Modeling of Mountain Generated Gravity Waves

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Abstract

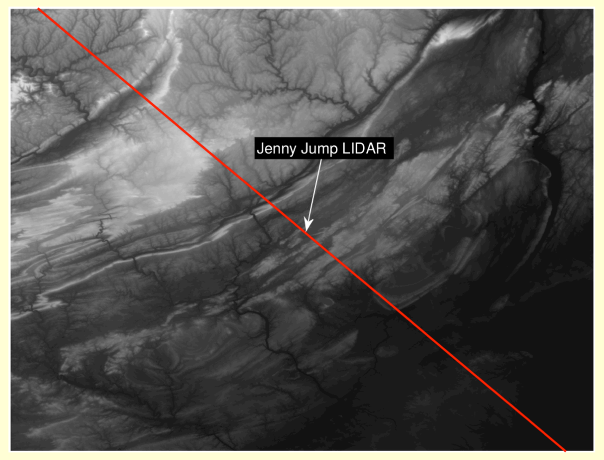
Molecular/aerosol lidar measurements taken from NJIT-CSTR's Jeffer Observatory [within Jenny Jump State Forrest] show an often replicated gravity wave feature in relative density measurements of the upper troposphere and stratosphere. This gravity wave pattern demonstrates phase variation in altitude, unlike traditional stationary wave phase patterns associated with mountain-generated gravity waves. Herein we present modeling efforts to describe and characterize this wave morphology. We demonstrate that the generation of secondary gravity waves, caused by the persistent breaking of mountain-generated waves from the Appalachian Plateau Regions, is the likely cause.

Data for Model and Observation

Topographic Data:
USGS, 1-Arc Second National Elevation Dataset, 2009, http://www.mrlc.gov/

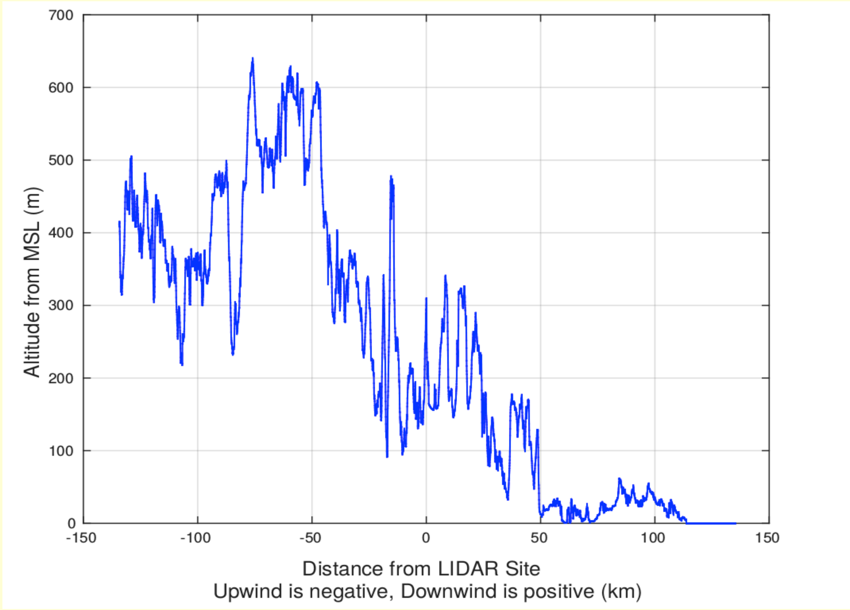
Weather Model Data:
NCEP FNL Operational Model Global Tropospheric Analyses, http://rda.ucar.edu/datasets/ds083.2/

Observational Lidar Data:
Taken by A. Teti, A. Gerrard, and G. Jeffer at the Jenny Jump Site on the night of September 23, 2013.

