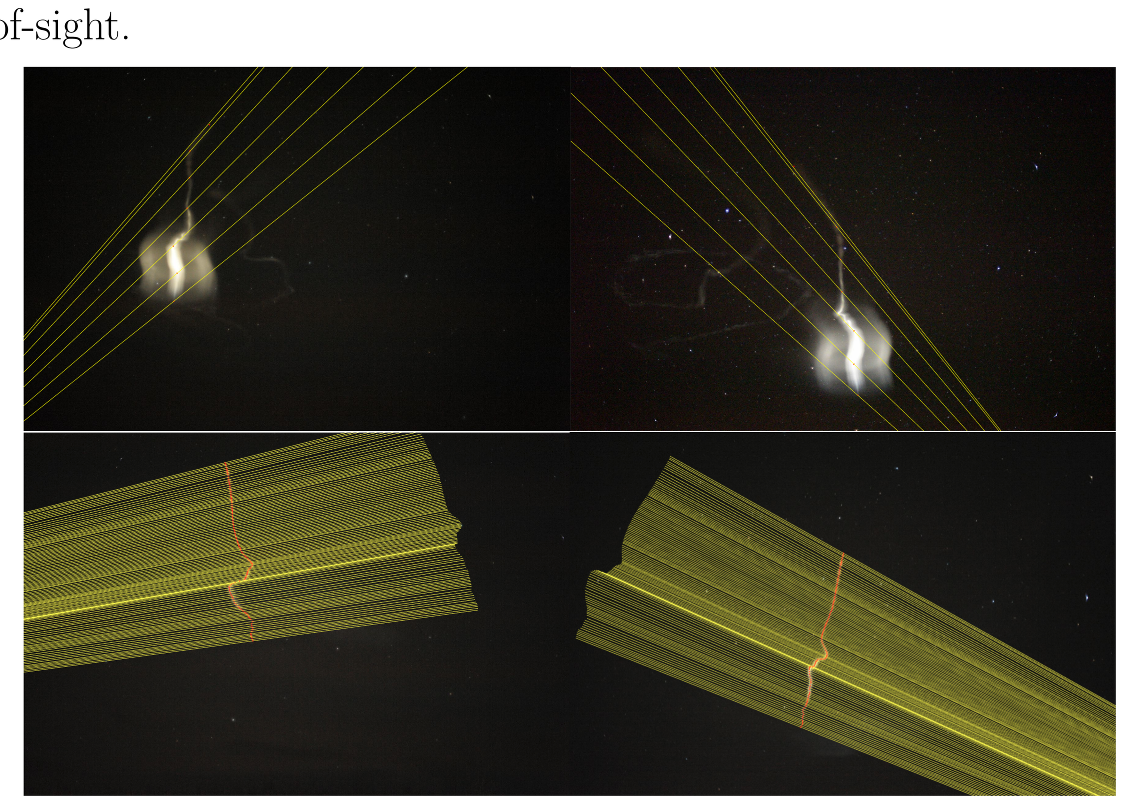

Figure 2: Triangulation of two pairs of images, from Cold Foot and the NASA-8 airplane.

