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

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Outline

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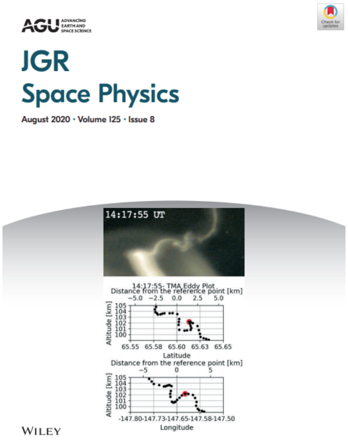

Figure: Mesquita et al. [2020].

Scientific questions

Science questions:

(a) Is there any turbulence above the mesopause/turbopause?

(b) What is the triggering mechanism for Kelvin-Helmholtz instability (KHI) in the low thermosphere?

(c) Is there any vertical transport between D- and E-regions?

Figure: Super Soaker Kelvin-Helmholtz instability.

Motivation

(a) Kelvin-Helmholtz instability (KHI or shear instability) occurs in the interface between two regions of a fluid with different velocities and densities.

(b) Quite common in the lower atmosphere.

(c) In the upper atmosphere more predominant in the mesosphere due to its statically unstable nature.

(d) Breaks down into smaller scale instabilities and causes turbulence.

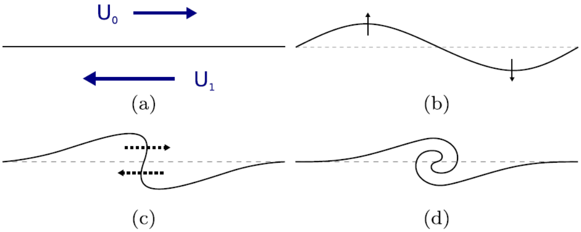

Figure: Kelvin-Helmholtz Instability development [Figure from Barbulescu and Erdélyi, 2018].

Overview of the Super Soaker

1 - Date: 01/26/2018;

2 - Rockets: 41.119, 41.120 and 41.122;

3 - Launch conditions: Quiet;

4 - Mission purpose: Study the impacts of short term variations in the mesospheric dynamics by releasing 50 gallons of water to create an artificial Polar Mesospheric Cloud (PMC).

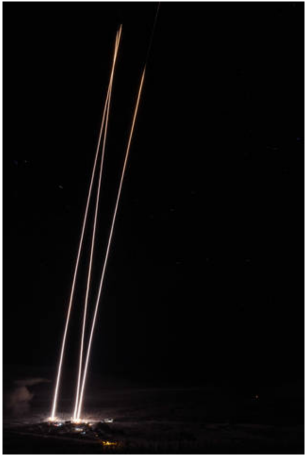

Figure: Super Soaker rockets (*Courtesy of NASA*).

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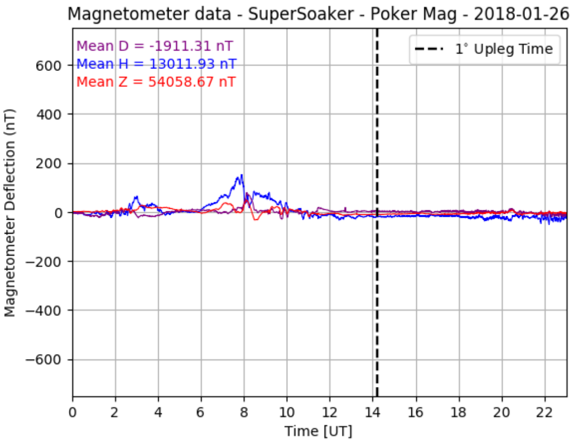

Figure: Magnetometer from Poker Flat.