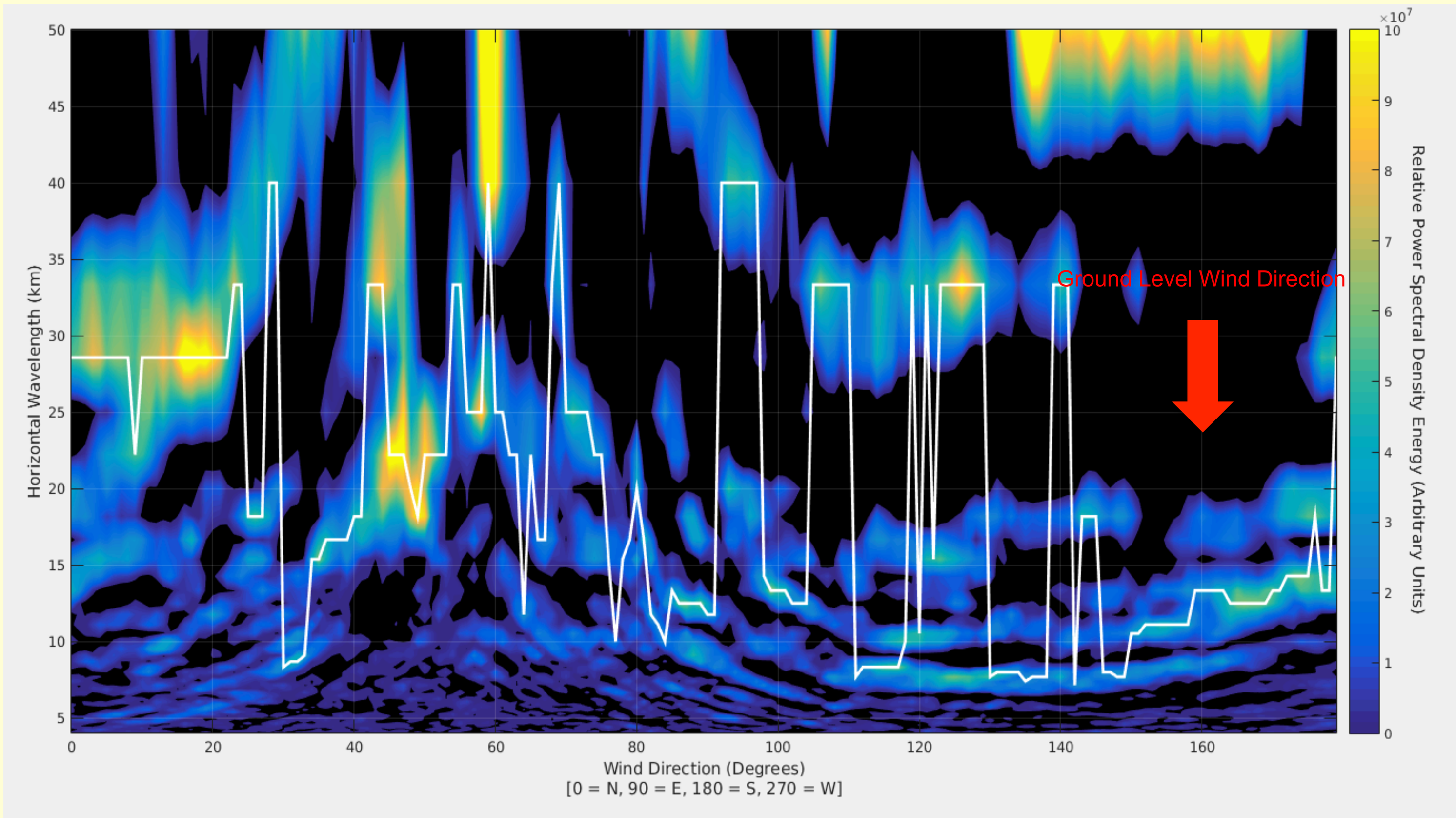


Area of Interest

The model assumes straight ground level winds over the region shown, and a cross section is taken for a given wind direction, as shown in the map figure with the red line. The figure right is the cross section shown of the topographic map, showing the Jenny Jump site at the peak at 0 km on the horizontal axis. This spatial series data is then processed into a residual power spectral density (RPSD), giving the dominant horizontal wavelengths of the terrain.