Wind Profiles

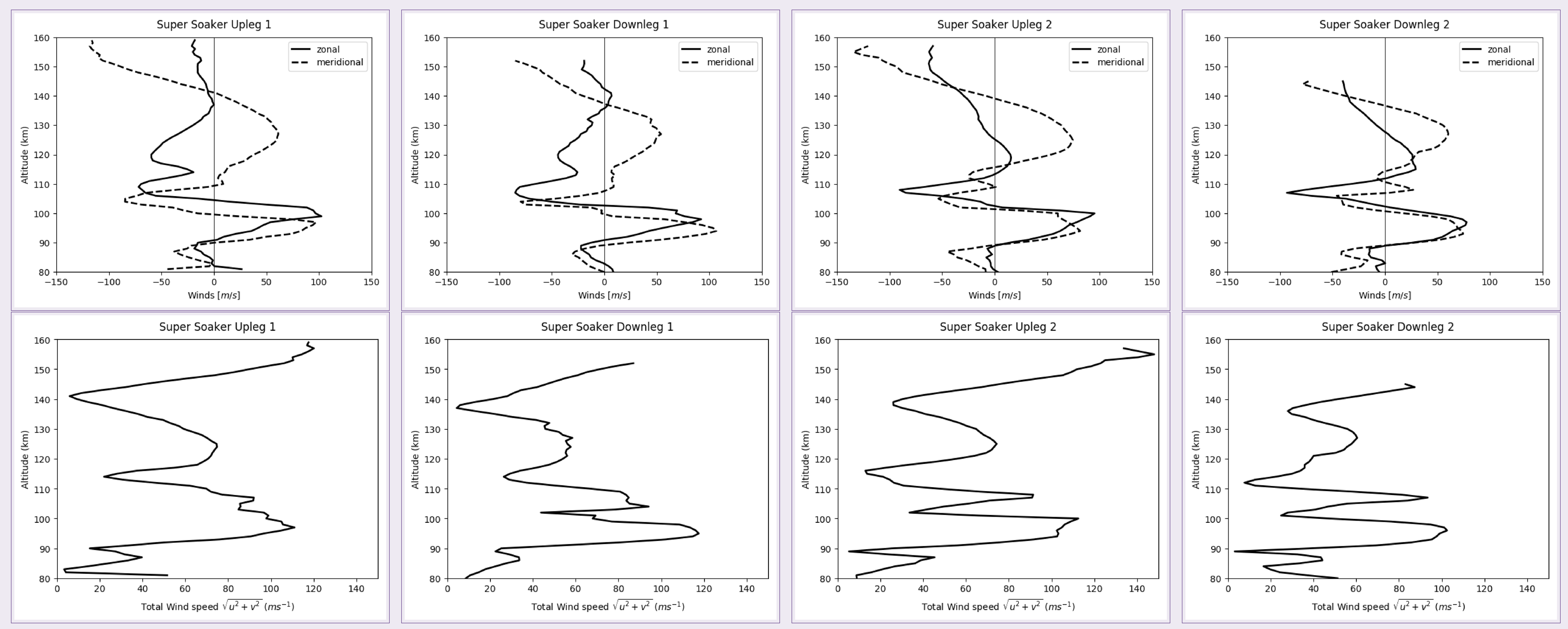

Figure 3: Zonal (u), Meridional (v) and total wind profiles for Upleg1, Downleg1, Upleg2 and Downleg2.

Kelvin Helmholtz Instability Billows

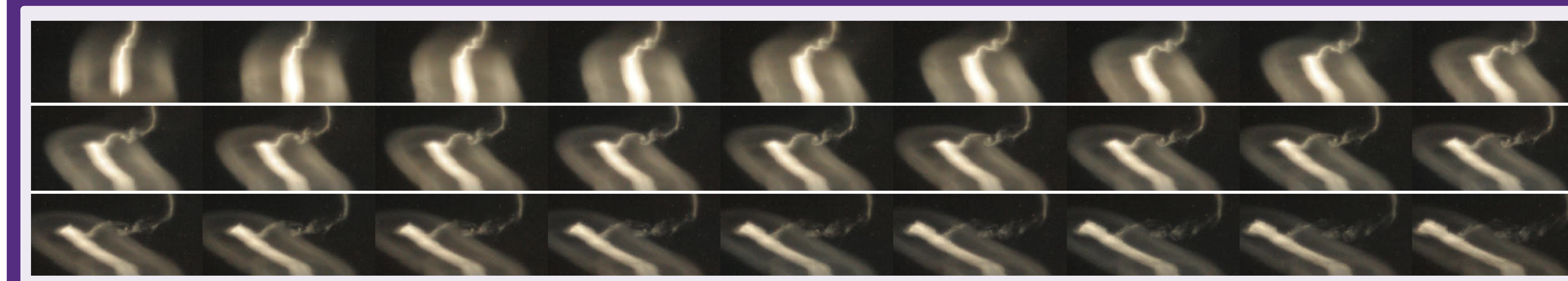

Figure 4: Zoomed-in TMA trail with the development of the KH instability in Downleg1 (Cold Foot images).