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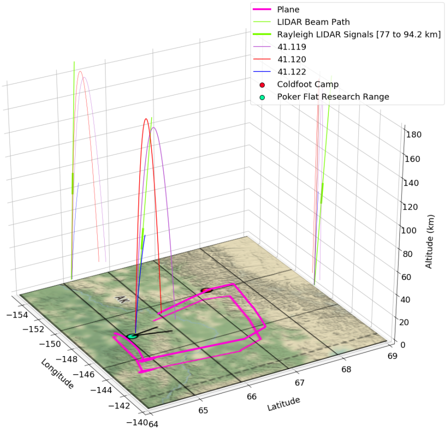

Figure: Geography of the launches.

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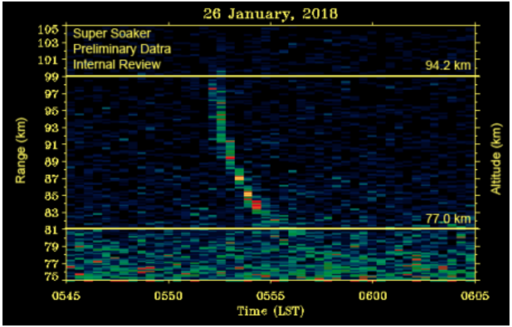

Figure: Rayleigh LIDAR signal accredited to the water release (*Courtesy of Rich Collins*).

Triangulation

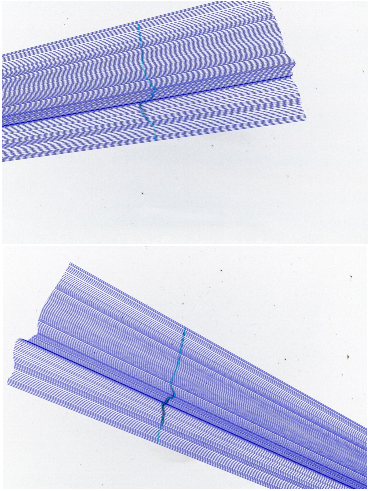

Figure: The triangulation technique.

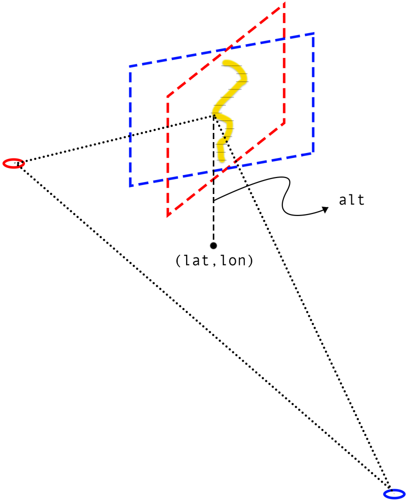

Figure: The triangulation technique.

Results - Winds

What is the triggering mechanism for Kelvin-Helmholtz instability in the low thermosphere?

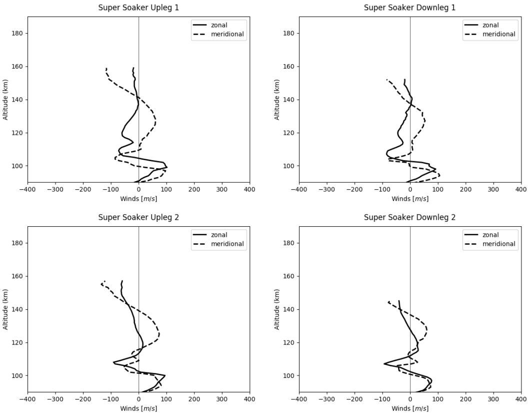

Figure: Super Soaker winds.

Results - Richardson Number

The Richardson number (Ri) is a dimensionless number that expresses the ratio of the buoyancy term to the flow shear term, and it can be written in the form

$$Ri = \frac{\frac{g}{T}\left(\frac{dT}{dz} + \frac{g}{c_p}\right)}{\left[\left(\frac{du}{dz}\right)^2 + \left(\frac{dv}{dz}\right)^2\right]}, \tag{1}$$

where g is the acceleration of gravity, c_p is the specific heat at constant pressure, and u and v are the zonal and meridional wind components, respectively. $Ri < 1/4$ indicates a possibility of shear instability development.