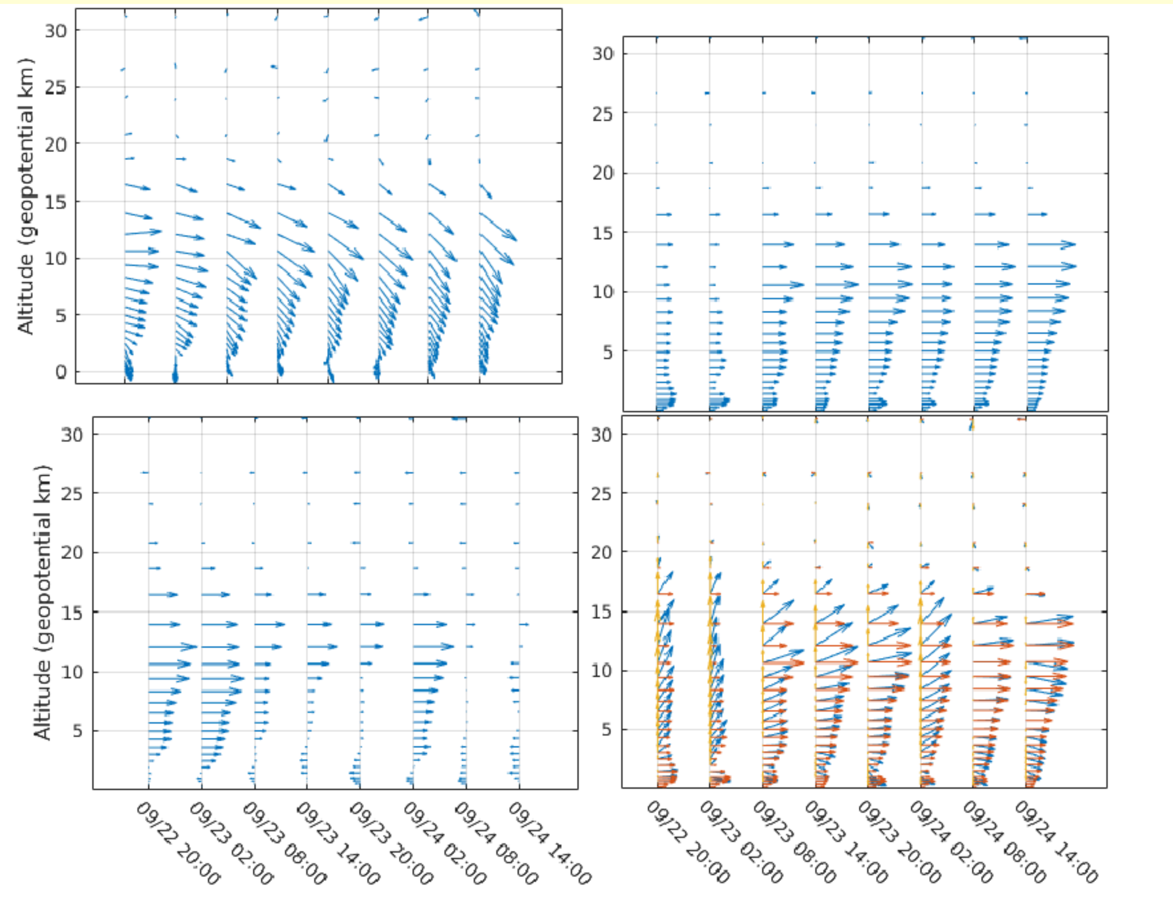
Horizontal and Vertical Spectrum



As with the above panel, a horizontal cross section is taken from from 0 to 180 degrees, the spectrum is the same modulo 180. The figure shows, as expected for parallel ridges, a minimum set of wavelengths when the wind is orthogonal to the ridge and increases as a 1/cos(Θ), becoming unbounded. *(See figure immediately right for Vertical Spectrum)*