Super Soaker Campaign

The original mission purpose of Super Soaker was to study the effects of an artificial Polar Mesospheric Cloud on mesospheric dynamics. As shown in Figure 2, Super Soaker was a rocket campaign that took place in a geomagnetically quiet period in January/2018. Two of the three rockets (Figure 5) were equipped with TMA, which were released between 80 and 160 km.

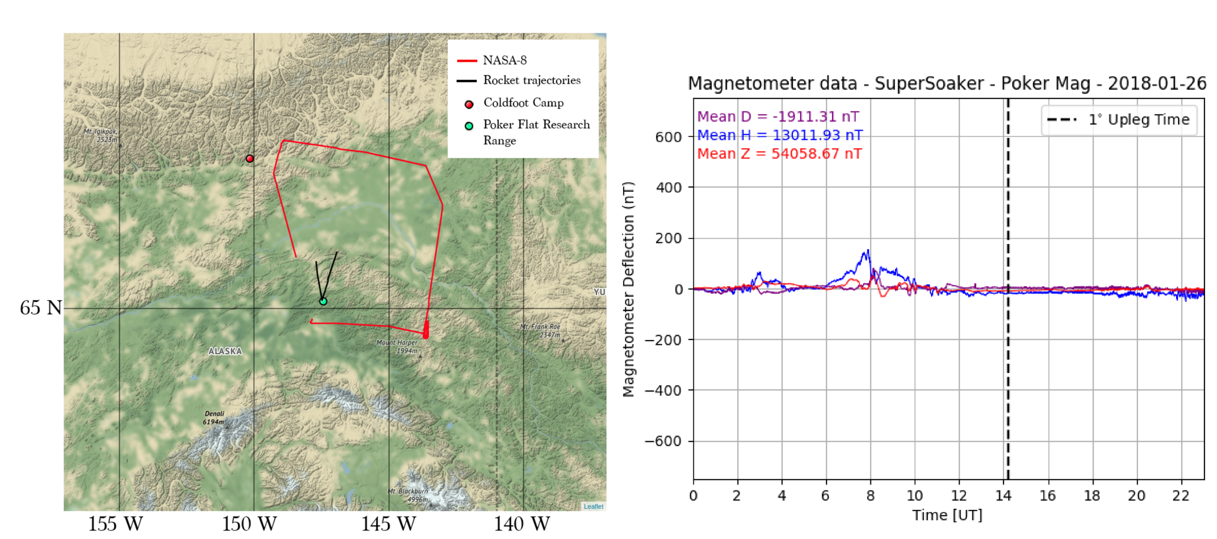

Figure 5: Map with the camera sites, including NASA-8, and the trajectory of the TMA rockets.

Kelvin Helmholtz Instability

Evidence for Kelvin Helmholtz (KH) instability was seen during the first launch (Downleg 1). Figure 4 shows the development of the eddy structure in the downleg trail.

One of the fully developed features evident in Figure 4 was triangulated resulting in an approximate height of 4 km and wavelength of 6.39 km. Figure 6 shows the result of this triangulation.