Results - Richardson Number

Is there any turbulence above the mesopause/turbopause?

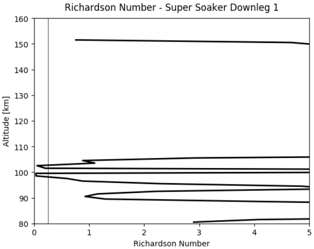

Figure: Super Soaker KH instability evidence and its *Ri* for Downleg 1.

Figure: DNS results from Fritts et al. [2014] with Ri = 0.05, Re = 2500 evolution in $0.5\,T_b$.

Results - Eddy triangulation

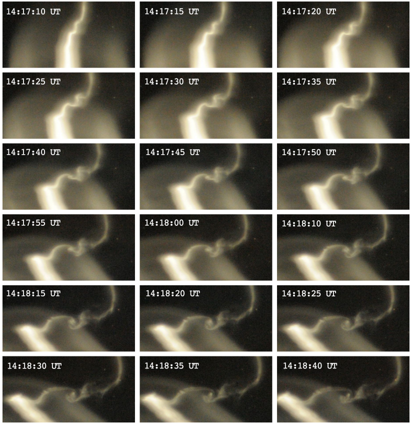

Figure: Picture of the KHI from the ground.

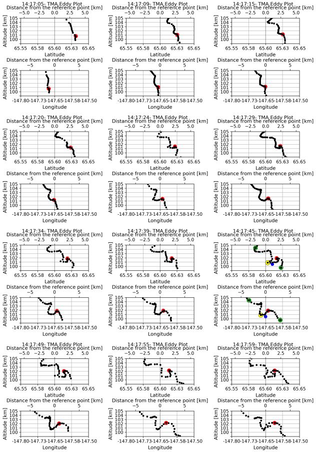

Figure: Triangulation of the KHI.

Is there any vertical transport between D- and E-regions?

(a) L_x=5.2 km
(b) L_z=3.8 km
(c) λ=9.8 km
(d) Fr=0.29
(e) Re=7.2 $\times 10^3$
(f) U_z=29.2 ms^{-1}
(g) U_x=39.5 ms^{-1} (calculated) and 42.5 ms^{-1} (measured)
(h) ϵ=38.1 Wkg^{-1}

See Mesquita et al. [2020] for details.

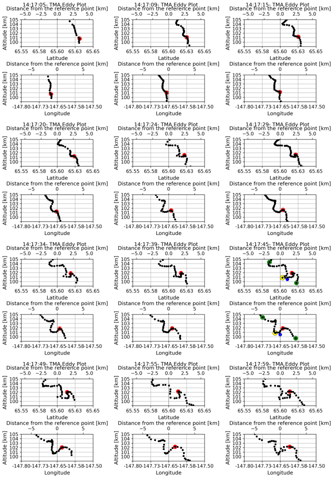

Figure: Triangulation of the KHI.

Summary

(A) The turbulence, which resulted from the KHI, is also evident in the altitude range above the mesopause/turbopause due to the faster dispersion of the TMA. The evidence of overturning structure and turbulence in this region is expected to produce mixing and vertical transport across the statically stable layer.

(B) The evolution of the KHI is such that the billow breaks down into turbulence from the edges in, which is compatible with the DNS analysis by Fritts et al. [2014].

(C) The high-resolution triangulation of the KHI allowed us to quantify L_x=5.2 km, L_z=3.8 km, λ=9.8 km, U_z=29.2 ms^{-1}, U_x=39.5 ms^{-1} (calculated) and 42.5 ms^{-1} (measured).

(D) This phenomenon represents a plausible explanation for the vertical transport of atomic oxygen between mesosphere and thermosphere.

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