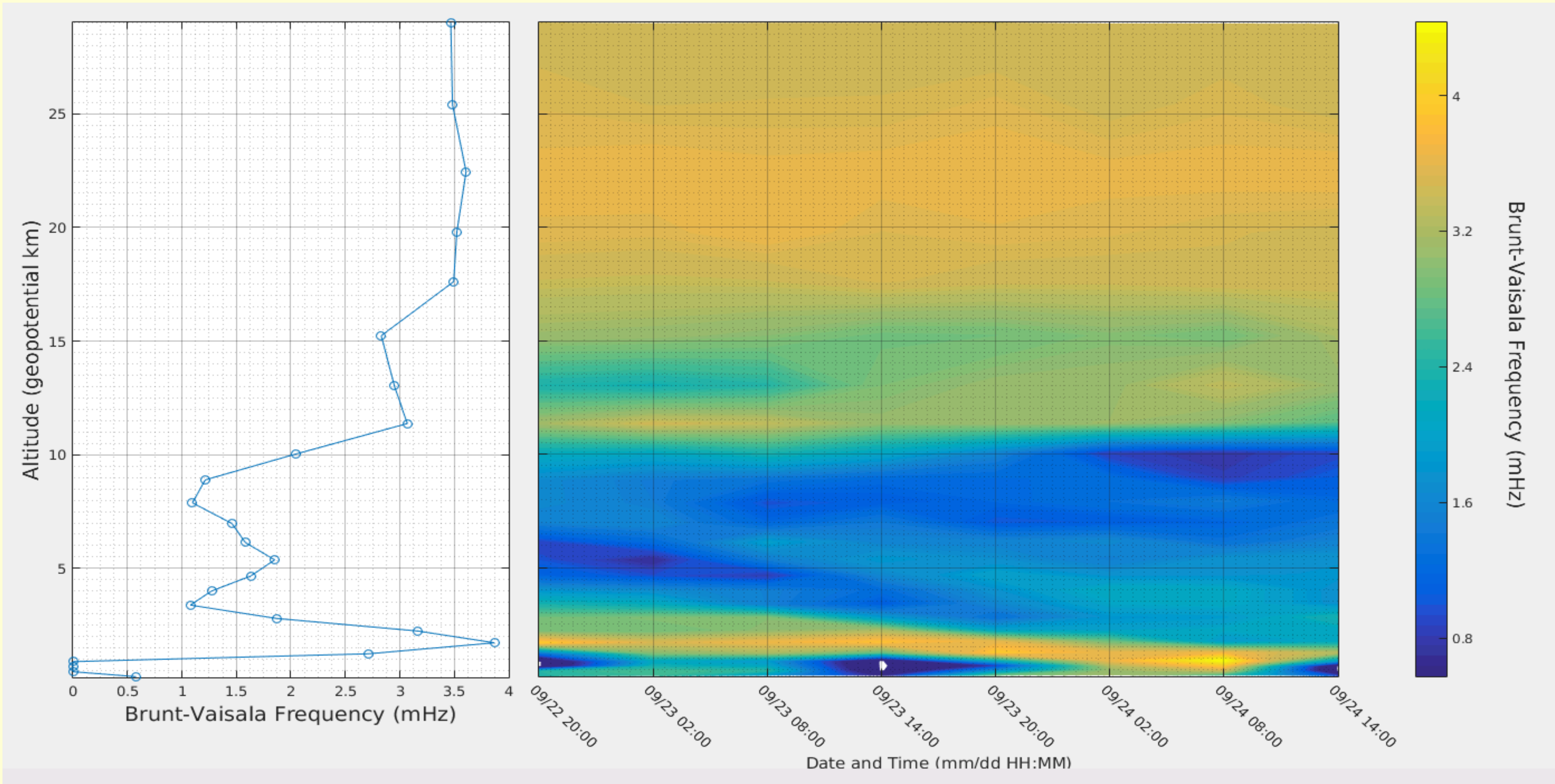
Wind Flow During Observation

The figure from NCEP data shows relative winds strength and direction changing with altitude and time. The top-left plot shows wind direction in the normal coordinate system (north is up, east is right). The remaining three plots are in a rotated reference frame with respect to the ground level wind direction, such that the ground level wind points east, and the rest are adjusted accordingly. The top-right figure is the wind strength parallel to this ground level direction, and the bottom left figure is the wind orthogonal to it. The final bottom right figure shows the components and total winds in the new reference frame.