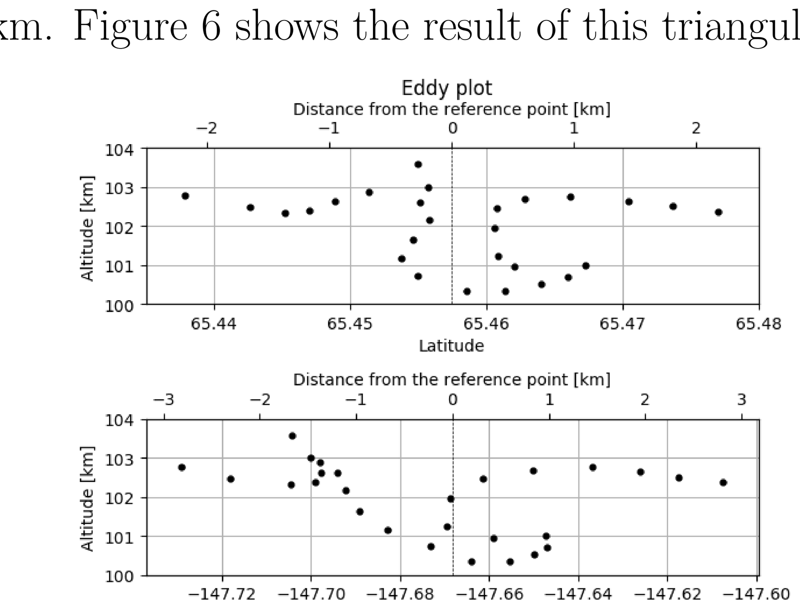

Figure 6: Triangulation of the eddy for the KH instability.

Richardson Number

In order to be KH unstable, the flow has to have Richardson Number (Ri) less than 1/4 [2]. The calculation of the Ri for the clearly unstable flow (Downleg1 as displayed in Figure 4) with NRLMSISE-00 (temperatures and neutral densities) results in Figure 7. Notice that the horizontal dashed line marks the height of the triangulated eddy from Figure 6.

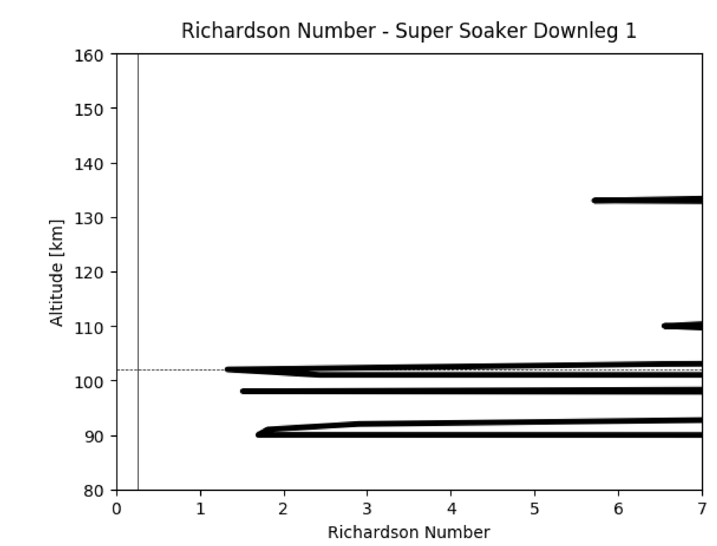

Figure 7: Ri calculated for Downleg 1 with 1 km vertical resolution.

Results and Conclusions

- Neutral shear instability appears in the high latitude mesosphere/lower thermosphere even in quiet geomagnetic conditions;
- Richardson Number calculated with NRLMSISE-00 is never below 1/4, however, the lowest value for Ri corresponds to the altitude of the KH instability.
- The vertical size of the triangulated billow (Figure 6) is ~4 km, which suggests that the depth of the initial unstable layer is of the order of 800 m [3];
- With a depth of 800 m and with $\lambda_c \sim 8h$ (see reference [2]), the expected unstable horizontal wavelength is 6.4 km, which agrees with the 6.39 km value obtained from Figure 6.

References

[1] MF Larsen.
Winds and shears in the mesosphere and lower thermosphere: Results from four decades of chemical release wind measurements.
Journal of Geophysical Research: Space Physics, 107(A8), 2002.

[2] MF Larsen.
A shear instability seeding mechanism for quasiperiodic radar echoes.
Journal of Geophysical Research: Space Physics, 105(A11):24931–24940, 2000.

[3] Richard Segar Scorer.
Dynamics of meteorology and climate.
John Wiley & Sons, 1997.

Acknowledgements

This research was partially supported by NSF grant AGS-1552214 and by NASA grant NNX16AF67G.

Contact Information

Email: rmesqui@clemson.edu