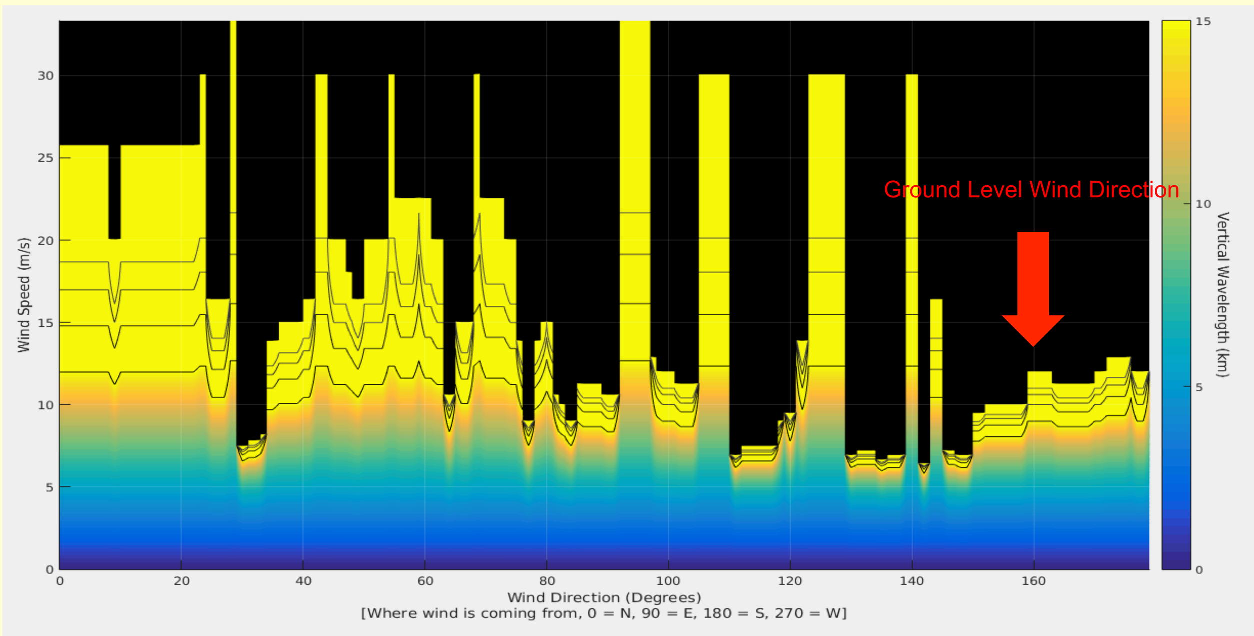
The figures show decaying wind speed above 15 km, and a strong shear component up to 15 km.

Brunt-Vaisala Frequency During Observation

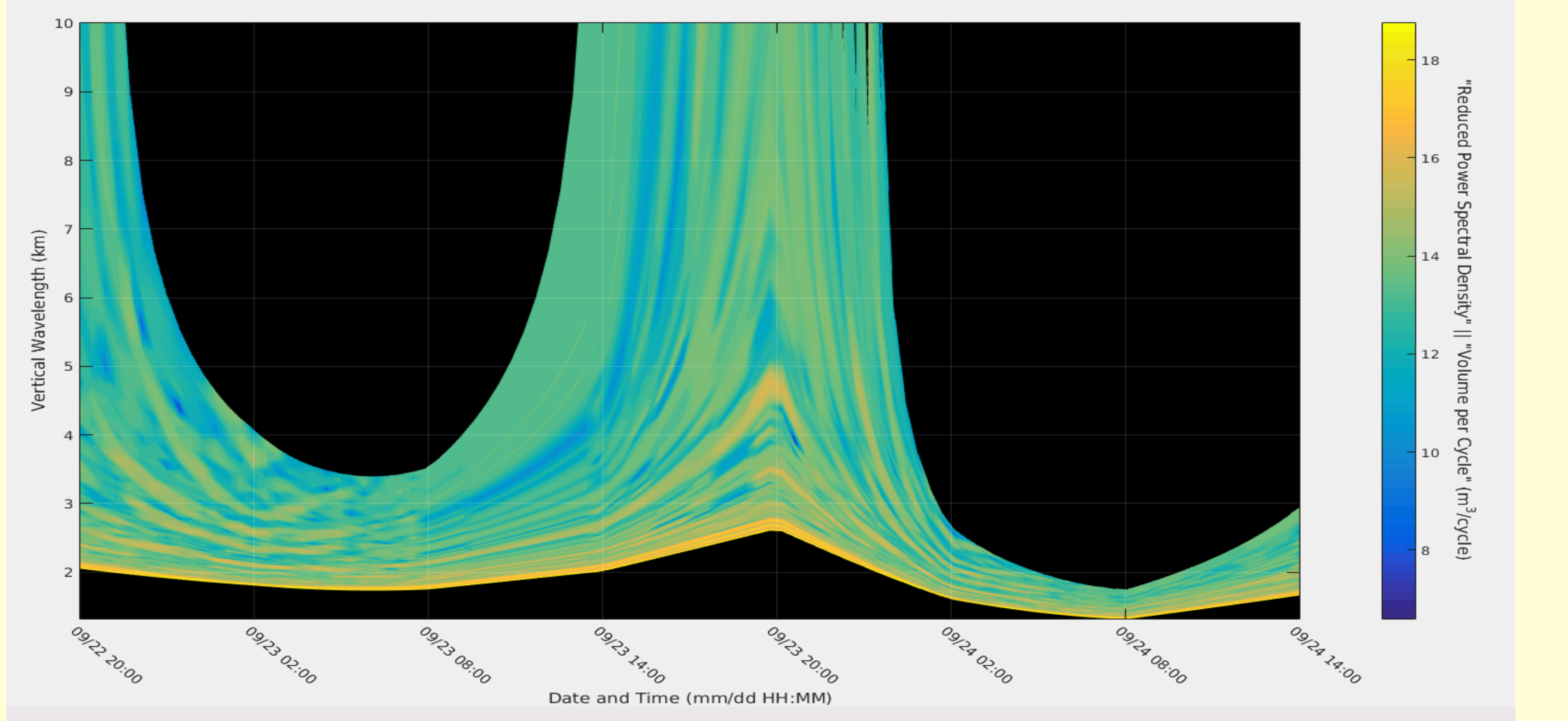


The figure above, also from NCEP data, shows the B-V frequency changing with time and altitude. The right subplot timeframe was over a time when observations with lidar were taken at Jenny Jump, up to the highest altitude (pressure level) available in the data set from NCEP. The left subplot is a cross section of the contour plot at 9/23 14:00, showing a typical BV frequency profile with altitude. Note the large changes around 1, 3, and 10 km, and the areas of stability above and immediately below the tropopause.

The highest RPSD for each direction (shown in white line) is then used to compute the vertical wavelength for different wind speeds and directions. To the figure right, areas in black are when the waves become absorbing (it's amplitude component becomes imaginary).



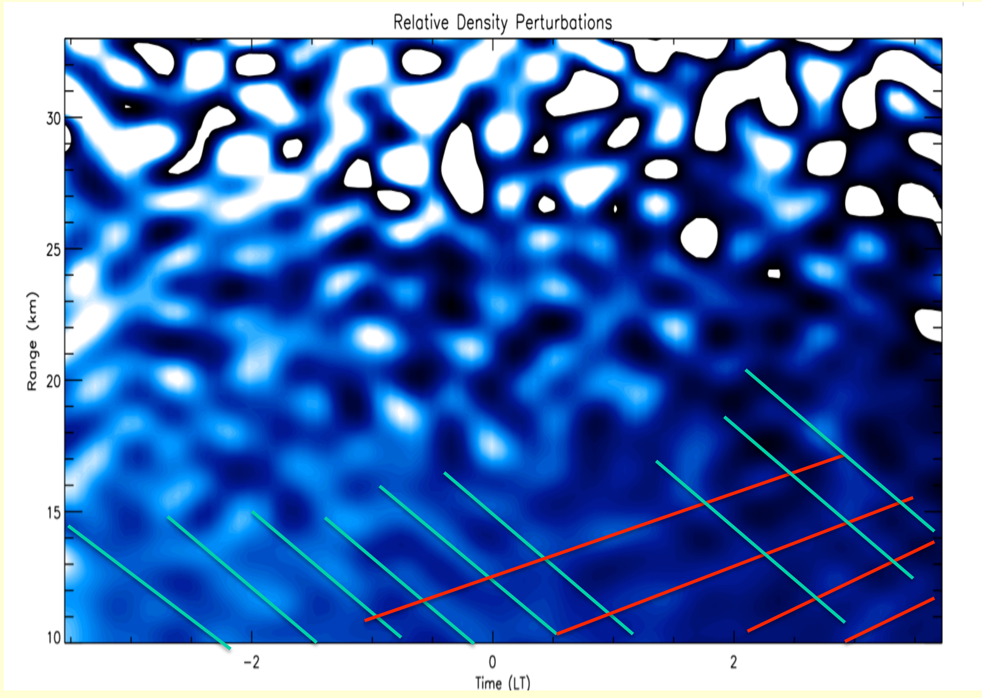
Vertical Wavelength with Time



The figure above is the expected vertical wavelength during the period of observation. This was determined through the "driving level" 100 m winds direction and magnitude to use the appropriate RPSD for the given direction. **As can be seen many of the horizontal wavelengths map onto a small band of vertical wavelengths between 2 and 4 km**. Winds during this time were generally going SSE.

Observational Data and Instrument

The figure to the right shows the relative density perturbations from the NJIT-CSTR lidar system for the night of 9/23/13. The perturbations have been low-pass filtered with 2 km vertical and 20 min temporal cut-offs. Brighter/whiter colors represent higher relative density variation, and while darker/black colors represent lower relative density variations. Apparent through the night is a slow loss of laser power, which was not corrected for due to possible aerosol contamination. The system noise floor is at ~27-km altitude.



Observed below ~17 km are crisscross patterns of upward (red) and downward (green) phase lines, indicative of downward and upward propagating gravity waves, respectively. Downward phase structure has vertical wavelengths of 2.5-3.5 km and observed periods of 45-65 min.

The photo left is the site of the lidar system outside the main UACNJ building. The system has been relocated to the Jeffer Observatory, and is being fiber coupled to a 48" fully steerable optical telescope.

Conclusions

Comparing the lidar data with the mountain wave model data, we see the following:

1) There do not seem to be any stationary gravity waves. That is, the waves we observe in the lidar data show phase progression. We speculate that stationary mountain waves are being generated at lower altitudes and are then breaking and forcing secondary waves [of comparable vertical wavelength], which are then observed above 10 km.

2) Above 10 km and below ~17 km, the observed, quasi-monochromatic gravity waves match the model predictions, in regards to the measured vertical wavelengths. This lends support to the speculation of secondary wave forcing presented above. We note that the BV frequency and the winds are relatively steady [in regards to both altitude and temporal variation] in this altitude regime.

3) Above ~17 km, the wave field seems to become incoherent. This is likely due to the rapidly decreasing winds as seen in the wind profiles. There is likely reflection of the waves above 17-km, resulting in the observed downward propagating gravity waves.

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